Edited by
Mohammad Reza Rahimpour
Babak Omidvar
Nazanin Abrishami Shirazi
Mohammad Amin Makarem

Crises in Oil, Gas and Petrochemical Industries

Disasters and Environmental Challenges

ELSEVIER

VOLUME 1

CRISES IN OIL, GAS AND PETROCHEMICAL INDUSTRIES

This page intentionally left blank

CRISES IN OIL, GAS AND PETROCHEMICAL INDUSTRIES

Disasters and Environmental Challenges

Volume 1

Edited by

MOHAMMAD REZA RAHIMPOUR
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

BABAK OMIDVAR
Graduate Faculty of Environment, University of Tehran, Tehran, Iran

NAZANIN ABRISHAMI SHIRAZI
Graduate Faculty of Environment, University of Tehran, Tehran, Iran

MOHAMMAD AMIN MAKAREM
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

ELSEVIER

Elsevier
Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

Notices

ISBN: 978-0-323-95154-8

For information on all Elsevier publications visit our website at https://www.elsevier.com/books-and-journals

Publisher: Candice Janco
Acquisitions Editor: Anita Koch
Editorial Project Manager: Kathrine Esten
Production Project Manager: Paul Prasad Chandramohan
Cover Designer: Vicky Pearson Esser

Typeset by TNQ Technologies

Contents

This page intentionally left blank

Contributors

A. Abdur Ravoof
Department of Applied Science and Technology, AC Tech, Anna University, Chennai, Tamil Nadu, India

Nazanin Abrishami Shirazi
Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Syed Istiyak Ahmed
Department of Civil, Environmental, and Geo- Engineering, University of Minnesota Twin Cities, Minnesota, MN, United States

Mohammad R. Alrbaihat
Ministry of Education, Dubai, United Arab Emirates

Abbas Yaghoobi Andarabi
Department of Environmental Planning, Management and Education, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Azrina Abd Aziz
Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Gambang, Malaysia

Jahanbakhsh Balist
Department of Environmental Planning, Management and Education, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Ali Behrad Vakylabad
Department of Materials, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran

Shahariar Chowdhury
Faculty of Environmental Management, Prince of Songkla University, Songkhla, Thailand

Masoud Dehghani-Soufi
School of Environment, College of Engineering, University of Tehran, Tehran, Iran

Nayef Ghasem
Department of Chemical and Petroleum Engineering, United Arab Emirates University, Al-Ain, United Arab Emirates

Md. Jafar Hossain
Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh; Energy Conversion Laboratory, Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh

J. Jayapriya
Department of Applied Science and Technology, AC Tech, Anna University, Chennai, Tamil Nadu, India

A.R. Karbassi
Department of Environmental Engineering, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

D. Keerthi Narayanan
Department of Applied Science and Technology, AC Tech, Anna University, Chennai, Tamil Nadu, India

Parvin Kiani
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

Mohammad Amin Makarem
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

Bahram Malekmohammadi
Department of Environmental Planning, Management and Education, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Behnam Mohamadzadeh
Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Sadaf Mohebi
Biosystems Engineering Department, College of Aburaihan, University of Tehran, Tehran, Iran

Minhaj Uddin Monir
Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh; Energy Conversion Laboratory, Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh

Zohre Moravvej
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

Vahid Mortezaeikia
School of Chemical Engineering, College of Engineering, University of Tehran, Tehran, Iran

Sina Mosallanezhad
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

M. Murugan
Department of Applied Science and Technology, AC Tech, Anna University, Chennai, Tamil Nadu, India

Abdul Rahim Nihmiya
Department of Civil and Environmental Technology, University of Sri Jayewardenepura, Nugegoda, Sri Lanka

Ahmad Nohegar
Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Babak Omidvar
Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Elham Rahimpour
Shiraz University of Medical Sciences, Shiraz, Iran

Mohammad Reza Rahimpour
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

Behnaz Rahmatmand
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

G. Revathi
Department of Applied Science and Technology, AC Tech, Anna University, Chennai, Tamil Nadu, India

Mahdi Rezaei
Department of Environmental Planning, Management and Education, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Parisa Rostami
Department of Chemical Engineering, Faculty of Engineering, Yasouj University, Yasouj, Iran

Priyanka Saha
Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh

H.M. Salman
Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh

Shaheen M. Sarkar
Department of Applied Science, Technological University of the Shannon: Midlands Midwest, Limerick, Ireland

Mansooreh Soleimani
Department of Chemical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

Maryam Takht Ravanchi
Petrochemical Research and Technology Company, National Petrochemical Company, Tehran, Iran

Kuaanan Techato
Faculty of Environmental Management, Prince of Songkla University, Songkhla, Thailand

Hemaloshinee Vasudevan
Tun Razak Graduate School, University of Tun Abdul Razak, Kuala Lumpur, Malaysia

Leila Zand
Department of Materials, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran

Sara Zolghadri
Department of Chemical Engineering, Shiraz University, Shiraz, Iran

Biographies

Mohammad Reza Rahimpour

Department of Chemical Engineering, Shiraz University, Shiraz, Iran
Email: rahimpor@shirazu.ac.ir

Prof. Mohammad Reza Rahimpour is a professor in Chemical Engineering at Shiraz University, Iran. He received his PhD in Chemical Engineering from Shiraz University joint with University of Sydney, Australia 1988. He started his independent career as Assistant Professor in September 1998 at Shiraz University. Prof. M.R. Rahimpour was a Research Associate at University of California, Davis, from 2012 till 2017. During his stay in University of California, he developed different reaction networks and catalytic processes such as thermal and plasma reactors for upgrading of lignin bio-oil to biofuel with collaboration of UCDAVIS. He has been a Chair of Department of Chemical Engineering at Shiraz University from 2005 till 2009 and from 2015 till 2020. Prof. M.R. Rahimpour leads a research group in fuel processing technology focused on the catalytic conversion of fossil fuels such as natural gas, and renewable fuels such as bio-oils derived from lignin to valuable energy sources. He provides young distinguished scholars with perfect educational opportunities in both experimental methods and theoretical tools in developing countries to investigate in-depth research in the various field of chemical engineering including carbon capture, chemical looping, membrane separation, storage and utilization technologies, novel technologies for natural gas conversion and improving the energy efficiency in the production and use of natural gas industries.

Babak Omidvar

Department of Civil-Environmental Engineering, Graduate Faculty of Environment, University of Tehran, Tehran, Iran
Email: bomidvar@ut.ac.ir

Dr. Babak Omidvar is an associate professor at the University of Tehran. He received his PhD in Civil Engineering from the Faculty of Engineering, University of Tehran in 2001. He started his work as Assistant Professor in September 2002 at the graduate Faculty of Environment, University of Tehran. His research interests are resilience, risk and reliability analysis in various fields of urban areas and infrastructures. The courses he teaches at the University of Tehran include "Disaster resistant structures," "Loss estimation studies," "Infrastructure protection against natural disasters," "Vulnerability assessment," "Risk analysis and management," "Resilience engineering," "Environmental statistics," "Environmental economics," "Reliability in water resource management," and "Engineering Mathematics." His recent research focus is on robust optimization, deep uncertainty, decision making under uncertainty, infrastructure performance assessment considering inter- and intra-dependencies, catastrophe theory, complex systems, network analysis, and multi-hazards analysis which all of them are used in natural disaster engineering and management category. In this regard, he has conducted many research studies and supervised more than 180 national and international graduate students in performing their PhD and MSc theses.

Nazanin Abrishami Shirazi

Graduate Faculty of Environment, University of Tehran, Tehran, Iran
Email: n.abrishami@ut.ac.ir

Nazanin Abrishami Shirazi is a PhD Candidates at University of Tehran. Her focus is on vulnerability assessment in various fields including engineering apparatus and materials, and finding proper solutions for crisis prevention and environmental side effects management. Recently she has collaborated in writing and editing various scientific works including book chapters with prestigious publishers such Elsevier and Springer.

Mohammad Amin Makarem
Department of Chemical Engineering, Shiraz University, Shiraz, Iran
Email: m.makarem@shirazu.ac.ir

Dr. Mohammad Amin Makarem is a research associate at Shiraz University. His research interests are gas separation and purification, nanofluids, microfluidics, catalyst synthesis, reactor design, and green energy. In gas separation, his focus is on experimental and theoretical investigation and optimization of pressure swing adsorption process, and in the gas purification field, he is working on novel technologies such as microchannels. Recently, he has investigated methods of synthesizing bio-template nanomaterials and catalysts. Besides, he has collaborated in writing and editing various books and book-chapters for famous publishers such as Elsevier, Springer, and Wiley.

This page intentionally left blank

Preface

Vol. 1: Disasters and environmental challenges

Dealing with disasters becomes significantly more important in oil, gas, and petrochemical plants nowadays considering their growing number of units and plants. Working with high-pressure and temperature apparatus such as reactors, vessels, columns, heat exchangers, etc., and also pipelines utilized for transportation purposes increases incident potential in these industries. On the other hand, long-term side effects on humans and the environment are incredibly important. Problems regarding venting toxic materials in the form of wastes, dust, and gases may lead to health problems, and releasing greenhouse gases results in global warming. Therefore, a systematic procedure for figuring out, classifying, and managing crises in the oil, gas, and petrochemical industries is an essential need.

This book is a collection of chapters illustrating various disasters in the oil, gas, and petrochemical industries. This includes the effects of natural disasters such as floods, and hurricanes as well as manmade incidents including fire events, explosions, and the release of dust and toxic substances on various related units and plants. Besides, the long-term side effects on both humans and the environment resulted from these industries are presented. Problems such as releasing wastes and venting gases into the environment, pollution from oil, gas, and petrochemical industries, and challenges from overusing natural resources and producing noise pollutants are discussed in detail.

The editors feel obligated to express their profound gratitude to the chapter writers and reviewers for their involvement and invaluable support in this undertaking. The authors and editors would also like to thank the Elsevier team for their invaluable and irreplaceable step-by-step support in preparing this book.

Mohammad Reza Rahimpour
Babak Omidvar
Nazanin Abrishami Shirazi
Mohammad Amin Makarem

This page intentionally left blank

SECTION I

Crisis management in oil, gas, and petrochemical industries

This page intentionally left blank

1

Introduction to decision-making and disaster management systems

Nazanin Abrishami Shirazi, Babak Omidvar and Ahmad Nohegar

Graduate Faculty of Environment, University of Tehran, Tehran, Iran

1. Introduction

Millions of people suffer serious disasters each year as an outcome of inadequate coping systems, or there are such conformations, but they do not become life-rescue science about endangered societies. Disaster is specified as an intense disturbance in the function of a region or society at any level due to hazardous incidents interacting with the exposure status, vulnerability, and potency, which leads to the following: losses and effects on materials, mankind, the environment, and economic [1]. A disaster can also allude to an abrupt and hazardous incident that disrupts the work of a society and reasons lesion that is beyond the society capacity to answer with the use of its sources. Substance and economic losses are also one of the consequences. It can be specified from both definitions that disasters can happen because of [2]:

i) the interaction among capacity, hazard, and vulnerability;

ii) serious lesion in terms of materials, mankind, the environment, and economic aspects; and

iii) causing disturbance to mankind's lives that is beyond the local capacity to cope with using their own capabilities, necessitating the need for exterior assistance.

Disaster management is defined as the set of policies and the decisions of administrators, operational works, performers, and methods related to the different steps of managing a disaster at all levels [3]. It is a main agent and an impressive tactic to downgrade any disaster effect, and also a strategic programming and a

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00008-6

manner that is managed and utilized to retain critical assets and infrastructures from hard lesions when man-made and indigenous catastrophic disasters happen. Disaster management as a normative procedure plans pre-disaster, within-disaster, and after-disaster action to protect mankind lives [4].

Decision-making in disaster management is a difficult work for modeling since it is complicated by agents such as multiple stakeholders, coordination and control principles, complex resource management, and communication [5]. Disasters are a set of interrelated works that happen in a fast-changing perimeter under high pressures and critical or extreme stress situations. Supporting the decision-making procedure within disaster management is hard because each decision involves multiple performers, multiple accidents, and the services engaged in that accident [6]. In this chapter, first an overview of disaster management is presented and then it is discussed how decision-making affects the disaster management procedure.

2. Disaster management

Disaster management procedure can be applied into phases that are defined by specific aims and sources. A phase can be defined with particular tasks, while each task can be defined with particular works. For a complete discussion of phases, it is necessary to know exactly about the major temporal segments that constitute the phases. Scientific sources discuss three distinct temporal (and logistic) steps [7,8]:

i) Before or pre-disaster: the period of time before the disaster occurrence

ii) Crisis: disaster aftermath

iii) After or post-disaster: the disappearance of the crisis period and returning to the normal state

Steps are rationally related to disasters. Indeed, before the disaster, organizations implement for potential disasters. Within the crisis, they deal with the current disasters. And finally, in after-crisis period, they are dealing with just-finished disasters and subsequences [3].

Before a disaster occurrence, mitigation and preparatory actions are focused. Mitigation refers to a set of attempts that lead to minimize the disaster risk through physical development, consciousness, and valency building to deal with the disaster menace. Preparation is a set of actions that are performed through appropriate and effective stages to predict disasters. Throughout a disaster, emergency responses are critical.

Emergency response is a set of actions performed to manage any adverse effects created at the time of a disaster and includes [1]:

i) Rescuing and depleting the victims
ii) Safety of assets
iii) Meet of basic needs
iv) Rescuing, sheltering, and handling of any emigre
v) Facilities and infrastructure reintegration

After-disaster includes two steps [1]:

i) **Rehabilitation:** Improving and restoring all public and civic services to a sensible level for after-disaster regions, the main purpose of which is normalizing the function of all government aspects and society life in after-disaster regions.
ii) **Reconstruction:** The rebuilding of all after-disaster region facilities, infrastructures, and institutions at society and government levels with the principal purpose of the development and growth in whole activities including cultural, social, and economic, vitalizing legislation and instruction, and increasing society partnership in all aspects of society life in the region, after the disaster.

2.1 Disaster management phases

Scientific sources [7,9–14] agree on a reference model for the disaster management procedure according to the following steps:

i) Mitigation and preparation (primarily before the disaster)
ii) Response (throughout the disaster)
iii) Recovery (after the disaster)

These steps are assumed fundamental in the discussions about disaster management. It is worth mentioning that these steps are interwoven and multidimensional, as they are highly interrelated [15].

Mitigation includes attempts and functions targeted at minimizing the risk degree against major disasters and decreasing the vulnerability of the environment and community system [16–18]. It was characterized that the principal operations should be hazard estimation, risk, and vulnerability depletion. Conversely, preparation entails steps for preparing respondents and ordinary people for after-disaster actions and tasks [19]. Response is the series of activities derived to control and manage different disaster effects (as well as ripple effects) and to minimize mankind and asset lesions. The principal operations [20,21] are depletion [22], embowering [23], health surveillance, probe and rescue, assets conservation, and lesion control. Recovery includes the activities that restore the damaged region back to a more normal situation [3].

Following an examination of various contributions, it is conceivable to claim that three further steps are logically necessary: strategy, acquirement, and signaling. Strategy is adapted from the literature of business methods, which asserts that any method involves a plan to achieve protracted objectives and outcomes. Acquisition is adapted from the persistent betterment and quality management literature, which states that any organization needs to examine methods and efficiency in order to detect and bridge the gap among configuration as it is and should be [24]. The content and intensity of signaling varies from step to step and peaks within the reaction. The main functions of signaling include the following: receive alerts and checks, and prepare and send alarm messages. Signaling necessitates on-going interaction to determine whether alerts are trustworthy and which organizations should be responsible for them. If organizations receive the wrong warnings, they may act when they do not need it (waste of time and materials) or they cannot work properly when needed (increased mortality and financial losses). Besides, the results may be frustrating if the right signal is sent to the wrong organization [7]. However, there are several instances about how a robust alert system might avoid disasters or predict the reaction to a crisis prior to its occurrence [25].

2.2 Disaster management performers

A systematic scrutiny determines the role of various performers in the disaster management process. Interference comes in two forms [3]: direct or indirect. Direct partnership occurs when performers are accountable for a stage, performance, and activity in the disaster management procedure. Conversely, indirect intervention occurs when performers are influenced or influence the procedure with their behaviors and or functions, without being entirely informed of their effect. When neighbors aid the injured after a landslide in a residential region without the necessary training, they are actually intervening indirectly. Their attempts can actually backfire. The performers will play leastwise one of the following four duties: researcher, agents, media, and population.

2.2.1 Population

The population is not known to be a passive performer for evacuation, healing, and shelter. It has at least one active role: assessment. This work is crucial for the prosperity of disaster management. If organizations do not gain the trust of the people, their success may be jeopardized. In addition, a large number of academic investigations are focused on the population potential role before disaster and on strategies [11,26,27]. The terms "public preparation" and "mitigation" are becoming increasingly used in the literature [9]. Public partnership, without a doubt, can be considered as one of the most powerful instances of a comprehensive approach. The effect of quasiofficial individuals has also been highlighted by several researchers [3]. They are ordinary people who volunteer to help with tasks such as search and rescue, depletion, and so on. They might be a risk source since they are guided by spontaneity rather than education, which can jeopardize the full procedure, even if this partnership is from the heart with good will.

2.2.2 Media

Recent research has studied on the media's role in disaster management, particularly the key responsibilities of postdisaster defeats. Whenever the media effectively educates the public and helps the many direct participants, it would be beneficial [12,28,29]. The media is unquestionably a vital link between the general public organizations [30]. The media, according to McLuhan [31], is a cold operator since it does not provide much precise information and relies on public participation to fill in the gaps. Drabek [32] states that individuals exhibit remarkable inventiveness when it comes to understanding disaster-related news; other researchers concur that suitable strainers among organizations and the media are required (i.e., spokespeople, information sorting, etc.) [3].

2.2.3 Agents and researchers

Direct participants include agents and researchers. These participants are referred regarded be "official" by Perry and Lindell [21] since they engage in disaster management and are held accountable for their actions. Throughout this perspective, academic studies naturally targeted them in recent years. Regardless that agents have received the most of the attention, research investigations have been infrequent [9,11]. When it comes to agents, two distinct study endeavors may be recognized: actor categorization and insights into their unique characteristics. On the one hand, Wybo and Kowalski [33] advocate for their classification scheme of actors and technology. Such assortment has been designed for command centers. Agents are divided into four groups based on their functions:

i) Perception (data gathering and processing)
ii) Analysis (decision-making)

iii) Communication (intraorganization)
iv) Information (intraorganization)

Researchers such as Kreps [20] and Drabek [32], on the other hand, advocate for a sector-based categorization that outlines the distinct sectors participating in disaster management. They specifically identify:

i) Public section (the most related and accountable performer);
ii) Private industry (containing all economic actors); and
iii) Volunteering organizations (i.e., Red Cross and NGOs).

The vast majority of research considers the government who has the whole responsibility as the primary agent for disaster management, while ignoring volunteers and private industries. Researchers have found the importance of other actors recently. Fitzgerald [34] and Cohen [35], for example, highlighted the necessity to include private industry in the plan to increase efficiency. Along the chain of responsibilities, the government may be thoroughly examined by concentrating upon many participating departments and organizations. Alternatively, it might be analyzed using the decentralization concept [3].

2.3 The role of technology and information in disaster management

According to the literature [3], information and data have three primary roles:

i) Comprehending of disasters and hazards
ii) Decision-making
iii) Signaling and communicating

Perception, communication, analysis, and information agents are the elements which facilitate such activities, according to Wybo and Kowalski [33]. Because such agents are supplementary components of the disaster management system, they should be interrelated and linked. To achieve an efficiency improvement, they need to act and collaborate in a distinct interoperable framework. Other research field is devoted to analyzing tools which assist organizations in explaining the reasons of a catastrophe, comprehending the context, developing effective strategies, and making proper decisions. There are a variety of strategies, but the most well-researched are undoubtedly [3]:

i) Markov, Petri, and Bayesian lattices [36,37]
ii) Hazard and Operability Analysis (HazOp) [38,39]
iii) Event and Fault Tree Analysis [40,41]

It's fascinating that much of this content originates through industrial risk assessment and could be utilized to disaster management with minimal disruption. Although the majority of researchers focus on enhancing a certain approach using various algorithms, some concentrate on other disaster management issues. Kuo et al. [41], for example, made an attempt to unify some of the approaches, whereas Aspinall et al. [36] demonstrate the utilization of Bayesian networks to a particular hazard assessment (i.e., volcano).

2.4 Knowledge management and disaster management

One of the key reasons of present disaster management underperformance is poor knowledge exchange and development of inefficient disaster management techniques [42]. Knowledge management (KM) is the process of obtaining the proper knowledge at the correct location and time. The KM objective is to ease the process of making, distributing, and utilizing information. While negative outcomes of disasters are not fully avoidable, attempts may be made to mitigate harmful effects, and understanding the techniques of disaster management, best practices in combination with learned lessons will surely aid in this endeavor through educated mitigation activities and preparation strategies [2].

Disaster management practitioners must be inventive and benefit from insights provided in actual and real-time scenarios in order to adopt best practices throughout the disaster management period. In summary, practitioners need to continually improve their skills and knowledge. Toward that aim, investing in network topologies, databases, and systems is required to build a culture of learning reflexively from previous knowledge as well as current best practices [43].

KM enables individuals, teams, and whole organizations to achieve their operational and strategic objectives via the collaborative and organized generation, distribution, and utilization of knowledge [44]. It aims at enhancing operational performance and effectiveness on the one hand, and increased innovation and competition on the other and to develop information knowledge and translate it into a sustainable competitiveness, such that it may be used to drive business prosperity.

KM deployment could be categorized into three groups: procedures, people, and information technology (IT). IT-based KM and/or supply emphasizes the requirement for (facilitated) accessibility to present information stored in databases or other locations. From a human standpoint, the emphasis of KM for (recorded) knowledge collections has been broadened to incorporate person-to-person relationships that enable community connections and their related technological accompaniment (i.e., customary knowledge environments) [45]. According to the foregoing, some scholars [46–48] employ at least four factors to define KM processes:

i) Process-oriented KM
ii) People-oriented KM
iii) Goal-oriented KM
iv) Technological-oriented KM

Prior findings reveal that people-oriented KM techniques are strongly connected with creativity, and various researchers have confirmed that utilizing people-oriented KM enhances knowledge processes (learning, dissemination, and production), which have an impact on innovation capability [2]. Regardless, people-centered KM methods proved to encourage and create a feeling of creativity through having a favorable impact on peoples' emotional involvement and impersonal confidence. The organization's performance would improve, when all of the effective management process-oriented KM strategies are implemented. Process-oriented KM practices include the notion of KM for management at the pyramid head, knowledge strategy goals diversity and KM tools, and incorporation support aspects (i.e., leadership and cultural principles) [44,45].

Technology-oriented KM assistance for persons that interact, connect, perform information searches, engage in real-time education, and model anticipating is related with a corporation's creativity and ingenuity. Researchers also stated that technologically focused KM is a main driving force of acquiring knowledge, its development, and distribution that speeding businesses' progress toward performance enhancement through creativity and organizational preparedness. Goal-oriented KM is oriented at improving the effectiveness of both organizations and individuals by assuring that the necessary knowledge is available in the proper form and style, at the appropriate location and time [44,45].

2.5 Cycle of disaster management

There are two types of disasters called man-made and natural [6]. Natural disasters are physical phenomena occurring naturally quickly or gradually including landslides, earthquakes, tsunamis, and volcanic activity. Man-made disasters include complex emergencies, famines, displacements, industrial accidents, and transport accidents occurring near or within human settlements. Disasters will become more frequent, complex, and severe as a result of these aggravating elements.

There is a cycle of disaster management that involves governments, communities, and NGOs planning and implementing measures to relieve disasters, deal with disaster consequences, and begin recovery after a disaster. Taking the best actions at every stage of the cycle leads to better preparation, earlier warning, reducing vulnerabilities, and disaster prevention in the future. In order to manage disasters effectively, policies and plans must be developed to change disaster conditions and mitigate their influence on people, properties, and infrastructures. Disaster management includes two types of activities: risk management and management of disasters [49]. While risk management focuses on preventing, mitigating, and preparing, crisis management includes responding, assessing the impact, recovering, and rehabilitating. There are generally four phases associated with disaster management [50]: mitigation, preparedness, response, and recovery following disaster impacts.

Managing disasters effectively is crucial to assure that every action done does not adversely affect decision-making during a disaster. As a result, it includes several factors, namely public warnings, transfer process, victim rescue, emergency assistance, damage assessment, support after the disaster, as well as immediate recovery and reconstruction of infrastructure. Responses aim to offer immediate assistance to affected populations in order to maintain their health, improve their spirits, and support their lives. The aid may consist of special but limited assistance, including victim transportation, temporary shelters, food, and temporary placement in camps. As long as more viable solutions cannot be found, priority should be given to keeping people safe and providing them with basic needs [51].

3. Process of decision-making

During the disaster management cycle, wise decisions need to be made at every stage. There are three common types of decisions namely unstructured decisions, semistructured decisions, and structured decisions. Making unstructured decisions requires judgment, assessment, and insight into the definition of the problem. Such decisions are not made according to any agreed-upon procedure [52]. Many problems have several solutions and paths to solutions, less manipulable parameters, and uncertainty about what assumptions, criteria, and principles are needed and how to organize them, as well as introducing the most-involved solution in terms of ambiguity and information deficiencies. These situations occur unexpectedly and therefore require creative solutions.

In contrast, semistructured decisions are the process of determining which parts of the problem have a straightforward solution based on a set of accepted procedures [53]. Structured and unstructured ranges are separated by this gray area. It is possible here to specify a decision element that allows for certain elements beyond our control. Finally, structured decisions are routine decisions posseting a defined process in order to manage them properly. Structured decisions should not be considered as a new decision. It is possible to plan ahead for them and develop specific strategies to address them or take preventative actions to avoid them [54].

Defining and analyzing the problem, gathering information, assessing the possible solutions, choosing the most suitable solution, employing the solution, and monitoring the solution after the disaster occurrence are required for each case of decision-making options. Each kind of decision-making choice depends on various factors including [53]: the location and time, the responsible person for the decision, the disaster severity, the stage of the disaster, and the disaster geographical location.

3.1 Making disaster management decisions in the mitigation phase

If all required preparations are made appropriately and in accordance with standard procedures, it is possible to detect the disaster using modern technology. Meanwhile, disasters can be minimized, especially in terms of their effects on humans. Prior to a disaster event, each country usually goes through a mitigation and preparation phase. Mitigation is the process of reducing the possibility of disasters or minimizing the impacts of disasters that cannot be prevented. The mitigation process is usually conducted by government agencies, NGOs, or communities in the local area. During disasters, there are several measures that can be taken, including employing building codes, which are vulnerability analysis updates, land use management, building security codes, health care prevention, and public awareness. The extent to which reductions will be achieved will be determined by the measures incorporated into the national and local development plans. In addition, effectiveness is determined by obtaining information regarding hazards, potential emergencies, and the necessary actions [55]. When it comes to mitigation, it is crucial that decisions are made to determine under-control events before and after the disaster.

3.2 Disaster management decision-making through the preparedness phase

Meanwhile, disaster preparedness means being physically and logistically ready for a disaster. The capacity of organization programs in terms of both technical and governmental aspects must be strengthened to maintain a desirable level of preparedness during any disaster situation. It is possible to enhance the response mechanisms of the government, the community, and NGOs by establishing short- and long-term policies, promoting public awareness, and developing systems for early warning. As part of the preparation process, governments, agencies, and individuals devise strategies to lessen disaster damage, decrease the risk of loss of life, and enhance disaster response. Among the steps involved in preparing for an emergency are readiness plans, developing emergency plans, conducting training exercises, designing warning systems, setting up emergency communication systems, identification of source inventory, establishing emergency contact lists, and cooperation agreements, and public education materials. Similar to mitigation efforts, reliance preparation depends on the implementation of effective strategies in the country and regional development plans. Lastly, its efficiency relies on how effectively governments, NGOs, and individuals can leverage information regarding required threats, emergency risks, and responses [6].

3.3 Disaster management decision-making through the response phase

Mitigation and preparedness are followed by the response phase. Disaster-related threats can be addressed quickly by immediate responding to the situation. Actions undertaken in this phase are intended to protect lives, mitigate suffering, respond to humanitarian demands, determine damage, repair, and provide resources. Prior to the preparedness phase, the development of plans for implementation will facilitate response activities [53]. The decision-making process during disasters leads to the security and resilience of communities. In disaster situations, the way decisions are made and the kinds of decisions taken will reveal if they work well or if they have increased the risks to the community [56]. In combination with ineffective decisions and measures, natural disasters bring high risks to communities. In order to make better decisions in real-life disaster situations, it is important to understand what sort of decisions are made in preparation for disasters, including [6]: unstructured, semistructured, and structured decisions.

3.4 The decision-making process during the disaster recovery phase

As soon as life-threatening conditions are over, the recovery phase begins. As quickly as possible, the affected area should be restored to its previous condition during the recovery phase. It differs from the response phase in that the focus is more on decisions that must be made after immediate needs have been met [57]. As part of this phase, the goal is to “build back better” and reduce risks associated with pre-disaster situations by repairing damaged structures, reemployment, and other fundamental infrastructure. Mitigative measures must be implemented to ensure the community is prepared for future disasters of the same magnitude or greater. When a disaster that has just occurred is still vivid in their minds, affected populations tend to support exceptional mitigation techniques more readily. After devastating disasters, restoring a community to its pre-disaster situation might seem difficult, depending on the extent of the disaster [58]. Because of uncertainty about the future, decisions are sometimes unstructured in the recovery phase, and usually include either middle or top management, even though in certain situations they may involve either semistructured or structured decisions. Decisions during the recovery phase are nonroutine, and procedures for making them are not standardized [53]. In light of the impact of the disaster, ambiguities may arise which may require multiple perspectives to solve the problems. In order to create an effective disaster recovery plan, it is crucial to identify decision-making authorities during the recovery phase. During every phase of disaster recovery, the leadership of a disaster recovery team will be required. A senior official with strong leadership abilities and appropriate authority will communicate regularly and transparently to ensure adequate resource allocation and prioritization [59].

3.5 Collaborative decision-making process

Scholars have extensively studied collaborative decision-making [60–62]; however, it has received little attention when it comes to emergency management. It can be defined as combining and utilizing sources and management techniques for the purpose of reaching a common goal by several entities. Several factors have contributed to the failure of emergency response operations, including inadequate organization and unpreparedness [63,64]. The result has been a reevaluation of conventional emergency management methods, focusing more on collaboration as a method for providing support.

In spite of the fact that collaboration can be traced back centuries, it is still relatively new [65]. Although it is a novel concept to many leaders, supervisors, and decision-makers, the tool has become practical and viable with a number of innovations that make collaboration feasible for better delivery of services to the public. Klitgaard and Treverton [66] introduce some of the factors as innovations in technology, dominance of the market as a social force, a shift from centralized to decentralized management, and interconnectedness between previously unrelated phenomena.

Collaboration has already taken place in a variety of industries and fields. Collaboration and partnership have been addressed using emergency and disaster management over the past few years. The collaborative approach to responding to complicated extreme events has become an indispensable tool over the last decade [67]. In large-scale disasters like Hurricane Katrina, for example, coordinating the response and recovery operations of a variety of organizations and jurisdictions can be challenging. In order to address this, organizations need inter- and intraorganizational systems that are closely linked to their ability to deal effectively with problems [64]. The issue of decision-making needs to be addressed as well as many other capacity problems related to emergency management.

3.5.1 Collaborative decision-making approach to emergency and disaster management

As a cornerstone of emergency management, the topic of decision-making has been extensively discussed [56,68–70]. The issue was addressed by some scholars individually [71,72] concentrating on behavioral principles; others concentrating on group behavior [73,74] focusing on trends and behaviors of groups. In addition, some researchers studied emergency decision-making from an organizational perspective [30,75] in order to identify how organizational decision-making should be approached in emergency situations. The majority of decisions in organizations or agencies are made by individuals, whether they are in teams or as individuals, so it is to be expected for decisions made by individuals to be given priority. There was also a distinction regarding the factors that affected emergency decision-making. Several factors have been highlighted in this regard, including [64]:

i) Complexity resulting from the difficulty of the situation and multiple organizations involved.

ii) Uncertainty resulted from a lack of information and chaotic environment.

iii) Time pressure caused by emergency situations that need immediate decisions.

iv) Stress due to the severity and complex nature of the situation as well as the urgency to make a substantial decision.

v) Taking risk in order to make critical and high-stakes decisions.

vi) Previous experience concerning the case at hand.

As opposed to previous experience, which is facilitating decision-making, the other items listed above would negatively impact emergency managers' decision-making process.

It is generally accepted that training, systems for making decisions, and simulation can technically boost and facilitate decision-making during emergencies [76–78]. Generally, the aim of these techniques is to mitigate the negative effects of abovementioned elements on emergency management decisions by developing organizational capacity and professional skills at the individual level.

There were also several different decision-making models presented in the literature, which differed in their inclusion of factors. Two continuums can be used to summarize this variation. An analytical-heuristic approach is one continuum, based on which decision-making focuses entirely on technical details [68,79]; alternatively, decision-making is based only on heuristic judgment [80,81], is supported by prior experience, or is based on situational factors. Second, the continuum consists of differences according to the number of decision-makers involved, ranging from just one person or organization to the maximum [68], whereas at the opposite extreme is the maximum number of organizations or individuals in a particular situation [79].

Due to the unpredictable characteristics of disasters and their consequences, involving a wide range of groups, companies, and stakeholders, collaboration is essential for achieving successful outcomes. Collaboration between a variety of entities is equally essential for increasing the effectiveness of response and reduction of casualties. It becomes more challenging for organizations to deal with when both fields of decision-making and emergency management collaboration are involved. To facilitate and boost decision-making procedures by implementing administrative, organizational, and psychological modifications and adjustments, it is essential that a certain agency or coordinating body have a comprehensive mechanism [82]. Several aspects have contributed to these differences in organizational requirements, adjustments, and methods of management.

Collaboration determines the level of interoperability changes required [83]. Interoperability refers to the functionality of exchanging and utilizing a variety of sources, methods, and mechanisms to enhance the quality of decision-making. As mentioned above, more information leads to a more reliable and low-risk decision, which is based on reducing uncertainty. As stated previously in the context of collaboration, implementing interoperability actively relies on the organization's commitment to collaborate. It is necessary to make sacrifices regarding organizational limitations in order to achieve interoperability. Two elements scholars advocate during emergencies are improvisation and adaptability [62].

The theoretical framework of collaborating on decision-making in emergency situations was proposed by Kapucu [64] based on the previous studies. The framework outlines the fundamental elements that influence shared decisions in emergency situations, crises, and natural disasters. These elements are primarily the systems through which organizations and institutions run and carry out their day-to-day activities, the sector's environment determined by situational factors, primarily related to emergencies, the ability of the parties to fulfill cooperative obligations, and actors' characteristics and preferences in addition to their relationships. The factors are supposed to influence decision-making at both a cognitive and functional level, specifically how organizations perceive and respond to emergencies, as well as how they carry out their duties in response to those perceptions. Factors create the desired collaborative environment that determines whether a collaboration succeeds or fails from a decision-making perspective. If properly coordinated, this would be a joint decision based on agreement among those involved in the joint decision-making.

3.5.2 Decision-making indices

There are two main types of information that decision-makers need: information about the hazardous processes (expected scale and frequency, occurrence time, and spatial extent) and details about the elements at risk. When it comes to endangered elements, a list of possibly impacted construction and infrastructure is very important. In addition, the location of individuals at risk and their social characteristics including age, impairment, salary, and educational status must be considered in decision-making.

This is because previous research has demonstrated that such properties contribute to risk reduction [84]. Natural hazards are likely to affect not all parts equally, so their physical vulnerability may vary [85]. The characteristics of a building, such as its material, scale, shape, and location, determine its vulnerability in a number of ways [86,87].

Indicators are commonly used to assess social vulnerability [88], but mathematical functions have been used to explain how proportional loss relates to hazard magnitude to assess physical vulnerability. In different kinds of hazards such as earthquakes [89], floods in rivers [90], debris flows [91], and tsunamis [92], vulnerability functions have been developed. Empirical data, nevertheless, are necessary to determine these functions. In these data, the magnitude of the process is recorded as well as the building's loss ratio. Several reviews have found that the curves produced are frequently case-specific and are not transferable [93], for instance, the vulnerability factors applicable to the Alps torrential hazards cannot be directly translated to those applicable to Mediterranean torrential hazards [94]. As a result, risk mitigation and disaster planning remain challenging; therefore, decision-makers and experts often feel overwhelmed when short-term mitigation actions need to be taken at the time of an event [93].

To fill this gap, composite indices have been frequently used to assist in decision-making. Despite their ability to improve risk mitigation, disaster management, and collaboration by interpreting complex issues quantitatively, it is possible that they will provide misleading information [95].

Several steps are involved in the development of indicators, such as the selection of indicators, the normalization process, weighting, and data aggregation. An indicator's weight is the most critical step in index construction, which can be determined statistically (by principal component analysis [PCA] or component analysis), collaboratively (by analytic hierarchy process [AHP]), or using the budget allocation process (BAP) [96]. Indicator weighting is intended to (a) detect duplicate information between indicators and (b) determine the most appropriate methods including weighting and aggregation to calculate final index. The statistical approach is based on robust data, whereas participatory approach involves subjectivity [97]. Although expert judgment often relies on extensive experiences, this may actually be a benefit.

In spite of the method employed, a comparison of a variety of risk assessment index construction studies found that the "equal weights" method was most commonly adopted (41.5%) [98].

Using this method, various indicators are included in the final index at the same level, namely the Environmental Vulnerability Index (EVI), the Human Development Index (HDI), and the Social Vulnerability Index (SoVI) [85]. Several studies employed weights determined by the authors, including the ESPON vulnerability index [99]. Participatory and statistical methods were employed in the rest of the studies. Participatory approaches for indicator weighting were most commonly used, as in the Risk Management Index [100], in which local authorities were involved in ranking attributes. The importance of weighting methods and their effect on the value of an index is highlighted through a study of three cases by Becker et al. [101]. Clearly, weighting techniques have a direct impact on the index value. Becker et al. [101] highlight three case studies that illustrate why weighting methods are important for index value and how they affect it. Three indexes (the Water Retention Index, the Good Country Index, and the Resource Governance Index) have been estimated with optimal and original weights, resulting in significant shifts in rankings. For example, as a result of optimizing the Good Country Index weights, resulted in 86 places improved out of 125 [101]. According to the comparison of applying three methods of multivariate vulnerability at the social level to the same dataset [102], it was found that various methodologies produced remarkably different results, suggesting that further research using a variety of indicators and measures is needed.

4. Conclusion

Disaster management consists of several phases, which are readiness, mitigation, response, and recovery. In each phase, proper decisions should be made in order to return the system back into its normal state. Various performers, including population, media, and agents, interfere directly or indirectly in the process of managing disasters. This is while technology plays an important role for making appropriate decisions by these performers and also KM is considered a key in this regard. Recently, the concept of collaborative decision-making has been proposed by researchers in order to improve the process of managing disasters. Besides, several indices have been proposed to quantify the disaster management process and help to increase its efficiency.

References

[1] Reduction, U.N.I.S.f.D. UNISDR terminology on disaster risk reduction. 2009.
[2] Oktari RS, et al. Knowledge management practices in disaster management: systematic review. International Journal of Disaster Risk Reduction 2020;51:101881.
[3] Lettieri E, Masella C, Radaelli G. Disaster management: findings from a systematic review. Disaster Prevention and Management: An International Journal 2009.
[4] (IFRC), I.F.o.R.C.a.R.C.S. What is a disaster?. 2022. Available from: https://www.ifrc.org/what-disaster.
[5] Bostick TP, Holzer TH, Sarkani S. Enabling stakeholder involvement in coastal disaster resilience planning. Risk Analysis 2017;37(6):1181–200.
[6] Arifah A, Tariq M, Juni MH. Decision making in disaster management cycle of natural disasters: a review. International Journal of Public Health and Clinical Sciences 2019;6(3):1–18.
[7] Hensgen T, Desouza KC, Kraft GD. Games, signal detection, and processing in the context of crisis management. Journal of Contingencies and Crisis Management 2003;11(2):67–77.
[8] Robert B, Lajtha C. A new approach to crisis management. Journal of Contingencies and Crisis Management 2002;10(4):181–91.
[9] Hwacha V. Canada's experience in developing a national disaster mitigation strategy: a deliberative dialogue approach. Mitigation and Adaptation Strategies for Global Change 2005;10(3):507–23.
[10] Mansor S, et al. Spatial technology for natural risk management. Disaster Prevention and Management: An International Journal 2004.
[11] McEntire DA, et al. A comparison of disaster paradigms: the search for a holistic policy guide. Public Administration Review 2002;62(3):267–81.
[12] Faulkner B. Towards a framework for tourism disaster management. In: Managing tourist health and safety in the new millennium. Routledge; 2013. p. 175–96.
[13] Henderson LJ. Emergency and disaster: pervasive risk and public bureaucracy in developing nations. Public Organization Review 2004;4(2):103–19.
[14] Shaluf IM, Ahmadun Fr. Technological disaster's criteria and models. Disaster Prevention and Management: An International Journal 2003.
[15] Neal DM. Reconsidering the phases of disasters. International Journal of Mass Emergencies and Disasters 1997;15(2):239–64.
[16] Menoni S, Pergalani F. An attempt to link risk assessment with land use planning: a recent experience in Italy. Disaster Prevention and Management: An International Journal 1996.
[17] Bakir PG. Proposal of a national mitigation strategy against earthquakes in Turkey. Natural Hazards 2004;33(3):405–25.
[18] Dai F, Lee CF, Ngai YY. Landslide risk assessment and management: an overview. Engineering Geology 2002;64(1):65–87.
[19] Simpson DM. Earthquake drills and simulations in community-based training and preparedness programmes. Disasters 2002;26(1):55–69.
[20] Kreps GA. The organization of disaster response: core concepts and processes. International Journal of Mass Emergencies and Disasters 1983;1(3):439–65.
[21] Perry RW, Lindell MK. Preparedness for emergency response: guidelines for the emergency planning process. Disasters 2003;27(4):336–50.

[22] Tobin GA, Whiteford LM. Community resilience and volcano hazard: the eruption of Tungurahua and evacuation of the faldas in Ecuador. Disasters 2002;26(1):28–48.
[23] Phillips BD. Cultural diversity in disasters: sheltering, housing, and long-term recovery. International Journal of Mass Emergencies and Disasters 1993;11(1):99–110.
[24] Choularton R. Complex learning: organizational learning from disasters. Safety Science 2001;39(1–2):61–70.
[25] Batho S, Williams G, Russell L. Crisis management to controlled recovery: the emergency planning response to the bombing of Manchester City Centre. Disasters 1999;23(3):217–33.
[26] Pearce L. Disaster management and community planning, and public participation: how to achieve sustainable hazard mitigation. Natural Hazards 2003;28(2):211–28.
[27] Dixit A. Floods and vulnerability: need to rethink flood management. Flood problem and management in South Asia. 2003. p. 155–79.
[28] Ritchie BW. Chaos, crises and disasters: a strategic approach to crisis management in the tourism industry. Tourism Management 2004;25(6):669–83.
[29] Ray S. A new flood rescue response model. Advanced Rescue Technology Magazine; February/March 2001.
[30] Quarantelli EL. Ten criteria for evaluating the management of community disasters. Disasters 1997;21(1):39–56.
[31] McLuhan M, Cesareo G. Gli strumenti del comunicare. Milano: Garzanti; 1986.
[32] Drabek TE. Understanding disaster warning responses. The Social Science Journal 1999;36(3):515–23.
[33] Wybo JL, Kowalski KM. Command centers and emergency management support. Safety Science 1998;30(1–2):131–8.
[34] Fitzgerald ME. The emergency response plan: key to compliance with the emergency response provisions of the hazardous waste operations and emergency response standard (29 CFR 1910.120). Applied Occupational and Environmental Hygiene 1996;11(9):1154–62.
[35] Cohen MJ. State-level emergency response to the September 11 incidents: the role of New Jersey's Department of Environmental Protection. Journal of Contingencies and Crisis Management 2003;11(2):78–85.
[36] Aspinall W, et al. Evidence-based volcanology: application to eruption crises. Journal of Volcanology and Geothermal Research 2003;128(1–3):273–85.
[37] Liu T, Chiou S. The application of Petri nets to failure analysis. Reliability Engineering & System Safety 1997;57(2):129–42.
[38] Khan FI, Abbasi SA. Towards automation of HAZOP with a new tool EXPERTOP. Environmental Modelling & Software 2000;15(1):67–77.
[39] Kletz TA. Hazop—past and future. Reliability Engineering & System Safety 1997;55(3):263–6.
[40] Demichela M, et al. How to avoid the generation of logic loops in the construction of fault trees. Reliability Engineering & System Safety 2004;84(2):197–207.
[41] Kuo D, Hsu D, Chang C. A prototype for integrating automatic fault tree/event tree/HAZOP analysis. Computers & Chemical Engineering 1997;21:S923–8.

[42] Kaklauskas A, Amaratunga D, Haigh R. Knowledge model for post-disaster management. International Journal of Strategic Property Management 2009;13(2):117–28.
[43] Moe TL, et al. Balanced scorecard for natural disaster management projects. Disaster Prevention and Management: An International Journal 2007.
[44] North K, Kumta G. Knowledge management: value creation through organizational learning. Springer; 2020.
[45] Inkinen H. Review of empirical research on knowledge management practices and firm performance. Journal of Knowledge Management 2016.
[46] Nonaka I, Takeuchi H. The knowledge-creating company: how Japanese companies create the dynamics of innovation. Long Range Planning 1996; 4(29):592.
[47] Shujahat M, et al. Translating the impact of knowledge management processes into knowledge-based innovation: the neglected and mediating role of knowledge-worker productivity. Journal of Business Research 2019; 94:442–50.
[48] Andreeva T, et al. When the fit between HR practices backfires: exploring the interaction effects between rewards for and appraisal of knowledge behaviours on innovation. Human Resource Management Journal 2017; 27(2):209–27.
[49] Noorhashirin H, Juni MH. Assessing Malaysian disaster preparedness for flood. International Journal of Public Health and Clinical Sciences 2016; 3(2):1–15.
[50] Herold S, Sawada MC. A review of geospatial information technology for natural disaster management in developing countries. International Journal of Applied Geospatial Research 2012;3(2):24–62.
[51] Desforges JF, Waeckerle JF. Disaster planning and response. New England Journal of Medicine 1991;324(12):815–21.
[52] Elliott T. Expert decision-making in naturalistic environments: a summary of research. 2005.
[53] Withanaarachchi J, Setunge S. Influence of decision making during disasters and how it impacts a community. 2014.
[54] Thompson SM, et al. Improving disaster response efforts with decision support systems. International Journal of Emergency Management 2006; 3(4):250.
[55] McDermott T, Surminski S. How normative interpretations of climate risk assessment affect local decision-making: an exploratory study at the city scale in Cork, Ireland. Philosophical Transactions of the Royal Society A: Mathematical, Physical & Engineering Sciences 2018;376(2121):20170300.
[56] Cosgrave J. Decision making in emergencies. Disaster Prevention and Management: An International Journal 1996.
[57] Khan H, Vasilescu LG, Khan A. Disaster management cycle-a theoretical approach. Journal of Management and Marketing 2008;6(1):43–50.
[58] Herrmann J. Disaster response planning & preparedness. Spiritual Care and Mental Health for Disaster Response and Recovery 2007:11.
[59] Benjamin GC, Brown L, Carlin E. Strengthening the disaster resilience of the academic biomedical research community: protecting the nation's investment. Washington, DC: The National Academies Press; 2017.
[60] Hills H. Collaborative decision making: how to make it work. Training Journal-Ely 2004:18–29.
[61] Raiffa H, Richardson J, Metcalfe D. Negotiation analysis: the science and art of collaborative decision making. Harvard University Press; 2007.

[62] Turoff M, et al. Dynamic emergency response management for large scale decision making in extreme events. In: Proceedings of the 5th International ISCRAM Conference. Washington, DC, USA: ISCRAM; 2008.
[63] Kapucu N, Van Wart M. The emerging role of the public sector in managing extreme events: lessons learned. Administration & Society 2006; 38(3):279–308.
[64] Kapucu N, Garayev V. Collaborative decision-making in emergency and disaster management. International Journal of Public Administration 2011;34(6):366–75.
[65] Kamensky JM. No one can achieve alone. Collaboration: Using networks and partnerships 2004:3.
[66] Klitgaard R, Treverton GF. Assessing partnerships: new forms of collaboration. Collaboration: Using networks and partnerships 2004: 21–60.
[67] Waugh Jr WL, Streib G. Collaboration and leadership for effective emergency management. Public Administration Review 2006;66:131–40.
[68] Flin R. Decision making in crises: the Piper Alpha disaster. Managing crises: Threats, dilemmas, opportunities 2001:103–18.
[69] Janis IL, Mann L. Emergency decision making: a theoretical analysis of responses to disaster warnings. Journal of Human Stress 1977;3(2):35–48.
[70] Rosenthal U, Boin A, Comfort LK. Managing crises: threats, dilemmas, opportunities. Charles C Thomas Publisher; 2001.
[71] Bigley GA, Roberts KH. The incident command system: high-reliability organizing for complex and volatile task environments. Academy of Management Journal 2001;44(6):1281–99.
[72] Flin R, Slaven G, Stewart K. Emergency decision making in the offshore oil and gas industry. Human Factors 1996;38(2):262–77.
[73] Driskell JE, Salas E. Group decision making under stress. Journal of Applied Psychology 1991;76(3):473.
[74] Takada A. The role of team efficacy in crisis management. International Journal of Emergency Management 2004;2(1–2):35–46.
[75] Rosenthal U, Kouzmin A. Crises and crisis management: toward comprehensive government decision making. Journal of Public Administration Research and Theory 1997;7(2):277–304.
[76] Crichton MT, Flin R, Rattray WA. Training decision makers—tactical decision games. Journal of Contingencies and Crisis Management 2000; 8(4):208–17.
[77] Lindell M, Prater C, Peacock W. Organizational communication and decision making in hurricane emergencies. Pomona, CA: Hazard Reduction & Recovery Center; 2005.
[78] Paton D. Stress in disaster response: a risk management approach. Disaster Prevention and Management: An International Journal 2003.
[79] Smith W, Dowell J. A case study of co-ordinative decision-making in disaster management. Ergonomics 2000;43(8):1153–66.
[80] Moynihan DP. Learning under uncertainty: networks in crisis management. Public Administration Review 2008;68(2):350–65.
[81] Lin D-YM, Su Y-L. The effect of time pressure on expert system based training for emergency management. Behaviour & Information Technology 1998;17(4):195–202.
[82] Raiffa H. Negotiation analysis: the science and art of collaborative decision making. Harvard University Press; 2007.
[83] Diniz VB, et al. Knowledge management support for collaborative emergency response. In: Proceedings of the ninth international

conference on computer supported cooperative work in design. IEEE; 2005.
[84] Kuhlicke C, et al. Contextualizing social vulnerability: findings from case studies across Europe. Natural Hazards 2011;58(2):789−810.
[85] Papathoma-Köhle M, et al. The importance of indicator weights for vulnerability indices and implications for decision making in disaster management. International Journal of Disaster Risk Reduction 2019;36: 101103.
[86] Fuchs S, Heiss K, Hübl J. Towards an empirical vulnerability function for use in debris flow risk assessment. Natural Hazards and Earth System Sciences 2007;7(5):495−506.
[87] Holub M, Suda J, Fuchs S. Mountain hazards: reducing vulnerability by adapted building design. Environmental Earth Sciences 2012;66(7): 1853−70.
[88] Tate E. Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. Natural Hazards 2012;63(2):325−47.
[89] Meslem A, Lang DH. Physical vulnerability in earthquake risk assessment. In: Oxford research encyclopedia of natural hazard science; 2017.
[90] Merz B, et al. Review article "Assessment of economic flood damage". Natural Hazards and Earth System Sciences 2010;10(8):1697−724.
[91] Papathoma-Koehle M, et al. Improvement of vulnerability curves using data from extreme events: debris flow event in South Tyrol. Natural Hazards 2012;64(3):2083−105.
[92] Tarbotton C, et al. The use of empirical vulnerability functions to assess the response of buildings to tsunami impact: comparative review and summary of best practice. Earth-Science Reviews 2015;142:120−34.
[93] Papathoma-Köhle M, et al. Matrices, curves and indicators: a review of approaches to assess physical vulnerability to debris flows. Earth-Science Reviews 2017;171:272−88.
[94] Karagiorgos K, et al. Multi-vulnerability analysis for flash flood risk management. Natural Hazards 2016;82(1):63−87.
[95] Nardo M, et al. Tools for composite indicators building. European Commission, Ispra 2005;15(1):19−20.
[96] Commission JRC-E. Handbook on constructing composite indicators: methodology and user guide. OECD Publishing; 2008.
[97] Simpson DM, Katirai M. Indicator issues and proposed framework for a disaster preparedness index (DPi). University of Louisville; 2006. p. 1−47.
[98] Beccari B. A comparative analysis of disaster risk, vulnerability and resilience composite indicators. PLoS currents 2016;8.
[99] Schmidt-Thomé P, Gensheimer M, van der Lecq R. Achievements and challenges of integrating risk management into European spatial development initiatives. Building Safer Communities. Risk Governance, Spatial Planning and Responses to Natural Hazards 2009:201−18.
[100] Novelo-Casanova DA, Suárez G. Estimation of the risk management index (RMI) using statistical analysis. Natural Hazards 2015;77(3):1501−14.
[101] Becker W, et al. Weights and importance in composite indicators: closing the gap. Ecological Indicators 2017;80:12−22.
[102] Willis I, Fitton J. A review of multivariate social vulnerability methodologies: a case study of the River Parrett catchment, UK. Natural Hazards and Earth System Sciences 2016;16(6):1387−99.

2

Introduction to oil, gas, and petrochemical industries: importance to the current world

Hemaloshinee Vasudevan[1], Sara Zolghadri[2] and Mohammad Amin Makarem[2]

[1] *Tun Razak Graduate School, University of Tun Abdul Razak, Kuala Lumpur, Malaysia;* [2] *Department of Chemical Engineering, Shiraz University, Shiraz, Iran*

1. Introduction

The petroleum industry, commonly referred to as the oil and gas industry, entails the processes of exploration, extraction, refining, global transportation (typically by oil tankers and pipelines), and marketing of petroleum products. Fuel oil and gasoline constitute most of the industry's volume products and supply more than 80% of the current worldwide primary energy demand [1], though they lead to some environmental problems like global warming [2–4] with approximately 98% of total carbon dioxide emission [5]. Pharmaceuticals, solvents, fertilizers, insecticides, synthetic scents, and plastics are just a few of the chemical products that use petroleum (oil) as a raw material. Oil and its byproducts have a very high monetary worth, earning them the nickname "black gold" [6]. Upstream, midstream, and downstream are the three main divisions of the industry. The downstream category also includes activity in the middle. Petroleum is a crucial concern for many nations because it is necessary for numerous sectors and to preserve industrial civilization in its current form. A significant portion of the world's energy consumption is constituted of oil, with the Middle East using 53% of it and Europe and Asia using as little as 32% [7,8]. Each year, the globe consumes 30 billion barrels (4.8 km^3) of oil, with industrialized nations consuming the most. The United States absorbed 25% of the oil produced in 2007 and had some positive impacts [9]. The world's most important industry in terms of financial value is petroleum

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00003-7

production, distribution, refining, and retailing. Almost every step of oil exploration and extraction [10], including the price of leasing oil fields and drilling equipment, is subsidized heavily by governments like the United States, including considerable public subsidies [11]. As this new technique plays a crucial and contentious role in new ways of oil production, hydraulic fracturing has recently risen to the top of the business [12]. The overall rights to oil and gas resources and entrusted with the responsibility of developing and adding value to these resources. It also ranks as the 13th most profitable corporation in the world and the most profitable in Asia [13—15]. Oil and gas industries offer a wide range of petroleum-related services, such as upstream oil and gas exploration and production to downstream oil refining, marketing and distribution of petroleum products, trade, gas processing and liquefaction, running a network of gas pipelines for transmission, marketing liquefied natural gas (LNG), manufacturing and selling petrochemicals, shipping, automotive engineering, and real estate investment.

2. An overview of the oil and gas industry in the world

Oil and natural gas production has had a significant impact on the American West ever since the 1860s, when the first oil wells were discovered in the territories of Colorado and California. The 1920s, 1950s, and 1980s saw waves of boom and recession in the contemporary western petroleum sector. The so-called “Shale Revolution” of the 2000s, which occurred most recently, brought in surges of the improved and new generation of wet and dry oil and natural gas. These events occurred immediately after the methane boom from the coal bed. Between 2000 and 2017, 150,000 wells were successfully completed in the main oil-rich geological basins in the west and northern Great Plains, with 40% of them being horizontally drilled [16]. Shale oil production and gas yields in the United States from 2007 to 2017 were mostly derived from the Niobrara and Bakken formations in the West, which are spread throughout a number of distinct geographic basins [17].

Oil and gas are the primary drivers of the modern economy and are among the main sources of income for the nation through the export of crude oil worldwide. Numerous domestic and international businesses have established themselves over the years, improving or increasing the capacity of their plants. Hengyuan (formerly known as Shell Refining), Petron, BASF, Lotte Chemical Titan, Idemitsu, Toray Group, Penfibre, Kaneka, Eastman Chemicals, Eternal, Polyplastic, UPC Group, Recron, Synthomer, Dairen, Mitsui, and Reliance Group are just a few of these significant businesses [18].

The global economy depends heavily on oil and gas, especially for the major oil-producing nations of the United States, Russia, Canada, China, and Saudi Arabia. The distinctive indicators and complicated terminology utilized in oil and gas operations may be easily overwhelming for novice investors [19]. Top oil-producing countries and companies are represented in Figs. 2.1 and 2.2, respectively.

Global oil and gas output has increased at an average pace of 15% annually during the last 10 years [21]. It is a result of the significant demand from developing nations, particularly China and India. Global growth between 2010 and 2020 suggests that the desire for oil and gas will change as developing economies rise. There won't be a substantial influence on oil and gas consumption in the decade when the green and decarbonization drive is in full swing [22].

An enormous structure applied for processing oil and natural gas is known as an oil rig, offshore rig, or wet oil rig (offshore). Additionally, it is to hold goods until they can be transported to a shore for refinement and marketing. Depending on the platform's condition, the platform also has accommodations for the workforce. A structure with an island that may float and be placed on the ocean floor. A flowline and a central connection are used to connect the subsea remote control of the well. As a result, the seabed may include one or more multiple centers for several wells or one or more subsea wells. Depending on the size and depth of the sea, many structures are employed offshore [23].

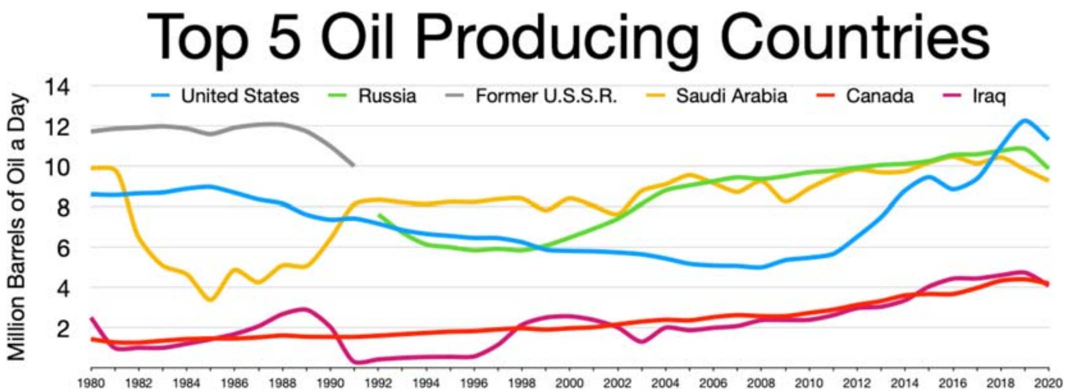


Figure 2.1 Top five oil-producing countries 1980–2020 [20].

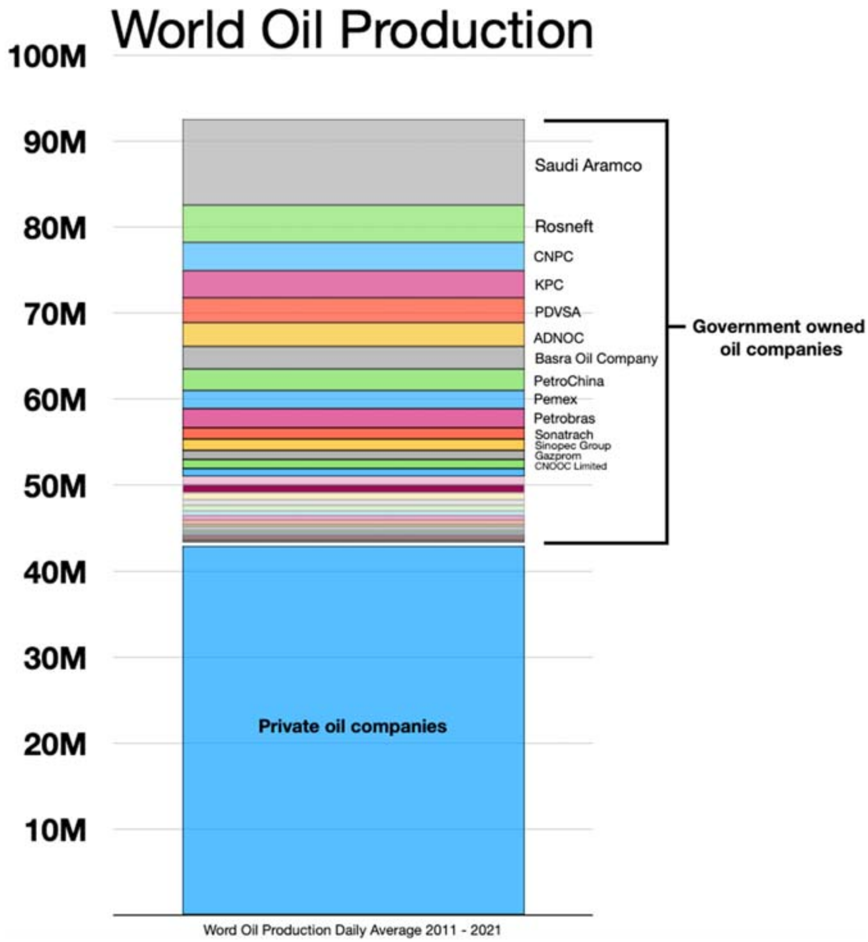


Figure 2.2 World oil production companies 2011–2021 [20].

Global oil and gas production capacity soared ahead of demand during the 2008–09 financial crisis. It led to a temporary but considerable decline in oil prices and ongoing turmoil in the global gas market. The gas market has become unstable due to increased domestic shale gas production in the United States. By the middle of this decade, a tighter balance between production and demand is anticipated in both oil and gas as demand growth outpaces production infrastructure. Growth in the upstream industry over the past 10 years has been influenced by growing oil and gas prices rather than by an increase in production [24,25].

The large-scale COVID-19 outbreak and pandemic control measures have hampered large-scale activity. Compared to the global financial crisis, weekly claims by the unemployed increased much faster, while industrial production and retail sales fell much more sharply. Meanwhile, falling oil prices have depressed investment in the US shale oil sector and announced long-term measures to stabilize the financial system [26,27]. Perhaps the profits of oil and gas companies depend on the world oil price. Upstream business companies will have a positive advantage if oil prices rise because their services are directly dependent on crude oil prices. Companies that provide brownfield operation services (explored oil wells) from the remediation subindustry have the most significant impact.

Although the oil and gas resource base is declining, there is potential in mature and technically more complex oil fields. Initiatives that will derive from growth in the future are enhanced oil procurement, innovative approaches to the development of small oil fields, or increased exploration activities to find oil and gas faster [28,29].

2.1 Asia

In 2025, significant projects in Southeast Asia are projected to produce 8.1 billion cubic feet per day (bcfd) of gas and around 223 thousand barrels of oil per day (mbd) of crude oil, respectively. Around 80% of the crude produced in the region in 2025 will come from Indonesia and Malaysia. Together, Thailand, Vietnam, Cambodia, and Myanmar generate the remaining portions of petroleum and condensate. With 3.1 bcfd of natural gas output in 2025, Indonesia will also be the top country in Southeast Asia. The remaining 62% of the region's gross domestic product (GDP) is anticipated to come from Malaysia, Vietnam, Myanmar, and Thailand in 2025. A significant portion of the world's crude production—roughly 223 thousand barrels per day (mbd)—will come from projects in Southeast Asia (Fig. 2.2). It can be observed with the oil discovery in Peninsular Malaysia's East Coast region in the late 1970s, which has given the local economy and Terengganu state's products a new lease on life. In these rural areas, the petroleum and natural gas industry has created an opportunity for the process development change. For those investors who desire to engage in this sector, the rising demand for the raw resources gas and oil is a better place to start. The oil and gas sector will contribute to the development of more groups. High income in this nation is a result of its great demand in the modern international market. The increasing demand for this industry's products will aid in the growth of this sector and provide additional job opportunities [30,31].

Increased collaboration among the Eurasian nations would have significant economic ramifications. The sea lines of communication (SLOCs) and Middle Eastern oil, which is now Northeast Asia's main source of energy, would be less dependent on via improved regional cooperation. Because of the region's dependence on Middle Eastern oil and the absence of alternatives, as well as the fact that shipping from the Middle East is prohibitively expensive, there is now insurance on oil imports to Northeast Asia of \$1—\$2 per barrel. With the premium described above, the total amount of oil imported in 2000 was 13.7 MBD, costing the economies of Northeast Asia an additional \$5—10 billion annually. Thus, if the Russian and Central Asian energy source were made available to Northeast Asia, it would result in a considerable reduction in the prices for the region's economy as well as an increase in investment in the Central Asian and Russian economies, which are more fragile [32].

2.1.1 Brunei Darussalam

For the past 90 years, Brunei Darussalam's economy [33] has benefited tremendously from the upstream and downstream oil and gas industries. The oil and gas sector in Brunei Darussalam has long been a crucial factor in the growth and development of the nation, beginning with the finding of the first well in Ayer Berkunchi in 1899 and continuing with the foundation of the Petroleum Authority of Brunei Darussalam in 2019. The first exploratory well in Brunei Darussalam was dug close to the nation's capital, Bandar Brunei, in 1899, marking the beginning of the country's oil business. Oil was then found in the Seria field in the Belait District in 1929, and a series of industrial discoveries came after that, leading to Brunei's first oil export in 1932. The major oil producer in Brunei Darussalam, Brunei Shell Petroleum (BSP) Sdn Bhd, generates around 90% of the nation's oil and gas earnings [34,35]. Brunei Darussalam has made considerable investments in the growth of its downstream sectors to broaden its product offering in the oil and gas value chain. Future predictions indicate that this tendency will continue, enabling us to satisfy the rising need for new technology and talents. Brunei Darussalam continues to optimize its mature oil and gas potential to meet the sector's needs in additional exploration and development efforts. Additionally, it ensures that the local populace is well educated and technically skilled. Cooperation between the government and oil and gas companies is essential to sustaining prospective activities and ensuring the long-term output of the nation. With a 49.6% contribution to the country's GDP in 2021, the oil and gas industry is the key driver of the nation's growth.

2.1.2 Malaysia

The first commercial well was found in Miri, Sarawak, at the beginning of 1910, which marked the start of Malaysia's petroleum industry [36]. After the manufacturing sector, this sector contributed the second-highest amount to the national economy in 1988. This sector contributed to most of the nation's commodity exports and global environmental challenges at the end of 1991. The development of the petroleum industry in Malaysia is influenced by some factors such as the extent of the contract area, the record of discoveries, the political situation of the country and the world, government policy, production distribution system, total demand, price of petroleum products, infrastructure facilities, labor force, and incentives offered. So, the country's contract area is approximately 530,000 square kilometers and up to now, with the remaining oil reserves of 3.8 thousand million barrels and gas reserves of 67.8 trillion cubic feet (TCF). Thus, the country's contract area is roughly 530,000 square kilometers, and its residual oil and gas reserves are 3.8 million barrels and 67.8 TCF, respectively. The nation's oil reserves can last for another 15 years, assuming no more reserves are found and an average daily oil production rate of 600,000 barrels. The nation's oil reserves can last for another 15 years, predictably no more reserves are found, and an average daily oil production rate of 600,000 barrels. With an average gas production rate of 1.7 thousand million cubic feet/day, the country's gas reserves can last for another 95 years [37].

The Petroleum Income Tax Act (PITA) Bill, which offers incentives for the development of offshore oil and gas wells in the nation, is one of the significant advancements made in the National Key Economic Areas (NKEAs) for the oil, gas, and energy sector in the last year. In response, the government has made several strategic moves to strengthen the nation's capacity, particularly in establishing an environment that can sustain the growth of the refining, storage, and trading chain. Various tax incentives and unique nontax incentives have been developed to assist private entrepreneurs' involvement in the evaluation of the oil and gas industry [38].

2.1.3 Singapore

An aggressive Singaporean petrochemical company is export-oriented, and the country continues to develop into a second petrochemical cluster, the largest in the world. Malaysia still imports most of the refined petroleum products from Singapore. In 2017, imports amounted to around RM 30 billion or 42% of the total. This number is expected to decrease significantly throughout the Pengerang Integrated Petroleum Complex (PIPC) operation. Although it looks like PIPC is taking market share from Singapore, PIPC only meets local demand and replaces imports. Singapore is expected to maintain its status as a major oil and gas trading hub in the Asia Pacific, even when the PIPC is fully operational later. It is because Singapore has a comprehensive ecosystem for trading, storage, transshipment, bunkering, manufacturing, and research and development (R&D) [39,40].

2.1.4 China

China has been identified as having the most immediate requirement for new energy sources among the Eurasian nations. China is becoming more and more dependent on energy imports as a result of the rate of its economic development and the resources required to support its modernization drive [41]. Since 1993, China has been forced to import petroleum products, and in 1995, the country's shortage of oil resources caused it to turn into a net importer of raw oil. According to official Chinese figures, between 1996 and 2002, the amount of imported oil rose from around 20 million tons to 70 million tons. According to studies on maritime oil transportation conducted by China's Ministry of Communications, the nation will import 100 million tons of crude oil in 2005, 150 million tons in 2010, and 250–300 million tons by 2020. Without a doubt, China will become more and more dependent on raw oil imports, with the percentage of raw oil imports growing from 31% in 2002 to 50% in 2007 [42].

2.1.5 Japan

In recent years, Japan's weak economic development has resulted in static energy consumption. Nevertheless, energy security is still a crucial problem for national security. It's due to Japan's lack of major indigenous energy resources, which forces it to import practically all of its energy requirements. More than 79% of the nation's major energy needs were imported in 2001 [43]. Until late 2003, when China passed Japan as the top oil importer, the United States remained in the first place. Iran has become a point of contention between China and Japan in their search for energy security. The greatest buyer of oil and gas from Iran at the moment is Japan, but China may soon surpass it. China and Iran struck a preliminary agreement last year for $100 billion, according to which China would buy 10 million tons of LNG annually for 25 years [42].

2.1.6 South Korea

South Korea is also joining the fray in the fuel race. South Korea was the fifth-greatest net oil importer and the world's seventh-largest oil user until 2003 [42]. In 2004, the South Korean Government visited the Kremlin, where he signed $4 billion worth of fuel contracts with Russian businesses, most of which were related to oil. One of these is the $250 million deal reached between Rosneft, an oil company with close ties to the Kremlin that is about to merge with the massive Gazprom natural gas company, and the Korea National Petroleum Company to investigate the oil resources of Sakhalin Island and distant Kamchatka at the extreme northeastern corner of Russia [42].

As has been suggested before, a gas and oil union may in reality provide a forum for debate on energy security that could have an influence on financial and investment choices as well as political involvement. The issue of energy cooperation is crucial in this context because it has the ability to forge long-term bonds of reciprocal engagement and beneficial dependence, reducing the likelihood of fierce battles in Eurasia.

2.2 United States

It is impossible to establish, based on current patterns in US energy consumption, that dramatically reduced natural gas costs influenced its replacement for oil. In addition, the Environmental Impact Assessment's (EIA's) predictions for the US energy market suggest that prices will have minimal impact on the replacement between gas and other fuels. Fig. 2.3 demonstrates that the consumption of natural gas in the United States began to increase in 2006. The great recession of 2008–09 had little to no impact on United States' natural gas usage. The usage of petroleum products in the United States also started to decline in 2005. Unlike natural gas, the great recession significantly reduced oil usage. With drops that started in 2009, it seems that decreasing natural gas prices have an impact on coal usage.

EIA anticipates that until 2034, US consumption of natural gas will continue to fall generally, but that consumption of oil will

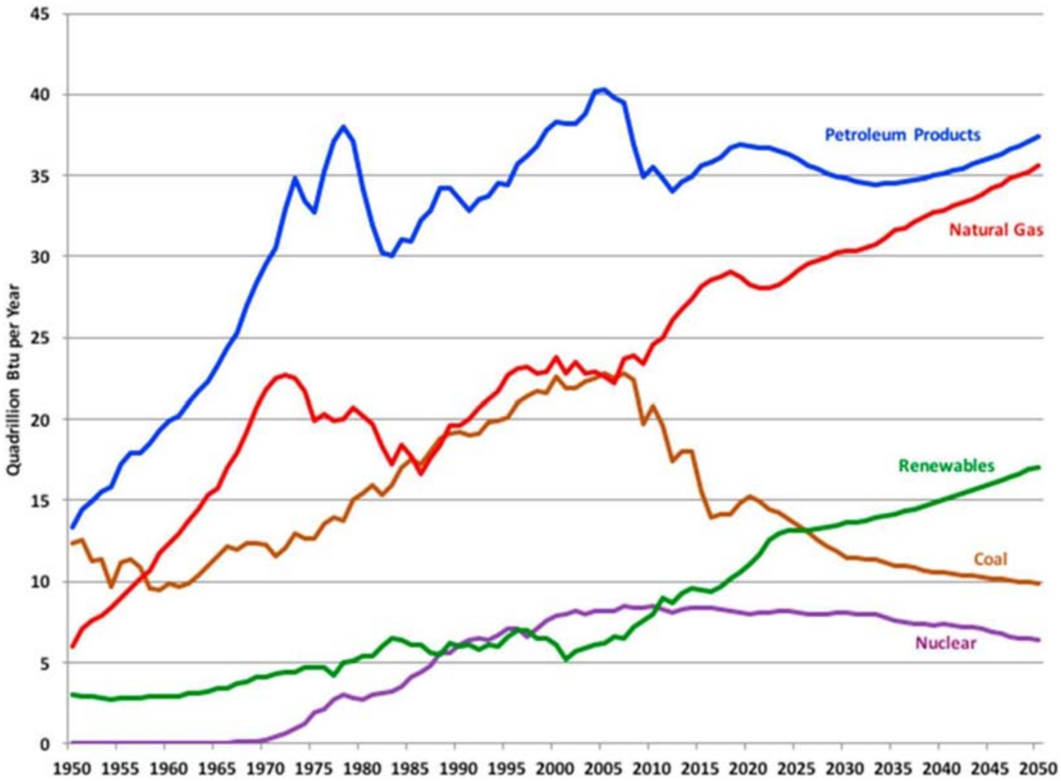


Figure 2.3 United States fuel consumption by main source [44].

stay mostly stable due to the growing utilization of biofuels as a substitute for petroleum products [5]. EIA forecasts gradual growth in the use of all liquids and petroleum products beyond 2034. Through 2022, according to the EIA, US natural gas consumption is forecast to be on the decrease, but, beyond that point, it is anticipated to increase. Additionally, the EIA anticipates relatively constant united state coal use until 2020, after that it is anticipated to start decreasing again [44].

Petroleum and natural gas products prices are often related to one another across the world via mechanisms such as interfuel substitution and contractual agreements. As the price of raw oil begins to rise, the United States will face significant market pressure to increase LNG exports due to the abundance of cheap, readily available natural gas. US LNG net exports are projected to increase from 0.09 TCF in 2016 to 4.38 TCF in 2017, according to the EIA's 2017 yearly forecast for energy, despite the fact that domestic natural gas prices are not expected to reach parity with global raw oil prices.

However, Barnes and Bosworth [45] and Neumann [46] show proof that there is some correlation between global LNG trade and natural gas prices, which is consistent with the EIA prediction. According to a study by Ebinger et al. [47], it is probable that US LNG exports have only somewhat increased United States gas prices. In a similar vein, the energy modeling forum [48] concludes that although United States LNG exports may raise natural gas prices in the country, such prices will still be below par with global raw oil prices on a British thermal unit (Btu) basis. The prices of natural gas in the United States won't be correlated with those of crude oil globally [44].

2.3 Australia

The economy of Australia is heavily dependent on energy use, and this dependence will only grow in the future. Nonrenewable energy sources including gas, coal, and oil presently provide 94% of Australia's overall energy needs. Fig. 2.4 shows the major main energy sources used by fuel type in 2015–16. Clearly, petroleum was the largest energy source, accounting for 37%, followed by

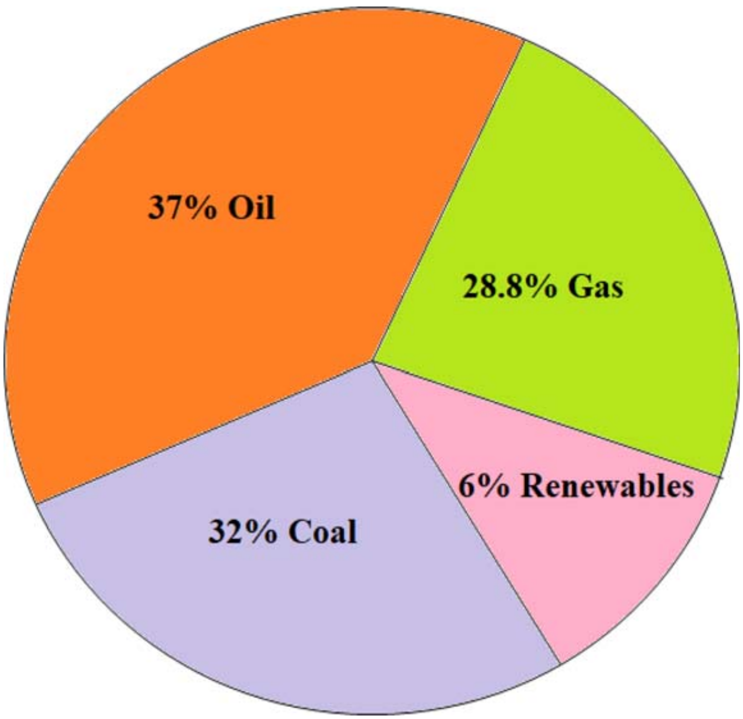


Figure 2.4 Australian energy usage (%) by type of fuel in 2015–16. Data adopted from Ref. [49].

coal at 32.2% and gas at 24.4%. Australia's energy consumption increased by 0.6% annually during the last decade. Only 6% of energy is renewable, and the bulk of bioenergy derived from biomass [49].

2.4 Africa

Africa has an abundance of petroleum, gas, as well as other sources of energy. Investigation for these elements on the continent began around the turn of the century, but commercial findings were not reported until the 1950s. In the 1970s, significant industrial and household activities in consuming nations were dependent on Middle Eastern oil, but subsequent changes in the Middle East pushed IOC operations to be relocated to oil-bearing areas in Africa. The Gulf of Guinea, which is expected to contain 5–12 billion barrels of raw oil, is a hotspot in the area.

According to experts, the continent provides for 8% and 10% of the globe's reserves of natural gas and oil, respectively, based on its current production levels. The development of raw oil output from less than 1 mmbd in the 1950s to well over 10 mmbd in 2006 may be attributed to the growing interest in the sector worldwide. Equatorial Guinea, Angola, and Sudan are now among the African countries that produce oil in recent decades [50].

2.5 Europa

Europe is heavily reliant on oil and natural gas as its main energy and as a significant supply of raw materials for the industrial and chemical sectors. Oil-derived petroleum products (petrol, diesel, and kerosene) are necessary fuels for transportation, whereas natural gas is commonly utilized to produce power and for warmth [51].

As much as it reflects technological advancements and regional geology, the history of the European oil and gas sector also reflects regional and global political events, economic restrictions, and the individual efforts of petroleum geoscientists. The current, international oil and gas sector was overwhelmingly shaped by Europe and Europeans. Europe used oil sparingly from at least the Iron Age until the 1850s, and it was virtually solely extracted from surface seeps and mine workings. In the 1860s, new technology in oil extraction and refining led to increased use of oil. Shale oil was commercially distilled in several regions of Europe in the late 18th and early 19th centuries, but by the second half of the century, the demand for mineral oils and gas, which came mainly from shale and coal, was no longer met. As a result, oil production directly from conventional oil fields began to dominate the European market [51].

The first oil wells used for commercial purposes in Europe were manually drilled in Poland in 1853, Romania in 1857, Germany in 1859, and Italy in 1860, before the early 1860s saw the increasing adoption of mechanized cable drilling rigs. One of the most productive hydrocarbon regions in the globe in the late 19th century was the northern Carpathian Mountains, which are located in what is now Poland and Ukraine. The oldest industrial oil field in the world is the Polish Carpathian foothills' Bóbrka Field, which was found in 1853 and is still in operation today [51]. Despite having never attained worldwide extremely high levels of conventional petroleum, a number of European nations, including France, Germany, and Italy, have a strong oil legacy that is rich in innovation and technology. This scarcity of conventional oil reserves impacted both their efforts to explore alternative energy sources and, in the second half of the 20th century, their residents' achievement as "oil finders" in the world's oil fields [52].

3. Overview of oil and gas industries

Three sectors—upstream, midstream, and downstream—make up gas and oil production [53]; the details of each sector are explained in the following section. Upstream, midstream, and downstream oil and gas operations are three related categories because they relate to a company's place in the production process. Oil and gas are extracted in the upstream phase, transported, processed, and stored in the midstream, and then transformed into finished goods for the general public's use in the downstream phase [54].

3.1 Upstream

This is the name for activities carried out in the sector that are related to the search for and extraction of gas and oil. Businesses in the upstream sector discover and extract from raw reservoirs. They generally deal with drilling and bringing oil and gas to the surface, which are the first phases of the production process. The abbreviation E&P, which stands for exploration and production, is frequently used to refer to upstream companies.

This market is frequently characterized by large investment capital requirements, lengthy durations, significant risks, and a focus on technology. The majority of these companies' statement line items and cash flow are directly related to the extraction of oil and gas [55].

3.2 Midstream

The midstream market is primarily concerned with anything needed to move and store gas and oil. Transporting extracted natural gas and oil to refineries for processing is the responsibility of midstream enterprises. Tank trucks, pumping stations, transcontinental tankers, and retail tank cars are just a few examples of the infrastructure needed to move these commodities across vast distances.

Pipelines, shipping, raw material storage, and trucking are often characteristics of midstream firms. They are also characterized by rigorous regulation and low capital risk. Naturally, the performance of upstream companies affects this sector [56].

3.3 Downstream

Downstream refers to the last ring in the gas and oil industry chain. They are refineries, which are businesses in charge of processing natural gas and raw oil into a variety of products that people use on a daily basis, including jet fuel, gasoline, asphalt, and heating oil. Long-chain hydrocarbons, which make up oil and gas, are used to make less noticeable but equally vital items like synthetic rubber, containers, preservatives, and plastics [57]. Additionally crucial to the domains of agriculture and medicine are downstream businesses. It seems to reason that downstream businesses may gain from an excess of oil and gas supplies in the upstream sector.

This sector of the oil and gas industry, which is the last step in the production process, includes refiners of raw oil and natural gas processing that are useable directly to end consumers. They also sell and distribute goods made from natural gas and raw oil. The downstream gas and oil market, to put it simply, is all that has to do with the operations that take place after the manufacture of natural gas and raw oil. Numerous goods that people use on a daily basis, such as propane, gasoline, natural gas, lubricants, diesel, heating oil, insecticides, and medications, are produced downstream.

Oil refineries, distributors of petroleum products, petrochemical facilities, distributors of natural gas, and retail establishments are among the businesses involved in the downstream process.

Additionally, diverse and active at all stages of the manufacturing process are several large downstream enterprises [58].

4. Oil and gas processing

4.1 Wellhead

The wellhead is positioned above the gas or oil well that leads to the storage. Additionally, a wellhead might be an infusion well that is used to reinject gas or water into the storage to regulate levels and pressure and increase production. Following the isolation of the gas, the process should complete allowing natural gas or petroleum to flow from the formation to the surface. It is necessary to finish a well in order to enable natural gas or oil to flow from the creation to the surface after drilling a natural gas or oil well and assessing the commercial amounts of oil and gas extracted. In order to effectively facilitate the flow of natural gas from the well, this technique entails strengthening the wellbore with a casing, measuring the temperature and pressure of the production, and fitting the necessary equipment. The flow of the well is controlled by a choke [59].

Onshore, a system of collection pipes and manifold networks transports each well fluid into the primary manufacturing facilities. These are designed to enable the configuration of production "well sets," allowing the optimal reservoir usage, well stream composition (oil, gas, and waste) to be chosen from the usable wells for a particular production level. For multiphase streams, the rising price of multiphase stream meters usually necessitates the utilization of software flow rate algorithms that utilize test results to determine the real flow [60].

4.2 Separation

Some wells generate pure gas, which may be sent straight to facilities for compression and/or gas treatment. Typically, the well produces a mixture of oil, gas, water, and pollutants that must be extracted and treated. Manufacturing separators are available in several shapes, with the density separator becoming the most common. Well stream is injected into a vertical vessel during the separation process. The retention period is typically 5 min, allowing gas to leave, water to gather at the bottom, as well as petroleum to be retrieved in the canter. In order to ease the controlled extraction of volatile compounds, the pressure often is reduced in certain areas. A quick decrease in pressure could permit flash vaporization, resulting in instability and safety risks [61].

4.3 Gas compression

Natural gas from a wellhead may contain sufficient pressure to enter a pipeline transport network directly. Generally, the gas from dividers has decreased pressure that has to be recompressed before it can be moved. Compression comprises a substantial amount of auxiliary equipment, including scrubbers (for eliminating liquid droplets), oil purification, and heat exchangers. Following natural gas has been extracted from the raw oil, often it is found in mixes with several hydrocarbons, primarily propane, pentanes, ethane, and butane. Additionally, crude gas includes hydrogen sulfide (H_2S), helium, water vapor, carbon dioxide, and nitrogen, among other chemicals.

The natural gas procedure involves removing all liquids and hydrocarbons from the raw gas in order to obtain dry gas in pipeline grade. Typically, important transport pipelines put limitations on the composition of the pure gas authorized to enter the pipeline. Therefore, pure gas should be cleansed prior to being delivered. Natural gas liquids (NGLs) are utilized as crude resources in oil refineries and petrochemical facilities, as well as energy sources [62].

5. Unconventional sources of oil and gas

Production of gas and oil from unconventional sources is becoming more appealing as demand rises, prices skyrocket, and new conventional resources are harder to come by. Very heavy crudes, coal-derived synthetic crude, coal bed methane, and oil shale are some of these unconventional sources. Oil and gas reserves that are conventionally confirmed and producible have varying estimates. Even with energy conservation measures, the present rate of consumption growth is less than 2% annually or 15%–20% over a 10-year period for various items. The time to go statistics mentioned above will be halved if this trend persists [63].

5.1 Extra heavy crude

Hydrocarbons classified as extremely heavy crude have an American Gas Association (API) grade of 15 or less. Venezuelan 8 API oil, which is now exploited, for example, in eastern

Venezuela, is the most extreme heavy crude. Crude will flow out of the reservoir if the temperature is high enough. Steam injection is necessary to promote formation flow in Canada, where the storage temperature is reduced [63].

When the crude reaches the surface, it needs to be blended with a diluent such as liquefied petroleum gas (LPG) so that it can flow through tubes. The crude has to be improved in a processing facility to create SynCrude, which is lighter and has a greater yield of high-value fuels. An API of 26–30 is typical for SynCrude. The diluent is recycled by separating it and sending it again to the wellhead site. The crude passes through multiple steps of hydrocracking and coking to remove coke and create lighter hydrocarbons. Sulfur (sour crude) is frequently present and must be eliminated [64].

5.2 Methane hydrates

The most recently discovered and studied type of unconventional fossil fuels is methane hydrates. These structures consist of a frozen water lattice that acts as a type of cage for the methane molecules. The majority of deepwater continental shelves investigated have indicated the presence of hydrates, which were originally found in permafrost areas of the Arctic. Methane may develop from organic decomposition. The hydrate is heavier than water at the ocean's bottom, where it will remain due to high pressure and low temperatures. They could be considerably more common than initially thought, according to research. The predictions range from 180 to more than 5800 trillion scm [65].

6. Conclusion and future outlooks

Gas and oil will still be the most significant sources of energy worldwide even as the transition to cleaner energy sources is underway. Petrochemical industry maintains that even as oil prices decline, it will continue to accelerate the transition to a low-carbon economy, prompting policy interventions and global cooperation across the industry. While gas remains a crucial and clean fuel source, diversification in renewable energy is urgently needed. Thus, this has made the global government realize how necessary it is to control an industry that has strategic economic importance to the country considering that the oil market is a market that can help generate and develop the national economy. In this chapter, the effect of the oil and gas industry on the continent of Asia, Europe, Africa, the United States, and investor countries was investigated and explained. Besides being the natural resource of the country, oil provides foreign exchange resources for global industries and accelerates economic growth. There are three categories of petroleum and gas mechanisms: upstream, midstream, and downstream. Numerous goods that people use on a daily basis, such as natural gas, gasoline, propane, heating oil, diesel, insecticides, medications, and lubricants, are produced downstream.

Although oil and gas resources are declining, there is potential for increased oil and gas capacity in mature and technically more advanced oil fields. Therefore, future research is needed to advance the technology of the oil and gas industry. Among the initiatives that will increase the growth of the oil industry in the future are: innovative approaches to the development of oil fields or increased exploration activities to find oil and gas faster, which should be carefully studied.

References

[1] Rahimpour MR, Makarem MA, Meshksar M. Advances in Synthesis Gas: Methods, Technologies and Applications. Volume 3: Syngas Products and Usages. 3. Elsevier; 2023.

[2] Rahimpour MR, Biniaz P, Makarem MA. Integration of microalgae into an existing biofuel industry. Bioenergy systems for the future. Woodhead Publishing; 2017. p. 481–519.

[3] Rahimpour MR, Kamali R, Makarem MA, Dehghan Manshadi MK. Advances in Bioenergy and Microfluidic Applications. Elsevier; 2021.

[4] Makarem MA, Kiani MR, Farsi M, Rahimpour MR. CFD simulation of CO_2 capture in a microchannel by aqueous mixtures of MEA and [Bmim]BF_4 modified with TiO_2 nanoparticles. International Journal of Thermophysics 2021;42:57. https://doi.org/10.1007/s10765-021-02812-1.

[5] Makarem MA, Moravvej Z, Rahimpour MR, Vakylabad AB. Biofuel production from microalgae and process enhancement by metabolic engineering and ultrasound. In: Advances in bioenergy and microfluidic applications. Elsevier; 2021. p. 209–30.

[6] Brew G. Petroleum and progress in Iran: oil, development, and the cold war. Cambridge University Press; 2022.

[7] Adebiyi FM. Air quality and management in petroleum refining industry: a review. Environmental Chemistry and Ecotoxicology 2022;4:89–96.

[8] Mahmood H, Maalel N, Hassan MS. Probing the energy-environmental Kuznets curve hypothesis in oil and natural gas consumption models considering urbanization and financial development in Middle East countries. Energies 2021;14(11):3178.

[9] Shahbaz M, Kablan S, Hammoudeh S, Nasir MA, Kontoleon A. Environmental implications of increased US oil production and liberal

growth agenda in post-Paris Agreement era. Journal of Environmental Management 2020;271:110785.
[10] Quitzow R, Bersalli G, Eicke L, Jahn J, Lilliestam J, Lira F, Xue B. The COVID-19 crisis deepens the gulf between leaders and laggards in the global energy transition. Energy Research & Social Science 2021;74:101981.
[11] Le MT. An assessment of the potential for the development of the shale gas industry in countries outside of North America. Heliyon 2018;4(2):e00516.
[12] Eckhouse G. United States hydraulic fracturing's short-cycle revolution and the global oil industry's uncertain future. Geoforum 2021;127:246–56.
[13] Doraisami A. Has Malaysia really escaped the resource curse? A closer look at the political economy of oil revenue management and expenditures. Resources Policy 2015;45:98–108.
[14] Gale B. Petronas: Malaysia's National Oil Corporation. Asian Survey 1981; 21(11):1129–44.
[15] Menon J. Government-linked companies: impact on the Malaysian economy. Policy Ideas 2017;45:1–26.
[16] IHS Markit. Enerdeq browser. 2018. https://ihsmarkit.com/products/oil-gas-toolsenerdeq-browser.html.
[17] Haggerty JH, Kroepsch AC, Walsh KB, Smith KK, Bowen DW. Geographies of impact and the impacts of geography: unconventional oil and gas in the American West. The Extractive Industries and Society 2018;5(4):619–33.
[18] Malaysian Investment Development. Malaysia's petrochemical industry. 2020. https://mida.gov.my/wp-content/uploads/2020/07/20200707111635_Petrochem.pdf.
[19] Semieniuk G, Holden PB, Mercure JF, Salas P, Pollitt H, Jobson K, Viñuales JE. Stranded fossil-fuel assets translate to major losses for investors in advanced economies. Nature Climate Change 2022:1–7.
[20] Wikipedia contributors. List of countries by oil production. Wikipedia, The Free Encyclopedia; 2022, December 2. Retrieved 10:04, December 5, 2022, from, https://en.wikipedia.org/w/index.php?title=List_of_countries_by_oil_production&oldid=1125236173.
[21] Barbosa F, Bresciani G, Graham P, Nyquist S, Yanosek K. Oil and gas after COVID-19: The day of reckoning or a new age of opportunity. McKinsey & Company; 2020.
[22] Khan MI, Yasmeen T, Shakoor A, Khan NB, Muhammad R. 2014 oil plunge: causes and impacts on renewable energy. Renewable and Sustainable Energy Reviews 2017;68:609–22.
[23] Adeola AO, Akingboye AS, Ore OT, Oluwajana OA, Adewole AH, Olawade DB, Ogunyele AC. Crude oil exploration in Africa: socio-economic implications, environmental impacts, and mitigation strategies. Environment Systems and Decisions 2021:1–25.
[24] Kee DMH, Liyana NA, LuXin Z, Atikah N, Alwanis N, Afniza R. Analyzing the impact of Covid-19 on the oil and gas industry: a case study of Petronas. Journal of the Community Development in Asia (JCDA) 2021;4(2):26–33.
[25] Khan RA, Liew MS, Ghazali ZB. Malaysian construction sector and Malaysia vision 2020: Developed nation status. Procedia-social and behavioral sciences 2014;109:507–13.
[26] Razek NH, McQuinn B. Saudi Arabia's currency misalignment and international competitiveness, accounting for geopolitical risks and the super-contango oil market. Resources Policy 2021;72:102057.
[27] Siegel JJ. Stocks for the long run: the definitive guide to financial market returns & long-term investment strategies. McGraw-Hill Education; 2021.

[28] Grant RM. The development of knowledge management in the oil and gas industry. Universia Business Review 2013;(40):92−125.
[29] Khor CS, Lalchand G. A review on sustainable power generation in Malaysia to 2030: historical perspective, current assessment, and future strategies. Renewable and Sustainable Energy Reviews 2014;29:952−60.
[30] Javaid M, Haleem A, Singh RP, Suman R, Gonzalez ES. Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability. Sustainable Operations and Computers 2022;3:203−17.
[31] Maddikunta PKR, Pham QV, Prabadevi B, Deepa N, Dev K, Gadekallu TR, Liyanage M. Industry 5.0: a survey on enabling technologies and potential applications. Journal of Industrial Information Integration 2022;26:100257.
[32] Kenny HJ. China and the competition for oil and gas in Asia. Asia-Pacific Review 2004;11(2):36−47.
[33] Aditiya HB, Aziz M. Prospect of hydrogen energy in Asia-Pacific: a perspective review on techno-socio-economy nexus. International Journal of Hydrogen Energy 2021;46(71):35027−56.
[34] Cheung JCS. Rentier welfare states in hydrocarbon-based economies: Brunei Darussalam and Islamic Republic of Iran in comparative context. Journal of Asian Public Policy 2017;10(3):287−301.
[35] Heilmaier J, Ling M. SMEs and HEIs: observations from Brunei Darussalam and Germany. Industry and Higher Education 2021;35(3):244−51.
[36] Jong J, Tan TQ, Kessler FL. Environmental impacts and social concerns-a case study associated with petroleum exploration activities from onshore Baram Delta, NW Sarawak. Bulletin of the Geological Society of Malaysia 2021;72.
[37] Kumar M, Stern JP. Gas industry reform and the evolution of a competitive gas market in Malaysia (No. 158). OIES Paper: NG. 2020.
[38] Kraal D. Petroleum industry tax incentives and energy policy implications: a comparison between Australia, Malaysia, Indonesia and Papua New Guinea. Energy policy 2019;126:212−22.
[39] Merkulov VI. Analysis of Russian Arctic LNG projects and their development prospects. In: IOP conference series: materials science and engineering, Vol. 940, No. 1. IOP Publishing; 2020, September. p. 012114.
[40] Notteboom T, Pallis A, Rodrigue JP. Port economics, management and policy. Routledge; 2021.
[41] Swanströms NIKLAS. China and Central Asia: a new great game or traditional vassal relations? Journal of contemporary China 2005;14(45): 569−84.
[42] Swanström N. An Asian oil and gas union: prospects and problems. International Affairs 2004;80:3.
[43] Chen WM, Kim H, Yamaguchi H. Renewable energy in eastern Asia: renewable energy policy review and comparative SWOT analysis for promoting renewable energy in Japan, South Korea, and Taiwan. Energy Policy 2014;74:319−29.
[44] Brown SP. Natural gas vs. oil in US transportation: will prices confer an advantage to natural gas? Energy Policy 2017;110:210−21.
[45] Barnes R, Bosworth R. LNG is linking regional natural gas markets: evidence from the gravity model. Energy Economics 2015;47:11−7.
[46] Neumann A. Linking natural gas markets-is LNG doing its job? The Energy Journal 2009;30(Special Issue).

[47] Ebinger C, Massy K, Avasarala G. Liquid markets: assessing the case for US exports of liquefied natural gas. Policy 2012.
[48] Energy Modeling Forum. EMF 31: North American Natural gas markets in transition. EMF 31 Working Group Report. Stanford University; October 7, 2015.
[49] Anwar M, Rasul MG, Ashwath N, Nabi MN. The potential of utilising papaya seed oil and stone fruit kernel oil as non-edible feedstock for biodiesel production in Australia—a review. Energy Reports 2019;5:280—97.
[50] Ariweriokuma S. The political economy of oil and gas in Africa: the case of Nigeria. Routledge; 2008.
[51] Craig J, Gerali F, MacAulay F, Sorkhabi R. The history of the European oil and gas industry (1600s—2000s). Geological Society, London, Special Publications 2018;465(1):1—24.
[52] Beltran A, Carré P. La vie électrique. Histoire et imaginaire XVIII-XXIè siècle. Paris: Editions Belin; 2016.
[53] Al-Janabi YT. An overview of corrosion in oil and gas industry: upstream, midstream, and downstream sectors. Corrosion Inhibitors in the Oil and Gas Industry 2020:1—39.
[54] Jacek A, Smith J, Elliott L, Rickel K, Millar P. Exploring consumer motivation at small-scale ski resorts. International Journal of Research in Tourism and Hospitality 2021;7(1):16—31.
[55] Briguet R. Assessment of price decomposition and distribution of fossil fuels (No. STUDENT). 2022.
[56] Kane JJ, Russell GB, Woodard SK, Thompson K. Rejection: how Bankruptcy Courts' treatment of midstream gathering agreements affects underwriting and restructuring. NC Bank. Inst. 2021;25:129.
[57] Sar AK. Competitive advantage and performance: an analysis of Indian downstream oil and gas industry. Academy of Accounting and Financial Studies Journal 2017;21(2):1—7.
[58] Blaylock B, Earle D, Smith D, Harrison JS. Chesapeake Energy Corporation. 2014.
[59] Liu X, Chen G, Chang Y, Zhang L, Zhang W, Xie H. Multistring analysis of wellhead movement and uncemented casing strength in offshore oil and gas wells. Petroleum Science 2014;11(1):131—8.
[60] Su Z, Liu E, Xu Y, Xie P, Shang C, Zhu Q. Flow field and noise characteristics of manifold in natural gas transportation station. Oil & Gas Science and Technology—Revue d'IFP Energies nouvelles 2019;74:70.
[61] Warrag SE, Peters CJ, Kroon MC. Deep eutectic solvents for highly efficient separations in oil and gas industries. Current Opinion in Green and Sustainable Chemistry 2017;5:55—60.
[62] Brun K, Kurz R, editors. Compression machinery for oil and gas. Gulf Professional Publishing; 2018.
[63] Devold H. Oil and gas production handbook: an introduction to oil and gas production. Lulu.com; 2013.
[64] Martínez-Palou R, de Lourdes Mosqueira M, Zapata-Rendón B, Mar-Juárez E, Bernal-Huicochea C, de la Cruz Clavel-López J, Aburto J. Transportation of heavy and extra-heavy crude oil by pipeline: a review. Journal of petroleum science and engineering 2011;75(3-4):274—82.
[65] Demirbas A. Methane hydrates as potential energy resource: part 2—methane production processes from gas hydrates. Energy Conversion and Management 2010;51(7):1562—71.

Further reading

[1] Amin S. Review on biofuel oil and gas production processes from microalgae. Energy conversion and management 2009;50(7):1834–40.

[2] Bhattacharya P, Hutchinson FE. Malaysia's oil and gas sector: constant expectations despite diminishing returns. ISEAS; 2022.

[3] Islam R, Dharfizi ADH, Pero SDA, Sultana S. Analyse the importance of energy in Malaysia's economy and diplomacy. International Journal of Energy Economics and Policy 2022;12(3):305–14.

[4] Sadeghi S, Ghandehariun S, Rosen MA. Comparative economic and life cycle assessment of solar-based hydrogen production for oil and gas industries. Energy 2020;208:118347.

[5] Teo K. Big three to fight 'Asian premium'on Saudi oil sales. The Standard (HK); 2004. p. 25.

[6] Yacob S. PETRONAS, oil money, and Malaysia's national sovereignty. Journal of the Malaysian Branch of the Royal Asiatic Society 2021;94(1): 119–44.

3

Application of disaster engineering in oil, gas, and petrochemical industries

Sina Mosallanezhad[1], Parvin Kiani[1], Mohammad Amin Makarem[1] and Mohammad Reza Rahimpour[1]
[1] *Department of Chemical Engineering, Shiraz University, Shiraz, Iran*

1. Introduction

Many efforts have been undertaken over the past decade to use resilience engineering ideas to make systems robust to disruptions in various fields. Our society has been urged to use resilience techniques in a wide variety of engineering sectors due to an increase in the incidence of catastrophic events. As a result, the idea of resilience has lately attracted a growing degree of interest from the scientific community. Because resilience is a new and upcoming engineering field, there has been a great deal of research defining resilience from an engineering standpoint. There are various definitions, all of which have changed through time. Jain et al. [1] contrasted some of the early definitions of resilience from 1973 across several study domains, demonstrating how they were adjusted better to realize the concept of resilience from a technological aspect. The capacity of a system to absorb any adjustments or shocks is one of the most obvious definitions of resilience. It should absorb disturbances effectively to reduce the impact of disturbances on system stability. In general, resilience is described as the capacity to come back when confronted with adversity [2]. However, there is no widely recognized definition since scholars have defined the word "resilience" in ways relevant to their study disciplines. As a result, there are many different definitions of resilience in the literature.

There are three system states in the functioning of an industrial process: normal, upset, and catastrophic (Fig. 3.1). The process systems should be kept in their usual condition. On the other

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00006-2

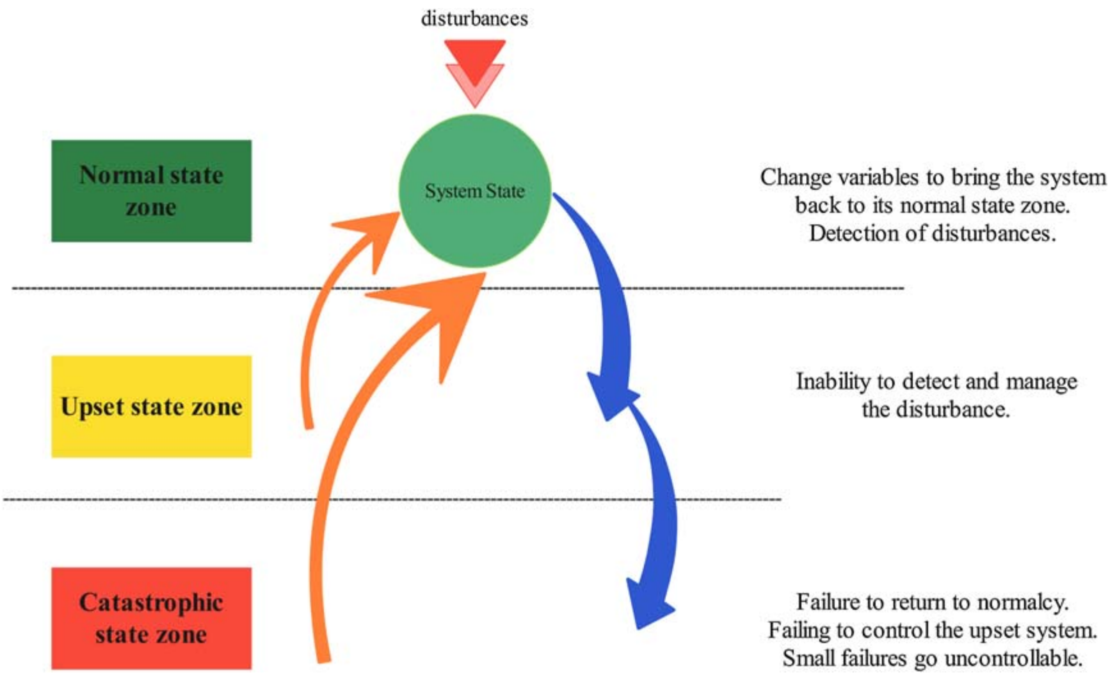


Figure 3.1 The transition of a system's status between three zones [2].

hand, unwanted disturbances are constantly present and drive the system state out of the normal-state zone. If the system can detect disruptions and adjust operational variables as needed (a feature of a process control system), it is likely to remain in normal condition. However, detection may fail, actions may be overlooked, and manipulation may be ineffective in maintaining the system's normal condition. These may result in a product not meeting requirements, tiny spills, or leaks. As a consequence, the system state may be disrupted. The system may be restored from an upset to a normal condition through proper recovery strategies.

If an upset system is not adequately handled and cannot be restored to its normal state, more acute events, for instance, enormous flammable or poisonous material spills, BLEVEs (boiling liquid expanding vapor explosion) may occur, and the system may enter a catastrophic condition. If the action occurs within a specified response time, this state may be restored to normal. The speed and effectiveness of this recovery will be determined not just by recovery strategies but also by the system's architecture.

Most process safety research focuses on preventing the system's status from shifting to a catastrophic state zone. Despite increased efforts to improve process safety, mishaps continue to occur. These catastrophes might be caused by technological and human errors, causing significant damage to industrial facilities. Furthermore, there are always additional dangers to chemical facilities. Natural causes (for example, storms) and purposeful human activities are examples of this (like terrorism and sabotage). Even with adequately implemented risk management in large-scale and complicated systems, unforeseen occurrences may arise. When these scenarios arise, operators prioritize minimizing damage and returning operations to normalcy. This is the notion of resilience in process industries [3].

Resilience in industrial processes, particularly chemical processes, is defined as the capacity to limit damage and quickly return operations to normal after an unfavorable incident [4]. The greater the resilience of an industrial process, the less the consequences and the faster the recovery. As a result, the risks (consequence and frequency of occurrence) to people, the environment, and businesses are reduced. However, despite its apparent potential safety, cost, and environmental advantages, the resilience idea has not been widely implemented in the process sector. There seem to be drawbacks that restrict the concept's implementation and need to be overcome to realize its potential fully. The fundamental challenge in researching resilience is that it is so conceptual. To conceptualize, manage, and even create resilience, fundamental contributing and principle aspects of resilience must be discovered. This chapter aims to present the principles and components that lead to the resilience of a chemical process disaster.

1.1 The definition of resilience

When the system fails or malfunctions, resilience aids in its recovery. Resilience is defined as the ability to return a system to its previous and standard state; otherwise, resilience will not help prevent an accident [5].

Assume a plant is harmed due to an unintentional (accidental) mishap or an external threat. In that situation, the lives of workers and employees, as well as members of the general public, may be jeopardized, and recovery time may vary depending on the extent of the damage. If the amount of damage is significant, recovery time will be extended, and the plants' market position may be lost as a result. When a warning is received, appropriate preparation is taken to respond to the threat, decreasing the amount of damage. Resilience necessitates good management, the correct disposition of the individuals involved, and the establishment of needs for the plants.

1.2 Is it worthwhile to consider resilience?

Because hazardous chemicals can endanger workers and the surrounding community, the safety of process plants is critical. If there is no threat to the plant, a resilience study is unnecessary; nevertheless, this is not the case in practice due to the ambiguity. Aside from cyberattacks, unforeseeable flaws, disasters, and human mistakes can also cause considerable damage. Risk identification methodologies such as HAZOP (Hazard and Operability Analysis), What if, and FMEA (Failure Modes and Effects Analysis) provide a faulty explanation of potential disasters. The major cause of subversion inadequate to process analysis was discovered by examining 100 facilities in the damage to the onshore oil and gas industry from 1996 to 2015 [6]. Many operational mishaps, such as restraint failure, column fluid overflow, the unintended opening of pressurized equipment, and others, are caused by human mistakes not covered by previous hazard identification [7]. Based on the foregoing arguments, it is argued that, despite numerous measures to prevent potential accidents such as loss of control and process disruptions, they may still occur, hence justifying the existence of resilience.

2. Research in the field of resilience engineering history

When attempting to tackle a resilient heat exchanger network problem in 1982, the term “resilience” was used for the first time from a chemical engineering standpoint [8]. The notion of resilience was studied in a variety of sectors from 1982 to 2009, including health care, finance, and cognitive sciences. During this time, the topic of resilience was also looked into from an engineering or technical standpoint. For example, Vidal et al. [9] illustrated how various teamwork tactics could strengthen the resilience of complex systems with multiple people coordinating with one another. Nevertheless, from 2010 to 2014, applications of resilience engineering in industrial processes were investigated. Dinh et al. [2] established principles and elements that influence the robustness of an industrial process. Various studies later in 2014 looked into new study subjects related to the chemical industry’s resilience. Azadeh and Salehi [10], for example, established a framework to resolve the gap between managers' and workers' perceptions of work. In a petrochemical facility, this approach was found to be helpful in closing the efficiency gap between employees and managers. The timeline for resilience engineering research is depicted in Fig. 3.2.

3. Measures of resilience

A slight disruption in the industry or industrial operations can result in hazardous incidents. A resilient system can be constructed to dramatically reduce the occurrence of bad occurrences by utilizing cutting-edge technologies, well-planned crisis procedures, and human activities [17].

If the system is in a situation where an accident is possible (between turbulence and upset), resilience measures will cause the system to return to its normal state in the meantime, but if these measures do not work, protective measures to maintain equipment and human lives are implemented. Resilience measures can only return the system to a stable and normal condition; they cannot avoid losses.

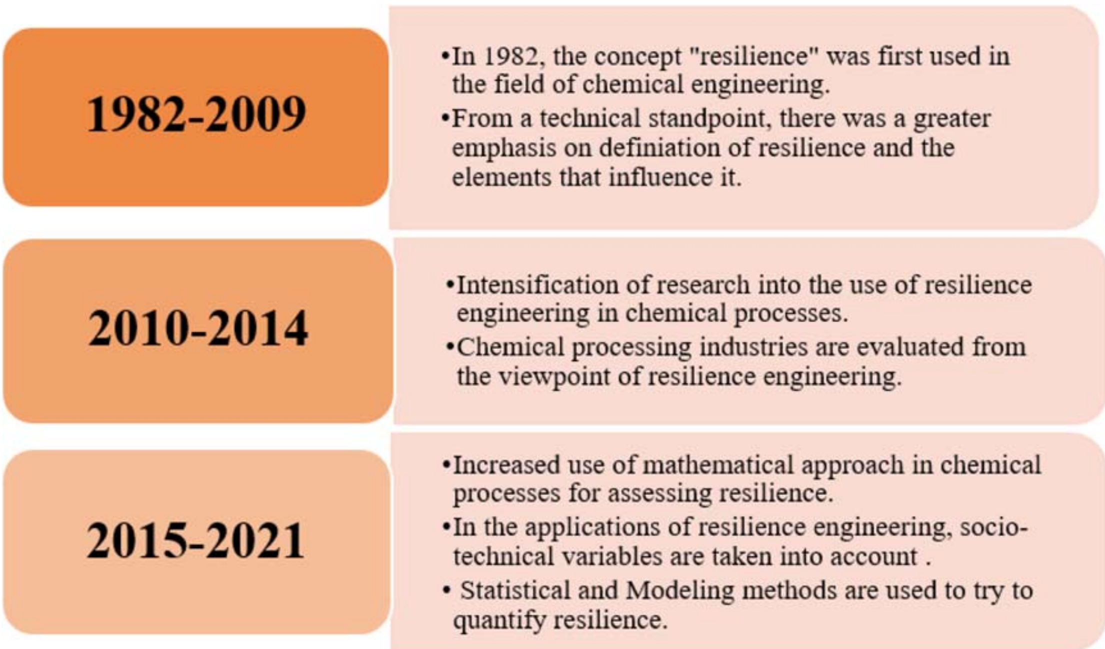


Figure 3.2 Research timeframe for evaluating resilience from the standpoint of chemical systems [2,8–16].

4. Strategies and principles of resilience

Effects limitation, early detection, controllability, flexibility, administrative controls and procedure (ACP), and failure minimization are the basic principles of resilience needed to achieve resilience [2]. Examining the state transition makes it clear that those principles must be in place and function as layers to carry out the resilience, as concluded in Fig. 3.3.

Consider the case of a gas leak; a gas leak indicates that the system is failing, and if the gas is combustible, a major explosion is possible. If an explosion happens with an ignited source, the system is perturbed, and another explosion is probable.

4.1 Failures minimization

When a system fails to achieve its goal, it breaks down, which is dangerous for people and equipment. As a result, failure should be minimized through preventive measures.

Suppose there is a possibility of toxic and flammable gas leakage in a system. In that case, preventive measures include maintaining a suitable environment, storing nonflammable gases, accurate and regular maintenance [18], and using gaskets to minimize the leakage of toxic and flammable gas to prevent

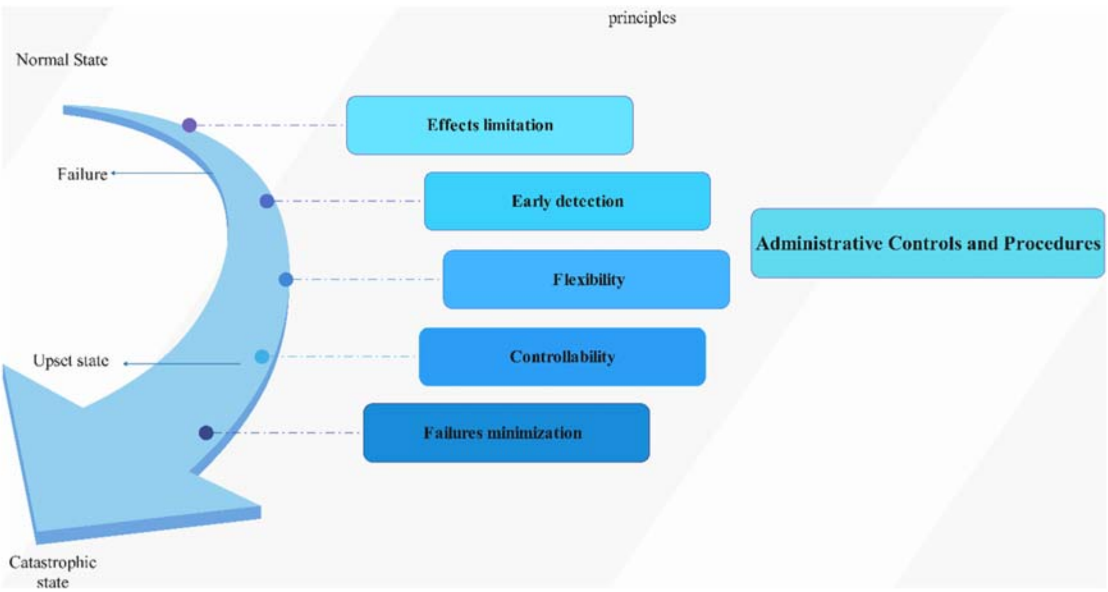


Figure 3.3 Principles of resilience [2].

the formation of the gas clouds. These initiatives can minimize the rate of failure.

4.2 Early detection

As preventive measures are useful in preventing an accident, early detection is critical. Even the most dangerous incidents are avoided if they are discovered in time. Early detection allows for a faster and more efficient response to the disaster, giving the operator more time to assess and respond. It has become an essential and fundamental part of the resilience [19,20]. Many authors [21–25] have said unequivocally that detection is required before the rest of the rehabilitation process can begin. The concept of detecting a deviation as part of a rehabilitation process was proposed in the literature [26]. The advantages of early detection in quick reaction have also been discussed in the context of emergency response management systems [27]. When a gas leak occurs, a gas cloud accumulates over time and causes an explosion; therefore, gas sensors must detect a gas leak as quickly as possible.

4.3 Flexibility

Another element and feature of resilience is flexibility [20,28–30]. If a system malfunctions but is still stable and operating within the desired range, it is called a flexible system. This range includes functional and physical specifications such as temperature, pressure, and product specifications. As a result, in a flexible system, the system needs to be restored as long as the system continues to operate within the desired range. Applications of flexibility include building materials resistant to corrosion, rust, and physical conditions or a heat transfer system that calculates the outlet temperature if the input conditions change.

According to the example of gas leakage, the system can be called flexible if, while the system is working, via reducing the pressure or bypassing the leakage equipment to prevent the formation of the gas cloud.

4.4 Controllability

The ability of a system to attain a given desired state is known as controllability [31]. It is defined by the system's ability to be managed effectively via feedback or feed-forward approaches. When an unanticipated input deviates the parameters from the setpoints, the process is controllable if the output parameters can be adjusted to target points in a reasonable amount of time.

The flexible design enables the process to run under bypassed or pressure-reduced settings in the case of a gas leak. The possibility of changes by the operator and its duration depends on the controllability of the process. Only after attaining new conditions, the cloud creation can be halted. The faster a new situation is established, the less flammable gas is emitted.

4.5 Effects limitation

When efforts to prevent an accident fail, it is critical to prevent further deterioration because the damage is directly tied to the recovery process and time. The greater the extent of the injury, the longer the recovery procedure and duration. Protective measures are used to reduce the effect.

Consider the same gas leaking scenario from earlier: if the design is done on a small scale, the amount of gas leakage and damage caused by igniting and explosion will be considerably smaller. In addition, walls called a firewall should be created between separate portions to prevent the spread of fire, and building an explosion wall is necessary to protect the control room [32].

4.6 Administrative controls and procedures

ACP must be part of a resilient system. All disasters in a system cannot be controlled by simply using design aspects such as controllability, flexibility, and the abovementioned points.

The role of the workforce and operators is crucial in times of danger. If the operator has a complete and accurate understanding of the process and can make the best decision at the risk of staying calm, he can prevent a catastrophe. This is where the ACP's vital role is training procedures and operational methods to take appropriate action in the event of a hazard comes into play [33].

Examples of gas leaks include several ACP measures such as complete plant evacuation, isolation, and proper maintenance.

In conclusion, the resilience concept in industrial processes was utilized to construct the resilience strategy, which served as a foundation for developing resilience principles. Fig. 3.4 displays a summary of them.

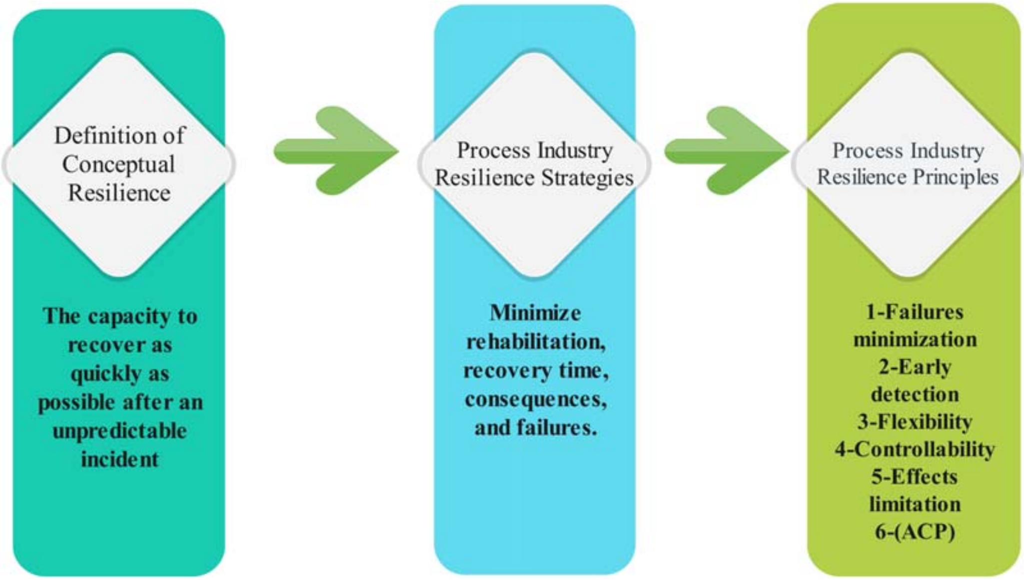


Figure 3.4 Development of principles and strategies of resilience derived from the definition of resilience [2].

4.7 Distinguish between controllability and flexibility

It is necessary to differentiate between flexibility and controllability. Flexibility is associated with steady states, whereas controllability is associated with dynamic states and is defined as the ability to achieve specified locations within a specific time [29,34].

Designing a more controlled process is the controllability concept for resilience. The flexibility concept enables processes to function in different situations, but the controllability principle allows them to switch from one state to another. To implement the resilience approach, both flexibility and controllability are required.

5. Chemical plants' resiliency

Fossil fuels are still considered as primary sources of energy [55] and base materials for producing valuable chemicals [54,56–58], despite the fact they lead to severe environmental problems such as climate change [59–61]. Chemical plants are usually made up of processes that run at high temperatures and pressures. As a result, they are particularly vulnerable to natural disasters as well as human-caused ones. Chemical factories are especially vulnerable to catastrophes since the chemicals used in the processes are poisonous or combustible. A chemical facility can be destroyed by a natural disaster such as an earthquake or storm. Natural technological (Na-Tech) disasters are the name given to such events. Several catastrophic disasters have occurred in the petrochemical industry in the past. For example, during Hurricane Harvey in Texas, the Na-Tech incident involving organic peroxides was kept in chilled trailers at the Arkema plant [35]. The cooling facility was shut down due to a power outage caused by the hurricane. It caused an exothermic decomposition of the compounds, which ended in a fire. Because of the complicated network of storage tanks and pipelines in chemical factories, these types of catastrophes occur regularly. Any malfunction in one of a chemical plant's process units might have an impact on some other process unit, resulting in a "domino effect." As a result, it is critical to improve chemical facilities' resilience to external disruptions to reduce physical and economic losses. When a calamity strikes, a robust design is required to ensure minimal loss of functionality. There are limited studies connected to chemical plant design from a resilience engineering standpoint. A resilience-based efficient firefighting approach was developed to minimize a domino effect in tanks. There are numerous frameworks for assessing resilience [36]. In the occurrence hazard like an earthquake, Caputo et al. [37] suggested an approach for assessing resilience. The approach is based on calculating capacity loss in a process system following a disaster. Mebarki [38] offered a comparable methodology for assessing the durability of industrial units in coastal areas against tsunamis, based on a similar model.

6. Different stages of resilience

When a system malfunction occurs, the system goes through three different stages, including absorption, adaptation, and restoration, as shown in Fig. 3.5 [1,40,41]. The capacity of a system to absorb external perturbations without causing significant deviations in output is referred to as absorption. Adaptation occurs when the absorption phase fails to absorb external shocks, and the system output deviates sufficiently from its expected value. During the adoption stage, the system's dynamics are altered such that it adjusts to external shocks, and there is no additional

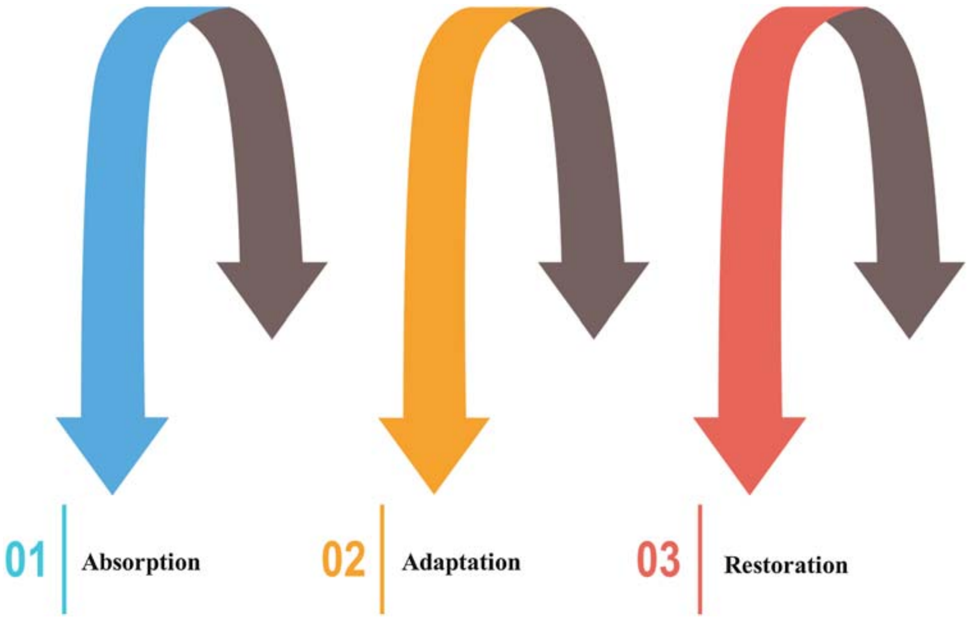


Figure 3.5 Different stages of resilience [39].

divergence in output. After that, the restoration stage kicks in to return to its previous condition.

7. Factors that contribute to resilience

The principle of controllability and flexibility leads to developing the reactor design factor. Process design plays a vital role in process resilience. Consider, a batch reactor in which a runaway reaction occurs. This reactor must be designed so that its operating pressure is high and resistant to high pressure. It must also have a very flexible temperature range and be resistant to cooling or heating changes.

Detection potential is the main factor in the implementation of early detection. In the previous example of the reactor, if a sensor detects temperature and pressure changes and then the data is checked by a signal processing device, they can report the disturbance as soon as possible and prevent a catastrophe.

The human aspect is essential in diagnostic systems. A functional design and a proper detection system can be helpful and efficient for resilience; as long as the human aspect, like accurate alerts management, fast and effective action is done correctly. As a result, workforce training is critical to rapid and accurate detection and appropriate action [26,42].

ACP is the ultimate principle of resilience that has been explored, which enhances resilience with proper procedures and management. ACP assessment is done through safety management review, which is the most critical part of safety management, staff training factor, and operators.

Another critical factor of the flexibility system is the ERP that allows the appropriate actions to be taken as quickly as possible and the recovery process to be faster. The five main factors for the system's supply provided by Linh T.T. Dinh [2] include ERP, design factor, detection potential, human factors, and safety management system, as shown in Fig. 3.6.

Consider a gas converter back leak. Gas leakage in this converter causes vibration and fluctuation in the converter pipes, and vibration and oscillation, in the long run, causes the pipe to break. Increased pressure due to gas flow in the high-pressure area causes the downstream pipes designed at low pressure not to withstand the pressure and break. Therefore, in terms of design, the pipes must be designed in the high-pressure area to be resistant to high pressure, or the design should be done so that vibrations and fluctuations are eliminated [43].

From the perspective of detection potential, the process and equipment must be equipped with a pressure and temperature control system to immediately detect a temperature and pressure disturbance and return the system to normal.

As explained earlier, the role of human factors is crucial. Human agents should be trained to detect the acoustic sound

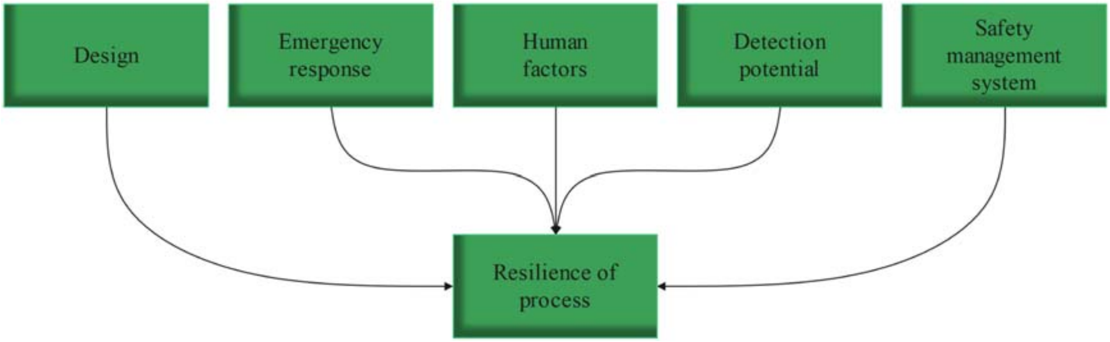


Figure 3.6 Process resilience contributing elements [2].

caused by the vibration of the tube and the different types of vibration to detect the occurrence of the vibration early.

In terms of ERP, the operator must be well trained to change the gas flow in case of vibration in the pipe, limit the increase of pressure in the pipe in case of leakage in the pipe, or cut off the gas flow to prevent an explosion. ERP is responsible for training such safety measures for operators [44].

Safety management can detect the source of vibration by analyzing system performance and hazards. It can also detect long-term vibrations by regular and proper maintenance. Fig. 3.7 shows the relationship between contributing factors and principles to achieve a resilient system.

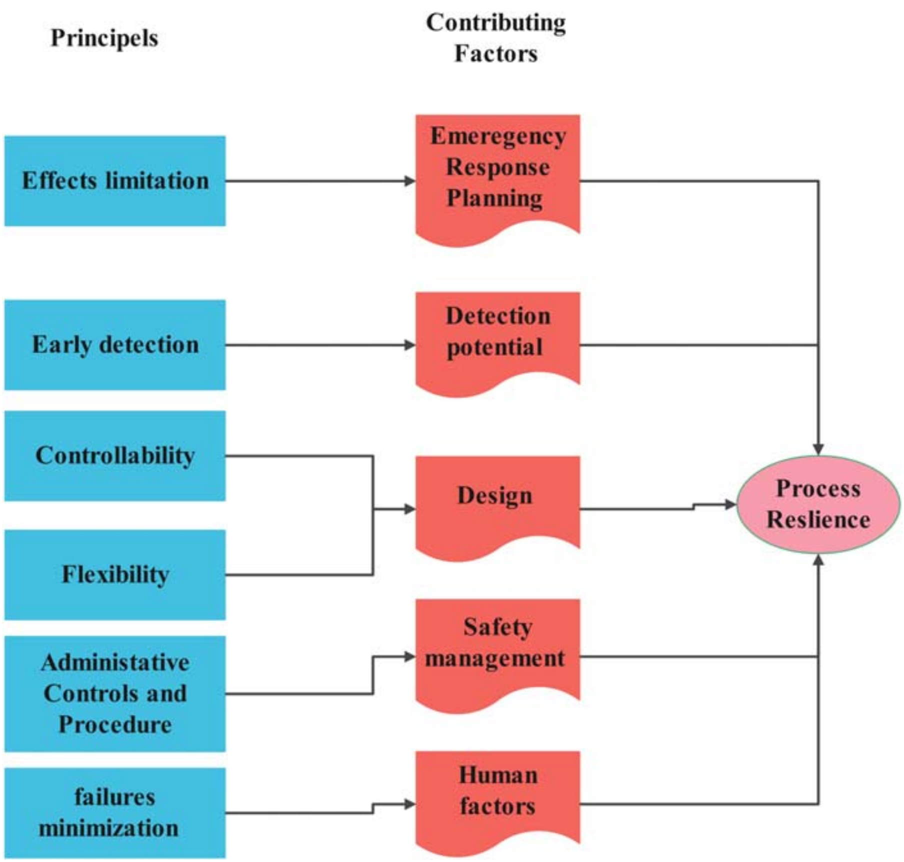


Figure 3.7 Process resilience contributing factors and principles [45].

8. Resilience characteristics

8.1 System procedure: sociotechnical system

Approaching a plant is a process that acts as a socio-technical system, a turning point in flexibility analysis [46]. A socio-technical system approach covers senior management or board members to lower management levels, regulators to operational layers, and technical facilities. Humans interact with each other in all layers, while in the lowest layer, humans interact with technology. All components can work as designed, but one or more interactions disable unrecognized inefficiencies in system design.

System-theoretic process analysis (STPA) claims that it can predict everything that might happen to the system [47,48]. It requires the analysis of the system at all technical and organizational levels on all control loops. Also, the defects of each processor, sensor, actuator, and interference with other loops should be analyzed. The control loop includes human and technical components. However, a complete factory cannot be analyzed with automatic tools because it includes many possibilities.

8.2 Critical elements or characteristics of resilience

The regulations and contributing characteristics are shown in Fig. 3.7, while Fig. 3.8 shows the exact figure in four more succinct and creative aspects.

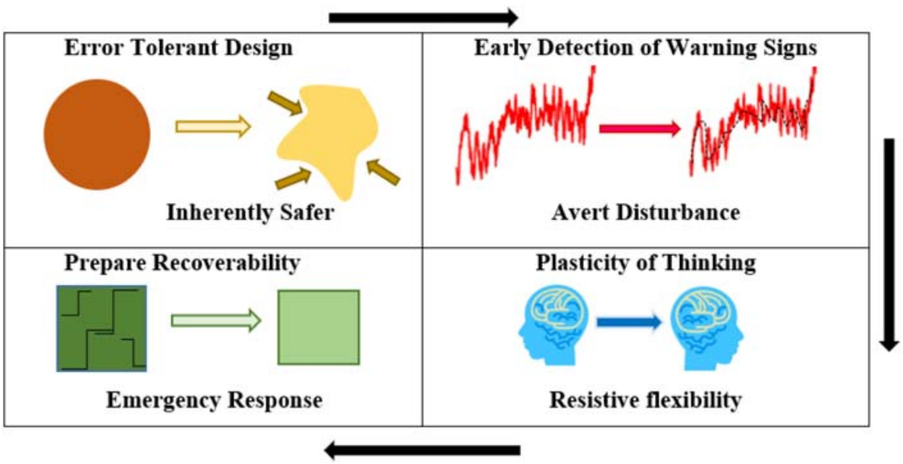


Figure 3.8 Elements of resilience [49].

8.2.1 Design for error tolerance

The concept of inherently safer design is to identify the principles of minimizing impacts and failures [45]. The principles of minimizing effects and failures are identified to implement preventive measures. Moreover, most of the accidents are due to design errors. As a result, the design process is critical. Error-resistant design reduces the cost of process safety and makes the process more resilient.

8.2.2 Premature warning

In order to receive timely warnings of dangers and threats, different sources must be received in weak signals. There are also various sources of danger such as corrosion, equipment energy consumption, floods, and earthquakes [50]. CMMS (centralized maintenance management system) and LIMS (laboratory information management system) provide critical updates. ERP (enterprise resource planning) information such as SAP (system analysis and program development) exists for enterprise business processes such as procurement, customer orders, and accounting.

8.2.3 Recoverability

The first requirement of recoverability is effective emergency response, which requires operational forces, appropriate equipment, and a team ready for analysis. The emergency command headquarters bridge the media and companies with the authorities. To be prepared, three issues must be considered:

i Self-rescue routes
ii Quick shutdown
iii Fire safety regulations of the facility

The longer the emergency response lasts, the greater the damage and the complete recovery later. Recyclability now includes the availability of stocks, alternative equipment, raw materials, financial reserves, and whatever facilities are needed to prevent business failure and market loss. Given the investment constraints in such cases, risk assessment based on resource distribution is essential for optimal business opportunity and the best outcome for business continuity [51].

8.2.4 Plasticity

Unknown and unexpected hazards must be identified first, and creativity may be necessary to deal with the threat without causing damage elsewhere. It requires both flexible thinking and restraint in jumping to conclusions, therefore resistive flexibility. It may also be described as flexibility in making dynamic decisions in the face of ambiguity. Qualities such as the correct mindset, sufficient process expertise, insight, and experience are required. Flexibility would be a beneficial equipment attribute to some degree. In the event of danger, process simulation and risk assessment will be beneficial in determining the best options at both the design and operational phases, as well as training employees for crisis circumstances [52].

9. Case study

Consider the case where a release of flammable materials leads to an explosion following a runaway reaction and rupture of the reactor due to an increase in temperature. It is desired to show how the principles and contributing factors can prevent the hazard scenario from developing and assist in getting the system back to normal quicker, meaning the system is more resilient [53].

The transition of states is examined to determine the metrics and elements that contribute to resilience. Disturbance, upset, and catastrophic repercussions will all be evaluated in this scenario.

Avoiding anything unpleasant from occurring is the most effective way to increase resilience based on the concept that no recovery will happen if an unfavorable incident does not happen. Conditions conducive to possible erroneous failures and technical difficulties in this case study can be avoided through adequate research information transfer, thorough knowledge of thermochemistry and reaction chemistry, threat assessments, adequate threat awareness, acceptable operating procedures, understanding of the origins of overpressure, containing component order and addition rates that have been checked carefully [2]. Then, depending on the situation, several actions and elements may be used to develop positive resilience. Table 3.1 summarizes these recommended metrics and variables.

Table 3.1 Principles, measures, and contributing factors for resilience [2].

Disturbance	The status of the system	Proceeding	Contribution factors	Principle
Unsuitable designs, including the material/heat balance, the halting of agitators owing to electric failures, and engine breakdowns, are examples of technical shortcomings.	Upset: The heat of the reaction is too hot for the cooling water system to regulate.	Create a reliable control system with a safety backup.	Detection potential; design	Controllability
		Create efficient heat transfer systems.	Design	Failures minimization
		Operators identify abnormal situations and take appropriate action.	Safety; human; ERP	ACP; early detection
		In the event of an unusual circumstance, such as a lack of agitation or cooling water, provide clear and specific process instructions.	ACP	ERP; safety manage ment
Operator overload, incorrect loading order, incompatible loading, or improperly changed feed are some of the wrong actions that can cause system malfunctions.	The pace at which the reaction heats up is too fast.	Lock software that is based on the values that are being monitored.	Design	Controllability
		Equipment, design processes, and procedures eliminate the possibility of human mistakes by including intrinsically safer design elements, such as interlocks.	Safety management,	ACP, failures minimization
		Add substances to the vessel at a specified rate to control the reaction rate.	Design	Controllability
		Rapid detection of abnormal conditions by the operator by examining the composition of the product percentage.	Design	
		The actions that should be taken when a problem or disorder occurs should be described in detail in the leaflets.	Safety management, human	ACP, early detection
			ERP, safety management	ACP

Continued

Table 3.1 Principles, measures, and contributing factors for resilience [2].—*continued*

Disturbance	The status of the system	Proceeding	Contribution factors	Principle
The heat rate of the reaction is too high or the water cooling system does not control the reaction's heat properly.	Upset: runaway reaction.	When a preset maximum safe temperature or rate of temperature increase is achieved, break off the feed and remove the heating from the vessel.	ERP, design	Controllability
		Equip the vessel with a high-temperature monitor and alarm system (for example, a high-pressure warning) to provide early indications of impending runaway.	Early detection	Detection potential
		Give the workers clear and explicit guidance to obey.		
		Add substances to counteract the catalyst's effects.	Safety management ERP, design	ACP Effects limitation
Explosion/fire	Catastrophic: harm to people.	Keep the number of persons around the reactor to a bare minimum.	Safety management	ACP, limitation of effect
Runaway reaction	Catastrophic: The reactor exploded/ruptured.	Use tanks designed to operate at high temperatures and pressures.	Design	Flexibility
		Identify abnormal conditions and take appropriate action.	Safety management, human, ERP	ACP, early detection
		Suitable valves and disc/relief valve bursts must be provided to control the pressure when the pressure rises.	Design	Minimization of failure
Flammable substance released	Catastrophic: Explosion/fire	Reduce the risk of ignition by using a limited access and permission to work (PTW) system to regulate the ignition source.	Safety management	ACP
		To avoid ignition sources, the equipment and area are categorized.	Design	Limitation of effects

Table 3.1 Principles, measures, and contributing factors for resilience [2].—*continued*

Disturbance	The status of the system	Proceeding	Contribution factors	Principle
		Use a device such as a water spray to prevent the secondary vapor cloud from exploding due to the mixture of air and hot material forming on top of the reactor.	Design	Effects limitation
Reactor ruptured	Catastrophic: Flammable substance released	In any catch tank that demands the discharge of compounds in the environment, use a vent scrubber equipped to handle atmospheric emissions in high-pressure circumstances.	Design	Effects limitation
		To withstand the pressure of emptying the reaction vessel, a catch pot must be designed to collect what is released	Design	Effects limitation

According to the analysis of this case study, the methods that cut short the sequence of unwanted occurrences or contribute to a positive resilience of various situations fall into the design, detection, human, emergency response plan, or management categories.

10. Conclusion

Risk assessment is critical for potentially high-impact chemical and other processes so that a judgment may be made about how safe is enough. Risk assessment, on the other hand, has several flaws. This chapter emphasized the need to address resilience characteristics in chemical processes, a field of study that has yet to be explored, and also it aims to study the contributing factors and principles that make up the flexibility of a chemical process.

Analyzing system state changes indicated that resilience is defined by a number of parameters or measurements. These methods operate in coordination to boost the ability of chemical processes to recover. Controllability, Flexibility, Early detection, Effects limitation, Failure minimization, and ACP were presented as resilience principles. These concepts serve as a framework for developing different contributing elements for statistically assessing resilience. Human Factor, Design, ERP, Detection Potential, and Safety Management were presented as the first layer of elements contributing to resilience. Besides, resilience is reflected in four elements as plasticity, premature warning, recoverability, design for error tolerance, which are discussed completely.

Abbreviations and symbols

ACP Administrative controls and procedures
BLEVE Boiling liquid expanding vapor explosion
CMMS Centralized maintenance management system
ERP Emergency response plan
ERP Enterprise resource planning
FMEA Failure modes and effects analysis
HAZOP Hazard and operability analysis
LIMS Laboratory information management system
Na-Tech Natural technological
SAP System analysis and program
STPA System-theoretic process analysis

References

[1] Jain P, Pistikopoulos EN, Mannan MS. Process resilience analysis based data-driven maintenance optimization: application to cooling tower operations. Computers & Chemical Engineering 2019;121:27−45.
[2] Dinh LTT, Pasman H, Gao X, Mannan MS. Resilience engineering of industrial processes: principles and contributing factors. Journal of Loss Prevention in the Process Industries 2012;25(2):233−41.
[3] Crowl DA, Louvar JF. Chemical process safety: fundamentals with applications. Pearson Education; 2001.
[4] Francis R, Bekera B. A metric and frameworks for resilience analysis of engineered and infrastructure systems. Reliability Engineering & System Safety 2014;121:90−103.
[5] Pooley JA, Cohen L. Resilience: a definition in context. Australian Community Psychologist 2010;22(1):30−7.
[6] Jarvis R, Goddard A. An analysis of common causes of major losses in the onshore oil, gas & petrochemical industries. Loss Prevention Bulletin 2017;255.

[7] Casal A, Olsen H. Operational risks in QRAs. Chemical Engineering Transactions 2016;48:589—94.
[8] Marselle DF, Morari M, Rudd DF. Design of resilient processing plants—II Design and control of energy management systems. Chemical Engineering Science 1982;37(2):259—70.
[9] Vidal MCR, Carvalho PVR, Santos MS, dos Santos IJL. Collective work and resilience of complex systems. Journal of Loss Prevention in the Process Industries 2009;22(4):516—27.
[10] Azadeh A, Salehi V. Modeling and optimizing efficiency gap between managers and operators in integrated resilient systems: the case of a petrochemical plant. Process Safety and Environmental Protection 2014; 92(6):766—78.
[11] Costella MF, Saurin TA, de Macedo Guimarães LB. A method for assessing health and safety management systems from the resilience engineering perspective. Safety Science 2009;47(8):1056—67.
[12] Shirali GHA, Motamedzade M, Mohammadfam I, Ebrahimipour V, Moghimbeigi A. Challenges in building resilience engineering (RE) and adaptive capacity: a field study in a chemical plant. Process Safety and Environmental Protection 2012;90(2):83—90.
[13] Azadeh A, Salehi V, Mirzayi M. The impact of redundancy and teamwork on resilience engineering factors by fuzzy mathematical programming and analysis of variance in a large petrochemical plant. Safety and Health at Work 2016;7(4):307—16.
[14] Macuzić I, Tadić D, Aleksić A, Stefanović M. A two step fuzzy model for the assessment and ranking of organizational resilience factors in the process industry. Journal of Loss Prevention in the Process Industries 2016;40: 122—30.
[15] Salehi V, Veitch B. Measuring and analyzing adaptive capacity at management levels of resilient systems. Journal of Loss Prevention in the Process Industries 2020;63:104001.
[16] Salehi V, Veitch B, Musharraf M. Measuring and improving adaptive capacity in resilient systems by means of an integrated DEA-Machine learning approach. Applied Ergonomics 2020;82:102975.
[17] Bowen DJ, Morasca AA, Meischke H. Measures and correlates of resilience. Women & Health 2003;38(2):65—76.
[18] Kletz TA, Amyotte P. Process plants: a handbook for inherently safer design. CRC Press; 2010.
[19] Sheffi Y. The resilient enterprise: overcoming vulnerability for competitive advantage, vol. 1. MIT Press Books; 2005.
[20] Sheffi Y. Building a resilient organization. The birdge: linking engineering and society. National Academy of Engineering 2007;1(37):32—8.
[21] Frese M. Error management or error prevention: two strategies to deal with errors in software design. 1991.
[22] Kontogiannis T. A framework for the analysis of cognitive reliability in complex systems: a recovery centred approach. Reliability Engineering & System Safety 1997;58(3):233—48.
[23] Kontogiannis T. User strategies in recovering from errors in man—machine systems. Safety Science 1999;32(1):49—68.
[24] Sellen AJ. Detection of everyday errors. Applied Psychology 1994;43(4): 475—98.
[25] Zapf D, Reason JT. Introduction: human errors and error handling. Applied Psychology 1994;43(4):427—32.

[26] Kanse LL. Recovery uncovered: how people in the chemical process industry recover from failures. Tijdschrift voor toegepaste Arbowetenschap 2004;1:13.
[27] Kim JK, Sharman R, Rao HR, Upadhyaya S. Efficiency of critical incident management systems: instrument development and validation. Decision Support Systems 2007;44(1):235–50.
[28] Abreu Saurin T, Costella MF, De Macedo Guimaraes LB. A method for assessing health and safety management systems from the resilience engineering perspective. Collection Sciences économiques et sociales 2008: 227–33.
[29] Morari M. Flexibility and resiliency of process systems. Computers & Chemical Engineering 1983;7(4):423–37.
[30] Saboo AK, Morari M, Woodcock DC. Design of resilient processing plants—VIII. A resilience index for heat exchanger networks. Chemical Engineering Science 1985;40(8):1553–65.
[31] Rosenbrock HH. State-space and multivariable theory. Wiley Interscience Division; 1970.
[32] Patriarca R, Bergström J, Di Gravio G, Costantino F. Resilience engineering: current status of the research and future challenges. Safety Science 2018; 102:79–100.
[33] Phimister JR, Oktem U, Kleindorfer PR, Kunreuther H. Near-miss incident management in the chemical process industry. Risk Analysis: International Journal 2003;23(3):445–59.
[34] Morari M. Design of resilient processing plants—III: a general framework for the assessment of dynamic resilience. Chemical Engineering Science 1983;38(11):1881–91.
[35] O'Connor M, Pasman HJ, Rogers WJ. Sam Mannan's safety triad, a framework for risk assessment. Process Safety and Environmental Protection 2019;129:202–9.
[36] Cincotta S, Khakzad N, Cozzani V, Reniers G. Resilience-based optimal firefighting to prevent domino effects in process plants. Journal of Loss Prevention in the Process Industries 2019;58:82–9.
[37] Caputo AC, Kalemi B, Paolacci F, Corritore D. Computing resilience of process plants under Na-Tech events: methodology and application to sesmic loading scenarios. Reliability Engineering & System Safety 2020;195: 106685.
[38] Mebarki A. Safety of atmospheric industrial tanks: fragility, resilience and recovery functions. Journal of Loss Prevention in the Process Industries 2017;49:590–602.
[39] Pawar B, Park S, Hu P, Wang Q. Applications of resilience engineering principles in different fields with a focus on industrial systems: a literature review. Journal of Loss Prevention in the Process Industries 2021;69:104366.
[40] Jain P, Mentzer R, Mannan MS. Resilience metrics for improved process-risk decision making: survey, analysis and application. Safety Science 2018; 108:13–28.
[41] Tong Q, Yang M, Zinetullina A. A dynamic Bayesian network-based approach to resilience assessment of engineered systems. Journal of Loss Prevention in the Process Industries 2020;65:104152.
[42] Schaaf TW, Kanse L. Errors and error recovery. In: Human error and system design and management. Springer; 2000. p. 27–38.
[43] Kusiak A. Open manufacturing: a design-for-resilience approach. International Journal of Production Research 2020;58(15):4647–58.

[44] Börekçi DY, Kiris SB, Batmaca S. Analysis of enterprise resource planning (ERP) system workarounds with a resilience perspective. Continuity & Resilience Review 2020;2:131—48.
[45] Dinh LTT. Safety-oriented resilience evaluation in chemical processes. Texas A&M University; 2011.
[46] Rasmussen J. Risk management in a dynamic society: a modelling problem. Safety Science 1997;27(2—3):183—213.
[47] Leveson N. A new accident model for engineering safer systems. Safety Science 2004;42(4):237—70.
[48] Leveson NG. Engineering a safer world: systems thinking applied to safety (engineering systems). MIT Press Cambridge; 2011.
[49] Pasman H, Kottawar K, Jain P. Resilience of process plant: what, why, and how resilience can improve safety and sustainability. Sustainability 2020; 12(15):6152.
[50] Alauddin M, Khan F, Imtiaz S, Ahmed S. A bibliometric review and analysis of data-driven fault detection and diagnosis methods for process systems. Industrial & Engineering Chemistry Research 2018;57(32):10719—35.
[51] Tan J, Lo K, Qiu F, Liu W, Li J, Zhang P. Regional economic resilience: resistance and recoverability of resource-based cities during economic crises in Northeast China. Sustainability 2017;9(12):2136.
[52] Belsky J, Pluess M. Beyond risk, resilience, and dysregulation: phenotypic plasticity and human development. Development and Psychopathology 2013;25(4pt.2):1243—61.
[53] Abbasi T, Pasman HJ, Abbasi SA. A scheme for the classification of explosions in the chemical process industry. Journal of Hazardous Materials 2010;174(1—3):270—80.
[54] Kiani Parvin, Meshksar Maryam, Makarem Mohammad Amin, Rahimpour Mohammad Reza. Syngas Conditioning (Catalyst, Process: Sulfur and Tar Cl, F). In: Gorimbo Joshua, et al., editors. Chemicals and Fuels from Biomass via Fischer—Tropsch Synthesis: A Route to Sustainability. Royal Society of Chemistry (RSC); 2022. p. 152—87.
[55] Rahimpour Mohammad Reza, Makarem Mohammad Amin, Meshksar Maryam. Advances in Synthesis Gas : Methods, Technologies and ApplicationsVolume 3: Syngas Products and Usages. Elsevier; 2023.
[56] Meshksar Maryam, Farsi Mohammad, Rahimpour Mohammad Reza. Hollow sphere Ni-based catalysts promoted with cerium for steam reforming of methane. Journal of the Energy Institute 2022;105:342—54. https://doi.org/10.1016/j.joei.2022.10.006.
[57] Kiani Parvin, Meshksar Maryam, Rahimpour Mohammad Reza, Iulianelli Adolfo. CO_2 utilization in methane reforming using La-doped SBA-16 catalysts prepared via pH adjustment method. Fuel 2022;322. https://doi.org/10.1016/j.fuel.2022.124248 Get rights and content.
[58] Kiani Parvin, Rahimpour Hamid Reza, Rahimpour Mohammad Reza. Chapter 4 - Steam reforming process for syngas production. In: Rahimpour Mohammad Reza, et al., editors. Advances in Synthesis Gas : Methods, Technologies and Applications. Volume 1: Syngas Production and Preparation. Elsevier; 2023.
[59] Makarem MA, Kiani MR, Farsi M, Rahimpour MR. CFD Simulation of CO_2 Capture in a Microchannel by Aqueous Mixtures of MEA and [Bmim]BF_4 Modified with TiO_2 Nanoparticles. International Journal of Thermophysics 2021;42:57. https://doi.org/10.1007/s10765-021-02812-1.
[60] Makarem MA, Farsi M, Rahimpour MR. CFD simulation of CO_2 removal from hydrogen rich stream in a microchannel. International Journal of

Hydrogen Energy 2021;46(37):19749–57. https://doi.org/10.1016/j.ijhydene.2020.07.221.

[61] Fouladi Niloufar, Makarem Mohammad Amin, Sedghamiz Mohammad Amin, Rahimpour Hamid Reza. Chapter 11 - CO_2 adsorption by swing technologies and challenges on industrialization. In: Rahimpour Mohammad Reza, et al., editors. Advances in Carbon CaptureMethods, Technologies and Applications. Elsevier; 2020. p. 241–67.

Hazards in oil, gas, and petrochemical industries

D. Keerthi Narayanan, A. Abdur Ravoof, J. Jayapriya, G. Revathi and M. Murugan
Department of Applied Science and Technology, AC Tech, Anna University, Chennai, Tamil Nadu, India

1. Introduction

Oil, gas, and petrochemical industries can typically be classified into upstream, midstream, and downstream industries [1]. The upstream industries carry out the exploration of underground natural gas or crude oil fields, as well as the drilling wells, from which hydrocarbons are extracted eventually in large quantities. The explored oil and gas are then transported to the processing facilities. In the midstream industries, oil and gas are separated, stored, and transported to downstream industries via tanker ships, pipelines, and truck fleets to refineries. In the downstream industries, the crude oil is refined and natural gas is purified for commercial distribution to consumers and end users. An array of products, such as natural gas, diesel oil, petrol, gasoline, lubricants, kerosene, jet fuel, asphalt, heating oil, and liquefied petroleum gas, are obtained directly or developed from crude oil fractions, besides other petrochemicals, such as propylene, ethylene, and propylene glycol. Put together, the up-, mid-, and downstream industries use a wide range of processes and environmental conditions in various operational units. The overview of the segments in the oil, gas, and petrochemical industry is given in Fig. 4.1.

The upstream segment involves drilling, multi-phase hydrocarbon fluid transportation, separators, and gas pipelines, while midstream processes involve oil and water separation, oil pipelines, oil storage tanks, water treatment facilities, gas sweetening, dehydration, gas compression, gas liquefaction, and LNG transportation. The downstream sector involves oil refinement operations, including distillation towers, heat exchangers reformers,

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00010-4

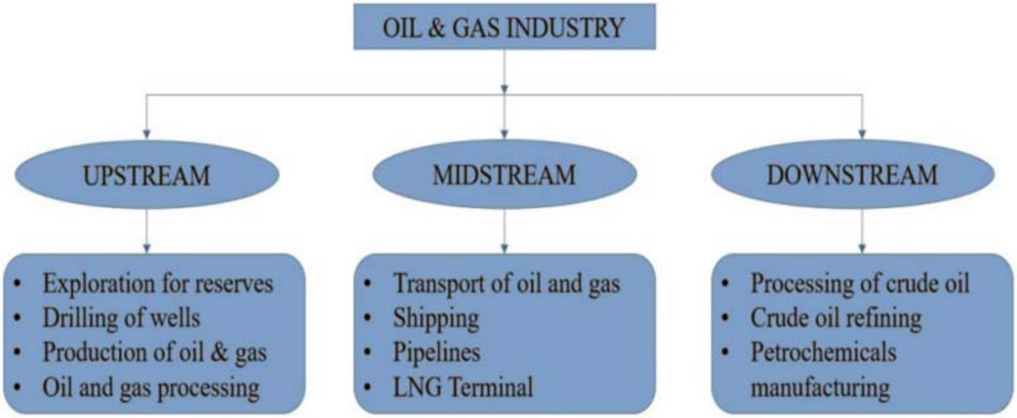


Figure 4.1 Overview of the oil, gas, and petrochemical industry segments.

catalytic crackers, finished petroleum product storage tanks, gasoline/diesel/jet fuel pipelines, absorbers, filters, and membrane separation processes [2]. Drilling and servicing oil and gas wells pose a significant risk to human lives, resulting in fatality rates due to the use and production of potentially hazardous chemicals, such as olefins/alkenes, natural gas, and fuel oils. According to a report by the International Association of Oil and Gas Producers (IOGP), United Kingdom published in 2021, the number of fatalities in the upstream sector has increased from 14 in 2020 to 20 in 2021 spanning 15 different accidents [3]. The accident statistics and fatalities in the oil and gas production (upstream) segment for the past 10 years are shown in Fig. 4.2.

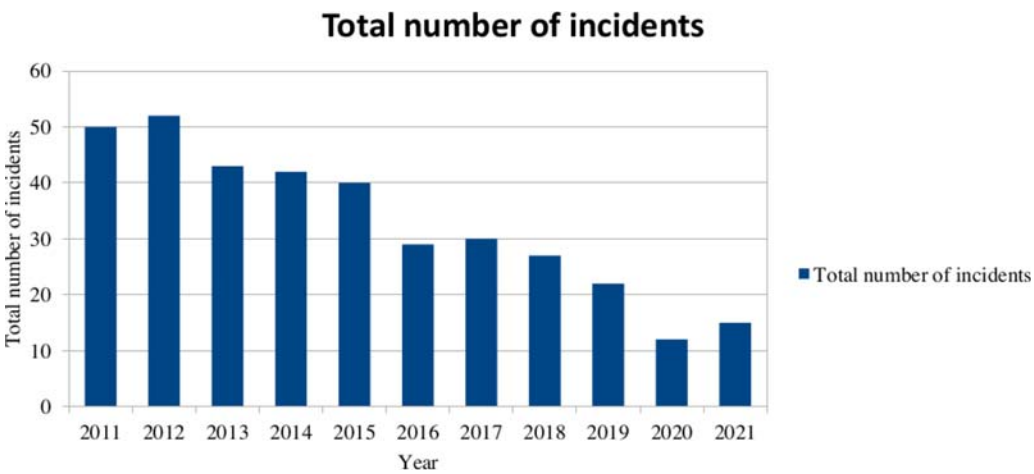


Figure 4.2 Fatal incidents in the upstream segment of the oil and gas industry (2011–21) [3].

The large onshore and offshore gas transmission pipelines developed rapidly are vulnerable to natural disasters [4]. Any damage to the pipeline infrastructure may increase the risk of spillage which can have detrimental effects on the environment. Almost 80% of pipeline accidents lead to the release of toxic chemicals [5], and only about 5% of industrial accidents that release hazardous substances are triggered by natural events [6]. Hence, there is an urgent necessity to develop inherent design strategies in the process safety and risk management areas to minimize accidents in the oil, gas, and petrochemical sector. Process safety refers to limiting flammable, toxic hydrocarbon gases and liquids in a safe working envelope within primary containment systems, such as pipelines, piping, separators, and storage tanks. If any condition exceeds the limit of the primary containment design, leakage of hazardous chemicals from primary containment happens, further leading to process safety hazards, such as fire, explosion, fireballs, and boiling liquid expansion vapor explosion (BLEVE).

In general, oil, gas, and petrochemical industries typically handle (a) high-pressure flammable gases, (b) high-temperature flammable gas/liquids, (c) highly toxic gases, and (d) low-temperature gases. These typical conditions have the potential to cause Process Safety hazards to people, material assets, and the community. In the following section, we discuss the types of hazards associated with these industries in detail.

2. Hazards in the oil and gas industry

The primary step in accident prevention is hazard identification. A hazard refers to any object, situation, or behavior that has the potential to cause injury, adverse health effects, or damage to property or the environment. Irrespective of the industrial segment (upstream/midstream/downstream), the hazards in the oil and gas sector are alike. In general, hazards are categorized as process safety hazards and personal safety hazards. Process safety hazards are not easy to detect or see but can result in massive events, such as fire and explosion, leading to multiple fatalities, great asset loss, and environmental damage and further impacting the reputation of the company and country [7]. Though the frequency of process safety accidents is less than personal accidents, their impact is far greater. Process safety hazards typically involve the contamination of processing plants by dust, gas, or vapor, the detonation of energetic materials and runaway exothermic chemical reactions. Personal safety hazards, or occupational hazards, are low-level hazards that occur at work on a regular basis, are easy to detect (falling objects, trip hazards, etc.), and can lead to injuries, but rarely result in fatalities [8]. In the oil and gas sector, the probability of both process and personal safety hazards are high. In this chapter, various hazards involved in oil and gas processing are explained.

2.1 Process safety hazards

This type of hazard is associated with the loss of primary containment of a hazardous/flammable substance. The main causes of the loss of containment can be scenarios, such as over/under pressure, high/low temperature, high/low volume of substance filled, corrosion, erosion, and seal leak.

2.1.1 Pressure hazards

a) Overpressure

During drilling operations or in hydrocarbon-operating facilities, all equipment, including piping, vessels, tanks, pipelines, compressors, and pumps, are designed to work within certain pressure and temperature limits, which are referred to as design conditions. Overpressure denotes a scenario wherein the pressure inside the pipe, vessel, pipeline, or other equipment exceeds the design conditions due to various operational issues, such as reservoir pressure/pressure build up in petroleum formation, operational error, controller failure, cooling water/steam failure, and reverse flow.

Overpressure scenarios can lead to the rupture of equipment or piping, causing the material in the pipe to spill out into the surrounding area with great force.

Likewise, overpressure in the downstream petroleum segment is caused in the following scenarios [9]:

- **Exposure to Fire:** When heated due to a fire, hydrocarbons contained in the vessel undergo vapourization and thermal expansion, which rises the internal pressure.
- **Excessive Process Heat Input:** Liquid or vapor expansion can occur in a system due to process-upsetting incidents that generate heat unexpectedly, which eventually lead to overpressure
- **Pressure Control Valve Failure**
- **Unexpected Chemical Reactions:** Unexpected/runaway chemical reactions may result in heat or vapor evolution under non-optimal conditions or due to the presence of unexpected impurities.

- **Cooling Water Supply/reflux failure:** When the flow of cooling water used to condense the vapors or the reflux pump in a vessel is impaired, an intense pressure drop occurs through the condensers, while the vessel pressure rises due to vapor expansion.
- **Isolation:** A complete or partial isolation of a vessel from the rest of the components can increase the internal pressure even under normal process conditions due to the lack of ventilation/outlets.
- **Failure of Heat Exchanger Tubes:** A rupture or leak in the internal heat exchange tube of the vessel leads to high pressure.
- **Reactive Foreign or Volatile Material in the Vessel**
- **Non-Condensable Gas Accumulation**
- **Outflow Rate Exceeds Inflow Rate:** When the material withdrawal of a tank or vessel is faster than its inflow rate, excessive suction creates a vacuum or negative pressure in the vessel, potentially leading to a collapse if the tank is not designed for such a condition.

In oil and gas industries, the following events can occur when hydrocarbons under high pressure come in contact with the atmosphere

- **Jet Fire**: Fuel sprayed continuously with force in a particular direction due to leakage, when ignited, causes a turbulent diffusion flame, referred to as a jet fire.
- **Flash Fire**: A flash fire happens when fuel mixed with oxygen comes in contact with an ignition source.
- **Boiling Liquid Expanding Vapor Explosion (BLEVE):** When a vessel containing a pressurized liquid reaches a temperature above the boiling point, the vessel ruptures due to the continuous production of flammable vapor, leading to BLEVE. Under pressure, i.e., in a pressurized vessel, the boiling point of a liquid is higher than normal, which helps it remain liquid for as long as the vessel is intact. However, a comprise in the vessel integrity causes a pressure drop and the liquid rapidly converts to gas and expands at a lower boiling point, resulting in vessel rupture and explosion [10].
- **Fireball:** The flammable vapor released during BLEVE forms a cloud, which is highly likely to get ignited after BLEVE, further producing a fireball and possibly a fuel—air explosion. The inner core of the released fuel vapor cloud consists mostly of pure fuel, whereas a flammable fuel—air mixture is present in the outer layer that ignites first and predominantly emits heat. The burning cloud with hot gases rises due to positive buoyancy and tends to form a spherical shape [11].

- **Pool Fire:** A turbulent diffusion flame formed under zero or low initial momentum by the combustion of vaporizing hydrocarbons above a horizontal pool of fuel that is static or "running." For example, in LNG spills caused by either low source pressure or pressurized releases, the liquid vaporizes and produces invisible clouds of flammable gas. Outdoor fires are usually well-ventilated (fuel-controlled), while those that occur in enclosed spaces are likely ventilation-controlled [12].

These events present a high probability of fatalities, asset damage, and environmental pollution, such as oil spillage into the seas. Apart from these, overpressure hazards can result in flying objects, such as projectiles of equipment harming people or cascading the event by hitting other hydrocarbon-filled pipes, tanks, and vessels. Moreover, some oil, gas, and petrochemical industries use steam for their operations. The steam is produced via a boiler. Under overpressure scenarios, although steam coming out of the boilers or pipes might not create a direct fire hazard, the high-pressure steam jet can however hit the working operators, leading to fatalities.

b) Under-pressure

Under-pressure refers to a condition when the pressure inside a pipe or container goes below the lower limit of the designated range [13]. This can cause the pipe or tank to get buckled in due to vacuum generation, and the material inside the system is exposed to the ambience, leading to a pool fire. This is a typical hazard encountered in storage tanks, leading to fire and explosion.

Gases that are stored at low-pressure conditions (under-pressure) can release large amounts of gas into the atmospheric air very quickly when released deliberately or leaked accidently, resulting in fire hazards depending on the properties of the gas. The Globally Harmonized System (GHS) has four groups for gases stored in under-pressure conditions, as shown in Table 4.1.

2.1.2 Temperature hazards

a) High temperature

Equipment, such as compressors, gas turbines, and steam turbines, which form a part of the facilities that process oil and gas, operate at high temperatures. Such high-temperature piping and equipment are prone to cause heat burns and other temperature-related hazards for the operator. If the temperature of the equipment exceeds the designed limit, it can result in the degradation of the metal, gasket, or flange, eventually leading to the loss of containment. For instance, the material inside the pipe is exposed to ambient conditions and then accidents.

Table 4.1 Category of The Globally Harmonized System (GHS) of the gases stored in under-pressure conditions [14].

S.No	Classification	Criteria
1	Compressed gas (example: hydrogen)	A gas that remains wholly gaseous in the under-pressure state at −50°C (−58°F), including all gases with critical temperature ≤ −50°C (−58°F)
2	Liquefied gas (example: propane, anhydrous ammonia)	A gas that exists partially as a liquid in under-pressure conditions at temperatures above −50°C (−58°F) (a) High-pressure liquefied gas: a gas with a critical temperature between −50°C (−58°F) and 65°C (149°F) (b) Low-pressure liquefied gas: a gas with a critical temperature above 65°C (149°F)
3	Refrigerated liquefied gas (example: liquid nitrogen)	A gas that is partially liquid under low temperature
4	Dissolved gas (example: acetylene)	A gas that is dissolved in a liquid phase solvent in under-pressure conditions

In the oil and gas sector, such events typically result in fire and explosions [15].

b) Low temperature

Based on the nature of the handled substance, certain equipment, such as Liquefied Natural Gas (LNG) pipelines and liquid N_2 pipes, are typically operated at very low temperatures up to −160°C. When exposed to such low-temperature equipment, operators are at a high risk of frostbites. Another type of low-temperature hazard occurs when the piping or equipment goes below its designed temperature limit. This scenario is possible when a high-pressure hydrocarbon-containing pipe is suddenly depressurized. The sudden drop in pressure causes a steep decline in the temperature of the equipment, leading to metal embrittlement and consequently rupture of the pipe, which can cause fire and explosion [16].

2.1.3 Level hazards

Storage of hydrocarbons is a quintessential step involved in oil, gas and petrochemical processing. The volume of stored crude oil, gasoline, jet fuel, or other petrochemicals must be maintained below the allowable safety level of the tank. Though the level of hydrocarbon itself is not a hazard, if the fluid in the tank exceeds the designated limit due to high incoming flow or low outgoing flow from the tanks, the chances of the tank overflowing escalate. In the case of flammable gases, gas cloud formation and the resultant flash fire or explosion is a possibility [17]. If the hydrocarbon is a stabilized oil, oil pool and oil fire are the potential hazardous outcomes.

2.1.4 Chemical hazards

Various chemicals are used for different processes in the oil and gas industries. During drilling activities, several chemicals are used as flocculants. Typical chemicals used in oil and gas industries include corrosion inhibitors, hydrate inhibitors, lube oils, and seal oils [18]. Operators can be exposed to these chemicals due to chemical dosing pump failure, injection tubing rupture, or chemical storage tank overfill. The lube oils used in various rotating equipment are combustible in nature. If the lube oil is spilled from the lube oil tanks or pumps, an oil pool fire can occur. In some circumstances, the spilled lube oil forms lube–oil particulates, which create flammable lube oil mist and lead to a flash fire if ignited.

The common sources of product leakage into the atmosphere during normal operations include open tanks, storage tank vents, safety pressure valves, pump glands, drains of processing vessels, oily water sewers (OWS), drain funnels, pipeline filters, and scraper traps. Moreover, bearing failure, inadequate lubrication, blade or diffuser failure, vibration or coupling failure in turbines, compressors, blowers, and gearboxes can contribute to the leakage of combustible fluids [19].

Another common leakage spots in open vessels are the sample collection points with malfunctioning sample valves or due to operational fault. Moreover, the sealing in rotating pumps wears with usage; in this case, preventing the leakage of volatile materials is extremely challenging. Similarly, in rotating equipment, stress is exerted on the piping due to the rotational force, making it the most vulnerable location for failure in petroleum industries [13].

2.1.5 Toxic hazards

The most common hazardous gases generated in the oil and gas industry are sulfur dioxide (SO_2), hydrogen sulfide (H_2S), carbon monoxide (CO), petroleum gases and inert gases, such as nitrogen (N) and carbon dioxide (CO_2) [20]. Some of these toxic gases may be lethal even at a low concentration, while others are less toxic yet harmful. These chemicals are to be released into the atmosphere at concentrations below their toxic limits. If the toxic gases released from the vents, tank breathers, and piping leak exceed the safe limit, they can have harmful effects on the operators, people living in the area and other living organisms. Some of the toxic gases emitted from the oil and gas industry and their effects on human health and the environment are described below.

a) Petroleum gases (benzene, butane, methane, etc.)

Petroleum gases and vapors, commonly called sweet gases, include harmful chemicals like benzene, butane, and methane. Operators working with oil and storage tanks have the highest risk of sudden exposure to high concentrations of these hydrocarbon gases, which are potent enough to cause immediate death. These gaseous mixtures may contain complex or exotic molecules, such as polycyclic aromatic hydrocarbons, some of which are mutagens and carcinogens, while dioxins may affect fertility. Overall, the severity depends on the chemical concentration, exposure, duration, and solubility.

b) Hydrogen sulfide (H_2S)

H_2S is one of the most toxic gases found during oil drilling, posing great risk to oilfield workers, service workers, and contractors. H_2S, which is known as sour gas, can numb the sense of smell high concentrations and even cause sudden death. The short- and long-term health effects of H_2S vary based on the exposure concentration.

c) Diesel exhaust

Diesel is the primary fuel that powers most equipment used in oil and gas exploration and processing. Diesel exhaust is a mixture of CO_2, CO, and particulate matter produced during diesel combustion, which are capable of triggering a wide range of ill health effects, such as respiratory diseases and lung cancer, in humans.

d) Mercury vapor

Mercury is naturally found in oil and gas and may accumulate in steel pipes and other processing equipment during operations. When the processed fluids are cooled, liquid mercury condenses, forming deposits on the insides of heat exchangers, separators, valves, and piping. When these equipment are taken apart for repair or maintenance, there is risk of mercury vapor inhalation by the service personnel, which can have neurotoxic effects and lead to neurological issues, such as behavioral changes, tremors, and nervousness.

e) Smoke

The incomplete oxidation of fuel during chemical combustion produces smoke. The main dangers of smoke exposure are the inhalation of narcotic gases, oxygen depletion, and respiratory irritation. Carbon monoxide (CO), hydrogen cyanide (HCN), and carbon dioxide (CO_2) are some of the common narcotic gases, which often lead to hyperventilation upon inhalation due to oxygen depletion.

These chemicals should be released into the atmosphere below their permissible threshold concentrations to avoid their ill effects on humans and other living organisms in the vicinity.

2.1.6 Corrosion hazards

The development of oil and gas reserves under aggressive environments causes the corrosion of materials used in the wells. Metallic equipment and structures that come in contact with a variety of petroleum products, solvents, water, the atmosphere, and soil in the oil refineries are highly prone to a range of corrosion phenomena, which escalate the risk of serious accidents. For instance, mercury, a naturally occurring component in gas and oil deposits (up to 5 mg/m^3 in natural gas and 600 ppm mg/kg in crude oil) [21], can trigger intensive electrochemical corrosion of aluminum alloys (e.g., heat exchangers) and liquid–metal embrittlement (LME) of steel, which may leading to grave accidents.

Some of the most common conventional corrosive compounds found in the downstream sector of the oil and gas sector are summarized in Table 4.2.

CO_2, SO_2, and H_2O present along with hydrocarbon chemicals can corrode the insides of the oil and gas pipes, deteriorating the metal quality and leading to pipe leaks and rupture. This can potentially result in the loss of hydrocarbons to the environment, leading to fire and explosion when ignited. If the released gas is toxic, potential fatalities related to toxic hazards are likely.

2.2 Personal safety hazards

a) Electrical hazards

Electrocution, arc flashing, battery fire and electric shocks are the most common personal safety hazards across oil fields and oil and gas facilities. The major causes for these hazards are overhead power lines, damaged electrical tools and equipment, inadequate wiring and overloaded circuits, non-ex-rated electrical equipment, improper grounding, damaged insulation, and wet conditions. Most of the processes in petroleum industries generate static electricity, which has the potential to lead to fire or explosion at sites involving flammable liquids/gases.

Table 4.2 Corrosion agents encountered in the process unit of the petroleum refining and petrochemical sectors [22].

S.No	Process unit	Causes of corrosion
1	Crude distillation unit	Sulfidation at elevated temperatures and corrosion attack by naphthenic acid (found in crude oil)
2	Fluid catalytic cracking unit	High-temperature carburization of steel, oxidation, and sulfidation
3	Delayed coking	• Carbon can lead to carburization at higher temperatures, cause steel embrittlement and reduce corrosion resistance, thereby allowing other corrosive compounds to initiate attacks. • Presence of ammonia, cyanide, and hydrogen sulfide
4	Hydrotreating	• Presence of ammonia, ammonium hydrosulfide, hydrogen sulfide, and polythionic acids • Steel embrittlement at high temperatures and pressures
5	Hydrocracking	Steel embrittlement and polythionic stress-corrosion cracking
6	Catalytic reforming	Formation of ammonium chloride and pitting corrosion from cooling water
7	Hydrogen plants	High temperatures and pressures, as well as frequent exposure to carbonic acid
8	Gas plants	• Presence of ammonia, chlorides, hydrogen cyanide, and hydrogen sulfide • Water with hydrogen blistering and sulfide cracking
9	Amine plants	Presence of hydrogen sulfides and carbonic acid

2.2.1 Static electricity

Static electricity is generated due to the imbalance between negative and positive charges in an object. There are three modes of static generation: contact, detachment, and frictional static build-up [23,24]. These charges accumulate on the surface of an object until they are dissipated or discharged. This can occur when liquids are poured, pumped, filtered, agitated, stirred, or flowed through pipes. Static generation is common in a variety of processes that involve the movement of liquid hydrocarbons, particle-contaminated gases contaminated (e.g., rust), liquid particles (e.g., steam), and dust or fibers (e.g., drive belts, conveyors).

Static electricity may be generated by a range of scenarios and hazardous locations, such as [25,26]

- The static charge increases when the liquid is pumped at a high velocity or passed through filters, valves and fittings.

- Reduction in pipe diameter and non-conducting pipe materials, such as polyvinyl chloride (PVC) or fiberglass, can increase the static charge.
- Jet nozzles and high-flow velocities increase fluid spraying inside the tank, making the walls susceptible to static charge build-up.
- In overhead tanks, friction is produced between the feed pipe and the liquid. Static charges accumulate both on the tank shell and liquid surface when insulated from the ground. Sparking can occur across the liquid surface or from the body to the ground.
- Splash filling leads to fine mist droplet build-up and the impact of solid particles on tank plates in processes, such as sandblasting and shotcreting, as well as sludge and rust fragments sedimented in tanks generate static charges as well.
- Static charges in tank trucks are produced when either the hydrocarbons or tires rub against the road. Spark generation between the dome and the fill pipe of the vehicle during liquid transfer is another possible situation.
- Poor conducting materials: When hydrocarbon liquids with poor electrical conducting properties flow along a pipe, the pipe wall absorbs their ions, forming an electrical double layer that resembles a capacitor plate. Some examples include gasoline, kerosine, fuel oils, jet fuels, and diesel. The charged pipe and liquid try to neutralize each other and stay close in this scenario, generating a small current of about 1 μA, which is high enough voltage to produce a spark.

Some practices adopted by the petroleum industry to minimize the generation of static electricity are summarized below [27,28]:

- The modules (containers, piping, funnels, pumps) used for dispensing flammable liquids must be electrically linked to a static grounding system using bonding wires, conductive materials and ground cables. Bonding refers to the electrical connection between two metal containers that ensures uniform electrical potential between them to avoid spark generation. For instance, it is important to bond the dispensing and recipient metal containers before a liquid is transferred. Meanwhile, connecting a container to an earth-grounded object (buried metal plate or a metallic underground gas piping system) to drain off the static charges is called grounding.
- The National Fire Protection Agency (NFPA) strongly suggests that a grounded dip pipe or grounded wire is dipped in the liquid while non-conducting portable containers are being filled. Further, if the liquid has low electrical conductivity,

the grounded dip rod must be retained in the liquid for around 30 s after the completion of the filling process.
- Filling ungrounded portable fuel tanks on plastic-lined truck beds presents the risk of spark-induced gasoline fires. Therefore, portable fuel tanks should be placed on the ground, in the turned-off mode and at a safe distance from the vehicle while being filled. Furthermore, the nozzle must be placed in contact with the container during the filling process.

b) Arc flash

Arc flash refers to the unintended flow of electric current through the air between two conductors or from a conductor to the ground. Arc flashes release enormous amounts of heat (above 35,000°F), light and sound (around 140 dB or more), creating arc blast waves (pressure over 2000 lb/sq. ft), which involve flying objects (molten metal pieces and projectiles from electrical equipment), fumes (vapourized metal), and fire.

c) Lightning

Lightning is caused when static electricity accumulated inside a storm cloud is discharged into the atmosphere [29]. Since most storage tanks release combustible vapor via the seals and vents, they are prone to lightning-induced fires. Lightning can directly strike and ignite combustible content in cone-roofed storage tanks if it is not bonded and grounded to the earth.

2.2.2 Gravity/dropped object hazards (lifting/hoisting)

Dropped Objects continue to account for the majority of potentially fatal incidents in the upstream oil and gas segment. Objects that fall or present the probability of falling off from their previous position are defined as gravity hazards. These include unnecessary/loose parts, unsecured elements, poorly stacked pieces of a structure, or even entire structures falling from a height without any force application [30]. A host of factors can contribute to a dropped object incident, and hence it is important to assess the worksite thoroughly for hazard identification. Often, objects fall as a result of offshore corrosion, poor maintenance, or incorrectly installed fixtures. In the case of dynamic dropped objects, usually, an external force, such as gravity, wind, heavy lifting and mechanical motion, can initiate a sequence of events. A typical example is when a light installation is hit by a lifting crane during unloading at a petroleum exploration or production site.

2.2.3 Working at height (slip/fall/trip)

Fall or slip hazard remains one of the leading causes of fatalities or major injuries in the oil and gas industries. Workers are required to access platforms and equipment placed high above the ground or sea. The majority of the incidents happen during drilling activities such as rigging up or down, or inserting or removing a drill pipe into a wellbore. Another significant hazard is climbing the derrick ladder used for servicing the rig. These ladders usually are taller than 100 feet and may be slippery, cold, or extremely narrow. Sometimes, the ladders are ill-positioned and workers need to transition between them or from the ladder to the derrick. Another possibility of falling from a height is through unguarded holes on the floor, such as hatchways, inspection holes and pits, into process tanks and on machinery.

2.2.4 Confined space hazards

Confined space refers to a completely or partially enclosed space that is at atmospheric pressure when occupied but not intended to be a regular workplace due to restricted entry/exit paths, insufficient ventilation/oxygen levels, or the presence of toxic/flammable/explosive gases.

Confined spaces can be classified as (i) non-permit spaces and (ii) permit-required spaces [31].

a) **Non-permit space**: This space is large enough for an employee to enter and perform an assigned work but has restricted means of entry and exit. Tanks, bins, mud pits, reserve pits and other excavated areas, storage containers and spaces around a wellhead are examples of non-permitted confined spaces.
b) **Permit-required space**: This space has the potential to turn into a hazardous environment, contains chemicals/gases that may engulf an entrant, or has an internal configuration that can potentially trap or asphyxiate a person. Examples of such constructions include inward-converging walls and a down-sloping floor that tapers to a smaller cross-section.

   A majority of deaths in confined spaces occur due to the following atmospheric hazards [32]:

   - **Toxic atmosphere**: A toxic atmosphere may be created in the presence of hazardous substances arising from previous processing or storage activities, sludge deposits, a fire within the space, or seepage from improperly isolated adjoining plants interfering with the processes implemented in confined spaces. For example, carbon monoxide is generated in the space from heating and mobile equipment exhaust. The decomposition of organic material occurs naturally and, in some environments, can generate H_2S. Solids in the powder form when disturbed in a confined space may result in an asphyxiating atmosphere. Such toxic atmospheres may have a range of acute effects, from the inability to think or act judicially to unconsciousness and even death.

- **Oxygen-rich or oxygen-deficient atmospheres**: Excess oxygen in the presence of fuel elevates the risk of fire and explosion. In some cases, oxygen deficiency occurs due to the displacement of air by other gases or absorption of air by steel surfaces, especially in damp conditions, when oxygen is utilized for chemical/biochemical reactions, such as rotting of organic matter, rusting of metals, burning, etc.
- **Excessive heat**: Confined spaces increase the risk of heat stroke or collapse from heat stress. The risk is exacerbated when the personnel wear personal protective equipment or due to the lack of ventilation in a heated environment.

2.2.5 Excavation hazards (laying buried pipes onshore)

Excavation is defined as breaking the ground or making trenches to lay pipelines, piping or electrical cables inside the process facilities. A variety of excavation methods are applied during pipeline construction, including vertical excavation, horizontal excavation, step trenching, and cofferdams. Onshore pipeline construction involves the operation of excavators, swamp buggy, pay-loader, bulldozer, and other heavy-duty equipment to lay the pipes in trench foundations on the pipeline right-of-way (ROW). The potential hazards during excavation in process facilities include [33]

- Rupture of underground facilities, such as existing hydrocarbon pipelines/piping, resulting in the loss of containment and jet/pool fire when ignited.
- Damages to the underground electrical cables, resulting in electrocution.
- Injury to personnel and falling of vehicles, equipment and materials inside the excavation pit.
- Equipment breakdown under harsh environmental conditions.
- Obstruction of excavation by ground rock formation, which went undetected in the initial survey stage.
- Concealed trip hazards or sharp objects in the muddy water at the bottom of the trench.
- Crushing hazard by the heavy mass of soil caving inward in very deep trenches. Even reinforced cave walls may give in due to structural damage caused by the vibrations and

resonance when heavy machinery or pneumatic drills are operated.

In addition to this, other major risks include the accidental severing of underground utility lines, falls into the excavation pit, and flooding of trenches.

2.2.6 Noise hazards (exploration/processing plants)

The noise emanating from exploration activities and equipment, such as heavy truck traffic, well pumps and compressors, drilling and fracturing, flaring and venting, is a major hazard associated with oil and gas industries [34]. Mud pumps at drilling sites account for one of the primary noise sources. The oil and gas facilities can house a variety of noise sources at different frequencies and durations, and thus, it is difficult to define or regulate the overall sound pressure levels at a particular site. The chief noise sources in the process and LNG facilities include pumps, compressors, generators and their drivers, compressor suction/discharge, recycle piping, air dryers, heaters, air coolers at liquefaction facilities, vaporizers used during re-gasification, and general loading/unloading operations of LNG carriers/vessels. Continuous exposure to noise hazards increases the risk of stress, sleep disturbance and deprivation, elevated blood pressure, and heart diseases, which can have both short- and long-term effects on the workers/operators.

2.2.7 Vehicle collision

Transport is an essential part of the industry to ferry workers and equipment to and from the drilling sites as wells are often located in remote areas and require long-distance travel. There is a potential risk of vehicle crashes due to mechanical failure in vehicles, human error, poor weather conditions, etc. [35]. In the case of offshore rigs and platforms, the transport is primarily aided by helicopters or transfer boats. There is a risk of boat collision/helicopter accidents at the platforms or rigs during rough weather conditions, which might result in injuries and fatalities. Helicopter crashes in the US oil and gas industry contribute to high fatality rates [36].

2.2.8 Ergonomic hazards

Ergonomic hazards refer to physical conditions that can cause musculoskeletal injuries or disorders. Some of the most common ergonomics-related injury risks encountered in the industry are lifting heavy items, bending, reaching overhead, pushing and pulling heavy loads, and working in unsupported body postures

[37]. Work-related musculoskeletal disorders (WMSDs), which refer to injuries and disorders of the soft tissues (muscles, tendons, ligaments, joints, and cartilage) and nervous system, are considered an important source of occupational morbidity. Some examples include carpal tunnel syndrome, tendonitis, thoracic outlet syndrome, and tension neck syndrome.

WMSDs occur when the physical capability of the worker does not match the physical requirements of the job. Some causes of WMSDs [38] are excessive force, repetitive or quick movements, awkward body postures, static postures for long hours, excessive vibration of a part or the entire body, and extreme temperatures in the working environment. The primary effects of these risk factors include tendon/tendon sheath irritation, nerve compression, and restricted blood flow (numbing), all of which result in muscle cramp, muscular or neural damage, pain, and fatigue. Particularly, compression caused while grasping sharp tools and cold temperatures can severely affect the manual dexterity and coordination of workers, forcing them to apply more force than normally required to performing the task.

When workers face discomfort on the job, they try to find shortcuts or workarounds that may result in mishaps, such as slips and falls, and injuries like lacerations. An ergonomics program that encourages the early reporting of ergonomic issues and provides appropriate solutions can not only prevent MSDs but other common workplace incidents as well. The recognition of ergonomic risk factors at a workplace is the critical first step toward rectifying them and improving workplace safety. Once recognized, the risk factors and associated consequences can be mitigated or even eliminated through interventions, such as pre-task planning, the use of right tools, appropriate placement of material/equipment/tools, and most importantly, educating workers about the risks and training them to implement the countermeasures besides early recognition and reporting of injury, signs, and symptoms [39].

2.2.9 Machine hazards

The most significant machine hazards are the rotating wellhead equipment, including top drives and Kelly drives, draw works, pumps, catheads, compressors, hoist blocks, conveyors, and belt wheels. Personnel injury is a possibility if they are exposed to moving parts of machinery (struck by) or caught between unguarded machines. Possible injuries include cuts, bruises, and fractures. Each phase of the machine life cycle, including transport, assembly, and installation, commissioning, usage, maintenance, dismantling, disabling, and scrapping, must be taken into account for risk assessment. Machine hazards are responsible for 3 of 5 oil and gas industry fatalities [40], which predominantly occur during site preparation, drilling, and the service phases of well operation.

2.2.9.1 Struck-by hazards

A struck-by accident refers to deaths and injuries caused by the impact of a moving object that strikes a part of the body. The probability of struck-by injuries is huge when equipment is operated near pedestrians. People can be struck by the equipment itself or the loads carried by the equipment. Struck-by hazards can be of three kinds [41].

i) Falling/flying objects

For instance, tools might slip from workers operating at a height and fall on other employees in working areas at lower levels. The possibilities range from loose pipes, scrap, lumber, and small objects like nuts and bolts, causing injuries and damage. Besides unfastened machine parts, suspended loads have the potential to fall, especially during hoisting and rigging equipment failure. Flying objects often involve the inappropriate or careless use of hand-held tools. For example, worn-out hammerheads can get detached from the handle while in use, go flying and strike a nearby worker with force. In the case of high-pressure lines and hoses, the nuts and bolts become projectiles when the connections break free; the pressurized lines themselves are likely to strike workers in the vicinity when disconnected unexpectedly during operation.

ii) Swinging objects

Oil and gas pipes and traveling blocks, while being lifted to the rig floor, as well as tongs and spinning chains used in drill pipe connections, pose the risk of swinging and striking personnel or Derrick's hands. Working at a height, especially during extreme weather, greatly increases the risk of disastrous consequences and major harm or injury. Besides these, cranes and excavators are other common sources swinging object hazards. Pre-inspection techniques, having a list of items to be inspected, use of equipment, LOTOTO, etc., are key to successful and safe crane and hoist operations.

iii) Rolling objects

The principal sources of rolling object hazards are fleet vehicles and mobile equipment, the weight and force of which can strike, crush, and injure employees. To prevent the struck-by hazards, which can cause serious injuries, the following best practices can be adopted: the use of specialized equipment while working with tools at a height, attaching the tools to the worker's belt or the platform structure, using toe boards, screens, or guardrail systems to avoid objects from falling to lower levels, barricading the areas below raised work zones and around the swing radius of cranes and excavators, and appropriate maintenance of all hoisting, lifting, and rigging equipment [42].

More importantly, the employees must be trained to hold appropriate positions when tripping pipes in or out and use wheel chocks on all parked equipment. When parked on a grade, the wheels must be turned in so that the equipment does not roll forward or backward.

2.2.9.2 Caught-in hazards

Oil and gas workers can get stuck under objects that have fallen or rolled onto them or caught between machinery and equipment. For instance, people can get caught in spinning chains, parts of the rotating system, or in draw works. Lacerations, amputations, major blood loss, or death can be the outcome of caught-in hazards. In addition to such machine hazards, oil and gas extraction workers are at the risk of friction, impact and stabbing or puncture hazards in a wide variety of rotating wellhead equipment, such as top drives and Kelly drives, draw works, pumps, compressors, catheads, hoist blocks, belt wheels, and conveyors.

2.2.10 High-pressure fluid injection hazards

High-pressure fluid injection is a hazard that can occur when fluids are forced into the body at high pressures, for instance, when a person is cleaning a machine with a high-pressure water hose and the nozzle break, or when a person is hit by a stream of high-pressure fluid from a ruptured hose. Another scenario is when a person is welding and the arc flashes back, injecting molten metal into the body [43].

3. Accidents and fatalities data in the oil, gas, and petrochemical industry

The accidents and number of fatalities recorded over the past 10 years due to various types of hazards in the upstream segment of the oil and gas industry sector [44] are shown in Figs. 4.3–4.5.

Our analysis demonstrates that a majority of the fatalities resulted from mechanical hazards followed by vehicle hazards.

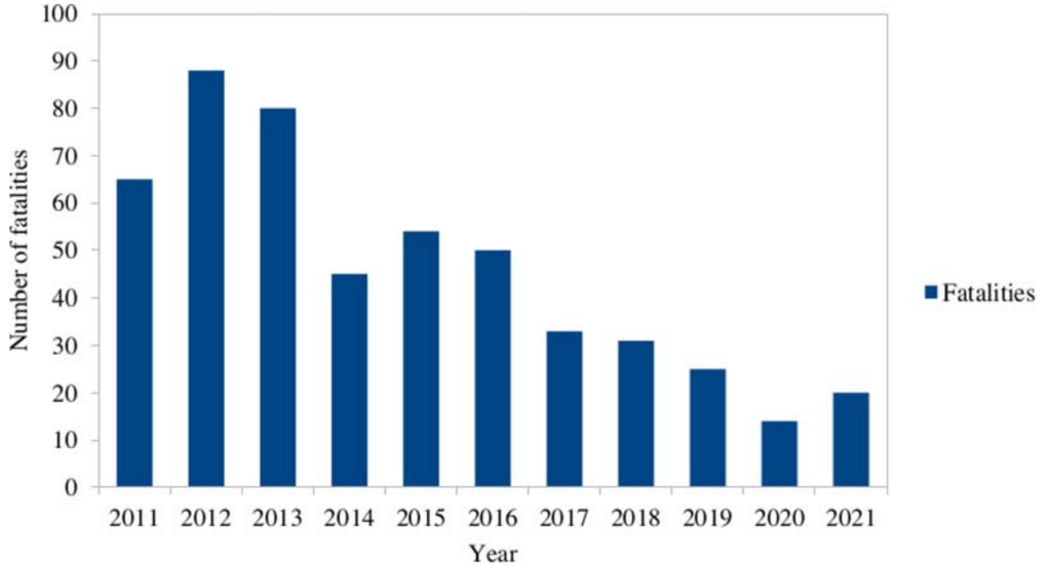


Figure 4.3 Fatalities reported in the upstream segment of the oil and gas industry (2011–21) [44].

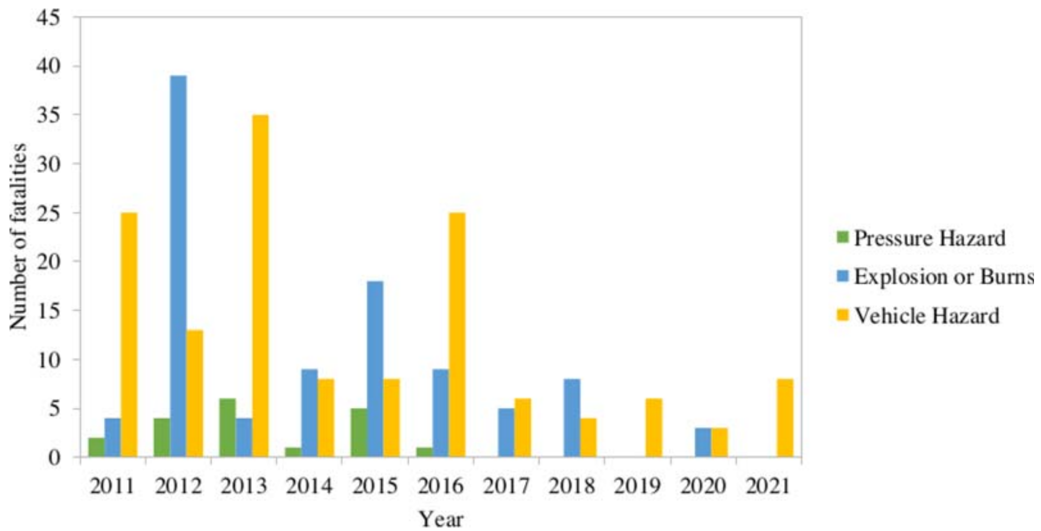


Figure 4.4 Fatalities reported due to process safety hazards in the upstream segment of the oil and gas industry (2011–21) [44].

Particularly, oil and gas extraction workers are exposed to a wide variety of rotating wellhead equipment, including top drives and Kelly drives, draw works, pumps, compressors, catheads, hoist blocks, belt wheels, and conveyors. They are at great risk of injury

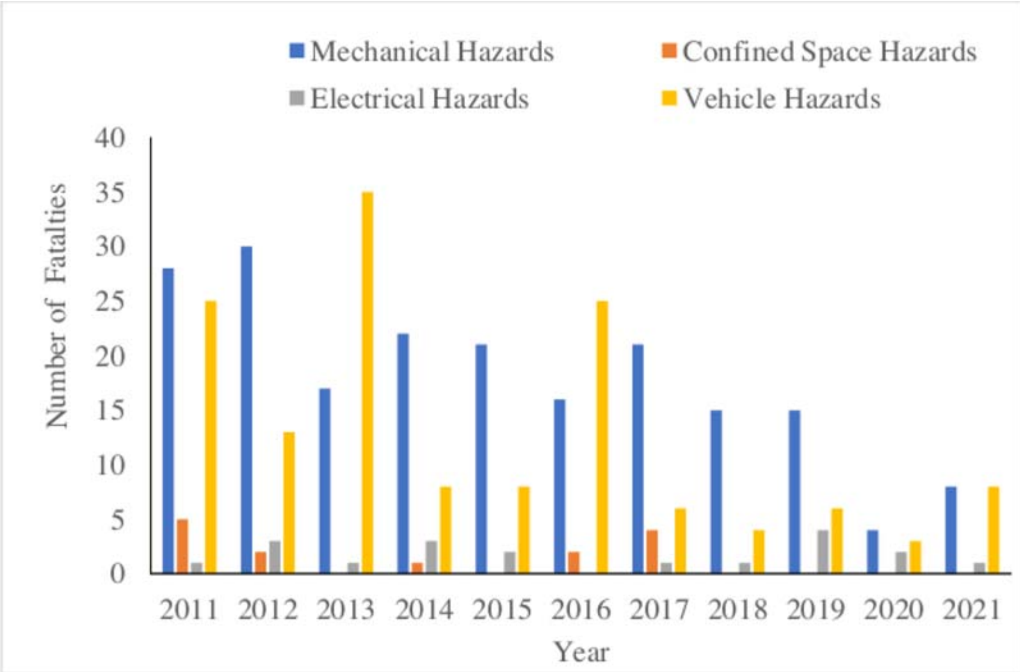


Figure 4.5 Fatalities reported due to personal safety hazards in the upstream segment of the oil and gas industry (2011—21) [44].

as they can be struck by or caught between unguarded machines. However, drilling personnel have been historically the most unfortunate as they are directly affected by the major incidents in the petroleum industry. Developing benchmark safety and environmental practice rules in line with the recognized global best practices is the need of the hour. Similarly, major accidents in the downstream sector are associated with the leakage of flammable substances from pipes/storage tanks, resulting in fire and explosion (Table 4.3).

The root causes of mishaps in the upstream, midstream, and downstream sectors involve human errors and organizational factors. This sector has been constantly reforming its safety practices over time by improving hazard hunt, risk identification, and management at workplaces to minimize the risk of fatal and nonfatal injuries.

Table 4.3 Accidents occurred in the downstream sector of the petroleum industry [45].

Type of accident	Date	Industry type	Accident description	Source
Release of natural gas into the atmosphere	2021-01-01	LNG storage and distribution (Manosque and Dauphin, Alpes-de-Haute-Provence, France)	Miscommunication regarding the controller system of an underground storage site that was out of service. A full safety shutdown was triggered, closing the automatic transfer valves. From the pipes, 20,090 m^3 of natural gas was discharged into the atmosphere, 5% above the SEVESO threshold.	Natural gas
Explosion at a production plant, destroying stored explosives	2020-12-21	Production and storage of explosives (Casalbordino—Miracoli)	During routine incineration of some materials, the explosive material was ignited and exploded. Specifically, this incident occurred in the area under a canopy close to the static furnace, from which products to be destroyed are fed into the furnace via a modeled sheet metal slide. At that time, nautical signaling flares and other materials contaminated with explosives were being incinerated in the furnace.	Explosive material
Explosion and fire at a coking plant	2020-11-20	Processing of metals (Dunkerque)	The electric connection of a detarrer was switched off because it was in the washing and draining phase. Some hypotheses for the cause of fire: Electrostatic energy was created by the friction between the nonpurified air/gas mixture that still contained dust and the metal plates, creating a source of ignition.	Coke oven gas

Table 4.3 Accidents occurred in the downstream sector of the petroleum industry [45].—*continued*

Type of accident	Date	Industry type	Accident description	Source
			Pyrophoric materials could potentially have caused the explosion when they came in contact with oxygen. A piece of metal potentially falling inside the detarrer could have created a spark.	
Fire in a hazardous waste warehouse (storage)	2020-03-12	Waste storage, treatment and disposal (Tiszaujvaros)	A barrel containing paint-foam waste (organic solvent) was presumably overfilled by its previous owner before it arrived at the plant and was stored in the open warehouse. A significant temperature rise the day before the accident led to the splitting of this barrel, which was placed next to activated charcoal waste (contaminated raw material), which had most likely spilled onto the ground prior to the accident. The methyl-acetate/ ethyl-acetate content in the organic solvent reacted catalytically with the activated carbon, leading to a dangerous exothermic reaction and local fire, which spread and caused the rupture and ignition of some nearby barrels, containing highly flammable organic solvents.	Hazardous waste sludges from on-site effluent treatment

Continued

Table 4.3 Accidents occurred in the downstream sector of the petroleum industry [45].—*continued*

Type of accident	Date	Industry type	Accident description	Source
Fire in the distillation unit of a refinery	2019-12-19	Petrochemical/oil refineries (France)	The fire was detected in a distillation unit. A gasoline leak had occurred on a pressure tap on a 3-inch flow meter, at a point where a hollow tubular support (trunnion) was located.	Gasoline
Loss of containment of crude oil from a de-salter	2019-03-23	Petrochemical/oil refineries	Though the alarms set at 20% of the lower explosive limit had gone off before the fire, the control room staff did not notice them.	Crude oil
Loss of containment oil	2018-10-12	Petrochemical/oil refineries (South shore of an estuary in West Whales)	From a 20-year-old, ill-maintained pipework (no records of inspection), the leak occurred through a hole of size about 80 mm by 50 mm. Gross external corrosion caused by external coating break down was detected.	Crude oil
Explosion of a chemical reactor with ethylene oxide	2020-01-14	Chemical installations—industrial gases (PoligonSud of Tarragona)	The accident occurred during the production of methoxypolyethylene glycol, MPEG 500. Initially, a loud depressurization noise was heard, lasting for about 15 s, followed by a loud explosion. The entire product contained in the reactor at the time of the accident was decomposed and burnt in the explosion, and the release of the toxic product to the exterior was not expected.	Methanol, sodium methylate, ethylene oxide acetic acid and propylene oxide

Table 4.3 Accidents occurred in the downstream sector of the petroleum industry [45].—*continued*

Type of accident	Date	Industry type	Accident description	Source
Release of gas from a tank with oil recovered from water the treatment plant	2019-11-22	Petrochemical/oil refineries (Mongstad)	The primary cause was sudden boiling with phase transition and foaming (slopover) in the tank due to overheating.	Hydrogen and H_2S
Fire in a plant manufacturing additives for oils and lubricants	2019-09-26	Chemical installations (Rouen)	There was a fire in a storage area for packaged products (200-L drums, 1000-L intermediate bulk containers IBC, pallets) in a plant producing additives for oils and lubricants, classified as an “upper-tier Seveso establishment.”	Propane

4. Risk management in the oil and gas industry

Risk assessment is the process of identifying potential hazards and analyzing the potential consequences. The process involves three steps: risk identification, risk analysis, and risk evaluation. Risk analysis is a tool for evaluating the probability and consequences of incidents to assess hazard implications.

Risk analysis is performed in four main steps [46]

- Identification of incident scenarios/occurrences
- Estimation of incident frequency
- Determination of the consequences of each event
- Development of risk valuations based on the frequency and consequences.

These techniques can be either qualitative or quantitative. Qualitative risk analysis involves rating or scoring based on human perception or judgment, while quantitative risk analysis relies specific and verified data.

The typical risk analyses undertaken in the petroleum industry to identify the process hazard analysis are [47,48]

a) Qualitative risk analysis: What if assessment, checklists, HAZOP, etc.,

b) Quantitative risk analysis: fault tree analysis, event tree analysis, failure modes, effects, and criticality analysis (FMECA), and Bow-tie analysis.

The rigor and effectiveness of the risk assessment process should be proportional to the risk involved. It is crucial that the hazard recognition process and control measures be thorough, particularly in the oil and gas industry, because of the sheer magnitude of potential damage implicated. Moreover, the success of this process reflects the effort undertaken by the industry in controlling risk fluctuations during operation. The standardized risk limit in most petroleum and chemical facilities is 1×10^{-4} per year. In scenarios where the risk is higher than the acceptable limit even when all reasonable risk mitigation/practical protection methods are exhausted, the risk is considered as low as reasonably practicable.

5. Conclusion and future outlook

Installation, repair, and maintenance of high-pressure lines and vessels are high-risk yet unavoidable mundane activities in the oil and gas industry. A variety of severe hazards, including the sudden release of pressure, exposure to dangerous chemicals, working in confined/contaminated spaces and falling objects, can occur due to human error, equipment failure, or external conditions, leading to acute and life-threatening medical conditions. Long-term effects due to constant exposure to chemicals and noise include occupational diseases of the lung, skin, or heart, as well as noise-induced hearing loss (NIHL). Often, the root of mishaps is the breach or non-adherence to safety protocols or poor maintenance/unavailability of safety equipment. Oil and gas industries need to be continuously operated without major disruptions to remain profitable. Hence, on-site mishaps and accidents can cause heavy damage to the companies and personal loss to the employees. Devoting funds to ensure the continual availability, reliability, and maintenance of equipment and materials is essential to hazard mitigation. The process has become easy in recent trends with the advent of intelligent digital risk assessment systems that aid in evaluating unforeseen risks and formulate high precise and optimum solutions superior to current industrial standards to assure efficient and safe operation.

References

[1] Al-Janabi Y. An overview of corrosion in oil and gas industry: upstream, midstream, and downstream sectors. 2020. https://doi.org/10.1002/9783527822140.ch1.
[2] Robinson P. Petroleum processing overview. 2007. https://doi.org/10.1007/978-0-387-25789-1_1.
[3] IOGP. IOGP fatal incidents [Internet]. London: International Association of Oil and Gas Producers; 2020. Available from: https://safetyzone.iogp.org/FatalIncidents/fatalincidents.asp.
[4] Badida P, Balasubramaniam Y, Jayaprakash J. Risk evaluation of oil and natural gas pipelines due to natural hazards using fuzzy fault tree analysis. Journal of Natural Gas Science and Engineering 2019;66:284–92. https://doi.org/10.1016/j.jngse.2019.04.010.
[5] Green KP, Jackson T. Safety in the transportation of oil and gas: pipelines or rail? Fraser Inst 2015:1–14.
[6] Michela C. Analysis of major industrial accidents triggered by natural events. Reported in the principal available chemical accident databases. JRC scientific and technical reports. European Commission; 2007.
[7] Attwood D, Khan F, Veitch B. Offshore oil and gas occupational accidents – what is important? Journal of Loss Prevention in the Process Industries 2006;19(5):386–98. https://doi.org/10.1016/j.jlp.2005.10.006.
[8] Jorgensen K. Prevention of “simple accidents at work” with major consequences. Safety Science 2016;81:46–58.
[9] Nolan DP. Handbook of fire and explosion protection engineering principles for oil, gas, chemical and related facilities. 2nd ed. 2011.
[10] Center for Chemical Process Safety (CCPS). Guidelines for use of vapor cloud dispersion models. 2nd ed. New York, NY: American Institute of Chemical Engineers (AIChE); 1996; Center for Chemical Process Safety (CCPS). Guidelines for vapor cloud explosion, pressure vessel burst, BLEVE and flash fire hazards. New York, NY: Wiley – American Institute of Chemical Engineers (AIChE); 2010.
[11] Assael MJ, Kakosimos K. Fires, explosions, and toxic gas dispersions: effects calculation and risk analysis. Boca Raton, Florida: CRC Press; 2010.
[12] National Fire Protection Association (NFPA). Fire protection handbook. 20th ed. Boston, MA: NFPA; 2008.
[13] Abdel Salam Hamdy M, Mahmood A. Handbook of materials failure analysis with case studies from the oil and gas industry. 2016.
[14] UNL Environmental Health and Safety (402) 472-4925. http://ehs.unl.edu.
[15] Devold H. Oil and gas production handbook: an introduction to oil and gas production. 2007.
[16] Kipker T. Drilling rigs in arctic deep temperature environments - design an operation challenges. In: Paper presented at the OTC arctic technology conference, Houston, Texas, USA; February 2011. https://doi.org/10.4043/22093-MS.
[17] Mkpat E, Reniers G, Cozzani V. Process safety education: a literature review. Journal of Loss Prevention in the Process Industries 2018;54:18–27.
[18] Saji VS, Umoren SA. Corrosion inhibitors in the oil and gas industry. U.S. Environmental Protection Agency (EPA); 1995. Profile of Petroleum Refining Industry. Office of Enforcement and Compliance Assurance, United States.
[19] Lyons WC, Plisga GJ. Standard handbook of petroleum and natural gas. 2nd ed. Elsevier Inc; 2005.

[20] U.S. Environmental Protection Agency (EPA). Study of selected petroleum refining residuals - industry study. United States; 1996.

[21] Perez TE. Corrosion in the oil and gas industry: an increasing challenge for materials. JOM 2013;65:1033–42. https://doi.org/10.1007/s11837-013-0675-3.

[22] Groysman A. Corrosion problems and solutions in oil, gas, refining and petrochemical industry. Koroze a ochrana materialu 2017;61. https://doi.org/10.1515/kom-2017-001.

[23] Britton LG. Avoiding static ignition hazard in chemical operations. New York: Wiley (AIChE); 1999.

[24] Pratt TH. Electrostat ignitions of fires and explosions. New York: Wiley (AIChE); 2000.

[25] Yuqin H, et al. A case study of electrostatic accidents in the process of oil-gas storage and transportation. Journal of Physics: Conference Series 2013; 418:012037.

[26] Property loss prevention data sheet 5-8, static electricity. Norwood, MA: FM Global; 2001.

[27] Property loss prevention data sheet 5-1, electrical equipment in hazardous (Classified) locations. Norwood, MA: FM Global; 2006.

[28] Property loss prevention data sheet 5-10, protective grounding for electric power systems and equipment. Norwood, MA: FM Global; 2003.

[29] Property loss prevention data sheet 5-11, lighting and surge protection for electrical systems. Norwood, MA: FM Global; 2000.

[30] ABS guide for dropped object prevention on offshore units and installations; 2017.

[31] American Petroleum Institute (API). RP 14G, recommended practice for fire prevention and control on fixed open-type offshore production platforms. 4th ed. Washington; 2007. https://www.uncp.edu/sites/default/files/2019-06/DOL%20-20A%20Guide%20to%20Confined%20Spaces.pdf.

[32] Safety moments in oil & extraction: hazards, controls & resources. https://naspweb.com/blog/safety-moments-in-oil-extraction-hazards-controls-resources/.

[33] Kim Y, Park J, Park M. Creating a culture of prevention in occupational safety and health practice. Safety and Health at Work 2016;7(2):89–96.

[34] Behrens and Associates. Gas well drilling noise impact and mitigation study. California: Hawthorne; 2006. http://pstrust.org/docs/GasWellDrillingNoiseImpactandMitigationStudy.pdf.

[35] Planas-Cuchi E, Gasulla N, Ventosa A, Casal J. Explosion of a road tanker containing liquefied natural gas. Journal of Loss Prevention in the Process Industries 2004;(17):315–21. Casal J, Arnaldos J, Montiel H, Planas-Cuch E, Vılchez JA. Handbook of Hazardous Spills. New York, NY: McGraw Hill; 2001.

[36] Yeoman K, O'Connor MB, Sochor S, Poplin G. Characterization of fatal injuries in oil and gas industry-related helicopter accidents in the Gulf of Mexico, 2004–2014. Injury Epidemiology December 7, 2020;7(1):64. https://doi.org/10.1186/s40621-020-00288-5.

[37] Mohan S. Identifying and controlling ergonomic risk factors construction. Journal of Ergonomics 2018;08. https://doi.org/10.4172/2165-7556.1000235.

[38] Barr AE, Barbe MF, Clark BD. Work-related musculoskeletal disorders of the hand and wrist: epidemiology, pathophysiology, and sensorimotor changes. Journal of Orthopaedic & Sports Physical Therapy 2004;34(10):610–27. https://doi.org/10.2519/jospt.2004.34.10.610.

[39] Costa G. Shift work and health: current problems and preventive actions. Safety and Health at Work December 2010;1(2):112–23. https://doi.org/10.5491/SHAW.2010.1.2.112. E-pub December 30, 2010.
[40] Fall Injuries Prevention in the Workplace. National Institute for Occupational Safety and Health (NIOSH) Workplace Safety & Health. www.cdc.gov/niosh/index.htm.
[41] National campaign to prevent falls in construction, CPW, NIOSH's Science Blog. www.cdc.gov/niosh.
[42] Oil and gas extraction worker fatalities 2014 NIOSH fatalities in oil and gas extraction (FOG) database. https://www.cdc.gov/niosh/docs/2017-193/2017-193.pdf.
[43] Rodríguez-Villar S, Kennedy R, Dall'Antonia M, Pilasi C. Management of industrial high-pressure fluid injection injuries (IHPFII): the Water Jetting Association (WJA) experience with water driven injuries. European Journal of Trauma and Emergency Surgery 2019:45. https://doi.org/10.1007/s00068-019-01106-4.
[44] IOGP. IOGP fatal incidents [Internet]. London: International Association of Oil and Gas Producers; 2019.
[45] EUROPA – eMARS Dashboard – European Commission. https://emars.jrc.ec.europa.eu/en/emars/content.
[46] Korkmaz KA, Sari A, Carhoglu AI. Seismic risk assessment of storage tanks in Turkish industrial facilities. Journal of Loss Prevention in the Process Industries 2011;24:314–20. https://doi.org/10.1016/j.jlp.2011.01.003.
[47] Pavanaditya B, Tamilpriya S, Jayapriya J. Risk analysis of hazardous activities using Fuzzy multicriteria decision making tools: a case study in a gas turbine manufacturing plant. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 2021. https://doi.org/10.1080/15567036.2021.2017519.
[48] Ramzali N, Lavasani MRM, Ghodousi J. Safety barriers analysis of offshore drilling system by employing Fuzzy event tree analysis. Safety Science 2015;78:49–59. https://doi.org/10.1016/j.ssci.2015.04.004.

This page intentionally left blank

SECTION II

Natural disasters in oil, gas, and petrochemical industries

This page intentionally left blank

5

Effects of floods on the oil, gas, and petrochemical industries: case study in Iran

Bahram Malekmohammadi, Mahdi Rezaei, Jahanbakhsh Balist and Abbas Yaghoobi Andarabi
Department of Environmental Planning, Management and Education, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

1. Introduction

Floods are unusual currents that may go against a river's natural flow and cause damage to nearby inhabitants. These components often depend on river flow and bed conditions and are not time-dependent [1]. Floods are transient situations where water covers dry land [2]. As the world's primary fuel sources, oil and natural gas are pioneer sectors in the energy sector and significantly impact the global economy. Oil and gas production and distribution systems are highly complicated, capital-intensive, and dependent on cutting-edge technology—the oil and gas industry is impacted by a changing climate and increased extreme weather. Floods and land subsidence are among the disasters that significantly impact gas, oil, and petrochemical infrastructure. Natural disasters, an inevitable part of existence and growing in number and variety daily, have made it extremely difficult for human society to evolve sustainably and have resulted in a significant rise in fatalities in recent years. Natural and man-made risks have an impact on both life and the economy everywhere. Growing urbanization and, more crucially, settlements frequently exposed to crises due to high population concentration and rapid development dynamics are two of the most significant aspects of this trend [3,21]. The flood phenomenon is one of these natural calamities that Iran has also experienced frequently in recent years. From mid-March to April 2019, considerable areas of Iran saw widespread flash flooding, most notably in Golestan, Fars,

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00014-1

Khuzestan, Lorestan, and other provinces. Over 2 weeks, Iran has been slammed by three significant waves of rain and flooding, causing flooding in at least 26 of Iran's 31 provinces and killing at least 70 people. On March 17, the first wave of rain began, causing floods in two northern provinces, Golestan and Mazandaran, with the former getting up to 70% of its average annual rainfall in a single day. Several huge dams have overflowed, mainly in Khuzestan and Golestan, resulting in the evacuation of many villages and cities.

Additionally, Natech accidents, accidents brought on by natural disasters, are significant. Natural hazards can impact oil transmission pipelines, potentially negatively affecting the population and the environment. They can also have a considerable financial impact on pipeline operators. Geological hazards were the most common (65%), followed by hydrological (20%) and climatic (10%) threats. Meteorological threats had a minor impact. Landslides were the most common incident initiators among geological hazards, with subsidence occurrences accounting for most of the rest. Natural disasters are frequently underreported as causes of events. The susceptibility of pipeline systems to natural hazard damage varies according to system type [75]. Natural hazards do not affect all pipeline system components equally, and some are more sensitive, and in some cases exclusively susceptible, to specific industrial hazards. Impact mechanisms at pipeline system sections other than the pipe run are not pipeline-specific and are comparable to those found in fixed industrial plants. In addition to directly causing events, natural hazards can exacerbate other incidents by hastening causes, aiding the transit of spilt substances, or impeding response and recovery efforts. Slow-onset dangers, as well as the time variation of some natural hazards, should be considered.

Iran is regarded as one of the leading participants in this industry and holds a prominent position among the nations with fossil energy resources. Iran ranks second in the world in terms of oil and gas reserves. Iran was the third-largest producer of natural gas in the world in 2019 and the fifth-largest producer of crude oil in OPEC in 2020. It ranks as the third and second-biggest oil and natural gas reserve holder worldwide and has tremendous quantities of proven oil and natural gas reserves. Iran has 12% of the world and 25% of the Middle East's oil reserves in 2020 [4]. Iran's infrastructure in the oil, gas, and petrochemical industries experiences natural disasters, including earthquakes, land subsidence, and floods, just like other infrastructure in those industries around the world. The South of Iran is primarily where Iran's gas, oil, and petrochemical industries are concentrated.

These areas are coastal areas that are vulnerable to flooding and land subsidence. Floods and land subsidence are closely related, particularly in deltaic regions. In this chapter, based on the literature review, land subsidence and floods are defined and the relationships between them are investigated. Types of floods are presented, because flash floods are dominant in arid—sub-arid regions, flash flood is presented here. Natural events such as landslides, floods, and lightning can cause secondary accidents in oil, gas, and industry. These phenomena, with some examples, are presented. The south gas field is chosen as a case study, and results based on the chapter structure are discussed. Due to this uncertain phenomenon, some recommendations are presented in decision-making under deep uncertainty [91].

2. Flood definition and flooding

Flooding is a natural occurrence when a body of water's level rises to the point that it exceeds its natural banks or constructed levees and submerges normally dry regions. Every year, a flood may occur along a stream. Typically, high water flow is controlled between natural banks or constructed levees; however, when the volume of flood waters cannot be kept within these natural or artificial boundaries, the water spreads into the surrounding region. The flood extent follows a dynamic propagation that is primarily influenced by the volume of water that overflows, the velocity of the water flow, and the topography of the surrounding regions [76]. Flooding is characterized by the overflow of water onto dry ground [77], which is part of the natural water cycle; the significant repercussions are influenced by both the frequency and volume of food episodes [78]. The combined effects of urbanization and climate change are projected to increase the frequency of extreme weather events that result in flooding [5—10,79]. This expected rise in food risk will have a detrimental impact on economies, livelihoods, infrastructure, and health. This has bolstered the need to investigate the physical reasons for flooding, its potential societal effects, and effective responses [93].

Coastal flooding, storms, high tides, sea-level rise, and inadequate protection; river/fluvial floods, snowmelt or high precipitation in catchment areas leading to flash floods or riverine floods; pluvial floods, extreme rainfall and failing drainage systems or compound floods from cyclonic monsoon effects amplifying intense rainstorms and surges together; or rapid snowmelt can cause different types of floods [80].

In clustering flood types, the selection of meteorological indices and the grouping of flood occurrences based on these indices are the two most significant factors. In mountainous catchments, distinct combinations of intense-short-duration precipitation, high antecedent precipitation limiting catchment storage, and snow cover contribute to diverse flood types [81]. These categories should be reflected in the clusters, and indicators should be able to distinguish between them.

2.1 Flash flood

A flash flood is described as a sudden and intense flow of high water into a typically dry region or a rapid increase in water level in a stream or creek over the designated flood level. When severe rainfall causes a sudden rush of rising floodwaters, persistent flooding may escalate into flash flooding. It often happens within 6 hours after heavy rain. However, flash floods may occur within minutes or even hours if a dam or levee breaks or if heavy rain causes fast pounding. Even in regions far from the cause, flash flooding is possible. People might be caught by surprise and unprepared for flash floods. You may only have a few minutes to prepare for these unexpected, devastating floods [11]. Flash floods are among the most significant threats to people and infrastructure in arid—semi-arid regions. Increasing exposure and susceptibility due to fast and uncontrolled development, inadequate infrastructure, and sociocultural issues, among other variables, exacerbate the related hazards [82].

2.2 River flooding

Riverine flooding occurs when streams and rivers surpass the capacity of their natural or man-made channels to accommodate water flow, resulting in water overflowing the banks and flooding nearby low-lying, dry land [12].

2.3 Coastal flooding

2.3.1 Storm surge

Another sort of flood is coastal flooding. Regarding tropical cyclones, wind velocity does not convey the whole picture. A tropical cyclone's storm surge poses the greatest risk to most significant properties along the shore. In the past, many of the great storms that have made landfall have been linked with high mortality tolls due to the ocean's rising. 2005's Hurricane Katrina perfectly illustrates the destruction and devastation that storm surges can wreak. Hurricane Katrina killed at least 1500 individuals, and many of these fatalities were caused directly or indirectly by storm surges. Understanding your susceptibility and taking the appropriate precautions may mitigate the consequences of a coastal flooding catastrophe [13].

2.3.2 Rising sea level

Low-lying coastal regions are inundated by the sea on a permanent basis as a result of rising sea levels brought on by climate change or isostatic rebound. Since weaker winds will also be able to raise the sea level enough to flood coastal communities, the chance of storm surges occurring and the intensity of their effects will also increase [13].

2.3.3 Tsunami

Tsunamis are enormous waves that may be caused by a number of different factors, including earthquakes, volcanic eruptions, meteor strikes, and basically anything else that causes a significant amount of water to be displaced in the ocean. Because of their rapid movement and inability to be detected in advance, tsunamis pose a significant threat to human life. The amplitude of the wave is quite modest when it is near the origin of the tsunami, making it harder to identify; but it moves extremely swiftly. This occurs farther out in the ocean (over 800 kmh^{-1}). The wave's speed substantially decreases as it reaches the beach, yet its amplitude continues to climb exponentially even when it does not break. The wave arrives at the shore with tremendous momentum, and as it continues to slow down, its amplitude keeps growing despite the fact that it is moving more slowly. Because of the tremendous amount of force that tsunamis possess, they are able to move many kilometers inland [13].

2.4 Inland flooding

By definition, inland flooding does not occur on the coast, but hazard professionals evaluate it alongside other coastal hazards since it is frequently the outcome of storms that make landfall along the coast. Flooding can also occur after many days of rain, during brief periods of severe precipitation, when the snowpack melts rapidly, or when dams or levees fail. Inland flooding can occur when the volume of water on land exceeds the ability of natural and man-made drainage systems to transport it away [14].

2.5 Flood causes

Extreme flooding results from meteorological phenomena, hydrological basin systems, and human activities [15,16]. Heavy and/or persistent precipitation is often the initial cause of significant flooding but not of minor flooding. Due to rapid urbanization or geographic differences, land use changes [16,17] will raise the runoff coefficient, increase runoff production, and increase flood peaks and river volume. Fluvial flooding happens when rivers overflow their banks or when dams/dikes fail. Dam overtopping is one of the main causes of dam failure [18]. When rainfall quantities surpass the infiltration capacity and drainage capacity, pluvial flooding occurs, resulting in the inundation of metropolitan areas. Flood catastrophe is a hazard to human life, property, and sensitive ecological and environmental regions caused by extreme flooding. Extreme flooding is defined by a bigger inundation range and more dangers, which likely results in a broader range of impacted locations. Consequently, the list of anticipated disaster-causing entities is substantially broader. Preventive systems are not only flood prevention forces but also disaster-bearing bodies in the case of major flooding [19]. In addition, catastrophic floods may have harmful effects on vulnerable biological regions and ecosystems, such as surface and groundwater reserves. The direct effects consist of economic, social, and environmental effects. The economic effects include the destruction of homes, farms, industries, and businesses. Infrastructures, including transportation, water supply, electricity supply, and communication networks. Social consequences are primarily to those impacted by evacuation, homelessness, or injury, as well as possible casualties [20]. Extreme floods may erode vulnerable ecological and environmental regions or pollute sensitive ecological and environmental areas by transporting contaminants. Moreover, in modern society, where the construction of urban flood control and drainage facilities lags behind the construction speed of urbanization, and where lifeline projects, such as communication, power supply, and water supply, have more vulnerabilities, extreme floods are likely to have much greater flood impacts than flooded areas. Then, severe floods likely have indirect effects outside the region or after the floods have occurred. For instance, the 2011 catastrophic river floods in Thailand severely interrupted global supply networks [83].

2.6 Flash floods in arid and semi-arid areas

In the 20th century, a trend toward a drier and more variable climate has greatly increased the frequency of severe (extreme) precipitation events at the cost of moderate occurrences [90]. This climatic shift is most felt in semi-arid (annual rainfall between 250 and 500 mm) and desert (annual rainfall less than 250 mm) parts of the globe. Despite widespread water shortage concerns, this transformation has resulted in a steady rise in damages caused by severe flood occurrences [21–23]. These flood occurrences might be brief and limited in space, or they can be extensive and long-lasting. Both forms of flooding have devastating implications. Since 1985, more than 350 million people worldwide have been relocated as a result of extensive flooding.

In the previous 19 years, 44 floods have displaced more than one million people each event. The majority of these catastrophic floods occurred in Asia during the summer months. According to Abdel-Fattah et al. flash floods are defined as floods that develop swiftly within a short period, often a few minutes or hours, owing to heavy rainfall. According to the Food and Agriculture Organization (FAO) of the United Nations, about one-third of the world's landmass is classified as arid or semiarid. Both climatic types are characterized by severe drought and infrequent precipitation [84] and are prone to flash flooding. As climate change accelerates, the devastation caused by flash floods in the 21st century has been emphasized, especially in the drier areas of the globe. Flash floods are regularly observed in arid and semiarid parts of Iran, Iraq, Egypt, and Oman [85]. For example, Iran's hilly provinces of Mazandaran and Golestan experience debris floods in the form of flash floods. From 1962 to 2002, there were also reports of flash flooding in many Iranian regions [86]. The total flood damage was estimated to reach 138 million dollars during this period. According to Roughani et al., high rainfall played a significant role in flash floods during this era. Recent flash floods in March and April 2019 caused about $3.5 billion in US dollars in damage to most Iranian regions [87].

2.7 Flood and infrastructures

Flood damage is one of the most prominent examples of disaster risk globally [24–26], and damage to infrastructure is one of the most expensive in Schulte in den Bäumen et al. [27].

Despite this, insufficient research has been conducted on the subject [81]. Risk and (critical) infrastructures [28] are major subjects of study and policy in Disaster Risk Reduction [29] or climate change risk assessments [89], however many components of disaster risk are not yet integrated [30].

Gilbert White's key study on flood risk and the impact of human activities on flood risk noted that, despite greater infrastructure and flood protection measures, flood damages (in the United States) continued to rise during the 1920 and 1940s [94]. White's study also drew attention to the "levee effect," noting that new and improved flood protection provided incentives for the construction of real estate behind the new levees. However, greater river floods that exceeded these levees would catch additional people off guard, ironically increasing the danger of flooding.

The connection between flood hazard, protection, economic development, and human behavior was established relatively early on, but the interplay between catastrophe knowledge and knowledge-based behavior remains one of the largest research challenges [31,32]. For instance, the United Nations Sendai Framework on Disaster Risk Reduction [29] has four objectives for global and local activities to be completed by 2030, with "understanding disaster risk" being the first.

Critical infrastructure (CI) such as energy, transportation, and water supply are a societal pillar that is in high demand during and after extreme river flood events that exceed the capabilities of both water engineers and emergency managers. Therefore, disaster resilience must account for power and water shortages, road and bridge blockages, and their so-called cascading effects or cascading failures [33] that impede the recovery of population, industry, and numerous aspects of daily life. It is crucial to address cascading effects because infrastructures exist as large-scale, linked networks whose effects reach beyond flood sites and flood catchments.

Building licenses and flood prevention in river flood zones already encounter obstacles surrounding property ownership for CI assets, since private businesses hold about 80% of CI in Germany [95], or the installation of additional power grid connections is met with public opposition. Moreover, while there are numerous programs or directives for flood hazard monitoring or even flood risk management, for instance in Europe, specific regulations for CI are less regulatory and obligatory [34].

Nevertheless, there are significant disparities in river flood preparedness and knowledge between homeowners and renters [96]. Analyses of disaster risk, vulnerability, and resilience examine the causes of various consequences of natural hazards such as floods on people, economies, and ecosystems using either semi-quantitative methods, such as indicator techniques, or qualitative methods, such as surveys [35,97].

Focusing on soft flood mitigation measures (early warning systems and societal awareness) can reduce the loss of life and damage to infrastructure caused by flash floods. The examination of sediment movement during flash flooding is also advised since silt has a significant influence on flood mitigation structures, hence increasing the danger of flash flooding and decreasing the effectiveness of flood mitigation structures. Therefore, it is essential to investigate this element and its relationship to properties like geomorphometry and soil type.

Detailed flood risk assessment based on additional land use and geomorphological characteristics is also recommended. Through international information and experience exchange, stakeholders and decision-makers have a variety of alternatives and strategies for flood-prone areas. In flood occurrences, infrastructure items and homes may be damaged by direct water pressures, erosion, or a mix of the two.

3. Flood literature and analysis method

Literature review was conducted based on the following steps (Fig. 5.1):

- ➢ More than 100 articles (from 1990 to 2022) were studied during a systematic process.
- ➢ Results from them have been categorized in four sections; Land subsidence and Flood, Natech accidents, Climate Hazards, and Case study.
- ➢ For case study South Pars gas field were chosen, based on previous sections, climate condition, floods, and preventive measures were investigated.

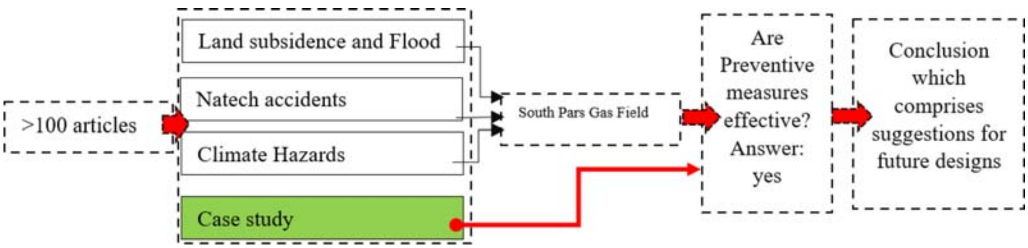


Figure 5.1 Flowchart of research steps.

3.1 Land subsidence

Land subsidence is a gradual settling or sudden sinking of the Earth's surface due to the removal or displacement of subsurface earth materials. The principal causes include aquifer-system compaction associated with groundwater withdrawals, drainage of organic soils, underground mining, and natural contraction or collapse, such as with sinkholes or thawing permafrost.

As a global environmental, geological, and geohazard, Land Subsidence (LS) has been extensively reviewed by Mehdi Bagheri-Gavkosh and coauthors in 2022 (Fig. 5.2). They gathered 290 case studies from 41 nations, most of which were done in sizable cosmopolitan cities like Bangkok, Beijing, California, Houston, Mexico City, Shanghai, Jakarta, and Tokyo. They looked at the impacts, leading causes, and spatial distribution of LS features (such as intensity, amplitude, and impacted area). Coastal plains and deltaic river zones were very susceptible to subsidence (47% of the 290 study sites). Compared to ground inspection, space-borne remote sensing monitoring of LS is the more prevalent technique (around 38% of all occurrences) (e.g., geological surveying, leveling, GPS, and modeling). Humans caused 76.92% of LS instances (Fig. 5.2).

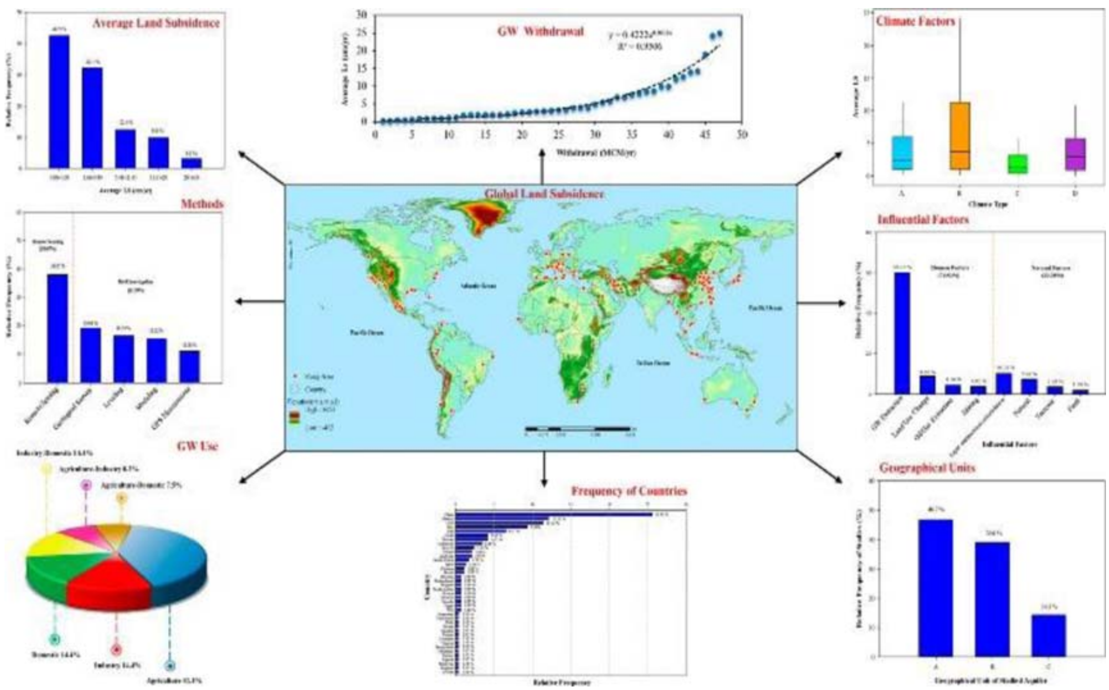


Figure 5.2 Schematic work by Bagheri-Gavkosh and coauthors.

3.1.1 Correlation between land subsidence and floods

Land subsidence and flooding are frequently treated individually. Reducing water entering the soil and lowering groundwater during the dry season are two benefits of treating floods by expediting flood flow into the sea. Groundwater supplies are reduced due to intensive groundwater extraction, which also causes land subsidence. This subsidence has caused the flood to spread out more [36]. Fig. 5.3 shows the mechanism.

Water will flow directly into a bottomland area suffering land subsidence due to a cone of subsidence or a subsidence bowl, creating a flood zone. The cone of sinking will widen if the subsidence persists over time in this situation. As a result, a considerable flooding extension is also likely to happen. The subsidence factor that could cause a flood (rain intensity, retention capacity, runoff, infiltration, land subsidence, land usage, etc.) will probably have the most significant long-term effect on the intensity and widespread of a flood. Typically, coastal flooding occurs in regions with high subsidence rates [37].

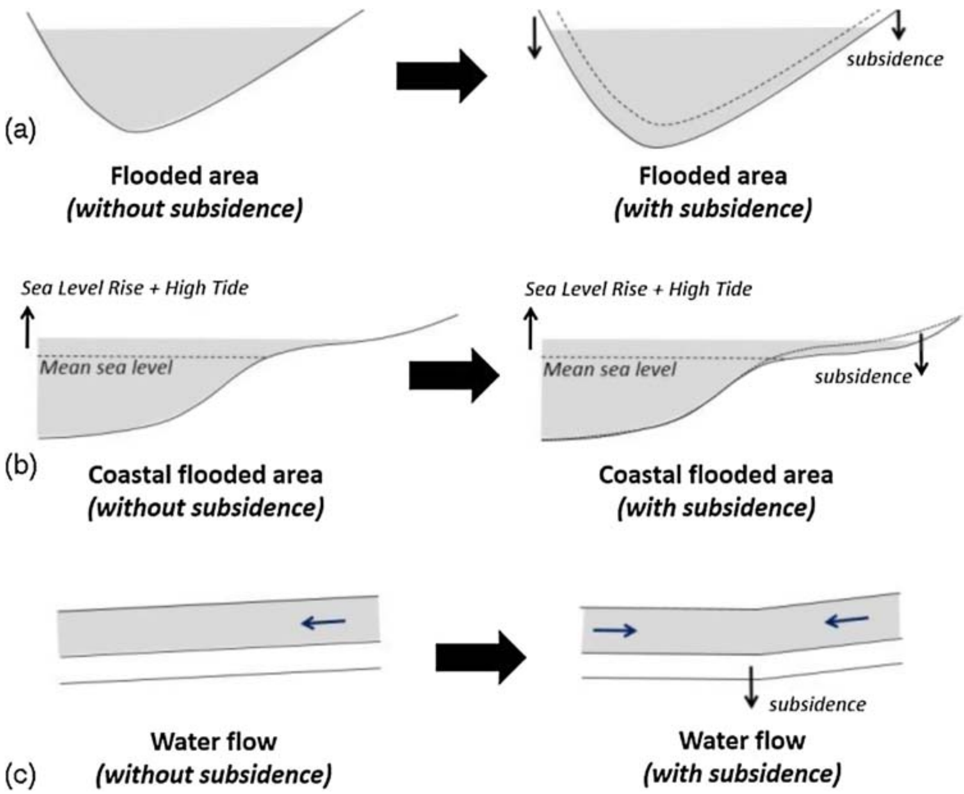


Figure 5.3 Impacts of land subsidence on flooding phenomena [37].

This phenomenon is being highlighted in East Asia, especially in three large urban areas in Indonesia: Jakarta, Bandung, and Semarang. Shirzaei and Millera based on the Chi-square test of independence, supported their hypothesis that subsidence altered base flood elevations and topographic gradients, increasing flood severity. By lowering flood control structures [38], changing the borders of floodplains and base flood drainage [98], and sinking wetlands, land subsidence can also exacerbate flooding [39]. In countries like Italy, Indonesia, and other coastal cities worldwide, subsidence studies have warned of increased flood threats. In 2013 and the eastern United States [40], Indonesia, and other coastal cities worldwide, subsidence studies have warned of increased flood threats, in 2013 and the eastern United States [40].

The construction was spurred by the combined impacts of land subsidence and sea level rise. Costly flood defense infrastructure in Bangkok, and Tokyo, raised housing in the cities of Shanghai, abandoned villages in the Philippines [41], and expanded Houston. The development of oil and gas from underground reserves alters the initial balance of rock mass. The shifting of the ground surface results from the rock mass trying to find a new, albeit transient, equilibrium. Infrastructure on the ground, including offshore platforms, pipelines, and buildings, may be affected by movements. A priori precise subsidence forecast is required to increase the effectiveness of preventive measures. Surface subsidence predictions must consider changes in pore pressure over time brought on by reservoir geometry and exploitation. Along coasts, earth dams, and on the banks of lakes, reservoirs, canals, and rivers in heavy rainfall, snowmelt, changes in groundwater levels, and surface water level fluctuations. Because both are related to precipitation, runoff, and the saturation of Earth with water, landslides and flooding are closely related.

Landslides may be caused by flooding by undercutting streams and river banks and by saturating slopes with surface water (overland flow). Additionally, mudflows and debris flow typically happen in narrow, steep stream channels and are sometimes misinterpreted by floods; Conversely, landslides can also result in flooding when they obstruct stream channels and other waterways with sliding rock and debris, causing significant water levels to back up behind such dams. If the barrier falls, this results in downstream flooding and backwater flooding. Furthermore, solid landslide debris can “bulk” or add volume and density to average streamflow. It might also obstruct or divert a channel, resulting in flood conditions or localized erosion [42].

Research has shown that subsidence caused by oil and gas extraction is more widespread than previously believed in the 1980s—two types of subsidence result from oil and gas production. One type is regional and focused on the water/oil/gas field from which the water/oil/gas is withdrawn. The second has a regional focus and typically covers many underground connected oil and gas fields. For over a century, reports of ground deformation brought on by oil or gas extraction from underground reserves have been made. Land subsidence is one of the main effects of oil/gas production on the environment. Suppose the field is adjacent to heavily populated and urbanized coastal areas, where a decrease in ground elevation of merely a few centimeters can dramatically increase the exposure of the shoreland to flooding during high tides and severe sea storms. In that case, this might be a cause for great concern. Over gas and oil reservoirs, subsidence typically resembles a bowl, with the most significant sinking occurring close to the field's center. The bowl's border may roughly mirror the field's border for a while following the start of pumping. Later, the subsiding area may go beyond the reservoir's boundaries, mainly if the pore pressure depletion brought on by gas oil withdrawal spreads to the lateral and/or bottom aquifer, which then begins to compact and actively contribute to the surface settlement. Furthermore, the confining aquifer could keep losing pressure even after the field has been abandoned. A significant settlement over fertile fields may result from the interaction of four elements. First, the depth of the depleted sediments is relatively shallow; second, there is typically high rock compressibility in alluvial or shallow marine basins; third, there is a significant pore pressure drawdown; and, finally, there is a substantial volume of the porous medium that is experiencing the pressure decline. Although factors one and three are somewhat antagonistic to one another, each of them can be connected to both factors two and four. Component four may manifest when an active, large-scale, permeable aquifer constrains the field [43].

3.2 Na-tech accidents

The term "Natech accidents" refers to technological hazards/disasters caused by natural disasters or hazards that have hazardous release effects (fire, explosion, chemical release). Due to the potential for several equipment failures to coincide, these incidents often have harsher consequences than conventional disasters [44]. Consequently, indirect scenarios, cascading occurrences, and domino consequences could occur [45]. Additionally, natural events have a more significant geographic influence than typical technological scenarios and may simultaneously damage multiple industrial sites. In this light, which may hinder the emergency response, it must deal with the technical environment and the natural occurrence itself [44]. Accidents can harm people's health, the environment, possessions, and other pieces of machinery (domino effects), resulting in financial losses [44]. Studies on potential environmental pollution and environmental damage that may occur in Natech occurrences received little attention despite their importance. Natech accidents continue to be a hazard despite an expanding body of research and stricter rules for the design and operation of industrial activities. It is partially due to the lack of information and specific risk-assessment tools and procedures. Flooding is the most common natural disaster that results in technological accidents. Storage tanks and pipes were discovered to be the equipment types most susceptible to flood damage, frequently resulting in containment and the potential for chemical reactions between released substances and water. Natural catastrophes and technology accidents are typically investigated as distinct phenomena. Therefore, there is little knowledge of how they interact. A Natech is a type of pollution that results from an oil leak following a flood. The following section offers two instances.

3.2.1 The Saga prefecture oil spill [45]

There was much rain in Saga prefecture in southwestern Japan on August 28, 2019. Due to the substantial precipitation, significant water has entered the Rokkaku and Ushizu rivers, which are a part of the same water system. Nine breaks in the water system and significant flooding that affected an area of around 69 km^2 caused the water system to collapse. Since 1900, there have been about 20 floods in the region, indicating that it is vulnerable to similar occurrences. The ironwork plant located 100 m away from the Rokkaku River embankment is the industrial area where the accidents occurred. Quenching, one of the operations at the facility, is carried out using an oil bath kept in open atmospheric storage tanks that are 3 m below ground level for safety matters. The water level inside the factory has fluctuated between 40 and 60 cm. Since the industrial site's flood prevention procedures were ineffective, floodwaters were allowed to pour into tanks and raise the oil. Guidelines for the plant's evacuation have been put in place since the oil spill was discovered. The accident caused a 103 m^3 oil spill, of which 54 m^3 spilled outside the factory's walls and covered a space of around 420,000 m^2. A hospital was affected by the oil sheen that traveled into residential neighborhoods and agricultural fields. Floodwaters in the vicinity delayed emergency measures intended to rescue and evacuate residents and collect the oil. The cleanup and restoration efforts have required more than 10 days since the cleanup and recovery efforts started. The remaining oil was still visible in damaged homes and agricultural areas a month after the event. The corporation added more safety precautions after learning from the catastrophe to lower the likelihood of incidents of this scale.

3.2.2 The Livorno oil spill

The Tyrrhenian region near Livorno was affected by a significant rainfall event on September 9 and 10, 2017, causing local rainfall amounts of up to 260 mm. According to estimates, the flash flood's affected area was more than 45 km^2. The main reason for the flooding of an oil refinery was the overflow of a little brook called Unione, which exacerbated the magnitude. Even though the natural disaster harmed no equipment, the stormwater catchment network reached capacity and overflowed. The remaining oil in the network and at the industrial site was dispersed in the floodwater and carried away. The evacuation plan at the location delayed the discovery of the oil spill. A portion of the oil eventually entered the sea after the tainted water overcame the wall enclosing the area. It is important to note that the site's walls were intended to serve as a perimeter barrier, not a containment mechanism. Booms for containment are used to stop oil spills from spreading. Procedures for recovery and cleanup have been used. More safety precautions were implemented against this happening again on the property.

3.3 Climate hazards

These estimate the likelihood of climate-related threats to structures and contribute to the illuminating evidence of functional or fundamental constraints. They have been divided into two groups: (i) drivers of climate (such as temperature, precipitation, and humidity), which are the coordinate results of either observational data or specific models, and (ii) the hazards of the climate (flood, drought and corrosion, high winds, hurricanes, sea level rise, storm surges), which are the coordinate results of the drivers of the climate. This study considers the similarities between unusual winds, storms, surges, and waves. Here are some critical industries, and adaptations measures.

3.3.1 Critical industry: oil extraction

Adaptation measures include the following: (i) surge assurance and adjustment criteria, including reevaluating flood-prone zones; (ii) avoiding construction in flood-prone areas whenever practical; (iii) choosing methods for reducing, regulating, and obstructing water; and (iv) raising buildings or building components above the level of a 100-year surge [46]; (v) plan preparation for personnel departure, increasing the stature of the platform [47], surge assurance and adjustment measures, including (i) the reevaluation of flood-prone zones; (ii) keeping buildings or building components away from flood-prone areas when it is practical to do so; (iii) choosing techniques for reducing, controlling, and blocking water; and (iv) raising buildings or building components above the 100-year surge form level. Building and hardware waterproofing, hardware security (such as locking capacity tanks and gas barrels), and adequate emergency response and risk planning can help downtimes, development of surge security alert systems [88]. Increasing the capacity of essential equipment and supplies increases the power of crucial supplies and hardware. i) Strong salt removal to a designated landfill; ii) Brine infusion; iii) Sea outfall; and iv) Salt treatment to make it suitable for use as table salt or for other commercial purposes.

3.3.2 Critical industries: gas extraction

Adaptation measures include sinking tanks and flooding seepage frameworks inside plants which increase the fire threat and scrubbing and floating off establishments [88]. Increased flow and fluctuations in safe water depth make it more challenging to plan and carry out separate booming and cleanup operations [48]. Enlarged stream and weight to control structures may cause expanded gas discharges due to back support and stream of things [48]. Deterioration of the soil in regions where refineries are located [46]. Pneumatic control frameworks, electrical equipment, electrical plants, substations, control valves, and electrical plants all fall short [88]. Pipelines, wastewater treatment facilities, control buildings, and paper mills should all increase in stream and weight. Where rivers altered flow, erosion and undercutting occurred, threatening access to locations [48].

3.4 Case study

The strategic oil and gas area of Iran is shown below (Fig. 5.4).

3.4.1 2019 Iran floods

The provinces of Golestan, Fars, Khuzestan, Lorestan, and others were hardest hit by massive flash flooding from mid-March to April 2019. At least 26 of Iran's 31 provinces have been impacted by floods as a result of three big waves of rainfall and flooding during the past 2 weeks. The initial rains occurred on March 17, causing floods in two northern provinces, Golestan and Mazandaran, with the former getting up to per cent of its usual annual rainfall in a single day. Several huge dams have overflowed, mainly in Khuzestan and Golestan, necessitating the

Figure 5.4 Selected Iran's oil and gas infrastructure, including major oil and gas fields [49].

evacuation of numerous villages and cities. About 1900 cities and villages across the nation have been devastated by severe flooding, as well as water and agriculture infrastructure to the tune of hundreds of millions of dollars. 78 highways were closed and 84 bridges' viability was questioned. By converting floodways and dry riverbeds to urban expansion without installing enough drainage infrastructure, the severity of the floods was significantly exacerbated. According to an Iranian official, more than 140 rivers have overflowed their banks and 409 landslides have occurred around the country as a result of unprecedented rains. Due to the Nowruz holiday, the impact of the floods was magnified; many Iranians were traveling, and flash flooding on roads and highways caused numerous deaths. About 36% of Iran's national road network, or approximately 12,000 km, was destroyed by the water. At least $2.2 billion (2019 USD) in damages were caused by the floods, with agricultural losses accounting for the majority. In addition, according to the Red Crescent, two million people require humanitarian assistance as a result of the severe floods [93].

3.4.1.1 Khuzestan flood

Dez River and Karkheh River flooded as a result of significant rainfall in the Zagros Mountains, and water gathered in Dez Dam and Karkheh Dam to the point where the Karkhe dam's reservoir in Khuzestan province reached 8400 m3/sec. As dams reached their maximum capacity, the Iranian power ministry was able to release water. The government has established 47 camps to host 30,400 individuals. In order to prevent a natural disaster, the Karkheh Dam, which was nearly full, was opened to release extra water. Germany donated 20 lifeboats for rescue operations in Iran's floods on April 8, 2019. Ali Khodadadi, director of the Khuzestan Red Crescent Society, said they will be used for rescue efforts in Dasht-e-Azadegan, Shush, Shushtar, Ahvaz, and other southern Khuzestan Province locations The Iranian government proclaimed a state of emergency for Khuzestan Province on March 31 [93].

3.4.2 South gas field

The special economic zone of Pars Energy is located on the Persian Gulf and in the area of 46 thousand hectares of Bushehr province, which consists of three regions: Pars One (Southern Pars) with an area of 14 thousand hectares that includes Asalouyeh city, Pars Two (Kangan) in room 16 thousand hectares that include Kangan city and Pars Three (Northern Pars) including 16 thousand hectares that include Dayyer, Dashti, Tangestan, and Bushehr cities. As a case study, region one and two of South Pars, with an area of approximately 30 thousand hectares, which includes Asaluyeh and Kangan, has been selected (Fig. 5.5).

In general, the main parts of this industrial complex include as following:

(i) Operational Zones: This region, which covers over 30,000 ha, features 15 petrochemical complexes, 16 gas processing phases, downstream petrochemical businesses, and other connected and semi-heavy industries.

(ii) Persian Gulf International Airport: It was designed and constructed to convey both passengers and cargo by the special region organization. With almost 6000 domestic, arriving, and outgoing flights and more than one million passengers moved annually, this airport plays a unique role in assisting the operation of the area.

(iii) Complex of South Pars ports: The South Pars service port comprises 10 berths, 2 breakwaters with lengths of 2280 and 1002 m, respectively, a pond with a surface area of 96.5 ha, and a backside with a surface area of 150 ha.

(iv) Refinery phases: Except for phase 14, all of the refinery phases, including 24 phases, are currently in use.

(v) Petrochemical Industries: There are already 27 operational petrochemical facilities in this area, and they have marketed it as the hub of Iran's petrochemical sector.

Figure 5.5 Case study map.

3.4.2.1 Climatic conditions of the study area

The region is distinctive in terms of climate because it is constrained by the Persian Gulf in the south and the continuing Zagros mountains in the north. In this area, high-intensity, little rainstorms make up most of the total precipitation [50]. Development and urbanization create more impermeable lands in various regions than virgin land. According to the study's findings in this area, the quantity of surface flooding will affect the time of concentration and vegetation cover, decrease the soil's permeability and capacity to absorb water, and alter the basin's behavior in the creation of runoff and flood hydrographs.

It has been noted that the peak discharge after the development (the1990s) is 2—3 times the peak discharge before the result, according to the output hydrographs of each sub-basin modeled under two different scenarios.

3.4.2.2 The effect of floods on the South Pars region

Most of the South Pars region's lands are in the alluvial cone. Most of these alluvial cones have been leveled after being removed from their natural condition and exploited for industrial operations. Under these circumstances, flooding will threaten all structures built in the region. According to historical records, field studies, and the identification of sediments concentrated by previous floods in the bed and sides of waterways and alluvial cones, areas prone to flooding were identified on aerial photographs and satellite images in research by Hatami et al.

3.4.2.3 Preventive measures

In constructing the main body of the South Pars flood control system, firstly, with regional surveys and study of existing land uses in the region, divisions and boundaries and the primary arteries and connections. The other thing also identified the possibilities and limitations of controlling and directing the flood flow. The whole system is designed in several engineering packages (master plan). It is worth noting that in the process of reviews and formation of design engineering packages, two thoughts, from entire to part and from part to entire, have been developed in parallel directions. In one orientation (entire to part), the packages are affected by macro divisions and demarcations. In the other direction (part to entire), the possible elements are formed throughout the identification range, and the system based on it is defined from their aggregation considering the limitations and divisions.

Each part of the strategy is a separate building used to either contain or prevent the flood, and it might be any of the following: i) Delay dam, ii) Input conversion diversion structure, and iii) Transfer channel (output conversion). They create flood control systems by combining several appropriate parts [50]. To build dams and channels (diversion channels) that go to the sea upstream of the facilities in the region, which are likely to play a significant role in lowering the flood discharge in the area. The various components used in the southern flood prevention and disposal plan are defined as follows [50]:

- Dams: Dams' primary function is to depreciate floods based on functional capacities, such as the realistic volume of the reservoir's safe level before the flood and the maximum level during the flood's discharge. Using them, the flood flow from any dam is a calmer process, with a lower peak discharge than the natural flood. Water accumulation has not been addressed in the region's current plan for any purpose other than changing the flow process. However, the unavoidable sedimentation of flood flows in the reservoir is considered one of the most potent variables in shaping and deciding their size.
- Embankments: Longitudinal embankments have shown to be the most effective component for directing or controlling floods in various areas. In reality, there is no point in these parts where it is possible to control the flow of a substantial region.
- Channels: With the role of directing and transferring floods, in the current plan following the prevailing limitations, particularly the high flow of floods (in terms of climatology and physiography) and the regulation of the corridor width of the channels and the appropriate slope, and thus the potential of transmission at higher speeds than the reinforced concrete channel used.

A chain of components upstream, continually following each other, develops a system until it meets the flood zone from each departure point of the flood control and diversion complex on the coastal side. Each system is meant to contain and direct a portion of the flooding upstream. Each system may include a dam (and related facilities), a downstream channel, and a release facility, as well as a diversion structure (inlet diversion), natural drainage improvement, and outlet preparation, or it may consist just of a water diversion dike. Each package's systems are independent or in parallel (branch) connections. Each engineering package is a collection of systems that are logically connected. This logic often depends on the protected complex, physically and in terms of administration. In general, engineering packages function independently of one another. Many engineering packages, each with its systems, have been used to safeguard the aforementioned operational areas.

3.4.2.4 Plans to flood controlling

Historically, responses to floods have evolved through several periods. Initially (prior to the 1980s), responses were aimed at controlling and defending against floods using "hard-engineering solutions" [91]. Countries (China, the Netherlands, Germany, and the United States) have evidently been using flood defenses to protect villages and towns in low-lying deltaic areas for centuries [51,52]; Parker and Ford paradigm of Òflood control" (the 1950 and 1960s) aimed to prevent floods that may affect agricultural productivity and jeopardize flood security, with an emphasis on technical procedures and materials (concrete). Improving land drainage structures and channelization were used to rapidly drain floodwater away from agricultural fields based on the premise of increasing land drainage capacity in-channel conveyance. Later in the 1970s, the "flood defense" paradigm was embraced as the economic interest in flood control expanded to include the industrial and tertiary sectors. This tries to lessen the effects of flooding on agriculture. As the commercial interest in flood control expanded to include industrial and tertiary sectors, the concept of "flood defense" was adopted later in the 1970s. This era of flood defense included structural engineering methods such as seawalls, dikes, embankments, breakwaters, and levees to protect infrastructure, people, and property. In the 1980s, a "flood management" strategy evolved that emphasized dealing with flooding as opposed to just suppressing floods. This arose when policymakers realized it was becoming more difficult to fight against all floods owing to rising climate extremes (intense precipitation), while also recognizing the importance of socioeconomic and environmental considerations. This shift in emphasis led to a greater emphasis on flood preparation and public awareness, as seen by the development of flood forecasting and warning systems throughout Europe. These modifications have formed the foundation for the Financial Risk Manager (FRM) paradigm's expansion [53,54]. In the 2000s, the emphasis shifted to more explicitly consider flood risk [26], including the probability of a given flood hazard (precipitation, storm frequency, sea-level rise) [55,56] and the vulnerability of, and consequences for, populations and economic assets exposed to that flood hazard [55,57,58].

Thus, FRM currently aims to avoid harm by decreasing the exposure and susceptibility of flood-prone persons and property.

Flood risk cannot be eliminated; thus, FRM examines the costs and benefits of flood risk reduction for society [59]. Thus, the purpose of FRM is to mitigate the negative effects of floods and to balance risk reduction with other political concerns and objectives. An essential part of FRM is managing flood risk via broader involvement with stakeholders (households, practitioners, politicians, flood engineers, planners, and communities) to find multi-disciplinary viewpoints and solutions [92].

4. Conclusion

Infrastructures for oil, gas, and petrochemical production are susceptible to quakes, floods, and land subsidence. Oil and gas equipment is crucial to the growth of this sector; however, owing to the harsh working conditions and operational environment, components and equipment have been lost, incurring large expenditures for these sectors. The interaction of various flood features with the system under investigation leads to the effects of flood damage in pipelines or industrial equipment. The most significant factors are water depth, flow rate, inundation time, sediment or debris load, and their interactions with the system. The following actions are required to examine the risk brought on by natural phenomena in process facilities [60].

(i) Description of the outside occurrence parameters for frequency and severity;
(ii) Recognition of the device being targeted list of potential target equipment;
(iii) Damage state identification, reference scenario identification, and event tree;
(iv) Damage probability estimation and equipment damage models;
(v) Evaluation of the reference scenario's consequences and models for consequences;
(vi) Identifying plausible event combinations and a set of event combinations;
(vii) Calculation of frequency and probability for each combination and frequency of event combinations;
(viii) Calculate the effects of each combination. calculation of risk indices, overall risk indices, and
(ix) Global vulnerability map of subsidence now outpaces absolute sea level rise in many coastal and deltaic zones by a factor of 10.

In addition to oil and gas extraction, excessive groundwater extraction linked to rapid urbanization and population increase is a pivotal contributor to severe land subsidence. Several activities are necessary for determining the relationship between land subsidence and floods, including precise flood risk estimates, detailed mapping of inundated areas during a flood event, and detailed mapping of the spatial and temporal rates and effects of land subsidence.

Cross-border cooperation is crucial while dealing with natural disasters. It may make sense to create or coordinate danger maps across borders, such as flood hazard maps or flood warning systems for river basins because natural hazards do not respect national boundaries. The site operators were urged to obtain site topography and more detailed flood modeling, as well as (1) assess the site's flooding risk and regularly check for flood warnings (which can acquire at the UK Environment Agency office); (2) create a flood emergency plan with the necessary action steps and information distribution; (3) take steps to increase flood resilience generally, such as optimizing hazardous material storage; enhancing the protection of safety-critical utilities; or enhancing communication between off-site emergency response teams. Uncertainty is a key driver which should be considered in research. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, the world's sea level will continue to rise throughout the 21st century, causing more common and harmful floods in coastal environments [61]. Coastal cities risk land subsidence and climate change [62–64]. The combined risk from eating extreme floods as a result of sea level rise, coastal cities are in danger due to climate change and land subsidence [62–64].

The combined risk from extreme floods is due to sea level rise, and coastal cities are in danger due to climate change and land subsidence [62–64]. The comprehensive worldwide risk will grow by two and four times, respectively, under Representative Concentration Pathway (RCP) 2.6 and RCP 8.5 carbon emission scenarios [65]. For coastal communities to build strategic planning and adaptation measures, risk analysis of extreme storm floods is essential [66,67,89]. In particular, floods with low probability and high magnitudes and consequences (Black Swans) have become the focus of recent studies [68]. Numerous studies have examined the relationship between climate change, land subsidence, floods, and rising sea levels in coastal cities [69,70]. Implementing several strategies to lessen the likelihood and potential effects of flood events is called flood adaptation. Cost–benefit analysis (CBA) is frequently used to assess the efficacy of flood adaptation methods and is a valuable tool for enhancing adaptation decision-making. Decisions must be formulated flexible and adaptable due to the extreme unpredictability of the changes. Research on decision-making and planning can benefit from using robust decision-making techniques, such as real options analysis (ROA), decision-making involving deep uncertainty, and dynamic adaptive policy pathways (DAPP).

By taking management flexibility and volatility into account, real options analysis is a technique for coping with the uncertainty of investment timing [71,72]. Because ROA offers the best possible order for making future investment decisions, adaptation is possible. Flexible options can provide more time to handle areas where investments may be overextended, or potential hazards are more remarkable than anticipated. The Dynamic Adaptive Policy Pathways (DAPP) methodology is a technique that investigates various investment choice sequences in the context of speculative future development and environmental changes to attain goals throughout time. Haasnoot et al. [73] used flood risk management in the Netherlands as a case study. They developed an economic evaluation framework to examine adaption routes or several strategic investment choices. Monitoring and reevaluation of the adaptation techniques should be ongoing, and it's crucial to identify investment tipping points early so that you may adjust your adaptation plans as necessary.

The DAPP and ROA methods involve modifying alternatives or strategies based on future realizations. Currently, these methods are becoming more popular. Used to create or organize possibilities for long-term adaption over longer terms and even decades [72,74].

According to the measures taken upstream of the case study region (South Pars gas field), which include the construction of dams and channels to divert the flood path and natural flood flows to the sea, special protection measures in a partial form (specific to one company) for companies and refinery complexes and petrochemical complexes, is not required. It is not being considered for special measures as one of the country's most crucial flood control systems; the South Pars flood containment and disposal plan has preserved the country's massive capital and national resources in the South Pars area over the years. Briefly, the reasons for the successful performance of this plan and the flood control systems under it can be seen as comprehensive preliminary studies, carrying out designs considering international standards and regional conditions, primary supervision of the implementation and monitoring of the implemented parts. In recent years, substantial petrochemical facilities and refineries in the South Pars region have constantly been exposed to destructive floods. Still, in the features where flood containment systems have been implemented, they have witnessed minor damage caused by floods in the project area.

On the other contrary, because the international airport of the Persian Gulf is located in a flood-prone area, which is practically outside the scope of operational sites, it is necessary to carry out essential studies regarding the identification, formulation, and implementation of preventive measures to deal with floods and Flood Proofing measures should be carried out according to the flood conditions of the region.

Because the area's rainfall is often intense and brief, only a tiny portion of it is absorbed by the basin's land, and a substantial amount of it flows into the sea. As a result, the basin lands are virtually always dry. It is suggested to consider a system for maintaining these runoffs that prevents these waters from entering the sea and bringing them to agricultural uses or causing them to be absorbed by the lands of the region so that the underground water table is fed and in the dry seasons of the year which reaches almost 8 months in a year, by digging wells and accessing these underground waters, the water needed for drinking and agriculture of the people of the region should be provided. One option to preserve the water resulting from rainfall is the construction of delayed dams that absorb the runoff from the region's land and empties the runoff from the basin with a delay. Measures have been taken in this regard, and considering their limited capacity; more is needed.

References

[1] Hojjati H. History of destructive floods in Iran. Institute of Political Studies and Research 2019:10–1.
[2] World Health Organization. Chemical release associated with floods. 2020. 8 P.
[3] Balist J, Malekmohammadi B, Jafari HR, Geneletti D. Detecting land use and climate impacts on water yield ecosystem service in arid and semi-arid areas. A study in Sirvan River Basin-Iran. Applied Water Science 2022a;12:4.
[4] The World Bank Group. Iran overview: development news, research, data. 2022.
[5] Balsells M, Barroca B, Becue V, Serre D. Making urban flood resilience more operational: current practice. Proceedings of the Institution of Civil Engineers-Water Management 2015;168:57–65.
[6] De Vleeschauwer K, Weustenraad J, Nolf C, et al. Green-blue water in the city: quantification of impact of source control versus end-of-pipe solutions on sewer and river floods. Water Science and Technology 2014;70:1825–37.
[7] Haghighatafshar S, Nordlof B, Roldin M, et al. Efficiency of blue-green storm water retrofits for flood mitigation—conclusions drawn from a case study in Malmo, Sweden. Journal of Environmental Management 2018;207: 60–9.

[8] Mignot E, Li X, Dewals B. Experimental modelling of urban flooding: a review. Journal of Hydrology 2019;568:334–42.
[9] O'Donnell E, Thorne C, Ahilan S, et al. The blue-green path to urban flood resilience. Blue-Green Systems 2019;2:28–45.
[10] Reynard NS, Prudhomme C, Crooks SM. Potential effects of changing climate and land use. Climate Change 2001;48:343–59.
[11] US Department of Commerce, NOAA, National Weather Service. Flash flooding definition. 2022. Retrieved from, https://www.weather.gov/phi/FlashFloodingDefinition.
[12] Department of Homeland Security. Riverine flooding | national risk index. 2022. Retrieved from, https://hazards.fema.gov/nri/riverine-flooding.
[13] Jackson A. Coastal flooding. 2014. Retrieved from, https://geographyas.info/coasts/coastal-flooding.
[14] U.S. Climate Resilience Toolkit. Inland flooding. 2022. Retrieved from, https://toolkit.climate.gov/topics/coastal-flood-risk/inland-flooding.
[15] Merz B, Blschl G, Vorogushy NS, Dottori F, Macdonald E. Causes impacts and patterns of disastrous river floods. Nature Reviews Earth & Environment 2021;2:592–609.
[16] Rosenzweig BR, McPhillips L, Chang H, Cheng C, Welty C, Matsler M, et al. Pluvial flood risk and opportunities for resilience. Wiley Interdisciplinary Reviews: Water 2018;5:1302.
[17] Sadeghi A, Galalizadeh S, Zehtabian G, Khosravi H. Assessing the change of groundwater quality compared with land-use change and precipitation rate (Zrebar Lake's Basin). Applied Water Science 2021;11:170.
[18] Sharafati A, Yaseen ZM, Shahid S. A novel simulation–optimization strategy for stochastic-based designing of flood control dam: a case study of Jamishan Dam. Journal of Flood Risk Management 2021;14:12678.
[19] Zhai X, Guo L, Liu R, Zhang Y. Rainfall threshold determination for flash flood warning in mountainous catchments with consideration of antecedent soil moisture and rainfall pattern. Natural Hazards 2018;94: 605–25.
[20] Philipp A, Grundmann J. Integrated modeling system for flash flood routing in ephemeral rivers under the influence of groundwater recharge dams. Journal of Hydraulic Engineering 2013;139:1234–46.
[21] Balist J, Malekmohammadi B, Jafari HR, Nohegar A, Geneletti D. Modeling the supply, demand, and stress of water resources using ecosystem services concept in Sirvan River Basin (Kurdistan-Iran). Water Supply 2022b;22(3): 2816–31.
[22] Kundzewicz ZW, Kaczmarek Z. Coping with hydrological extremes. Water International 2000;25(1):66–75.
[23] Sadeghi A, Khaledi J, Nyman P. Rainfall variability and land-use change in arid basins with traditional agricultural Practices; insight from ground water monitoring in Northwestern Iran. Journal of Earth Science & Climatic Change 2018;9:498.
[24] Barredo JI. Major flood disasters in Europe: 1950–2005. Natural Hazards 2007;42:125–48.
[25] Kron W. Flood risk= hazard values vulnerability. Water International 2005; 30:58–68.
[26] Plate EJ. Flood risk and flood management. Journal of Hydrology 2002;267: 2–11.
[27] Thieken AH, Bessel T, Kienzler S, Kreibich H, Müller M, Pisi S, et al. The flood of June 2013 in Germany: how much do we know about its impacts. Natural Hazards and Earth System Sciences 2016;16:1519–40.

[28] Emanuelsson M, Mcintyre N, Hunt C, Mawle R, Kitson J, Voulvoulis N. Flood risk assessment for infrastructure networks. Journal of Flood Risk Management 2014;7:31–41.
[29] United Nations. Sendai framework for disaster risk reduction 2015–2030. 2015 [Geneva].
[30] Di Baldassarre G, Kemerink JS, Kooy M, Brandimarte L. Floods and societies: the spatial distribution of water-related disaster risk and its dynamics. WIREs Water 2014;1:133–9.
[31] Weichselgartner J, Kasperson R. Barriers in the science-policy-practice interface: toward a knowledge-action-system in global environmental change research. Global Environmental Change 2010;20:266–77.
[32] White GF, Kates RW, Burton I. Knowing better and losing even more: the use of knowledge in hazards management. Environmental Hazards 2001;3: 81–92.
[33] Hernandez-Fajardo I, Dueñas-Osorio L. Probabilistic study of cascading failures in complex interdependent lifeline systems. Reliability Engineering and System Safety 2013;111:260–72.
[34] FMIG - Federal Ministry of the Interior of Germany. Protecting critical infrastructures—risk and crisis management. In: A guide for companies and government authorities. 2nd ed. Berlin, Germany: Federal Ministry of the Interior of Germany; 2011.
[35] Fuchs S, Thaler T. Vulnerability and resilience to natural hazards. New York, NY: Cambridge University Press; 2018. p. 350.
[36] Pramona I. Nature-based solutions for integrating flood and land subsidence: a case study in Jakarta and Semarang. IOP Conference Series: Earth and Environmental Science 2021;874:012001.
[37] Abidin HZ, Andreas H, Gumilar I, Wibowo IRR. Correlation between urban development, land subsidence and flooding phenomena in Jakarta Conference: IUGG 2015At: Prague Volume. Proceedings of IAHS 2015;370: 15–20. 2015.
[38] Dixon TH, Amelung F, Ferretti A, Novali F, Rocca F, Dokka R, et al. Subsidence and flooding in new Orleans. Nature 2006;441(7093):587–8.
[39] Shirzaei M, Bürgmann R. Global climate change and local land subsidence exacerbate inundation risk to the San Francisco Bay Area. Science Advances 2018;4(3):9234.
[40] Karegar MA, H. Dixon T, Rocco M, Jürgen K, Engelhart Simon E. Nuisance flooding and relative sea-level rise: the importance of present-day land motion. Scientific Reports 2017;7(1):11197.
[41] Jamero ML, Onuki M, Esteban M, Billones-Sensano XK, Tan N, Nellas NA, et al. small-island communities in the Philippines prefer local measures to relocation in response to sea-level rise. Nature Climate Change 2017;7: 581–6.
[42] Bobrowsky P. The landslide handbook—a guide to understanding landslides by Lynn M. Highland, United States geological survey, and Peter Bobrowsky. Geological Survey of Canada; 2013.
[43] Bau D. Residual land subsidence over depleted gas fields in the Northern Adriatic basin. Environmental and Engineering Geoscience 1999;(4): 389–405.
[44] Krausmann E, Cruz AM, Salzano E. Natech risk assessment and management, reducing the risk of natural-hazard impact on hazardous installations. Amsterdam, NL: Elsevier; 2017.

[45] Misuri A, Landucci G, Cozzani V. Assessment of risk modification due to safety barrier performance degradation in Natech events. Reliability Engineering & System Safety 2021;212:107634.
[46] Young S, Balluz L, Malilay J. Natural and technologic hazardous material releases during and after natural disasters: a review". Public Health Resources 2004;322:3–20.
[47] Huizinga J, Moel H, de Szewczyk W. Global flood depth-damage functions. Sevilla, Spain: European Commission, Joint Research Centre, Edificio Expo; 2017. p. 114.
[48] Lepore M. Lessons learned in the front range flood of September 2013. Denver, CO: Colorado Oil and Gas Conservation Commission; 2014.
[49] Fanack. Chronicle of the Middle East and North Africa. 2022. Iran. Retrieved from, https://fanack.com/fanack-energy/iran.
[50] Poor T, Mohamadreza M, Mohamad A. The 6th Iranian dam and tunnel conference and exhibition, Plan for flood prevention and disposal in South Pars region. 2021 [Tehran, Iran].
[51] Van Stokkom HTC, Smits AJM, Leuven RSEW. Flood defense in The Netherlands—a new era, a new approach. Water International 2005;30: 76–87.
[52] Wang ZY, Hu S, Wu Y, Shao X. Delta processes and management strategies in China. International Journal of River Basin Management 2003;1:173–84.
[53] Lumbroso D, Stone K, Vinet F. An assessment of flood emergency plans in England and Wales, France and The Netherlands. Natural Hazards 2011;58: 341–63.
[54] Parker D, Fordham M. An evaluation of flood forecasting, warning and response systems in the European Union. Water Resources Management 1996;10:279–302.
[55] Kundzewicz ZW, Budhakooncharoen S, Bronstert A, Hoff H, Lettenmaier D, Menzel L, et al. Coping with variability and change: floods and droughts. Natural Resources Forum 2002;26:263–74.
[56] Tol RSJ, Van Der Grijp N, Olsthoorn AA, Van Der Werff PE. Adapting to climate: a case study on riverine flood risks in The Netherlands. Risk Analysis 2003;23:575–83.
[57] Brown JD, Damery SL. Managing flood risk in the UK: towards an integration of social and technical perspectives. Transactions of the Institute of British Geographers 2002;27:412–26.
[58] Galalizadeh S, Karimi H, Malekmohammadi B, Sadeghi A, Shirzadi S. Environmental risk assessment and mapping of oil installations to Chamshir Dam water basin using GIS and HAZOP method. International Journal of Risk Assessment and Management 2020;23(3):207–22.
[59] Butler C, Pidgeon N. From 'flood defence' to 'flood risk management': exploring governance, responsibility, and blame. Environment and Planning C 2011;29:533–47.
[60] Antonioni G, Bonvicini S, Spadoni G, Cozzani V. Development of a framework for the risk assessment of Na-Tech accidental events. Reliability Engineering and System Safety 2009;94:1442–50.
[61] IPCC (Intergovernmental Panel on Climate Change). Climate change 2021, the physical science basis. Contribution of working group I to the Sixth assessment report of the intergovernmental Panel on climate change. Cambridge and New York: Cambridge University Press; 2021. www.ipcc.ch/report/ar6/wg1/. [Accessed 26 May 2022].
[62] Abadie LM, Jackson LP, de Murieta ES, Jevrejeva S, Galarraga I. Comparing urban coastal flood risk in 136 cities under two alternative sea-level

projections: RCP 8.5 and an expert opinion-based high-end scenario. Ocean and Coastal Management 2020;193:105249.
[63] Catalao J, Raju D, Nico G. Insar maps of land subsidence and sea level scenarios to quantify the flood inundation risk in coastal cities: the case of Singapore. Remote Sensing 2020;12(2):296.
[64] Strauss BH, Orton PM, Bittermann K, Buchanan MK, Gilford DM, Kopp RE, et al. Economic damages from Hurricane Sandy attributable to sea level rise caused by anthropogenic climate change. Nature Communications 2021; 12(1):2720.
[65] Magnan AK, Pörtner HO, Duvat VKE, Garschagen M, Guinder VA, Zommers Z, et al. Estimating the global risk of anthropogenic climate change. Nature Climate Change 2021;11:879–85.
[66] Scussolini P, Tran TVT, Koks E, Diaz-Loaiza A, Ho PL, Lasage R. Adaptation to sea level rise: a multidisciplinary analysis for Ho Chi Minh City, Vietnam. Water Resources Research 2017;53(12):10841–57.
[67] Wang XM, Xu LL, Cui SH, Wang CH. Refections on coastal inundation, climate change impact, and adaptation in the built environment: Progress and constraints. Advances in Climate Change Research 2020;11(4):317–31.
[68] Tang J, Li WJ, Fang JY, Zhang ZH, Du SQ, Wu YJ, et al. Scenario-based economic and societal risk assessment of storm flooding in Shanghai. International Journal of Climate Change Strategies and Management 2021; 13(4–5):529–46.
[69] Ngo LM, Kieu LT, Hoang HY, Nguyen HB. Experiences of housing adapted to sea level rise and applicability for houses in the can Gio District, Ho Chi minh city, Vietnam. Sustainability 2020;12(9):3743.
[70] Nguyen MT, Sebesvari Z, Souvignet M, Bachofer F, Braun A, Garschagen M, et al. Understanding and assessing flood risk in Vietnam: current status, persisting gaps, and future directions. Journal of Flood Risk Management 2021;14(2):12689.
[71] Erfani T, Pachos K, Harou JJ. Real-options water supply planning: multistage scenario trees for adaptive and flexible capacity expansion under probabilistic climate change uncertainty. Water Resources Research 2018; 54(7):5069–87.
[72] Kim MJ, Nicholls RJ, Preston JM, de Almeida GAM. An assessment of the optimum timing of coastal food adaptation given sea level rise using real options analysis. Journal of Flood Risk Management 2019;12(2):12494.
[73] Haasnoot M, Aalst MV, Rozenberg J, Dominique K, Matthews J, Bouwer LM, et al. Investments under non-stationarity: economic evaluation of adaptation pathways. Climatic Change 2020;161(3):451–63.
[74] Woodward M, Kapelan Z, Gouldby B. Adaptive flood risk management under climate change uncertainty using real options and optimization. Risk Analysis 2014;34(1):75–92.
[75] Morin E, Maddox RA, Goodrich DC, Sorooshian S. Radar Z-R relationship for summer monsoon storms in Arizona. Weather and Forecasting 2005; 20(4):672.
[76] Luino F. Sequence of instability processes triggered by heavy rainfall in the northern Italy. Geomorphology 2005;66(1–4):13–9. https://doi.org/10.1016/j.geomorph.2004.09.010.
[77] Parker D. Floods: Physical Processes and Human Impacts. John Wiley & Sons; 2000.
[78] Roxy S, Ireson AM, Hall JW, Neal C. Estimating river flow and flood inundation frequency from satellite imagery: A UK case study. Science of the Total Environment 2017;576:634–45. https://doi.org/10.1016/j.scitotenv.2016.10.102.

[79] Miller JR, Hutchins M. Floods: Hazards of Surface and Groundwater Systems. Wiley; 2017.
[80] Kundzewicz ZW. Floods: Physical processes and human impacts. Wiley; 1999.
[81] Merz R, Blöschl G. Floods in a changing climate: recent advances in flood forecasting and risk management. Hydrological Sciences Journal 2008;53(1): 1–20.
[82] Alharbi A, Mills B. Flood Risk Management: A Comprehensive Guide to Mitigating the Impact of Floods. Routledge; 2022.
[83] Perucca E, Angillieri C. Floods in Italy: past and future scenarios. Hydrological Sciences Journal 2009;54(3):437–54. https://doi.org/10.1623/hysj.54.3.437.
[84] Lin A. An evaluation of flood risk in the South-East Region of England. Journal of Flood Risk Management 1999;2(4):257–72. https://doi.org/10.1111/j.1753-318X.1999.tb00226.x.
[85] Banihabib E, Tanhapour M. An optimal model for flood preparedness and response management using system dynamics. Water Resources Management 2020;34(2):819–37. https://doi.org/10.1007/s11269-019-02499-w.
[86] Tabari M, Willems P. Floods in Europe since AD 1500: Science, History, and Society. Cambridge University Press; 2016.
[87] Aminyavari M, Jamali H, Aminyavari S. Hydrological modeling of flash floods using rainfall-runoff models. International Journal of Hydrology Science and Technology, 2019;9(2):186–96. https://doi.org/10.1504/IJHST.2019.10014808.
[88] Doyle T. An analysis of the causes and impacts of the 2013 flood in Colorado. Natural Hazards Review 2013;14(3). https://doi.org/10.1061/(ASCE)NH.1527-6996.0000101.
[89] Du, S.Q., P. Scussolini, P.J. Ward, M. Zhang, J.H. Wen, L.Y. Wang, E. Koks, and A. Diaz-.
[90] Intergovernmental Panel on Climate Change Cambridge and New York: Cambridge University Press; 2022. www.ipcc.ch/report/ar6/wg1/. [Accessed 26 May 2022].
[91] Penning-Rowsell, E., Johnson, C., and Tunstall, S.: 'Signals' from pre-crisis discourse.
[92] Pitt M. Learning lessons from the 2007 floods, final report. London, Ka: The Cabinet Office; 2007.
[93] Wikipedia Contributors 2019 Iran floods. Wikipedia, the free Encyclopedia; July 13, 2022. Retrieved 10:21, November 5, 2022, Retrieved from https://en.wikipedia.org/w/index.php?title=2019_Iran_floods&oldid=1097947890.
[94] UNISDR Technical guidance for monitoring and reporting on progress in achieving the global targets of the Sendai framework for disaster risk reduction. Geneva, Switzerland: United Nations; 2017.
[95] US Government. The President's Commission on critical infrastructure protection (PCCIP), executive order 13010. 1996 [Washington DC].
[96] Taherynia MH, Ghazifard A, Fatemi SM. Predicting subsidence in the south pars' gas field, Iran. Electronic Journal of Geotechnical Engineering 2013;18: 2621–7.
[97] Birkmann J, Welle T, Solecki W, Lwasa S, Garschagen M. Boost the resilience of small and midsized cities. Nature 2016;537:605–8.
[98] Wang J, Yi S, Li MY, Wang L, Song CC. Effects of sea level rise, land subsidence, bathymetric change and typhoon tracks on storm flooding in the coastal areas of Shanghai. Science of the Total Environment 2018;621: 228–34.

This page intentionally left blank

6

Effect of hurricane and storm on oil, gas, and petrochemical industries

Parisa Rostami[1] and Mohammad Reza Rahimpour[2]

[1]*Department of Chemical Engineering, Faculty of Engineering, Yasouj University, Yasouj, Iran;* [2]*Department of Chemical Engineering, Shiraz University, Shiraz, Iran*

1. Introduction

The tropical zone is one of the earth's five regions with a hot and humid climate. This region is equally far from the equator from the north and south. Due to the proximity of the tropical region to the equator, it is clear that the air temperature and ocean waters are warmer in this region than in other parts of the world. The heat and humidity in this region motivate extreme weather instability in certain conditions. This instability causes the air to rise sharply, and at the same time, due to the Coriolis force induced by the rotation of the earth around itself, air circulation conditions are provided. This air circulation and ascent usually form over the oceans and then move toward the land. Due to the very high speed of the wind in these storms and the amount of moisture in the oceanic areas, the intensity of the rain and wind resulting from them is extremely high. The combination of high winds and water makes cyclones a serious hazard for coastal areas in tropical and subtropical areas of the world.

Every year in a few months, from July to September in the Northern Hemisphere and from January to March in the Southern Hemisphere, hurricanes cover areas of the globe, including the Gulf Coast of North America, Northwest Australia, Bangladesh East, and India. Historically, the US is one of the most hurricane-prone areas on the planet. This country spends a lot of money every year to compensate for the damage resulting from the hurricane [1].

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00017-7

The GOM region, which is located in the south of America, is the bed of some world's largest oil and gas fields. A large number of oil and gas drilling rigs, pipelines and their appliances, refineries, petrochemicals, storage tanks, chemical plants, and other industrial facilities are scattered there. At the same time, the GOM is the site of the most destructive storms every year, which damage oil, gas, and petrochemical facilities and forces the countries of this region to spend a lot of money to compensate for these damages [2,3].

From 1980 to 2021, climate disasters cost the US a total of $310 billion. Of these disasters, tropical storms (hurricanes) resulted in the most damage: more than $1.1 trillion in total. That's an average of $20.5 billion per storm.

Hurricane disasters can, directly and indirectly, significantly influence offshore oil and gas production, the shutdown of petrochemical and refineries production and export operations, damage to infrastructure and coastal facilities, the creation of environmental crises, and even the development of serious social disturbances [4,5]. Extreme winds can affect atmospheric storage tanks due to their intrinsic structural vulnerability combined with their capacity to store large quantities of hazardous material, often flammable. A short time before and after the storm, usually the most intense and the greatest number of lightning occurs [6].

2. Hurricanes and their components: Categories and features

Every year, beginning on June 1, tropical cyclones activate and damage human lives in the Gulf countries and the east coast. Each hurricane, according to its intensity, has some components, including high winds, waves/storm surges, terrible lightning, heavy rains, and flooding, which can cause large-scale disruptions to a country's infrastructure [7,8].

2.1 Classification of hurricanes and storms

Hurricanes are categorized on the Sapphire Simpson Hurricane Wind Scale (SSHWS), a 1–5 rating based on a hurricane's intensity. The SSHWS required minor modifications to address some conversion issues, which were done in 2012. Table 6.1 represents the updated version for different categories with their particular specifications.

Based on a summary made for a 30-year climate period of the Atlantic Ocean basin (Atlantic Ocean, Caribbean Sea, and GOM)

Table 6.1 Updated categories of storms according to the SSHWS [9].

Category	Wind speed	Damage potential
1	119–153 km/h *(74–95 mph)*	Minimal
2	154–177 km/h *(96–110 mph)*	Moderate
3	178–208 km/h *(111–129 mph)*	Extensive
4	209–251 km/h *(130–156 mph)*	Extreme
5	≥252 km/h *(157 mph or higher)*	Catastrophic

until 2020, each year in the hurricane season, the Atlantic Ocean encountered an average of 4 major hurricanes (Category 3–5), 8 hurricanes, and 15 named storms [10]. It is important to note that although a Category 1 or 2 hurricane is rated as minimal to moderate in terms of potential wind and storm surge damage only, the damage from lightning, heavy rainfall, and resulting flooding can lead to catastrophic effects on various industries.

2.2 Wind and storm surge

Hurricanes are categorized by their destructive winds. The storm itself or the tornadoes it produces lead to the creation of these winds. The wind resulting from storm damages the electrical energy transmission infrastructure and disables the devices, destroys the houses and makes them unlivable, damages the land, sea, and air transportation system, and makes them unusable. Hurricane winds will quickly disperse the contaminant and reduce its impact region, but these winds will not prevent the toxic compound from exposing communities adjacent to the release point compound. In case of the leakage of a hazmat due to damage to industrial equipment, storm winds quickly disperse the pollutant and reduce its impact area, but these winds do not prevent this toxic compound from being exposed to communities near the point of release. In order to have enough time to evacuate human forces from vulnerable areas, turn off devices and evacuate some conveyors of refinery materials, it is necessary to monitor a storm regularly. This work is done by the responsible authorities and the local emergency services are informed so that, if necessary, the shutdown can be done about 3 days before the storm winds reach the target areas [11–14]. Of important effects of a storm that comes from strong wind and has a high potential for destruction is the wave loading on the deck, which in some cases may cause destruction and major damage such as the complete overturning of the upper parts and tilting of the platforms. According to the experience obtained from various storms in these years, in some cases, this wave can also overturn the platforms without destroying the structure and spill dangerous materials into the seas. Hurricane-induced storm surges may also be highly destructive, and, in the case of Category 5 hurricanes, it is possible to reach more than 5.5 m. In Category 5 hurricanes that occur in southeast Louisiana, the wave level reaches 7.5 m, and in Category 2 or 3 hurricanes it reaches 2.4 m. A wave height of 7.5 m was observed in 1969 when Hurricane Camille hit the Mississippi coastline [15–17]. Almost all port facilities and half of the interstate highways are vulnerable to storm surges of 5.5 m and above [18].

2.3 Flood

Floods can generate in two ways: torrential rain accompanied by hurricanes or storm surges generated by hurricanes. Heavy rains over short time periods, with soil saturation, led to landslides and damage to roads, bridges, and ports. Flooding made by heavy rain damages petrochemical equipment, refineries, and oil storage tanks, and then leads to serious problems by releasing oil and other dangerous pollutants. When a hurricane creates a flood because of storm surges, the water level of canals, rivers, and lakes that are connected to the sea rises and the industrial equipment inside these passages will also be temporarily or permanently disabled. One such incident in 1994 in the San Jacinto River, Texas, released more than 35,000 barrels of oil and petroleum products into the environment [19].

The flooding in August 2021 resulted from Hurricane Ida disrupting Louisiana refineries and oil and gas offshore infrastructure [20].

2.4 Lightning

As with other disasters associated with hurricanes, in the case of lightning, the necessary forecasts are made to reduce the effects of possible consequences by the officials of the areas exposed to hurricanes. But lightning in many cases leads to fire, power outages and power fluctuations in the refinery [6]. Power outages in boilers, pumps, storage units, safety devices, and control panels lead to fire and destruction of sensitive electronic components. If a tank containing chemicals is directly exposed to lightning, the explosion will damage nearby equipment and puncture pipelines and causes water and air pollution [21–25].

2.5 Rainfall

Heavy rains accompanied by storms are one of the major damaging components, which in many cases lead to the overloading of air filters, damage to pipelines, electrical damage to equipment, weakening of structures, unpredictable stoppage of oil refining processes, and mold growth in facilities [17,26]. The rain caused by the storm can have both a positive and negative effect on the leakage of gases in the air. Dissolving toxic gases in themselves will have a positive effect, and creating acid rain in the surrounding areas will have a negative effect.

3. Hurricane effects on oil, gas, and petrochemical industrial facilities

Because of the massive offshore and onshore energy resources and infrastructure in the Gulf and its coastal region, this area has extensive economic importance to the US. According to the US Energy Information Administration report, there are currently about 3500 structures in the GOM, and of these, more than 3200 are in operation using for the production of 1.6 mb/d oil and 0.9 trillion cubic feet of natural gas, in the GOM federal offshore. Over 47% (8,490,690 b/d) of total US petroleum refining capacity is located along the Gulf Coast, as well as 51% of total US natural gas processing plant capacity.

Overlay, hurricane landfall can have unpleasant consequences for the oil, gas, and petrochemical industry; for example:

- Disruption of storage activities
- Taking out power supplies and control systems
- Cutting overhead power lines inside the refinery area
- Increase flow and pressure on underground infrastructure like pipelines
- Leakage of toxic chemicals due to flooding and rupture of tanks and pipelines
- Damages to electromechanical equipment (like pipes, valves) and utilities (like power, communications, steam, compressed gasses)
- Unforeseen shutdowns of unitary or refinery processes (steam boilers, cooling systems, pumps, and electrically operated safety control mechanisms) [24,27–30].

3.1 Hurricane impacts on oil and gas platforms

In the Gulf of Mexico, wells drilled to extract oil and gas are located 5 miles below the water's surface. Fig. 6.1 shows the location of these structures in GOM. Petroleum compounds are transferred from the well to the separation platforms. These platforms, the primary separation sites for gas, oil, and water, have different types. In shallow water (less than 1000 feet), fixed platforms, compliant towers, or tension-leg platforms attached to the bottom are used. Floating structures are usually used in deep waters. About 47 major natural gas processing plants are located in several Gulf Coast states. Of these, about nine factories can extract individual liquid components of natural gas, including ethane, propane, butane, and pentane. Storm surge causes serious damage to production equipment as well as onshore support facilities by tilting or breaking the structure of drilling rigs. In violent conditions with wind speeds of 240 km/h and waves of more than 25 m height in the GOM, hurricanes pose serious challenges to the design and operation of offshore facilities [32].

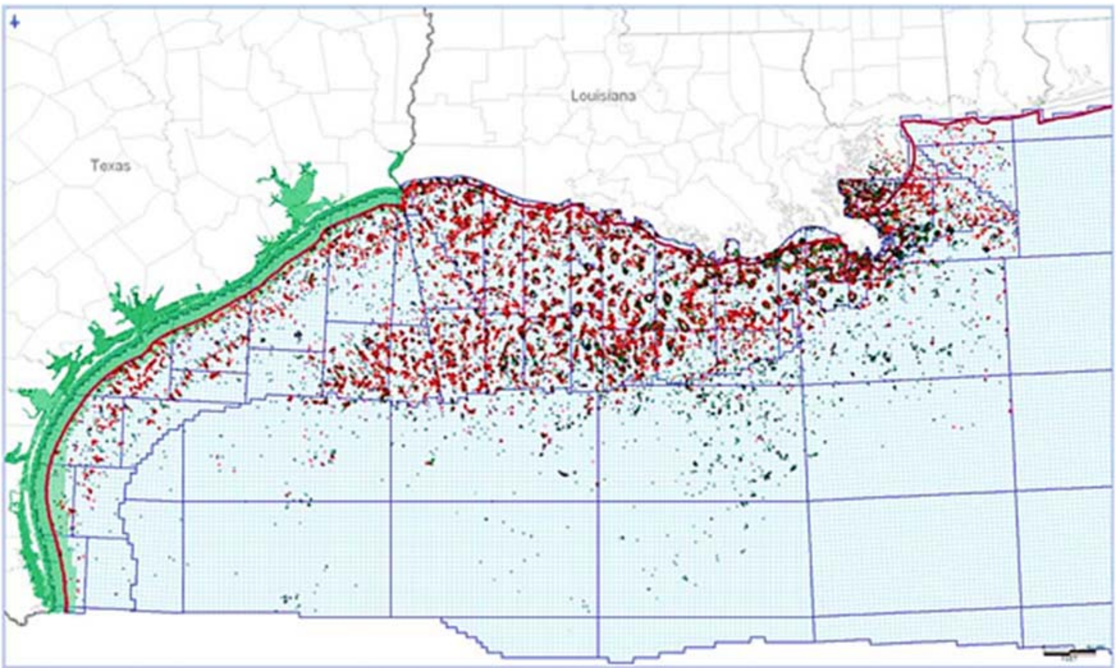


Figure 6.1 GOM-offshore oil and gas structures map. Red dots (dark gray in print): gas wells, green dots (light gray in print): oil wells, and black dots: dry holes [31].

Hurricane Ivan in 2004 is one of the costliest hurricanes for the offshore oil and gas industry in US history. Ivan led to a lot of concern among industrialists, operators, and government officials with the many damages it caused in the oil and gas drilling industry and production activities [33,34].

Eight refineries, hundreds of drilling rigs, and many oil and gas production facilities were shut down in 2005 when hurricanes Katrina and Rita hit the central GOM coast [16]. "Hub platforms" in shallow water, because they are closer to the shore, connect deep water platforms far from the shores to the shore in order to transfer gas and oil, through pipes of different sizes, to countries. Each production platform is usually used to drill 5—20 wells. Before the hurricanes made landfall in 2005, more than 700 platforms in the Gulf were responsible for producing and transporting more than 90% of oil and more than 83% of gas to coastal areas [35]. Hurricanes Katrina and Rita completely destroyed 113 platforms and severely damaged 53 platforms in shallow waters between 10 and 120 m, according to a post-hurricane damage assessment and reports submitted by MMS in May 2006 [36,37]. It took about 2 years for the US to repair the damage caused to the oil industry.

The total number of annual gas and gas condensate wells are represented in some government statistical sites. According to a report, from 1989 to 2014 the total number of wells increased from 262,483 to 586,213. The last reported number of wells relates to 2020. That is 483,326 wells [29].

After Katrina and Rita, natural gas production in the GOM dropped from an average of approximately 10 bcm/day to less than 2 bcm/day and did not recover for several months due to damage to production platforms and infrastructure. Because the repair of offshore infrastructure usually takes several months. Construction companies are required to comply with the established rules in the Code of Federal Regulations, Title 30, Part 250 (30CFR250) for the design, maintenance, and evaluation of offshore structures. The American Petroleum Institute (API) requires oil companies to develop design requirements for offshore facilities that require the design of platforms and permanent floating systems to withstand severe storms with a return period of 100 years [38—40]. These 100-year criteria correspond to a wind speed of about 180 km/h in sustained 1-min winds and a maximum wave height of 22 m. For MODUs, such as jack-up rigs or semi-submersibles, the 10-year design criteria are specified when a MODU operates adjacent to an adjacent permanent structure. Otherwise, stricter regulations apply and the 5-year criterion is used [41,42].

The change in the amount of oil and gas extraction from the fields due to the closure of the platforms causes price fluctuations in the oil and gas markets. In 2017, when Hurricane Harvey shut down about 25% of oil and gas production in the GOM and 105 production platforms (15% of the total), such price fluctuations were also experienced [43].

According to a Reuters report, 91% of offshore crude oil production and 62.2% of natural gas production in the US-controlled northern GOM were shut down for a few days following Hurricane Delta (2020, Category 4) [44].

Ida was a Category 4 hurricane (on the SSHWS) that caused catastrophic damage in southeastern Louisiana in 2021. It also made landfall in western Cuba as a Category 1 hurricane. Federal data showed that approximately 75% of platforms and 47% of pipelines were inactive or abandoned during the storm. Moreover, spills from Hurricane Ida took a toll on the fragile coastline.

3.2 Hurricane impacts on the pipeline system

The pipeline is responsible for transporting oil and gas underwater and on land. This transfer is done between platforms, from platform to shore, and between states. The pipeline system, in addition to pipes of different sizes, consists of valves, measuring points, compressors, dehydration and separation facilities, and subsea valves, which are all coordinated together to establish fluid flow.

The force of wave can break offshore pipelines by causing vertical displacement or endanger underground pipelines by destabilizing sand. This wave can cause damage to ground infrastructures such as valves, pumping stations, and river crossings. It disables the sensors installed inside the pipelines and by breaking the pipes, it causes leakage of gas and hazmat in the environment [28,45]. As a result of severe flooding, the foundations and supports of underground pipes are eroded. Landslides or subsidence caused in petrochemical sites may also lead to pipeline accidents [46]. Each pipeline is designed for a certain maximum pressure. In some cases, increased pressure by more energetic waves causes it to break. As the pipes are moved due to the pressure caused by the storm, sometimes a pipe gets in the way of ships and breaks [18].

Offshore pipelines were damaged in relatively large numbers during Hurricanes Andrew (1992), Ivan (2004), and Katrina (2005). During Hurricane Andrew 485 pipelines and flow lines were damaged. 87% of the pipeline damages occurred in small diameter pipes and most in water depths <30.5 m, with most of the pipeline failures in depths less than 30 m of water. 120 pipelines were damaged following Hurricane Lili. 85% of the pipeline failures occurred in small diameter pipelines. Hurricane Ivan resulted in approximately 168 pipeline damage reports, although the vast majority of GOM offshore pipelines performed well during its passage. After the massive destruction of offshore oil and gas facilities by Hurricane Ivan, many researchers began to assess and investigate the damaged pipelines [34,47–50]. According to the report of US Minerals Management, 542 offshore oil and gas pipelines were damaged as a result of Hurricanes Katrina and Rita [18]. Surprisingly, it is approximately 35,405 km out of the 53,108 km of pipelines in the path of Katrina and Rita [46].

3.3 Hurricane impacts on storage tanks

In 2007 and after Hurricane Katrina, a study on reservoirs found that storage tanks in Texas and Louisiana would suffer serious problems if exposed to hurricane-induced flooding. After that, from 2004 to 2013, more than 1500 chemical releases and/or explosions from tanks killed and injured thousands [51].

Hurricane Katrina first struck the peninsula south of New Orleans on August 29. There were several tank farms and refineries in this area that were severely damaged by Hurricane Katrina.

Storage tanks, because of rainfall as a result of tropical storms, suffer from problems including collapse, loss of containment (flammable and combustible liquids), weakening of structures and in some cases the presence of mold, due to the water accumulation on the rooftops moreover in some cases activation of the extensive explosion could severely damage exposed instrumentation and structures [52–55].

Tank headspace may decrease because of flooding, thereby buffer space available to prevent overflow/overfill displaced, leading to oil spill accidents. Foundations and scouring may be floated due to the storms. The sinking of tanks and flooding of the internal plant drainage systems increase the risk of a fire threat [54,56].

In order to prevent storm damage to tanks, it is crucial to follow the necessary standards. The API in the US reviews specified standards for reservoir tank design every few years. The API-620 and API-650 [57,58] govern the design of atmospheric storage tanks against external wind loads. Today, the construction of tanks without anchors is common in most factories. In this type of tank, floatation and moving of tank is easily possible to prevent damage to an empty tank or a tank with a low liquid level during a flood. During a storm due to strong wind, an empty tank may tilt or break due to the low resistance to deformation of the structure, or the tank may be separated from the foundation in case of flooding. If the tank is filled with liquids, it is more resistant to wind and flooding due to its weight and internal pressure [59,60].

4. Released oil, gas, and petrochemical after hurricanes

Floods, lightning, strong winds, and storms can give rise to gases released into the atmosphere and hazmat liquid leaks in petrochemical facilities, fires, and explosions [54]. Hurricanes Katrina and Rita caused great damage to the oil and gas industry [16]. The volume of oil spills alone released by these storms, both onshore and offshore (30.2 million Lt) [61], is in the same order of magnitude as the Exxon Valdez oil spill (41 million Lt) in Alaska [62]. Moreover, in May 2006, MMS reported that Hurricanes Katrina and Rita had caused six spills of 1000 barrels or greater [37] containing at least 100 hazmats that had been stored on platforms. This hazmat spilled because of the destruction or damage of 528 offshore platforms and 83 pipelines by wind or wave action. This is while, at the time of the spill, remedial action has been taken for only 30% of these cases [63].

Among the available reports, there are more natural gas leaks from pipes than from platforms. Detecting natural gas releases from underwater pipelines is easier than platforms. It is due to the fact that bubbles on the surface of the water make the gas diagnosis more comfortable than oil.

Flammable liquids of petrochemicals and refineries may be stored in pressurized or atmospheric storage tanks. Flammable liquids when exit suddenly from a pressurized tank may either flow and burn or evaporate and make vaporous clouds. If a flammable vapor cloud is formed, with its movement and exposure to inflammable agents, a vapor cloud explosion will occur, which will be very dangerous and harmful. In the case of the atmospheric tank, the leakage of flammable liquids from these tanks or pipe systems can lead to fire and explosion due to lightning or other incidents [64,65].

One of the important reports related to the release of flammable liquids is related to Hurricane Katrina. In this storm, the air of the city of New Orleans was heavily polluted by volatile organic compounds released by the explosion and fire of petrochemical facilities. About 30,000 cubic meters of hazmat were also released in the waters spread due to the hurricane-associated flood [66].

After Hurricane Harvey, due to damage to a petrochemical plant, more than 16,000 pounds of 1.3-butadiene (a known carcinogen material) have been released [67]. More than 5.5 million pounds of chemicals that stimulate respiration or growth of cancer were reported in some cities of Texas and Harris [68], and repeated release of benzene vapors created a carcinogenic vapor cloud [69].

5. Hurricane effects on oil, gas, and petrochemical economic: Advantages and disadvantages

According to oil and gas economics surveys, energy prices react to hurricanes and tropical storms in anticipation of the storm's arrival. Every year, with the increase in the temperature of seas and oceans as a result of global warming, the situation of hurricane formation worsens [70]. Understanding and reviewing strategic planning, disaster reaction, and trouble recovery issues, vulnerabilities, and threats in the oil supply chain will further help in evaluating the direct and indirect impacts of hurricanes on primary and secondary markets, business intelligence, and disaster comeback efforts [71–73].

One of the responses to extreme climate change is stock prices. It signals the energy company's managers to design a good plan and get a good profit from this situation. When a hurricane is predicted to hit the US, some research predicts that the stock market will have a devastating negative movement when it is actually trending positively (such as Hurricane Irma in 2017). When a hurricane is predicted to hit the US, some research predicts that the stock market will have a devastating negative movement when it is trending positively (such as Hurricane Irma in 2017) [74,75].

A study in the oil and gas industry showed that tropical storms in oil and gas markets cause shocks and cause prices to deviate from the long-term equilibrium [76].

As a result of Hurricanes Irene (2011) and Sandy (2012), the price of West Texas Intermediate and Brent crude oil did not change, but in the Northeast, due to the disruption of the oil supply chain, it affected the reserves of petroleum products and their prices.

According to the report presented by the Office of Electricity Delivery and Energy Reliability, a few days after the storm made landfall northeast, conventional gasoline stocks had fallen. Generally, this reduction leads to a growth in gasoline prices. Moreover, because the Northeast receives gasoline shipments by pipeline from the Gulf Coast and this is costly, the price of gasoline in New York Harbor increased more than Gulf Coast region. This price increase was not permanent because the production accelerated within 2 weeks and returned to its original state [77,78]. This fluctuation in production rate and prices were also observed for Sandy Hurricane, but the change rate was more severe and took longer to return to pre-hurricane conditions.

Although hurricanes can negatively impact natural gas production, processing, and transportation, their effects on gas demand can also be negative. Because when there is a storm, due to the closure of some commercial facilities and the disruption of electricity production, natural gas consumption also decreases [79]. If storm damage is minimal, a negative demand effect will apply in its market and natural gas prices will decrease.

6. Reduction in destructive effects of hurricanes on oil, gas, and petrochemical industry

After every storm or tropical storm, it is necessary to return to full production as quickly and safely as possible. At the same time, in every field of industry that the storm has damaged, necessary arrangements must be made to maintain the integrity of the chain of industrial units. The USA oil and natural gas industry is responsible for protecting the environment and continuously increasing its hurricane preparedness.

API plays two main functions for the industry in preparing for hurricanes. First, the API generally shares how the industry prepares for and reacts to critical events before, during, and after the event, to reduce some of the limitations on companies proactively responding to potentially unfavorable events. Second, API works with associate companies and federal, state, and local governments to quickly and safely prepare for hurricanes and recovery processes.

Researchers and industrialists are trying to reduce the harmful effects of hurricanes on industry and human life. Technologies such as computational fluid dynamics (CFD) are being used to estimate the performance of offshore platforms under harsh operating conditions. CFD simulates storm surges, winds'

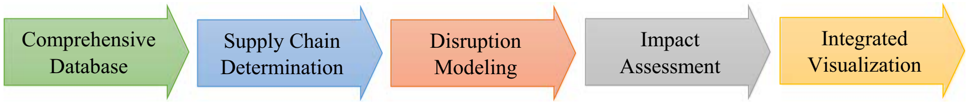


Figure 6.2 Integrated modeling approach [81].

aerodynamic effect, and waves' hydrodynamic effect on platforms using super-computer technology [80].

Evaluation of a destructive disaster effect on primary and secondary markets in the oil and refinery industry was done, and the model's ability was investigated by Mohan et al. [81]. Some parameters were gathered, including the supply chain of crude oil and refined products, market balance in different areas, and connections with other areas. Then the obtained database using an integrated visual platform was simulated. Fig. 6.2 represents a total view of this approach.

Finally, the effect of the hurricane, as a specific disaster, on the petroleum infrastructure and supply chain was analyzed by the model to predict market reactions after the hurricane. In the case of hurricanes, the input elements were landfall location, highest wind speed, the magnitude of wind radius, and forward speed and direction of the storm.

7. Conclusion and future outlook

Hurricane and storm activity is generally expected to be affected by climate change, mainly due to a warmer and wetter environment. The oil industry and its infrastructure have experienced countless outages and disruptions due to both natural disasters and man-made impacts. Floods, strong winds, high waves, and lightning associated with hurricanes have targeted drilling facilities, refineries, petrochemical plants, and pipeline systems and every year caused very high costs to the owner governments. Any geographical area exposed to the dangers of tropical storms must be able to protect its equipment and clean environment against damages caused by these disasters. Following the existing rules and standards in the construction, repair and placement of offshore and onshore equipment are very appropriate. Analyzing storm damage at oil and gas facilities provides a valuable opportunity to learn how to better prepare for storms to prevent future damage and losses. This issue is significant in hurricane-prone countries, such as the US, where coastal areas are covered with large and important industrial equipment.

With more severe storms likely in the future, the offshore industry must take steps to improve risk management to reduce the risk of large hazmat releases in future hurricanes.

Continuing to advance the assessment and mitigation of vulnerabilities to extreme weather events, particularly in a region prone to hurricanes and flooding, especially given complex supply chain dynamics, can be one of the best outcomes.

Taking measures such as emptying pipelines before a hurricane can be effective in preventing oil and gas releases. In addition, in the case of hazmat processed or stored on board, it is better to discharge.

Abbreviations and symbols

API	American Petroleum Institute
b/d	Barrel per day
bcm	Billion cubic meter
CFD	Computational fluid dynamics
hazmat	Hazard-materials
km/h	Kilometer per hour
Lt	Liter
mb/d	Million barrels per day
MODUs	Mobile offshore drilling units
mph	Mile per hour
SSHWS	Sapphire Simpson Hurricane Wind Scale
US	United States

References

[1] Weinkle J, Landsea C, Collins D, Musulin R, Crompton RP, Klotzbach PJ, Pielke R. Normalized hurricane damage in the continental United States 1900–2017. Nature Sustainability 2018;1(12):808–13.

[2] Yang Z, Wang T, Leung R, Hibbard K, Janetos T, Kraucunas I, et al. A modeling study of coastal inundation induced by storm surge, sea-level rise, and subsidence in the Gulf of Mexico. Natural Hazards 2014;71(3): 1771–94.

[3] Mapbox. World oil map 2021. 2022. https://www.oilmap.xyz/.

[4] Mikellidou CV, Shakou LM, Boustras G, Dimopoulos C. Energy critical infrastructures at risk from climate change: a state of the art review. Safety Science 2018;110:110–20.

[5] Tay WH, Lau KK, Lai LS, Shariff AM, Wang T. Current development and challenges in the intensified absorption technology for natural gas purification at offshore condition. Journal of Natural Gas Science and Engineering 2019;71:102977.

[6] Samsury CE, Orville RE. Cloud-to-ground lightning in tropical cyclones: a study of Hurricanes Hugo (1989) and Jerry (1989). Monthly Weather Review 1994;122(8):1887–96.

[7] Eyre B, Twigg C. Nutrient behaviour during post-flood recovery of the Richmond River Estuary, Northern NSW, Australia. Estuarine, Coastal and Shelf Science 1997;44(3):311–26.
[8] Greening H, Doering P, Corbett C. Hurricane impacts on coastal ecosystems. Estuaries and Coasts 2006:877–9.
[9] Schott T, Landsea C, Hafele G, Lorens J, Taylor A, Thurm H, et al. The Saffir-Simpson hurricane wind scale. NOAA/National Weather Service; 2012. p. 1–4.
[10] National Hurricane Center and Central Pacific Hurricane Center. Atlantic hurricane season. 2022. https://www.nhc.noaa.gov/data/tcr/index.php?season=2022&basin=atl.
[11] Cozzani V, Campedel M, Renni E, Krausmann E. Industrial accidents triggered by flood events: analysis of past accidents. Journal of Hazardous Materials 2010;175(1–3):501–9.
[12] Petrova EG. Natural factors of technological accidents: the case of Russia. Natural Hazards and Earth System Sciences 2011;11(8):2227–34.
[13] Rasmussen K. Natural events and accidents with hazardous materials. Journal of Hazardous Materials 1995;40(1):43–54.
[14] Young S, Balluz L, Malilay J. Natural and technologic hazardous material releases during and after natural disasters: a review. Science of the Total Environment 2004;322(1–3):3–20.
[15] Schaeffer R, Szklo AS, de Lucena AFP, Borba BSMC, Nogueira LPP, Fleming FP, et al. Energy sector vulnerability to climate change: a review. Energy 2012;38(1):1–12.
[16] Cruz AM, Krausmann E. Damage to offshore oil and gas facilities following hurricanes Katrina and Rita: an overview. Journal of Loss Prevention in the Process Industries 2008;21(6):620–6.
[17] Katopodis T, Sfetsos A. A review of climate change impacts to oil sector critical services and suggested recommendations for industry uptake. Infrastructures 2019;4(4):74.
[18] Savonis M, Burkett VR, Potter JR. Impacts of climate change and variability on transportation systems and infrastructure: Gulf Coast study, phase I. 2008.
[19] Forzieri G, Bianchi A, e Silva FB, Herrera MAM, Leblois A, Lavalle C, et al. Escalating impacts of climate extremes on critical infrastructures in Europe. Global Environmental Change 2018;48:97–107.
[20] EU-CIRCLE. Case study 2. 2022. http://www.eu-circle.eu/research/case-studies/case-study-2/.
[21] Grenzeback LR, Andrew TL, Cambridge Systematics. Case study of the transportation sector's response to and recovery from hurricane's Katrina and Rita. Transportation Research Board; 2008.
[22] Kulesa G. Weather and aviation: how does weather affect the safety and operations of airports and aviation, and how does FAA work to manage weather-related effects?. In: The potential impacts of climate change on transportation. US Department of Transportation Center for Climate Change and Environmental Forecasting; US Environmental Protection Agency; US Department of Energy; and US Global Change Research Program; 2003.
[23] U.S. EIA. Hurricane Harvey caused US Gulf coast refinery runs to drop, gasoline prices to rise. Today in Energy 2017;11.
[24] Sueta HE, Shigihara M, Grimoni JAB, Francisco Burani G, Nascimento WJD. Risk analysis associated to lightning in oil refinery construction sites. In:

2010 30th international conference on lightning protection (ICLP). IEEE; 2010. p. 1–6.
[25] Chang JI, Lin C-C. A study of storage tank accidents. Journal of Loss Prevention in the Process Industries 2006;19(1):51–9.
[26] Roads H. Hampton roads. 2022. https://www.hrpdcva.gov/.
[27] Udie J, Bhattacharyya S, Ozawa-Meida L. A conceptual framework for vulnerability assessment of climate change impact on critical oil and gas infrastructure in the Niger delta. Climate 2018;6(1):11.
[28] FEMA. Multi-hazard loss estimation methodology: flood model. HAZUS-MH MR4 Technical Manual 2009.
[29] U.S. Energy Information Administration. Open data. 2022. https://www.eia.gov/opendata/v1/qb.php?sdid=NG.NA1170_NUS_8.A.
[30] Carlson C, Goldman G, Dahl K. Stormy seas, rising risks: what investors should know about climate change impacts at oil refineries. Center for Science and Democracy at the Union of Concerned Scientists; 2015.
[31] Smyth RC, Thomas III PG, Heiligenstein C. Concerning offshore geologic storage of carbon dioxide in the USA. Energy Procedia 2014;63:5822–6.
[32] Wolf J. Effects of climate change on wave height at the coast. In: EGS-AGU-EUG Joint Assembly; 2003. p. 13351.
[33] Wisch DJ, Ward EG. Offshore standards: the impact of hurricanes Ivan/Katrina/Rita. In: International conference on offshore mechanics and arctic engineering. vol 42681; 2007. p. 631–41.
[34] Ward EG, Gilbert R. 2005 hurricane readiness and recovery conference. 2005.
[35] Feltus A. Katrina takes a terrible toll. Petroleum Economist (English edition) 2005;72(10).
[36] MMS. Impact assessment of offshore facilities from hurricanes Katrina and Rita. News Release; 2006. p. 3418.
[37] Wisch DJ, Puskar FJ, Laurendine TT, O'Connor PE, Versowsky PE, Bucknell J. An update on API RP 2A section 17 for the assessment of existing platforms. In: Offshore technology conference. OnePetro; 2004.
[38] API. Recommended practice for planning, designing and constructing tension leg platforms. API recommended practice 2T. 2nd ed. American Petroleum Institute; 1997.
[39] API. Recommended practice for planning, designing and constructing fixed offshore platforms—working stress design. API recommended practice 2A-WSD. 21st ed. American Petroleum Institute; 2000.
[40] API. Recommended practice for design and analysis of station keeping systems for floating structures. API recommended practice 2SK. 2nd ed. American Petroleum Institute; 1996.
[41] Ghoneim A, Colby C, Houston DNV. GoM offshore structures design criteria. In: SNAME Texas section meeting, vol 13; 2005.
[42] Tuscaloosanews.com. Hurricane. 2022. https://www.tuscaloosanews.com/news/.
[43] Reuter. After hurricane Harvey. 2022. https://www.reuters.com/article/us-storm-delta-energy-production.
[44] FEMA. Multi-hazard loss estimation methodology hurricane model. HAZUS—MH 2.1 User Manual 2013.
[45] Cruz AM, Steinberg LJ, Vetere-Arellano AL. Emerging issues for natech disaster risk management in Europe. Journal of Risk Research 2006;9(5):483–501.
[46] Veritas DN. Pipeline damage assessment from hurricanes Katrina and Rita in the Gulf of Mexico. MMS Project 2007;581.

[47] Veritas DN. Pipeline damage assessment from hurricane Ivan in the Gulf of Mexico. No. 44038570. Technical Report. 2006.
[48] Cox AT, Cardone VJ, Counillon F, Szabo D. Hindcast study of winds, waves, and currents in Northern Gulf of Mexico in hurricane Ivan (2004). In: Offshore technology conference. OnePetro; 2005.
[49] Mirza S, Skinner J, Mathew A, Ekstrom L. Hurricane Ivan-pipeline damage, integrity assessment, and on-bottom stability observations. In: Offshore technology conference. OnePetro; 2006.
[50] Godoy LA. Performance of storage tanks in oil facilities damaged by Hurricanes Katrina and Rita. Journal of Performance of Constructed Facilities 2007;21(6):441—9.
[51] Graumann A, Houston TG, Lawrimore JH, Levinson DH, Lott N, McCown S, et al. Hurricane Katrina: a climatological perspective: preliminary report. 2006.
[52] Ecowatch. Oil companies were not held accountable for 10.8 million gallons of oil spilled in gulf of Mexico. 2022. https://www.ecowatch.com/oil-companies-gulf-oil-spills-2642236518.html.
[53] Cruz AM, Steinberg LJ, Luna R. Identifying hurricane-induced hazardous material release scenarios in a petroleum refinery. Natural Hazards Review 2001;2(4):203—10.
[54] Renni E, Krausmann E, Cozzani V. Industrial accidents triggered by lightning. Journal of Hazardous Materials 2010;184(1—3):42—8.
[55] Steinberg LJ, Sengul H, Cruz AM. Natech risk and management: an assessment of the state of the art. Natural Hazards 2008;46(2):143—52.
[56] FEHLING, Texas, Energy and Environment Reporting for Texas. How hurricanes that hit the Texas coast can float giant tanks. Energy and Environment Reporting for Texas; 2022. https://stateimpact.npr.org/texas/2013/10/07/how-hurricanes-that-hit-the-texas-coast-can-float-giant-tanks/.
[57] A. P. I. Standard. 620, design and construction of large, welded, low—pressure storage tanks. This Standard Applies to Operating Temperatures 2013;121.
[58] A. P. I. Standard. Welded steel tanks for oil storage. 1988.
[59] Olivar OJR, Mayorga SZ, Giraldo FM, Sánchez-Silva M, Pinelli J-P, Salzano E. The effects of extreme winds on atmospheric storage tanks. Reliability Engineering & System Safety 2020;195:106686.
[60] Dollar JJ, Coyne MJ. Hurricane Ivan forces vigorous response and repairs. Oil & Gas Journal 2005;103(32):75—86.
[61] Davis DW. Oil spills and other issues in the aftermath of Hurricanes Katrina and Rita: an overview. 2006.
[62] NASA. The earth observatory. 2022. https://earthobservatory.nasa.gov/.
[63] Tubb R. MMS director overviews impact of hurricanes Katrina and Rita. Pipeline and Gas Journal 2005;232(11):69—71.
[64] Chang NB, Wei YL, Tseng CC, Kao CYJ. The design of a GIS-based decision support system for chemical emergency preparedness and response in an urban environment. Computers, Environment and Urban Systems 1997;21(1):67—94.
[65] Birk AM. Propane and LPG BLEVE incident simulation for plant safety analysis, emergency response planning and training. Kingston, ON, Canada: Department of Mechanical Engineering, Queens University; 1998.
[66] Picou JS. Katrina as a natech disaster: toxic contamination and long-term risks for residents of New Orleans. Journal of Applied Social Science 2009;3(2):39—55.

[67] Texas Commission on Environmental Quality. Hurricane Harvey response 2017. 2022. https://www.tceq.texas.gov/assets/public/response/hurricanes/hurricane-harvey-after-action-review-report.pdf.
[68] Sadasivam N. Experts: much of Harvey-related air pollution was preventable. Texas Observer 2017.
[69] Thomas KA, Elliott JR, Chavez S. Community perceptions of industrial risks before and after a toxic flood: the case of Houston and Hurricane Harvey. Sociological Spectrum 2018;38(6):371–86.
[70] Webster PJ, Holland GJ, Curry JA, Chang H-R. Changes in tropical cyclone number, duration, and intensity in a warming environment. Science 2005; 309(5742):1844–6.
[71] Rose A, Benavides J, Chang SE, Szczesniak P, Lim D. The regional economic impact of an earthquake: direct and indirect effects of electricity lifeline disruptions. Journal of Regional Science 1997;37(3):437–58.
[72] Tierney K. Impacts of recent disasters on businesses: the 1993 midwest floods and the 1994 Northridge earthquake. In: Economic consequences of earthquakes: preparing for the unexpected; 1997. p. 189–222.
[73] Webb GR, Tierney KJ, Dahlhamer JM. Businesses and disasters: empirical patterns and unanswered questions. Natural Hazards Review 2000;1(2): 83–90.
[74] Ramelli S, Wagner AF, Zeckhauser R, Ziegler A. Stock price rewards to climate saints and sinners: evidence from the Trump election. National Bureau of Economic Research; 2018.
[75] Monasterolo I, De Angelis L. Blind to carbon risk? An analysis of stock market reaction to the Paris Agreement. Ecological Economics 2020;170: 106571.
[76] Hsu K, Zhu Z. Tropical storms and the US natural gas demand: how have hurricanes impacted natural gas consumption? Applied Economics 2022: 1–24.
[77] Kalghatgi G, Levinsky H, Colket M. Future transportation fuels. Progress in Energy and Combustion Science 2018;69:103–5.
[78] Hoffman P, Bryan W. Comparing the impacts of Northeast hurricanes on energy infrastructure. Washington DC, USA: US Department of Energy; 2013.
[79] Considine TJ, Jablonowski C, Posner B, Bishop CH. The value of hurricane forecasts to oil and gas producers in the Gulf of Mexico. Journal of Applied Meteorology 2004;43(9):1270–81.
[80] Ferguson S. Ride the wave. Engineering 2007;248(4):42–4.
[81] Mohan H, Kuczma G, Carolus M. Integrated approach to model liquid fuels supply chain Interactions due to disasters and accidents. In: SPE annual technical conference and exhibition. OnePetro; 2021.

SECTION III

Manmade disasters in oil, gas, and petrochemical industries

This page intentionally left blank

7

Fire event in oil, gas, and petrochemical industries

Babak Omidvar and Behnam Mohamadzadeh
Graduate Faculty of Environment, University of Tehran, Tehran, Iran

1. Introduction

One of the key industries that influences economic stability and constant growth in many countries and international petroleum companies is the safe and uninterrupted operation of their oil, gas, and petrochemical facilities. The most considerable threat to human lives and financial losses in process plants and during transportation ever since this industry has existed is fire [1]. Because of the highly flammable materials and complex processing procedures by the immense complicated facilities and numerous personnel, the risk of different accidents leading to fire break out is predicted as a high level [2]. When a man-made or technological accident causes combustible vapor formation accompanied by an initial ignition, due to the massive fuels reachable by the fire and possible secondary explosions, the fire propagation at a disastrous scale would be anticipated. Due to the characteristics of hydrocarbon materials, the degree of flammability varies in a wide range. These fires form high-rise turbulent flames with massive heat emissions. Based on the combustible material state and other environmental factors, different kinds of fires such as large-scale quick fires, pool fires, jet fires, and even explosions happen. Even though each kind of petrochemical fire has its devastating effects, in addition, the domino effect should be kept in mind. They could result in numerous related losses and deaths initiated by an initial ignition from a neglectable inadvertence. These fires could happen at any stage of production including the refining and processing, transporting, and storage phase and they have increased in number in recent years [3].

Given that, oil, gas, and petrochemical production are categorized as high-risk industries, fire protection activities are a key element to maintain functionality and provision of raw materials

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00015-3

for downstream industries. Thus, proper efforts in designing fire protection systems and law enforcement, risk analysis, and assessment and safety legislation at the operation stage are essential [4]. Fig. 7.1 shows a part of the process equipment in a petrochemical plant including absorption towers and horizontal drums which have a high potential to break out devastating fires.

2. Combustion theory

Fire is a phenomenon that combines a specific material with oxygen [5]. In another word, combustion is defined as the occurrence of a chemical reaction or a series of chain reactions that is accompanied by the emission of light and heat [6]. To ignite and continue the fire growth, the existence of four factors, known as the fire pyramid as shown in Fig. 7.2, is necessary. These factors include:

I. Heat
II. Oxygen
III. Combustible material
IV. Chain reactions

Figure 7.1 A part of a petrochemical plant including absorption towers and horizontal drums.

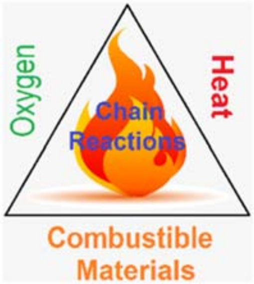


Figure 7.2 A schematic sketch of the fire pyramid.

It will not be possible to continue the burning process without any of these factors. A fire occurs when the initial ignition leads to the fire and the primary flame is not controlled and grows anyway.

To have initial ignition, the reaction of combustible material and oxygen and sufficient heat is needed. Sometimes the required heat is obtained from chemical reactions and sometimes it is supplied from an external source. The amount of heat required to start burning depends on the type of combustible materials [7]. Finally, there will be a burning reaction and a fire, if these reactions start in such a way. The most important ignition initiators are listed as follows:

- Direct ignition
- A gradual rise in temperature
- Chemical reactions
- Creating friction
- The concentration of light rays
- Static and current electricity
- Explosion
- The excessive density of combustible material in vapor or gas state

If the heat is more than a determined amount for any specified material to turn it to the vapor state, and if this heat is accompanied by a spark or a small flame there will be a great chance of producing an ignition. Of course, for gaseous materials, the density of gas in the air should be considered, which means that gaseous substances can explode at a certain density [8]. The initial heat derived from ignited vapor creates more vapors that are ready to burn. The presence of air and vapored burning material mixture beside the sufficient amount of heat and an open flame will lead to chain reactions.

The burning process continues until either all the combustible material participates in the reaction, oxygen inadequacy prevents the continuation of chain reactions, removing the combustible materials is performed or a cooling operation is done.

2.1 Combustible materials

It can be said that all materials can burn or oxidize if they are exposed to sufficient heat in the presence of oxygen and an ignition initiator. But the state of the material has a significant effect on the burning severity [9]. For example, wood in the form of powder or sawdust is more flammable than wooden boards. As such, combustible materials are divided into three categories of flammable solids, flammable liquids, and flammable gases. For solids and liquids, combustion properties depend on their mass fractions, while gaseous materials combustion relays on the volume fraction [10].

2.2 Flammability

The flammability of a material refers to its ease of ignition, its amount of burning speed, heat release rate, and fire severity [11]. Materials flammability is hard to define exactly because of the different tests and approaches that are existed for determining the degree of flammability. Thus, there should be one kind of test for two different materials in case of comparing their degree of flammability [12].

2.2.1 Flammable solids

It refers to those solid materials that contain carbon compounds. Among these materials, we can mention wood, paper, plastic materials, fabric, and even metals. The flammability of these materials depends on the amount of energy required to break the chemical bonds of the substances. For example, metals have lower flammability than wood due to the solid bonding of the particles [13]. Some solid materials that have a low degree of ignition are called flammable solids.

2.2.2 Flammable liquids

Due to their easier evaporation, liquids have a lower ignition point than solid materials and have a higher risk to cause a fire. For example, gasoline, liquid paraffin, white alcohol, thinner, and oil paints are categorized as flammable liquids. Due to the broad variance of flashpoints in liquids, in terms of flammability, this group is divided into four categories according to their flash point temperature [14]:

I. **Extremely flammable**: liquids with a flash point below 73.4°F (23°C) and a boiling point at or below 95°F (35°C).

II. **Highly flammable**: liquids with a flash point below 73.4°F (23°C) and a boiling point above 95°F (35°C)

III. Flammable: liquids with a flash point at or above 73.4°F (23°C) and at or below 140°F (60°C)
IV. Combustible: liquids with a flash point above 140°F (60°C) and at or below 199.4°F (93°C)

2.2.3 Flammable gases

The difference between vapor and gas is that when a flammable vapor is mentioned, it means that one of the flammable solid or liquid substances has turned into vapor before burning. But flammable gas means a flammable substance that is in the gaseous phase at room temperature. When the chain reactions occur in flammable gas, because of rapid combustion, the burning process appears as an explosion [15].

2.3 Fire classes

In the petroleum industry, fires will be categorized into four classes based on combustible material properties [16]. Those classes are defined as follows:

- **Class A:** A fire caused by ordinary solid combustibles such as wood and cloth.
- **Class B:** Fire of liquid and gaseous flammables.
- **Class C:** Electrical fires.
- **Class D:** Fires that involve combustible metals.

2.4 Fire outcomes

The burning process has outputs that include flame, smoke, light, and heat [7]. In some cases, the flame is mentioned as the visible part of fire (excessive hot gases). The devastating part of the fire in the oil, gas, and petrochemical industries is the heat. It is the main suspect of the fire growth, direct and indirect losses, and the number of deaths. In addition, the smoke part is lethal to humans by its poisonous effect, especially in closed compartments such as buildings or industrial sheds.

2.5 Heat transfer

The four mechanisms of heat transfer in fire propagation are conduction, convection, radiation, and direct flame contact [17]. In industrial fires, occasionally, the fire grows in a short time and the ambient temperature rises quickly, thus, heat transfer through convection is not considered because it requires a long time compared to other modes of heat transfer, and usually in the modeling of fire events in oil, gas, and petrochemical industries are not included.

3. Fire growth and propagation factors in oil, gas, and petrochemical industries

Given that, the fire occurs as an explosion in flammable gases, in this chapter, when it refers to combustible materials, it means flammable solids and liquids. After the initial ignition, if the suited conditions are met, the fire will grow and spread in the contaminated area [18]. In oil, gas, and petrochemical fires, some key factors are involved in fire growth rate and its severity including:

3.1 Leakage flow rate, area, and vastness of the propagation or available combustible materials

Concerning the high flammability of combustible materials, in this case, the most important factor in the spread of fire is the availability of combustible materials. Usually, leakage and propagation of combustible materials occur in oil and chemical accidents. Thus, the extent of propagation and the amount of combustible material available to burn play an important role in the disaster severity. Moreover, the area and vastness of the propagation should be considered and in case of flammable gas leakage, an explosible fuel—air mixture will be formed [19].

3.2 Flammability of the combustible materials

Another important factor in the fire severity is the flammability of combustible material. In this case, a more energetic material with a lesser flash point degree leads to a more devastating fire with more heat release rate.

3.3 Geometries and the shape of combustible materials or their containers

Flammable solids deposit in specific storages and different kinds of them are prepared in unique shapes and geometries. Depositing form influences the burning process. In the case of flammable liquids, because of the necessity to use containers, storage tanks, and pipelines, the properties of this element such as volume, shape, the strength of the container's material, and received heat flux must be considerable.

3.4 Distance and flammability of adjacent materials and equipment

One of the most repeated phenomena in fire events in oil, gas, and petrochemical plants is the spread of fire to adjacent equipment such as another reservoir tank or another processing unit. Fire propagation can lead to a more complicated and dangerous situation that amplifies damages drastically. Generally, the amount of heat received by an adjacent target depends on its geometries and the distance from the source of fire [20]. On the other way, the lesser distance between plant elements and their plenitude in a cramped area leads to a higher risk of fire propagation which means that in the designing phase it should be considered acutely.

3.5 Possible secondary explosions

In some cases, after a fire breaks out in a refinery plant, there will be a chance of an explosion in any adjacent part. Moreover, there might be a boiling liquid expanding vapor explosion (BLEVE) if a fire occurs in a confined reservoir. If it happens, fire will propagate instantly in a wide range area and make a major influence on the fire spread rate [21].

3.6 Shape, slope, and penetrance of the ground

This factor is taken into calculation when some flammable liquids have leaked on the ground. Occasionally in the plants, a dike system prevents the leakage flow to form a dangerous uncontrolled pool fire. But in some cases that the leakage happens without any precaution, mostly in transporting phase, the shape and slope of the ground and its porosity and permeability property influence the characteristics of fire.

3.7 Wind speed and direction

The performance of wind in severe fires is such that the higher wind velocity provides more oxygen for the fire and therefore the intensity of the fire increases. Perhaps, it won't be easy for firefighters if a fire breaks out on a windy day in a refinery plant. Besides, if the wind blows in a direction along with another adjacent flammable element, the distance between the flame and target combustibles decreases, and the heat flux rate will increase. This situation will be accompanied by increasing the fire severity because of wind velocity that makes it much more vulnerable to start burning. Another hazard of wind direction is a threat to firefighters. When they choose an area for settling their forces and facilities, usually they pick the upward side against the wind direction because of the lesser heat and smoke. In these circumstances, if the wind direction changes suddenly, it probably will harm firefighters or influence their operation efficiency.

3.8 Fire suppression efficiency

The last factor that should be taken into account in oil, gas, and petrochemical fires is the efficiency of fire suppression efforts. Occasionally, in addition to the fixed fire suppression facilities, all the big plants in the oil, gas, and petrochemical industries have a fire brigade unit that is ready to intervene in the case of fire. These precautions could control the fire completely or they could reduce its spread rate and severity.

4. Fire hazards in oil, gas, and petroleum industries

There are three different stages in the petroleum industry that have specific kinds of fire hazards. These stages include refining and processing, transportation, and during storage phase [22]. In the sequel, each phase will be discussed in more detail.

4.1 Phase one; refining and processing

At this phase, raw materials or crude oil after some engineering chemical process turn into useful products. Based on the different situations of any region, each plant has its properties, units, and design. Consequently, different fire threats and disasters could happen from one to another. The fire hazard could be appeared as large-scale fires, jet fires, pool fires, running liquid fires, and BLEVEs. Each one of these kinds of fire may break out at any part of the plant that involves the flammable materials separately. Fig. 7.3 shows a furnace of a petrochemical plant that provides the required amount of heat for the fluid in the process equipment.

Figure 7.3 A petrochemical furnace to produce the required heat for the process.

4.2 Phase two; transportation

Transportation part may take place via pipelines, shipping, railroad, and tank trucks. In pipelines, reached from the liquid or gas properties, especially its flammability and pressure, there is a probability of happening large-scale fires, jet fires, pool fires, and running liquid fires. Other transporting systems have their fire hazard based on the volume of the cargo, state of materials (solid, liquid, or gas), degree of flammability, and whether the container is pressurized or not [23]. Pressurized containers are mostly used for gaseous materials transportation. In this case, the threat is gas leaking and explosion. If the materials are in a liquid state, the risk of leakage and pool fire or running liquid will be expected. For solid flammables, large-scale fire is the most predicted hazard that could happen. In some cases when pressurized reservoirs are transported, an external accident involving heat or a hit could lead to BLEVE which amplitude the fire rapidly.

4.3 Phase three; storage

One of the challenging stages in the oil, gas, and petrochemical industries is the storage phase. Most of the disasters in this industry happen in storage fields. Fire could happen in a huge reservoir tank sometimes with an explosion. There will be a risk of massive leakages, large-scale fires, and pool fires. The common characteristic of storage tank fires is that they could last as days and the fire might propagate in a wide area. Moreover, solid flammables are inclined to make big fires. Storage tanks are made with a safety mechanism that is implemented in their roof. Accordingly, different kinds of storage tanks can be found in the storage fields including fixed roof and floating roof tanks, and spherical and cylindrical tanks [24]. Moreover, floating roof tanks are subdivided into internal and external floating roof ones. An external floating roof tank is shown in Fig. 7.4.

Figure 7.4 An external floating roof tank.

5. Different fire types

In oil, gas, and chemical sites numerous varied equipment and parts such as storage tanks and reservoirs, pipelines, furnaces, drums, process equipment, and other hazardous parts can be found every single part has its hazards and could make a unique kind of fire based on its properties and flammable fuel inside. Because of the major difference between fire types and their specific suppression procedure, given that each type of fire has its specific appearance and consequences, the recognition and suppression method should be considered before the fire occurrence. So, it is necessary to review fire types that could occur in stated industries. They are explained as follows:

5.1 Large-scale fire

It refers to a fire of solid or liquid flammables with a large amount of combustible material reachable by the fire. In this kind of fire, commonly, the propagation among the combustibles takes place rapidly and the amount of produced heat and smoke is considerable. Because of the high energy release rate, the risk of transporting fire to adjacent facilities is high. Moreover, if the fire breakouts from a tank or container, the risk of reservoir structure failure must be inspected.

5.2 Pool fire

Pool fires occur in case of liquid flammable leakage on the ground or water and an ignition happens accidently. This kind of fire is accompanied by a turbulent high-rise flame with low initial momentum which is recognizable easily from different kinds of fire. In pool fires, flame height is a related variable to the heat release rate of pool fire and environmental parameters [25]. A regular type of pool fire that happens in the petroleum industry is when the liquid spills in a dike and forms a dike fire. Another important pool fire in this industry is the storage tank. Pool fires flame is disastrous to adjacent facilities and personnel due to its massive heat and energy. Fig. 7.5 provides an example of a pool fire in an immense storage tank that is producing extensive amounts of heat and smoke.

5.3 Jet fire

Jet fire could be defined as a turbulent pressurized and a constantly continuous jet of liquid flammable leaks from a source

Figure 7.5 A large-scale tank pool fire.

such as a pipe or a reservoir accompanied by the combustion of fuel with a very hot flame that emits massive heat flux. Because of their impingement, they could originate disastrous damages if they hit any adjacent structure [1].

5.4 Running liquid fire

This kind of fire happens in liquid flammables when there is a leak of materials on the steeped ground and combustion starts during the movement of the materials. This situation forms a running flame that amplifies because moving speed plays a wind speed role in this case. The challenge of this kind of fire is when fire moves toward another flammable material or facility. Moreover, it could be harmful to the natural environment and vegetation [26].

5.5 BLEVE and fireball

BLEVE stands for "Boiling Liquid Expanding Vapor Explosion." This phenomenon occurs when an external fire increases vapor pressure resulting from the boiling of liquid in a closed and pressurized tank which finally leads to the rupture of the vessel by an explosion. When the tank contains materials that are kept at a temperature higher than the critical point in atmospheric pressure, if it is exposed to heat or the liquid inside the tank starts to boil in any way, boiling liquid increases vapor pressure at the gaseous portion of the tank. The rupture of the tank structure will happen if the pressure gets higher than the structure strength which has become weaker by the heat. After the explosion, a large volume of burning flammable materials is tossed into the air and sometimes they form a fireball phenomenon [27].

6. Fire protection in oil, gas, and petrochemical industries

Fire prevention depends on several measures including an engineered design accompanied by the use of proper construction quality and materials and the assurance of fire precaution efforts that are implemented accurately. An appropriate fire detection system would notify firefighters or activates fire suppression systems to control and put out fires at the initial stage which prevents fire propagation and further losses. Because disastrous fire events are unpredictable in results and consequences, there are always scenarios of failure of fire suppression systems or incapacity of controlling the fire. Thereupon, the existence of a well-trained fire brigade with proper fire trucks and portable fire suppression facilities assures the potential of fire propagation risk control.

Generally, in any kind of industrial fire-prone site, safety regulations, fire control, emergency preparedness, and evacuation plans are necessary [28]. Fire protection in petroleum industries could be done in two separate approaches. The first one namely active fire protection refers to those actions and preparedness to suppress a fire when breaks out. It contains the number and quality of fire trucks, their facilities, and well-trained firefighters to deal with any possible fire. Moreover, fixed automatic or semiautomatic fire suppression systems prepared in any hazardous part of the plant that need to be activated to control the fire are subdivided in this category. On the other hand, passive fire protection consists of any inherent, engineered or procedural safety effort to prevent a fire take place and future spread at the initial stage that perform their function without any actuation mechanism.

6.1 Fixed fire protection systems

Fixed fire protection systems could operate completely intellectually without human intervention namely automatic fire suppression or they could be designed in a way that human assistance would be necessary to activate and control the system to suppress the fire. Any kind of those has its pros and cons and usually in a high-risk region such as refinery plants they are provided and installed together to maximize their effectiveness. Both automatic and semiautomatic systems are using one of the recognized fire suppression materials including water, foam, dry and wet chemical powders, and gas agents [29]. Some of the well-known different kinds of fixed fire suppression systems that are commonly used in oil, gas, and petrochemical industries are listed below:

- Foam chamber system
- Water curtain system
- Firewater spray ring cooling system
- Foam deluge systems
- Ordinary water sprinklers
- Water mist system
- Gas and clean agent fire suppression systems
- Fixed ground and mounted monitors
- Dry chemicals fire suppression system
- Hose reels and standpipes

Fig. 7.6 is an example of a storage tank that is equipped with a water spray ring system for exterior wall cooling that can be seen

Figure 7.6 A storage tank equipped with water cooling and foam chamber systems.

under the highest level of the wall all around the tank. Moreover, a foam chamber system is installed to provide the required extinguishing foam in case of a fire at the top of the roof right beside the ladder.

6.2 Fire brigade unit in oil, gas, and petrochemical industries

Fire brigade unit is essential in oil and petrochemical plants because of the probability of fixed fire suppression systems or incapability of controlling the fire. Mostly there exists a fire station in the plant area with proper allocation. Based on the plant properties and special fire-related threats and existing combustible materials, specific equipment and training must be provided and necessary fire trucks are prepared.

The basic approach to putting out flammable liquids is preventing oxygen to reach the fire. Given that considerable heat is emitted, attention should be paid to the heat transfer in the lower parts of the flame. In most tank fires, we will face a tank without a roof. The floating roof of the tank has been immersed or its fixed roof has been destroyed due to the explosion. The mixture of combustible vapor and air could burn easily. The overall procedure to suppress a tank fire is as follows:

6.2.1 Tank wall cooling operation

Every storage tank should be equipped with a water spray ring system to reduce the temperature of the tank wall in fire events. This system automatically actuates and cools the tank structure to prevent its failure due to the accumulative temperature. But sometimes this system breaks out as collateral damage of the initial fire and possible explosion. Moreover, there is a possibility of inadequate water spray capacitance or lack of water available in the system. In that case, firefighters spray water over the tank wall using several firefighting monitors. In Fig. 7.7, an ongoing wall cooling operation is being undergone to prevent wall rupture in a storage tank filled with fuel oil in a petrochemical plant. As can be seen, because of the initial explosion, the tank's roof is tossed away and all of the fixed fire protection systems are destroyed.

In this operation, it should be noticed that water must not be sprayed into the tank because it makes the fire more severe than it is. Moreover, water should be sprayed at the top of the wall where its behind is empty because the flammable liquid inside the tank works as a heat conductor and prevents early rupture.

Figure 7.7 Tank wall cooling operation.

But the empty part of the tank has no reinforcement material behind the wall and the rupture in this part will cause a spill of flammables to the ground. During this operation, concurrent cooling of adjacent tanks that are susceptible to heat should be considered.

6.2.2 Unloading tank contents if possible

Emptying the tank from its liquid content using an outlet pipe system will reduce the time of firefighting operation and the risk of fire propagation. So, in most cases, if that is possible, the best strategy is to empty the tank and avoid the fire to reach combustible materials.

6.2.3 Suppression of propagated fire to adjacent combustibles

The other important issue that should be addressed is other propagated fires that spread to adjacent combustibles due to the main fire heat emission. If they are neglected, it will lead to multiple large-scale fires that are hard to control. Therefore, concurrent with the suppression of the main fire, other ignitions should be suppressed at the beginning. If there is a leak of liquid flammables that forms a grounded pool fire, using aqueous film-forming foam (AFFF) is the best choice [29]. In case of a jet fire, the foam doesn't have the proper application and using dry chemicals or water spray with fixing the leak is recommended.

6.2.4 Suppression of the tank pool fire

The main fire of tank storage appears as an enormous severe pool fire by a turbulent upward flame accompanied by a massive amount of smoke and hot gases. Because of the fuel complexities and specific environmental situations, suppressing an oil tank fire is challenging [30]. The proper action to put out the fire, concurrent with unloading tank contents, is attacking the fire using firefighting monitors and adding a massive amount of foam on the surface of the liquid inside to prevent oxygen from reaching the fire. Moreover, the foam layer in contact with the hot surface can perform a cooling mechanism [31]. Fig. 7.8 is another picture of the same fire event which showed formerly in Fig. 7.7. At this phase, the next level of operation to suppress the fire is being applied by firefighters namely foam operation. At this phase, the flow rate of the foam stream and time are important factors because if the flow rate is lower than the required rate and the

Figure 7.8 Storage tank fire operation using foam to suppress the fire.

foam is spilled slowly, the enormous heat of the fire would destroy foam bubbles and prevents a complete foam layer formation.

7. Conclusion

Based on particular characteristics of fire events in oil, gas, and petrochemical sites, it should be accepted that fire could propagate quickly with severe consequences and it is hard to be controlled. To prevent and protect from these fires, their devastating power including the fire-type event that could take place at any part of the site, their severity, and potential to release heat and energy, fire outcomes and their effects on adjacent equipment should be assessed. Hence, a proper fire risk assessment for each part of the site is necessary. Moreover, being familiar with fixed fire protection systems is essential for those who are in charge of this kind of fire crisis. In addition, improper firefighting strategy will lead to devastating fire spread and secondary explosions. So, adequate implementation of fixed fire suppression systems along with a proper firefighting plan with sufficient knowledge of fuel type and its combustion qualities could effectively control the fire before the fire turns into an out-of-control event. Hereupon, it is strongly advised to use both adequate fixed fire protection systems with an updated fire brigade service simultaneously in petroleum industries.

References

[1] Casal J, Gómez-Mares M, Muñoz Messineo M, Palacios A. Jet fires: a "minor" fire hazard?, vol 26; 2012. https://doi.org/10.3303/CET1226003.
[2] Liu X, Zhang Q, Xu X. Petrochemical plant multi-objective and multi-stage fire emergency management technology system based on the fire risk prediction. Procedia Engineering 2013;62:1104–11. https://doi.org/10.1016/j.proeng.2013.08.167.
[3] Yazdi M, Adesina K, Korhan O, Nikfar F. Learning from fire accident at Bouali Sina petrochemical complex plant. Journal of Failure Analysis and Prevention 2019;19:1–20. https://doi.org/10.1007/s11668-019-00769-w.
[4] Dehkordi M, Behnam B, Pirbalouti R. Probabilistic fire risk analysis of process pipelines. Journal of Loss Prevention in the Process Industries 2022; 80:104907. https://doi.org/10.1016/j.jlp.2022.104907.
[5] Tiwari A, Choukse R. Fire & explosion prevention strategy in refineries. International Journal of Engineering Research and Technology 2015;4.
[6] Muckett M, Furness A. Safety policy. Introduction to fire safety management. 2020. p. 45–51. https://doi.org/10.4324/9780080551791-9/SAFETY-POLICY-MARTIN-MUCKETT-ANDREW-FURNESS.
[7] Muckett M, Furness A. Introduction to fire safety management. 2007. https://doi.org/10.4324/9780080551791.

[8] Rubtsov N. The modes of gaseous combustion. 2015. https://doi.org/10.1007/978-3-319-25933-8.
[9] Herrmann H, Bucksch H. Combustible material. 2014. https://doi.org/10.1007/978-3-642-41714-6_33361.
[10] Dehli M, Doering E, Schedwill H. Combustion 2022:465–96. https://doi.org/10.1007/978-3-658-38910-9_11.
[11] Lautenberger C, Torero J, Fernandez-Pello C. 1 - Understanding materials flammability. In: Apte transport and mining VBBT-FT of MU in C. Woodhead Publishing; 2006. p. 1–21. https://doi.org/10.1533/9781845691042.1.
[12] Horrocks AR, Price D, editors. Advances in fire retardant materials. 1st ed. Cambridge, England: Woodhead Publishing; 2008.
[13] Fox M. Flammable solids and division 4.1. 1999. p. 99–103. https://doi.org/10.1007/978-3-662-11890-0_34.
[14] 1910.106 - Flammable liquids. | Occupational Safety and Health Administration. n.d. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.106. [Accessed 16 September 2022].
[15] Addai DE. Investigation of explosion characteristics of multiphase fuel mixtures with air. University of Magdeburg; 2010. https://doi.org/10.13140/RG.2.2.32190.89923.
[16] (CCPS) C for CPS. Guidelines for fire protection in chemical, petrochemical, and hydrocarbon processing facilities. Wiley-AIChE; 2010.
[17] Lee SW, Davidson RA. Physics-based simulation model of post-earthquake fire spread. Journal of Earthquake Engineering 2010;14:670–87. https://doi.org/10.1080/13632460903336928.
[18] Lee SW, Davidson RA. Application of a physics-based simulation model to examine post-earthquake fire spread. Journal of Earthquake Engineering 2010;14:688–705. https://doi.org/10.1080/13632460903336936.
[19] Wang Y, Chen Y, Zhao H, Xiong Y. Study on the influence of barriers in the diffusion process of liquid hydrogen leakage. IOP Conference Series: Earth and Environmental Science 2020;546:42048. https://doi.org/10.1088/1755-1315/546/4/042048.
[20] Wang X, Fan Y, Zhou K, Yu Y. Multi-layer cylindrical flame model for predicting radiant heat flux from pool fire. Procedia Engineering 2018;211:768–77. https://doi.org/10.1016/j.proeng.2017.12.074.
[21] Pike H. Learning from the experience. Methods in chemical process safety. vol 1; 2017. p. 37–86. https://doi.org/10.1016/bs.mcps.2017.02.002.
[22] Abbasi T, Tauseef SM, Ramesh S, Abbasi SA. Types of accidents occurring in chemical process industries and approaches to their modeling. International Journal of Engineering, Science and Mathematics 2017;6:424–55.
[23] Park Y, Hwang M, Lee H, Lee S, Lee C. A study on the fire hazard of transportation oil. Journal of the Korean Society of Safety 2014;29:114–20. https://doi.org/10.14346/JKOSOS.2014.29.3.114.
[24] Reza M, Tabari R, Sabzalipour S, Peyghambarzadeh SM, Jalilzadeh R. Dispersion of volatile organic compounds in the vicinity of petroleum products storage tanks. Environmental Engineering and Management Journal 2021;20:1119–36. https://doi.org/10.30638/eemj.2021.104.
[25] Miao Z, Wenhua S, Ji W, Zhen C. Accident consequence simulation analysis of pool fire in fire dike. Procedia Engineering 2014;84:565–77. https://doi.org/10.1016/j.proeng.2014.10.469.
[26] Mealy C, Benfer M, Gottuk D. Liquid fuel spill fire dynamics. Fire Technology 2014;50. https://doi.org/10.1007/s10694-012-0281-x.

[27] Wang Y, Li J, Hao H. A state-of-the-art review of experimental and numerical studies on BLEVE overpressure prediction. Journal of Loss Prevention in the Process Industries 2022;80:104920. https://doi.org/10.1016/j.jlp.2022.104920.
[28] Sakib N, Islam M, Uddin M. Various risks and safety analysis to reduce fire in oil refinery plant. IOP Conference Series: Materials Science and Engineering 2021;1078:12028. https://doi.org/10.1088/1757-899X/1078/1/012028.
[29] Shafiq I, Hussain M, Shafique S, Hamayun MH, Mudassir M, Nawaz Z, et al. A comprehensive numerical design of firefighting systems for onshore petroleum installations. Korean Journal of Chemical Engineering 2021;38:1768–80. https://doi.org/10.1007/s11814-021-0820-6.
[30] Zhao H, Liu J. The feasibility study of extinguishing oil tank fire by using compressed air foam system. Procedia Engineering 2016;135:61–6. https://doi.org/10.1016/j.proeng.2016.01.080.
[31] Conroy M, Ananth R. Surface cooling mechanism of fire suppression by aqueous foam. 2013. p. 39012.

8

Explosion in oil, gas, and petrochemical industries

Behnam Mohamadzadeh and Babak Omidvar
Graduate Faculty of Environment, University of Tehran, Tehran, Iran

1. Introduction

The possibility of any technical malfunction leading to an explosible cloud that forms a hazardous atmosphere is the most challenging threat in the oil, gas, and petroleum industries. Because of the abundance of reactive compounds in this industry, the risk of explosion is extremely high. Typically, in the chemical process industries, an accidental explosion can lead to a series of secondary disastrous events and cascading effects would happen. Because of the massive released energy through an explosion, in most situations, other adjacent structures will be destroyed or become a new source of hazard. There are so many recorded accidents in the history of petroleum industries that have led to severe explosions. In some cases, a primary explosion breaks out secondary fires and explosions. Moreover, mechanical damages to the source vessel and other structures are noticeable. One of the biggest disasters in petroleum industries occurred on March 23, 2005 in the Texas refinery where massive amounts of flammable vapor cause a powerful explosion. Due to this incident, 15 people were killed and approximately 180 injured. The economic losses were estimated more than 1.5 billion [1]. The explosion in the Punto Fijo[1] refinery on August 25, 2012 is another incident where more than 50 people were killed and over 100 were injured [2]. Another example is the explosion at Pembroke Refinery on June 2, 2011 in the United Kingdom due to a tank explosion with serious casualties and economic losses [3]. Given that, there are too many incidents in the chemical process industries, a more detailed analysis of explosion risk

[1]Capital city of Carirubana, Venezuela.

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00007-4

and its prevention and protection approaches should be considered for any hazardous area in the discussed industries.

2. Explosion theory

An explosion is defined as a sudden high-energy release when a chemical reaction of a combustible material happens quickly in the presence of oxygen and is usually accompanied by gases [4]. A certain amount of flammable vapor should be mixed with air to form an explosive atmosphere. In the case of a rich or poor mixture, because of upper and lower explosive limits, the explosion could not happen until the concentration level reaches between these limits.

Explosive limits define as the proportion of flammable gas in air which will burn if an initial ignition happens and is influenced by gas temperature, pressure, and environmental situations [5]. There is an upper explosive limit (UEL) or lower explosive limit (LEL) which mostly are stated as percent by volume of flammable in the air. When the percentage of fuel—air mixture is between LEL and UEL, the risk of explosion is high. But, below the LEL which is called poor mixture, the mixture doesn't have enough potential to burn and an explosion will not happen even if an ignition happens. On the contrary, in the case of a rich mixture whose portion of the fuel is way higher than air, the mixture isn't capable of explosion. In this situation, the risk of lowering fuel concentration and explosion should be considered.

The major difference between fire and explosion is the energy release rate. When the chain reactions of combustion occur, because of the rapid reaction's progress, the whole combustible material burns in a split second, and all of the energy that is supposed to emit during the burning process will release suddenly. Same as the fire triangle, there is a pentagon for the explosion. Its sides consist of fuel, ignition, oxidant, confinement, and mixing [6]. Fig. 8.1 shows five elements of the explosion pentagon.

2.1 Explosive divisions

Typically, different articles and substances (including mixtures and solutions) which can cause an explosion are assigned to different divisions based on their sensitivity and explosion hazard as follow [7]:

- **Division 1:** Explosive materials and substances with mass explosion hazard which produce severe shock waves and major projection effect.

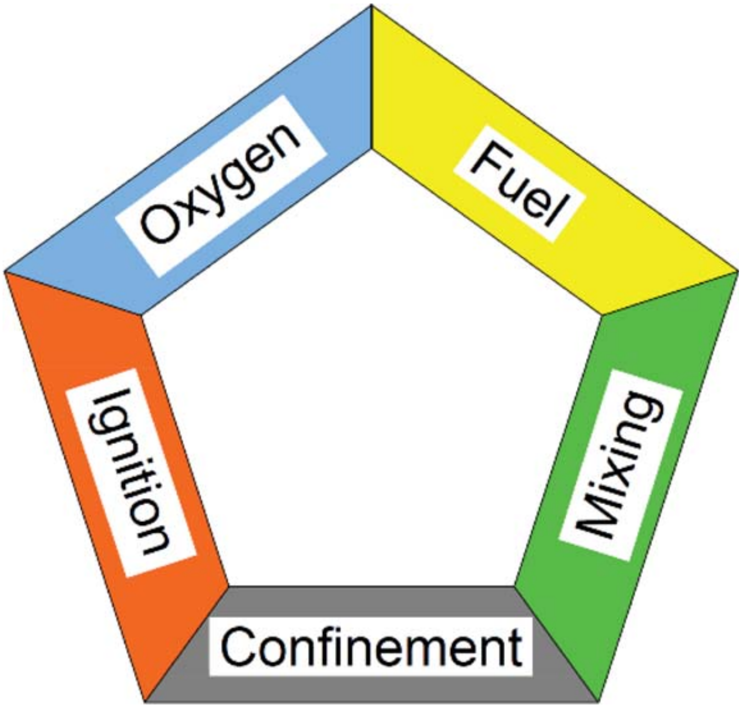


Figure 8.1 Explosion pentagon elements.

- **Division 2:** Materials that have an explosion hazard are fewer than division 1 but still are dangerous with a projection hazard.
- **Division 3:** Materials that have a fire hazard with a possibility of an explosion with a minor shock wave or projection effect.
- **Division 4:** Materials with a low hazard of explosion.
- **Division 5:** Very insensitive materials which provide a mass explosion hazard.
- **Division 6:** Extremely insensitive materials which do not provide mass explosion hazard.

Moreover, flammable and pressurized non-flammable gases under particular circumstances can be categorized as explosive.

2.2 TNT equivalent

A widely used method for describing explosion energy is the TNT (trinitrotoluene) equivalent. This method describes the amount of released energy during an explosion which is called the heat of explosion. Some factors are considered for assessing an explosion's severity including heat of the explosion, applied force to adjacent equipment, and damage severity to the other structures. The heat of explosion denoted by Q_{expl} represents the quantity of heat released from the decomposition of an energetic compound during the explosion process [8]. This parameter is one of the most important interpreters of explosion properties which is measured as a portion of its energy content at 298.15°K [9–11] and defines the amount of released energy from the explosion [10]. In this convention, released energy from an explosion of 1000 kg TNT which equals 4.184 GJ is held as a unit to depict the strength of explosions. In addition, more detailed properties of detonations can be calculated using existing softwares including the Keshavarz method, EXPLO-5, EXTEC, and LOTUSES [12].

2.3 Explosion types

The chain reactions might be a result of combustion, decomposition, or rapid exothermic reactions. This kind of explosion which happens due to the initial ignition in an explosive or flammable air mixture is categorized as a chemical explosion. There is another kind of explosion based on the detonation mechanism which is called a physical explosion [13]. This type of explosion occurs when the pressure of a confined gas raises more than the maximum bearing of the container. The other occurrence mechanism is the sudden phase change of a substance to a gaseous state due to excessive heat [14]. An overview of different kinds of explosions and their categorization is shown in Fig. 8.2.

As seen in Fig. 8.1, a physical explosion caused by a vessel rupture could lead to a boiling liquid expanding vapor explosion (BLEVE). Moreover, a rapid phase transition of a liquefied gas

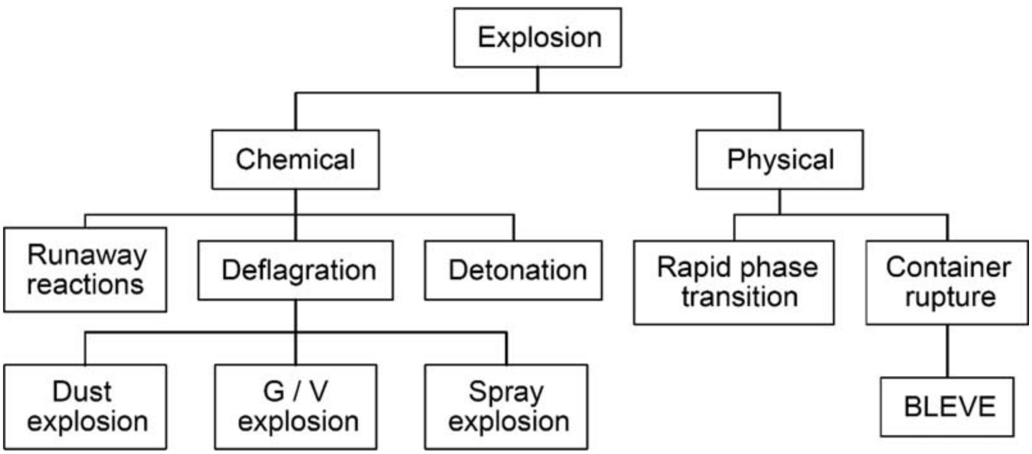


Figure 8.2 Relation between explosion types.

can occur as a physical explosion. On the other hand, chemical explosions are categorized into three different kinds, namely deflagration, detonation, and runaway reactions. In the following, each type is defined briefly.

2.3.1 Detonation

Detonation is defined as a super-fast chemical reaction propagation in an energetic material accompanied by an ultrasonic shock wave through the material without heat wave propagation [15]. This kind of explosion stands as the most destructive one. Its major mechanism of destruction is the shock wave which moves with more than sonic speed and can reach 3000 m/s in hydrocarbon–air mixtures. In this condition, the peak pressure of the shock wave can reach 20 bar which is destructive to any adjacent property. For a constant energy release of an explosion in an open area, the distance between the explosion source and affected property has a meaningful impact on damage severity. Accordingly, less distance results in more severe damage to the property. Detonation in oil, gas, and petrochemical industries mostly happens in pipelines when a flammable gas–air mixture detonates directly via a strong initial ignition. It could occur when a deflagration changes to detonation due to a rapid acceleration of the flame front.

2.3.2 Deflagration

An explosion in a flammable cloud of gas or vapor and air mixture is called deflagration when the combustion happens at the subsonic speed [16]. Accordingly, for a hydrocarbon fuel–air mixture, the speed of flame propagation can reach 300 m/s with pressure up to 10 bar [17]. In oil, gas, and petrochemical industries if deflagration happens in a long pipe, it could transit to a detonation under specific conditions. In the transition of deflagration to detonation, flame propagation speed rises quickly greater than supersonic speed because of the accelerating effect. Different kinds of deflagration are stated below:

2.3.2.1 Gas/vapor explosion

A vapor consists of two or more substance states mostly liquid and gaseous phases, while gas is made from a single thermodynamic state in which its particles can move freely in any direction and has unlimited expansion capability at room temperature [18]. When a flammable gas or vapor mixes with a certain amount of air and forms an explosible gas–air mixture between the lower and upper explosion limits, in case of an initial ignition, flammable gas will burn suddenly as an explosion. In this case, explosion characteristics depend on the explosibility of the cloud and the confinement situation of the space. There are three kinds of environments in that an explosion can take place in:

- **Confined space**

  A confined space is defined as a fully closed obstacle that can bear partial high pressure [19]. In this kind of environment, a high amount of gas can be pressurized and stored such as pressurized gas containers. When a pressurized gas in a confined space is exploded, because of the rupture in the container's wall, a sudden extensive release of energy will happen. This type of explosion can result from either combustible or non-combustible gases. Because of the physical nature of confined explosions, the most challenging problem is the blast wave which appears as a supersonic wave expanding from the explosion source. It is the major mechanism of the blast responsible for losses. If the exploded gas—air mixture is flammable, it will burn during the explosion and a heat wave propagated around the expansion source spherically. In case of toxicity, a lethal poisonous effect would be accompanied by other consequences. This kind of explosion is the most destructive mechanism that is used for intentional explosions. A confined explosion in an oil, gas, or petrochemical plant can occur in any pressurized part such as reservoirs, tanks, pipes, and process equipment [19].

- **Semi-confined space**

  A semi-confined explosion would appear in an area that is confined but the walls don't have much potential to bear high amounts of pressure. The brightest example of a semi-confined space is a regular building or a room with closed doors and windows. Fig. 8.3 shows an explosion in the stairs of a building which leads to a bending in the windows frame. When a combustible gas is propagated in a room, gas pressure cannot rise upper than the resistance of the window glasses, and seams of doors and windows work as pressure relief paths. Nevertheless, gas still could be concentrated in a confined space which is empowered to make a destructive explosion. The consequences depend on flammability, the concentration of the gas cloud, and the geometries of the enclosure [19,20]. An explosion will occur when the condition of the gas—air mixture is within a specific concentration between the LEL and UEL of the mixture.

- **Unconfined space**

  Generally, an unconfined space is assigned to an open area outside of buildings and equipment. In an unconfined space, the expansion capacity of gas is infinite and the pressure equals

Figure 8.3 A semi-confined explosion due to natural gas leakage in a building.

the atmospheric amount. When a flammable gas accidently leaks into the air, it will form a combustible cloud that could be exploded if the LEL and UEL range is met and an initial ignition happens. This type of blast is called an unconfined explosion and sometimes is accompanied by open flame propagation and heat waves [21]. Based on the leaked material characteristics and climate conditions, leaked gas will concentrate on the ground if the gas is heavier than the air and the wind speed doesn't be enough to deconcentrate the mixture to less than the LEL level.

2.3.2.2 Dust explosion

Explosive dust is defined as the dust of solid particles that can explode when its cloud mixture with air or other oxidizing concentration is in a particular range, regardless of the size and geometries of the combustible particle [22]. Hence, a dust explosion will happen if a combustible dust—air cloud over the LEL and UEL range is subjected to a proper source of ignition which leads to rapid flame propagation accompanied by the increase of temperature and pressure in the surrounding environment. Mostly, in the petrochemical industries, a dust cloud is produced from an accumulated source of dust. Hereupon, due to the primary explosion of the dust cloud, the produced wave can cause more dust to suspend in the air which forms a more amount of explosive dust—air mixture. This new flammable cloud in the presence of the heat of primary explosion as its required initial ignition will explode if the concentration reaches its proper range. This phenomenon is called a secondary dust explosion.

2.3.2.3 Spray explosion

Microscopic droplets of a combustible liquid could be burnt easier than their bulk because of their higher surface in comparison to a liquid state in a constant volume. When a liquid material is changed to a spray by forcing the pressurized liquid through a tiny nozzle, its volume is divided into numerous microscopic droplets. A flammable cloud of spray is explosible based on the droplet's size and other deflagration conditions. When the diameter of droplets is below 10 μm, the spray cloud acts like a vapor—air mixture, but bigger droplets up to 100 μm have the potential to form an explosive spray cloud which has a particular flame propagation mechanism [14]. In this case, when a droplet ignites, the released heat is emitted to the adjacent droplets and makes them ignite. Eventually, the flame is propagated to the whole droplets in the cloud via a cascading effect.

2.3.3 Runaway reactions

In a chemical system when an exothermic chain reaction happens in certain conditions with accelerating velocity of propagation up to an explosion wave it is called a runaway reaction. This phenomenon is accompanied by a rapid increment in temperature and pressure in the surrounding environment which appears as a deflagration.

2.3.4 Container rupture

A pressurized liquid or gaseous substance which is stored in a confined space such as a reservoir can be exploded if the container wall is ruptured in a way. The rupture could be a result of excessive pressure increment of contained gas due to an external source of heat such as an open flame or it can occur because of an external collision or metal fatigue in the walls of the container. Eventually, a rupture in a pressurized container can lead to a devastating explosion namely BLEVE which is an abbreviation for "Boiling Liquid Expanding Vapor Explosion." This phenomenon which is categorized as a physical explosion is described as follows.

2.3.4.1 BLEVE

When a container that has been filled with a liquid is implemented to excessive heat such as an external open flame and the liquid temperature goes up to a boiling point, vapourization would happen. In this situation, pressured gas should be evacuated via the safety valve, but when the pressure goes up to the vessel bearing limit, a rupture in the wall leads to a sudden hot and pressurized gas evacuation that releases an extensive amount of vapor into the air. This phenomenon produces violent liquid impingement accompanied by a pressure wave at the same time that can lead to missile production. Moreover, aging, metal fatigue, corrosion, or missile from an exploded adjacent tank can make the container weaker and prone to failure [23]. If the liquid is flammable, the explosion will occur with burning liquid propagation to the air called a fireball. In addition, the superheat limit theory will exaggerate the explosion. Superheat limit is assigned to a pressurized liquid as the maximum temperature that the liquid can reach before the transition to a gaseous phase. There are two approaches for determining the superheat limit of a given liquid. The first approach is in constant pressure when the temperature rises to the threshold value equal to the minimum amount of temperature that the liquid tends to be nucleated. The second one is at a constant temperature when the pressure of contained liquefied gas drops suddenly [24]. Both these ways lead to an extreme expansion of the system's volume in a few milliseconds. BLEVEs can be subdivided into hot and cold ones. A hot BLEVE occurs when the liquid reaches its superheat limit while a cold one takes place before the liquid's superheat limit and occurs in a weaker container and naturally has a mild consequence than a hot BLEVE [25].

2.3.5 Rapid phase transition

In the oil, gas, and petrochemical industries, this type of explosion might happen in liquefied natural gas equipment. Rapid phase transition or RPT is defined as a sudden phase change of a liquid into a gaseous state which appears as an explosion. In this kind of explosion, the chemical reactions do not occur in terms of combustion but a massive amount of heat will be released in a fraction of a second that can cause serious damage [26].

2.4 Effects of explosion

An explosion can cause several consequences. There are six different effects explained as follows. It should be noted that an explosion could have one or more of these effects and no explosion needs to have them all at once.

2.4.1 Mechanical shock wave

This outcome that is called blast wave has a mechanical mechanism of destruction that applies an impact force to any affected mass. This wave that moves outward through an open environment produces a peak pressure at the front line which decreases along its path.

The consequences of this mechanism are related to both explosion characteristics and impacted property. A more severe explosion will provide more power to the shock wave. Moreover, properties of the impacted equipment or building including its geometries, distance to the explosion source, and degree of vulnerability are accounted as key factors for the effect of the mechanical shock wave.

2.4.2 Thermal effect

Because of local heat released due to chemical reactions of an explosion in the core, a thermal effect appears as heat radiation that can propagate around the explosion source, making a sudden increase in temperature that leads to possible secondary fires and injuries.

2.4.3 Generation of missile

When an explosion occurs in a confined space, part of the energy results in cracking the confinement into smaller fragments that are tossed into the environment and thrown forcibly along with the blast wave. These projectiles are called missiles and can cause serious damage to even far away structures [27]. This effect takes place in oil, gas, and petrochemical industries when a BLEVE happens. Missiles might be generated from external objects that are moved by the shock wave namely secondary fragments. In addition, because of the high temperature of the fragments, those missiles can cause secondary fires when colliding with flammable targets.

2.4.4 Fireball

A fireball can be a result of a BLEVE or ignition of a flammable cloud. When the initial ignition happens the flammable fuel—air mixture will burn and in specific conditions including buoyancy and initial momentum of explosion a fireball is formed. The size of the fireball may vary depending on the amount of air entering and the heat release rate.

2.4.5 Ground shock

This effect can be seen only when a powerful explosion happens near the surface of the earth which causes ground shaking and leads to damage to structures.

2.4.6 Crater

A severe explosion near the ground surface can cause a crater. The size and geometries of the crater depend on several factors such as the explosion type and severity, explosive material, ground stiffness and properties, and position of the charge.

3. Explosion hazards

Because of numerous flammable substances in the oil, gas, and petrochemical industries that can make explosible clouds or appears as pressurized gases at the process stages, an explosion hazard is a possible event that may occur at any time in the process facilities or storage fields. Moreover, a primary explosion can lead to other secondary explosions which extend the damage to massive destruction in the site, and cascading effect would be expected. The explosion is predictable in pressured units of the process area and pipelines. Moreover, any leakage can form a flammable cloud in the case of an ignition source such as a hot surface which can lead to an explosion and secondary events. Given that, the term risk is defined as the likelihood of a particular damage resulting from a specific threat, there are four different categories of risk in oil refinery plants as follows [28–30]:

3.1 Electrical risk

The risk of facing electrical faults such as short circuits, networks, or high voltage in oil, gas, and petrochemical plants is so high because of the presence of numerous different electromechanical equipment. Hereupon, international electrotechnical commission (IEC) has developed a classification of hazardous areas for both explosive gas and dust atmospheres. In this regard, areas with the potential of flammable gas cloud formation are considered hazardous areas which are classified as follows [7,31]:

I. **Zone 0:** This zone is defined as an area in which an explosive gas cloud is expected to happen continuously or for long period or frequently.

II. **Zone 1:** This zone is defined as an area in which an explosive gas cloud is expected to happen occasionally in normal operation.

III. **Zone2:** This zone is defined as an area in which the possibility of the explosive gas cloud formation is low, but if happens it won't last for a long period.

IV. **The extent of the zone:** This zone is defined as the distance from the leakage source and the gas concentration in this length is lower than the LEL after the release happened.

V. **Zone NE:** This zone is defined as the negligible hazard area in which if an ignition happens, the consequences would be negligible.

Moreover, areas that have a potential for explosive dust atmosphere and combustible dust layers formation are classified as follows:

I. **Zone 20:** A hazardous atmosphere of combustible dust with a low possibility of dust layer formation which is continuous or is available for a long period or frequently in the air.

II. **Zone 21:** A hazardous atmosphere of combustible dust mostly accompanied by a dust layer which is likely to occur in normal operation but not frequently and in a limited short period in the air.

III. **Zone 22:** A hazardous atmosphere of combustible dust with dust layer formation in the air which is not likely to occur in normal operation and if happens, it will appear for a short period.

Moreover, IEC 60079-0[2] has provided an electrical equipment classification for use in explosible environments namely equipment protection level (EPL) for both explosive gas and dust atmosphere including

I. **EPL Ga or Da:**
"Very high" protected devices for use in explosible environments without any ignition during a normal operation where there is a low chance of electrical fault or malfunction occurrence. In this regard, Ga devices are designed to use in zone 0 and Da devices are suitable for zone 20 hazardous areas.

II. **EPL Gb or Db:**
"High" protected devices for use in explosible environments without any ignition during a normal operation where there is a normal chance of electrical fault or malfunction occurrence. These devices are designed to use in zone 1 and zone 21, respectively.

III. **EPL Gc or Dc:**
"Extended" protection level for devices that are designed to use in explosible environments without any ignition during normal operation and some additional passive and active explosion protection systems are implemented to ensure that no ignition will happen in case of regular faults or malfunctions. So, Gc and Dc devices are suitable to use in zone 2 and zone 22, respectively.

In the noted divisions, letter G is referred to explosive gases and letter D is referred to explosive dust clouds [7,31]. In other words, they represent the specific zone class of explosive cloud that is propagated in the hazardous area.

3.2 Mechanical risk

One of the most common types of failure in process facilities is leakage in the walls and joints of the equipment. This fault happens due to excessive stresses or metal fatigue or an external collision. Moreover, malfunction of gaskets and other sealing devices occurs frequently which can lead to a hazardous explosive atmosphere. Moreover, direct stress of pressurized liquids or gasses inside process equipment can lead to an explosion.

[2]Explosive atmospheres—Part 0.

3.3 Civil risk

This type of risk is referred to as natural or manmade disasters which can lead to mechanical or electrical failures in the facilities. For instance, an earthquake can shake equipment in a process area violently that causes leakage in the joints or drifting equipment to fall which leads to an explosion. Moreover, they can cause unpredicted short circuits in hazardous areas. In general, any disaster including flooding, tornado, earthquake, and sabotage which tends to produce an excessive force on the process equipment can cause serious damages and explosions.

3.4 Chemical risk

Crude oil is the basic compound of the most flammable substances in the oil, gas, and petrochemical industries. Moreover, many reactive substances can be found as flammable or explosive solids, liquids, gases, vapors, spray, mists, dust, powder, and wet dust which have explosive characteristics under special conditions. Table 8.1 illustrates the most important reactive chemicals in the industry under discussion which are noted based on their physical state.

4. Explosion protection

In order to explosion protection in the oil, gas, and petrochemical industries four stages should be considered simultaneously. The order of these stages is shown in Fig. 8.4.

As can be concluded from Fig. 8.4, to achieve an acceptable level of risk of explosion, these four stages should be satisfied simultaneously in any high-risk portion of the plant. In the following, each of these stages in the petroleum industry will be covered separately.

4.1 Inherent safety

In general, inherent safety is related to the designing phase of a chemical processing unit. It means that the designer should plan the system in a such way that if an undesirable accident happens, the consequences will appear as minimal damages. For this purpose, the four following approaches should be considered in the designing procedure [38].

Table 8.1 Important reactive compounds and explosive chemicals in the oil, gas, and petrochemical industries [8,32–37].

Material state	Reactive compounds and explosive chemicals
Solid/Gelatin	Barium nitrate, Guanidine nitrate, Hexamine, Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine(HMX), Nitric acid, Octanitrocubane(ONC), Potassium chlorate, Potassium nitrate, Potassium nitrite, Potassium perchlorate, Research department explosive(RDX), Sodium azide, Sodium chlorate, Sodium nitrate, Sodium nitrite, Sodium perchlorate, TNT,[3] Urea, Calcium hypochlorite, Citric acid, Pentaerythritol, Sulfur
Liquid/Gas/Vapor/Spray/Mist/Aerosol	Methylbenzene, Toluene, Hydrogen, Propyl acetate, Acetic anhydride, Acetone, Calcium ammonium nitrate, Hydrogen peroxide, Nitromethane, Perchloric acid, Sulfuric acid, Heptane, Ethanol, Methanol, Ethylene glycol, Ethyl acetate, Glycerin, Hydrochloric acid, Mercury, Methyl ethyl ketone, 1,2-Dichloroethane, Acetaldehyde, Acetylene, Petrol fuels, Ammonium, Benzene, Methylbenzene, Cyclohexanone, Diesel fuels, Acetic acid, Ethane, Ethyl ethanoate, Ethyl chloride, Ethylene, Diethyl ether, Ethylene oxide, Fuel oil, i-Amyl acetate, Carbon monoxide, Methane, Methyl chloride, Ethoxyethane, Naphthalene, n-Butanol, n-Hexane, n-Propyl alcohol, Phenol, Propane, Carbon disulfide, Hydrogen sulfide
Dust or powder	**Powdered metals:** Aluminum, atomized and flake, fines (fewer than 75 μm), Magnesium (fewer than 75 μm), Aluminum-magnesium alloy, milled (fewer than 150 μm), Titanium (fewer than 105 μm), Zirconium (fewer than 50 μm), Iron, carbonyl 99% Fe (fewer than 54 μm), Tin, atomized (fewer than 54 μm), Niobium (fewer than 80 μm), Tantalum (fewer than 100 μm) **Plastic dust:** Acetal, linear (fewer than 75 μm), Methyl methacrylate polymer and copolymers (fewer than 75 μm), Acrylonitrile polymer and copolymers (fewer than 75 μm), Cellulose acetate (fewer than 75 μm), Nylon (fewer than 75 μm), Polycarbonate (fewer than 75 μm), Polyethylene (fewer than 75 μm), Polypropylene (fewer than 75 μm), Polyvinyl butyral (fewer than 75 μm), Polyester, dust from grinding and polish (fewer than 20 μm), Epoxy (fewer than 75 μm), Phenol furfural (fewer than 75 μm), Phenol formaldehyde (fewer than 75 μm), Polyurethane foam with isocyanate (fewer than 75 μm), Coumarone-indene (fewer than 75 μm), Cashew oil phenolic (fewer than 75 μm), Gum (fewer than 75 μm), Lignin hydrolyzed-wood-type (fewer than 75 μm), Rosin (fewer than 75 μm), Shellac (fewer than 75 μm), Lacquer, stripped from gas cylinders (fewer than 75 μm), Isophthalic acid (fewer than 75 μm), Salicylic acid (fewer than 75 μm), Terephthalic acid (fewer than 75 μm), Rubber dust, from grinding (fewer than 135 μm)

Continued

Table 8.1 Important reactive compounds and explosive chemicals in the oil, gas, and petrochemical industries [8,32–37].—*continued*

Material state	Reactive compounds and explosive chemicals
	Chemical dust:
	Toner dust (fewer than 75 μm), Benzoic acid (fewer than 75 μm), Stearic acid (fewer than 75 μm), Methionine (fewer than 20 μm), Dehydroacetic acid (fewer than 75 μm), Diphenyl (fewer than 75 μm), Isatoic anhydride (fewer than 75 μm), Sorbic acid (fewer than 75 μm), Aspirin (fewer than 75 μm), Methylcellulose (fewer than 75 μm), Ethyl cellulose (fewer than 75 μm), Dimethyl terephthalate (fewer than 32 μm), Ferrocene (fewer than 125 μm), Naphthalene (fewer than 500 μm), Naphthalic acid anhydride (fewer than 63 μm), 2_Naphthol (fewer than 71 μm), Pentaerythrite (fewer than 500 μm), Lead stearate (fewer than 75 μm), Calcium stearate (fewer than 500 μm), Zinc stearate (fewer than 75 μm)
	Carbonaceous dust:
	Charcoal, hardwood mixture (fewer than 75 μm), Gilsonite (fewer than 75 μm), Pitch, coal tar and petroleum (fewer than 75 μm), Asphalt, brown petroleum resin (fewer than 75 μm)
Wet dust	Following compounds in the dust state will form an explosive atmosphere because of hydrogen released if they are dispersed in the air and react with moisture or water.
	Alkali metal and alkali metal alloys (Lithium, Sodium, Potassium, Rubidium, Cesium, Francium), Aluminum carbide, Aluminum ferrosilicon powder, Aluminum hydride, Uncoated aluminum powder, Aluminum smelting products, Barium, Cesium, Calcium, Calcium carbide, Calcium cyanamide, Calcium phosphide, Cerium, Chlorosilanes, Some cosmetic dust, Ferrosilicon, Magnesium powder, Phosphorous pentasulfide, Potassium phosphide, Stannic phosphides, Titanium powder, Zinc, Zirconium

[3] 2,4,6-trinitrotoluene.

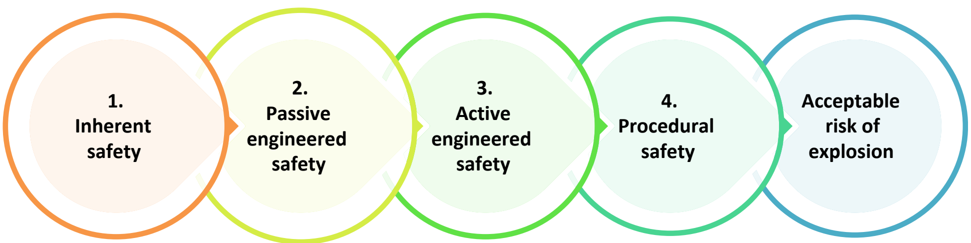


Figure 8.4 Hierarchy of explosion protection factors.

4.1.1 Minimization

To fulfill this approach which schematically is shown in Fig. 8.5, the amount of hazardous material should be eliminated or decreased in required equipment through the processing operation. Thereupon, in case of an accident, consequences will be lesser due to less amount of combustible materials.

4.1.2 Substitution

For this purpose, the designing approach should be relayed on the substitution of explosives or high flammables with less hazardous materials to reach the same goal in the processing procedure. This principle is shown in Fig. 8.6.

4.1.3 Moderation

In the moderation approach which is shown in Fig. 8.7, the same hazardous material is used in a less severe physical environmental condition. Especially, less pressure and less required temperature lead to more safe operational conditions.

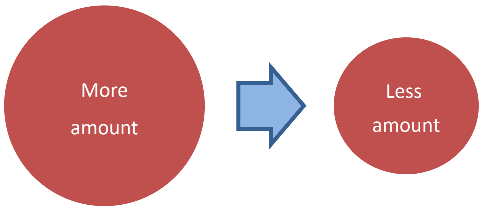


Figure 8.5 Minimization of hazardous material in the processing facilities.

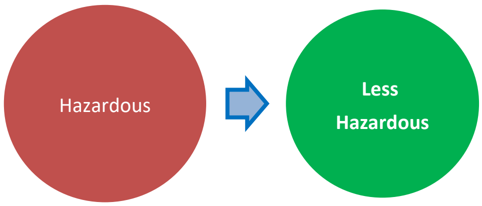


Figure 8.6 Substitution of hazardous material in the processing facilities.

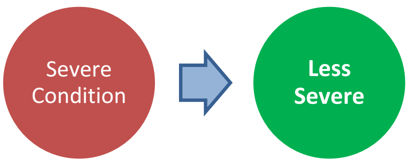


Figure 8.7 Moderation of hazardous material in the processing facilities.

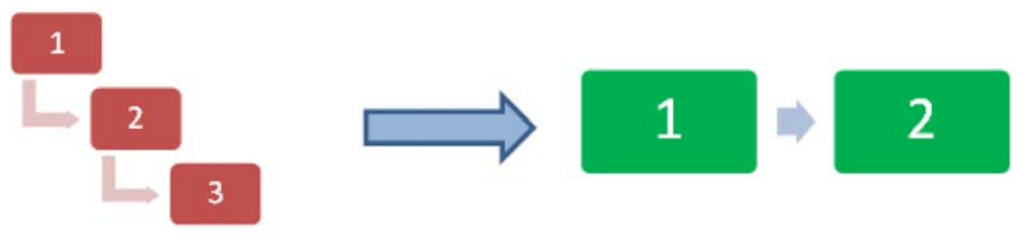


Figure 8.8 Simplification of the procedure in the processing unit.

4.1.4 Simplification

As a principle in design which is shown in Fig. 8.8, avoidance of complexities is a key factor to avoid unpredicted error. In this regard, it should be held as an approach in designing procedures that more simple process facilities lead to a safer conditions.

4.2 Passive engineered safety

A passive safety element is addressed as a fixed not active part of the equipment that adds a safety characteristic to the host facility. The nature of this type of protection is that safety elements don't need to be activated and have no function except the one during the explosion which is activated by the hazard occurring mechanism and not by a third-party device [39]. Hereupon, fewer complexities due to the elimination of redundant equipment lead to fewer possible faults and errors which makes them more reliable in case of an explosion. Some important passive explosion protection systems are described as follows [32]:

4.2.1 Explosion relief panel

To reduce the shock wave, the most important passive safety element is the explosion relief panel [40]. This element works as a portion of the wall of pressurized containers which have less pressure bearing than the original wall structure. Thus, in case of excessive pressure increment, the explosion will happen when the pressure reaches the bearing limit of the weaker part (relief panel). This mechanism prevents a more powerful explosion due to the rupture of the tough wall.

4.2.2 Deflagration relief vent equipped by flame arrestor

When the explosion takes place in the shape of deflagration, there will be a front flame plus the shock wave. In this case, if a panel has been installed, the explosion pressure would be released but the flame be extracted and a possible type of fire such as a fireball will be formed. For this reason, for confined deflagration hazards, it will be suited if the vessel has equipped with a flame arrestor just in along with the relief vent to stop the flame outflow.

4.2.3 Flow-actuated flap valve

This type of passive protection consists of a flap valve installed over the upstream section of the container which is equipped with a deflagration relief vent to stop the flame outflow from the inlet pathway in case of a deflagration.

4.2.4 Flow actuated float valve

This valve acts as a barrier in the outlets and exhaust system to conduct explosion pressure to the relief vent in the vessel. These valves could be closed very quickly due to the sudden pressure increase in case of deflagration.

4.2.5 Flame front diverter

This device consists of a relief panel in a housing downstream pathway with a significant direction change in the stream pathway just after the panel. In this order, if an explosion happens, the produced pressure accompanied by the front flame will be extracted from the relief panel.

4.2.6 Rotary valve

A specific type of rotary valve that acts as an air block assembly is installed over the outlet pathway of the vessel which allows a defined amount of flow to exit but will act as a flame barrier in case of an explosion.

4.2.7 Static discharge controlling

In order to control the static discharge, two different conductive objects are connected via a proper connector to make them at the same electrical potential due to spark prevention. This method is called bonding. Another discharge control is grounding. In grounding, every conductive part is connected to the ground via proper connectors, thus, their electrical potential is equal to zero.

4.2.8 Barrier wall

Another passive safety element against explosion is a barrier wall. This kind of wall must have considerable toughness and robustness to bear the shock wave of a possible explosion and protect adjacent properties from damage. Moreover, assigning proper distance to the explosion source can protect and reduce damages to an acceptable risk level.

4.3 Active engineered safety

This term is referred to those active protection systems which prevent explosion occurrence or limit its consequences by using an active mechanism that influences the explosion hazard directly right at the time of occurrence or just before the explosion. These systems are subdivided into detection and suppression systems. In this regard, active systems need to be activated automatically or manually and are responsible for a complex multi-level tasks. Because of those complexities, these systems aren't reliable as the passive ones described before. Some of the most important parts in active engineered safety systems against explosion are listed below [32,41]:

4.3.1 The hazardous atmosphere detection system

There are different detection systems including conventional and addressable fire alarm systems, air sampling systems, and portable gas detectors. The main element of all the noted systems is the gas sensor which is subdivided into four kinds including electromechanical, catalytic, infrared, and photoionized sensors. Moreover, there are specific sensors for different flammable atmospheres. When a suitable detector is installed in a space, in case of hazardous atmosphere occurrence, after a predefined concentration, the device will detect the hazard and send a signal to the warning and suppression systems.

4.3.2 Spark detection and extinguishing system

In this system, optical sensors are used to detect produced sparks mostly in a combustible dust flow. After the detection, a signal is sent to the suppression unit which regularly relays on water. Water is sprayed over the sparks to extinguish them using a cooling operation. Moreover, in the case of water-reactive dust, water should not be used and other suppression agents such as carbon dioxide must be taken in place.

4.3.3 Chemical deflagration barrier system

This system is based on a chemical agent stopping the chemical reaction during deflagration. For this purpose, a pressurized cylinder that contains a proper chemical agent to the combustible compound is installed near the hazardous zone, and the suppressing agent can reach the vessel via high-pressure heat resistance pipes and nozzles. Moreover, an actuating system is embedded which can act automatically by the heat, pressure, or via the detection system. In these kinds of systems, moreover, other suppressing agents including inert gases or carbon dioxide could be implemented.

4.3.4 Fast-acting gate valves and pinch valves

The difference between fast-acting gate/pinch valves with other kinds of valves explained in the previous section is that these kinds of valves have an active actuation mechanism which is actuated by a detection system and the valve itself drives using a pneumatic device or a rapid gas generation system. These kinds of valves are mounted over the ducts to prevent flame propagation.

4.3.5 Explosion suppression HRD canisters

HDR stands for high rate discharge. An HRD system is a package of other explosion protection systems that work as a united system to provide maximum protection against the explosion. This system is a modern explosion protection system consisting of a very sensitive detection unit and a protected area equipped with passive and active suppression and controlling devices. This package is mounted over the vessel and the explosion frame and pressure be conducted to the provided space in the HRD system to be taken care of.

4.3.6 The high-speed abort gate system

This kind of device is equipped with a diversion gate which changes the flow path to a safe place. High-speed abort gates are actuated by a spark detection system and provide extra safety by eliminating the fuel from the hazardous atmosphere. It should be noted that these systems are not suited for controlling an explosion because they are not fast enough to act before the shock wave. For this reason, high-speed abort gates should be used only on the upstream pathways.

4.4 Procedural safety

This approach to explosion safety can be counted on as the least effective method in comparison with the other three former described ones but it is an applicable way considering the cost–benefit principle. Procedural safety has consisted of [4,32]:

I. Safe work standard procedures
II. Job safety analysis worksheet
III. Standard operation plans (SOPs) for emergencies
IV. Safe work practices and training
V. Hot work permits in hazardous zones
VI. Other dangerous work permits in explosible atmospheres
VII. Explosive dust cleaning standard procedures in process units
VIII. Personnel training to eliminate error and ignition sources in hazardous zones
IX. Scheduled inspection and servicing of equipment with predictable faults and errors in hazardous zones.

5. Conclusion

Since that, use of flammable and explosive materials is inevitable in the oil, gas, and petrochemical industries, the risk of explosion is assessed as high in four divisions including electrical, mechanical, chemical, and civil risks. Hence, knowing different material and their explosive characteristics is deemed essential. Moreover, explosion effects and possible damages should be considered for the processing plants and storage fields. To reduce the risk of explosion, four approaches including inherent safety, active protection, passive protection, and procedural safety measures should be implemented simultaneously. In this regard, for constructing a new plant, considering the inherent safety measures which decrease the risk of explosion in a reliable way with the minimum cost is highly recommended. On the other hand, to protect the existing plants and industrial sites, the use of passive and active devices along with implementing the updated procedural rules would be effective.

References

[1] Abbasi S, Khourdustan P, Sayyadi R, Jalilpour S, Shamseddin S. BP Texas refinery incident causes: a literature review. International Journal of Occupational Hygiene 2022;12:256–70.
[2] Sajid Z, Khan M, Rahnama A, Moghaddam F, Vardhan K, Kalani R. Computational Fluid Dynamics (CFD) modeling and analysis of

hydrocarbon vapor cloud explosions (VCEs) in Amuay refinery and Jaipur plant using FLACS. Processes 2021;9:960. https://doi.org/10.3390/pr9060960.
[3] Mamon P. Refinery explosion analysis - Chevron Pembroke Amine regeneration unit explosion. 2020.
[4] Tiwari A, Choukse R. Fire & explosion prevention strategy in refineries. International Journal of Engineering Research and Technology 2015;4.
[5] Ma Q, Guo Y, Zhong M, You J, He Y, Chen J, et al. Theoretical prediction model of the explosion limits for multi-component gases (multiple combustible gases mixed with inert gases) under different temperatures. Fire 2022;5:143. https://doi.org/10.3390/fire5050143.
[6] Crowl D. Fundamentals of fires and explosions. 2010. p. 9–112. https://doi.org/10.1002/9780470925287.ch2.
[7] Bozek A. Application of IEC 60079-10-1 edition 2.0 for hazardous area classification. IEEE Transactions on Industry Applications 2017:1. https://doi.org/10.1109/TIA.2017.2785258.
[8] Keshavarz MH, Klapötke TM. Energetic compounds. De Gruyter; n.d. https://doi.org/10.1515/9783110521863.
[9] Sikder AK, Maddala G, Agrawal JP, Singh H. Important aspects of behaviour of organic energetic compounds: a review. Journal of Hazardous Materials 2001;84:1–26.
[10] Keshavarz MH, Klapötke TM. The properties of energetic materials. The Properties of Energetic Materials de Gruyter 2021.
[11] Sikder AK, Sikder N. A review of advanced high performance, insensitive and thermally stable energetic materials emerging for military and space applications. Journal of Hazardous Materials 2004;112:1–15. https://doi.org/10.1016/j.jhazmat.2004.04.003.
[12] Balachandar KG, Thangamani A. Design of new energetic materials based on derivatives of 1,3,5-trinitrobenzenes: a theoretical and computational prediction of detonation properties, blast impulse and combustion parameters. Heliyon 2020;6:e03163. https://doi.org/10.1016/j.heliyon.2020.e03163.
[13] CCPS. Fire and explosion hazards. 2022. p. 53–83. https://doi.org/10.1002/9781119831075.ch4.
[14] Addai DE. Investigation of explosion characteristics of multiphase fuel mixtures with air. University of Magdeburg; 2010. https://doi.org/10.13140/RG.2.2.32190.89923.
[15] Klapötke TM. Chemistry of high-energy materials. De Gruyter; n.d. https://doi.org/10.1515/9783110536515.
[16] Foust H. Deflagration 2021:301–31. https://doi.org/10.1007/978-3-030-87387-5_12.
[17] Ogle RA. Chapter 3 - Thermodynamics of dust combustion. In: Ogle RABT-DED. Butterworth-Heinemann; 2017. p. 53–100. https://doi.org/10.1016/B978-0-12-803771-3.00003-X.
[18] Zabetakis MG. Flammability characteristics of combustible gases and vapors. U.S. Department of the Interior, Bureau of Mines; 1965.
[19] Feldgun V, Edri I, Karinski Y, Yankelevsky D. Some characteristics of confined and partially confined explosions. 2013.
[20] Karinski Y, Feldgun V, Tzemakh D, Yankelevsky D. Openings' shape and location effects on the pressure field in a partially confined explosion. Applied Mechanics and Materials 2011;82. https://doi.org/10.4028/www.scientific.net/AMM.82.509.
[21] Brunoro Ahumada C, Papadakis-Wood F-I, Krishnan P, Yuan S, Quddus N, Mannan MS, et al. Comparison of explosion models for detonation onset

estimation in large-scale unconfined vapor clouds. Journal of Loss Prevention in the Process Industries 2020;66:104165. https://doi.org/10.1016/j.jlp.2020.104165.
[22] Association NFP. NFPA 654: Standard for the prevention of fire and dust explosions from the manufacturing, processing, and handling of combustible particulate solids. National Fire Protection Association; 2005.
[23] Hurley MJ, Gottuk D, Hall Jr JR, Harada K, Kuligowski E, Puchovsky M, et al. SFPE handbook of fire protection engineering. 5th ed. 2016. https://doi.org/10.1007/978-1-4939-2565-0.
[24] Abbasi T, Abbasi SA. The boiling liquid expanding vapour explosion (BLEVE): mechanism, consequence assessment, management. Journal of Hazardous Materials 2007;141:489–519. https://doi.org/10.1016/j.jhazmat.2006.09.056.
[25] Shaluf I. An overview on BLEVE. Disaster Prevention and Management 2007;16:740–54. https://doi.org/10.1108/09653560710837037.
[26] Ustolin F, Odsæter L, Reigstad G, Skarsvåg H, Paltrinieri N. Theories and mechanism of rapid phase transition. Chemical Engineering Transactions 2020;82:253–8. https://doi.org/10.3303/CET2082043.
[27] Hauptmanns U. A procedure for analyzing the flight of missiles from explosions of cylindrical vessels. Journal of Loss Prevention in the Process Industries 2001;14:395–402. https://doi.org/10.1016/S0950-4230(01)00011-0.
[28] Li S, Wu X. A functional safety assessment methodology for explosion protection with application to a variable frequency drive system. Energies 2021;14:7872. https://doi.org/10.3390/en14237872.
[29] Wu D. Progress of hybrid mixture explosions: from safety characteristics, explosion criteria to explosion regimes. 2022. https://doi.org/10.13140/RG.2.2.22562.09929.
[30] Palymskiy I, Fomin P, Latifi A. On convection stability of hydrocarbon-oxygen gas mixture and explosion safety 2020. https://doi.org/10.31618/ESU.2413-9335.2020.6.71.
[31] Popa C, Păun F, Gabor D. Aspects regarding the explosion risk assessment of installations in atmospheres with combustible dust. MATEC Web of Conferences 2022;354:10. https://doi.org/10.1051/matecconf/202235400010.
[32] OSHA Technical Manual (OTM) – Notice: Section IV, Chapter 6, Combustible Dust – ADDITION | Occupational Safety and Health Administration; n.d. https://www.osha.gov/enforcement/directives/ted-01-00-015-7. [Accessed 14 November 2022].
[33] Ortega Montoya CY, Ávila Galarza A, Briones Gallardo R, Razo Soto I, Medina Cerda R. Differences in the risk profiles and risk perception of flammable liquid hazards in San Luis Potosi, Mexico. Case Studies in Fire Safety 2014;2:37–44. https://doi.org/10.1016/j.csfs.2014.10.002.
[34] Eckhoff RK. Dust explosions in the process industries: identification, assessment and control of dust hazards. 3rd ed. 2003. p. 1–719.
[35] Bilal T, Malik HK, Rashid S. Nature sucks up explosives. 2022. p. 351–68. https://doi.org/10.1016/B978-0-323-89874-4.00015-7.
[36] Cooper PW. Explosives engineering. VCH; 1996.
[37] Teipel U. Energetic materials: particle processing and characterization. John Wiley & Sons; 2006.
[38] Safety C. The Concept of inherent safety. 2010. p. 9–19. https://doi.org/10.1002/9780470925195.ch2.

[39] Land CM. Procedural, active, and passive safety. 2018. p. 7−16. https://doi.org/10.1002/9781118745427.ch2.
[40] Bakke J, Skogrand P. Explosion relief panels and their effect on gas explosion overpressure. 2004. https://doi.org/10.1115/OMAE2004-51005.
[41] Szkudlarek Z, Janas S. Active protection of work area against explosion of dust−gas mixture. International Journal of Coal Science & Technology 2021; 8. https://doi.org/10.1007/s40789-020-00387-0.

9

Release of toxic substances in disasters of oil, gas, and petrochemical units

Mohammad R. Alrbaihat
Ministry of Education, Dubai, United Arab Emirates

1. Introduction

Toxic materials released from oil, gas, and petrochemical units, agrochemical pollution, asbestos dust, and aerosolized radionuclides might not be hazards that immediately come to mind when considering the types of damage associated with a natural disaster [1,2]. When hazardous materials are released during extreme natural events (such as volcanic eruptions, earthquakes, landslides, hurricanes, tornadoes, and blizzards), humans are at an increased risk of being exposed to hazardous materials or secondary hazards like fires or explosions that are caused by the ignition of flammable materials [3].

Increased instances of community contamination by hazardous or toxic materials in recent decades are intrinsically linked to industrial disasters, careless corporate disposal of toxic wastes, and poorly planned home projects in hazardous environments. The total number of technical and natural catastrophes has climbed significantly from the 1990s to 2006, according to the 2007 World Disaster Report (International Federation of Red Cross and Red Crescent Societies, 2007). Communities' "toxic exposure" has been compared by Edelstein (1988) to a modern disease with long-lasting effects [4]. He created the phrase "contaminated community," which refers to any residential area or human settlement situated inside or close to the boundaries of exposure to a known environmental hazard [5].

The two main sources of community contamination are hazardous waste dumps and unintentional discharges of harmful chemical substances. According to the Agency for Toxic Substances and Disease Registry (ATSDR), the cost of just four

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00018-9

childhood health conditions—asthma, lead toxicity, cancer, and developmental disabilities—associated with hazardous chemical exposure in the community exceeds 54 billion dollars annually. The majority of toxic disasters have human or technical causes. A hazardous contamination event disturbs the natural balance as well as the social relationships. A toxic community generally developed as the dispute between the disaster's perpetrator and its victims grew more heated [6]. Toxic waste is sometimes referred to as the disease of the 20th and 21st centuries, which is a metaphor that fits the expanding number of damaged towns worldwide rather well.

This chapter aims to discuss systematic and industrial disasters that release hazardous and toxic wastes into the biophysical and built environments culminating in the contamination of communities and the subsequent adverse health consequences among the exposed populations and to discuss variables that could affect the disaster mitigation efforts of oil and gas projects.

2. Overview of oil and gas disasters

The global economy's development depends largely on the oil and gas industry [7]. In contrast, petrochemicals are taken from the surface of the land and deep seawater through the use of oil and gas drilling activities [8]. For oil and gas drilling teams, this operation is significantly linked to risk factors that pose a life-threatening threat. Due to a lack of health and safety laws and prevention strategies, hundreds of accidents and fatalities have been reported at onshore and offshore drilling sites throughout the years [9,10]. However, only a small percentage of risk variables have been under control in recent years due to the unpredictable character of the drilling industry [11].

The oil and gas drilling and production industries account for hundreds of fatalities and tens of thousands of injuries each year [12]. Since many chemicals are unexpected and dangerous, there have been numerous reports of safety, environmental, and ergonomic risks worldwide [11,12]. While several fatalities and serious injuries have been reported during drilling and maintenance activities worldwide, both onshore and offshore. Large-scale deserters have occurred over a period of 17 years for a variety of reasons [13]. In Table 9.1, the number of fatalities and injuries among the drilling crew during the previous 18 years is highlighted along with an in-depth analysis of drilling and production disasters involving oil and gas. Table 9.1 [8,10,12–17] indicates that the majority of oil and gas release accidents and disasters

Table 9.1 An overview of disasters related to oil, gas, and petrochemical units [2–7].

Year	Country	Operator	Reason investigated
2002	Saudi Arabia	Saudi Aramco	Blowing up
2004	Egypt	Petrobel	Out of control
2005	Mumbai High, Indian Ocean	Oil and Natural Gas Corporation (ONGC)	An explosion of fire
2006	United States of America	Raleigh	Explosion
2007	Saudi Arabia	Saudi Aramco	Fire during pipeline maintenance
2009	Australian	Montara Production Platform	Blowout of the Montara oil well
2010	Russia	Gazprom	As a result of the fire, the helicopter crashed
2012	Nigerian Delta Region	Chevron	Explosion
2012	Malaysia	PETRONAS	Fire explosion
2012	Malaysia	PETRONAS	Fire explosion
2013	Saudi Arabia	Saudi Aramco	Sank maintenance platform
2014	Malaysia	Sapura Kencana	Dropped from eight
2015	Azerbaijan	SOCIAL	Fire explosion due to leakage
2016	Gulf of Mexico	Whistler Energy II LLC	Drop items
2017	Pakistan	Shell	Fire explosion
2018	Malaysia	PETRONAS	Drill engine fire explosion
2019	New Mexico, United States of America	Exxon Mobil(XOM.N)	A pump jack
2022	Alabama. United States of America	Southern Natural Gas	Pipeline accident

occur during drilling in Middle Eastern and Southeast Asian nations due to the diversity of the environment, a lack of effective resources for both drilling domains for accident prevention, and insufficient industrial safety and health protocols.

In the oil and gas sector, there have been numerous incidents that have resulted in numerous fatalities, substantial financial loss, and/or significant environmental damage [4]. Major factors that contribute to an accident's occurrence include things like natural causes, insufficient training, material, structural, and mechanical failures and malfunctions [5]. Employees can sustain injuries from falling objects, slips and falls, and chemical exposure [6–8].

Various oil, gas, and petrochemical disasters are illustrated in recent studies. In August 2009, the Montara production platform accident occurred in Australian waters without causing any fatalities. Due to the failure of concrete and cement at the Montara oil well, a major oil spill and fire occurred. There had been no installation of a blowout preventer. Abridged to the Montara platform by a bridge, the West Atlas drilling rig burned down completely and was demolished. As a result of the complicated arrangements between regional and national authorities, the Montara accident caused significant problems. Oil and gas offshore regulations in Australia were changed as a result of this accident [18].

Furthermore, there are multiple causes for significant incidents, some of which are latent, and each of which contributes to the sequence of incident escalation [19], hence, there main causes of oil and gas accidents, Failure of the control system, including a lack of effective control and maintenance issues with safety-sensitive equipment [20], Procedural failures [21], Human factors [22], Severe Weather [23], Mechanical failures [24], Escape, evacuation, and rescue failures [25], Design flaws [26], Ecotoxicity [27], Earthquake [28], Soil pollution [29], Social disruption [30], Chemical exposure [31].

3. Categorization of oil and gas hazards

Due to the intricate and potentially fatal operations and occurrences, oil and gas disasters are always seen to be among the most difficult and dangerous [11,16]. While both onshore and offshore oil and gas drilling operations have some potential risks [14,32]. As shown in Fig. 9.1, most of them can be divided into four main categories: physical, chemical, ergonomic, and environmental dangers.

(i) Physical hazards

One of the most prevalent and regular working risks in practically every industrial setting is common hazards. One of the most frequent hazard categories in onshore and offshore drilling operations for oil and gas exploration is safety hazards [33]. Additionally, the following risks were listed by safety and health specialists as being present during oil and gas drilling activities: slipping and falling, falling from a height, dropping an object, getting stuck by equipment, being electrocuted, and being in a confined space [33,34].

(ii) Chemical hazards

Many injuries and fatal burns are reported each year as a result of the improper handling of hazardous drilling fluids during the oil and gas drilling process [34]. A variety of drilling fluids and chemical-based muds must be handled by drilling crews

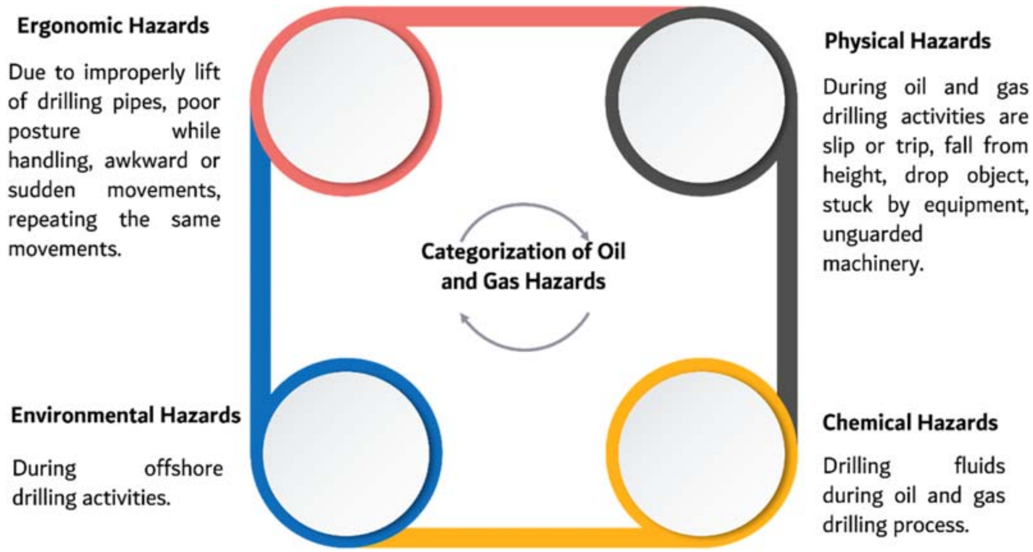


Figure 9.1 Oil and gas hazards categorization.

throughout the oil and gas exploration process, which translates into chemical dangers. Furthermore, chemical hazards are posed by the interaction of dangerous drilling fluids with natural radioactive materials (NORM), fires, and exposure to lethal gases such as hydrogen sulfide (H_2S) [15,35].

(iii) Ergonomic hazards

Inside petrochemical units, the oil and gas drilling process is strongly linked to ergonomic risks [15,36]. While most of the lifting and handling tasks are now carried out using sophisticated technology or cranes, the rate of ergonomic injuries is still rising as a result of poor handling and lifting techniques. While the inappropriate lifting of drilling pipes, poor handling posture, clumsy or abrupt motions, repetition of the same movements, and using excessive force during activities have all been linked to ergonomic hazards at onshore and offshore drilling sites [37].

(iv) Environmental hazards

One of the main issues facing the global upstream oil and gas sectors is environmental hazard [17]. However, compared to onshore drilling, the rate of accidents caused by environmental concerns was substantially reported. Additionally, during offshore drilling operations, these environmental dangers have impacted maritime and helicopter operations. A significant worry that might be exceedingly dangerous for the maritime environment and offshore environment is the frequent oil spills that occur during the drilling and production processes [38].

One of the main causes of water pollution, which results in severe environmental harm and economic devastation, is marine oil spills. They significantly reduce aquatic biodiversity by disrupting the biological balance of the seas and other bodies of water [39]. Numerous policy concerns surrounding the secure transportation of oil volumes are brought up by the potential of oil leaks. For the preservation of the marine environment and life, effective cleanup of these spills is a must. To reduce the negative effects on the environment and human health, onshore and offshore oil response measures must be implemented at the spill site together with continuous monitoring systems.

4. Release of toxic substances from oil and gas accidents

Toxic or hazardous material is dangerous to the environment or increases the risk of injury, death, or serious illness because of its chemical, physical, or infectious characteristics. The toxicity and concentration of a substance, as well as its quantity and concentration, all play a significant role in its danger [3].

During oil, gas, and petrochemical disasters, many types of toxic materials are released [40]. Sulfur Dioxide (SO_2), Hydrogen Sulfide (H_2S), and Ammonia (NH_3) are some of these substances [40]. However, H_2S is a health hazard and a corrosion catalyst. Sulfur is recovered from it and used to manufacture sulfuric acid, medicines, fertilizers, cosmetics, and rubber products. There is a major concern at this stage about the possibility of leaks that could negatively impact both humans and the environment. Besides causing leaks, leaks also cause pipelines to be taken out of service to be repaired. Many factors can cause leaks, such as earthquake-induced deformation, corrosion, wear and tear, material flaws, and even intentional damage [40].

A flammable, extremely toxic gas, hydrogen sulfide is colorless and lighter than air. It is soluble in water and is extremely toxic. At concentrations well below its very low exposure limit, it emits an odor that is similar to that of rotten eggs. Hydrogen sulfide causes irritation, dizziness, and headaches when exposed at low levels, depression, and eventually death when exposed at levels that exceed the prescribed limits [41]. H_2S also negatively impacts the ecological system in addition to harming human beings. As an example, H_2S in water may cause a change in PH value, resulting in ecological imbalances between microbes and aquatic species.

To manage and control toxic and hazardous wastes in an environment that protects both human health and the environment, it is crucial to identify and classify waste accurately. Hazardous waste has been categorized several times over the years. Toxic waste is typically a part of hazardous waste [42]. As a basic grouping method, wastes can be categorized according to their risk to humans and the environment. Thus, wastes are divided into three risk categories: high-, intermediate-, and low-risk; some examples are shown in Table 9.2.

Numerous studies have found that the drilling for and extraction of oil and gas expose workers to numerous harmful substances and environmental risks [49,50]. When an offshore facility or its people are attacked by fire or explosion, they can suffer immediate damage (oil rigs and installed equipment can be destroyed or damaged, while staff members may be injured or killed) [51]. Hydrocarbon releases can permanently damage the environment, including wildlife and people around the area that is directly affected by these oil and gas disasters [18,52]. According to this logic, the greatest risks include:

(i) Fires and explosions can result from hydrocarbon releases (gases or liquid drops dispersed in clouds can ignite when they contact the air).

(ii) Sea surface and underwater oil spills.

The oil and gas industry has experienced several accidents resulting in many deaths, property losses, and environmental damage [53]. Accidents can be caused by a variety of factors

Table 9.2 Risk categories of oil and gas toxic materials.

Risk categories	Properties	Examples	References
High	Extremely toxic, bio-accumulative, migratory, and harmful substances.	Solvents containing chlorides, persistent organic pollutants (POPs), wastes containing heavy metals including lead and cyanide, and wastes containing polychlorinated biphenyls (PCBs).	[43,44]
Intermediate	Wastes have poor mobility and are largely insoluble.	Sludges containing metal hydroxide.	[45–47]
Low	Wastes typically consist of large quantities of foul-smelling, harmless wastes.	Municipal solid wastes.	[48]

including defects in materials, structures, and mechanical parts, malfunctions, human errors, and natural disasters [54]. An injury to employees can result from an object being thrown at them, slipping and falling, or being exposed to chemicals [55].

There are three types of releases of hazardous materials from oil, gas, and petrochemical units through disasters:

1. An incidental release that can be dealt with using readily available and readily available items that are readily available, spill kits, or spill guns. At the job site, employees in the vicinity manage accidental discharges. The near surrounding is a visual field in which the employee is physically present.
2. Operations Level Releases are releases that need special personal protective equipment to clear up, specific materials or equipment, or spills that surpass the capacity of the department's cleaning employees. Employees in the vicinity can safely handle spills and releases at the operations level with the right PPE and training. These spills may be rather enormous, but they are not life-threatening, and they need to be contained with the use of specialized equipment that isn't often kept in the unit.
3. Dangerous Substances (Technician Level) Releases are accidents that demand a Disaster Response team to respond and use active control methods to prevent the leak of a dangerous substance. By caulking, patching, or otherwise fixing a leak, the team may be able to stop the flow of materials. Examples of emergency disaster team responses include a spilling oil tank and a polychlorinated biphenyl (PCB) oil line on electrical equipment.

5. Oil and gas disaster risk mitigation

There are several risks associated with oil and gas projects: massive capital investments, the involvement of numerous parties, complex technology, and significant environmental and social consequences [56]. The impacts of disasters can be minimized if a disaster management strategy is adopted. The possibility of disasters is unavoidable, and they can happen at any time. Disasters can be prevented by mitigating risks from the start. The assessment of disaster risk should be integrated with risk analysis [57].

The impacts of disasters can be minimized by implementing a strategy to deal with them. Disasters can occur at any time and cannot be prevented [58]. There is always the possibility of an uncertain, unexpected, and even undesirable event affecting the prospects of a particular investment [2]. In the oil and gas industry, there have always been social conflicts and casualties because of gas leaks [3]. Many parameters in the industrial system can contribute to the occurrence of risks and hazards in the oil and gas sector [4].

The disaster risk assessment must therefore incorporate any risk analysis. Project life cycles have inherent risks that must be identified to develop an effective framework for assessing risks. Additionally, constructors should give priority to the concept of sustainable development in their activities as a means of addressing social, environmental, and economic challenges in the construction sector [59].

To achieve sustainable development, the top oil and gas companies today are required to have implemented risk management and adhered to ISO 31000:2009 as a framework. A framework like this can be used to integrate various management processes, such as the management of health, safety, and environmental risks [60]. Even so, the continued actions continue to have harmful effects on the environment. Furthermore, modern international oil and gas corporations place a greater emphasis on preventive measures than coping mechanisms, indicating that sustainable development has not been fully integrated into risk management applications [31].

For construction projects, risks must be managed by the Sustainable Development Goals, which include goals aimed at improving sustainability and eradicating poverty. Efforts to reduce poverty must be combined with progressive economic growth so that all risks that could harm the economy can be managed. This includes risks related to disasters and vulnerabilities in the development plan [61].

It is imperative to understand risk management so that sustainable development goals can be achieved. Researchers have explored the issue using different approaches. As a result of the AHP (analytic hierarchy process) approach, researchers [27,62,63] developed the concept of risk management, which is a decision-support system that can be used to determine maintenance options for oil and gas pipelines so that the pipeline project can survive while taking into account the pipes' quality and the environment [63].

Several risk-reduction measures were adopted before risk mitigation in the oil, gas industry, and petrochemical units. Numerous studies cited disasters as having contributed to the prevention of releases. Many of these are recommended for use in the catastrophe mitigation process because they are accepted business practices. Fig. 9.2 illustrates these actions [64].

Additionally, it was noted that a significant proportion of incidents in the oil and gas sector are linked to movable structures. All of the events that have been looked into have served as stark reminders to the oil and gas sector that risk management and uncertainty reduction need to be continually improved if safe operations are to be ensured as well as the danger of accidents, significant accidents, and disasters is reduced. In the oil and gas business, however, proactive learning and the creation of a dynamic risk culture are required to supplement reactive learning following significant accidents and disasters [65].

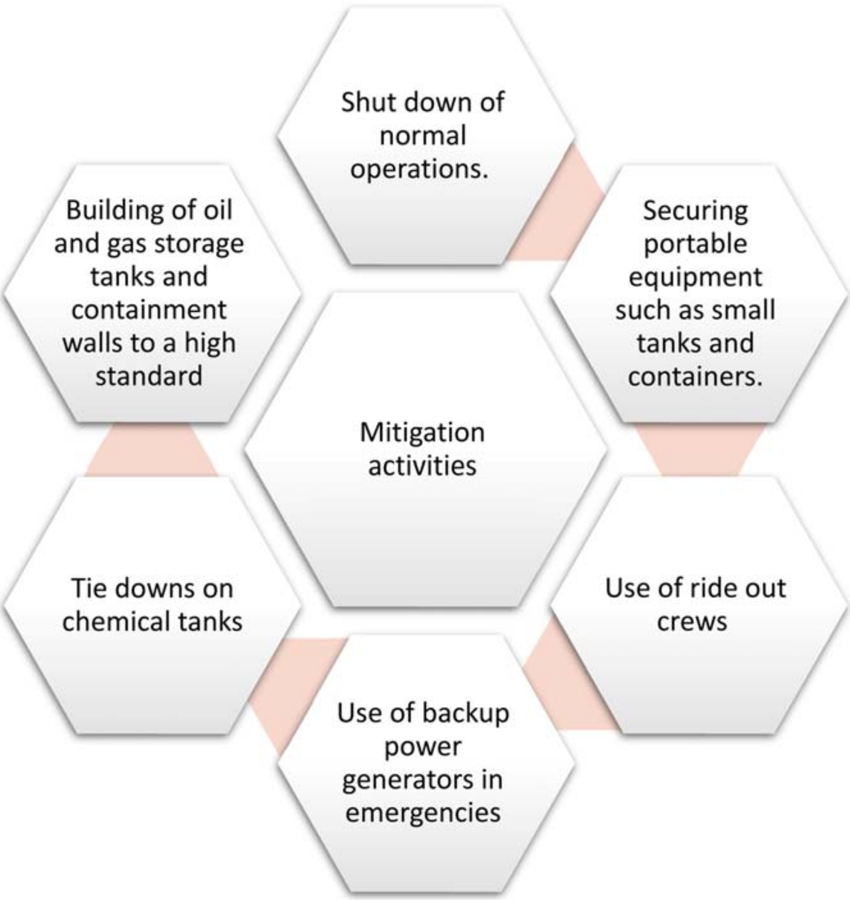


Figure 9.2 Mitigation activities during the oil and gas disasters.

6. Conclusions and future outlooks

Disasters at petrochemical, oil, and gas facilities are thought to be the leading cause of the release of harmful compounds into the environment. Furthermore, they are thought to be more dangerous than accidents in the construction sector and twice as risky as accidents in other sectors of the economy. According to the overall conclusion of this chapter, it has been specified that the categories of toxic materials released from the oil and gas industry have been divided into three levels: high-, intermediate-, and low-risk categories. Additionally, it has been revealed more than 12 main causes of oil and gas accidents as well as risk reduction techniques to lessen the toxicity of petrochemical materials released during oil and gas disasters.

Therefore, oil, gas, and petrochemical units and risk management teams must develop risk plans in the industrial areas for oil, gas, and petrochemical units to be aware of any types of risks and be aware of the nature of released materials to deal with them carefully and to reduce their potential risks.

We recommend conducting different research studies on the types of disasters and the nature of hazardous materials that could pose a real danger to humans and the environment, and research studies about environmentally friendly equipment that can be used to address risks.

References

[1] Lee C. Toxic waste and race in the United States. In: Race and the incidence of environmental hazards. Routledge; 2019, ISBN 0429303661. p. 10–27.

[2] Ilankoon I, Ghorbani Y, Chong MN, Herath G, Moyo T, Petersen J. E-waste in the international context—a review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Management 2018;82:258–75.

[3] Young S, Balluz L, Malilay J. Natural and technologic hazardous material releases during and after natural disasters: a review. Science of the Total Environment 2004;322:3–20.

[4] Edelstein MR. Contaminated communities: the social and psychological impacts of residential toxic exposure. Westview Press; 1988, ISBN 0813374472.

[5] Adeola FO. Hazardous wastes, industrial disasters, and environmental health risks: local and global environmental struggles. Springer; 2011, ISBN 0230339530.

[6] Willow AJ. The new politics of environmental degradation: un/expected landscapes of disempowerment and vulnerability. Journal of Political Ecology 2014;21:237–57.

[7] Hassan RB, Asad MM, Soomro QM, Sherwani F. Severity of the casing and cementing operation with associated potential hazards in the drilling

process in the on and offshore oil and gas industry: a cross-sectional investigation into safety management. Pertanika Journal of Social Sciences & Humanities 2017;25:129–38.
[8] Asad MM, Hassan RB, Soomro QM, Sherwani F. Development of KBES with hazard controlling factors and measures for contracting health and safety risk in oil and gas drilling process: a conceptual action plan. Social Sciences 2017;12:584–94.
[9] Asad MM, Hassan R, Latif K, Sherwani F. Identification of potential ergonomic risk factors and mitigating measures for Malaysian oil and gas drilling industries: a conceptual research proposition. In: Proceedings of the IOP conference series: materials science and engineering, vol 530. IOP Publishing; 2019. p. 12052.
[10] Ali D, Yusof Y, Adam A. Safety culture and issue in the Malaysian manufacturing sector. In: Proceedings of the MATEC web of conferences. vol 135. EDP Sciences; 2017. p. 31.
[11] Nolan DP. Handbook of fire and explosion protection engineering principles: for oil, gas, chemical and related facilities. William Andrew; 2014, ISBN 032331144X.
[12] Asad MM, Hassan RB, Sherwani F, Rind IA, Maiji Y. Development of a novel safety and health educational management information system (HAZ-PRO) for oil and gas production operation: a proposed framework. Journal of Engineering, Design and Technology 2020;18:959–71.
[13] Clarke S, Cooper C. Managing the risk of workplace stress: health and safety hazards. Routledge; 2004, ISBN 0203644360.
[14] Retzer KD, Ridl S, Hill RD. Oil and gas extraction worker fatalities, 2014 mid-year report: January 1, 2014–June 30, 2014. 2015.
[15] Esswein EJ, Alexander-Scott M, Snawder J, Breitenstein M. Measurement of area and personal breathing zone concentrations of diesel particulate matter (DPM) during oil and gas extraction operations, including hydraulic fracturing. Journal of Occupational and Environmental Hygiene 2018;15: 63–70.
[16] Bergh LIV, Hinna S, Leka S, Zwetsloot GIJM. Developing and testing an internal audit tool of the psychosocial work environment in the oil and gas industry. Safety Science 2016;88:232–41.
[17] Biezma MV, Andrés MA, Agudo D, Briz E. Most fatal oil & gas pipeline accidents through history: a lessons learned approach. Engineering Failure Analysis 2020;110:104446.
[18] Brkić D, Praks P. Probability analysis and prevention of offshore oil and gas accidents: fire as a cause and a consequence. Fire 2021;4:71.
[19] Landucci G, Argenti F, Spadoni G, Cozzani V. Domino effect frequency assessment: the role of safety barriers. Journal of Loss Prevention in the Process Industries 2016;44:706–17.
[20] Misuri A, Landucci G, Cozzani V. Assessment of safety barrier performance in the mitigation of domino scenarios caused by Natech events. Reliability Engineering & System Safety 2021;205:107278.
[21] Misuri A, Landucci G, Cozzani V. The role of safety barrier performance depletion in the escalation of Natech scenarios. Chemical Engineering Transactions 2022;90:181–6.
[22] Hosseinnia Davatgar B, Paltrinieri N, Bubbico R. Safety barrier management: risk-based approach for the oil and gas sector. Journal of Marine Science and Engineering 2021;9:722.

[23] Guo X, Zhang L, Liang W, Haugen S. Risk identification of third-party damage on oil and gas pipelines through the Bayesian network. Journal of Loss Prevention in the Process Industries 2018;54:163–78.
[24] Landucci G, Misuri A, Cozzani V. Mitigation of fire-induced domino scenarios. In: Dynamic risk assessment and management of domino effects and cascading events in the process industry. Elsevier; 2021. p. 271–91.
[25] Chen J, Zhang W, Wan Z, Li S, Huang T, Fei Y. Oil spills from global tankers: status review and future governance. Journal of Cleaner Production 2019; 227:20–32.
[26] Wanasinghe TR, Wroblewski L, Petersen BK, Gosine RG, James LA, De Silva O, et al. Digital twin for the oil and gas industry: overview, research trends, opportunities, and challenges. IEEE Access 2020;8:104175–97.
[27] Al-Khalil M, Assaf S, Al-Anazi F. Risk-based maintenance planning of cross-country pipelines. Journal of Performance of Constructed Facilities 2005;19: 124–31.
[28] Durst S, Bruns G, Henschel T. The management of knowledge risks: what do we really know?. In: Global business expansion: concepts, methodologies, tools, and applications. IGI Global; 2018. p. 258–69.
[29] El-Abbasy MS, Senouci A, Zayed T, Mirahadi F, Parvizsedghy L. Condition prediction models for oil and gas pipelines using regression analysis. Journal of Construction Engineering and Management 2014;140:4014013.
[30] Conner H. Managing environmental risk in the oil and gas industry. 2015.
[31] Bakhtiari S. Risk management: a powerful instrument for sustainable development. OIDA International Journal of Sustainable Development 2014; 7:95–104.
[32] Ridl S, Retzer KD, Hill RD. Oil and gas extraction worker fatalities 2014: NIOSH fatalities in oil and gas extraction (FOG) database. 2017.
[33] Asad MM, Hassan RB, Sherwani F, Soomro QM, Sohu S, Lakhiar MT. Oil and gas disasters and industrial hazards associated with drilling operation: an extensive literature review. In: Proceedings of the 2019 2nd international conference on computing, mathematics and engineering technologies (iCoMET). IEEE; 2019. p. 1–6.
[34] Benson C, Dimopoulos C, Argyropoulos CD, Mikellidou CV, Boustras G. Assessing the common occupational health hazards and their health risks among oil and gas workers. Safety Science 2021;140:105284.
[35] Wood MH, Fabbri L. Challenges and opportunities for assessing global progress in reducing chemical accident risks. Progress in Disaster Science 2019;4:100044.
[36] Bugarski AD, Cauda EG, Janisko SJ, Mischler SE, Noll JD. Diesel aerosols and gases in underground mines; guide to exposure assessment and control. 2011.
[37] Nandan A, Siddiqui NA, Kumar P. Assessment of environmental and ergonomic hazard associated to printing and photocopying: a review. Environmental Geochemistry and Health 2019;41:1187–211.
[38] Jung S, Woo J, Kang C. Analysis of severe industrial accidents caused by hazardous chemicals in South Korea from January 2008 to June 2018. Safety Science 2020;124:104580.
[39] Singh H, Bhardwaj N, Arya SK, Khatri M. Environmental impacts of oil spills and their remediation by magnetic nanomaterials. Environmental Nanotechnology, Monitoring & Management 2020;14:100305.
[40] reza Akhondi M, Talevski A, Carlsen S, Petersen S. Applications of wireless sensor networks in the oil, gas and resources industries. In: Proceedings of

the 2010 24th IEEE international conference on advanced information networking and applications. IEEE; 2010. p. 941–8.
[41] Reiffenstein RJ, Hulbert WC, Roth SH. Toxicology of hydrogen sulfide. Annual Review of Pharmacology and Toxicology 1992;32:109–34.
[42] LaGrega MD, Buckingham PL, Evans JC. Hazard waste management. 2nd ed. New York: McGraw-Hall. Inc.; 2001.
[43] Hussain M, Mumtaz SE-W. Impacts, issues and management strategies. Reviews on Environmental Health 2014;29:53–8.
[44] Cousins IT, DeWitt JC, Glüge J, Goldenman G, Herzke D, Lohmann R, et al. The high persistence of PFAS is sufficient for their management as a chemical class. Environmental Science: Processes & Impacts 2020;22: 2307–12.
[45] Amakiri KT, Canon AR, Molinari M, Angelis-Dimakis A. Review of oilfield produced water treatment technologies. Chemosphere 2022:134064.
[46] Kroukamp E, Wepener V. Toxic trace metals in the environment, a study of water pollution. Environmental and Biochemical Toxicology Concepts, Case Studies and Challenges 2022:191.
[47] Sullivan C, Tyrer M, Cheeseman CR, Graham NJD. Disposal of water treatment wastes containing arsenic—a review. Science of the Total Environment 2010;408:1770–8.
[48] Abdullah JJ, El-Imam AA, Greetham D, Du C, Tucker GA. The application of fungi for bioleaching of municipal solid wastes for the production of environmental acceptable compost production. Journal of Environmental Science and Public Health 2017;1:167–94.
[49] Brittingham MC, Maloney KO, Farag AM, Harper DD, Bowen ZH. Ecological risks of shale oil and gas development to wildlife, aquatic resources and their habitats. Environmental Science & Technology 2014;48:11034–47.
[50] Brki D. Probability analysis and prevention of offshore oil and gas accidents: fire as a cause and a consequence. 2021.
[51] Rundmo T. Perceived risk, safety status, and job stress among injured and noninjured employees on offshore petroleum installations. Journal of Safety Research 1995;26:87–97.
[52] Beyer J, Trannum HC, Bakke T, Hodson PV, Collier TK. Environmental effects of the deepwater horizon oil spill: a review. Marine Pollution Bulletin 2016;110:28–51.
[53] Zareie S, Zabihollah A. A study of pre-straining shape memory alloy (SMA)-based control elements subject to large-amplitude cyclic loads. Ships and Offshore Structures 2021;16:306–13.
[54] Tang KHD, Dawal SZM, Olugu EU. A review of the offshore oil and gas safety indices. Safety Science 2018;109:344–52.
[55] Xue L, Fan J, Rausand M, Zhang L. A safety barrier-based accident model for offshore drilling blowouts. Journal of Loss Prevention in the Process Industries 2013;26:164–71.
[56] Rodhi NN, Anwar N, Wiguna IPA. A review on disaster risk mitigation in the oil and gas project. In: Proceedings of the IOP conference series: earth and environmental science, vol 106. IOP Publishing; 2018. p. 12009.
[57] Van Thuyet N, Ogunlana SO, Dey PK. Risk management in oil and gas construction projects in Vietnam. International Journal of Energy Sector Management 2007.
[58] Kousky C. Using natural capital to reduce disaster risk. Journal of Natural Resources Policy Research 2010;2:343–56.
[59] Leal Filho W, Tripathi SK, Andrade Guerra J, Giné-Garriga R, Orlovic Lovren V, Willats J. Using the sustainable development goals towards a

better understanding of sustainability challenges. The International Journal of Sustainable Development and World Ecology 2019;26:179–90.
[60] Govender D. The use of the risk management model ISO 31000 by private security companies in South Africa. Security Journal 2019;32:218–35.
[61] Khan M, Haque A, Hussain A. Sustainable cities—a reality to fight against climate change and a road map for renewables. IETI Transactions on Social Sciences and Humanities 2020;11:59–73.
[62] Hameed A, Raza SA, Ahmed Q, Khan F, Ahmed S. A decision support tool for bi-objective risk-based maintenance scheduling of an LNG gas sweetening unit. Journal of Quality in Maintenance Engineering 2019;25: 65–89.
[63] Nielsen JS, Tcherniak D, Ulriksen MD. A case study on risk-based maintenance of wind turbine blades with structural health monitoring. Structure and Infrastructure Engineering 2021;17:302–18.
[64] Godoy LA. Performance of storage tanks in oil facilities damaged by hurricanes Katrina and Rita. Journal of Performance of Constructed Facilities 2007;21:441–9.
[65] Ibrion M, Paltrinieri N, Nejad AR. On disaster risk reduction in Norwegian oil and gas industry through life-cycle perspective. In: Proceedings of the international conference on offshore mechanics and arctic engineering, vol 58783. American Society of Mechanical Engineers; 2019. V003T02A077.

10

Hazardous materials and dust release in disasters of oil, gas, and petrochemical units

Behnaz Rahmatmand[1], Mohammad Amin Makarem[1] and Mohammad Reza Rahimpour[1]
[1] *Department of Chemical Engineering, Shiraz University, Shiraz, Iran*

1. Introduction

The oil, gas, and petrochemical industries have become vital contributors to society, providing essential chemicals and fulfilling the increasing demand for energy [1–3]. However, they pose a significant threat to the environment, particularly with regards to climate change and global warming [4–6] . On the other hand, the rapid development in the number of such units has resulted in an increased risk of severe industrial accidents as well as an increased emission of hazardous chemicals and dust [7]. Such releases may be the result of industrial mishaps that were caused by human or system failures, or they may be the result of Natechs that were carried out by natural hazard occurrences, including explosions at power plants that were caused by tsunamis [8]. In this context, natural disasters such as storms, flooding, and earthquakes can result in the discharge of hazmat and dust. However, in the majority of cases, scholars consider natural catastrophes and technology disasters to be distinct phenomena rather than joint occurrences. In a review of the potential for hazmat and dust releases in the oil and petroleum sectors, this chapter takes into consideration both types of events: natural disasters and technological disasters. In the following parts, we first reviewed the dangerous material and dust releases that were caused by natural catastrophes, and then we moved on to discuss the technical disasters that occurred. The first discussion is about the size of dust, and then the release of dust and hazardous materials by different types of natural disasters is investigated, and

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00005-0

the last part is about the explanation of dust explosions and their effect on the environment.

1.1 Dust

According to BS 2955: 1958 [9], solids are considered to be "powders" when the size of their individual particles is less than 1000 μm. On the other hand, particles are referred to as "dust" when their average diameter is lower than 76 μm. According to NFPA [10], "dust" refers to any finely split solid that has a diameter of 420 μm or less. It might be better to accept a little bit wider approach of Palmer [11], which cannot work except in his treatment even species diameters larger than 1000 μm [9]. This is because the sizes prescribed by BS 2955 and NFPA 68 differ by roughly six orders of magnitude from one another. In this piece, we will refer to all particulate matter as "dust," despite the fact that the particles might range in size from very little to very large. A dearth of information is currently accessible regarding dust releases brought on by natural disasters. The few studies that are currently available point to an increase in natural disasters that have caused dust releases over the past 20 years. This finding is consistent regardless of whether the increase is measured in terms of enhancement in financial damages, as shown by information from Marsh and McLennan (1997) [12], or as rises in the total number of dust release events, as reported by Showalter and Myers (1994) [13] and Lindell and Perry (1997) [14]. On the other hand, the emergency management plans to deal with hazardous releases caused by natural disasters are quite limited, if they ever exist at all. According to the Occupational Safety and Health Administration laws, businesses in the United States that use hazmat must do a process hazard analysis and prepare process safety management and emergency response plans. Because of the low probability associated with natural hazards and the widespread belief that natural catastrophes are not likely to cause dust emissions, there are no rules in place to handle the threat posed by concurrent events. This may be the reason for the absence of such restrictions. Hurricanes are an extremely uncommon occurrence. For instance, the National Oceanic and Atmospheric Administration have determined that the likelihood of a major hurricane striking a particular 80-kilometer stretch of coastal area along the United States Gulf Coast in any specified year is extremely low, with estimates ranging from close to 0.0%−4.0%. This is based on their analysis of past hurricane activity [15]. In spite of this, the aftermath of a large hurricane hitting land can be extremely catastrophic. If the hurricane causes a dust release, the effects of the disaster on the community will be amplified, making it more difficult for them to recover. The reveal of large quantities of oil during Hurricane Georges in 1998 from a lowered floating roof of storage taken at an oil refinery in Mississippi is one example of this type of release. Other examples include the release of oil and other hazardous materials during Hurricane Camille in 1969 from petroleum storage and loading facilities in Venice, Louisiana [16]. At the same time, a tank at this equipment that was holding potentially dangerous gasoline additives became detached from its supports [17]. Drums of hazardous chemicals that had been placed drifting from industrial equipment during Hurricane Floyd in 1999, when the structure was at the strength of a tropical storm, were recovered just in time to avert a spill of hazmat into the Raritan River in New Jersey. This narrowly averted disaster saved lives and prevented environmental damage [17]. The storm may concurrently impair water, electric, communications, and transportation lifelines both within and outside the plant, which will hinder on-site reaction to the hazmat and dust reveals. Hazmat leaks are particularly dangerous because of this possibility. It is possible that emergency professionals who are ordinarily accessible for responding to hazmat will be involved in mitigating the effects of the hurricane itself. As a result, this personnel will not be available to respond to the dust emission. Releases of hazmat and dust may result in unusually dangerous situations. For instance, a scenario that involves the discharge of an acidifying gas, such as hydrogen fluoride, which, when dissolved in rainwater, results in the formation of hydrofluoric acid, would be one of the most catastrophic possible outcomes [18].

1.2 Dust and hazmat released by natural disaster

According to this study, the number of natural disasters and the resulting losses has increased significantly over the past 30 years. By Mileti (1999), who was compiling data for the International Decade for the Mitigation of Natural Disasters, the mean annual loss per million mankind in the United States jumped from $20 million in 1970 to $100 million by 1994 [19]. According to Mileti, this rise should not come as a surprise, given the huge increase in the nation's capital stock that occurred throughout these years. In addition, the type of natural disasters is growing further complicated as population and industrialization density continue to rise in regions that are susceptible to natural disasters. This complication is multiplied when the thinking about the natural catastrophe itself is considered; one also thinks about technological disasters that are induced by natural phenomena. Between

1980 and 1989, one of the few studies that are now available on the proceeding of natural disaster-making hazardous material and dust discharges evaluated the frequency with which these kinds of incidents happened in the United States. Showalter and Myers (1994) performed a survey with the goal of determining the number of hazardous chemical releases that were the result of natural disasters during this time [13]. The survey was distributed to emergency management agencies in all 50 states. They discovered that earthquakes accounted for the vast majority of natural disaster incidences (228 reported occurrences), observed by storms, hurricanes, lightning, floods, and winds. A significant conclusion from their research was that there was an obvious upward trend toward a growing number of hazmat and dust release occurrences during the time period that was investigated. Lindell and Perry (1997) conducted a report of the earthquake of Northridge that occurred in 1994 and discovered that 134 natural hazards material “issues” occurred and 60 natural hazards material leak occurrences that were officially documented [14]. According to their findings, the number of occurrences had almost tripled in comparison to reveal what occurred during the Loma Prieta earthquake in 1989; however, underreported the events that occurred during the Loma Prieta earthquake might explain a few numbers of this discrepancy. In addition, a study that was carried out in 1998 by the assurance company Marsh and McLennan (1997) on the 100 most expensive feature losses that occurred in the hydrocarbon-chemical application revealed that there was an increase in both the number of losses and their severity between the years 1967 and 1997 [12]. Natural disasters caused 8% of the total number of incidents that were investigated. During the review period, the startup and shutdown processes were responsible for 13 percent of all losses. This is significant because, in the majority of cases, in order to safely evacuate a petrochemical unit during hurricane season, evacuation procedures involve shutting down the process units [20].

According to the findings of the study, property damage at oil and petrochemical facilities was significantly greater than in other kinds of hydrocarbon and chemical complexes. Explosions in vapor clouds, which are generated by the abrupt release of pressurized combustible gas, were responsible for a greater amount of property damage rather than other sorts of material release. Marsh and McLennan also emphasized several natural disasters caused significant losses among the last decades of the study period. These disasters included the hurricane of Hugo in 1989, the hurricane of Andrew in 1992, the earthquake that occurred in San Francisco in 1989, the Midwest floods that occurred in 1993, and the

Northridge earthquake that occurred in 1994. However, the vast majority of these losses were not covered by insurance and were consequently excluded from their investigation. Showalter and Myers (1994) and Both Mileti (1999) concluded that there is an immediate need to keep track of the frequency of dust and hazardous material discharges as well as their effects. It is only through collecting data of this kind that it will be possible to draw conclusions about what can be learned from past experiences and to set a standard against which future dust and hazardous substance and dust releases may be measured.

The hot waters of the Gulf of Mexico, North Atlantic Ocean, and South Pacific Oceans, Caribbean Sea, as well as the Central and Eastern are where tropical cyclones, also known as hurricanes, are thought to be their points of origin [21]. Although fast winds are often confined to a 100 km radius of the storm's center, hurricanes have the potential to affect radii as far out as 500 km [22]. The Saffir–Simpson Hurricane Wind Scale is utilized to categorize hurricanes. There are five hurricane categories of potential damage: minimum, moderate, extensive, severe, and catastrophic, based on the speed of wind and storm rush [23]. The dust discharge that frequently accompanies storms may be highly detrimental to oil and petrochemical plants. This is in addition to the damaging effects that are caused by the strong winds and the storm surge. A lightning disaster on a floating roof of a storage tank holding naphtha in Indonesia sparked a flame that engulfed six other storage tanks of fuel. The incident occurred in Indonesia [12]. In June of 2001, a dust release destroyed a petroleum unit in Norco, Louisiana, causing a storage tank including about five million gallons of gasoline to take flame. As a result of this incident, persons living in the surrounding area were instructed to remain inside for a period of 18 h [24]. Samsury and Orville (1994) conducted an analysis of the data collected on the amount of dust released by the Hugo hurricanes in 1989. In addition, they found that the majority of dust emission occurs in the front and back right of the storms. Cecil and Zipser (1999) also found that rainbands of hurricanes produce significantly more dust than the eyewalls do [22].

2. Dust and hazardous materials releases

It is possible to define a hazardous material and dust as a material in a concentration, size, quantity, or shape that poses a significant potential danger to the health of people or the environment when it is inappropriately managed in terms of its treatment, storage, disposal, or other management practices. Compounds that are both toxic and combustible are two types of hazardous materials that can be found. Propane, liquefied petroleum gas (LPG), hydrogen fluoride (anhydrous), hydrogen sulfide, and ammonia (anhydrous) are the hazardous compounds that are of particular relevance to this investigation. Oil and chemical units often have the capacity to store substantial amounts of these commodities. If the conditions are normal (non-hurricane), a toxic compound may go far distance from the place where it was released. It should be noted that the harmful effects of the hazardous materials and dust dispersion must be decreased to the desired and safe level of concentration so that no risks to people's health are threatened. The distance traveled depends on the toxicity of the compound as well as its physical and chemical characteristics. Winds from the hurricane will swiftly disperse the contaminant, so minimizing the region in which it will have an impact. However, the winds will not be able to stop the toxic compound from traveling dust. In addition, rain has the ability to break down some harmful gases. This can affect lowering the concentration in the gaseous form, but the kind of gas being released is important due to the secondary consequence of producing significantly acidic precipitation in the zone surrounding the release point. Regarding crisis control and reduction personnel to prepare for hurricane-making hazardous material and dust releases at petrochemical units, it is crucial to develop a plan to understand the kind of releases that probably occur, as well as the conditions that these materials can be released. Only then can crisis control and reduction personnel be ready for these releases. In the following part, we will build many potential scenarios that can be used for identifying industrial hazardous material releases that may occur due to storm circumstances. These releases may be detrimental to human health. The potential for hazardous chemical and dust emissions at oil and petrochemical operations as a result of a hurricane is broken down into four different categories of potential causes. Flooding, high winds, lightning, and tornadoes are all examples of these types of natural disasters.

2.1 The influence of hurricane in hazmat and dust releases

In order to guarantee that vulnerable communities have adequate time to evacuate, the workers responsible for local emergencies start monitoring an approaching hurricane for a couple of weeks before the cyclone makes landfall. In normal circumstances, a unit monitoring oil and petrochemical production will keep in communication with local emergency officials while also keeping an eye on the storm. In the event that an evacuation is necessary, the steps for shutting down begin approximately 72 h before the hurricane winds make landfall. When a plant's processing units are "deinventoried," this means that any potentially dangerous substances are moved to storage tanks located in other parts of the facility, away from the processing units themselves. The removal of potentially harmful components from the less secure units is one of the benefits of utilizing this approach. However, due to the fact that the hazardous material is concentrated in a single site, the scale of any potential leak, as well as the prospective consequences, may be increased. In the event of a storm, steam boilers, power stations, and water-cooling towers will typically continue to operate. This is done to keep the inside of the storage tanks at a constant level. In most cases, only a small number of employees will stay at the petrochemical plant in order to carry out the shutdown procedures, attend to any crises that may arise, and ensure a speedy restart after the danger has passed. However, in the event that severe weather conditions are present, these staff will not react to any emergencies. When the danger posed by the hurricane has passed, it may take 2 or 3 days to restart the processing units. It is possible that additional time will be needed for inspection and repairs in the event that the storm causes damage.

2.2 The influence of very high wind speeds in hazmat and dust releases

One of the most significant dangers that a storm poses is strong winds. These winds could be caused by the storm itself, or they could be caused by the tornadoes that the hurricane creates. The specific wind speeds that buildings and other structures are built to withstand are determined by the meteorological features of the region. The National Weather Service was principally responsible for the changes that occurred in the availability of data in 1995, which is why the wind speeds that were recorded were not the fastest mile wind speeds but rather the 3-s peak gust wind speeds. Toppling storage facilities and roofing on petrochemical buildings are also examples of ways in which high-speed winds can cause damage to the structure of buildings and in an oil and petrochemical plant. Pipelines and connections between storage and process units are especially susceptible to damage from the wind because of their location. It is possible that high wind speeds could create a power outage or a short circuit, which would then result in the destruction of steam boilers and cooling water towers, as well as the release of hazardous materials and dust. When there is a strong wind, things like tree limbs, signs, and even verandah can get blown into the atmosphere.

2.3 The influence of flooding in hazmat and dust releases

It is possible for there to be flooding as a result of the heavy rain that is connected with storms or the storm surge that is caused by the hurricane winds. A storm surge can generate an unusual rise in water levels in waterways directly related to the sea, such as canals, bayous, lakes, and rivers. In an oil and petrochemical facility, one of the most significant water risks is the flooding of electrical equipment (such as electrical cables and pumps), which can result in either a short circuit or a loss of power. Steam boilers, pumps, cooling towers, and electrically driven safe mechanisms of control will all be rendered inoperable if they are left operating while the hurricane is in progress or if a short circuit or power outage occurs. It is possible for the internal plant drainage systems that hold waste oil to flood, which would cause the oil to float to the top and exit the drainage system. It is possible for this oil to generate an explosion or fire if it is ignited during a lightning storm or by any other source of ignition. The flooding of containment dikes can enable storage tanks that are empty or almost empty to float, which has the potential to destroy pipe connections and result in a discharge of hazardous materials and dust. Heavy rains can cause the roofs of the floating tank to sink and create a potential flame hazard if lightning or another ignition source is present. In conclusion, a storm surge can potentially demolish or relocate building structures and carry away parked storage tanks, vehicles, fences, transformers, pumps, and other things that it takes up as it shifts in an area. When moving up on the opposite sides of hazardous material storage, any of these vehicles may result in massive damage and perhaps dangerous materials and dust leak [25].

2.4 The influence of lightning in hazmat and dust releases

Lightning can occur in conjunction with hurricanes regardless of how intense the tropical cyclone actually is. At a petrochemical facility, lightning has the potential to start fires, bring about power outages, and bring about power surges. There are several reports of lightning effects at oil and petrochemical operations. This is the case despite the fact that precautions are typically caused to reduce the risk of lightning-related chemical disasters. The tallest buildings or objects that are in the path of lightning are most likely to be struck. The structures most likely to be struck are those that protrude into the air, such as roofs, vents, towers, stacks, and the like [26]. A loss of power and a huge current wave can cause damage, which can happen as a release in control panels, pumps, steam boilers, storage units, and safety devices. These problems could also be caused by the destruction of sensitive electronics. Lightning also be able to destroy storage structures carrying flammable subjects triggering fires directly. Metal pieces from a burst vessel penetrate neighboring tanks, following in hazardous and dust discharges [27].

3. Hazardous chemical and dust releases by industrial disasters

All natural disasters discussed in the previous parts can all result in hazmat and dust releases in a petrochemical plant. Fires, explosions, and poisonous or flammable air emissions can all be caused by the release of hazmat. If an oil or petrochemical facility releases hazardous waste into an adjacent or nearby community, it will have an effect on human health or infrastructure based on its chemical properties (such as a toxin or flammable concentration or density), quantity released, storage conditions, and local weather patterns. Fires, explosions, and poisonous or flammable air emissions are all examples of the types of discharges that hazmat can cause [28]. Hazard to human life and infrastructure around an oil and chemical plant depends on a variety of factors, including chemical properties (such as flammability and toxicity) and the amount present at the time of the spill or leak (due to storage conditions), and local weather circumstances. Hydrogen fluoride gas, for example, can be kept either at room temperature or under pressure. Toxicity can spread via the plant and affect nearby residents in both circumstances, providing a severe health hazard. Hydrogen fluoride, which is very soluble in water, can be dissolved in rainwater during a thunderstorm and generate highly corrosive rainwater. Storage tanks for flammable materials can be pressurized or non-pressurized. In the event of a pressurized tank release, the liquid can pool and burn or evaporate.

"Vapor cloud explosions," which can cause catastrophic damage, can occur when flammable gas is conveyed as a vaporous cloud and comes into touch with an ignition source [29]. The release of one material may lead to the release of another. BLEVE may develop in the vicinity of pressure tanks carrying flammable liquid gas (e.g., propane) that have been ignited or other strong heat sources that have provided sufficient thermal energy in the vicinity of the tanks [30]. When a BLEVE occurs, it is possible that it will immediately result in a burst of compressed air caused by the massive release of squeezed fluids. If the contents of the pressure tanks are ignited immediately during the leak, there is a possibility that a fireball will result. The high-velocity jet that can arise as a result of a malfunctioning tank is responsible for the emission of fireballs into the atmosphere. Fireballs have the ability to travel several hundred meters, and they could perhaps enter the community that is located next door. A BLEVE projectile is something that can be launched even further than a BLEVE fireball and is created when fragments of the burst vessel are propelled into the air. Flammable liquefied gases may be released during the explosion, but if they do not ignite immediately, they may produce an explosion into the wind of the initial explosion. The dust that is treated in the industry is flammable more than 70 percent of the time [31]. This suggests that the vast majority of industrial operations with dust processing equipment are at risk for dust explosions. In the following part, we will go into detail regarding the dust explosion.

3.1 Dust explosion

An explosion caused by dust is sparked by the quick burning of combustible grains that are floating in the air. Any solid substance that is capable of burning in the atmosphere will happen with a degree of harshness and high which the substance is subdivided [32]. This continues till a restricted stage is gained, at which point particles that are too small in size attend to clump with each other. A flash fire is all that would result from a burned dust cloud that is allowed to spread freely. However, if the cloud of ignited dust is contained, even in part, even partly, the heat of the combustion may result in the quick development of pressure, with flame propagation over the cloud of ignited dust, as well as the expansion of the huge amount of reaction outcomes. An explosion is caused as a result of the frenetic rate of these events. In addition to the size of the particles involved, the extremity of an explosion like this is determined by the pace of energy release caused by combustion in comparison to the degree of heat losses. If the reactions take place by ignition so quickly that pressure increases inside the dust cloud more rapidly than it can vanish at the corner of the cloud [33], then there is a possibility that a destructive explosion could occur even in an unconfined dust cloud. This is the case in exceptional circumstances. Air is the primary contributor to the oxygen that is necessary for burning. The conditions essential for dust burning are the coincident existence of a dust cloud with a proper concentration in the atmosphere that will help burn throughout the procedure and an appropriate flammable source. This is necessary for an explosion to take place. In the exposition of dust composed of evaporative material, the explosion might take place in three stages, each of which may continue the previous one in swift cycles. These steps are palletization, mixing the gas phase of fuel (let out via dust), and oxidant (typically air). Each of these steps may take place very quickly after the previous one. When distributed as a cloud in the atmosphere and combustion, much flammable dust will let the fire spread throughout the cloud, similar to the dispersion of flame in a combination of fuel and oxidant in a gas phase [34]. In most cases, the synthesis of oxide is involved in a dust explosion.

$$\text{Fuel} + \text{oxygen} \rightarrow \text{oxide} + \text{heat}$$

However, dust that metals have produced also combines with N_2 or CO_2 to produce heat, which can then be used to ignite an explosion. The equation of state for perfect gases is a mathematical expression that can be used to describe the interdependence of the many parameters that determine the explosion pressure. If all other elements remain constant, the enhancement in temperature that occurs as a result of the heat generated by the burning dust cloud is the one that ultimately determines the explosion pressure. The conclusion that can be drawn from this is that the severity of an explosion will likely be larger if the heat of ignited dust per mole of oxygen absorbed is higher. The temperatures at which a selection of commonly found dust can be burned are listed in Table 10.1. From this vantage point, it is clear that metals can produce extremely dangerous dust [9]. There is always the possibility of an explosion occurring anywhere dust is created, stored, or processed, as well as in locations where conditions can arise when these components are mixed together in the air [35,36]. The blend is said to be “explosible” if there are flammable dust in the air in sufficient quantities for there to be a possibility of an explosion occurring upon ignition.

Table 10.1 Heat of combustion of some common dusts [25,37,38].

Material	Oxidation products	Heat of combustion (kJ/mol O_2)
Calcium	CaO	1270
Magnesium	MgO	1240
Aluminum	Al_2O_2	1100
Silicon	SiO_2	830
Chromium	Cr_2O_2	750
Zinc	ZnO	700
Iron	Fe_2O_3	530
Copper	CuO	300
Sucrose	$CO_2 + H_2O$	470
Starch	$CO_2 + H_2O$	470
Polyethylene	$CO_2 + H_2O$	390
Carbon	CO_2	400
Coal	$CO_2 + H_2O$	400
Sulfur	SO_2	300

3.2 Illustrative case studies pertaining selection to significant dust explosions

Although references to dust explosions can be found in published works as far back as 1785 32, systematized data were not accessible before the 20th century. On the 12th of January in the year 1807, an accident that was caused by a dust explosion took place in Leiden, the Netherlands [39]. This accident was one of the oldest recorded and also one of the most dangerous. A ship with a lot of black powder had traveled from Ouderkerk, which is close to Amsterdam, and had anchored in the middle of Leiden, despite the fact that this was against all laws. It is thought that the four-person crew's attempts to cook their foods in an oven led to the ignition of the dust, which in turn led to an explosion that was approximated to be comparable to 9000 kg amount of bursting TNT. The ignition was responsible for 151 fatalities and around 2000 injuries. People throughout the city were injured as a result of being struck by the glass, flying debris, and roof tiles. The ship caused houses to fall up to a distance of 155 m from it. A further disastrous dust explosion occurred in the pre-modern age in 1916 at the Peavey terminal elevator in Duluth, United States. This explosion contained grain dust. Following the explosion, the cribbed seed bins took fire, leading to the devastation of the elevator. It was said to be one of the "enormous flames" observed in a dust explosion [40]. 5 years later, in the same type of plant in Illinois (the United States), a dust explosion caused 42 fatalities [9]. On September 24, 1952, a grain dust explosion tore into grain elevator no. 4A of the Saskatchewan grain pools, resulting in the deaths of 6 people and injuries to 14 more. The initial blast, which occurred in a shipping container, was then followed by a secondary explosion that involved significant quantities of dust that had been permitted to build up inside the building. In addition, the roof gallery that was located above the bins was ruined [40]. Explosions caused by dust are a common occurrence in feed mills. Three people were killed and thirteen others were injured on May 25, 1955, when a corn dust explosion occurred in the Wayne Feeds in Waynesboro, in the United States. The force of the explosion resulted in significant damage being done to the property. In the year 1958, Kansas City, in the United States, was the site of yet another devastating explosion, which caused significant damage to the Murray elevator. The fire severely spoiled the headhouse of the steel building and damaged all of the building's installations. The Kampffmeyer grain silo in Albern, which is located close to Vienna, Austria, experienced a dust explosion on July 4, 1960. The explosion was caused by the welding of a spout that had become excessively worn as a result of the flow of grain. On August 7, 1965, a massive explosion broke up the mill building at the Sun flour mills in London, United Kingdom, and set a cribbed-construction wheat storage silo on fire. As a result of the explosion, 4 persons were killed and 37 others were injured. It is thought that the explosion was caused when a welding flame was used on a storage container that contained flour [40]. The grain silos at Kiel-Nordhafen on the Kaiser Wilhelm shipping canal, which connects the North and Baltic seas, were completely destroyed by a severe dust explosion that occurred on December 14, 1970. It was the most serious accident of its kind that had ever occurred in Germany. 6 soldiers were killed and 17 were injured. It is expected that the damage to the plant, buildings, and machinery will cost 10 million dollars. An enormous dust explosion caused significant damage to a Bunge Corporation terminal elevator at Destrehan, which was located close to New Orleans in the United States. The elevator had the ability to hold 8,000,000 bushels. The wind tore off the entire roof gallery that was located above the storage tanks. The concrete storage bins and the neighboring workhouse sustained significant damage as a result of the heat generated by the explosion and the subsequent fire [40]. In 1972, a dust explosion occurred at a silicon fine particles grinding factory in Norway. As a result of the explosion, five workers were killed and four others were seriously injured. The explosion, which took place in the milling part of the plant, was significant. It caused the majority of the process equipment to crack or buckle, and it blew out almost all of the wall panels of the factory building [41]. At an explosive slurry factory in Norway in 1973, the main explosion took place in a 5.2 m^3 batch mixer when fine aluminum flakes, sulfur, and some other ingredients were being mixed. This caused a larger dust cloud to be generated and ignited by a subsequent explosion caused by the blast and flame from the primary explosion. The large secondary explosion took the lives of 5 of the 10 workmen who had been at the location at the time of the incident and critically injured two others. A significant amount of the plant was completely destroyed [25]. On April 11, 1981, a devastating explosion occurred at a big export seeds silo growth near Texas, USA. As a result of the explosion, 9 people were killed and another 30 were injured. It was estimated that the loss of material was about $30 million [42,37,38]. It is possible that one of the dust collecting equipment experienced an electrostatic spark, which then led to the fire. After that, the explosion spread to the plant's other seven dust collecting units, completely destroying the majority of the facility. In August of 1990, a plant that produced benzoyl peroxide at the Dai-ichi Kasei Kogyo Company in Japan experienced an explosion involving dry benzoyl peroxide. The disaster resulted in the deaths of 9 workers and injuries to 17 more. Because benzoyl peroxide can fire even in the absence of being scattered in air, storing an illegitimate large amount of dry benzoyl peroxide allegedly caused substantially greater harm than would have occurred [9]. In June of 1992, a dust explosion occurred at the Daido Kako Enka Firework production company in Moriya, Japan. As a result of the explosion, 3 people were killed and 58 others were injured. During the mixing process, friction-induced sparks are the likely culprit that led to this disaster [9]. These sparks ignited a powdery mixture of potassium chlorate and aluminum, which caused the accident. In the same year, a significant dust explosion took place at the Kanaya Shoe producing facility located close to Tokyo, resulting in 5 fatalities and 22 injuries. The static electricity that was created in the fine rubber waste dust was the primary contributor to the explosion [37,43]. In August of 1997, a grain storage facility in the town of Blaye, France, was the site of a large explosion caused by dust. Along with a gallery and 28 silos, two towers that held bucket elevators and dust collection equipment were completely obliterated in the incident. 11 people were killed when concrete debris crashed through the ceiling of the control room. The fact that the facility worked with whole grain, which is normally considered to pose a low risk, is the element of this disaster that is the most concerning to experts. The explosive properties appeared to be on the low end as well; the samples went through a sieve with a mesh size of 500 m, and the maximum absolute explosion pressure values were only 6 bar. The maximum rate of pressure increase (KSt) values were also on the low side [44]. In April of 1997, a deadly catastrophe happened as a result of a tantalum dust explosion that took place inside a bag filter dust collection system. There was one worker who was murdered and another who was critically injured. In October of 2000, an explosion occurred at a plant that manufactured electronic gadgets when dust containing a Mg—Al alloy went off within a bag filter dust collecting device. There was one worker who passed away and another who was hurt [37]. Six workers were killed, and fourteen people were injured when an explosion occurred in a powerhouse owned by the Ford Motor Company in Michigan on February 1, 1999. It was determined that the major explosion was brought on by a buildup of natural gas in a boiler that had been shut down for routine maintenance at the time. It has been hypothesized that the primary damage was brought about by secondary explosions that involved coal dust. These explosions would have been caused by the coal dust. The powerhouse building and the facilities that were connected to it sustained extensive damage. It is the overprice mishap during the past decades of the United States, with costs exceeding one billion dollars [45]. On February 25, 1999, an ignition occurred in a mold production one of station in Massachusetts. It harmed a total of 12 employees, three of whom passed away as a result of the burns they sustained [46]. It is believed that the explosion was caused by either the buildup of a combination of natural gas and air in one of the ovens or the combustion of an airborne cloud of flammable resin dust in the hot oven. Both of these scenarios are possibilities. On May 16, 2002, an explosion at a rubber recycling plant owned by Rouse Polymerics International Inc. in Mississippi caused five employees to suffer serious burns, which ultimately led to their deaths. It is suspected that sparks escaping from an oven exhaust pipe produced the original ignition, which prompted a secondary ignition of the dust explosion that had stored in the structure. Rubber dust had various fine particle size, ranging from 75 to 180 μm, which contributed to the extremely high risk of igniting [31,47]. The CTA Acoustics manufacturing plant in Corbin, Kentucky, United States, was severely destroyed by an explosion and fire on February 20, 2003. Seven employees were killed as a result of the incident. An unintentional igniting of accumulated resin dust in a manufacturing line that had been temporarily shut down for wiping was the root cause of the explosion. It would appear that a dense cloud of dust that had been scattered by wiping tasks was lit on fire by the fires in a stove whose door had been left open.

3.3 The eruption of dust at the pentagon

While a fire can only start when what is known as "the fire triangle"—fuel, oxidant, and ignition—come together, a dust ignition requires two additional elements: the mix of air and dust and incarceration. The "fire triangle" is what allows a fire to start in the first place (of the dust cloud). The dust explosion pentagon [48] is created when all five of the following factors come into play at the same time (Fig. 10.1):

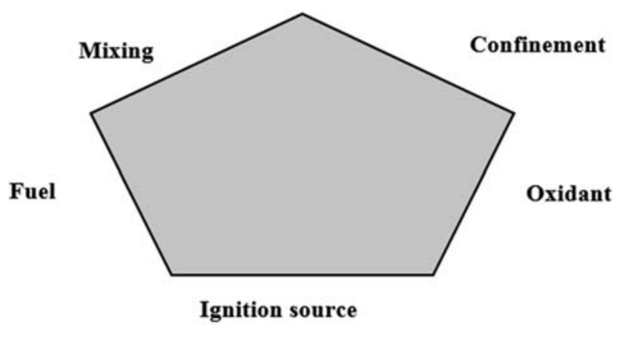
(i) the existence of finely split flammable dust;
(ii) the oxidant's accessibility;
(iii) the existence of an ignition source;
(iv) a level of confinement;
(v) mixed condition of reactants.

The fact that even a partial restriction of an explosive dust cloud might generate a very devastating explosion should be taken into consideration. Dust clouds act similarly to combustible gas clouds in this respect as well.

3.4 The different categories of dust

A layer of dust is said to be "combustible" if it is capable of being ignited by an external source, and the local fire that is generated by this process continues to spread adequately after the external source has been removed [49]. Combustible dust should all be explosible dust, although not all flammable dust is assuredly combustible [50]. Combustible dust should all be combustible. For instance, although having high heat of combustion, coal

Figure 10.1 The pentagon dust explosion [48].



and graphite are not smoothly combustible and so do not pose a risk of explosion. Experiments have been necessary because there is not yet an adequately attentive theory accessible to predict the capability of being exploded of flammable dust; therefore, this issue has been left up to the discretion of the researcher. If one is aware of the constituents that make up the dust, one can determine whether or not it is combustible by reading the list of dust that has been put through experimental testing and published by HM Company Inspectorate of the Department of Employment in the United Kingdom. When it comes to this classification [51], dust that was able to sustain a flame after being ignited has been placed in the Group A category. The dust that did not support the growth of a flame has been categorized as belonging to Group B. At the time of ignition, dust at or close to the atmosphere's temperature (25°C) is considered to fall under this group. Some of the dust in Group B have the potential to explode when exposed to higher temperatures. It is possible for dust that is ignitable but not explosible to become explosive if they are admixed with fuel dust. For instance, ignitable but non-explosible fly ash can turn explosive if it is contaminated with powdered or petroleum coke [52,53]. This takes place as a result of an increase in volatile stuff that is provided by fuel dust.

4. Conclusion

The previous studies have given a bit of attention to the probability of junction technological and natural catastrophes. This chapter has listed the possibility of a technological catastrophe in an oil and petroleum unit activated with a hurricane and industrial errors. An oil and petroleum unit could potentially leak toxic substances and dust during natural and industrial disasters. Several scenarios have been devised. There is a risk of damage to structures and tanks from hurricane-induced flooding, severe winds, tornadoes, as well as lightning. Some examples of natural disasters include broken pipelines and connections. The damaged infrastructure could lead to the release of toxic materials and dust. Projectiles that operate like missiles can also puncture atmospheric and pressurized storage tanks and pipes, causing leaks to occur. In addition to the possibility of a spill or an explosion, there is also the potential for air emissions, firing, and ignitions. Design rules protect against wind-making releases; however, the highest hurricane and tornado winds might still surpass the design standard for wind loads. A hurricane may influence a vast region, increasing the likelihood of simultaneous reveals of hazmat and dust at the same plant or at neighboring facilities. Another possible scenario is that a contaminated plume ignited by lightning or sent hurtling through the air by BLEVE strong winds might set off a secondary chemical explosion downwind. Government leaders and emergency planners should pay close attention to the possibility of combined disasters at industrial complexes. According to this chapter, coupling disasters in oil and petroleum plants are a real risk, which provides examples of how this could happen. There should be similar studies done on other industrial types of equipment to identify their susceptibility to concurrent calamities. Furthermore, it is necessary to estimate the dangers posed by the various hypotheses that have been put out. Risk quantification should be done utilizing a team of experts, as there is minimal field information on significant hurricanes on which to build an empirically determined risk analysis, according to the authors of this chapter. Findings like this will be crucial in building industry-specific disaster response strategies for collaborative catastrophes, designing mitigation measures to prevent collaborative catastrophes, and developing plan standards to decrease the possibility of hazardous materials being released and disaster damages.

List of abbreviation

BLEVE boiling liquid expanding vapor explosion
Hazmat hazardous material
LPG liquefied petroleum gas
VCE vapor cloud explosions

References

[1] Rahimpour MR, Makarem MA, Meshksar M. Advances in Synthesis Gas : Methods, Technologies and Applications. Volume 1: Syngas Production and Preparation. Elsevier; 2023.
[2] Rahimpour MR, Makarem MA, Meshksar M. Advances in Synthesis Gas : Methods, Technologies and Applications. Volume 3: Syngas Products and Usages. Elsevier; 2023.
[3] Kiani P, Meshksar M, Makarem MA, Rahimpour MR. Chapter 5: Syngas Conditioning (Catalyst, Process: Sulfur and Tar Cl, F). In: Gorimbo; Joshua, et al., editors. Chemicals and Fuels from Biomass via Fischer–Tropsch Synthesis: A Route to Sustainability. Rodriguez Jose, et al., editors. Catalysis Series. Royal Society of Chemistry; 2022.
[4] Makarem MA, Farsi M, Rahimpour MR. CFD simulation of CO_2 removal from hydrogen rich stream in a microchannel. International Journal of Hydrogen Energy 2021;46(37):19749–57. https://doi.org/10.1016/j.ijhydene.2020.07.221.

[5] Makarem MA, Kiani MR, Farsi M, Rahimpour MR. CFD simulation of CO_2 capture in a microchannel by aqueous mixtures of MEA and [Bmim]BF_4 modified with TiO_2 nanoparticles. International Journal of Thermophysics 2021;42:57. https://doi.org/10.1007/s10765-021-02812-1.
[6] Makarem MA, Moravvej Z, Rahimpour MR, Behrad Vakylabad A. Biofuel production from microalgae and process enhancement by metabolic engineering and ultrasound. In: Rahimpour MR, et al., editors. Advances in Bioenergy and Microfluidic Applications. Elsevier; 2021. p. 209—30.
[7] Shin IJ, Prevention A, Division P. Major industrial accidents in Korea : the characteristics and implication of statistics 1996—2011. 2013. p. 32. https://doi.org/10.1002/prs.
[8] Wei MC, Cheng YC, Lin YY, Kuo WK, Shu CM. Applications of dust explosion hazard and disaster prevention technology. Journal of Loss Prevention in the Process Industries 2020;68:104304. https://doi.org/10.1016/j.jlp.2020.104304.
[9] Abbasi T, Abbasi SA. Dust explosions—cases. Causes , Consequences, and Control 2007;140:7—44. https://doi.org/10.1016/j.jhazmat.2006.11.007.
[10] NFPA 664, 2020. Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities. 2020. 8. 535 1, (2006) 288—294.
[11] Shinbrot T, Lamarche K, Glasser BJ. Triboelectrification and razorbacks: geophysical patterns produced in dry grains. Physical Review Letters 2006; 96:1—4. https://doi.org/10.1103/PhysRevLett.96.178002.
[12] Sullivan JD. Strategical disasters: some significant trends in US emergency planning and mitigation. Journal of Contingencies and Crisis Management 1993;1:185—8. https://doi.org/10.1111/j.1468-5973.1993.tb00108.x.
[13] Sands P, Myers MF. Natural disasters in the United States as release agents of oil, chemicals, or radiological materials between 1980—1989: analysis and recommendations Pamela Sands show alter˺ and Mary Fran Myers2, vol 14; 1994.
[14] Lindell MK, Perry RW. Hazardous materials releases in the Northridge earthquake: implications for seismic risk assessment. Risk Analysis 1997;17: 147—56. https://doi.org/10.1111/j.1539-6924.1997.tb00854.x.
[15] Policy P. PUP volume 3 issue 1 Cover and Back matter. Journal of Public Policy 1983;3. https://doi.org/10.1017/s0143814x00003718. b1—b5.
[16] Society E. The effects of hurricane Camille on the Marshes of the Mississippi river Delta author(s): Robert H. Chabreck and A.W. Palmisano. vol 54. Published by: Wiley on behalf of the Ecological Society of America Stable; 2017. p. 1118—23. URL, http://www.jstor.org/stable/1935578.JST.
[17] Cruz AM, Steinberg LJ, Luna R. Identifying hurricane-induced hazardous material release scenarios in a petroleum refinery. Natural Hazards Review 2001;2:203—10. https://doi.org/10.1061/(asce)1527-6988(2001)2:4(203).
[18] IEC. Proposed change to the scope of TC 31, IEC document 31/405/Q, 2002-02-01. Geneva: International Electrotechnical Commission; 2002.
[19] Mileti D, Henry AJ. Disasters by design: a reassessment of natural hazards in the United States. Natural Hazards 1999:1—372.
[20] Carpenter AR, Ogle RA. Toxic gas release caused by the thermal decomposition of a bulk powder blend containing sodium dichloroisocyanurate. Process Safety Progress 2003;22:75—82. https://doi.org/10.1002/prs.680220202.
[21] Wilson J, Oyola-Yemaiel A. The evolution of emergency management and the advancement towards a profession in the United States and Florida.

Safety Science 2001;39:117–31. https://doi.org/10.1016/S0925-7535(01)00031-5.

[22] Journal A, African I. International African institute Africans in Colonial Louisiana: the development of Afro-Creole Culture in the Eighteenth Century by Gwendolyn Midlo Hall review by Stephan Palmié 2014;64: 168–71.

[23] Kareem A. Wind effects on structures: fundamentals and applications to design. Choice Reviews Online 1997;34:34–3889. https://doi.org/10.5860/choice.34-3889. 34-3889.

[24] Swerczek M. Refinery blaze extinguished but neighbors are fired up. June 9. Metro, B4: The Times-Picayune; 2001.

[25] Nifuku M, Katoh H. Incendiary characteristics of electrostatic discharge for dust and gas explosion. Journal of Loss Prevention in the Process Industries 2001;14:547–51.

[26] Nifuku M, Enomoto H. Evaluation of the explosibility of malt grain dust based on static electrification during pneumatic transportation. Journal of Loss Prevention in the Process Industries 2001;14:509–14. https://doi.org/10.1016/S0950 4230(01)00047-X.

[27] Wolanski P. Deflagration, detonation and combustion of dust mixtures. American Institute of Aeronautics and Astronautics 1990:3–31.

[28] Klemens R, Szatan B, Gieras M, Wolanski P, Maranda A, Nowaczewski J, et al. Suppression of dust explosions by means of different explosive charges. Journal of Loss Prevention in the Process Industries 2000;13: 265–75.

[29] Bin Chang N, Wei YL, Tseng CC, Kao CYJ. The design of a GIS-based decision support system for chemical emergency preparedness and response in an urban environment. Computers, Environment and Urban Systems 1997;21:67–94. https://doi.org/10.1016/S0198-9715(97)01009-0.

[30] Birk AM. Propane and LPG BLEVE incident simulation for plant safety analysis, emergency response planning and training. Ont, Canada: Dept. Mech. Engrg., Queens Univ. Kingston; 1998.

[31] Vijayaraghavan G. Impact assessment, modelling, and control of dust explosions in chemical process industries. Dep. Chem. Eng. Coimbatore Inst. Technol; 2004. MTech Thesis (Advisor: Prof. S. A. Abbasi).

[32] Eckhoff RK. Dust explosions in the process industries. Gulf Prof. Publ; 2003.

[33] Cashdollar KL. Overview of dust explosibility characteristics. Journal of Loss Prevention in the Process Industries 2000;13:183–99. https://doi.org/10.1016/S09504230(99)00039-X.

[34] Proust C. A few fundamental aspects about ignition and flame propagation in dust clouds. Journal of Loss Prevention in the Process Industries 2006;19: 104–20. https://doi.org/10.1016/j.jlp.2005.06.035.

[35] Kosinski P, Hoffmann AC. Dust explosions in connected vessels: mathematical modelling. Powder Technology 2005;155:108–16. https://doi.org/10.1016/j.powtec.2005.05.052.

[36] Jaeger N. Safety strategy against potential hazards due to the handling of powders in a blending unit. Journal of Loss Prevention in the Process Industries 2001;14:139–51. https://doi.org/10.1016/S0950-4230(00)00036-X.

[37] Abbasi T, Abbasi SA. Dust explosions–Cases, causes, consequences, and control. Journal of Hazardous Materials 2007;140(1–2):7–44. https://doi.org/10.1016/j.jhazmat.2006.11.007.

[38] Eckhoff RK. Dust Explosions in the Process Industries (3rd ed.). USA: Gulf Professional Publishing; 2003.

[39] Reitsma HJ. The explosion of a ship, loaded with black powder, in Leiden in 1807. International Journal of Impact Engineering 2001;25:507–14. https://doi.org/10.1016/S0734-743X(00)00067-1.
[40] Theimer OF. Cause and prevention of dust explosions in grain elevators and flour mills. Powder Technology 1973;8:137–47. https://doi.org/10.1016/0032-5910(73)80076-2.
[41] Abbasi T, Abbasi SA. The boiling liquid expanding vapour explosion (BLEVE): mechanism, consequence assessment, management. Journal of Hazardous Materials 2007;141:489–519. https://doi.org/10.1016/j.jhazmat.2006.09.056.
[42] Kauffman RFHCW. An investigation of fourteen grain elevator explosions occurring between January 1979 and April 1981. DC: Occupational Safety and Health Administration; 1984.
[43] Ravi Maniarasu. A computational and experimental study on using adsorbent to mitigate CO2 and other emissions from diesel engine. Research Square 2023. https://doi.org/10.21203/rs.3.rs-2455860/v1.
[44] Barton J, editor. Dust explosion prevention and protection: a practical guide. Warwicksh: inst. Chem. Eng. (IChemE); 2002.
[45] MIOSHA News. OSHA.Michiganvol. 3; 1999.
[46] Zalosh R. A tale of two explosion. In: Proceedings of the 34th annual loss prevention symposium. New York: Am. Inst. Chem. Eng; 2000.
[47] 2000 Investigation. OSHA press release on Rouse Polymerics, http://www.osha.gov/pls/oshaweb/owadisp.show document?p table= NEW RELEASES&p id=9830 (cited in [25]).
[48] Kauffman CW. In: Lee JHS, Guirao CM, editors. Agricultural dust explosions in grain handling facilities. Fuel-air explosions. Waterloo, Ontario, Canada: University of Waterloo Press; 1982. p. 305–47.
[49] Siwek R. Determination of technical safety indices and factors influencing hazard evaluation of dusts. Journal of Loss Prevention in the Process Industries 1996;9:21–31. https://doi.org/10.1016/0950-4230(95)00057-7.
[50] Eckhoff RK. Partial inerting-an additional degree of freedom in dust explosion protection. Journal of Loss Prevention in the Process Industries 2004;17:187–93. https://doi.org/10.1016/j.jlp.2003.11.004.
[51] Matsuda T, Yashima M, Nifuku M, Enomoto H. Some aspects in testing and assessment of metal dust explosions. Journal of Loss Prevention in the Process Industries 2001;14:449–53. https://doi.org/10.1016/S0950-4230(01)00033-X.
[52] Dastidar A, Amyotte P, Going J, Chatrathi K. Inerting of coal dust explosions in laboratory- and intermediate-scale chambers. Fuel 2001;80:1593–602. https://doi.org/10.1016/S0016-2361(01)00038-2.
[53] Amyotte PR, Basu A, Khan FI. Dust explosion hazard of pulverized fuel carry-over. Journal of Hazardous Materials 2005;122:23–30. https://doi.org/10.1016/j.jhazmat.2005.03.025.

This page intentionally left blank

11

Short-term and long-term health problems in exposure to chemicals

Sara Zolghadri[1], Elham Rahimpour[2] and Mohammad Reza Rahimpour[1]

[1]*Department of Chemical Engineering, Shiraz University, Shiraz, Iran;* [2]*Shiraz University of Medical Sciences, Shiraz, Iran*

1. Introduction

Oil, gas and petrochemical industries play an important role in providing the world needs. Indeed, fossil fuels provide nearly 80% of the world's annual required energy [1,2]. However, their harmness is not limited to well-known problems such as global warming and climate change [3,4]. Numerous environmental paths exist by which the exploration, manufacture, and transportation of petroleum products may have an impact on people's health. From the standpoint of people's health, contaminants generated by Upstream oil and gas (UOG) operations are of significant relevance. Through the channels of air, water, soil, or other surfaces, contaminants may directly affect human health, as well as indirectly through a number of paths. Oil and gas activities may have a negative impact on people's health indirectly via resource depletion, stress, noise, and non-contaminating visual or auditory stimulation. The expanding UOG sector has recently sparked concerns about its potential negative effects on human health [5].

In oil and gas extraction, dangerous chemicals are used and produced. The "fracturing" of subsurface land formations involves the high-pressure injection of liquids and/or solids into the earth. Although some of the substances utilized in this procedure are brought to the surface and may contaminate soil, air, and water, others are left underground and may contaminate subterranean aquifers. Drilling fluids and other industrial commodities can potentially contain additives and esters, olefins, paraffins,

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00009-8

ethers, freshwater or saltwater muds, oil-based muds, or synthetic polymers. Additions of metals, acrylic polymers, organic polymers, surfactants, and biocides may also be included in these fluids. The precise composition of the chemicals used in drilling muds and fracking fluids is often not made public and is frequently regarded as confidential [6].

Toxic pollutants are more prone to enter the air around oil and gas generating regions. Many pollutants, including methane and other hydrocarbons (ethane, propane, and butane), hydrogen sulfide (H_2S), and water vapor, may be present in fugitive natural gas emissions. These emissions may originate from manufacturing facilities, landfills, or pipelines. Condensate from certain natural gas wells may include complex and aromatic hydrocarbons including benzene, toluene, ethyl benzene, and xylene (BTEX). Polycyclic aromatic hydrocarbons (PAHs), including naphthalene, benzene, toluene, xylenes, ethyl benzene, formaldehyde, acrolein, propylene, acetaldehyde, and hexane, are just a few of the dangerous substances that may be produced by natural gas flaring. BTEX leaks into the atmosphere may be created by glycol dehydrators, which are used to extract water from natural gas [6].

Several Federal statutes, including the Clean Air Act (CAA), the Safe Drinking Water Act (SDWA), the Resource Conservation and Recovery Act (RCRA), the Clean Water Act (CWA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Emergency Planning and Community Right-to-Know Act (EPCRA), exclude gas and oil production and exploration activities from health protection standards. The purpose of these regulations is to protect people's health by providing clean air and water [6].

Fig. 11.1 shows the general schematic of chemicals and their effects on human health.

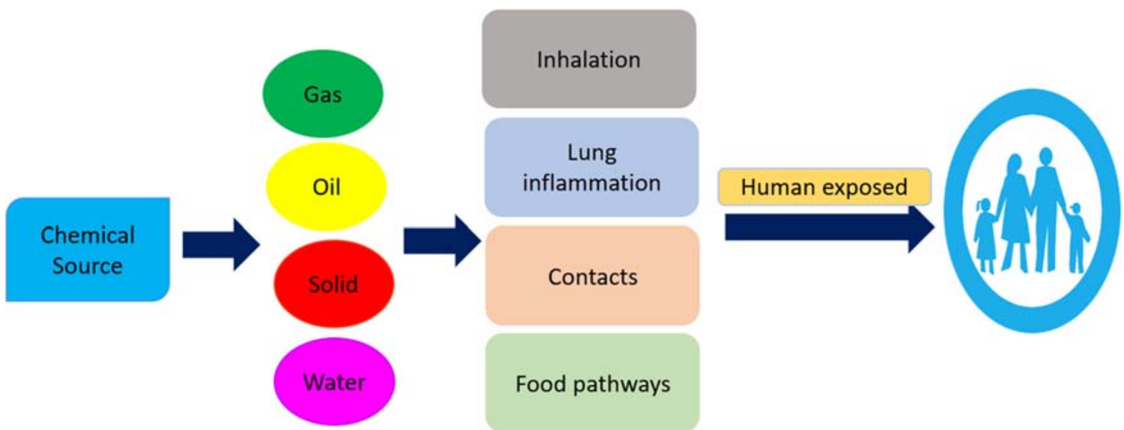


Figure 11.1 Dangers and harms of chemicals on human health.

2. Long-term and short-term effects

Chemicals have a range of effects on human health. For instance, several organic solvents (carbon-based) can cause dizziness by having a similar impact on the brain. A little variation in chemical structure may result in substantial variations in the sort of health impact caused. Such as certain cancer-causing chemical solvents. A chemical's impact on the human body might be chronic or acute [7].

2.1 Acute

Acute (short-term) impacts manifest shortly after chemical exposure. They might be trivial, including irritation of the throat or nose, or maybe they're serious, including eye damage or passing out from chemical fumes [7].

2.2 Chronic

Chronic (long-term) impacts are often induced by repeated, prolonged exposure to hazardous substances. Therefore, the effects are often lasting. Several substances have chronic and acute side effects. As an example, inhaling solvent fumes might cause immediate confusion (an acute effect). However, persistent exposure to the same fumes over a number of years might induce liver damage (a chronic impact). A chemical must interact with or enter the body before it may pose a risk to human health. There are four essential routes: (I) Inhalation (breathing) (II) contact (a) skin (b) eye contact (III) Digestive system (ingestion or eating) (IV) Intravenous [7].

3. Ways of exposure to chemicals

3.1 Inhalation

Inhalation is the primary essential route for toxic chemicals to reach the human body. The kind and severity of hazardous substances depend on the quantity of absorption, the structure of the chemical, the pace of absorption, as well as a variety of other variables. Inflammation is the body's' natural response to severe injuries, infections, and hypersensitivity [7].

3.1.1 Lung inflammation

The lung is susceptible to oxidant damage due to its special anatomy and function. The lung epithelium is constantly exposed to internal oxidants produced during metabolic activities and external oxidants present in the surrounding air, such as nitrogen dioxide, automobile exhaust ozone, and cigarette smoke [8]. Additionally, environmental pollution significantly impacts a significant impact on the severity of asthma as well as the reactivity of the airways [9,10]. The bulk of chronic lung disorders are based on of acute lung inflammation (ALI). Because the lung is subjected to external factors through the airways or the bloodstream, such as sepsis, endotoxin, and fat, there are many different causes of lung inflammation. Severe cases might led to acute respiratory distress syndrome (ARDS), a variety of lung conditions that may cause widespread alveolar destruction, respiratory failure, as well as a severe inflammatory method in the lung tissue can be detected [9,10]. The relevance and effects of the systemic reaction after ALI have been discovered and thoroughly documented since the 1970s and 1980s, but knowledge of the systemic reaction in chronic inflammatory lung disorders has been available for the last 10 years [11–13]. Numerous studies have shown that substances that cause lung inflammation, such as ultrafine particles, lipopolysaccharides (LPS), as well as other bacterial toxins, may move from the airspaces to the circulation [14–16]. The following are by far the most common hazardous compounds that are inhaled:

(I) Chemical compounds, such as a) Chlorine gas, that is breathed in through cleaning products like chlorine bleach, following industrial mishaps, or surrounding swimming pools, (b) sulfur mustard (SM), gas and nitrogen mustard (NM), and (c) nanomaterials.

(II) Harmful pesticide fumes.

(III) Smoke (from home fires and wildfires) [17–19].

Chronic chemical pneumonitis may only develop after long-term, low-dose exposure to a chemical. This results in inflammation and might make the lungs rigid. As a consequence, the lungs begin to become less effective in supplying the body with oxygen. This illness may lead to death and failure if left untreated. Severe inflammation might be fatal because the lung is a vital organ for gaseous exchange. Because harmful microorganisms are continuously exposed to the lung, a quick and powerful defensive response (mostly inflammation) is required to get rid of the attackers as fast as feasible. The most fundamental organ for chemical agents like SM and NM gas is the lung [20,21].

3.2 Contact

3.2.1 Skin contacts

Skin and eye contact are additional routes through which chemicals can cause harm. Various chemicals can cause skin irritation. Some of chemicals remove lipids and oils from the skin. If this happens, the skin cracks and becomes dry. Similarly, irritants can lead to serious burns. Or, irritants can cause hair follicles and sweat ducts to become clogged with oils and waxes. This may result in dermatitis and acne [22,23]. Skin contact with chemicals may have negative long-term or short-term health impacts. These negative effects on health might happen immediately after chemical contact, or the chemical could enter the body via skin injury like a wound or by permeating the skin. The chemical could then enter the bloodstream and travel throughout the body, generally creating or enhancing a health issue everywhere. Numerous physical, chemical, and toxicological characteristics that affect human health are acquired by laboratory compounds [24,25]. The worst kind of skin inflammation is caused by chemical burning and irritability. Many chemicals may cause systemic effects including skin and eye burns when ingested or inhaled, demanding medical or surgical treatment in many cases. Given the type of the implicated agents and the severity of the damage, lung injury, ocular involvement [26,27]. Skin is susceptible to a variety of various sorts of injury in addition to issues brought on by microbiological and chemical agents, electromagnetic and thermal radiation, and mechanical stress. injuries. Invasion by pathogenic microbes is the most damaging result of skin disturbance, and the need for an efficient response against this threat has been a driving factor in the development of the immune system [28]. In most circumstances, skin inflammation is a beneficial and protective response to injury or illness [29]. However, severe inflammatory reactions may also cause chronic inflammation, auto-inflammation, and auto-immunity in the skin [30]. Among the compounds that cause skin harm are [7]

(I) Cement.
(II) Acid: (a) Sulfuric acid, (b) Hydrofluoric acid, and (c) Hydrochloric acid.
(III) Alkali: (a) Potassium hydroxide and (b) Sodium hydroxide.

3.2.2 Eye contact

Chemical eye injuries may severely damage the cornea, anterior segment, and ocular surface epithelium, leaving behind a permanent loss of vision in one or both eyes. Chemical or heat burns that result in unrelenting inflammation and limbal stem cell deficiency (LSCD) are two of the most severe disorders of the cornea [31]. The following pathophysiological events all of which are modifiable therapeutically may have an impact on the ultimate ocular prognosis: (I) Eye surface injury, repair, and distinction; (II) Corneal stromal matrix damage, repair, and ulceration; and (III) Ocular and stromal inflammation [32,33]. The majority of unintentional eye burns happen at work. An examination of selected instances revealed that 28% of accidents were private and 72% were occupational. 63% of instances included alkaline substances such as lime or sodium hydroxide, 22% various acids, and 15% involved thermal burns from liquid metals or reworks [34,35]. There are two categories in which chemicals most often occur eye damage: (I) Alkali (II) Acid. According to Tielsch et al. [36], ammonia, a common ingredient in many household cleaning products, lye, and drain cleaners, is linked to very substantial alkali effects [35,37]. Lime is the most common alkali that causes eye damage, but fortunately, it does not cause as much damage as the alkalis that penetrate more quickly.

3.3 Digestive system (ingestion or eating)

Plant products receive pollutants from water, soil, and air and absorb them through their leaves and enter them into their tissue. Some toxins, such as polycyclic aromatic hydrocarbons (PAH), are directly absorbed by plants, and some, such as benzene in the soil, evaporate into the air before being absorbed by plants [38]. Radionuclides are among the substances that are absorbed by plants through the roots and can be deposited on food products [38]. Eating food from its plant tissue is exposed to chemicals and poisons, it is much more dangerous than inhaling exposed to chemicals. Some pollutants, including radioactive substances, are exhaled, but radionuclides enter the stomach and intestines through eating and damage organs. They follow the internals of the human body [39].

4. Chemicals and their effects on human health

4.1 Hydrofluoric acid

Although hydrofluoric acid is a very toxic material, it is employed in a variety of businesses and domestic settings [40]. This drug produces serious burns or system consequences, even in situations when the damage to the skin does not look severe. There are two causes of tissue injury [41]:

(I) The hydrogen ions create burns on the skin's surface.

(II) Fluoride enters deeper tissues, resulting in liquefaction necrosis of soft tissue.

4.2 Sulfuric acid

Sulfuric acid is a corrosive chemical that can cause chemical burns, skin burns, and thermal burns if used incorrectly. This chemical causes permanent blindness if it comes into contact with the eyes, burns internal organs if swallowed, and causes death if consumed in excess. Exposure to sulfuric acid aerosols has different effects according to their concentration. Sulfuric acid in low concentrations leads to erosion of teeth and in high concentrations leads to damage to internal tissues, lungs, and eyes. According to the mentioned cases, it is important to use personal protective equipment (PPE) in industrial and chemical environments. One of the substances that cause acid burns most frequently is sulfuric acid [42,43]. This dangerous chemical substance is found in the following cases:

(I) Metal cleaners.
(II) Drain cleaners.
(III) Car battery fluid.
(IV) Fertilizer manufacturing [7].

4.3 Mustard gas

Bis (2-chloroethyl) sulfide, often known as sulfur mustard, was first produced in the early and mid-1800s [44]. Meyer developed mustard gas for the first time in 1886, and the German army first utilized it as a vesicant factor for war during world war. Mustard gas at ambient temperature is a viscous liquid, not a gas. Mustard gas might be held in a shell for the length of its use and dispersed as an aerosol by an explosion. Inflammation and blistering of the skin, a burning feeling in the eyes, and charring of the lining of the lungs are symptoms of mustard gas exposure [45–47]. Only 15–20 years after its usage was its progressively dangerous late-onset effects identified. Three major areas are affected by mustard gas harm:

(I) Eye and skin damage following absorption via the epidermis and the eye area, respectively.
(II) Respiratory harm after breath.
(III) Systemic toxicity following ingestion or severe exposures, characterized by toxicity to the gastrointestinal tract, blood vessels, kidneys, and bone marrow [45,48–50].

One of the most frequent long-term side effects of SM intoxication is lung dysfunction, which is often accompanied by uncontrolled production of pro-inflammatory cytokines. Furthermore, systemic inflammation is present in individuals with late pulmonary consequences of SM and plays a critical role in SM pathogenesis. Interleukin-6 (IL-6) and high-sensitivity C-reactive protein (hs-CRP) levels, in particular, have been observed to be associated with the severity of respiratory symptoms [51–53]. On its victims, mustard agent exerts very powerful vesicant effects. Furthermore, due to its alkylating characteristics, it is highly carcinogenic and mutagenic [54]. Workers who are exposed to the mustard agent on a regular basis have been shown to be at an enhanced risk of oral and lung cancer. According to several research, those who were exposed to mustard gas acquired a variety of chronic pulmonary illnesses, including interstitial lung inflammation, asthma, bronchiectasis, and chronic bronchitis [55,56]. SM mainly affects the upper respiratory tract when inhaled. The respiratory tract is very vulnerable to this chemical exposure, much like the eye.

4.4 Toxic chemicals

Toxic chemicals have immediate or long-term effects on the environment, or they may pose a threat to human health or safety, or to the ecosystem that supports life [57]. According to Krzyzanowski (2009) [5], most of the petroleum and gas generated in northeast British Columbia (NEBC) is "sour" and contains high levels of H_2S. H_2S is still emitted via exploration, venting, incomplete flare combustion, leaks, and sweetening operations, despite the fact that the majority of it is either extracted and sequestered or burned via flare stacks to produce SO_2 [5]. H_2S concentrations between 1 and 5 ppm may temporarily impair health, whereas concentrations above 1000 ppm can completely knock someone out or cause death [58].

Chronic inhalation of methanol may result in headaches, nausea, and further effects on the eyes or neurons in addition to the neurological problems that might result from acute exposure to the substance [57]. Methanol is employed in a liquid state as an anti-freeze throughout hydro testing and other UOG procedures as well as a component in fracking fluids. Except for possible on-site exposure of personnel handling methanol, it is thought unlikely that environmental methanol levels at NEBC would ever achieve quantities that may have an impact on people's health.

Acetaldehyde is a byproduct of both full and partial fuel combustion as well as a breakdown byproduct of amine-based gas cleaning and sweetening chemicals utilized to eliminate H_2S or CO_2 (carbon dioxide) from crude flue gases. Acetaldehyde may irritate the skin and respiratory system when exposed briefly, but it can also make people feel intoxicated when exposed over time. According to classification, acetaldehyde is a possible carcinogen [5].

4.5 Secondary pollutants

It is well recognized that secondary contaminants are especially harmful to human health. According to Koren et al. [21], ozone, which is created when nitrogen oxides (NOx) and volatile organic compounds (VOC) combine, may harm human lungs immediately. It can also aggravate respiratory disorders like asthma and raise the risk of heart disease [59]. Acidic aerosols were created when the major pollutants SO_2 and NOx undergo atmospheric transformations, as well as they have been shown to harm the lungs and inflame the lungs [60,61]. Similar to ozone, peroxyacetyl nitrate (PAN) is created when NO_2 and VOC combine under sunshine. PAN is a mild mutagen that may harm the lungs [62].

Naturally occurring radioactive materials (NORM) are associated with the upstream equipment and products of the oil and gas industry and their activities. Because naturally occurring radioactive materials are often found in underground hydrocarbon pools. NORM release ionizing beta (β), or alpha (α) particles, and gamma (γ) rays. They are often found as radium (Ra) and its products, such as radon (Rn) [63–65]. Radon (a gas that emits particles) is regarded as a major risk factor for lung cancer [39].

While the skin may filter incoming radiation, inhalation and ingestion directly expose interior organs to radiation [66]. Over specific thresholds, exposure to NORM, especially gamma rays, is known to cause numerous malignancies and genetic abnormalities [5,67]. Furthermore, to naturally existing radioactive sources, radioisotopes are often utilized to track workovers throughout maintenance in the UOG sector. If these isotopes are mixed with nonhazardous solid waste, they don’t need special disposal and might be disposed of on land [5].

4.6 Miscellaneous chemicals

If there is an oil leak on open water, dispersants are deployed. According to studies, these dispersants may be harmful to people health both when consumed and when absorbed via the skin. Surfactants, detergents, and petroleum distillates are among the substances included in dispersants, which may irritate the respiratory system and produce headaches and nausea [68]. Due to the rare and isolated use of these products, its long-term effect on human health is not considered.

Cleaning UOG instruments and equipment involves the use of degreasing solutions. Degreasing compounds are thought to be unlikely to contaminate soil or water unless there is an accident or spill, since water depletion from cleaning procedures should be disposed of at an “approved disposal facility” [5]. Non-ionic alcohol ethoxylates and nonylphenol ethoxylates, that are commonly used chemicals in degreasing agents, detergents, and surfactants but do not occur in nature, are common [69].

Investigations have demonstrated that the family of substances known as nonylphenol ethoxylates is hazardous even at low levels. The effects of exposure comprise eye or skin irritation, immediate liver and kidney injury, and enhanced estrogenic activity, albeit each single nonylphenol ethoxylate exhibits its own distinct mechanism and amount of toxicity. Information on these substances’ realistic human toxicity is scarce, but they also have extensive effects on ecosystems as well as many other living things [70]. It is unclear how harmful non-ionic alcohol ethoxylates are. Dehydrators often employ ethylene glycol to dry unprocessed natural gas. Underground infusion is a common method for disposing of used ethylene glycol. Ethylene glycol divides into the soil and surface water in the environment and typically biodegrades within 24 days. According to research, ethylene glycol may harm the kidneys [70].

4.7 Heavy metals

Heavy metals such as mercury, lead, and cadmium are often found in gas and oil flows [68]. Heavy metals may also be present in drilling mud and fluids [5], and arsenic, copper, nickel, zinc, aluminum, lead, and cadmium are all present in produced waters from gas fields existing all over the world [71].

The exposure levels of each metal and its effects on human health are different. All metals have the potential to be dangerous in high and/or sustained doses. Where the source of fuel includes metals, heavy metals may be released as combustion byproducts at flare stacks, pits, or incinerators. Heavy metals that have been ingested may bind to DNA and produce oxidative cellular damage. Arsenic and nickel, two airborne elements, harm the kidneys and induce cardiovascular and pulmonary issues. Lead, mercury, and arsenic are hazardous to the neurological system [72]. Hexavalent chromium, nickel, arsenic, and lead have all been linked to lung and other malignancies [73].

Heavy metals can enter the environment through discharge and leakage into water or land. Heavy metals were crustal components or may occur naturally in certain groundwater aquifers.

When metals are ingested, they have comparable effects to when they are breathed; however, instead of entering the lungs and creating lung cancer, they may induce malignancies of the bladder, kidneys, liver, or pancreas [73,74]. Metals, whether breathed or eaten, enter the bloodstream, accumulate in tissues, cause cellular and molecular harm, and significantly affect fetal growth [72]. In addition to persisting in the environment and bio-accumulating in food chains, metals are also persistent in the environment.

5. Conclusion

Chemicals from oil and gas have harmful effects on human health. These effects can be long-term or short-term. Chemical substances enter the human body through breathing, skin and digestive system and as a result affect human health. Human receptors may be exposed to pollutants from UOG activities through air, water, soil, and food. Some pollutants such as radiation or PAH may enter the body through all these routes and affect humans. A large number of these pollutants, including air pollutants, radiation (such as radon), and volatile hydrocarbons in the air or soil, are linked to lung cancer, respiratory diseases, and mortality.

So far, modeling results and observations have shown that certain pollutants exist at levels high enough to cause adverse effects on human health. However, further studies are needed in the future to identify the extent to which pollutants associated with the oil and gas industry are responsible for human health harm.

List of abbreviation

ARDS acute respiratory distress syndrome
BTEX benzene, toluene, ethyl benzene, xylene
CAA clean air act
CERCLA comprehensive environmental response, compensation, liability act
CWA clean water act
EPCRA emergency planning and community right act
LSCD limbal epithelial stem deficiency
NEBC Northeast British Columbia
NM nitrogen mustard
NORM naturally occurring radioactive materials
NOx nitrogen oxides
PAHs polycyclic aromatic hydrocarbons
PPE personal protective equipment
RCRA resource conservation and recovery act

SDWA safe drinking water act
SM sulfur mustard
VOC volatile organic compounds

References

[1] Zolghadri Sara, Rahimpour Hamid Reza, Rahimpour Mohammad Reza. Chapter 10 - Co-electrolysis process for syngas production. In: Rahimpour Mohammad Reza, Makarem Mohammad Amin, Meshksar Maryam, editors. Advances in Synthesis Gas : Methods, Technologies and Applications. Volume 1: Syngas Production and Preparation. Elsevier; 2023. p. 237–60.

[2] Makarem Mohammad Amin, Moravvej Zohre, Rahimpour Mohammad Reza, Behrad Vakylabad Ali. 8 - Biofuel production from microalgae and process enhancement by metabolic engineering and ultrasound. In: Rahimpour Mohammad Reza, Kamali Reza, Makarem Mohammad Amin, Dehghan Manshadi Mohammad Karim, editors. Advances in Bioenergy and Microfluidic Applications. Elsevier; 2021. p. 209–30.

[3] Zolghadri Sara, Honarvar Bizhan, Rahimpour Mohammad Reza. Synthesis, application, and characteristics of mesoporous alumina as a support of promoted Ni-Co bimetallic catalysts in steam reforming of methane. Fuel 2023;335. https://doi.org/10.1016/j.fuel.2022.127005.

[4] Makarem MA, Kiani MR, Farsi M, Rahimpour MR. CFD Simulation of CO_2 Capture in a Microchannel by Aqueous Mixtures of MEA and [Bmim]BF_4 Modified with TiO_2 Nanoparticles. International Journal of Thermophysics 2021;42:57. https://doi.org/10.1007/s10765-021-02812-1.

[5] Krzyzanowski J. Environmental pathways of potential impacts to human health from oil and gas development in northeast British Columbia, Canada. Environmental Reviews 2012;20(2):122–34.

[6] Witter R, et al. Potential exposure-related human health effects of oil and gas development: a white paper. Colorado School of Public Health. Denver, CO, USA: University of Colorado; 2008.

[7] Akbarzadeh A, et al. The effects of various chemicals on lung, skin and eye: a review. Toxin Reviews 2016;35(3–4):187–95.

[8] Crystal RG. Oxidants and respiratory tract epithelial injury: pathogenesis and strategies for therapeutic intervention. The American Journal of Medicine 1991;91(3):S39–44.

[9] Boskabady MH, et al. The effect of Nigella sativa alone, and in combination with dexamethasone, on tracheal muscle responsiveness and lung inflammation in sulfur mustard exposed Guinea pigs. Journal of Ethnopharmacology 2011;137(2):1028–34.

[10] Matthay MA, Zimmerman GA. Acute lung injury and the acute respiratory distress syndrome: four decades of inquiry into pathogenesis and rational management. American Journal of Respiratory Cell and Molecular Biology 2005;33(4):319–27.

[11] Friedman GD, Klatsky AL, Siegelaub A. The leukocyte count as a predictor of myocardial infarction. New England Journal of Medicine 1974;290(23):1275–8.

[12] Grimm RH, Neaton JD, Ludwig W. Prognostic importance of the white blood cell count for coronary, cancer, and all-cause mortality. JAMA 1985;254(14):1932–7.

[13] Weiss ST, et al. Relation of FEV1 and peripheral blood leukocyte count to total mortality: the Normative Aging Study. American Journal of Epidemiology 1995;142(5):493–8.
[14] Clarke RW, et al. Inhaled concentrated ambient particles are associated with hematologic and bronchoalveolar lavage changes in canines. Environmental Health Perspectives 2000;108(12):1179–87.
[15] Kido T, et al. Diesel exhaust inhalation induces heat shock protein 70 expression in vivo. Inhalation Toxicology 2011;23(10):593–601.
[16] Oberdörster G, et al. Extrapulmonary translocation of ultrafine carbon particles following whole-body inhalation exposure of rats. Journal of Toxicology and Environmental Health, Part A 2002;65(20):1531–43.
[17] Moritz AR, Henriques Jr FC, McLean R. The effects of inhaled heat on the air passages and lungs: an experimental investigation. American Journal Of Pathology 1945;21(2):311.
[18] Sunil VR, et al. Pentoxifylline attenuates nitrogen mustard-induced acute lung injury, oxidative stress and inflammation. Experimental and Molecular Pathology 2014;97(1):89–98.
[19] Wallace R. Chemical breathing apparatus with alarm device. Google Patents; 1973.
[20] Holtzman M, et al. Importance of airway inflammation for hyperresponsiveness induced by ozone. American Review of Respiratory Disease 1983;127(6):686–90.
[21] Koren HS, et al. Ozone-induced inflammation in the lower airways of human subjects. American Review of Respiratory Disease 1989;139(2):407–15.
[22] Mattax JB, McCulley JP. Corneal surgery following alkali burns. International Ophthalmology Clinics 1988;28(1):76–82.
[23] Papimeisier B, et al. Pathology produced by sulfur mustard in human skin grafts on athymic nude mice. I. Gross and light microscopic changes. Journal of Toxicology - Cutaneous and Ocular Toxicology 1984;3(4):371–91.
[24] Safety O, et al. Training requirements in OSHA standards and training guidelines. Occupational Safety and Health Administration; 1998.
[25] Staples CA, et al. A review of the environmental fate, effects, and exposures of bisphenol A. Chemosphere 1998;36(10):2149–73.
[26] He Y-G, et al. Experimental transplantation of cultured human limbal and amniotic epithelial cells onto the corneal surface. Cornea 1999;18(5):570–9.
[27] Schrage N, et al. Eye burns: an emergency and continuing problem. Burns 2000;26(8):689–99.
[28] Robert C, Kupper TS. Inflammatory skin diseases, T cells, and immune surveillance. New England Journal of Medicine 1999;341(24):1817–28.
[29] Feldmeyer L, et al. Interleukin-1, inflammasomes and the skin. European Journal of Cell Biology 2010;89(9):638–44.
[30] Nestle FO, et al. Skin immune sentinels in health and disease. Nature Reviews Immunology 2009;9(10):679–91.
[31] Wagoner MD. Chemical injuries of the eye: current concepts in pathophysiology and therapy. Survey of Ophthalmology 1997;41(4):275–313.
[32] Abel R, et al. The results of penetrating keratoplasty after chemical burns. Transactions of the American Academy of Ophthalmology & Otolaryngology 1975;79:584–95.
[33] Alldredge OC, Krachmer JH. Clinical types of corneal transplant rejection: their manifestations, frequency, preoperative correlates, and treatment. Archives of Ophthalmology 1981;99(4):599–604.
[34] Rihawi S, Frentz M, Schrage N. Emergency treatment of eye burns: which rinsing solution should we choose? Graefe's Archive for Clinical and Experimental Ophthalmology 2006;244(7):845–54.

[35] Kuckelkorn R, et al. Retrospektive betrachtung von schweren alkaliverätzungen der Augen. Klinische Monatsblätter für Augenheilkunde 1993;203(12):397–402.
[36] Tielsch JM, Parver L, Shankar B. Time trends in the incidence of hospitalized ocular trauma. Archives of Ophthalmology 1989;107(4):519–23.
[37] Kottek A, et al. Early treatment of severe eye burns with an excimer laser. Vision Research 1995;(35):S93.
[38] Collins CD, Finnegan E. Modeling the plant uptake of organic chemicals, including the soil–air–plant pathway. Environmental Science and Technology 2010;44(3):998–1003.
[39] Al Zabadi H, et al. Exposure assessment of radon in the drinking water supplies: a descriptive study in Palestine. BMC Research Notes 2012;5(1): 1–8.
[40] Ohtani M, et al. Pathological demonstration of rapid involvement into the subcutaneous tissue in a case of fatal hydrofluoric acid burns. Forensic Science International 2007;167(1):49–52.
[41] Kirkpatrick J, Enion D, Burd D. Hydrofluoric acid burns: a review. Burns 1995;21(7):483–93.
[42] Mozingo DW, et al. Chemical burns. The Journal of Trauma 1988;28(5): 642–7.
[43] Wibbenmeyer LA, et al. Our chemical burn experience: exposing the dangers of anhydrous ammonia. Journal of Burn Care & Rehabilitation 1999;20(3):226–31.
[44] Reutter S. Hazards of chemical weapons release during war: new perspectives. Environmental Health Perspectives 1999;107(12):985–90.
[45] Ghabili K, et al. Mustard gas toxicity: the acute and chronic pathological effects. Journal of Applied Toxicology 2010;30(7):627–43.
[46] Graham JS, Schoneboom BA. Historical perspective on effects and treatment of sulfur mustard injuries. Chemico-Biological Interactions 2013; 206(3):512–22.
[47] Solberg Y, Alcalay M, Belkin M. Ocular injury by mustard gas. Survey of Ophthalmology 1997;41(6):461–6.
[48] BLODI FC. Mustard gas keratopathy. International Ophthalmology Clinics 1971;11(3):15.
[49] Borak J, Sidell FR. Agents of chemical warfare: sulfur mustard. Annals of Emergency Medicine 1992;21(3):303–8.
[50] Duke-Elder S. Non-mechanical injuries. System of ophthalmology; 1972. p. 888–96.
[51] Attaran D, et al. Highly sensitive C-reactive protein levels in Iranian patients with pulmonary complication of sulfur mustard poisoning and its correlation with severity of airway diseases. Human & Experimental Toxicology 2009;28(12):739–45.
[52] Attaran D, et al. Interleukin-6 and airflow limitation in chemical warfare patients with chronic obstructive pulmonary disease. International Journal of Chronic Obstructive Pulmonary Disease 2010;5:335.
[53] Panahi Y, et al. Short-term curcuminoid supplementation for chronic pulmonary complications due to sulfur mustard intoxication: positive results of a randomized double-blind placebo-controlled trial. Drug Research 2015;65(11):567–73.
[54] Safarinejad M, Moosavi S. Ocular injuries caused by mustard gas: diagnosis, treatment, and medical defense. Military Medicine 2001;166(1):67–70.
[55] Boskabady MH, Attaran D, Shaffei MN. Airway responses to salbutamol after exposure to chemical warfare. Respirology 2008;13(2):288–93.

[56] Emad A, Rezaian GR. The diversity of the effects of sulfur mustard gas inhalation on respiratory system 10 years after a single, heavy exposure: analysis of 197 cases. Chest 1997;112(3):734–8.
[57] Ellis J. Developments in Canadian environmental law: self regulatory initiatives under the New Canadian environmental protection ACT. OPENAIRE; 2002.
[58] Guidotti TL. Hydrogen sulfide: advances in understanding human toxicity. International Journal of Toxicology 2010;29(6):569–81.
[59] Brook RD, et al. Air pollution and cardiovascular disease: a statement for healthcare professionals from the expert panel on population and prevention science of the American heart association. Circulation 2004; 109(21):2655–71.
[60] Burtraw D, Bharvirkar R, McGuinness M. Uncertainty and the net benefits of emissions reductions of nitrogen oxides from electricity generation. Land Economics 2003;79(3):382–401.
[61] Finkelman FD, et al. Molecular mechanisms of anaphylaxis: lessons from studies with murine models. Journal of Allergy and Clinical Immunology 2005;115(3):449–57.
[62] Vyskocil A, Viau C, Lamy S. Peroxyacetyl nitrate: review of toxicity. Human and Experimental Toxicology 1998;17(4):212–20.
[63] Hamlat M, Djeffal S, Kadi H. Assessment of radiation exposures from naturally occurring radioactive materials in the oil and gas industry. Applied Radiation and Isotopes 2001;55(1):141–6.
[64] Eriksen D, et al. Radionuclides in produced water from Norwegian oil and gas installations—concentrations and bioavailability. Czechoslovak Journal of Physics 2006;56(1):D43–8.
[65] Shakhawat C, Tahir H, Neil B. Fuzzy rule-based modelling for human health risk from naturally occurring radioactive materials in produced water. Journal of Environmental Radioactivity 2006;89(1):1–17.
[66] Canadian N. Working Group of the federal provincial territorial. Radiation protection committee. Canadian guidelines for the management of naturally occurring radioactive materials (NORM). Minister of Public Works and Government Services Canada; 2000.
[67] Roman AI. Avaliação da poluição do ar com base nos aspectos anatômicos foliares e genotóxicos em Tradescantia pallida (Rose) Dr Hunt var. Purpurea. 2015.
[68] Zock J-P, et al. Health effects of oil spills: lessons from the Prestige. American Thoracic Society; 2011. p. 1094–6.
[69] Penny GS, Dobkins TA, Pursley JT. Field study of completion fluids to enhance gas production in the Barnett Shale. In: SPE gas technology symposium. OnePetro; 2006.
[70] Act C. Canadian Environmental Protection Act, 1999. Priority substances list assessment report. Nonylphenol and its ethoxylates. Environment Canada. Health Canada; 2001.
[71] Tibbetts P, et al. A comprehensive determination of produced water composition. In: Produced water. Springer; 1992. p. 97–112.
[72] Ishii S, Bell J, Marshall F. Phytotoxic risk assessment of ambient air pollution on agricultural crops in Selangor State, Malaysia. Environmental Pollution 2007;150(2):267–79.
[73] Belpomme D, et al. The multitude and diversity of environmental carcinogens. Environmental Research 2007;105(3):414–29.
[74] Cantor KP. Drinking water and cancer. Cancer Causes and Control 1997; 8(3):292–308.

SECTION

IV

Environmental issues regarding oil, gas, and petrochemical industries

This page intentionally left blank

12

Global warming and greenhouse effect resulted from oil, gas, and petrochemical units

Maryam Takht Ravanchi[1] **and Mansooreh Soleimani**[2]

[1]*Petrochemical Research and Technology Company, National Petrochemical Company, Tehran, Iran;* [2]*Department of Chemical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran*

1. Introduction

Low rainfall, temperature rise, and seasons fluctuations cause a decrease in global agricultural output and subsequently climate change [1]. There are many parts of the world in which, because of unwanted climate change, drought is experienced and that place is no longer suitable for commercial farming. On the other hand, soil and water degradation are caused by incessant precipitation and temperature changes. Although human activities have unwanted unfavorable emissions, but even upon their cease, climatic conditions would still change [2]. Global warming, desertification, acidification of the ocean, and weather condition changes are outcome of anthropogenic pollution and greenhouse gas emissions. Some examples of impacts of climate change are rise in sea levels, health problems, severe storms in coastal areas, and increase in economic damage [3].

In order to solve the problems of global warming and its subsequent climate change, some treaties were signed by some countries around the world for minimizing CO_2 (as a specific greenhouse gas) emission to the atmosphere. These treaties are [4]

- 1979 Geneva Convention
- 1987 Montreal Protocol
- 1997 Kyoto Protocol
- 2012 Doha amendment
- 2015 Paris agreement

Moreover, the Intergovernmental Panel on Climate Change (IPCC) prepared guidelines for control of greenhouse gases in

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00002-5

the member countries [5]. According to Paris agreement in 2015, any increase in interior Earth temperature should be maintained lower than 2°C in comparison to its value at pre-industrial level. Van-Soest et al. [6] reported that in order to achieve Paris agreement targets, until 2030, 1 Gt/year of CO_2 must be captured and stored.

It was reported [7] that globally, 33%–40% of CO_2 emission is related to fossil fuel–fired power plants and coal-fired power plants are the main contributors. As an example, 2–3 Mton/year CO_2 is emitted from a 500 MW power plant [8].

Some direct human activities on forestry such as soil degradation, deforestation, and agricultural land cleaning, cause anthropogenic CO_2 emission [9]. Human respiration, power plants, airplane emissions, and automobiles are other sources for anthropogenic CO_2 emissions. Climate change is not directly happened because of CO_2 emission into the atmosphere. At first, CO_2 emission depletes ozone layer; due to which Earth's surface is directly exposed to UV radiations from sun and consequently global warming and the unwanted inevitable climate change occurred (Fig. 12.1).

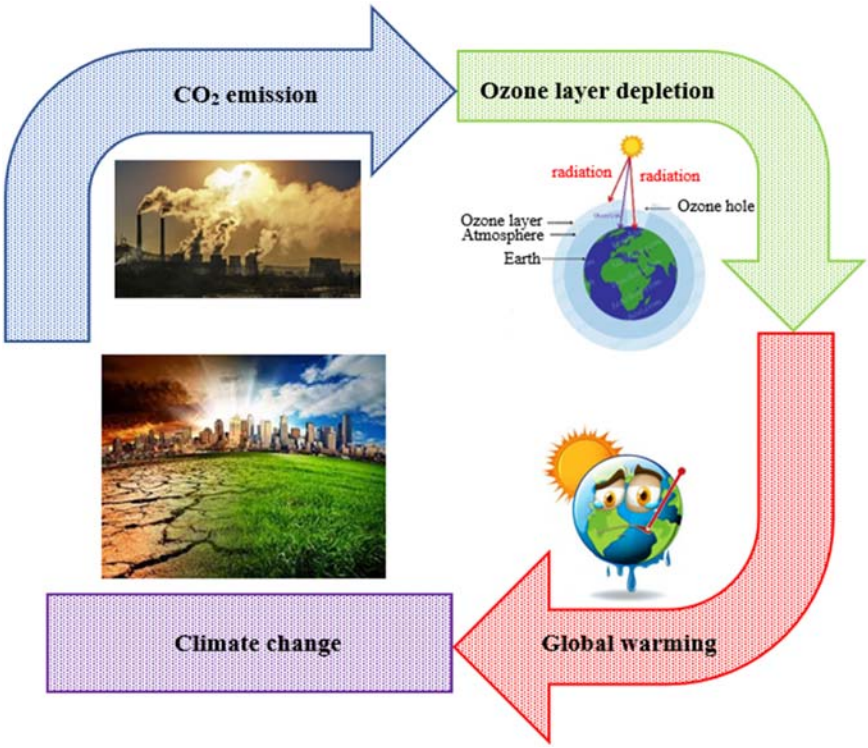


Figure 12.1 Global warming and its subsequent climate change from fossil fuel combustion.

It is predicted that in spite of expansion of renewable energy market in these days, oil and gas would still be the main energy infrastructure in the future. A 20%−35% increase (in comparison to its 2018 levels) is predicted for global energy consumption. Among different fuel sources, oil is the first and natural gas is the second one. It is predicted that by 2040, 25% of the global energy production will be based on natural gas [10]. Due to the global need for minimizing CO_2 emissions, the first highly recommended target is reducing anthropogenic carbon dioxide emissions from power plants. CCS[1] technology is a possible option for concurrent utilization of fossil fuels and minimization of CO_2 emissions [11].

In this chapter, global warming, greenhouse gases, and the impact of oil, gas, and petrochemical units on greenhouse effects are discussed in detail.

2. Climate change

Air atmosphere is made of different gases, mostly comprising N_2 (∼78%), oxygen (∼21%), Ar (∼0.9%), H_2O vapor (∼0.25%), and CO_2 and other gases [12].

Water vapor may have different concentrations (that is due to the location, humidity, and weather condition of its place) and consequently air in the atmosphere can have other chemical compounds as well. Moreover, dust from organic material and mineral deposits might be present in air. Chlorine and fluorine compounds, sulfur gas and mercury are industrial contaminants presented in the atmosphere.

Greenhouse effects, global warming, and ozone layer depletion are three terms in the theory of climate change. Normally, some anthropogenic replacements in the atmosphere or land utilization can cause climate change. As UNFCCC[2] clarifications mentioned, any (in)direct human activity that cause a change in global atmosphere composition (in addition to natural variations of climate) is called "climate change." Moreover, because of decades of global warming, climate change happened.

2.1 Global warming

Greenhouse is a place in farms in which plants are nurture and grow all over the year for maximum output. Normally, the

[1]Carbon Capture and Storage.
[2]The United Nations Framework Convention on Climate Change.

walls and roof of a greenhouse are made from polyethylene or glass. By controlling temperature, light, soil moisture, humidity, heat levels, and air quality in greenhouse, an artificial environment is created [12].

Usually, in greenhouses, objects are warmed-up by sunlight passing through translucent polyethylene or transparent glass of windows and roof. These materials do not let out the heat and temperature-rise occur inside greenhouse which provide the necessary heat of all seasons. This temperature-increase which is obtained by trapped heat is named "greenhouse effect."

There is a similarity between earth and greenhouse. As earth atmosphere is similar to windows and roofs of a greenhouse, it is transparent to solar radiations and shortwaves. The sun radiated energy, part of which is absorbed by the Earth's surface and the rest is sent back to the atmosphere as long waves; this causes Earth to warm up. Generally, in the atmosphere, keeping the greenhouse gas (GHG) level to an optimum value is necessary to avoid its global warming effect.

One source of releasing large amount of greenhouse gas and specifically CO_2 to the atmosphere is fossil fuel burning. Because of forests rapid eradiation, the growth of Earth's vegetation is exhausted and its subsequent capability for CO_2 absorption is decreased. By rising the unabsorbed CO_2 in the earth, radiation of solar energy to the space is inhibited. This trapped heat caused an increase in global temperature.

As earth is a big greenhouse, heat is trapped in it and causes global warming; that is gradual increase in global temperature. In a global climate report, Murdoch et al. [13] reported an average 0.07 °C per decade increase in ocean and land temperature, since 1880. As water has high thermal capacity, an instant reaction in ocean temperature (because of trapped heat by GHGs) is not observed.

2.2 (Non)Greenhouse gases

Nitrogen, oxygen, and argon are called non-greenhouse gases, because by their vibration there is not any change in their electrical charge distribution and they are unaffected by infrared radiation. Carbon monoxide and hydrogen chloride are also called as non-greenhouse gases, as they are short-lived.

The presence of greenhouse gases is somehow vital for habitable temperature of the Earth. If there are no greenhouse gases in the atmosphere, the average surface temperature of the Earth might be −18 °C [14].

Among different greenhouse gases, methane, water vapor, and carbon monoxide are the ones that are emitted due to oil and gas activities and fluorocarbons and nitrous oxide are the ones emitted because of human activities and wastewater treatment plants (WWTPs). For GHGs, their main anthropogenic sources, their global warming potential and their expected concentration in 2030 are provided in Table 12.1 according to which it is concluded that because of fossil fuel burning (that is necessary for power generation and some industrial activities), CO_2 is the most emitted GHG and chlorofluorocarbons (CFCs) are the least emitted GHGs (as the application of refrigerants in most of refrigeration systems are phased out) [12,15,16].

Chlorofluorocarbons are responsible for 25% of the anthropogenic production of GHGs. Generally, CFC caused depletion of stratospheric ozone layer. Any leak from air conditioners and refrigerators, plastics production and industrial solvent evaporation are human sources for CFC production. It is reported that CFCs can remain in the atmosphere for 65–135 years (based upon its variant). For its reach to stratospheric ozone layer, 10–20 years is needed. Recently, hydrofluorocarbons (HFCs) are replacing chlorofluorocarbons, as they have less GHG impact.

It is worth mentioning that the most abundant GHG is water vapor but it has insignificant influence on climate change due to its lowest greenhouse effect. Hence, the major GHGs that cause average temperature rise in the atmosphere are methane

Table 12.1 Main greenhouse gases.

Gas	Anthropogenic sources	Average life time in the atmosphere	Global warming potential	Preindustrial concentration in 1860 (ppb)	Emission in 2019 (%)	Predicted concentration in 2030 (ppb)
CH_4	Rice fields, fossil fuel production, biomass combustion, agricultural wastes	10 years	21	850	13	2300
CO_2	Fossil fuel burning, deforestation	100 years	1	290,000	76	500,000
CFCs	Refrigerants, aerosol sprays	60–100 years	1500–8100	0	1	2.4–6
N_2O	Fertilizers, biomass burning, deforestation	Few days	310	7	10	50

Adapted from Ref. [12] and [3].

(CH_4), carbon dioxide (CO_2), chlorofluorocarbons (CFCs), and nitrous oxide (N_2O) [17,18].

3. Fossil fuel birth

Million years ago, plants and animals' death body drowned in the bottom of the sea and their remains were buried. For millions of years, dead organism is buried in the soil and transferred into rocks where, in the absence of oxygen, organic matters are preserved. Due to the pressure inserted on dead organic matter, it is transformed to dark liquid oil which is subsequently extracted from the rock and called fossil fuel; which mainly consist of carbon and hydrogen with varying proportions; they can have volatile components with low C—H proportions such as butane gas, petroleum oil, and anthracite coal (that is pure nonvolatile carbon).

The extracted fossil fuel, as a non-renewable energy resource, is finally purified and used in homes, organizations, and industries and emitted greenhouse gases. It was announced that about 30% of global emissions are from global industrial sector.

Due to modern humanity and industrial revolution and subsequent fossil fuel burning, a 40% increase in atmospheric CO_2 concentration was observed; that is 280 ppm (in 1750) to 315 ppm (in 1959) and to 404 ppm (in 2016). The combustion of oil, coal, and natural gas (as fossil fuels), soil erosion, large cattle production, and unsustainable forest consumption are main culprit of this increase in CO_2 concentration. As nature cannot balance CO_2 concentration, humans must change their actions and behaviors.

4. Health-relevant emissions

Oil and gas production has negative impact on communities' health that reside near operation sites and also has primary contribution to global climate change. Particularly, greenhouse gases and air pollutants such as methane, ground ozone (O_3), volatile organic compounds (VOCs), hydrogen sulfide (H_2S), and particulate matter (PM) are major health threats [19,20].

During oil and gas production, different emissions are obtained that worsen climate change and causes subsequent air pollution, heat stress, weather events, mental health disorders, food insecurity, and waterborne illness.

4.1 Methane (CH_4)

Coal mining, municipal landfills, oil and gas production and subsequent distribution, guts of termites, and digestive tracts of cattle, goats, sheep, horses, pigs, rice and live-stock farming, wastewater and sewage treatments, and biomass combustion are different causes for increasing atmospheric methane concentration [21]. Energy sector (such as oil systems, coal mining, and natural gas systems) and fixed/mobile combustion systems are largest sources for CH_4 emissions. Some agricultural activities (e.g., breeding of cattle) and management of wastes can produce and emit methane (CH_4). Approximately 18% of methane is produced by human activities, 40% came from rice paddies, waterlogged soils, marshes, and bogs. Any temperature rise will cause a 20%–30% increase in CH_4 emission and subsequently increases global warming [16].

As biogas industry has impacts on climate change, the study of methane emission is important. Furthermore, it is largely released during biogas combustion [22]. During conservation and management of biomass and sludge treatment, some wastes are generated, that subsequently caused significant CH_4 emissions. In order to reduce biogenic CH_4 emissions, other forms of biomass management strategies must be taken into account.

Poeschl et al. [23] reported that cattle manuring and suitable managing of digestive products is one essential route for reducing methane emission. After decomposition, biomass has high methane emissions. If a non-decomposing feeding strategy is implemented for animals, before 2030, global CH_4 emissions can be reduced by 20%. One strategy for reducing emissions from coal mining and oil and gas sectors is preventing gas leak during its transportation and distribution, and its usage at production stage. By this strategy, more than 65% emission reduction can be obtained.

Methane is the main component of natural gas. Furthermore, it is a potential GHG with important contribution in global warming. Czolowski et al. [24] announced that methane, in comparison to carbon dioxide, after being released to the atmosphere, has 84 times more global warming potential (GWP). Moreover, oil and gas extraction sites have considerable contribution in methane emission; 96% of which is from oil and 57% is from natural gas.

As there are some methane emissions in different stages of exploration, transmission and processing of natural gas, decreasing these emissions is necessary for managing GHG emissions in the upstream. During recent years, different sectors tried to reduce their methane emissions but because of venting/flaring (due to safety reasons) and leaks or abnormal operating conditions methane emissions were increased by oil and gas producers. Generally, methane emissions occurred by pneumatic controllers (due to their malfunctions) happened onshore.

Methane, by itself, is non-toxic, but as it is the main natural gas component, its leak confirmed the availability of other gases. CH_4 emission plays an important role to man-made climate change and any health effects obtained by it. Generally, one-third of the methane is produced by natural sources and the rest is produced by human activities. It is predicted that methane be in the troposphere for 7−15 years.

4.2 Hazardous air pollutants

Hazardous air pollutants (HAPs) are regular oil and gas production byproducts with negative health effects and ability to cause cancer diseases. Having no specific shape and structure, they are grouped according to their human health impact. BTEX[3] are most common HAPs. They are naturally available in petroleum and released by vehicle emissions. During oil production, wellheads, large dehydrator tanks, and large separator tanks are significant sources for HAP emissions [12].

4.3 Hydrogen sulfide (H_2S) and sulfur dioxide (SO_2)

Hydrogen sulfide (H_2S) is a colorless harmful gas with many death cases in oil and gas industry. H_2S is a common crude oil impurity. Moreover, incomplete flare combustion, equipment leaks, improperly plugged gas and oil wells, and rapid pressure change of tanks can generate H_2S. Based upon NIOSH[4] announcement, 100 ppm of H_2S is hazardous as it can restrict the human's ability to escape from the location [11].

After being combusted by flaring, H_2S produced large amount of sulfur dioxide (SO_2). If inhaled, SO_2 has negative health impacts; its long exposure can cause respiratory illness and subsequently lung's defenses and worsen cardiovascular disease [25].

In the procedure of combusting carbonaceous fuels (such as diesel, coal, and petroleum) and any other materials containing sulfur, SO_2 is emitted. Fossil fuel combustion from power plants and other industrial complexes are main sources for SO_2 emission into the atmosphere. Metal processing, volcanoes, fuel-burning equipment, and locomotives are other SO_2 emission sources.

[3]Benzene, Toluene, Ethylbenzene, and Xylene.
[4]National Institute for Occupational Safety and Health.

Usually, high SO_2 sources are recorded around large industrial facilities [26]. As USEPA[5] announced, short-term SO_2 content has adverse health effect. By combining SO_2 with air poisons, sulfate particles are formed, inhaling and exposing to which can cause cardiovascular and respiratory health issues [27].

From another viewpoints, the combination of SO_2 and NO_x can lead to acid deposition which reduce visibility. Moreover, high SO_2 concentration can destroy vegetation by increased leaf damage, low crop yield, stunted plant growth, and reduced plant varieties in the ecosystem. The occurrence of acid rains that are harmful to ecosystem is a consequence of presence of high SO_2 concentration in the atmosphere. The corrosion of the materials used in buildings, monuments, and statues can be accelerated in the presence of SO_2 [28–30].

4.4 Particulate matter

Particulate matter that is a mixture of solid particles and liquid droplets, is produced by fossil fuels combustion. After being inhaled, particulate matter can cause lungs malfunction and probable cancers. Coronary artery disease, asthma, chronic obstructive lung disease, myocardial infarction, and bronchitis are common lung and heart disease linked to the presence of particulate matter [31].

In oil and gas industry and specifically in the upstream section, gas-powered and diesel equipment have increased application. Due to the long-term use of generators, hydraulic-fracturing pumps and trucks, air quality is affected near well sites and farther downwind [32].

4.5 Volatile organic compounds and ground ozone

There are volatile organic compounds (VOCs) in oil and gas production steps and leaks during natural gas exploration. Their volatility and their ability for participation in photochemical reactions are their specific characteristics. According to McMullin et al. [33] report, several hundred VOCs are emitted from oil and gas operations. As oil and gas wells are naturally pressurized and soluble, in all production sites, VOCs are available with different health risks.

The reaction between VOC and other chemicals is probable. Based upon the photochemical reaction between oxygen and ground pollutants (such as VOC and nitrogen oxides), ground

[5]US Environmental Protection Agency.

ozone is produced. In warm climate of industrialized complexes, ambient ground ozone level may increase from its allowable target values and people present in that place are vulnerable to ozone-related respiratory diseases.

4.6 N_2O emission

Approximately 6% of the global warming is due to nitrous oxide emissions, which is produced by dissociation of nitrogen fertilizers in the soil, biomass burning, nitrate-contaminated groundwater, wastewater, and human sewage and livestock wastes. It remains few days in the troposphere and depletes ozone in the stratosphere.

N_2O emission from biogas production processes cause global warming. Any wastewater containing organic-based nitrogen materials can be the source for N_2O emission [34]. Temperature, BOD[6] and N_2 concentration, and acidity of wastewater determined the amount of N_2O emissions. Soils, oceans, and tundra are natural N_2O sources. The first human contributor for N_2O emissions is fertilizers that are rich in nitrogen. Since 2005, N_2O emissions have grown by more than 35% [35].

5. CO_2 emission

Originally, CO_2 is available in the atmosphere from coal combustion in power plants. If CO_2 emission in the atmosphere is not controlled, its high concentration is continuously increased. Apadula et al. [36] reported a 45% increase in CO_2 concentration from 1980 to 2019. Moreover, during the last decade, CO_2 concentration was increased with the rate of 2 ppm/year [37] and since 1950, more than 400% increase for global CO_2 emissions from human activities was announced and atmospheric CO_2 concentration was increased to 410 ppm.

There are three different routes for reducing CO_2 emission; that are

- *CO_2 storage*: developing new capturing and sequestration technologies is needed.
- *CO_2 use*: using chemical reactions by which CO_2 is transformed to valuable chemicals and fuels.
- *Reduction in CO_2 production*: improving energy efficiency and shifting from fossil fuel to renewable energies.

[6] Biochemical Oxygen Demand.

Takht Ravanchi and Sahebdelfar [38] reported that a potential route for reducing CO_2 emission is CO_2 valorization by which about 10% per year reduction in world emission could be obtained.

For CO_2 capturing, as it is produced by different processes, a one-size-fits-all technology cannot be used for its capture. Pre-combustion, post-combustion, and oxy-fuel combustion are common technologies used for CO_2 capture. Interested researcher is refereed to Refs. [39,40] and [41] for the detailed description of these processes.

Physical or chemical absorption, adsorption, membrane separation, and cryogenic distillation are common techniques used for CO_2 separation from a process stream. As the detailed explanation of these processes is not within the scope of this chapter, interested reader is referred to Ref. [42].

By burning fossil fuels (such as natural gas, coal, and oils), trees, biological materials, and solid wastes, CO_2 is emitted to the atmosphere. Furthermore, some chemical reactions, such as cement production, have CO_2 emission. Some human activities such as fossil fuel burning and deforestation can also change carbon cycle [43].

As plants absorbs carbon dioxide, it is naturally sequestered from the atmosphere. In coal-fired power plants, the co-gasification of coal and biomass is another route for CO_2 emission mitigation [44].

Schubert and Jahren [45] reported that among different CO_2 emissions, natural ones are greater than human activities, but the former are closely balanced by rocks weathering and photosynthesis. Before, the start of the industrial era, for 10,000 years, the atmospheric CO_2 concentration was as low as 260–280 ppmv [46].

Different CO_2 emission sources and methods for their minimization are reported in Table 12.2. According to Table 12.2, as most of the main anthropogenic CO_2 emissions are from stationary point sources, CCSU[7] is the most suitable preventive option for CO_2 emission. In the CCSU protocols, waste CO_2 from large stationary points (such as coal or gas-fired power plants) is captured and deposited in safe storage location that cannot emitted back to the atmosphere [50].

The CO_2 release by fossil fuel burning happened in different major areas, as below:

[7]Carbon Capture Storage and Utilization.

Table 12.2 Main sources of CO_2 emissions.

Nonanthropogenic/natural sources	Prevention option	Anthropogenic/human sources	Prevention option
Volcanic eruptions	——	Cement production plants	CCSU
Ocean-atmosphere exchange	——	Transportation	Fuel blending with biomass
Plant, animal, and human respiration	——	Fossil fuel combustion	CCSU
Soil respiration and decomposition	——	Power generation (coal-fired power plants)	CCSU, integration to methanol plant
		Land use changes	—
		Industrial manufacturing	CCSU

Adapted from [47,48,49].

- In fossil fuel—fired power plants, electricity is generated by burning coal and natural gas. If nuclear and solar sources (as other cleaner alternatives) are replaced for power generation, lower CO_2 is emitted to the atmosphere.
- High CO_2 levels are obtained in the atmosphere by coal, diesel, and petrol combustion (that is used for running jets and automobiles). Global warming and climate change are consequences of these CO_2 levels. At high CO_2 volumes, CO_2 emission from automobile is non-stationary and, in this case, blending automobile fuels with bio-based ones or complete application of electricity or biofuels is good option for CO_2 emission mitigation [51].

  Orimoloye et al. [52] announced that in case of not reducing CO_2 emissions, devastating phenomena may occur in the Earth temperature:
- A 2 °C increase by 2050 and 4 °C increase by 2100 will occur in atmosphere temperature of coastal areas.
- A 4 °C increase by 2050 and 7 °C increase by 2100 will occur in the interior temperature of the Earth.
- Adversely affected world food security.
- The increase in invasive plants and their negative influence on Earth water resources.
- Forest fires occurred all around the world.

6. Reduction in the emission of GHG in different industries

6.1 Power generation

Being cheap and having available raw material sources, nowadays, in many countries, electricity is produced by burning fossil fuels. In comparison to petroleum or natural gas, coal has more carbon and consequently it emitted larger amounts of CO_2 per unit of produced electricity [53]. Hence, minimizing its CO_2 emission is highly needed. Some remedies are

- Application of efficient power plants by which fuel supply/unit of energy is reduced.
- Considering technologies with 35%–50% increase in coal plants efficiency.
- Using gasification in coal-fired power plants and subsequently combined cycle is used.
- Changing open cycle gas turbines to combined cycle for increasing installation efficiency.

These days, the combined application of renewable and nuclear energy sources is necessary. Wind, solar, and nuclear power plants are reasonable and cheap solution for low emission power generation [54].

6.2 Petrochemical plants

By crude oil distillation and subsequent reforming and cracking, different chemicals and fuels are produced in oil refineries. Any reaction with oxygenates produced CO_2. In a petrochemical plant, 20%–50% of CO_2 is produced in FCC[8] unit [55]. In ethylene oxide and ammonia plants, high-purity CO_2 is a byproduct stream. In the petrochemical industries, mostly, CO_2 is emitted from fuel oil combustion and combustible gas combustion [56]. In order to mitigate GHG emission from petrochemical plants, CO_2 capture from streams and flares are necessary. Absorption, adsorption, and membrane separation are different techniques that can be used in petrochemical industry for mitigating CO_2 emission.

6.3 Iron and steel industry

About 7% of global anthropogenic CO_2 emission is from steel and iron industry [57]. It is expected that by 2050, global steel

[8]Fluid catalytic cracking.

production be increased by 30%. Hence, reducing CO_2 emission in this industry is vital. In 2017–18, for each ton of produced steel, 1.83 tons of CO_2 were emitted [58]. By burning fossil fuels in iron and steel industry, 7%–9% direct CO_2 emission is obtained [59]. For improving plant efficiency and minimizing CO_2 emissions, the application of dry coke cooling, continuous casting, pressure recovery turbines and furnace gas recovery facilities is recommended. There are some strategies by which CO_2 emissions can be reduced such as

- Energy optimization; upgrading to new technologies with efficient energy usage.
- Fuel change; the application of a cleaner and less expensive fuel instead of coal.
- Scrap metal recycle instead of forging new steel.
- Training iron and steel operators in a manner that they can work with machineries in an optimized way with low CO_2 emissions and high steel production efficiency.

6.4 Cement industry

For reducing CO_2 emissions in the cement industry, the same approach as iron and steel industries is used [60], that is

- Changing wet production processes to dry ones.
- The application of alternative additives for replacing cement clinker.
- Changing coal and petroleum coke to biomass or co-gasified coal and biomass as fuel.

Moreover, extruded production capacity with precalciners and preheaters must be replaced by rotary kilns as modern dry production apparatus. As clinker production has direct CO_2 release to the atmosphere, cement production in clinker must be replaced by white cement factories. In clinkers, 60% of CO_2 is released from calcination and 40% is from combustion [61]. For cement production, a 18%–40% increase in other fuels supply is predicted for 2010–50 [62].

6.5 Wastewater treatment plants

According to the literature, wastewater treatment plants are one of the main sources of GHGs emission (approximately 3% of the global GHGs emissions). From the life-cycle perspective, 70%–94% of GHGs emission from these plants is obtained from activated sludge processes. GHGs emissions in WWTPS are generally classified into on-site and off-site or direct and indirect emission [63]. It was demonstrated that CH_4, N_2O, and CO_2 are

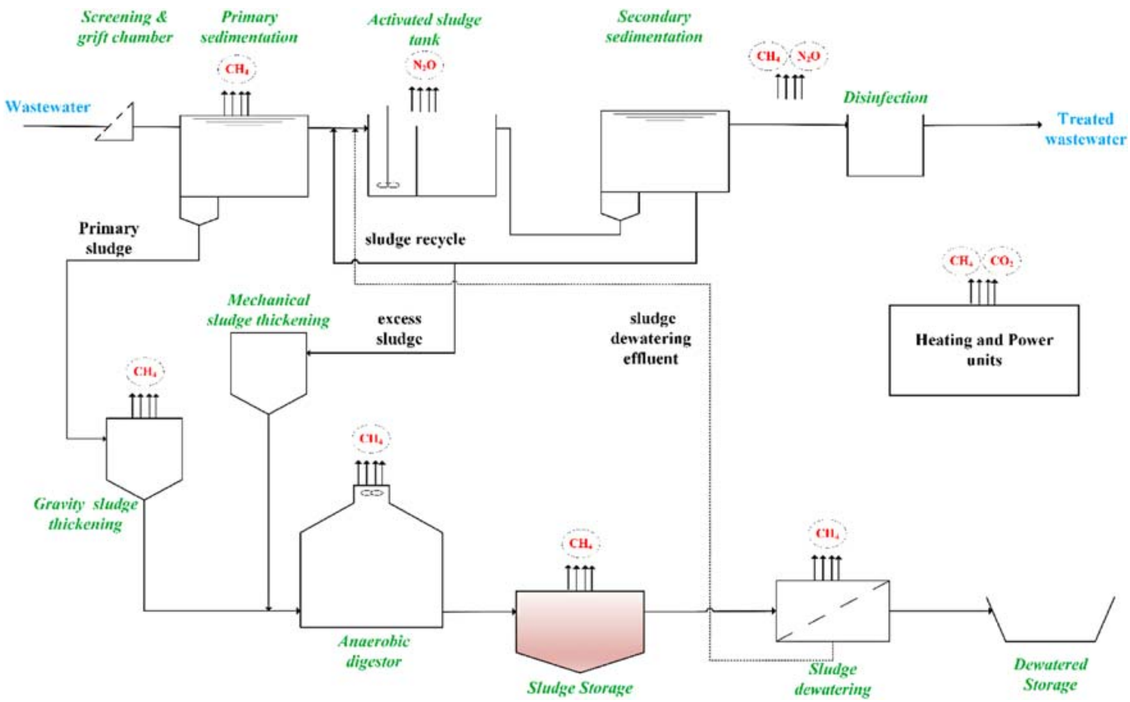


Figure 12.2 GHGs production and emission at wastewater treatment plants. (re-drawn from Refs. [65] and [66].

the main GHGs in these plants, which have a global warming potential of 25, 298, and 1 in 100 years, respectively [64]. These gases can be produced and emitted at various treatment stages (Fig. 12.2).

According to the IPCC guidelines, the main sources of CO_2 were the consumption of electricity, and aerobic and/or anaerobic biodegradation units of WWTPs [67]. Based upon the treatment stages in plants, Kumar et al. [16] suggested the following order for the CO_2 emissions:

aerobic reactors > CH_4 combustion facilities ≥ energy consumption.

Approximately, 26% of total greenhouse gases emitted from WWTPs is N_2O [68]. Most of the N_2O was produced and emitted from the sludge treatment process as an indirect emission [67]. Autotrophic and heterotrophic bacteria, respectively, have partial nitrification and denitrification activities by which N_2O emission occur. Kumar et al. [16] reported that N_2O production takes place in activated sludge processes.

CH_4 is produced mainly in anaerobic environments (such as lagoon unit and anaerobic digestion) and ordinary sewage treatment units (for example, such as sedimentation tanks and aeration tanks). The emissions from ordinary sewage treatment units were not considered in the emission factors (EFs) [67]. Campus et al. [69] announced that about 75% of methane emissions are from sludge line units. Proper sludge handling, capturing by hoods, and covering disposal tanks are three remedies for minimizing these emissions.

Based on EPA report, for rapidly developing countries (Eastern and Southern Asia), during 1990–2020, a 50% and 25% increase for CH_4 and N_2O emissions from wastewater plants were reported [70]. Hence, a thorough research is needed to understand potential sources of GHG emissions from WWTPs and propose their reduction approaches. Nowadays, modeling and operational tools are used for predicting GHG emissions. Researches are still needed to find effective reduction strategies for WWTPs.

7. CO_2 utilization

CO_2 valorization is classified as two groups [71,72]:

- Direct physical use of concentrated carbon dioxide
- Carbon dioxide conversion into fuels/chemicals

Since the Industrial Revolution, versatile applications are reported for carbon dioxide; for instance, in beverage industries for carbonated drink. Fire extinguisher, process fluid and welding medium, refrigerant, solvent, and dry ice are other small-scale utilization targets of CO_2. Large-scale industrial CO_2 utilization are EOR (Enhanced Oil Recovery), EGS (Enhanced Geothermal Systems), ECBM (Enhanced Coal-Bed Methane), and EGR (Enhanced Gas Recovery).

Carbon dioxide is a C_1 building block that can be used for chemicals synthesis. Moreover, as a carbon source, it can be used in the production of different C_1 building blocks. As CO_2 is thermodynamically very stable ($\Delta G^o{}_f = -394$ kJ/mol), its conversion has different kinetic and thermodynamic barriers and consequently, high-energy co-reactants and suitable catalysts are needed [50]. Carbon dioxide has highest carbon oxidation state (+4) and for its conversion, any reduction reactions to a negative-going oxidation state or mineralization to a lower Gibbs free energy is used for its conversion [73,74]. Nowadays, different chemicals are commercially produced from CO_2. Urea synthesis and methanol synthesis are two examples.

Based upon the oxidation state of C atom, CO_2 conversions are categorized to [75]:

- Reaction in which carbon dioxide is fixed onto an organic substrate. In these reactions, no alteration in carbon oxidation state (+4) is occurred and heat of reaction is small. Typically, lower temperatures of −30−150 °C is favorable for these reactions.
- Reactions in which CO_2 is converted to C_1 or C_n hydrocarbons used as fuels. Hydrogen, electrons, or heat are energy sources required for these reactions. Typically, higher temperatures of 300−700°C is suitable for these reactions.

The production of ureas, carboxylates and lactons, carbamates, carbonates, and isocyanates are examples of first group reactions. Hydrocarbons, carbon monoxide, formats, formaldehyde, oxylates, and methanol are examples of second group reactions.

Generally, different applications of CO_2 in catalytic conversions are categorized as

- CO_2 as mild oxidant
- CO_2 hydrogenation
- CO_2 to polymers
- CO_2 to fine chemicals

7.1 Carbon dioxide as mild oxidant

As CO_2 can dissociate on catalyst surface, active oxygen species can be produced that can be used as mild oxidants in heterogeneous catalyzed reactions. H-transfer agent, soft oxidant, and surface modifier are other roles of CO_2 in catalytic transformation processes [76]. High heat capacity and low oxidizing ability are characteristics of CO_2 molecule, due to which, by its application, the risk of hot-spot occurrence in the reactor and subsequent catalyst deactivation can be minimized. CO_2 is a promising oxidant in oxidative dehydrogenation reactions.

Methane dry reforming (Eq. 12.1) is an interesting CO_2 reaction in which CO_2 and natural gas (CH_4) are simultaneously used and transformed to syngas (CO and H_2) as a valuable product. The obtained syngas has highest CO/H_2 ratio. Furthermore, natural gas resources that are low-graded (because of the presence of CO_2 impurities) can be used for this reaction. Metal oxides, mono- and bi-metallic catalysts, and supported metal catalysts are used for methane dry reforming. Co, Ni, Rh, Ir, Pt, Ru, and Pd are different metals used in these catalysts and La_2O_3, CaO, CeO_2, Al_2O_3, SiO_2, MgO, ZrO_2, and TiO_2 are different oxide supports used for these catalysts [77].

$$CH_4 + CO_2 \Leftrightarrow 2CO + 2H_2 \quad \Delta H^o_{298} = 248\ kJ/mol \tag{12.1}$$

Alkane oxidative dehydrogenation by CO_2 is another reaction of this category, which is endothermic (Eq. 12.2). Many of the bulk and supported oxide catalysts can be used for this reaction [78].

$$C_3H_8 + CO_2 \Leftrightarrow C_3H_6 + CO + H_2O \quad \Delta H^o_{298} = 164\ kJ/mol \tag{12.2}$$

Oxidative dehydrogenation of ethylbenzene (Eq. 12.3) for styrene production in the presence of CO_2 is another example of this category. Zeolite supported iron oxide catalyst is the most common catalyst for this reaction. Generally, Fe, Cr, and V oxides supported on oxides (such as Al_2O_3, SiO_2, ZrO_2, MgO, WO_3, and ZnO), zeolites, and carbons can be used as catalysts [79].

$$C_6H_5 - CH_2CH_3 + CO_2 \Leftrightarrow C_6H_5 - CH = CH_2 + CO + H_2O \quad \Delta H^o_{298} = 159\ kJ/mol \tag{12.3}$$

Oxidative coupling of methane (OCM) in the presence of CO_2 (Eqs. 12.4 and 12.5) is the last example of this category [80]. MgO, $Na_2WO_4/Mn/SiO_2$, $CaO-CeO_2$, CeO_2, $CaO-ZnO$, and $CaO-MnO/CeO_2$ are different catalysts evaluated for this process [76].

$$2CH_4 + CO_2 \Leftrightarrow C_2H_6 + CO + H_2O \quad \Delta H^o_{298} = 106\ kJ/mol \tag{12.4}$$

$$2CH_4 + 2CO_2 \Leftrightarrow C_2H_4 + 2CO + 2H_2O \quad \Delta H^o_{298} = 284\ kJ/mol \tag{12.5}$$

7.2 Carbon dioxide hydrogenation

Fuels and basic chemicals are common CO_2 hydrogenation products with the largest market. Most of CO_2 hydrogenation technologies are in the research and development stage [81].

Methanol and hydrocarbons are common CO_2 hydrogenation products that can be used as clean fuel for internal combustion engines. Yang et al. [82] recommended to use electrolysis for water splitting to have renewable H_2 for CO_2 hydrogenation.

Methanol is one product of CO_2 hydrogenation (Eq. 12.6). It is an exothermic reaction with more water production (in comparison to CO hydrogenation of methanol synthesis). A major advantage of methanol production from pure CO_2 is limited production of ethanol, acetone, dimethyl ether (DME), and methyl ethyl ketone (MEK) as by-products. Generally, metal-based catalysts with Cu and Zn as the active phase and B, Ce, V, Cr, Zr, Al, Si, Ti, or Ga as promoters is used for this process [83].

$$3H_2 + CO_2 \Leftrightarrow CH_3OH + H_2O \quad \Delta H^o_{298} = -49.4\ kJ/mol \tag{12.6}$$

Dimethyl ether is another product of CO_2 hydrogenation that can be obtained by indirect (Eq. 12.7) or direct (Eq. 12.8) reaction routes.

$$2CH_3OH \Leftrightarrow CH_3OCH_3 + H_2O \quad \Delta H^o_{298} = -24.0\ kJ/mol \qquad (12.7)$$

$$6H_2 + 2CO_2 \Leftrightarrow CH_3OCH_3 + 3H_2O \quad \Delta H^o_{298} = -122.8\ kJ/mol \qquad (12.8)$$

In the indirect route, at first, methanol is synthesized by CO_2 hydrogenation (Eq. 12.6) and then dehydrated to DME (Eq. 12.7) [84]. One advantage of the indirect route is that the produced water in the internal stage can be removed and its adverse effect on catalyst is avoided.

Synthetic natural gas (SNG) is another product of CO_2 hydrogenation, namely CO_2 methanation (Eq. 12.9) that is highly exothermic and thermodynamically favorable. Moreover, lower temperature is favorable for complete equilibrium conversions [85]. All metals of group 8–10 of periodic table are active for methanation reaction. Ni, Rh, Co, Pd, and Ru as transition metals can be used for CO_2 methanation reaction. Because of their low cost, Co- and Ni-based catalysts are the best ones [86].

$$CO_2 + 4H_2 \Leftrightarrow CH_4 + 2H_2O \quad \Delta H^o_{298} = -165\ kJ/mol \qquad (12.9)$$

The production of C_{2+} hydrocarbons is another route for CO_2 hydrogenation. The common reaction of this category is Fischer-Tropsch in which CO is used as carbon source for hydrocarbon synthesis. Substituting CO by CO_2, a thermodynamically difficult reaction obtained (Eqs. 12.10 and 12.11) [87]. This process is a direct one for the synthesis of olefins and alkanes from carbon dioxide. As iron can promote C–C bond coupling, Fe-based catalysts are used in this reaction.

$$CO_2 + 3H_2 \Leftrightarrow -(CH_2)- + 2H_2O \quad \Delta H_{500} = -119\ kJ/mol \qquad (12.10)$$

$$CO_2 + 2H_2 \Leftrightarrow -(CH_2)- + H_2O + CO \quad \Delta H_{500} = -79.6\ kJ/mol \qquad (12.11)$$

7.3 Carbon dioxide to polymers

As carbon dioxide has high activity in polymerization reactions, its conversion has high yields. Alper and Orhan [88] suggested to use polymers with over 200 million tons per year production capacity for CO_2 chemical fixation.

Generally, polymer synthesis from CO_2 is performed from two approaches [89]:

- Direct route; in which CO_2 is directly used as a co-monomer in polymerization reaction. The synthesis of polyurea, polycarbonates, and polyurethanes from CO_2 are examples of this category.
- Indirect route; in which CO_2 is firstly converted to monomer, which in turn subsequently transformed to polymers.

The co-polymerization of CO_2 and epoxides for polycarbonates production is the favorable reaction of this category. Commonly, cyclohexane oxide, epichlorohydrin, and propylene oxide are used as epoxides.

By co-polymerizing propylene oxide and CO_2, poly(propylene carbonate) is obtained that is an eco-friendly cheap polymer [90].

7.4 Carbon dioxide to fine chemicals

High-cost industrial products that have well-defined purity and produced in small quantities are called "fine chemicals." Due to their small production capacity, they do not have any significant impact on global CO_2 mitigation. Salicylic acid is one example of fine chemicals that is produced based on carbon dioxide and it is commercialized for many years.

8. Conclusion

Researchers did their best to reduce anthropogenic CO_2 emission into the atmosphere. The available CO_2 capture technologies are naturally highly energy- and material-intensive and consequently CO_2 capture is an expensive technology. By applying process integration techniques, high energy and material requirements can be reduced in these CO_2 capture technologies.

CO_2 emission, at first, depletes the ozone layer that cause global warming (due to greenhouse effects) and subsequently climate change occurred. By using CO_2 capture technologies, fossil fuel combustion for power generation may still continue. Simultaneous integration in heat and mass exchanger networks can minimize cost as well.

Abbreviations and symbols

BOD biochemical oxygen demand
BTEX benzene, toluene, ethylbenzene, and xylene
CCS carbon capture and storage
CCSU carbon capture storage and utilization

CFC chlorofluorocarbon
DME dimethyl ether
ECBM enhanced coal-bed methane
EF emission factor
EGR enhanced gas recovery
EGS enhanced geothermal systems
EOR enhanced oil recovery
FCC fluid catalytic cracking
GHG greenhouse gas
GWP global warming potential
HAP hazardous air pollutant
HFC hydrofluorocarbon
IPCC Intergovernmental Panel on Climate Change
MEK methyl ethyl ketone
NIOSH National Institute for Occupational Safety and Health
OCM oxidative coupling of methane
PM particulate matter
SNG synthetic natural gas
UNFCCC The United Nations Framework Convention on Climate Change
USEPA US Environmental Protection Agency
VOC volatile organic compound
WWTP waste water treatment plant

References

[1] Sekoai PT, Yoro KO. Biofuel development initiatives in sub-Saharan Africa: opportunities and challenges. Climate 2016;4:33.
[2] VijayaVenkataRaman S, Iniyan S, Goic R. A review of climate change, mitigation and adaptation. Renewable and Sustainable Energy Reviews 2012;16:878–97.
[3] Yoro KO, Daramola MO. CO_2 emission sources, greenhouse gases, and the global warming effect. Advances in Carbon Capture 2020:3–28.
[4] Ourbak T, Magnan AK. The Paris Agreement and climate change negotiations: small islands, big players. Regional Environmental Change 2018;18(8):2201–7.
[5] Qiao S, Hou CY, Wang X, Zhou JT. Minimizing greenhouse gas emission from wastewater treatment process by integrating activated sludge and microalgae processes. Science of the Total Environment 2020;723:139032.
[6] Van-Soest HL, de Boer HS, Roelfsema M, den Elzen MGJ, Admiraal A, van Vuuren DP, et al. Early action on Paris Agreement allows for more time to change energy systems. Climate Changes 2017;144:165–79.
[7] Zhang Z. Making the transition to a low-carbon economy: the key challenges for China. Asia and the Pacific Policy Studies 2016;3:187–202.
[8] Koerner B, Klopatek J. Anthropogenic and natural CO_2 emission sources in an arid urban environment. Environmental Pollution 2002;116:45–51.
[9] Freund P. Anthropogenic climate change and the role of CO_2 capture and storage (CCS). In: Gluyas J, Mathias S, editors. Geological storage of carbon dioxide (CO_2). Sawston, Cambridge: Woodhead Publishing; 2013. p. 3–25.
[10] Newell R, Raimi D, Aldana G. Global energy outlook 2019: the next generation of energy. 2019. Available: https://media.rff.org/documents/GEO_Report_8-22-19.pdf.

[11] Lee J, Sorensen C, Lemery J, Workman CF, Linstadt H, Bazilian MD. Managing upstream oil and gas emissions: a public health-oriented approach. Journal of Environmental Management 2022;310:114766.

[12] Ahove MA, Bankole SI. Petroleum industry activities and climate change: Global to national perspective. The Political Ecology of Oil and Gas Activities in the Nigerian Aquatic Ecosystem 2018:277−92.

[13] Murdoch A, Mantyka-Pringle C, Sharma S. The interactive effects of climate change and land use on boreal stream fish communities. Science of the Total Environment 2020;700:134518.

[14] Olaniyi OA, Olutimehin IO, Funmilayo OA. Review of climate change and its effect on Nigeria ecosystem. International Journal of Rural Development, Environment and Health Research 2019;3:92−100.

[15] Saleh S, Pirouzfar V, Alihosseini A. Performance analysis and development of a refrigeration cycle through various environmentally friendly refrigerants. Journal of Thermal Analysis and Calorimetry 2019;136:1817−30.

[16] Kumar A, Thanki A, Padhiyar H, Singh NK, Pandey S, Yadav M, et al. Greenhouse gases emission control in WWTS via potential operational strategies: a critical review. Chemosphere 2021;273:129694.

[17] Miller GT. Environmental science sustaining the earth. California: Wadsworth Publishing; 1991.

[18] Miller GT, Spoolman SE. Living in the environment. 17th ed. Australia: Brooks/Cole; 2012.

[19] Jun. Garcia-Gonzales DA, Shamasunder B, Jerrett M. Distance decay gradients in hazardous air pollution concentrations around oil and natural gas facilities in the city of Los Angeles: a pilot study Environmental Research 2019a;173:232−6.

[20] Apr. Garcia-Gonzales DA, Shonkoff SBC, Hays J, Jerrett M. Hazardous air pollutants associated with upstream oil and natural gas development: a critical synthesis of current peer-reviewed literature Annual Review of Public Health 2019b;40:283−304.

[21] Turner AJ, Frankenberg C, Kort EA. Interpreting contemporary trends in atmospheric methane. Proceedings of the National Academy of Sciences of United States of America 2019;116:2805−13.

[22] Matuszewska A, Owczuk M, Zamojska-Jaroszewicz A, Jakubiak-Lasocka J, Lasocki J, Orlinski P. Evaluation of the biological methane potential of various feedstock for the production of biogas to supply agricultural tractors. Energy Conversion and Management 2016;125:309−19.

[23] Poeschl M, Ward S, Owende P. Environmental impacts of biogas deployment-part I: life cycle inventory for evaluation of production process emissions to air. Journal of Cleaner Production 2012;24:168−83.

[24] Czolowski ED, Santoro RL, Srebotnjak T, Shonkoff SBC. Toward consistent methodology to quantify populations in proximity to oil and gas development: a national spatial analysis and review. Environmental Health Perspectives 2017;125:086004.

[25] Khalaj F, Sattler M. Modeling of VOCs and criteria pollutants from multiple natural gas well pads in close proximity, for different terrain conditions: a Barnett Shale case study. Atmospheric Pollution Research 2019;10:1239−49.

[26] Rogers JF, Thompson SJ, Addy CL, McKeown RE, Cowen DJ, Decoufle P. Association of very low birth weight with exposures to environmental sulfur dioxide and total suspended particulates. American Journal of Epidemiology 2000;151:602−13.

[27] Jiang XQ, Mei XD, Feng D. Air pollution and chronic airway diseases: what should people know and do? Journal of Thoracic Disease 2016;8:31−40.

[28] Zeng Y, Li K. Influence of SO_2 on the corrosion and stress corrosion cracking susceptibility of supercritical CO_2 transportation pipelines. Corrosion Science 2019:108404.
[29] Wang X, Li Y, Zhang W, Zhao J, Wang Z. Simultaneous SO_2 and NO removal by pellets made of carbide slag and coal char in a bubbling fluidized-bed reactor. Process Safety and Environmental Protection 2020;134:83–94.
[30] Joo SH, Bhatti UH, Park HJ, Jeong DH, Baek IH, Nam SC, et al. Selective removal of SO_2 from coal-fired flue gas by alkaline solvents using a membrane contactor. Chemical Engineering and Processing: Process Intensification 2019:107772.
[31] Epa U. Health and environmental effects of particulate matter (PM). 2016. Available: https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm.
[32] Bunch AG, Perry CS, Abraham L, Wikoff DS, Tachovsky JA, Hixon JG, et al. Evaluation of impact of shale gas operations in the Barnett Shale region on volatile organic compounds in air and potential human health risks. Science of the Total Environment 2014;468:832–42.
[33] McMullin TS, Bamber AM, Bon D, Vigil DI, Van Dyke M. Exposures and health risks from volatile organic compounds in communities located near oil and gas exploration and production activities in Colorado (U.S.A.). International Journal of Environmental Research and Public Health 2018;15:1500.
[34] Paolini V, Petracchini F, Segreto M, Tomassetti L, Naja N, Cecinato A. Environmental impact of biogas: a short review of current knowledge. Journal of Environmental Science and Health, Part A: Environmental Science and Engineering 2018;53:899–906.
[35] Zhang J, Han X. N_2O emission from the semi-arid ecosystem under mineral fertilizer (urea and superphosphate) and increased precipitation in northern China. Atmospheric Environment 2008;42:291–302.
[36] Apadula F, Cassardo C, Ferrarese S, Heltai D, Lanza A. Thirty years of atmospheric CO_2 observations at the plateau rosa station Italy. Atmosphere 2019;10:418.
[37] Kelektsoglou K. Carbon capture and storage: a review of mineral storage of CO_2 in Greece. Sustainability 2018;10:4400.
[38] Takht Ravanchi M, Sahebdelfar S. Catalytic conversions of CO_2 to help mitigate climate change: recent process developments. Process Safety and Environmental Protection 2021;145:172–94.
[39] Takht Ravanchi M, Sahebdelfar S, Tahriri Zangeneh F. Carbon dioxide sequestration in petrochemical industries with the aim of reduction in green-house gas emissions. Frontiers of Chemical Science and Engineering 2011;5:173–8.
[40] Kargari A, Takht Ravanchi M. Carbon dioxide: capturing and utilization. In: Liu G, editor. Greenhouse gases—capturing, utilization and reduction. Intech Open; 2012. https://doi.org/10.5772/33953.
[41] Takht Ravanchi M, Sahebdelfar S. Carbon dioxide capture and utilization in petrochemical industry: potentials and challenges. Applied Petrochemical Research 2014;4:63–77.
[42] Takht Ravanchi M, Soleimani M. Porous materials for CO_2 fixation; Activated carbon, MOFs, nanomaterials. In: Kumar A, Sharma S, editors. Chemo-biological systems for CO_2 utilization. CRC Press; 2020.
[43] Amaral SS, Costa MAM, Neto TGS, Costa MP, Dias FF, Anselmo E, et al. CO_2, CO, hydrocarbon gases and $PM_{2.5}$ emissions on dry season by

deforestation fires in the Brazilian Amazonia. Environmental Pollution 2019;249:311–20.
[44] Ozonoh M, Aniokete TC, Oboirien BO, Udeh BC, Yoro KO, Daramola MO. Prediction of emissions and profits from a biomass, tyre, and coal fired co-gasification CHP plant using artificial neural network: Nigerian and South African perspectives. Journal of Physics: Conference Series 2019;1378:022021.
[45] Schubert BA, Jahren AH. The effect of atmospheric CO_2 concentration on carbon isotope fractionation in C_3 land plants. Geochimica et Cosmochimica Acta 2012;96:29–43.
[46] Liu M, Wu J, Zhu X, He H, Jia W, Xiang W. Evolution and variation of atmospheric carbon dioxide concentration over terrestrial ecosystems as derived from eddy covariance measurements. Atmospheric Environment 2015;114:75–82.
[47] Davis SJ, Caldeira K, Matthews HD. Future CO_2 emissions and climate change from existing energy infrastructure. Science 2010;329:1330–3.
[48] Oertel C, Matschullat J, Zurba K, Zimmermann F, Erasmi S. Greenhouse gas emissions from soils—a review. Geochemistry 2016;76:327–52.
[49] Cai Q, Yan X, Li Y, Wang L. Global patterns of human and livestock respiration. Scientific Reports 2018;8:1–7.
[50] Nocito F, Dibenedetto A. Atmospheric CO_2 mitigation technologies: carbon capture utilization and storage. Current Opinion in Green and Sustainable Chemistry 2020;21:34–43.
[51] Shukla SK. Renewable biofuels and their by-products for automotive applications. In: Encyclopedia of renewable and sustainable materials, 3; 2020. p. 180–6.
[52] Orimoloye IR, Mazinyo SP, Kalumba AM, Ekundayo OY, Nel W. Implications of climate variability and change on urban and human health: a review. Cities 2019;91:213–23.
[53] Wang Q, Ge S. Uncovering the effects of external demand on China's coal consumption: a global input-output analysis. Journal of Cleaner Production 2020;245:118877.
[54] Jenkins JD, Luke M, Thernstrom S. Getting to zero carbon emissions in the electric power sector. Joule 2018;2:2498–510.
[55] Al-Sabawi M, Chen J, Ng S. Fluid catalytic cracking of biomass-derived oils and their blends with petroleum feedstocks: a review. Energy and Fuels 2012;26(9):5355–72.
[56] Vooradi R, Anne SB, Tula AK, Eden MR, Gani R. Energy and CO_2 management for chemical and related industries: issues, opportunities and challenges. BMC Chemical Engineering 2019;1:7.
[57] An R, Yu B, Li R, Wei YM. Potential of energy savings and CO_2 emission reduction in China's iron and steel industry. Applied Energy 2018;226:862–80.
[58] Sun W, Zhou Y, Lv J, Wu J. Assessment of multi-air emissions: case of particulate matter (dust), SO_2, NO_x and CO_2 from iron and steel industry of China. Journal of Cleaner Production 2019;232:350–8.
[59] Xu W, Wan B, Zhu T, Shao M. CO_2 emissions from China's iron and steel industry. Journal of Cleaner Production 2016;139:1504–11.
[60] Morrow WR, Hasanbeigi A, Sathaye J, Xu T. Assessment of energy efficiency improvement and CO_2 emission reduction potentials in India's cement and iron and steel industries. Journal of Cleaner Production 2014;65:131–41.

[61] Leung DYC, Caramanna G, Maroto-Valer MM. An overview of current status of carbon dioxide capture and storage technologies. Renewable and Sustainable Energy Reviews 2014;39:426—43.
[62] Shen W, Cao L, Li Q, Zhang W, Wang G, Li C. Quantifying CO_2 emissions from China's cement industry. Renewable and Sustainable Energy Reviews 2015;50:1004—12.
[63] Lu JJ, Dong Z, Li P, Yan W, Yuan J, Dong W, et al. Reduction of greenhouse gas (GHG) emission in the vegetation-activated sludge process (V-ASP) involving decontaminated plants for decentralized wastewater treatment. Journal of Cleaner Production 2022;362:132341.
[64] IPCC Climate Change. The physical science basis. 2007.
[65] Masuda S, Suzuki S, Sano I, Li YY, Nishimura O. The seasonal variation of emission of greenhouse gases from a full-scale sewage treatment plant. Chemosphere 2015;140:167—73.
[66] Paravinici V, Svardal K, Krampe J. Greenhouse gas emission from wastewater treatment plants. Energy Procedia 2016;97:246—53.
[67] IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html; 2006.
[68] Wang X. A refined assessment methodology for wastewater treatment alternatives. In: Energy consumption, chemical use and carbon footprints of wastewater treatment alternatives. Singapore: Springer; 2020. p. 57—77.
[69] Campos JL, Valenzuela-Heredia D, Pedrouso A, Val del Río A, Belmonte M, Mosquera-Corral A. Greenhouse gases emissions from wastewater treatment plants: minimization, treatment, and prevention. Journal of Chemistry 2016:3796352.
[70] US EPA. Global anthropogenic non-CO_2 greenhouse gas emissions: 1990—2020. 2006. p. 1—16. http://www.epa.gov.
[71] Tahriri Zangeneh F, Sahebdelfar S, Takht Ravanchi M. Conversion of carbon dioxide to valuable petrochemicals: an approach to clean development mechanism. Journal of Natural Gas Chemistry 2011;20:219—31.
[72] Sahebdelfar S, Takht Ravanchi M. Heterogeneous catalytic hydrogenation of CO_2 to basic chemicals and fuels. In: Kumar A, Sharma S, editors. Chemo-biological systems for CO_2 utilization. CRC press; 2020.
[73] Duan Y, Zhang K, Li XS, King DL, Li B, Zhao L, et al. Ab initio thermodynamic study of the CO_2 capture properties of M_2CO_3 (M=Na, K)- and $CaCO_3$-promoted MgO sorbents towards forming double salts. Aerosol and Air Quality Research 2014;14:470—9.
[74] Wang WN, Soulis J, Yang YJ, Biswas P. Comparison of CO_2 photo reduction systems: a review. Aerosol and Air Quality Research 2014;14:533—49.
[75] Aresta M, Dibenedetto A. Carbon dioxide fixation into organic compounds. In: Carbon dioxide recovery and utilization. Dordrecht; Boston; London: Kluwer Academic Publishers; 2003.
[76] Ansari MB, Park SE. Carbon dioxide utilization as a soft oxidant and promoter in catalysis. Energy & Environmental Science 2012;5:9419—37.
[77] Wittich K, Krämer M, Bottke N, Schunk SA. Catalytic dry reforming of methane: insights from model systems. ChemCatChem 2020;12:2130—47.
[78] de Oliveira JFS, Volanti DP, Bueno JMC, Ferreira AP. Effect of CO_2 in the oxidative dehydrogenation reaction of propane over Cr/ZrO_2 catalysts. Applied Catalysis, A: General 2018;558:55—66.
[79] Reddy BM, Jin H, Han DS, Park SE. Oxidative dehydrogenation of ethylbenzene to styrene with carbon dioxide over Fe_2O_3/TiO_2-ZrO_2 catalyst: influence of chloride. Catalysis Letters 2008;124:357—63.

[80] Sahebdelfar S, Takht Ravanchi M, Gharibi M, Hamidzadeh M. Rule of 100: an inherent limitation or performance measure in oxidative coupling of methane? Journal of Natural Gas Chemistry 2012;21:308–13.
[81] Zhou W, Cheng K, Kang J, Zhou C, Subramanian V, Zhang Q, et al. New horizon in C_1 chemistry: breaking the selectivity limitation in transformation of syngas and hydrogenation of CO_2 into hydrocarbon chemicals and fuels. Chemical Society Reviews 2019;48:3193–228.
[82] Yang C, Ma Z, Zhao N, Wei W, Hu T, Sun Y. Methanol synthesis from CO_2-rich syngas over a ZrO_2 doped Cu-ZnO catalyst. Catalysis Today 2006;115: 222–7.
[83] Arena F, Barbera K, Italiano G, Bonura G, Spadaro L, Frusteri F. Synthesis, characterization and activity pattern of Cu-ZnO/ZrO_2 catalysts in the hydrogenation of carbon dioxide to methanol. Journal of Catalysis 2007;249: 185–94.
[84] Rafiee A, Khalilpour KR, Milani D. CO_2 Conversion and Utilization Pathways. In: Polygeneration with polystorage for chemical and energy hubs. Academic Press; 2019. p. 213–45.
[85] Sahebdelfar S, Takht Ravanchi M. Carbon dioxide utilization for methane production: a thermodynamic analysis. Journal of Petroleum Science and Engineering 2015;134:14–22.
[86] Li W, Wang H, Jiang X, Zhu J, Liu Z, Guo X, et al. A short review of recent advances in CO_2 hydrogenation to hydrocarbons over heterogeneous catalysts. RSC Advances 2018;8:7651–69.
[87] Muleja AA, Yao Y, Glasser D, Hildebrandt D. Variation of the short-chain paraffin and olefin formation rates with time for a cobalt Fischer-Tropsch catalyst. Industrial & Engineering Chemistry Research 2017;56:469–78.
[88] Alper E, Orhan OY. CO_2 utilization: Developments in conversion processes. Petroleum 2017;3:109–26.
[89] Langanke J, Wolf A, Peters M. Polymers from CO_2- an industrial perspective. In: Styring P, Quadrelli A, Armstrong K, editors. Carbon dioxide utilization-closing the carbon cycle. Amsterdam, Boston, Heidelberg: Elsevier; 2015.
[90] Klaus S, Lehenmeier MW, Herdtweck E, Deglmann P, Ott AK, Rieger B. Mechanistic insights into heterogeneous zinc dicarboxylates and theoretical considerations for CO_2-epoxide co-polymerization. Journal of the American Chemical Society 2011;133:13151–61.

13

Environmental concerns of wastes released from oil, gas, and petrochemical units

Vahid Mortezaeikia[1], Masoud Dehghani-Soufi[2] and Sadaf Mohebi[3]

[1]*School of Chemical Engineering, College of Engineering, University of Tehran, Tehran, Iran;* [2]*School of Environment, College of Engineering, University of Tehran, Tehran, Iran;* [3]*Biosystems Engineering Department, College of Aburaihan, University of Tehran, Tehran, Iran*

1. Introduction

Human efforts to improve quality of life have resulted in significant waste exposure in the environment. Natural resources are being depleted, leading to environmental destruction [1]. Over the last few decades, environmental concerns have risen in the oil and gas sectors since providing energy security makes industrial plants grow faster. Petrochemical plants have increased dramatically in oil- and gas-producing countries. Excluding the scale of production of major industrial chemicals, one can understand the relative importance of the petrochemical sector relative to the chemical industry as a whole [2].

The various environmental problems that have been solved over the years were in an everyday global context during the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in June 1992. The main environmental issues facing the oil and gas exploration and production industries locally and globally include habitat and biodiversity protection, air emissions, marine emissions, and fresh water, oil spills and incidents, and soil and groundwater pollution [3].

The oil and gas industrial plants were classified as upstream—the exploration and production sector of the industry; and downstream—which deals with refining and processing of crude in the oil and gas products. Regarding the plant type, generated

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00011-6

wastes are different. The waste generated is classified as hazardous and non-hazardous according to the Basel Convention and the Environmental Protection Agency's Waste Classification List. Typically the oil and gas units generate a significant portion of wastewater, industrial waste, and air pollution with various toxic substances; they can be considered an important source of hazardous waste, consisting of highly toxic chemicals and some complex chemical compounds [4].

According to a report by the World Bank Group [70], about 80% of the waste generated in the oil and gas industries is composed of hazardous materials, for example, toxic organic compounds and heavy metals [5].

This chapter is majorly focused on the potential harms of the waste generation in oil and gas sector. Firstly, a background study of the literature available on the toxic effects of oil, gas, and petrochemical industries waste is reviewed. This is followed by a review of the health risks of the oil and gas sector wastes on community, workers, and wildlife, followed by the reliability of processes available for petrochemical waste degradation. Further, regulatory concerns, such as limitations and future perspectives, are critically reviewed. Main environmental problems in different sectors of oil, gas, and petrochemical plants are surveyed according to the literature review.

2. Concerns regarding population health

2.1 Public health

Upstream oil and gas production, including exploration and operation to extract crude oil and natural gas to the surface, frequently happens close to human communities. Developing the ability to practice health-sensitive and carbon measurements for the oil and gas sector is essential for protecting human health. Research investigations (implementing various techniques for sampling) have reported raised risks for people living within one mile from active oil and gas sites. Table 13.1 shows the typical public health threats of the oil and gas industry.

Although some studies mentioned in Table 13.1 found a positive relationship between cancer mortality rate and living near active sites, Moolgavkar et al. [69] saw no difference between regions in cancer mortality rates. Despite efforts, current studies lack health risk assessment based on different sampling methods employment.

Table 13.1 Various chronic diseases and acute symptoms caused by the oil and gas industry.

Diseases	Company/ Country	Outcome concerns	Reference(s)
Cancer	Amazon basin	Childhood blood stem cells increased	[6]
	US	Children with acute lymphoblastic leukemia were 4.3 times more likely to live near working oil and gas wells than controls (children with non-hematologic cancers)	[7]
	Ecuador	Significant increase in relative risk of leukemia in children younger than 14 years	[8]
Acute and chronic effect	New Mexico	Increased prevalence of rheumatic diseases, lupus, respiratory symptom, cardiovascular problems, and neurological symptom compared to remote communities	[9]
	Assam/India	Evidence of alteration of liver abnormality	[10]
	Kazakhstan	Evidence of allergic disease	[11]
	Kazakhstan	A significant increase in thyroid volume in school-age children	[12]
	Nigeria	Higher rates of neurological symptoms	[13]

2.2 Labors health

Several epidemiological studies of oil industry workers have been conducted to investigate whether there is excess mortality from cancer. Most of these were confined to oil refinery (or "downstream") workers. An increased incidence of hematopoietic cancers, particularly acute myelogenous leukemia (AML) and multiple myeloma, has been found in Norwegian offshore operators and is most likely related to benzene exposure [14].

Hydrogen sulfide is the significant cause of gas inhalation deaths in workplaces. Either 100 ppm concentration of H_2S endangers laborers health, as the gas volume instantly occupies one's lung capacity, which H_2S has a higher density than air, and reduces the potential of break out from the location [15].

2.3 Flora and fauna health

Quality and quantity of animals and vegetation decrease in areas nearby the oil and gas sites, and this will happen in each phase of construction and operation until post-operation phase. Creating sites for the oil and gas plants will clear lands and reduce the amount of the land for natural habitat. Furthermore, in the case that site placed in the forest area, it will increase the amount of deforestation. Heavy equipment running and the intense illumination can cause disorientation for the body's biological hour and metabolism time [16]. Animals will get confused by the light and assume it is morning.

Furthermore, the heat effect caused by flaring activity could be the reason for the death toll of animals and make the terrestrial vegetation less productive. The companies should address these issues and conduct reforestation after the project is completed.

3. Potential environmental exposure concerns

Regarding pollution, the oil and gas industry belongs to the group of large-scale enterprises with heavy pollution. The generation of petroleum waste, gas burning in burners, and the displacement of crude oil are among the significant environmental impacts of the oil and gas industry, paving the way for water, soil, and air pollution [17].

3.1 Upstream facilities

Drilling waste is the second largest volume of waste generated in the E&P industry, after water is produced [18]. Previously, the composition of drilling muds had significant toxicity to humans and the environment. However, the composition has changed over the years, with a general trend toward less toxic materials [19] (Table 13.2).

3.1.1 Air pollution

The gas emission in the production step of oil and gas is of particular concern due to exposure to high concentration volatile organic compounds (VOCs), particulate matter (PM), and other gases that function as air pollutants. Fig. 13.1 shows environmental concerns about releasing methane and other gases during upstream activities in the oil and gas industry.

Flaring and unintentional leaks are another source of air pollution. CO_2, CO, and SO_2 are the products of flare gas combustion reactions, released continuously into the atmosphere. Table 13.3 shows concerns regarding the emissions classified as VOCs, gases at ambient pressure and temperature.

Table 13.2 Wastes component and Environment-related constituents [20].

Type of waste	Main components	Possible environment-related constituents
Waste lubricants	Grease, lube oil	Heavy metals, organics
Spacers	Surfactants, detergents, and mineral oil	Aromatics, hydrocarbon, and alcohol
Spent water-based muds	Biodegradable matter, whole mud, and mineral oil	Organics, BOD, hydrocarbons, inorganic salts, heavy metals
Water-based muds cutting	Solids, mineral oil	Inorganic salts, heavy metals, hydrocarbons, biocides, heavy metals
Spent/contaminated oil-based muds	Whole mud mineral oil	Hydrocarbons, heavy metals, inorganic salts, solids, BOD, organics, surfactants
Oil-based mud cuttings	Formation solids, oil-based mud	Heavy metals, inorganic salts, hydrocarbons, solid/cutting
Spent special products	H_2S scavengers Defoamers, tracers	Zinc carbonates, iron oxides, hydrocarbons, silicon oils, potassium salts, radioactive material
Spent bulk chemical	Thinners, viscosities, bentonite, barites, fluid loss reducers, cement	Heavy metals, hydrocarbons, organics, solids

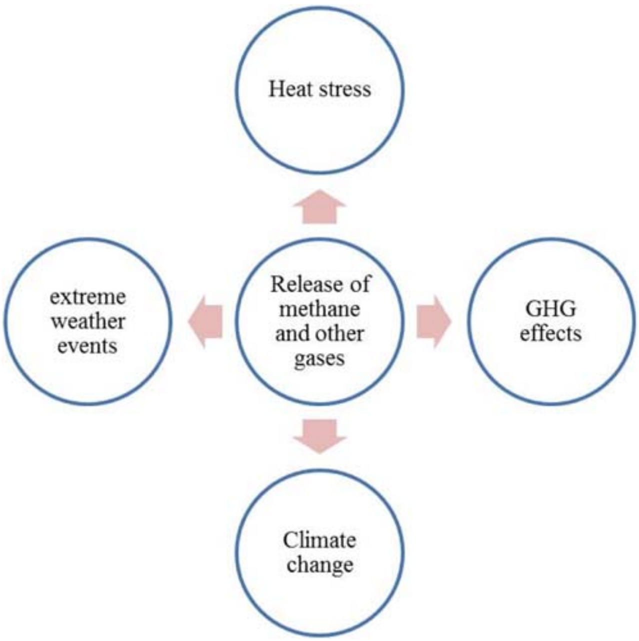


Figure 13.1 Environmental effects of methane and other gases release in upstream operational areas.

Table 13.3 Main VOCs emitted from upstream plants and related concerns.

VOCs	Negative effect	Reference(s)
Benzene and ethyl benzene	• Anemia, leukemia, and immunological effects	[21]
	• Neural tube defects	[22]
	• Congenital heart defects	[23–25]
	• Endocrine disruption	[26]
Toluene	• Endocrine disruption	[26]
	• Nervous system damage	[24]
Acrolein	• Irritation of eye, nose, and throat, difficulty breathing	[27]
Xylenes	• The uneasiness of breath, chest pain, palpitations, nausea, vomiting	[28]
	• Nervous system impairment	[24,25]

Moreover, VOCs can react with other substances to create tropospheric ozone. When sunlight starts a photochemical reaction between oxygen and ground pollutants (VOCs and Nitrogen Oxides), O_3 is created.

The other significant concern regarding emissions is the amount of gas emitted, public exposure levels, the prevalence of health effects, and lack of consensus on the completeness of previous studies. This discrepancy makes it difficult to effectively quantify health impacts, create effective regulations, and provide operational recommendations to the oil and gas industry [29].

3.1.2 Soil contamination

The earth is contaminated in the drilling process when spills of liquid during transportation via trucks or sewage pipelines, breaches in well casings, or leaking tank pipes can expose contaminated areas to direct ingestion, skin contact, harvesting, and inhalation of indoor and outside soil particles, and/or through diffusion into groundwater, labors and neighborhood residents at highest risk of exposure [30].

3.1.2.1 Organics

Polycyclic aromatic hydrocarbons (PAHs) are considered one of the most stable forms of hydrocarbons and are mostly concentrated in contaminated soils. Both natural and manufactured sources are important and should be evaluated. Qi et al. estimated increased lifetime cancer risk (ILCR) of soil contaminated by 15 priority PAHs (polycyclic aromatic hydrocarbon) in 11 cities of Shanxi province, China, cancer risk among potentially low residents showed significant increases in two areas [31]. On the other hand, the higher the molecular weight of PAHs, the deeper they are detected. PAHs of concern to environmentalists have been categorized into 16 priorities by the Environmental Protection Agency (EPA): acenaphthene, acenaphthylene, anthracene, benz(a)anthracene, naphthalene, benzo(a)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd) pyrene, phenanthrene, and pyrene [32].

Hundreds of individual chemicals in the form of total petroleum hydrocarbons (TPH) from various processes, including spillage during transportation, accidental leakage during mining, disposal, treatment, and production of waste from industrial activities, contribute to soil pollution. Typically, the sum of volatile PHs (VPHs) and extractable PHs (EPHs) refers to TPHs. VPHs include C_6-C_{12} aliphatic, BTEX, methyl tertiary-butyl ether (MTBE), naphthalene, and C_9-C_{10} aromatics. EPHs include C_9-C_{35} aliphatic and $C_{11}-C_{22}$ aromatics. TPH concentrations are expected to adversely affect soil quality, and microbial health, can remain in the water and accumulate in sediments [33].

3.1.2.2 Inorganics

Heavy metals associated with drilling fluid additive components are a concern, but their low concentrations and low solubility limit their potential to leach out of pits and contaminate groundwater [20]. Some trace elements are referred to as heavy metals, for example, copper (Cu), selenium (Se), and zinc (Zn). Although they are necessary to maintain the body's metabolism, but still are toxic in higher concentrations. Heavy metals can enter the body to a small extent through food, water, and air. The heavy metals related to environmental studies mainly include Pb, Hg, Cd, Cr, Cu, Zn, manganese (Mn), nickel (Ni), silver (Ag), and vanadium (V). Excess amounts of heavy metals are harmful because they destabilize ecosystems by bioaccumulating in organisms and cause toxic effects on biological populations and even death to most organisms [34]. Moreover, several studies conducted on the impact of heavy metals are listed in Table 13.4.

Nwankwo et al. experimented soil samples from Nigerian oil and gas sites, and their result indicated that areas where hazardous substances are dumped are treated aseptically due to the presence of many metals, such as Organic Carbon (g/kg), Calcium (mmol/kg), Chlorine (mmol/kg), Zn (mg/kg), Cu (mg/kg),

Table 13.4 Maximum contamination of heavy metals in soil and effect of excess exposures, regulated by EPA.

Heavy metal	Maximum contamination level in sludge (soil)—ppm	Negative effects	Reference(s)
Lead Zinc Mercury Cd	420 7500 <1 85	• Dispersion in soil and irrigated plants contaminate food and, therefore, is dangerous to humans and animals. • It has low solubility; and it usually prefers to accumulate in soil and, as a result, in plants. • Cd persist in soil and then seep into groundwater leading to antioxidant enzymatic activities in plants or adsorbed with solid soil particles. • Carrot root can absorb about 5, 8, and 12 times more cadmium than allowed for men, women, and children. • High Cd in soil leads to Itai-Itai disease in Toyama, Japan.	[35–38]

Mn (mg/kg), Iron (mg/kg). These metals render the soil impotent and infertile, allowing plants and trees to sprout, implies that the dumping of hazardous wastes harms agriculture by causing the land unusable [37].

3.1.2.3 Radioactive materials

Radioactivity is the spontaneous decay of unstable atomic nuclei that emit electromagnetic radiation in the form of particles such as beta rays, alpha rays, neutrons, or gamma rays. Radioactive contamination of the environment should be a top priority as ionizing radiation has a detrimental effect on the tissues of living organisms, but it occurs very rarely. Adverse effects are directly related to the amount of energy absorbed, the exposure time, the penetrating power of the radiation, and the rate of cellular regeneration in a particular tissue [39]. Exposure to radioactive in surface oil resulting from oil extraction has been investigated by several authors. Uncontrolled water discharge from oil and gas production into evaporation ponds without precautions can lead to heavy contamination of large volumes of soil with radium isotopes (226Ra and 228Ra) [40]. Agbalagba et al. [41] conducted an evaluation of gross alpha and beta activities in crude oil—contaminated soil in the Niger Delta and reported relatively high values compared to values reported in some parts of the country. Oil-contaminated soil is contaminated with radionuclides that occur naturally in ground around petroleum product sales points. Long-term exposure to them can pose an intrinsic hazard to human health [42].

3.1.3 Water contamination

During the oil production process, water from the reservoir and previously injected into the formation are brought to the surface. This is known as product water, which makes up most of the effluent from oil and gas production (over 80%). A complex mixture containing dissolved and dispersed organic and inorganic compounds (Cl^-, Na^+, SO_4^{2-}), heavy metals (Cd, Zn, Cu, Pb), chemicals used in the extraction process (corrosion inhibitor, biocide, and emulsifiers), radionuclides, that cause severe operational problems such as corrosion and formation of scale. The biological and environmental effects of PW have raised concerns related to human health. A study from Akwa Ibom University has revealed that surface and groundwater contamination with organic and inorganic chemicals, radionuclides, and microorganisms occurs in most oil-producing host communities in the Niger Delta [43].

3.1.3.1 Surface water

A poor-quality surface water resource is recognizable by sight, and frequently by smell. Bonetti et al. combined surface water measurements and water quality with horizontally drilled wells to build an extensive geocoded database using a large-sample statistical approach and found very slight concentration increases associated with new wells for barium, chloride, and strontium, but not for bromide. All ions showed more significant but small increases after 91—180 days of well pudding [44]. Wang et al. determined the significant survival and growth of a fish in PW-contaminated surface water compared with the reference [45]. The main environmental issue for PW in onshore areas is salinity (especially the relative ratio of sodium to other ions), at the same time, in offshore areas, organic matter content and non-standard injections or surface discharges to land and sea also affect soil as well as surface water and underground water [46].

3.1.3.2 Drinking water contamination

The most frequent contaminants of drinking water near the oil and gas field are TPH, PAH, arsenic (As), and manganese (Mn).

Teng et al. found higher levels of TH in limited aquifers near oilfields and aquifers near agricultural lands, suggesting direct contamination of the aquifer from exploration wells, injection well leakage, and open wells. In another study conducted in Bolivia, high levels of exposure to metals, PAHs, and TPH in drinking water near oil fields were measured. In contrast, several studies found no evidence of drinking water contamination, especially in the United States.

3.2 Downstream facilities

Over 80% of hazardous waste in petrochemical plants is solid waste. Usapein and Chavalparit [1] studied the three olefin plants to improve waste management. They found that 59 distinct types of waste were generated in the factory at the production, maintenance, packaging, and wastewater treatment sections. Approximately 91% of these wastes were classified as hazardous, making concerns growing regarding suitable waste management. As illustrated in Fig. 13.2, production and maintenance activities account for most of generated waste in the petrochemical plants. Among chemical cleaning waste, oily wastewater and caustic are those with higher amounts.

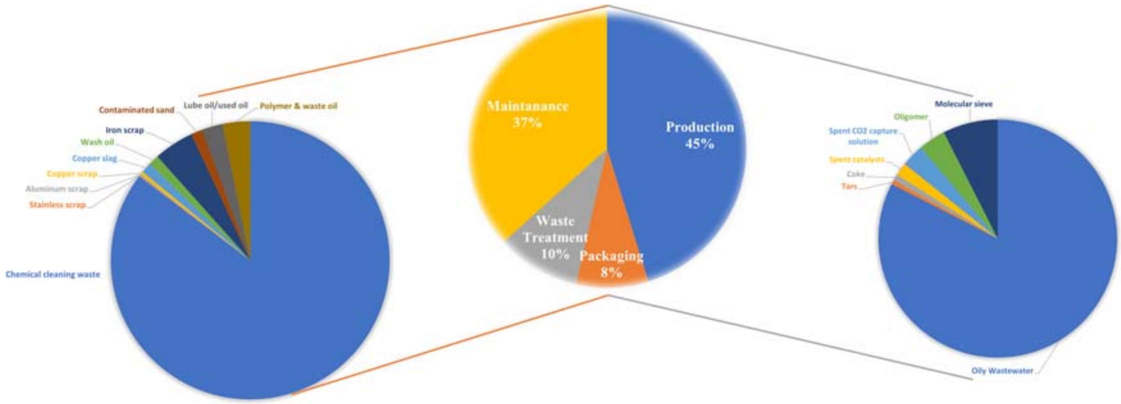


Figure 13.2 Sources of waste generation in petrochemical plants. Data from Usapein and Chavalparit (2014) [1].

3.2.1 Air pollution

Air pollution and air quality impacts have been studied for many years around the world, and there are significant concerns to varying levels. Most activities related to the oil and gas industry are conducted in refineries and a broad set of petrochemical industries. Regarding these activities, it is well established that petrochemical industries and oil refineries emit some air pollutants, which can negatively affect weather and, therefore, those people living in the surroundings [47]. Human exposure to some of the chemicals frequently found in air around petrochemicals was investigated by some researchers through blood and urine analysis. Studies have shown that exposure to the air pollution is associated with several adverse effects, including acute lower respiratory tract infections, chronic obstructive pulmonary disease, asthma, cardiovascular disease, and lung cancer. Various epidemiological studies show that air pollution is now a significant environmental health problem [48].

A study in Wuhan city, China, revealed that the petrochemical industry contributed 14.4% of VOCs emission in urban areas. Furthermore, knowing the atmospheric lifetime of VOCs is vital for understanding the distance they can travel in the air. Table 13.5 can infer that methane has longer atmospheric lifetimes indicating longer distances that can be crossed in the atmosphere, when compared to styrene, which has an atmospheric lifetime of just 4.9 h. Monod et al. studied the monoaromatics compound in different industrial cities. Based on their data, it can be concluded that the concentrations of BTEX are higher in Asian countries, when compared to other continents due to

Table 13.5 VOCs emitted from petrochemicals and their atmospheric lifetime [49].

VOCs	Atmospheric lifetime
m-Xylene	11.8 h
p-Xylene	19.4 h
o-Xylene	20.3 h
Benzene	9.4 days
Toluene	1.9 days
Ethylbenzene	1.6 days
Ethene	1.3 days
Ethyne	13 days

temperature differences, increased energy demand, and industrialization, and looser regulatory criteria [49].

Although refinery plants are the primary source of industrial VOC emissions, they produce a massive amount of chemicals, many of which are released from factories as solid waste, emissions, or wastewater. The commonly made air pollutants are sulfur oxides (SO_2), nitrogen oxides (NOX), small particles, NH_3, CO, H_2S, and trace metals. Table 13.6 shows the health concerns and quality standards related to some combustion products in petroleum refineries.

3.2.2 Soil contamination

An enormous range of harmful components could contaminate the encircling soil because of poor management, less control, and equipment fault. Alshahri and El-Taher [71] collected samples of surface soil randomly from 34 sites in Ras Tanura near the oil refinery, in Saudi Arabia, and suburb. Their results showed that measured values of heavy metals, including Cd (39.9 mg/kg), Mo (13.2 mg/kg), Eu (4.01 mg/kg), Hf (6.09 mg/kg), Tb (8.23 mg/kg), and Yb (3.88) in soil samples, were higher than the values of world average soil contamination.

In general, trace elements accumulation in agricultural soils surrounding petrochemical companies is produced from process units, toxic catalytic processes, and end products throughout

Table 13.6 Ambient air quality standards and adverse effects on human health [50].

Pollutant	Quality standards (from WHO)[1]	Related concerns
NO_x	0.05 ppm	• Associated with various health complications such as people with respiratory symptoms, especially asthma and respiratory complications with health symptoms such as shortness of breath, tightness in the chest, and wheezing.
SO_2	37—38 ppb	• Short-term SO_2 exposure is associated with respiratory complications in children and the elderly.
CO	25 ppm	It reduces the blood's ability to carry oxygen, reducing the supply of oxygen to tissues and organs, such as the heart.
O_3	0.08 ppm	• Potentially reduced mobility. • long-term exposure can exacerbate health problems such as emphysema, bronchitis, asthma, and damage the lung muscles leading to sudden death.

[1]World health organization.

sewage application and disposal of petrochemical waste. Petrochemical waste disposal can severely pollute nearby agricultural soils with various elements (for example, Cu, Pb, Cr, Zn, Cd, and Ni). In a study, the accumulation risk of trace elements in food systems near the petrochemical company in north China showed that soil contamination factor and enrichment factor are mild to moderately polluted by multiple trace elements [51].

Hydrocarbon-contaminated soil causes significant damage to nearby nature since pollutants accumulated in flora and fauna tissue may cause serious health problems. The method used for the soil remediation includes mechanical, embedding, evaporation, dispersion, and washing. However, these technologies are expensive and may result in incomplete decomposition of materials [52].

Microbial biomass and hydrolase activity inhibited in hydrocarbon polluted soil. Moreover, earthworm survival reduces by more than 40% in the soil with 1.5% oil content. Furthermore, pollution of soil by TPH (total petroleum hydrocarbons) and heavy metals has a negative interaction effect on population species like earthworms [53].

3.2.3 Water pollution

Wastewater in petrochemical companies is generated from different sources of process operations (for example, vapor condensers, utility water, and aromatic plants and spent caustic in crackers), rotary device cooling systems, blow down of cooling towers, cooling water, drains, and stormwater drainage [54].

Wastewater in oil refineries contains soluble and insoluble chemicals. Water-pollutant parameters in refineries are BOD (biochemical oxygen demand), COD (chemical oxygen demand), total petroleum hydrocarbon index (TPH-index), total hydrocarbon content (THC), TOC (total organic carbon), ammoniac nitrogen, total nitrogen, TSS (total suspended solids), phosphates, fluorides phenols, cyanides, total metals, Hg, Pb, Cd, Ni, and xylene, acids, taste and odors, heat, and sulfides [55,56]. Major water pollutants and related sources in refineries are listed in Table 13.7.

The process of treating water that is produced by process units in an industry is an undesirable by-product named wastewater treatment. The treated industrial wastewater is reusable and may release into the sewer systems or surface water. Wastewater generated in some industrial plants can be processed in sewage treatment system. Many big industries such as crude oil refineries and chemical and petrochemical companies have their

Table 13.7 Major water pollutants in refineries [54].

Pollutant	Source
Oil	H_2 hydrocracking distillation, visbreaking, hydrotreating, lube oil, catalytic cracking, ballast water, spent caustic, utilities.
H_2S (RSH)	Hydro-cracking, hydrolysis, and elemental sulfur production.
NH_3 (NH_4^+)	Sanitary blocks, distillation units, hydrotreating, visbreaking, catalytic cracking, hydrocracking, lube oil.
Phenols	Distillation units, visbreaking, catalytic cracking, spent caustic, ballast water.
Organo chemicals (BOD, COD, TOC)	Distillation units, hydrotreating, visbreaking, catalytic cracking, hydrocracking, lube oil, spent caustic, ballast water, utilities (rain), sanitary blocks.
CN^-(CNS^-)	Visbreaking, catalytic cracking, spent caustic, ballast water.
TSS	Distillation, visbreaking, hydrotreating, lube oil, catalytic cracking, ballast water, spent caustic, utilities.
Amines compounds	CO_2 removal in gas sweetening units.

specialized facilities to treat their own effluents so that the waste product concentrations within the treated wastewater befit the rules concerning disposal of wastewater into sewers or rivers, lakes, or oceans.

4. Laws and regulatory concerns

The aim of regulatory agencies is to manage human health and control the environmental impacts of wastes thorough investigation the exposure to hazardous material. Waste materials, in any form, with the ability to cause cancer, and, or toxicity to communities and surrounding nature, are determined by governments through regulations. Guidelines issued by relevant international or regional organizations are usually used when governments have no specified regulations.

Most of the oil and gas product chain suppliers are in developing countries, in which the big concern is the effectiveness of regulations toward the sustainable management of waste. Each step in the oil and gas sector (which includes exploration, production, refining, storage, transportation, and petrochemical activities) has its own share in the generation of the waste and, as a result, contributes to extended environmental pollution [57]. For instance, Nigeria has its framework for waste regulations, which should pave the road to sustainability, Still, the uncontrolled pollution of soil, water, and air, which is related to the Nigeria oil and gas sector, has reduced the capability of the Niger Delta ecosystem to sustain the life of the community in the area, and activate the destruction of local nature [58,59].

Weakness of implementation is another problem that the oil and gas industry faces regarding sustainable waste management policies. Multiple agencies with the duty of regulation spanning waste results in parallel efforts; generally, weak implementation at the hierarchical level exists. Labors training is another challenging issue in these agencies since the translation of regulation and implementation to actual actions are of concern. There are some limitations to pursue by operatives, and companies take advantage of conflicting sets of regulations. The operative agencies have restriction in equipment and technology, to detect waste and measure. The lack of measuring devices and required planning for waste stream monitoring makes the implementation of laws insufficient. Another drawback of the agencies is the unclear output of their performance and insufficient documentation of their duties. It comes out that these agencies are unable to confront antienvironmental effects of the oil and gas industry [60].

The government and regulatory agencies should coordinate to unite the regulatory policies. For instance, VOCs exposure limits are different between agencies in which the range has high variability based on short-term and life-time exposure [61].

In terms of waste management, various sections of legislation, instead of passing more regulations, can be a successful waste plan and lead to less waste generation and more recycling [62].

5. Concerns regarding the effectiveness of disposal methods

The selection of waste disposal method mainly depends on the properties of the waste, physical or chemical, legal requirements, and technical limitations. There are some process and technology concerns regarding the effectiveness of disposal methods and so much research trying to overcome the disadvantages of these methods; however, the main concerns remained. The most important solid waste in upstream section of the oil and gas industry is oil sludge. Several treatment methods and disposal techniques applied to oil recovery cause some concerns that briefed in Table 13.8.

Table 13.8 Treatment and disposal methods comparison for oil recovery: concerns [54].

Treatment method	Concerns
Oil-recovery includes:	
✓ Solvent extraction	✓ Higher energy costs ✓ Higher consumption of organic solvents leads to environmental concerns ✓ Low efficiency and high variability
✓ Centrifugation	✓ Higher capital cost ✓ Increased noise pollution ✓ Higher processing cost and environmental concerns
✓ Surfactant enhanced oil recovery (SEOR)	✓ Higher costs of producing bio-surfactants
✓ Distillation/Pyrolysis	✓ Fire hazard and corrosion problems ✓ Emission of VOCs, PAHs ✓ Chemical structure change of hydrocarbons ✓ Heavy residual tar formation on the solids is possible ✓ Requires higher heating cost ✓ High operational cost ✓ They contain a substantial portion of PAHs (the well-known highly carcinogenic substances) ✓ Liquid products lower price ✓ Complicated process required for scale-up
✓ Microwave irradiation method	✓ High irradiation and reaction rates due to the short heating time ✓ More less toxicity index for PAHs ✓ Require special-designed equipment ✓ Operating costs are higher ✓ Heavy metals are untreatable
✓ Freeze/thaw (F/T) treatment	Oil content, freezing time and temperature, thawing procedure and conditions, moisture content, salinity, solid contents, and surfactants amount in emulsion should take into considerations
✓ Electro-kinetic (EK) method	✓ Various physical, chemical, and electrical parameters have effects on its performance ✓ Lower capacity of treatment ✓ Operational difficulty ✓ Lack of investigation in large-scale cost
✓ Ultrasonic irradiation method	✓ Expensive equipment and higher maintenance cost ✓ Low ultrasonic intensity
✓ Froth flotation	✓ Not suitable for high viscosity oil sludge ✓ Heavy metals deposits ✓ Pretreatment of oil sludge to remove solids and decreasing viscosity

Table 13.8 Treatment and disposal methods comparison for oil recovery: concerns [54].—*continued*

Treatment method	Concerns
	✓ Higher water consumption
✓ Adsorption	The nature of both the contaminant and the solids can affect the effectiveness of the process
✓ High-temperature reprocessing (HTR) or heating	✓ Higher energy costs
✓ Filtration	✓ Ineffective in reducing hydrocarbon concentrations to low levels ✓ Sand filtration is not suitable because oil sludge filtration residue adheres strongly to the sand filter and is difficult to regenerate
Disposal methods include:	
Surface discharge	✓ Require permission ✓ Forbidden in some areas
Underground storage	✓ High costly processing and requirement to control
Burial	✓ Potential pollution for soil and ground water contamination
Oxidation	✓ Higher energy required ✓ High consumption of chemical reagent ✓ Higher operational and capital cost
Incineration	✓ Require control of combustion parameters ✓ Atmospheric pollution and hazardous emissions ✓ Higher operating costs
Biodegradation	✓ Higher operational costs ✓ Lower rate of processing
Landfilling	✓ Surface and groundwater contamination ✓ Heavy metal leaching from landfills ✓ In some cases, pre-treatment is required ✓ Exposing to infiltration from precipitation

In general, disposal methods for other types of waste such as PW and flue gas are performed in different procedure and cause some concerns which are shown in Table 13.9.

Depending on waste type, different methods are used for waste management in petrochemical plants. Concerns regarding proper waste disposal generated in petrochemical industry are shown in Table 13.10.

Table 13.9 Concerns of upstream waste disposal methods.

Type of waste	Disposal methods	Concerns	Reference(s)

Produced water (PW)	• Physicochemical
	  ◦ Hydro cyclone
	  ◦ Coagulation
	  ◦ Membrane
	  ◦ Adsorption
	  ◦ Oxidation
	• Thermal
	  ◦ Multi-effect distillation
	  ◦ Multi-stage flash
	  ◦ Vapor-compression distillation
	• Biological
	  ◦ Aerobic
	  ◦ Anaerobic
	  ◦ Phytoremediation
		• **Hydro-cyclones** are unable to remove dissolved solids
		• **Coagulation:** Higher dosage of coagulant poses negative effect
		• **Adsorption:** Regeneration of adsorbents needs chemical and heat treatment
		• **Membrane technology:** Membrane fouling, and higher energy required for backwashing
		• **Oxidation:** High chemical costs and toxic production
		• **Thermal:** Scale up problems
		• **Biological:** Microalgae growth limitation, economic feasibility, and improper handling of digestate
			[63–65]

Flue gas	• Desulfurization • CO_2 removal	• Catalyst highly cost • Extensive energy requirement • Higher solvent consumption • Corrosion leads to extra generation of waste	[66,67]

Table 13.10 Petrochemical wastes, disposal methods, and concerns [17,68].

Type of waste	Disposal method	Concerns
Spent molecular sieve	Landfilling	• Heavy metal and toxins leaching
Spent catalyst	Recycling	• Higher energy required
Stone wool	Landfilling	• Does not decompose or breakdown when disposed
Polymer waste	Heat recovery	• Air pollution, emission of PAHs, VOCs
Sand blast	Landfilling	• Soil contamination
Spent industrial soil	Recycling	• Higher energy required and lower recycling rate
Polymerized solvent sludge	Heat recovery	• Air pollution, emission of PAHs, VOCs
Sludge	Heat recovery	• Air pollution, emission of PAHs, VOCs
Spent activated carbon	Landfilling	• leaching problems

6. Conclusion and future outlook

An enormous waste generated in upstream and downstream sections of the oil and gas industry causes significant environmental concerns that affect human, flora, and fauna health. Several studies show the harmful effects of drilling, exploration and operational waste exposure on nearby plant and animal life. Although there are some pieces of evidence for raising disease in the surrounding area of the oil and gas workplace, still lacks sufficient measuring methods and procedures. Petrochemical companies and refineries represent the largest downstream producers of waste in the oil and gas section with various types of solid, liquid, and air pollutants. There are several disposal methods, deployed in both upstream and downstream sections, and each suffers from some aspects of unsustainability. Therefore, reducing waste production and reuse/recycling options are still before disposal methods. Making regulations regarding oil and gas sector's waste production should be in complete coordination with local laws. Educated personnel of regulatory agencies, as well as providing measurement devices for them, are essential to a better inspection of waste streams to control further environmental pollution.

References

[1] Usapein P, Chavalparit O. Development of sustainable waste management toward zero landfill waste for the petrochemical industry in Thailand using a comprehensive 3R methodology: a case study. Waste Management and Research 2014/06/01;32(6):509–18. https://doi.org/10.1177/0734242X14533604.

[2] Hocking MB. Handbook of chemical technology and pollution control. Elsevier; 2016.

[3] McCammon AL. United Nations conference on environment and development, held in Rio de Janeiro, Brazil, during 3–14 June 1992, and the'92 global forum, Rio de Janeiro, Brazil, 1–14 June 1992. Environmental Conservation 1992;19(4):372–3.

[4] Israel A, Obot I, Umoren S, Mkpenie V, Ebong G. Effluents and solid waste analysis in a petrochemical company-a case study of Eleme Petrochemical Company Ltd, Port Harcourt, Nigeria. E-Journal of Chemistry 2008;5(1):74–80.

[5] Group WB. Petroleum refining, project guidelines: industry sector guidelines, pollution preservation and abatement handbook. 1998.

[6] San Sebastián M, Armstrong B, Córdoba JA, Stephens C. Exposures and cancer incidence near oil fields in the Amazon basin of Ecuador. Occupational and Environmental Medicine 2001;58(8):517–22.

[7] McKenzie LM, Allshouse WB, Byers TE, Bedrick EJ, Serdar B, Adgate JL. Childhood hematologic cancer and residential proximity to oil and gas development. PLoS One 2017;12(2):e0170423.

[8] Hurtig A-K, Sebastián MS. Incidence of childhood leukemia and oil exploitation in the Amazon basin of Ecuador. International Journal of Occupational and Environmental Health 2004;10(3):245–50.
[9] Dahlgren J, Takhar H, Anderson-Mahoney P, Kotlerman J, Tarr J, Warshaw R. Cluster of systemic lupus erythematosus (SLE) associated with an oil field waste site: a cross sectional study. Environmental Health 2007; 6(1):1–15.
[10] Dey T, et al. Role of environmental pollutants in liver physiology: special references to peoples living in the oil drilling sites of Assam. PLoS One 2015; 10(4):e0123370.
[11] Yermukhanova L, Zhexenova A, Izimbergenova G, Turebaev M, Bekbauova A, Zumabekov E. Immunodeficiency states in persons residing in the oil-producing regions of Kazakhstan. Research Journal of Medical Sciences 2017;11(1):16–8.
[12] Kudabayeva KI, Bazargaliev YS, Baspakova AM, Darzhanova KB. Estimation of thyroid volume in children from oil-gas producing areas of West Kazakhstan. Biology and Medicine 2014;6(1):1.
[13] Kponee KZ, Chiger A, Kakulu II, Vorhees D, Heiger-Bernays W. Petroleum contaminated water and health symptoms: a cross-sectional pilot study in a rural Nigerian community. Environmental Health 2015;14(1):1–8.
[14] Kirkeleit J, Riise T, Bratveit M, Moen B. Increased risk of hematopoietic malignancies in a historical cohort of upstream petroleum workers in Norway. American Journal of Epidemiology 2007;165(11). Oxford Univ Press Inc Journals Dept, 2001 Evans RD, Cary, NC 27513 USA, pp. S102-S102.
[15] Rubright SLM, Pearce LL, Peterson J. Environmental toxicology of hydrogen sulfide. Nitric Oxide: Biology and Chemistry 2017;71:1.
[16] Rusparyati E. Pengaruh Penambahan Cahaya Kontinu Terhadap Produktivitas Tanaman Karet Rakyat (Hevea Brasiliensis Muell Arg.) Di Tanjung Jabung Barat, Provinsi Jambi. 2012.
[17] Ghazizade MJ, Koulivand H, Safari E, Heidari L. Petrochemical waste characterization and management at Pars special economic energy zone in the south of Iran. Waste Management and Research 2021;39(2):199–208.
[18] Haut R, Rogers J, McDole B, Burnett D, Olatubi O. Minimizing waste during drilling operations. In: Proceedings AADE national technical conference and exhibition, Houston, Texas; 2007. p. 10–2.
[19] Gardner R. Overview and characteristics of some occupational exposures and health risks on offshore oil and gas installations. Annals of Occupational Hygiene 2003;47(3):201–10.
[20] Onwukwe S, Nwakaudu M. Drilling wastes generation and management approach. International Journal of Environment and Sustainable Development 2012;3(3):252.
[21] McKenzie LM, Witter RZ, Newman LS, Adgate JL. Human health risk assessment of air emissions from development of unconventional natural gas resources. Science of the Total Environment 2012/05/01/2012;424: 79–87. https://doi.org/10.1016/j.scitotenv.2012.02.018.
[22] Lupo PJ, et al. Maternal exposure to ambient levels of benzene and neural tube defects among offspring: Texas, 1999–2004. Environmental Health Perspectives 2011;119(3):397–402.
[23] Wennborg H, Magnusson LL, Bonde JP, Olsen J. Congenital malformations related to maternal exposure to specific agents in biomedical research laboratories. Journal of Occupational and Environmental Medicine 2005: 11–9.

[24] Maskrey JR, Insley AL, Hynds ES, Panko JM. Air monitoring of volatile organic compounds at relevant receptors during hydraulic fracturing operations in Washington County, Pennsylvania. Environmental Monitoring and Assessment 2016;188(7):1−12.
[25] Ethridge S, Bredfeldt T, Sheedy K, Shirley S, Lopez G, Honeycutt M. The Barnett Shale: from problem formulation to risk management. Journal of Unconventional Oil and Gas Resources 2015;11:95−110.
[26] Le Cornet C, et al. Parental occupational exposure to organic solvents and testicular germ cell tumors in their offspring: NORD-TEST study. Environmental Health Perspectives 2017;125(6):067023.
[27] Garcia-Gonzales DA, Shonkoff SB, Hays J, Jerrett M. Hazardous air pollutants associated with upstream oil and natural gas development: a critical synthesis of current peer-reviewed literature. Annual Review of Public Health 2019;40:283−304.
[28] Rajan ST, Malathi N. Health hazards of xylene: a literature review. Journal of Clinical and Diagnostic Research: Journal of Clinical and Diagnostic Research 2014;8(2):271.
[29] Lee J, Sorensen C, Lemery J, Workman CF, Linstadt H, Bazilian MD. Managing upstream oil and gas emissions: a public health oriented approach. Journal of Environmental Management 2022/05/15;310:114766. https://doi.org/10.1016/j.jenvman.2022.114766.
[30] Johnston JE, Lim E, Roh H. Impact of upstream oil extraction and environmental public health: a review of the evidence. Science of the Total Environment 2019;657:187−99.
[31] Qi H, Chen X, Du Y-e, Niu X, Guo F, Li W. Cancer risk assessment of soils contaminated by polycyclic aromatic hydrocarbons in Shanxi, China. Ecotoxicology and Environmental Safety 2019/10/30;182:109381. https://doi.org/10.1016/j.ecoenv.2019.109381.
[32] Gitipour S, Sorial GA, Ghasemi S, Bazyari M. Treatment technologies for PAH-contaminated sites: a critical review. Environmental Monitoring and Assessment 2018/08/23;190(9):546. https://doi.org/10.1007/s10661-018-6936-4.
[33] Ubogu M, Odokuma LO. Growth and lolerance evaluation of selected plants to crude oil contamination for rhizoremediation potentials in the Niger Delta. Kuwait Journal of Science 2019;46(4).
[34] Pandey G, Madhuri S. Heavy metals causing toxicity in animals and fishes. Research Journal of Animal, Veterinary and Fishery Sciences 2014;2(2): 17−23.
[35] Jolly YN, Islam A, Akbar S. Transfer of metals from soil to vegetables and possible health risk assessment. Springer Plus 2013/08/15;2(1):385. https://doi.org/10.1186/2193-1801-2-385.
[36] Iannelli MA, Pietrini F, Fiore L, Petrilli L, Massacci A. Antioxidant response to cadmium in Phragmites australis plants. Plant Physiology and Biochemistry 2002;40(11):977−82.
[37] Nwankwo CN, Gobo AE, Israel-Cookey C, Abere SA. Effects of hazardous waste discharge from the activities of oil and gas companies in Nigeria. Central Asian Journal of Environmental Science and Technology Innovation 2020;1(2):119−29. https://doi.org/10.22034/cajesti.2020.02.07.
[38] Roy M, McDonald LM. Metal uptake in plants and health risk assessments in metal-contaminated smelter soils. Land Degradation and Development 2015;26(8):785−92.

[39] Ayeni DA, Adebiyi FM. Evaluation of natural radioactivity and radiation hazards of soils around petroleum products marketing company using gamma ray spectrometry. Tanzania Journal of Science 2022;48(2):304–12.
[40] Desouky OS, Morsi T, El-Marakby SM. Evaluating the radiological hazards of contaminated soil with natural radioactive materials (NORM) resulting from produced water during oil and gas production. Arab Journal of Nuclear Sciences and Applications 2021;54(1):162–72.
[41] Agbalagba EO, Egarievwe SU, Odesiri-Eruteyan EA, Drabo ML. Evaluation of gross alpha and gross beta radioactivity in crude oil polluted soil, sediment and water in the Niger Delta region of Nigeria. Journal of Environmental Protection 2021;12(8):526–46.
[42] Olalekan EO, Adebiyi FM. Measurement of radioactivity levels in oil impacted soils around petroleum products retailing stations. Petroleum Science and Technology 2020/01/02;38(1):53–63. https://doi.org/10.1080/10916466.2019.1656240.
[43] Ite AE, Harry TA, Obadimu CO, Asuaiko ER, Inim IJ. Petroleum hydrocarbons contamination of surface water and groundwater in the Niger Delta region of Nigeria. Journal of Environment Pollution and Human Health 2018;6(2):51–61.
[44] Bonetti P, Leuz C, Michelon G. Large-sample evidence on the impact of unconventional oil and gas development on surface waters. Science 2021; 373(6557):896–902.
[45] Wang N, Kunz JL, Cleveland D, Steevens JA, Cozzarelli IM. Biological effects of elevated major ions in surface water contaminated by a produced water from oil production. Archives of Environmental Contamination and Toxicology 2019;76(4):670–7.
[46] Bagheri M, Roshandel R, Shayegan J. Optimal selection of an integrated produced water treatment system in the upstream of oil industry. Process Safety and Environmental Protection 2018;117:67–81.
[47] Broitman D, Portnov BA. Forecasting health effects potentially associated with the relocation of a major air pollution source. Environmental Research 2020/03/01;182:109088. https://doi.org/10.1016/j.envres.2019.109088.
[48] Wang C-W, et al. Urinary thiodiglycolic acid is associated with increased risk of non-alcoholic fatty liver disease in children living near a petrochemical complex. Environment International 2019/10/01;131:104978. https://doi.org/10.1016/j.envint.2019.104978.
[49] Monod A, Sive BC, Avino P, Chen T, Blake DR, Rowland FS. Monoaromatic compounds in ambient air of various cities: a focus on correlations between the xylenes and ethylbenzene. Atmospheric Environment 2001;35(1): 135–49.
[50] Adebiyi FM. Air quality and management in petroleum refining industry: a review. Environmental Chemistry and Ecotoxicology 2022;4:89–96.
[51] Cao L, et al. Health risk assessment of trace elements exposure through the soil-plant (maize)-human contamination pathway near a petrochemical industry complex, Northeast China. Environmental Pollution 2020;263: 114414.
[52] Das N, Chandran P. Microbial degradation of petroleum hydrocarbon contaminants: an overview. Biotechnology Research International 2011; 2011.
[53] Teng Y, Zhou Q, Miao X, Chen Y. Assessment of soil organic contamination in a typical petrochemical industry park in China. Environmental Science and Pollution Research 2015;22(13):10227–34.

[54] Jafarinejad S. Petroleum waste treatment and pollution control. Butterworth-Heinemann; 2016.
[55] Izady A, et al. Risk-based stochastic optimization of evaporation ponds as a cost-effective and environmentally-friendly solution for the disposal of oil-produced water. Journal of Water Process Engineering 2020;38:101607.
[56] Jafarinejad S. Pollution and wastes from the petroleum industry. In: Petroleum waste treatment and pollution control. Oxford, UK: Butterworth-Heinemann; 2017. p. 19–83.
[57] Kingston KG, Okere E. The problems and prospects of Nigerian laws on waste management in the onshore and offshore oil and gas facilities. African Journal of Law and Criminology 2019;9:57–71.
[58] Suberu O, Ajala O, Akande M, Olure-Bank A. Diversification of the Nigerian economy towards a sustainable growth and economic development. International Journal of Economics, Finance and Management Sciences 2015;3(2):107–14.
[59] Ali SH, de Oliveira JAP. Pollution and economic development: an empirical research review. Environmental Research Letters 2018;13(12):123003.
[60] Datti SM, Aliyu FA, Aboki HA. Sustainable waste management in the Nigeria oil and gas industry: the regulatory challenges. Sau Journal of Management and Social Sciences 2021;6(1):111–84.
[61] McMullin TS, Bamber AM, Bon D, Vigil DI, Van Dyke M. Exposures and Health Risks from Volatile Organic Compounds in Communities Located near Oil and Gas Exploration and Production Activities in Colorado (U.S.A.). International Journal of Environmental Research and Public Health 2018; 15(7):1500 [Online]. Available: https://www.mdpi.com/1660-4601/15/7/1500.
[62] Tchobanoglous G, Kreith F. Handbook of solid waste management. McGraw-Hill Education; 2002.
[63] Igunnu ET, Chen GZ. Produced water treatment technologies. International Journal of Low Carbon Technologies 2014;9(3):157–77.
[64] Jiménez S, Micó M, Arnaldos M, Medina F, Contreras S. State of the art of produced water treatment. Chemosphere 2018;192:186–208.
[65] Knudsen B, et al. Meeting the zero discharge challenge for produced water. In: SPE international conference on health, safety, and environment in oil and gas exploration and production. OnePetro; 2004.
[66] Srivastava VC. An evaluation of desulfurization technologies for sulfur removal from liquid fuels. RSC Advances 2012;2(3):759–83.
[67] Rufford TE, et al. The removal of CO2 and N2 from natural gas: A review of conventional and emerging process technologies. Journal of Petroleum Science and Engineering 2012;94:123–54.
[68] Abbasi M, Kamalan H. Quality and quantity of wastes generated in marun petrochemical complex and evacuating recovery potential. Journal of Hydrosciences and Environment 2018;2(3):1–8.
[69] Moolgavkar. SH Multistage carcinogenesis and epidemiologic studies of cancer. Modeling and Inference in Biomedical Science—In Memory of Andrei Yakovlev. Institute of Mathematical Statistics Collections Series; 2014.
[70] World Bank Group. Prevention, Pollution, and Abatement Handbook. Washington, DC: World bank group; 1998.
[71] Alshahri F, El-Taher A. Assessment of heavy and trace metals in surface soil nearby an oil refinery, Saudi Arabia, using geoaccumulation and pollution indices. Archives of Environmental Contamination and Toxicology 2018;75: 390–401.

14

Environmental challenges of gases vent from flares and chimneys

Ali Behrad Vakylabad[1] and Zohre Moravvej[2]

[1]*Department of Materials, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran;* [2]*Department of Chemical Engineering, Shiraz University, Shiraz, Iran*

1. Introduction

Gas flaring is a simple technique to safely, operationally, and economically dispose of the gases associated with petroleum in three main phases of oil exploration, drilling, and production. While drilling into the high-pressure underground reservoirs, the dissolved or dispersed light hydrocarbons and other impurities in the heavier hydrocarbon compounds (crude oil) are released into the well head up to the surface facilities. Then, these light gases flared or vented into the atmosphere [1]. The necessities of gas flaring and venting in oil production are [2]

- Absence of technological base for collection, treatment, transport, and utilization of the associated gases;
- Lack of access to demand market by manufacturing and production sites like offshores.
- The relatively low and variable volumes of gas associated with oil in many fields have made technological development uneconomic for its collection.
- The presence of impurities associated with these gases, such as acidic gases H_2S, CO_2, etc., makes their treatment operation very costly and complicated.
- Finally, safety and operational considerations and issues have added to the complexity of processing and recycling flare gases.

However, we should keep in mind that flare gases are a valuable energy source that will contribute greatly to the economy of the

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00004-9

production process if technological development is developed to recycle them. Flare gas has four important characteristics [3]:

(I) Economically: it can generate billions of dollars in revenue from valuable gas content

(II) Environmentally: it is a regional disaster if it is not recycled

(III) Globally: it is also a major environmental problem

(IV) From an energy perspective: it can also be considered a valuable resource

In this regard, according to World Bank statistics (Table 14.1), for example, in 2011, about 140 billion cubic meters (Bcm) of flare gas were burned, equivalent to 5% of global natural gas production. Economically, this value equals 10 billion USD lost, i.e., 2.4 million barrels of oil equivalent per day. From an environmental perspective, 400 million tons per year of CO_2 have entered the atmosphere [5].

More in part, environmental impacts can be investigated from six angles. (I) Flare gas burned per year is equivalent to the output emissions of 77 million vehicles (equivalent to 34% of the US transportation fleet). (II) This gas is equivalent to 2% of global CO_2 emissions of the origin of energy production. (III) This source's fine for carbon production is six billion US dollars ($15 per tonne). (IV) This amount of flare gas is equivalent to 20% of the CO_2 emissions of the world's steel industry. (V) This amount of

Table 14.1 Gas flaring and oil production for the period of 2007–2021 for the top 20 gas flaring countries [4].

	2007–2010							
	2007		2008		2009		2010	
	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.
Country	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)
Russia	52.3	9878	42	9797	46.6	9934	35.6	10,157
Nigeria	16.3	2353	15.5	2169	14.9	2212	15	2459
Iran	10.7	4039	10.8	4177	10.9	4178	11.3	4243
Iraq	6.7	2097	7.1	2385	8.1	2399	9	2403
USA	2.2	8469	2.4	8564	3.3	9134	4.6	9685
Algeria	5.6	1967	6.2	1955	4.9	1910	5.3	1881

Table 14.1 Gas flaring and oil production for the period of 2007–2021 for the top 20 gas flaring countries [4].—*continued*

2007–2010								
	2007		2008		2009		2010	
	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.
Country	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)
Kazakhstan	5.5	1446	5.4	1431	5	1542	3.8	1609
Angola	3.5	1747	3.5	1979	3.4	1908	4.1	1948
Saudi Arabia	3.9	10,249	3.9	10,782	3.6	9819	3.6	10,642
Venezuela	2.2	2682	2.7	2656	2.8	2510	2.8	2405
China	2.6	3956	2.5	4037	2.4	4067	2.5	4363
Canada	2	3449	1.9	3344	1.8	3319	2.5	3442
Libya	3.8	1845	4	1874	3.5	1790	3.8	1789
Indonesia	2.6	1041	2.5	1065	2.9	1053	2.2	1039
Mexico	2.7	3500	3.6	3184	3	3001	2.8	2979
Qatar	2.4	1121	2.3	1204	2.2	1213	1.8	1441
Uzbekistan	2.1	112	2.7	110	1.7	107	1.9	107
Malaysia	1.8	705	1.9	731	1.9	694	1.5	683
Oman	2	715	2	760	1.9	819	1.6	870
Egypt	1.5	674	1.6	706	1.8	729	1.6	717
2011–14								
	2011		2012		2013		2014	
	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.
Country	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)
Russia	37.4	10,239	17.8	10,656	20.9	10,807	19.5	10,927
Nigeria	14.6	2555	12.9	2409	9.2	2276	8.3	2273
Iran	11.4	4265	17.1	3810	12.0	3609	13.1	3714
Iraq	9.4	2629	11.7	3079	13.3	3099	13.8	3239
USA	7.1	10,136	5.8	8931	9.3	10,103	11.4	11,807
Algeria	5	1863	3.4	1537	8.8	1485	9.2	1589
Kazakhstan	4.7	1638	2.5	1664	3.7	1737	3.8	1710
Angola	4.1	1800	-	1734	3.2	1738	3.5	1701

Continued

Table 14.1 Gas flaring and oil production for the period of 2007–2021 for the top 20 gas flaring countries [4].—*continued*

2011–14								
	2011		2012		2013		2014	
	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.
Country	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)
Saudi Arabia	3.7	11,264	-	11,622	2.7	11,393	2.5	11,519
Venezuela	3.5	2489	11.0	2704	9.8	2680	10.5	2692
China	2.6	4363	1.9	4155	2.4	4216	2.5	4246
Canada	2.4	3597	1.8	3740	1.6	4000	2.1	4271
Libya	2.2	502	3.8	1539	4.1	1048	2.9	518
Indonesia	2.2	1016	6.4	917	3.3	871	3.2	847
Mexico	2.1	2960	1.4	2911	5.1	2882	5.7	2792
Qatar	1.7	1641	0.7	1868	1.7	1887	1.6	1881
Uzbekistan	1.7	106	0.8	72	1.5	69	1.3	63
Malaysia	1.6	626	1.3	663	3.1	627	3.6	649
Oman	1.6	891	1.3	918	2.3	942	2.5	943
Egypt	1.6	726	0.4	715	2.6	710	3.0	714

2015–18								
	2015		2016		2017		2018	
	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.
Country	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)
Russia	21.1	11,087	23.9	11,342	21.0	11,374	21.2	11,562
Nigeria	7.5	2199	7.2	1898	7.5	1968	7.3	2005
Iran	12.7	3853	17.0	4578	18.5	4854	18.1	4608
Iraq	15.8	3986	17.5	4423	17.5	4538	17.6	4632
USA	12.0	12,783	9.0	12,354	9.6	13,140	14.1	15,310
Algeria	9.6	1558	9.7	1577	9.2	1540	9.4	1511
Kazakhstan	3.6	1695	2.6	1655	2.4	1838	2.0	1904
Angola	4.2	1796	4.5	1745	3.8	1671	2.8	1519
Saudi Arabia	2.7	11,998	3.1	12,406	2.9	11,892	2.9	12,261

Table 14.1 Gas flaring and oil production for the period of 2007–2021 for the top 20 gas flaring countries [4].—*continued*

2015–18								
	2015		2016		2017		2018	
	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.
Country	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)
Venezuela	9.9	2864	10.2	2566	8.0	2220	9.3	1631
China	2.5	4309	2.3	3999	1.8	3846	2.0	3802
Canada	1.9	4388	1.4	4464	1.4	4813	1.4	5244
Libya	2.7	437	2.4	412	4.0	929	4.7	1165
Indonesia	3.0	838	2.9	873	2.5	837	2.2	808
Mexico	6.0	2593	5.8	2461	4.5	2227	4.5	2072
Qatar	1.4	1805	1.4	1790	1.3	1756	1.3	1793
Uzbekistan	1.1	60	1.0	57	0.8	61	0.8	64
Malaysia	3.9	696	3.4	726	3.1	718	2.5	713
Oman	2.4	981	2.8	1004	2.6	971	2.6	978
Egypt	3.0	726	3.0	691	2.5	660	2.4	674

2019–2021						
	2019		2020		2021	
	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.
Country	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)
Russia	23.8	11,679	25.1	10,667	26.4	11,474
Nigeria	7.8	2101	7.0	1828	6.5	1805
Iran	14.6	3399	14.2	3084	18.5	3883
Iraq	17.7	4779	17.2	4114	17.7	5031
USA	17.3	17,114	12.4	16,458	9.7	17,986
Algeria	9.7	1487	9.3	1330	8.1	1429
Kazakhstan	1.5	1919	1.5	1806	1.5	1907
Angola	-	1420	-	1318	-	1368
Saudi Arabia	2.6	11,832	2.8	11,039	2.8	11,804
Venezuela	10.5	1022	9.4	640	9.2	780
China	2.2	3848	2.9	3901	2.7	3746

Continued

Table 14.1 Gas flaring and oil production for the period of 2007–2021 for the top 20 gas flaring countries [4].—*continued*

	2019–2021					
	2019		2020		2021	
	Gas flaring	Oil pro.	Gas flaring	Oil pro.	Gas flaring	Oil pro.
Country	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)	(Bcm/y)	(Mbbl/d)
Canada	1.1	5372	1.2	5130	1.3	5606
Libya	5.1	1228	2.5	425	5.9	678
Indonesia	2.2	781	2.0	742	1.7	747
Mexico	5.3	1921	6.7	1912	7.8	1695
Qatar	1.6	1727	1.3	1714	1.4	1692
Uzbekistan	0.6	67	0.5	61	0.5	60
Malaysia	2.7	672	2.7	616	2.1	684
Oman	2.6	971	2.5	951	2.6	985
Egypt	2.5	653	2.5	632	2.3	632

flare gas is equivalent to 35% of CO_2 emissions from the origin of the world's cement industry. (VI) In terms of energy, it is equivalent to 125 medium power plants with a power of total 63 GW (GW) [5].

Netherlands Environmental Assessment Agency reports the global CO_2 emissions of around 250 million tons from gas flaring during oil production [6]. Carbon Dioxide Information Analysis Center (CDIAC) (CDIAC, 2014) also has similar statistics about CO_2 emissions. CDIAC reports 360 million tons for earlier years (the 1980s). Another study indicates an amount of around 150 billion cubic meters per year from global natural gas flaring. This amount of emission may contaminate the environment with 400 million tons of CO_2 annually [7]. The main parameters responsible for gas-flaring-related CO_2 emissions are produced crude oil, investment in gas utilization, gas-to-oil ratio, natural gas price, and flare reduction regulations and policies [8]. In this way, long-term relationships exist between gas flaring volume, oil price, CO_2 emission amount, and the total natural resources rent of the Gross domestic product (GDP) for eight developing countries, including Iran [9]. According to the World Bank reports, in 2015, about 140 billion cubic meters of natural gas from oil production fields were flared [4]. Most of the gas flaring is related in developing countries owing to a lack of gas processing, recycling, or utilizing infrastructures [10].

2. Gas flaring

In terms of the Canadian Association of Petroleum Producers, gas flaring is defined as the controlled burning of a part of natural gas which is not processable from technical or economic viewpoints [11,12]. A chimney flare or vertical pipe is an extension that is used as one of the essential parts in oil wells, refineries, petrochemicals, chemical plants, incinerators, and other process units to burn waste, flammable and toxic gases, and liquids discharged and can prevent the risks of fires, explosions, and damage to employees. Flare converts flare toxic and corrosive vapors into less harmful compounds. It is one of the most important methods of immunization of industrial devices against high pressure [13,14]. Flare is a burning and combustion process in which organic matter and additional burning gases are sent from all parts of the unit by a network of pipelines to an area with a suitable distance from operational units and burned in a controlled manner before causing any problems for the installations. By burning these gases, which are made of fuel gases, a significant source of energy in the form of flare gas enters the environment. These burning gases cause environmental pollution and waste of the country's economic resources. As a result of burning gases in the flare system, greenhouse gases such as COX, NO_x, and SO_x are emitted into the atmosphere. In addition, gases from the flaring process have detrimental effects on human health and also cause global temperatures to rise [15]. Nowadays, due to the increasing need for energy as well as non-renewable fossil energy resources, attention to the issue of waste gas management in the oil and gas industries has also increased. The amount of production of hydrocarbon emissions is proportional to the degree of combustion. The degree of combustion depends largely on the rate and amount of air-fuel mixing and the flame temperatures obtained and maintained. In flare dissipation gases that do not contain nitrogenous compounds, NO is still made up of combining atmospheric nitrogen with oxygen or by reactions between released hydrocarbon radicals in combustion products and atmospheric nitrogen through the middle stages of CN, HCN, and OCN. The amount of SO_2 emitted depends directly on the amount of sulfur in flare gases [16]. Flares always produce heat and sound during activity. The amount and type of gases emitted from the flare to the environment are subject to combustion efficiency and the type of gases sent to the flare [17].

Suppose the gases sent to the flare are from the origin of the gas tanks. In that case, it is naturally expected that all hydrocarbons in this stream will be harvested and consumed after refining, but when a country does not have the necessary equipment and facilities to contain these gases, the easiest thing to do in its industry is to. Therefore, this does not mean that any country that has more flaring is more industrialized and prominent in the world of oil and gas, but a country that is more industrialized and can have flare gas collection facilities will normally have less flaring [18].

2.1 The necessity of flares in the oil and gas industries

Flares in the oil and gas industries are integral units of these industries to safely dispose of a significant amount of flammable gases. Any chemical process such as refinery and petrochemical processes is required to use a flare system to observe the safety of workers and equipment. But solutions can be presented to minimize the flow of gases sent to flare, the world's leading issue of flaring elimination (zero flaring), whose ultimate goal is to minimize the flow of waste gases to flare, also believe that it is not possible to remove or turn off a flare and is merely used as a term for targeting the reduction of flaring [19].

2.2 Composition of gas flaring

The flared gas contains a mixture of different gases, the composition of which depends mainly on the source of the gas flowing into the flaring chimney. In general, natural gas (more than 90% methane (CH_4) and ethane (C_2H_6)) is the main constituent with a small amount of other hydrocarbons, and inert gases like N_2 and CO_2. In comparison, a mixture of hydrocarbons and in various cases H_2 is the common composition of flaring from refineries and other process operations. Moreover, a mixture of CH_4 and CO_2 along with small amounts of other inert gases are major components of landfill gas, biogas, or digester gas. As such, there are several groups of gas flaring based on its gas parameters. The physical parameters like the heat transfer capabilities of the gas are changed based on the gas composition. Such parameters affect the performance of the measurement by the flow meter. Table 14.2 summarizes typical waste gas compositions [12].

Table 14.2 Compositions of a typical gas flaring plant [12].

Chemical	Composition, %		
	Minimum	Maximum	Mean
Methane (CH_4)	7.17	82	43.6
Propane (C_3H_8)	2.04	64.2	20.3
Isobutane (C_4H_{10})	1.33	57.6	14.3
Hydrogen (H_2)	0	37.6	5.54
Ethane (C_2H_6)	0.55	13.1	3.66
n-Butane (C_4H_{10})	0.199	28.3	2.78
Propylene (C_3H_6)	0	42.5	2.73
Nitrogen (N_2)	0.073	32.2	1.3
Water (H_2O)	0	14.7	1.14
Ethylene (C_2H_4)	0.081	3.2	1.05
Carbon dioxide (CO_2)	0.023	2.85	0.713
1-Butene (C_4H_8)	0	14.7	0.696
n-Hexane (C_6H_{14})	0.026	3.53	0.635
Isopentane (C_5H_{12})	0.096	4.71	0.53
Oxygen (O_2)	0.019	5.43	0.357
n-Pentane (C_5H_{12})	0.008	3.39	0.266
Hydrogen sulfide (H_2S)	0	3.8	0.256
Carbon monoxide (CO)	0	0.932	0.186
neo-Pentane (C_5H_{12})	0	0.342	0.017

The composition of the gas is the key factor in deciding about processing or disposing of it. For example, the heating value of the gas is important for assessing its economic value. The H_2S content of the gas is deterministic for transport in the upstream pipeline network [20]. The flaring systems may be classified into three categories: (I) Initial start-up flaring is the result of fluids injection into new facilities and equipment during the dedication and early start-up phases of a plant or process unit operation [21]; (II) Continuous production flaring occurs after the plant or process unit has been operating for some time. This type of flaring is a regular, uninterrupted gas stream sent to a flare chimney stack, due mainly to no economical flash gas venting in upstream production to enhance the value of gas; (III) Operational/non-continuous production flaring appears because of routine checks, facility closures, well completions, workovers, and fluids unloading, etc., as planned flaring. Plus, unplanned flaring in this category is non-continuous production flaring including mechanical equipment faults, instrument failures, and difficulties in restarting well production [22].

2.3 Flaring system design

Gas flares, also known as flare chimney stacks, eliminate waste gas and lower non-waste gas pressures with the potential of failing the equipment. As a part of safety systems, flare stacks are used with non-waste gases by reducing gas pressures with pressure-relief valves. The flares keep gas processing equipment from becoming over-pressurized and reduce the equipment strain. The pressure regulator automatically releases fluids when the industrial equipment is burdened with excessive pressure. It is essential to industrial design rules, standards, and regulations. The discharged fluids from the regulators may be transferred to the vertically raised flare headers with massive pipe systems. The gases are burnt as they leave the flare stacks. The flares' resulting inferno depends on the combustible material's flow rate in joules per hour. A knockout drum is installed upstream of the industrial plant flares to segregate significant volumes of liquid usually accompanying the released gases (Fig. 14.1). The controlled injection of steam into the flame frequently hinders the production of soot. Continuous burning of a tiny amount of gas, like a pilot light, may keep the flare system running and ready as an over-pressure safety device [1]. The main

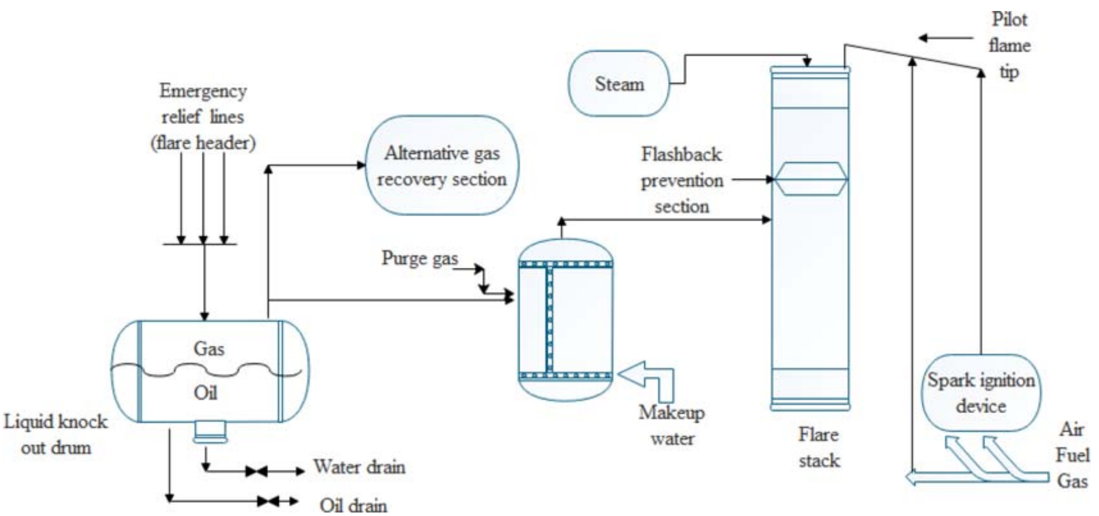


Figure 14.1 A typical flowsheet of the elevated industrial design of the flare chimney stack system [23].

parts of the elevated industrial design of the flare chimney stack system are

- Knockout drum for eliminating any residual liquid from the discharged gases. A variety of high-pressure and low-pressure knockout drums are used to divert flow away from their respective pressure equipment.
- Water seal drum keeps the flame from flashing back from the flare stack's top.
- Gas recovery system is designed for partial plant starting and shutdowns, as well as other times.
- Steam injection system provides an outward impulse force for optimal air-to-relieve-gas mixing and combustion without smoke.
- Continuous pilot flame (with its ignition mechanism) ignites flare gases.
- Flare chimney stack includes a flashback avoidance component toward the top [24–26].

Fig. 14.2 shows three main types of gas flares, including ground flares, pit flares, and elevated flares. Ground flares may be either

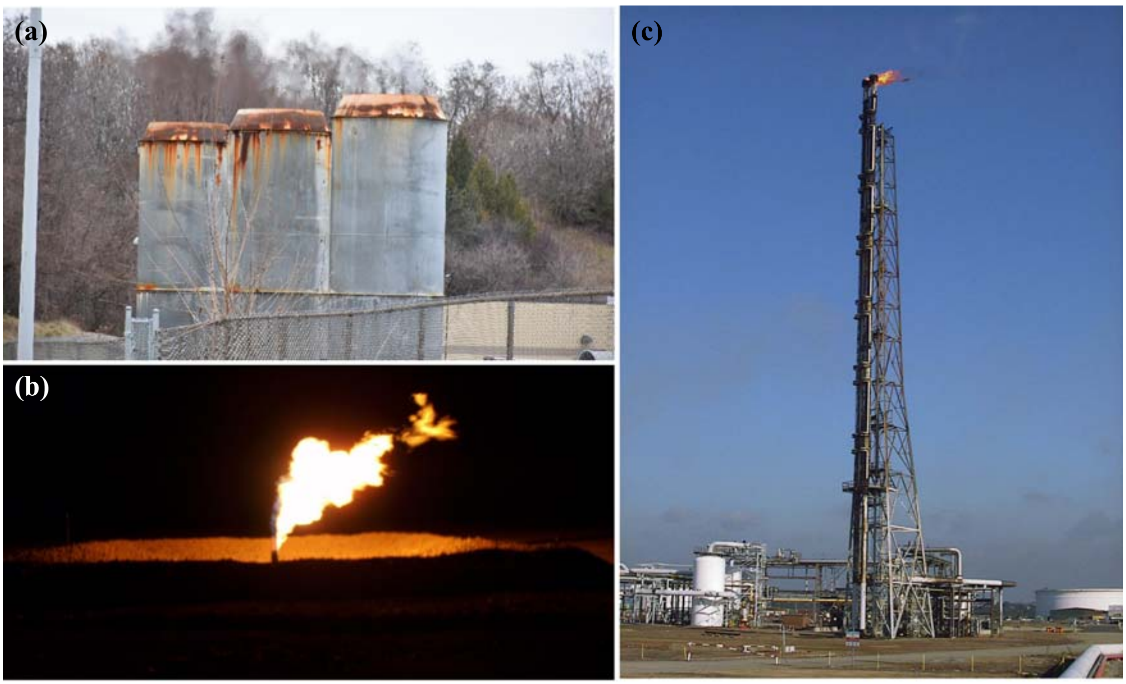


Figure 14.2 Types of flares: (a) Closed ground flare, (b) pit flare, (c) elevated flare [27].

closed or open pits (Fig. 14.2A). Their specific benefits are concealing the flame, as well as reducing radiant energy and noise. They may be installed in a wide range of places either offshore on floating production storage and offloading complexes, or onshore in environmentally sensitive places (FPSOs) [28]. The second type is pit flares or pilot burners, which are horizontally positioned and located through a Fire Brick Wall, Earthen wall, and/or Fence surrounding the pit (Fig. 14.2B). They are often farther (at least 1000 feet (305 m) long) from all common work areas and operating plants to prevent personnel threaten or equipment damage from the smoke and associated thermal plume [27]. The third is elevated flares in which the waste gas is channeled through a vertical chimney for subsequent combustion at the flare tip at a high elevation (Fig. 14.2C) [1].

2.4 Operating conditions of the flare unit

In general, flare systems burn gases in three different modes of factory operating conditions.

(I) Normal factory conditions: In this case, gases released from certain processes are burned along with discharge gases in the flare. Combustion products in these conditions are water vapor, carbon dioxide, and sulfur oxide.

(II) Unit turbulence conditions: These conditions arise when starting or stopping the factory completely, in this case, the volume of gases sent to the flare is more than normal conditions.

(III) Unit emergency: When accidents such as technical failure of the device or power outage occur, some gases are unintentionally sent to the flare. In this case, due to the sudden release of gases to the flare, adjusting the fuel and air ratio is inappropriate and, in most cases, creates a black and smokey flame. Emergencies can occur for a variety of reasons [6], some of which include changes in feed input, technical defects in equipment, inappropriate maintenance, human errors, power outages, and operation over design capacity.

3. Environmental considerations

Gas flaring affects the environment locally, regionally, and globally [29]. A typical regional example is Niger Delta, the environmental and health impacts indicate the likely magnitude and extent of associated pollution across the region [30]. Emergency burners release large volumes of gases into the atmosphere in a short period, causing atmospheric disturbances. If the combustion in the flare is complete, only water vapor, carbon dioxide, and sulfur dioxide will be produced in the amount of the combustion product. Unfortunately, due to the lack of sufficient time in the combustion process, many burned gases from the burner enter the environment, smoke, and create an unpleasant odor in the burner due to their incomplete burn (Fig. 14.3). Unfortunately, the uncertain efficiency of burners is one of the most important problems, researches have been conducted to show that the volume of toxic compounds released from incomplete combustion is much higher than expected. Torches play a significant role in causing environmental problems such as the destruction of resources, global warming, and acid rain. According to 2000 official papers published in the Canadian Public Health Association, 250 different known poisons are discharged into the air during the flare process, some of which are soot, gasoline, mercury, nitrogen oxides, carbon dioxide, arsenic, carbon disulfide, chromium, methane, carbonyl sulfide, toluene, acidic gases, and polycyclic aromatic hydrocarbons [31]. According to reports in 2011 on gases that burners, pollution is equivalent to the annual pollution of 77 million vehicles, carbon dioxide produced is equivalent to 20% of the amount produced in the world's steel industry or 35 carbon dioxide produced in the cement industry [1]. This amount of gas that becomes a torch can generate GW 63 electricity. According to the Carbon Data Analysis Center Dioxide, annually 150 million cubic meters of gas are burned, of which 400 million tons of carbon dioxide are sent to the environment annually [32,33]. If the flare gas that burns is accompanied by the burning of this gas, whose methane is the largest amount,

Figure 14.3 Burning gas flare with a huge amount of waste gas, Bayport industrial District, Harris County, Texas [27].

methane is converted to carbon dioxide, but if it is released into the environment, the risk is higher because methane is 25 times more dangerous than carbon dioxide [17]. The side effects of the wide range of toxins are acidity causation, temperature increase, and significant influence on the immediate environment, particularly on human health and agricultural activities [30].

3.1 Acidification

Burning flare gas enters plenty of combustible vapors into the atmosphere, the consequence of which is acid rain, especially in the humid environment offshore. This corrosive-nature rain may greatly damage the environment, causing extensive destruction or ruin to vegetation and surface water [8,34]. Moreover, freshwater, coastal, and mangrove ecosystems are significantly affected by acid rain [35]. It increases the SO_4^{2-} and NO_3^- concentrations, the direct result of which is lowered pH values to around 5.06 [36]. Nigeriarain water acidity around the gas flare sites shows significant environmental impact so that the acidity decreases with increasing distance from the sites [36]. Furthermore, environmental acidification rapidly causes corrosion of galvanized iron sheets in the oil-producing complexes [35]. As the flare source approaches, the equipment's corrosion rate increases rapidly so that the corrosion of 4.23 mg weight loss at a distance of 1000 m reaches 7.62 mg at a distance of 500 m from the chimney stack. Noting that the normal corrosion rate is 1.17 mg for the non-flaring zone [37].

3.2 Thermal expansion

The effect caused by the heat of gas flaring on the Ebedei community of Delta State, Nigeria has been studied based on temperature variation with distance from the flare point for both the wet and dry seasons [38]. Measurements show that thermal pollution is within a distance of 2.15 km for the wet season and 2.06 km for the dry season [38]. Detailed studies monitor parameters of surface temperatures, distances, latitudes, and longitudes away from the flaring point for the four cardinal directions with the thermometer, a fibrous meter tape, and a global positioning system (GPS). They report a surface temperature elevation of about 9.1°C above the mean normal daily temperature within a radius of 210 m. Besides, a temperature gradient of 0.050°C/m is recorded [38,39]. The same study advises maintaining a distance of 250 m away from the flare stack for residential buildings [39]. The specific physical, chemical, and biological conditions caused by high temperatures are harmful to human health and plant and soil microorganisms [38].

3.3 Thermal radiation

Radiant heat may be originated from some of the products of complete combustion, such as CO_2 and H_2O. This thermal radiation around flares is not fully known. Numerous parameters may contribute to the heat radiation losses like chimney stack exit velocity, crosswind velocity, the aerodynamics of the flame, etc. [40].

3.4 Photochemical reaction

The photochemical reaction, also known as the photochemical effect, is the consequence of a chemical reaction induced by light or ultraviolet radiation. This phenomenon causes O_3 formation in the troposphere. It goes ahead with the oxidation of nitric oxide (NO) to nitrogen dioxide (NO_2) by organic-peroxy (RO_2) or hydro-peroxy (HO_2) radicals [41]. Large research projects (The Second Texas Air Quality Field Study (TexAQS-II), and TexAQS-II Radical and Aerosol Measurement Project (TRAMP)) have gained a better understanding of atmospheric chemical processes. The importance of short-radical lived sources such as HCHO and HONO in increasing O_3 productivity has been proven in the TexAQS-II Radical and Aerosol Measurement Project (TRAMP) so that the daytime HCHO pulses of around 32 ppb have been registered to be related to industrial activities upwind in the Houston Ship Channel (HSC). Even this value has been reported to be 52 ppb in situ surface monitors in the HSC. According to the studies, flares from local refineries and petrochemical facilities are responsible for increasing O_3 by $\sim$30 ppb, owing mainly to the primary produced HCHO [42].

3.5 Agriculture consequences

Although methods such as bioremediation can improve the destructive effects of petroleum contaminants in soil, such methods include their pros and cons [43]. In the surrounding environments of the oil and gas industry, the main destinations of petroleum pollutants such as benzene, toluene, ethyl benzene, and xylenes (BTEX), aliphatic and polycyclic aromatic hydrocarbons (PAHs) are the soils and sediments [35]. Of these pollutants, a significant concern is related to PAHs with two to five fused aromatic rings. The mutagenicity of these compounds and their tendency to bioaccumulate in organic tissues due to their lipophilic character and electrochemical stability make them an outstanding concern

[35]. The adverse impacts of the gas flaring on soil fertility and biogeochemical nutrient cycles and the negative effects on the physiochemical properties of the soil come from its thermal pollution. This pollution contributes to microbial populations, participating in organic matter decomposition and nitrogen formation processes. It declines inorganic matter and total nitrogen, as well as microbial populations, humid (topsoil) formation, nutrient availability, and soil fertility. Subsequently, modification of the microclimate in the region due to flaring may adversely affect some crops [35]. Even, the negative effects of gas flare and chimney vent systems have been observed in some aquatics so that with increasing intensity of gas flares, the phylogenetic position and reduction in their relative sensitivity status of these aquatic animals have changed [35]. The tangible temperature increase has been observed in air, soil, and leaves around 110 m from the flare sites. Also, the relative humidity of the air has decreased in this flare environmental radius [44]. The recommendation is against planting in the flare-affected area due to the negatively responding of crops to high-temperature variation [38,45]. As a case study, the microclimate and yield of maize in the Niger Delta near the Ovade flare site are affected by the rise in the air and soil temperatures of the flare site, relative humidity, soil moisture, and all the soil chemical parameters, the consequence of which is the reduced yield of maize in the induced microclimatic condition with uneconomical viability within 2 km from the flare site [38,45].

Of course, we should add to all these environmental problems the impact on human health, which comes from sources such as elevated levels of petroleum hydrocarbon contaminant mixtures, PAHs, and metals (especially vanadium via harvested rainwater usage) [35].

4. Reducing the emissions sent to flare

As mentioned earlier in each chemical process, combustible excess gases are discharged into the burner network both during normal factory operations and when the process operations of the factory are problematic [46]. The sources of these gases are generally control valves, safety valves, compressors, sour water units of the factory, and more [47]. With increasing production and life of the unit and lack of proper operation staff, more waste gases are produced, which increases the volume of burned gases in the burner. In unit design, the nominal amount of permanent flow of gas is determined and the amount of gases produced is predictable, only in cases where the amount of gases produced exceeds the design value should be checked. In different and variable conditions, the performance of employees and operational conditions play a key role. The frequency of unit failure or high change in the number of waste gases produced indicates the performance of the unit. The problems of the units are due to inappropriate leadership or the lack of correct control parameters, which can be identified by full re-envision of the unit and the problems are possible.

Full identification of each of these items will help to identify and present solutions to reduce the gases sent to flare. Since identifying these resources requires familiarity with the chemical processes in the desired factory, it is important to use operators' operational experience in implementing final solutions. In the following, solutions to reduce flare emissions are presented by improving the conditions of the processes [48–50].

(I) Preventing leakage of safety valves and other similar devices
(II) Preventing leakage in compressors
(III) Process reform of sour water units
(IV) Replacement of nitrogen-stripping hydrocarbon
(V) Replacement of nitrogen-coated hydrocarbon
(VI) Equipment capacity reform
(VII) Use of multi-flow measurements
(VIII) Use of multi-phase pumps

4.1 Recent achievements and research

Burning gases in large industries, especially oil, gas, and petrochemical industries through the flaring system cause environmental problems and waste of many economic resources. Due to the high amounts of energy waste in these industries, as well as the environmental requirements that are increasingly more serious and stricter, over the past 11 years, extensive research has been conducted on reducing and recovering the gases sent to flares, which we will continue to review in this chapter. In 1987 at the Petrochemical Complex Sunolin Chemical Co, adjacent to a refinery south of Philadelphia, a system was provided for directly burning flare gas in a steam boiler package in the complex [51]. The results of the boiler vapor registrar chart showed that the recycling system reduced the common costs by about 10%. In 1991, the Flare Gas Recovery Project was first implemented in Norway. The recovery of gases sent to flare became a reality in Norway when the Norwegian government, in January 1991, adopted effective tax laws on CO_2 emissions. The Norwegian government's tightening result is a 50% reduction in the burning of flare gases in units of Norwegian oil fields [52,53].

John Zinke is the oldest (from 1928) and most successful flare design and manufacturing plant in the oil, gas, and petrochemical industries. The company's reputation is due to the design and manufacture of flares that consume less fuel and steam during operation, which is a positive result in extending the life of the flare crater. At the same time, the company's efforts are aimed at designing flares that produce less smoke. In 2005, the company began designing flare gas recovery systems. These systems use liquid-rim compressor technology, and due to the design of the recovery system compressor based on the type of flare system in question, today it is among the most successful flare gas recovery systems [54,55]. In 2006, major oil companies such as Shell achieved acceptable results by identifying the main units of flare gas to reduce emissions, resulting in installation. Launching a flare gas recovery system for all process flares with an average recovery efficiency of 90% and finally implementing the "Flaring Minimization Plan" [56].

Research on the conversion of flare gases from refineries to methanol is limited. In 2008, Atlantic Methanol Production Company established a methanol unit adjacent to gas processing facilities on Baiko Island in Guinea. The processing stages of gas and other hydrocarbon products of alba sea resources are processed on the coast and additional gases are burned at the output of the processing facilities. This unit takes the production of methanol from flare gases and converts it into useful products for use in international markets [57]. In 2009, a general method is presented for reducing flaring for an ethylene production unit using a dynamic simulation. The process succeeded in reducing the unit's flaring by 60% at the time of the unit's launch, which directs a significant amount of valuable gas to the flaring chimney [58]. In 2009, a study is conducted on the feasibility of converting Flare gas to Gas-to-Liquid (GTL), as a significant option to reduce Nigeria's emissions, which ranks second in the world for flaring [59]. In 2011, to reduce greenhouse gas emissions, a GTL cycle is introduced to convert flared natural gases in a gas refinery into higher molecular-weight hydrocarbons. This process offers an alternative method instead of conventional flares for gas burning to minimize CO2 emissions and produce liquid fuel such as gasoline [60].

In 2013, a study is conducted to identify the main units producing flare gas at Assaluyeh Gas Refinery. The result of this study was a 55% reduction in flaring through the gas circulation of the desulfurization unit in phase 1 of the South Pars Gas Complex [61].

In this chapter, instead of burning gases, the potential of oil and gas refineries in converting flare gas into a valuable material has been obtained by providing a conceptual method and appropriate model. The conceptual method is based on studying the composition of gases and economical investigation for their proper processing and use. The production of a valuable material can be the conversion of flare gas into liquefied petroleum gas, methanol, compression, and injection as fuel to the main pipelines or power generation. The appropriate criterion for selecting any of these technologies is directly related to the cost of initial investment and return on capital of each of these methods. Presenting this plan and implementing it in addition to economic profitability in refineries helps to reduce the environmental pollutants of refineries and causes greenhouse gases.

5. Treatment methods of flared gas

The methods mentioned above can prevent additional gases from producing units to a certain extent, but often by modifying process equipment, these gases will still be produced. On the other hand, the amount of these gases is considerable and cannot be easily ignored from the loss of this huge energy source. The issue of burning and releasing gases discharged from different units of oil, gas, and petrochemical industries has become one of the most significant problems in these industries today. The off-gases from the combustion of these gases have detrimental effects on human health and also cause global temperatures to rise. In addition, by burning these gases, a huge and valuable source of energy enters the environment in the form of flare gas without efficient use [17]. Iran ranks third in gas flaring in the world, making clearer the importance of studying the reduction of burning these valuable gases [1]. Instead of burning gas, it is tried to obtain the potential of oil and gas refineries in converting flare gas into a valuable material by presenting a conceptual method [62]. The conceptual method is based on the analysis of different designs on flare gas samples. These different designs can be the conversion of flare gas to liquefied petroleum gas (LPG), methanol, compression, and injection as fuel to the main pipelines of the pipe or power generation [63–66]. The appropriate criterion for selecting any of these technologies is directly related to the cost of initial investment and return on capital of each of these methods [67]. The overall result shows that in the case of flare gases of gas refineries with about 70% mole methane, the plan for power generation from flare gas has more return on capital than methanol and gas fuel production projects, and then gas and methanol production projects have more return on capital, respectively [68]. Also, the result of sensitivity analysis of the LPG production plan from flare gases of oil refineries shows that in the amount of molar percentage of 50% of the mixture of propane and butane flare gas, the lowest return time is obtained [69,70]. Also, the plan to use flare gas as gas fuel, in about three oil refineries, resulted in a return on capital of fewer than 7 months [71].

There are generally a variety of ways to treat gases sent to flare: (I) Physical: In this method, flare gases are purified under certain methods and condensed as needed to be used as fuel or feed for other process units. (II) Chemical: in this method, flare gas is converted into useful and useable industrial materials by the necessary reactions in the presence of catalysts. (III) Biological: One of the newest methods of treatment is that flare gas is decomposed by using bacteria and decomposition reactions in towers to its constituent factors [72].

5.1 Conversion

Recovery and conversion of flare gases using new and environmentally friendly technologies are the most attractive methods of flaring reduction. One of these technologies is the production of synthesis gas. The gas is a mixed synthesis of hydrogen, carbon monoxide, and carbon dioxide that is used in various chemical and metallurgical processes. The importance of synthesized gas production is evident because its use as the raw feedstock of GTL and methanol production is of particular importance. The tendency to convert gas to liquid technology and methanol production is increasing day by day due to the cleanness of these types of fuels, as well as easy transportation, among the various options for combustion. GTL technology consists of three stages: producing synthesis gas, converting combined gas into liquid hydrocarbons, and improving product quality. The Fisher-Tropsch synthesis section includes Fisher-Tropsch reactors, recovery and compression of unresponsive synthesis gas, and product separation from other impurities. The Fisher-Tropsch synthesis unit is the main unit of the GTL process and its reactor is the heart of the whole unit [70].

Another case of gas consumption is synthesis, its use as a feed unit of methanol production. Methanol is used in large quantities as an energy producer or as an additive to fuels [66]. Because it is burned without the production of suspended pollutants such as NO_x, SO_x, and ash, as well as when mixed with gasoline, less carbon monoxide is produced [66].

5.2 Liquefied natural gas production

Liquefied petroleum gas is a hydrocarbon compound generally consisting of propane, and butane (normal butane, isobutane) that are in the gaseous phase at ambient temperature and pressure and in the case of storage or transportation, are liquid phases. Liquefied petroleum gas is a clean fuel and has a variety of applications, some of which are for domestic, commercial, and industrial fuels, gasoline production, feed for petrochemical complexes, etc. [67].

The recovery of heavy hydrocarbons from flare gases leads to the storage of valuable hydrocarbons and the possibility of local use of them. The interesting thing about liquefied petroleum gas is its ease of storage and transmission, which can often be used locally. Flare gases, especially flare oil refineries, are rich in heavy hydrocarbons, so the separation of liquefied petroleum gas from flare gas significantly reduces carbon emissions and the thermal value of the gas is recovered. In some situations, the use of liquefied petroleum gas recovery system allows the residual methane to be easily recovered in simple CNG (compressed natural gas) and LNG (liquid natural gas) units, but in most cases, the amount of methane is not high enough to make it economical. To produce liquefied petroleum gas, absorption, and cryogenic systems are traditionally used, which requires the use of moving parts and chemicals at a very high cost. A very suitable solution is the use of membrane systems so that the combination of two different membranes is used to recover liquefied petroleum gas as well as hydrogen. The first membrane passes the pure hydrogen in the gas, then the obtained gas is sent to another membrane that passes the compounds through itself. The remaining fluid flow from the membrane separation process is rich in hydrogen and lighter gaseous hydrocarbons such as methane and ethane and can be used as fuel or sent to a hydrogen purification unit [73]. The collected gas streams are piped toward a storage tank, processed to separate impurities, and separated into liquefied petroleum gas components.

5.3 Flared gas as fuel

In many cases, the most basic and practical solution for using recovered flare gases is their consumption as fuel in existing equipment. Normally, the recovered flare gas is injected into the gas fuel system of the unit. Recovered gas fuel can be used directly in equipment such as furnaces, heaters, and low-pressure burners, or used as auxiliary fuel in equipment such as steam generators. In cases where the fuel consumption has a certain range for primary properties or high amounts of hydrogen sulfide are available in flare gases, the recovered gas fuel may need preparations such as increased pressure, sweetening, or separation. It is worth noting that among the mentioned cases, increasing the pressure of flare gas seems more vital than the rest.

5.4 Power generation

The solution of using the recovered flare gas to generate electricity is the state of consumption of flare gas as gas fuel. Because of the importance and attractiveness of this solution, especially in places far from the main power grid, such as offshore platforms with wellhead facilities or units with high electrical energy consumption, power generation from flare gas is considered a separate solution. The feed of power generation units in oil refineries contains about 80% methane molar. Therefore, power generation from flare gases of oil refineries is not economically suitable, because in oil refineries, the percentage of flare methane is not more than 15%–30%. Power generation from gases along with oil wells and platforms and flare gases of gas refineries containing a significant percentage of methane can be considered a significant solution [74,75].

5.5 Injection into oil wells to increase harvesting

Injection of associated gases is one of the ways to prevent burning. Re-injecting gas into tanks to the increase in oil harvesting means that 11 million cubic feet of gas per day can be saved. Research has shown that the use of gas with a high percentage of hydrogen sulfide is also possible. In Iran, in addition to the initial harvesting, which is natural products from the reservoir, secondary harvesting methods (gas or water injection in most reservoirs are being planned and implemented, which increases the harvest by about 5%). In secondary recycling, the goal is to increase the natural energy of the reservoir by injecting gas or water to maintain pressure or increase the pressure of the reservoir or improving the production methods such as the installation of in-well pumps, horizontal drilling, and inter-well drilling. Such practices of increasing the harvesting of reservoirs should be done [76].

6. Conclusion and future outlook

While gas flaring is known as a valuable energy resource, its lack of technology management can be a local environmental disaster and a global environmental problem with millions of tons of air pollutants and greenhouse gases each year coinciding with the loss of multi-billion dollars. More than 90% of the global gas flaring is from about 20 countries. It accounts for approximately 150 billion cubic meters of natural gas around the world, which equals contaminating the environment with 400 million tons of CO_2 annually. Although all oil, gas, and petrochemical industries produce flare gas, the maximum amount is related to oil production. The emission factor, i.e., the amount of gas flaring compared to the oil production, may vary between 1 and 50 cubic meters per barrel of oil produced. It also fluctuates with the time and location of production. As such, it is difficult to exactly estimate the volume and composition of flare gases. Although numerous procedures and technologies are available to minimize gas flaring, effective mitigation measures and real actions have been insufficient. The reasons are the restricted financial resources, the limited regulatory measures, and constraints like sanctions to access the required technologies by developing countries.

Abbreviations

Bcm Billion cubic meters
BTEX Benzene, Toluene, Ethyl benzene, and Xylenes
CDIAC Carbon Dioxide Information Analysis Center
CDM Development Mechanism
FPSOs floating Production Storage and Offloading
GDP Gross Domestic Product
GPS Global Positioning System
GTL Gas to Liquid
GW Gigawatts
HSC Houston Ship Channel
LPG Liquefied Petroleum Gas
TRAMP TexAQS-II Radical and Aerosol Measurement Project
UNFCCC United Nations Framework Convention on Climate Change

References

[1] Soltanieh M, et al. A review of global gas flaring and venting and impact on the environment: case study of Iran. International Journal of Greenhouse Gas Control 2016;49:488–509.

[2] Olujobi OJ, et al. The legal framework for combating gas flaring in Nigeria's oil and gas industry: can it promote sustainable energy security? Sustainability 2022;14(13):7626.
[3] Fawole OG, et al. Dispersion of gas flaring emissions in the Niger delta: impact of prevailing meteorological conditions and flare characteristics. Environmental Pollution 2019;246:284–93.
[4] World Bank Group. Global gas flaring reduction partnership (GGFR). 2016. 2016 report. Available from: http://www.worldbank.org/en/programs/gasflaringreduction.
[5] Farina M. Flare gas reduction: recent global trends and policy considerations GE energy global strategy and planning. 2010.
[6] Olivier JG, Peters JA, Janssens-Maenhout G. Trends in global CO_2 emissions. 2012. 2012 report.
[7] Andersen RD, et al. Efforts to reduce flaring and venting of natural gas world-wide. Trondheim, Norway: Norwegian University of Science and Technology; 2012.
[8] Hassan A, Kouhy R. Gas flaring in Nigeria: analysis of changes in its consequent carbon emission and reporting. In: Accounting forum. Elsevier; 2013.
[9] Pourhassan S, Taravat A. Effect of gas flaring on environmental variables in developing countries. International Journal of Business and Management 2014;2(1):101–6.
[10] Aregbe AG. Natural gas flaring—alternative solutions. World Journal of Engineering and Technology 2017;5(01):139.
[11] Sangsaraki ME, Anajafi E. Design criteria and simulation of flare gas recovery system. In: Proceedings of the international conference on chemical, food and environment engineering (ICCFEE'15). Dubai: UAE; 2015.
[12] Peterson J, et al. Minimize facility flaring: process and plant optimization. Hydrocarbon Processing 2007;86(6):111–5.
[13] Banerjee K, Cheremisinoff PN. Flare gas systems pocket handbook. Gulf Publishing Company; 1985.
[14] API Standard 521. Pressure-relieving and depressuring systems. API Publishing Services, Texas A&M University; 2014.
[15] Mohanty C, Adapala S, Meikap B. Removal of hazardous gaseous pollutants from industrial flue gases by a novel multi-stage fluidized bed desulfurizer. Journal of Hazardous Materials 2009;165(1–3):427–34.
[16] Refining Department. Manual on disposal of refinery wastes. 1980.
[17] Emam EA. Gas flaring in industry: an overview. Petroleum & Coal 2015; 57(5):532–55.
[18] Huang K, Fu JS. A global gas flaring black carbon emission rate dataset from 1994 to 2012. Scientific Data 2016;3(1):1–11.
[19] Beer J. Combustion technology developments in power generation in response to environmental challenges. Progress in Energy and Combustion Science 2000;26(4–6):301–27.
[20] Johnson MR, Coderre AR. Compositions and greenhouse gas emission factors of flared and vented gas in the Western Canadian Sedimentary Basin. Journal of the Air & Waste Management Association 2012;62(9): 992–1002.
[21] Bahadori A. Natural gas processing: technology and engineering design. Gulf Professional Publishing; 2014.
[22] Elvidge CD, et al. The potential role of natural gas flaring in meeting greenhouse gas mitigation targets. Energy Strategy Reviews 2018;20:156–62.

[23] Barati A, Pirozfar V. Flare gas review in oil and gas industry. Journal of Biochemical Technology 2018;2:71–89.
[24] Kayode Coker A. Ludwig's applied process design for chemical and petrochemical plants. Amsterdam: Gulf Professional Publishing; 2007. p. 371–443.
[25] Frank, et al. Lees' loss prevention in the process industries. Butterworth-Heinemann; 2005.
[26] Shore D. A proposed comprehensive model for elevated flare flames and plumes. In: Flaregas corporation. AIChE 40th Loss Prevention Symposium; April 2006. 2006.
[27] Wikipedia. Gas flare. 2023. Available from: https://en.wikipedia.org/wiki/Gas_flare.
[28] Argo J. Unhealthy effects of upstream oil and gas flaring: a report prepared for Save our Seas and Shores (SOSS) for presentation before the public review commission into effects of potential oil and gas exploration, drilling activities within licences 2364, 2365, 2368 [For US Standard Industrial Classification 1311 and 1389]. 2002.
[29] Ismail OS, Umukoro GE. Global impact of gas flaring. 2012.
[30] Anejionu OC, et al. Contributions of gas flaring to a global air pollution hotspot: spatial and temporal variations, impacts and alleviation. Atmospheric Environment 2015;118:184–93.
[31] Grant WM, Schuman JS. Toxicology of the eye: effects on the eyes and visual system from chemicals, drugs, metals and minerals, plants, toxins and venoms; also systemic side effects from eye medicationsvol 1. Charles C. Thomas Publisher; 1993.
[32] Florides GA, Christodoulides P. Global warming and carbon dioxide through sciences. Environment International 2009;35(2):390–401.
[33] U. S. Department of Energy. Carbon Dioxide Information Analysis Center (CDIAC). 2021. 2021 report. Available from: https://cdiac.ess-dive.lbl.gov/.
[34] Nwankwo C, Ogagarue D. Effects of gas flaring on surface and ground waters in Delta State, Nigeria. Journal of Geology and Mining Research 2011;3(5):131–6.
[35] Ite AE, Ibok UJ. Gas flaring and venting associated with petroleum exploration and production in the Nigeria's Niger Delta. American Journal of Environmental Protection 2013;1(4):70–7.
[36] Efe S. Spatial variation in acid and some heavy metal composition of rainwater harvesting in the oil-producing region of Nigeria. Natural Hazards 2010;55(2):307–19.
[37] Ovri J, Iroh M. Corrosion effect of gas flaring on galvanized roofing sheet in Imo State, Nigeria. International Journal of Engineering Science 2013;2(1): 339–45.
[38] Anomohanran O. Thermal effect of gas flaring at Ebedei area of Delta State, Nigeria. The Pacific Journal of Science and Technology 2012;13(2):555–60.
[39] Julius OO. Thermal gradient due to the gas flared at umusadege marginal oilfield, Umusadege-Ogbe Kwale Delta State, Nigeria. Archives of Applied Science Research 2011;3(6):280–90.
[40] Guigard S, Kindzierski W, Harper N. Heat radiation from flares. Report prepared for science and technology branch. Edmonton, Alberta: Alberta Environment; 2000.
[41] Brown J, Bowman C. Integrated science assessment for ozone and related photochemical oxidants. Washington, DC, USA: US Environmental Protection Agency; 2013.

[42] Webster M, et al. The effect of variability in industrial emissions on ozone formation in Houston, Texas. Atmospheric Environment 2007;41(40): 9580–93.

[43] Thapa B, Kc AK, Ghimire A. A review on bioremediation of petroleum hydrocarbon contaminants in soil. Kathmandu University Journal of Science, Engineering and Technology 2012;8(1):164–70.

[44] Isichei AO, Sanford WW. The effects of waste gas flares on the surrounding vegetation in South-Eastern Nigeria. Journal of Applied Ecology 1976;13: 177–87.

[45] Odjugo P, Osemwenkhae E. Natural gas flaring affects microclimate and reduces maize (Zea mays) yield. International Journal of Agriculture and Biology 2009;11(4):408–12.

[46] Hodges J, et al. Injecting hydrogen into the gas network-a literature search. 2015.

[47] Pauletto G, et al. Techno economic analysis of a micro gas-to-liquid unit for associated natural gas conversion. Renewable and Sustainable Energy Reviews 2021;150:111457.

[48] Strosher MT. Characterization of emissions from diffusion flare systems. Journal of the Air & Waste Management Association 2000;50(10):1723–33.

[49] Giwa SO, Adama OO, Akinyemi OO. Baseline black carbon emissions for gas flaring in the Niger Delta region of Nigeria. Journal of Natural Gas Science and Engineering 2014;20:373–9.

[50] Lorenzato G, et al. Financing solutions to reduce natural gas flaring and methane emissions. Washington, DC: World Bank; 2022.

[51] Brenner W. Recovering flare gas energy-a different approach. 1987.

[52] Rregjeingen.no, Norwegian Government Security and Service Organisation (G.S.S.O.). Available from: https://www.regjeringen.no/en/id4/.

[53] Nunthaworrarat R, Srivaranon S. The future of zero continuous flare operation at greater Bongkot North field. In: Offshore technology conference Asia. OnePetro; 2022.

[54] Worrell E, Galitsky C. Energy efficiency improvement and cost saving opportunities for petroleum refineries. 2005.

[55] Blanton R. Environmentally and economically beneficial flare gas recovery projects in petrochemical facilities. In: National petroleum refiners association environmental conference, San Antonio; 2010.

[56] Shell Global. The Shell company. 2018. 2018 report and data. Available from: http://www.shell.com.

[57] Kanshio S, Agogo HO, Chior TJ. Techno-economic assessment of mini-GTL technologies for flare gas monetization in Nigeria. In: SPE Nigeria annual international conference and exhibition. OnePetro; 2017.

[58] Xu Q, et al. Chemical plant flare minimization via plantwide dynamic simulation. Industrial & Engineering Chemistry Research 2009;48(7): 3505–12.

[59] Stanley IO. Gas-to-Liquid technology: prospect for natural gas utilization in Nigeria. Journal of Natural Gas Science and Engineering 2009;1(6):190–4.

[60] Rahimpour M, et al. Conversion of refinery natural purge gases to liquid hydrocarbons in GTL loop with hydrogen-permselective membranes: an alternative to gas flaring. Journal of Natural Gas Science and Engineering 2011;3(3):461–75.

[61] Davoudi M, et al. The major sources of gas flaring and air contamination in the natural gas processing plants: a case study. Journal of Natural Gas Science and Engineering 2013;13:7–19.

[62] Promoppatum P, Viswanathan V. Identifying material and device targets for a flare gas recovery system utilizing electrochemical conversion of methane to methanol. ACS Sustainable Chemistry & Engineering 2016;4(3):1736–45.
[63] Thomas S, Dawe RA. Review of ways to transport natural gas energy from countries which do not need the gas for domestic use. Energy 2003;28(14): 1461–77.
[64] Mousavi SM, Alavi-Mehr J, Amidpour M, Arjmandi R, et al. Technical, economic, and environmental assessment of flare gas recovery system: a case study. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 2020;42(20):2489–501. https://doi.org/10.1080/15567036.2020.1737597.
[65] Barekat-Rezaei E, et al. Thermo–economical evaluation of producing liquefied natural gas and natural gas liquids from flare gases. Energies 2018; 11(7):1868.
[66] Khanipour M, et al. Enhancement of synthesis gas and methanol production by flare gas recovery utilizing a membrane based separation process. Fuel Processing Technology 2017;166:186–201.
[67] Zolfaghari M, Pirouzfar V, Sakhaeinia H. Technical characterization and economic evaluation of recovery of flare gas in various gas-processing plants. Energy 2017;124:481–91.
[68] Nezhadfard M, Khalili-Garakani A. Power generation as a useful option for flare gas recovery: enviro-economic evaluation of different scenarios. Energy 2020;204:117940.
[69] Qeshta HJ, et al. Sweetening liquefied petroleum gas (LPG): parametric sensitivity analysis using Aspen HYSYS. Journal of Natural Gas Science and Engineering 2015;26:1011–7.
[70] Rahimpour M, et al. A comparative study of three different methods for flare gas recovery of Asalooye Gas Refinery. Journal of Natural Gas Science and Engineering 2012;4:17–28.
[71] Zadakbar O, Vatani A, Karimpour K. Flare gas recovery in oil and gas refineries. Oil & Gas Science and Technology 2008;63(6):705–11.
[72] Brzustowski T. Flaring in the energy industry. Progress in Energy and Combustion Science 1976;2(3):129–41.
[73] Hajizadeh A, et al. Technical and economic evaluation of flare gas recovery in a giant gas refinery. Chemical Engineering Research and Design 2018; 131:506–19.
[74] Horlock JH. Advanced gas turbine cycles: a brief review of power generation thermodynamics. 2013.
[75] Silva E, et al. Gas turbine performance analysis operating with lowheating value fuels. Revista de Engenharia Térmica 2013;12(2):08–15.
[76] Rahimpour MR, Jokar SM. Feasibility of flare gas reformation to practical energy in Farashband gas refinery: no gas flaring. Journal of Hazardous Materials 2012;209:204–17.

This page intentionally left blank

15

Environmental effects of dust release from oil, gas, and petrochemical units

Abdul Rahim Nihmiya[1] and Nayef Ghasem[2]

[1] *Department of Civil and Environmental Technology, University of Sri Jayewardenepura, Nugegoda, Sri Lanka;* [2] *Department of Chemical and Petroleum Engineering, United Arab Emirates University, Al-Ain, United Arab Emirates*

1. Introduction

Hydrocarbons can combine in different means to form a variety of compounds. Naturally formed hydrocarbon deposits' physical composition can differ significantly. However, they are commonly grouped into two broad classes: crude oil or natural gas as shown in Fig. 15.1, depending on whether the primary output is liquid or gas [1]. The petroleum is heavier and more viscous if the proportion of carbon to hydrogen in the deposit is greater. Conventional crude oil is a liquid mixture of paraffinic and other hydrocarbons spanning a varied range of molecular weights and comprising different amounts of sulfur, nitrogen, and other elements. The word *crude oil* denotes the unrefined state of oil in its "crude" form. Oil as it derives from the ground. After crude oil has been extracted from the earth's surface it should be carried to a refinery and to be refined to be segregated into components including kerosene, naphtha, gasoline, lubricating oils, paraffin wax, aviation fuel, fuel oil, asphalt, etc., before it reaches the consumer [1,2]. Natural gas is a combination of hydrocarbons that are at normal temperature and pressure in a gaseous state. Methane is the primary element of natural gas [1]. But it also contains other simplest and lightest hydrocarbon gases such as ethane, propane, butane, and pentane. Natural gas is always contaminated with carbon dioxide, hydrogen sulfide,

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00019-0

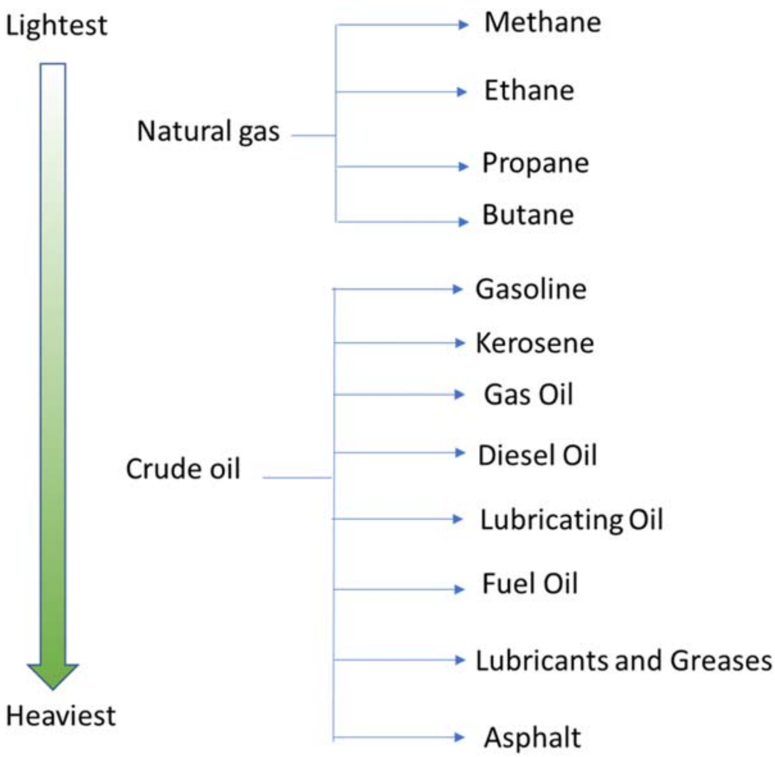


Figure 15.1 Petroleum and its components [1].

water vapor, and nitrogen. The main objective of this chapter is to discuss the environmental effects of PM release from oil, gas, and petrochemical units.

2. Petroleum and its components

Petroleum is well known as "black gold" due to its great commercial value together with its refined products. Petroleum if well managed substantially enriches the economy of a producing nation as it is a crucial raw material for various industries [2,3]. Petroleum's key prominence is because of its usefulness as a potent non-renewable energy source. Petroleum provides the fuel to run the internal combustion engines of machinery such as automobiles, ships, tractors, generators, and tanks which are still used today. Further petroleum's importance originates due to the reason that it fuels most of the types of equipment in our technologically advanced society. In addition, petroleum is also used as a raw material feedstock for the petrochemical industry that

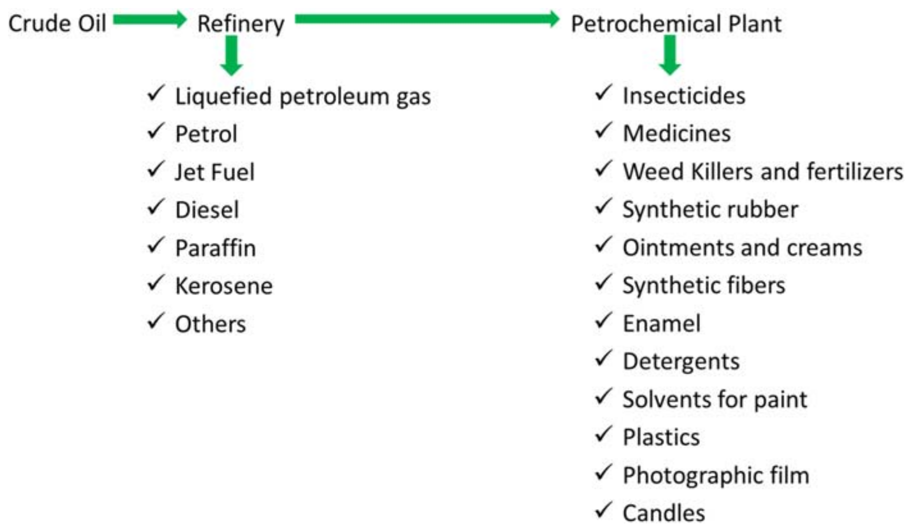


Figure 15.2 Petroleum products [3].

manufactures various products including cosmetics, detergents, plastics, fertilizers, insecticides, paints, pharmaceuticals, solvents, pesticides, and even food supplements (Fig. 15.2) [3].

The petroleum industry is also stated as the gas and oil industry undertaking various types of activities such as exploration, extraction, refining, transportation, and selling of crude oils, natural gases, and petroleum products. This industry is characteristically divided into three main subdivisions: upstream, midstream, and downstream [4]. The activities involved from exploration to extraction of crude oil and natural gas are characterized as upstream. Activities involved with conveyance and storage are characterized as midstream, whereas downstream covers purifying crude oil and natural gas into various end products. The petroleum industry is huge and worldwide its operations involve almost every region.

The total petroleum industry throughout the whole range of activities from exploration to final utilization emits a different range of hazardous air pollutants into the environment [5–7]. The environmental impact caused by the petroleum industry mostly depends on the conditions and operations of the amenities themselves. Design and operating practices of the industry such as inspection and maintenance frequency, equipment condition, operating procedures, treatment technologies, and appropriate environmental and conservation regulations affect the pollution level. In addition, occasional accidents, and equipment failures such as pipeline breaks, tank explosions, tanker accidents, and well blowouts also may pollute the environment.

3. Petroleum product

Historically, many petroleum industries have not operated responsibly toward environmental management. Therefore, toxic chemicals, including substantial amounts of carcinogens like benzene and butadiene, were emitted into the environment, and short- and long-term exposure to these chemicals placed the public at high risk [8–11].

A typical petroleum industry can emit a huge volume of contaminants into the environment, comprising inorganic acidic trace gases such as SO_x, NO_x, and H_2S, dust particles, and several kinds of trace metals such as Nickel, Cadmium, Chromium, Vanadium, Arsenic, Mercury, Lead, and Manganese [12–15]. A comprehensive list of various atmospheric emissions released by petrochemical industries and the detail properties and toxicity effects of these pollutants are available in the literature [12,13,16–29]. Amoatey et al. [22] described the air pollutants emission detail from certain oil industries in various countries. World Health Organization (WHO) reported in 2014, that air pollution exposure was the cause of more than 10% of global deaths (approximately seven million people) [22]. Compared to previous approximations, the number of deaths is more than double, and it confirms that now polluted atmosphere is the global biggest environmental health threat. In recent years several conventional air pollution control technologies to treat atmospheric emissions from refinery plants and petrochemical industries have been employed to reduce emissions and minimize their environmental impacts. Unfortunately, in developing countries because of a lack of both proper regulations and awareness air quality has been worsening evermore.

4. Particulate matter and their detrimental effects

Dust particles, often referred to as particulate matter (PM), in the air are solid or liquid state microscopic particles suspended in the atmosphere [30–33]. PM is also referred to as atmospheric aerosol particles or suspended particulate matter (SPM). Categories of PM are suspended particulate matter which is thoracic and respirable particles; inhalable coarse particles which are particles with a diameter of 10 μm or less and designated as PM_{10}; fine particles with a diameter of 2.5 μm or less and designated as $PM_{2.5}$; ultrafine particles with a diameter of 100 nm or less; soot (Table 15.1) [30,33]. In recent years, PMs attract more concern

Table 15.1 Types of dust particle [30,33].

Type of dust particle	Characteristic
Suspended particulate matter	• Thoracic and respirable particles
Inhalable coarse particles	• Particles with a diameter of 10 μm or less • Designated as PM_{10}
Fine particles	• Particles with a diameter of 2.5 μm or less • Designated as $PM_{2.5}$
Ultrafine particles	Particles with a diameter of 100 nm or less
Soot	Mass of impure carbon particles

as investigations have confirmed the link of PMs concentration with different types of adverse well-being effects such as cardiovascular and respiratory illness, and even lung cancer [18,27,34]. Generally, exposures to PM are related to stunted lung function and deteriorated allergic symptoms. It may also surge birth weight issues and newborn death as a consequence of breathing disorders [35]. The group of people who are most vulnerable to effects related to PM regular interactions is those with earlier lung and heart diseases or poor socioeconomic status.

Characteristically, most aerodynamic particles which are greater than 10 μm in diameter are set down in the throat or nose, and not possible to reach the respiratory tract lower tissues [35]. But PMs with tiny diameters can pierce the lungs bottom, thus in the pulmonary parenchyma area set down in the bronchioles and alveoli. Therefore, PMs of very small diameter are so challenging, and more concerns are developing on it. Consequently, in many regions, PMs with a size of less than 2.5 μm are the focus of measurement and regulation standards. As per WHO guidelines, $PM_{2.5}$ should not go above 10 $\mu g/m^3$ yearly arithmetic mean concentration whereas $PM_{2.5}$ less than 25 $\mu g/m^3$ is the daily mean concentration [36].

PMs can be grouped into two types as per the formation mechanism which are primary and secondary PM. Primary PM is straightly emanated from the cause to the surrounding air. The significant concentration of $PM_{2.5}$ and/or PM_{10} emitted from the petroleum industry are produced from the fluidized bed catalytic cracking unit (FCCU) that is made up of alumina and silica catalyst [22]. Diverse elemental compositions such as aluminum, silica, cerium, etc., are emitted from FCCU. Many scientific studies proved that PMs badly affect materials ecosystems and climate.

PM, mainly $PM_{2.5}$, changes the absorption and scattering pattern of the light in the atmosphere causing visibility problems. By referring to climate alteration ambient PM has climate warming as well as cooling properties. Constituents like black carbon of the atmospheric PM mixture stimulate climate warming, whereas constituents like nitrate and sulfate have a cooling influence. PM can have adverse effects on ecosystems as well including soil water and plants through the deposition. Deposition into the water can upset water quality and clearness. The deposition of metal and organic compounds in the PM on plants' leaves and subsequent uptake have the highest possibility to change plant growth and yield [4,22].

Secondary PM is principally formed in the atmosphere by liquid-phase or photochemical reactions in clouds or fog droplets with precursor gases such as VOCs, SO_2, and NO_x [22]. Sulfuric acid and nitric acid are formed because of the oxidation of SO_2 and NO_x, respectively. SO_2 oxidizes in two methods. One method is photochemical reactions that occur during the daytime. During photochemical oxidation, SO_2 is oxidized to sulfate, and nitrogen and hydrocarbon oxides catalyze the process. On the other hand, in the droplets in clouds, SO_2 can be oxidized to sulfate. The soluble SO_2 gas dissolves in the water molecules when air molecules pass through the clouds and then get oxidized to sulfate. The rate of the first mechanism is accelerated by hydrocarbon discharges created by the petrochemical units and petroleum refineries. Secondary nitrates and sulfates scatter light well, causing foggy conditions and poor visibility [37].

Secondary aerosol comprises particles produced as secondary organic aerosols (SOA) as a consequence of the photochemical oxidation and atmospheric of VOCs. The $PM_{2.5}$ concentration was evaluated over 6 years in a survey conducted in Edmonton Canada [37]. SOAs were the key contributor and then secondary nitrate and secondary sulfate. 16.7% of evaluated $PM_{2.5}$ (mass concentration) is secondary nitrate. 15.4% of evaluated $PM_{2.5}$ (mass concentration) is secondary sulfate, which was determined to be the third main constituent, subsidizing the total $PM_{2.5}$ concentration. At the Edmonton sampling location, it was identified that the petroleum complex was the principal cause of the existence of secondary sulfates. A study was conducted to calculate the emissions of aerosol particulates in Rio de Janeiro [37]. It was witnessed that 52%—75% of the fine aerosol's emission was due to oil combustion and traffic. Industrial emanations also upsurge the concentration of sulfur present within $PM_{2.5}$ emissions. Due to the emissions from the industry, there is also a probability of the existence of metals in the PM. At Gela, Italy a study was carried out to study the outcome of petroleum refining processes and vehicular discharges on airborne PM. The study showed that there was a substantial involvement of many metals and metalloids in the airborne PM. From further analysis, it was noticed that the existence of nickel, arsenic, sulfur, selenium, molybdenum, zinc, and vanadium was due to the petrochemical industry releases. These metals are possibly lethal, and the combination of these metals with the air aerosols can have contrary health effects. Another experiment carried out in Houston, Texas, witnessed the existence of metals in airborne PM, due to the emissions during occasional activities like a startup, shutdown, equipment failures, and maintenance activities. To the existence of metals in $PM_{10,}$ petroleum purifying operations can also contribute because in FCC catalysts lighter lanthanoids are enriched [37].

Another important pollutant that is produced by petrochemical industries is Persistent Organic Pollutants (POPs). In the year 2002, research was executed in Spain at Tarragona County to investigate the levels of POPs in the soil deposited due to the petrochemical industry emissions [37]. The data had been utilized to evaluate the pollution due to polychlorinated biphenyls (PCBs), polychlorinated naphthalene (PCNs), polychlorinated dibenzo-p-dioxins, and dibenzofurans (PCDD/Fs), and polycyclic aromatic hydrocarbons (PAHs) [38].

Soot and aerosol formation are due to reactive gaseous elements that are emitted by the petroleum units. It is commonly agreed that aerosols, which emanated from oil units could able to (i) Exist for an extended period in the surrounding atmosphere; (ii) diffuse through the inside environment, and (iii) go through a long array of alteration and transport phenomena to an original atmosphere. Through condensation and coagulation mechanisms tiny aerosols can produce a different critical nucleus by the nucleation process and then develop continuously to produce a bigger aerosol [4,22,37].

5. Global scenario on dust release

Although petrochemical industries fulfill the world energy requirements and produce a variety of valuable chemicals, they significantly deteriorate air quality and are responsible for detrimental environmental effects. Hence, several standards and rules have been defined by international organizations such as WHO, EU, Occupational Safety and Health Administration (OSHA), etc. However, the lack of industry cooperation and investment continues to emit pollutants. Karagulian et al. show in their study industrial activities were responsible for 15%–18% of PM emissions with which major contribution being petrochemical industries [39]. Assessments of the global burden of diseases have revealed in 2013 that mortality cases due to $PM_{2.5}$ were 3.3 million, whereas it shows a sharp increase in 2017 and it was 4.3 million [40]. According to the US EPA, PM has a great possibility of getting deposited into the lungs. Therefore, exposure to pollutants can be able to readily cause pulmonary deaths. The concerned populations are those who already get treatment for lung diseases.

Understanding the worldwide situation and trends of emissions from different petrochemical industries in the world can provide an insight into the contaminants that are being recognized in the atmosphere nearby these causes, and the manner they can reduce the quality of fresh. This section focuses on measured dust discharges from the selected oil industries and several well-being effects because of petrochemical industries from designated locations throughout the world.

As per EPA, 2011 report, continuous emission monitoring system (CEMS) records of a representative oil refining unit witnessed that to produce crude oil of 50,000 barrels, by default yearly 189.5 and 208 tons of $PM_{2.5}$ and PM_{10} were, respectively, released. Based on CEMS evaluations, for a nonstop refinery combustion process, annually 940 tons of NO_x and 3.5 tons of SO_2 were released into the surrounding atmosphere. The average emission factor for nickel, mercury, lead, and cadmium in pounds per million British thermal units (lb MMBtu-1) were 5.59×10^{-3}, 3.23×10^{-4}, 2.42×10^{-3}, and 2.38×10^{-3}, respectively (EPA, 2011) [37].

In 2016, Brand et al. [41] studied in two Canadian provinces among young children hospital admissions due to respiratory illness. The sample population was selected from those who live near oil refineries, pulp mills, and metal smelters. In the study period, important amenities released an average yearly 414.18 tons of NO_2 2252.63 tons of SO_2, and 284.75 tons of $PM_{2.5}$. They found rough estimates for greater than before breathing problem hospitalizations in young children due to everyday exposure to total industrial emissions of $PM_{2.5}$ and SO_2. In 2014 Smargiassi et al. [42] performed a panel study of youngsters who have asthma and resided very closer to Montreal and Quebec refinery units, to evaluate the connections concerning their specific everyday exposure to air contaminants and abnormalities in selected indicators of cardiovascular health and pulmonary function. Average $PM_{2.5}$ concentrations and total poly-aromatic hydrocarbons (PAHs) were, respectively, 130 mg/m^3 and 5.7 mg/m^3. Pearson correlation coefficients amid total $PM_{2.5}$, PAHs, NO_2, and benzene, ranged from −0.11 to 0.11, and the connection among contaminants and individual temperature and relative humidity ranged from 0.04 to 0.11. With total concentrations of PAHs, a minor decline in breathing function was observed in the study [42].

The environmental effect of No.6 Naphtha Cracking Complex which is presently the biggest Taiwan petrochemical unit was investigated by Chen et al. in 2018 [43]. The sample population was recruited from three regions: (i) Zhutang Township which is 19.9 km from the source and 372 people participated; (ii) Dacheng Township which is 9.2 km from the source and 1333 people from the other 14 villages participated; and (iii) Taisi Village which is 5.5 km from the source and 229 people participated. To characterize exposure to pollution from the cracking unit urinary heavy metal concentrations were used as indicators. Urinary creatinine was used to standardize the study subjects' urinary exposure biomarkers. The concentrations of 11 heavy metals in the urine, including chromium, manganese, vanadium, copper, nickel, strontium, arsenic, lead, cadmium, thallium, and mercury, were investigated using an ICP-MS (inductively coupled plasma mass spectrometry) system. Taisi occupants had considerably greater concentrations of heavy metals than Dacheng and Zhutang residents. Researchers determined that the overall cancer threat was significantly increased for Taisi occupants residing close to the No. 6 Naphtha Cracking unit for 10−16 years afterward the unit initiated its operation [43].

Chuang et al. [44] estimated the link between the exposure roots in the surrounding area of a petrochemical unit in Taiwan and the bioreactivity of $PM_{2.5}$ in vitro. The measured typical $PM_{2.5}$ was 30.2 $\mu g/m^3$ during the study period. In this study a new method to explore particle bioreactivity was demonstrated and which recommended that petrochemical released $PM_{2.5}$ must be an alarm for neighboring occupants' health. In vitro consecutive toxicity was determined resulting from $PM_{2.5}$, accumulated from the petrochemical unit area. Four significant outcomes are informed: (i) significant and slight industrial exposures and long-range transport were recognized by the wind direction and speed, (ii) $PM_{2.5}$ produced considerable differences based on dose in cell viability, and lactate dehydrogenase (LDH), 8-isoprostane, and interleukin (IL)-6 levels, (iii) $PM_{2.5}$ from key industrial exposure was considerably associated with elevated 8-isoprostane and IL-6 levels, and (iv) lead was connected with LDH in key industrial released $PM_{2.5}$, whereas selenium and lead were linked with 8-isoprostane in major industrial $PM_{2.5}$ [44].

5.1 Modeling and health risk evaluation of dust particles

The modeling and health threat evaluation of $PM_{2.5}$ emitted by Tema Oil Refinery, Ghana, were carried out by Amoatey et al., and they utilized an air dispersion modeling system (AERMOD) to model the concentration of $PM_{2.5}$ emitted by Tema Oil Refinery and to evaluate the non-carcinogenic threat and deceases of the exposed people [45]. The AERMOD results revealed that both daily $PM_{2.5}$ concentration levels which is 38.8 $\mu g\, m^{-3}$ and yearly $PM_{2.5}$ concentration levels which is 12.6 $\mu g\, m^{-3}$ were out of the international standards. Health risk assessment (HRA), specified by hazard index (HI), exposed that the concentration of Al_2O_3 present in the $PM_{2.5}$ triggered an important non-carcinogenic health threat to the exposed people comprising both grown-ups and youngsters within the Metropolis ($HI = 2.4$ for grown-ups and $HI = 1.5$ for youngsters). Furthermore, cardiopulmonary disease connected deaths because of $PM_{2.5}$ exposure which is 181 deceases among grown-ups and 24 deceases among youngsters, which were significant values compared to deceases that happened because of lung cancer which is 137 deceases among grown-ups and 16 deceases among youngsters [45].

Civan et al. [46] measured ambient concentrations of VOCs, NO_2, SO_2, and ground-level ozone O_3 at different 55 sites around a densely crowded industrial zone in Western Turkey, holding a petroleum refinery (Tupras), a petrochemical complex (Petkim), a gas-fired power plant, ship-dismantling amenities, and several iron and steel plants. Traffic was identified as the important reason to evaluate total VOCs concentrations. However, the petrochemical complex at Petkim and petroleum refinery at Tupras also considerably contribute to measured pollutants levels. Moderated carcinogenic risk estimated due to benzene inhalation by using a Monte Carlo simulation was roughly four per-one-million people, which exceeded the US EPA benchmark of one per one million people.

Campa et al. investigated the size range and composition of chemicals of metalliferous stack emission in the San Roque petroleum refinery unit situated in southern Spain [47]. They demonstrated that there is a significant dissimilarity in the size distribution and composition of chemicals of metalliferous PM existent with petrochemical unit chimney stacks. PM samples from cascade impactor within the size range from 0.33 to 17 μm were gathered and analyzed from inside stacks. Metals with the significant dangerous concentrations averaged overall size ranges were Nickel up to 3295 $g m^{-3}$, chromium up to 962 $g m^{-3}$, vanadium up to 638 gm^{-3}, zinc up to 225 gm^{-3}, molybdenum up to 91 gm^{-3}, and cobalt up to 94 gm^{-3}. Many metal PMs are intensely concentrated into the optimum portion less than 0.33 μm, even though some processes, like purified terephthalic acid (PTA) making emission reveal rougher size ranges. The fluid catalytic cracking stack emits a significant quantity of lanthanum (>200 gm^{-3} in PM 0.67–1.3), chromium, and nickel in a moderately rough PM size range (0.7–1.4). Their distinctive database, straightly analyzed from chimney stacks, assures that oil refinery units like SanRoque are a strong source for a different type of fine, deeply inhalable metalliferous atmospheric PM pollutants.

A study on oil refinery emission along with vehicle exhausts and ships emission of ultrafine particles (UFPs) to the ambient air was presented by González et al. [48]. It is considering a data set gathered at Santa Cruz de Tenerife City from 2008 to 2010 in the ambient air. Particle numbers rougher than 2.5 nm (N), $PM_{2.5}$, PM_{10}, black carbon (BC), and gaseous pollutants (SO_2, NO_x, O_3, and CO) were measured. At the sample location, an earlier study set up a connection between exposure to UFPs in the atmospheric air and hospitalizations due to heart failure. It was recognized that vehicle emissions create the basic level UFPs, while elevated UFP episodes were created because of the exhausts from ships and refinery. The level of UFP related to vehicle emanate exposure was significant in the morning (07:00–09:00 GMT, 5000–25,000 cm^{-3} = 25th–75th percentile), while those connected to ship (15,000–45,000 cm^{-3}) and refinery (25,000–95,000 cm^{-3}) exhaust was high in the 10:00–17:00 GMT period because of the photochemistry and meteorology effects [48].

The Korean Ulsan metropolitan city contains two state industrial units On–San Industrial Complex (OSIC) and Ulsan Petrochemical Industrial Complex (UPIC) which manufacture a range of industrial products. Nearby residential areas of these industrial complexes are at high potential health risks due to heavy air pollution. Therefore, Lee et al. [49] tried to estimate the distribution concentration of significant air pollutants, PM_{10} and SO_2. Total annual PM_{10} emissions were projected to be 6667.6 tons, with a point source. Total annual SO_2 emissions were projected to be 63,877 tons/year. This is roughly 10 times more than P_{M10} emissions, due to many plants in Ulsan utilizing the elevated–sulfur fuels like bunker fuel and coal for an extended period.

PM_{10} emission was studied at La Linea, LL (urban area) and Puente Mayorga, PMY (industrial area) in Southern Spain with data gathered from 2005 to 2014 by Li et al. [50]. These two cities are situated, respectively, on the east and north of Algeciras Bay in Southern Spain. The bay is vastly covered by industries including the biggest oil refinery in Spain known as CEPSA oil refinery, Acerinox stainless steel manufacturing plant at PMY and oil- and coal-fired power plants. The daily emission level of PM_{10} was in the range of 9–126 mg/m^3 at LL and 8–119 mg/m^3 at PMY. The yearly mean PM_{10} ranged from 26 to 42 mg/m^3 at LL and from 24 to 42 mg/m^3 at PMY. The concentrations of pollutants in the air started to decrease from 2005 to 2014 at both sites. This decline in the inter-yearly PM_{10} trend was described by the described three phases: (i) The early PM_{10} concentrations moved toward or surpassed the yearly PM_{10} European Union Air Quality Standard of 40 mg/m^3 from 2005 to 2009 at PMY and 2005 to 2007 at LL. (ii) Then PM_{10} quickly reached 30 mg/m^3 which is roughly 25% drop, during 2010–2011 at PMY and during 2008–2011 at LL. (iii) Lastly, the concentrations slowly decreased to less than 30 mg/m^3 from 2012 to 2014 [50]. The outcome of the study was effective air quality enhancement in a vastly industrialized area in Southern Spain was credited to the mitigation involvement of industry, town transportation, and efficient utilization of fossil fuels.

Concentrations, sources, and comparative effects of trace metals including copper, cadmium, nickel, chromium, iron, manganese, lead, titanium, vanadium, and zinc observed in PM_{10} in the Altamira in Northern Mexico petrochemical industrial zone are conveyed by Rodriguez-Espinosa et al. [51]. Results revealed that emission from mining, oil refining, alloys, metallurgical processes, fertilizer, and steel manufacture industries are significantly contributing to PM_{10} and metal level in the atmosphere. PM_{10} levels varied from 21 to 92 $\mu g\ m^{-3}$ and topped the reviewed daily average of 75 $\mu g\ m^{-3}$ which is the Mexican standard. The significant metal concentrations were iron—1.64 $\mu g\ m^{-3}$, manganese—0.57 $\mu g\ m^{-3}$, and titanium—0.29 $\mu g\ m^{-3}$.

Yuan et al. [52] in a study noticed the public residing in the nearby places of a petrochemical unit situated in Mailiao Township of Yunling County, on the west coast of central Taiwan are more vulnerable to cancer. It is the biggest petrochemical unit in Taiwan with more than 64 plants and a total area of 2603 ha. A significant amount of pollutants were released from the facilities at this complex including two naphtha cracking plants that produce 160 million tons of ethylene, one 1.8 million kW/year electricity generating capacity coal-fired power plant, three oil refineries with an oil production capability of 25 million tons/year, 2.82 million kW total electricity capacity three cogeneration plants and various petrochemical processing units. The study employed who reside within a 40 km radius of the complex. 2388 long-term occupants old above 35 years in 2009–2012 were chosen for the study. Cancer frequencies among those who reside more than 10 km from the unit (low exposure, LE) and those who reside fewer than 10 km from the unit (high exposure, HE) were compared by using internal exposure biomarkers of urinary carcinogenic metals measurements. The researchers witnessed that the residents who live in HE areas had greater urinary cancer-causing metal concentrations, including arsenic, cadmium, mercury, lead, and vanadium. Further, the residents who lived in LE areas have a lesser occurrence rate of hepatitis C than those who lived in HE areas. Also, concluded that senior and woman occupants residing within 10 km of the petrochemical unit had greater hazardous exposure and cancers than those residing distant away from the unit after the unit had been functioning for 10 years. The researchers also in another study investigated the ecological contaminants such as vanadium and polycyclic aromatic hydrocarbons (PAHs) metabolic effects of on occupants living in proximity to this petrochemical complex [53]. As per results, the urinary levels of 1-hydroxypyrene and vanadium were, respectively, 20 and 40 times more in the higher exposure subjects compare to the low-exposure subjects. Elevated urinary levels of stress biomarkers, comprising 8OHdG, 8-isoPF2α, HNE-MA, and 8-NO2Gua, were also witnessed between the high-exposure subjects than the low-exposure subjects. Among the high-exposure people, levels of carbohydrate and amino acid metabolites were lower compared to the low-exposure people. Exposure to PAHs and vanadium may reduce the levels of carbohydrates and amino acids by increasing insulin signaling and PPAR, along with oxidative/nitrosative stress.

5.2 Effect of dust particles

Like health effects, the ecological impact of dust particles is also vitally important [22]. Specifically, relative to urban forests PM makes an adverse impact on biodiversity. It has been identified fine PM deposition on leave surfaces mutates the properties of leaf surface, increases the extent of surface moisture level, and changes the epiphytic organisms habitation, causing elevated threats from pathogens [54]. Moreover, PM affects photosynthesis as well through abrasion, stomata obstruction, and smothering of the leaves. Moreover, it has been identified that PM set down straight to the land can disturb nutrient cycling, particularly that of nitrogen, over its special effects on the microorganisms. As fungi are one of the main decomposers, modifying the fungal community eventually deteriorates the decomposer community and decreases the degree of litter decomposition. With of buildup of mineral nutrients and carbohydrates, litter that little by little decomposes affects nutrient availability within the ecosystem. Other than PM, secondary air pollutants are also doubted to have an intense adversarial influence on the forest ecosystem. Reduced radiation interception by plant canopies can be caused by increased PM levels. This probably diminishes rainfall through various types of physical effects and eventually changes the global climate. Radiation energy is absorbed by dark particles specifically black carbon. Also, cloud droplets and coarse particles created by the water vapor condensation on particles have radioactive effects. This may cause local and global influences on climate variation [55]. PM is one of the main attributes for various environmental issues, specifically climate change and ground-level ozone variation. Through, general precursors, sources, and atmospheric processes $PM_{2.5}$ and ground-level ozone are very much connected. As of this inter-related connection, differences in the releases of one contaminant can cause differences in the level of ground-level ozone or PM. By the wind PM and its precursors can be taken away for longer distances and ultimately be set down on the land or in water. This set down cause streams and lakes acidic, reduces the nutrients in the soil, deteriorates delicate forests and farm crops, varies the nutrient stability in large river basins and coastal waters and boosts eutrophication, and disturbs the variety of ecological systems. PM also carries toxic elements like mercury, which can destruct water standards and consequently aquatic biodiversity.

5.3 Effect of heavy metals

Heavy metals such as sulfur, copper, zinc, and iron are essential for the biosynthesis of auxin, enzymes, and some protein, vital for the standard development and growth of plants [22]. Disturbance in their concentration can substantially alter biochemical processes in plants, causing a reduction in production, poorer yield, and poor quality of crops. PAHs impact membrane physicochemical properties, which can cause inhibition of both respiration processes and photosynthetic processes [55]. Physiological and biochemical processes happening in the development and growth of plants are influenced by PAHs and/or products of their biotransformation and photo modification.

PM pollutants the genotoxic influence on the ecological system, with the development of resistant species, is too significantly important. As a larger portion of our biosphere is covered by plants and it is set up a dynamic association with the food cycle, genotoxic effects on plants caused by toxic compounds are significantly important. Therefore, evaluating the genotoxicity of PM is crucial to assess the threat to the plant health and atmosphere. Moreover, greater parts of these PM contaminants including heavy metals, halogenated aliphatic hydrocarbons, and polycyclic aromatic compounds (PACs) are genotoxic [22]. Taller plants may be renowned as delicate and effective indicators of genotoxicity when related to other chemical and physical means. The advantages of utilizing plants as genotoxicity bioindicator are that they are susceptible to emission time varying from a few minutes to weeks, are relaxed to operate and arrange, and are reasonably priced related to traditional indicator methods. The outcomes of plant bioassays can show up as a warning of air pollution and environmental stress even though plant reactions to air toxics may not be generalized straightly to estimate the influence on human health. For example, even though PAHs are comparatively chemically inert elements, through metabolic activation to electrophilic are capable of covalent interaction with nucleophilic centers of DNA. These adducts of PAH to DNA result in base pair replacements, S-phase arrest, frame shift changes, deletions, strand breakage, and a variety of chromosomal changes.

6. Conclusion

Petroleum is a highly important natural resource among fossil fuels because it is a more significant resource to many businesses as an energy source and feedstock for the production of a range of product assortment. The petroleum industry is involved with various activities such as exploration, drilling, mining of crude oil, refining as well as transportation, storage of crude, and refining of crude oil into various end products. The petroleum industry is closely connected with environmental degradation with almost all its operations. A typical petroleum industry can emit chains of effluents in significant concentrations into the environment, comprising inorganic acidic trace gases such as SO_x, NO_x, and H_2S, particles ($PM_{2.5}$ and PM_{10}), and several types of trace metals such as Nickel, Cadmium, Chromium, Vanadium, Arsenic, Mercury, Lead, and Manganese.

Historically, many petroleum industries have not operated responsibly toward environmental management. Therefore, different types of toxic chemicals including substantial amounts of carcinogens like benzene and butadiene emitted into the environment, and short- and long-term exposure to these chemicals placed the public at high risk. It is of utmost importance to launch and strictly implement environmental protocols in the petroleum refining industry for governing air pollution to safeguard vegetation and wildlife as well as human beings. Furthermore, the atmospheric air standards should be managed systematically in developing countries where emissions increased dramatically and subsequently the air quality deteriorated significantly due to escalated energy demands, industrialization, and overpopulation.

As refineries and petrochemical industries emanate several pollutants into the surrounding air, it is of utmost necessity to develop operational control strategies by identifying the sources of toxic waste in these industries and the nature of the waste products. Efforts must be supported by research that can offer facts on avoidance and diminishing environmental deterioration related to petroleum refining processes. All the refining plants should also put up wastes recollect functional systems, purge effluent releases, and deterioration of the ecosystem with toxic materials to the negligible slightest levels. Petroleum industry authorities must ensure environmental strategies to prevent or diminish pollutant releases into the ecosystems.

For the oil and gas industry knowing production process related environmental variables have been a compulsory and important predicament requirement. In this advanced era, the obligation of any entity to support community sustainable development is more than just ethical, moral, and financial assurances, because individuals and governments may be predisposed by the adverse reputation accompanying entities that damage the environment. This work aims to disseminate dispersed information about the petrochemical industry and related environmental effects of dust released from oil, gas, and petrochemical units. Understanding the global situation and trends of waste emission around different petrochemical complexes in the world can offer a comprehensive knowledge of the contaminants that are being recognized in the atmosphere around these sources and the methods by which they can influence air standards subsequently threatening human health and eco cycle natural balance.

Abbreviations

AERMOD Air dispersion modeling system
CEMS Continuous emission monitoring system
EPA Environment Protection Agency
FCCU Fluidized bed catalytic cracking unit
HI Hazard index
HRA Health risk assessment
OSHA Occupational Safety and Health Administration
PAC Polycyclic aromatic compounds
PAH Polycyclic aromatic hydrocarbons
PCB Polychlorinated biphenyls

PCDD/Fs	Polychlorinated dibenzo-p-dioxins, and dibenzofurans
PCN	Polychlorinated naphthalene
PM	Particulate matter
PM10	Particles with a diameter of 10 μm or less
PM2.5	Particles with a diameter of 2.5 μm or less
POP	Persistent organic pollutants
SOA	Secondary organic aerosols
SPM	Suspended particulate matter
VOC	Volatile organic compounds
WHO	World Health Organization

References

[1] Barker C. Chapter 2: Origin, composition and properties of petroleum. In: Donaldson EC, Chilingarian GV, Yen TF, editors. Enhanced oil recovery, I. vol 17. Elsevier; 1985. p. 11–45.

[2] Adebiyi FM. Paraffin wax precipitation/deposition and mitigating measures in oil and gas industry: a review. Petroleum Science and Technology 2020; 38(21):962–71.

[3] Fagan AJ. An Introduction to the petroleum industry. Newfoundland: Department of Mines and Energy; 1991.

[4] Adebiyi FM. Air quality and management in petroleum refining industry: a review. Environmental Chemistry and Ecotoxicology 2022;4:89–96.

[5] Cui J, Duan L, Jiang Y, Zhao C, Anthony EJ. Migration and emission of mercury from circulating fluidized bed boilers co-firing petroleum coke and coal. Fuel 2018;215:638–46.

[6] Liu Y, Yan S, Poh K, Liu S, Iyioriobhe E, Sterling DA. Impact of air quality guidelines on COPD sufferers. International Journal of Chronic Obstructive Pulmonary Disease 2016;11:839.

[7] Damian C. Environmental pollution in the petroleum refining industry. Ovidius Univ Ann Chem 2014;24(2):109–14. https://doi.org/10.2478/auoc-2013-0018.

[8] Alnahdi A, Elkamel A, Shaik MA, Al-Sobhi SA, Erenay FS. Optimal production planning and pollution control in petroleum refineries using mathematical programming and dispersion models. Sustainability 2019; 11(14):3771.

[9] Bari MA, Kindzierski WB. Fine particulate matter (PM2.5) in Edmonton, Canada: source apportionment and potential risk for human health. Environmental Pollution 2016;218:219–29. https://doi.org/10.1016/j.envpol.2016.06.014.

[10] Wei W, Lv Z, Yang G, Cheng S, Li Y, Wang L. VOCs emission rate estimate for complicated industrial area source using an inverse-dispersion calculation method: a case study on a petroleum refinery in Northern China. Environmental Pollution 2016;218:681–8. https://doi.org/10.1016/j.envpol.2016.07.062.

[11] Sojinu SO. Environmental challenges associated with processing of heavy crude oils. In: Gounder RM, editor. processing of heavy crude oils. Rijeka: IntechOpen; 2019. Ch. 15.

[12] Sarnela N, et al. Sulphuric acid and aerosol particle production in the vicinity of an oil refinery. Atmospheric Environment 2015;119:156–66.

[13] Thepanondh S, Outapa P, Saikomol S. Evaluation of dispersion model performance in predicting SO_2 concentrations from petroleum refinery complex. International Journal of GEOMATE 2016;11(23):2129–35.

[14] Adebiyi FM, Oluyemi EA, Akande AA. Measurements of physicochemical, elemental, and total petroleum hydrocarbon contents as pollution indicators of soils in petroleum products retailing station surrounding areas. Energy Sources Part A 2015;37(3):299–308. https://doi.org/10.1080/15567036.2011.585385.

[15] Obanijesu EO, Adebiyi FM, Sonibare JA, Okelana OA. Air-borne SO_2 pollution monitoring in the upstream petroleum operation areas of Niger-Delta, Nigeria. Energy Sources Part A 2009;31(3):223–31. https://doi.org/10.1080/15567030701399479.

[16] Abdul-Wahab SA, En SCF, Elkamel A, Ahmadi L, Yetilmezsoy K. A review of standards and guidelines set by international bodies for the parameters of indoor air quality. Atmospheric Pollution Research 2015;6(5):751–67.

[17] Abdul-Wahab S, Fadlallah S, Al-Rashdi M. Evaluation of the impact of ground-level concentrations of SO_2, NOx, CO, and PM10 emitted from a steel melting plant on Muscat, Oman. Sustainable Cities and Society 2018; 38:675–83.

[18] Abdolahnejad A, Jafari N, Mohammadi A, Miri M, Hajizadeh Y, Nikoonahad A. Cardiovascular, respiratory, and total mortality ascribed to PM_{10} and $PM_{2.5}$ exposure in Isfahan, Iran. Journal of Education and Health Promotion 2017;6:109.

[19] Omidvarborna H, Baawain M, Al-Mamun A. Ambient air quality and exposure assessment study of the Gulf cooperation council countries: a critical review. Science of the Total Environment 2018;636:437–48.

[20] Lin C-K, Hung H-Y, Christiani DC, Forastiere F, Lin R-T. Lung cancer mortality of residents living near petrochemical industrial complexes: a meta-analysis. Environmental Health 2017;16(1):1–11.

[21] Shtripling LO, V Bazhenov V. Emission process system organisation of pollutants into the atmosphere for refinery enterprises. Procedia Engineering 2015;113:349–56.

[22] Amoatey P, Omidvarborna H, Baawain MS, Al-Mamun A. Emissions and exposure assessments of SOX, NOX, PM10/2.5 and trace metals from oil industries: a review study (2000–2018). Process Safety and Environmental Protection 2019;123:215–28.

[23] US EPA. Particulate matter (PM) basics. United States Environmental Protection Agency; 2020. Available from: https//www. epa. gov/pm-pollution/particulate-matter-pm-basics.

[24] Ancona C, et al. Mortality and morbidity in a population exposed to multiple sources of air pollution: a retrospective cohort study using air dispersion models. Environmental Research 2015;137:467–74.

[25] Amiry H, Sutherland H, Martin E. Environmental management and technology in oil refineries. In: Environmental technology in the oil industry. Springer; 1997. p. 291–329.

[26] Ambituuni A, Amezaga JM, Werner D. Risk assessment of petroleum product transportation by road: a framework for regulatory improvement. Safety Science 2015;79:324–35.

[27] Al-Hemoud A, Al-Dousari A, Al-Shatti A, Al-Khayat A, Behbehani W, Malak M. Health impact assessment associated with exposure to PM10 and dust storms in Kuwait. Atmosphere 2018;9(1):6.

[28] Agarwal A, Mangal A, Satsangi A, Lakhani A, Kumari KM. Characterization, sources and health risk analysis of PM2. 5 bound metals during foggy and non-foggy days in sub-urban atmosphere of Agra. Atmospheric Research 2017;197:121–31.

[29] Al-Haddad A, Ettouney H, Saqer S. Oil refineries emissions: source and impact: a study using AERMOD. 2012.
[30] Dominici F, Greenstone M, Sunstein CR. Particulate matter matters. Science 2014;344(6181):257–9.
[31] Kim K-H, Kabir E, Kabir S. A review on the human health impact of airborne particulate matter. Environment International 2015;74:136–43.
[32] Davidson CI, Phalen RF, Solomon PA. Airborne particulate matter and human health: a review. Aerosol Science & Technology 2005;39(8):737–49.
[33] Harrison RM, Yin J. Particulate matter in the atmosphere: which particle properties are important for its effects on health? Science of the Total Environment 2000;249(1–3):85–101.
[34] Pope III CA, Dockery DW. Health effects of fine particulate air pollution: lines that connect. Journal of the Air & Waste Management Association 2006;56(6):709–42.
[35] U. S. EPA. Integrated science assessment (ISA) for particulate matter (final report, Dec 2009). Washington, DC: United States Environmental Protection Agency; 2009.
[36] WHO. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005. Geneva, Switzerland: WHO; 2006.
[37] Ragothaman A, Anderson WA. Air quality impacts of petroleum refining and petrochemical industries. Environments 2017;4(3):66.
[38] Nadal M, Schuhmacher M, Domingo JL. Long-term environmental monitoring of persistent organic pollutants and metals in a chemical/petrochemical area: human health risks. Environmental Pollution 2011;159(7):1769–77. https://doi.org/10.1016/j.envpol.2011.04.007.
[39] Karagulian F, et al. Contributions to cities' ambient particulate matter (PM): a systematic review of local source contributions at global level. Atmospheric Environment 2015;120:475–83.
[40] Ostro B, et al. Assessing the recent estimates of the global burden of disease for ambient air pollution: methodological changes and implications for low- and middle-income countries. Environmental Research 2018;166:713–25.
[41] Brand A, et al. Respiratory hospital admissions in young children living near metal smelters, pulp mills and oil refineries in two Canadian provinces. Environment International 2016;94:24–32.
[42] Baig MM, GholamHosseini H, Connolly MJ. Multiple physical signs detection and decision support system for hospitalized older adults. Physiological Measurement 2015;36(10):2069–88. https://doi.org/10.1088/0967-3334/36/10/2069.
[43] Lu J-G, Zheng Y-F, Cheng M-D. Wetting mechanism in mass transfer process of hydrophobic membrane gas absorption. Journal of Membrane Science 2008;308(1):180–90.
[44] Chuang H-C, Shie R-H, Chio C-P, Yuan T-H, Lee J-H, Chan C-C. Cluster analysis of fine particulate matter (PM2. 5) emissions and its bioreactivity in the vicinity of a petrochemical complex. Environmental Pollution 2018;236:591–7.
[45] Amoatey P, Omidvarborna H, Baawain M. The modeling and health risk assessment of PM2. 5 from Tema Oil Refinery. Human and Ecological Risk Assessment 2018;24(5):1181–96.
[46] Civan MY, et al. Spatial and temporal variations in atmospheric VOCs, NO_2, SO_2, and O_3 concentrations at a heavily industrialized region in Western Turkey, and assessment of the carcinogenic risk levels of benzene. Atmospheric Environment 2015;103:102–13.

[47] Sánchez de la Campa AM, Moreno T, de la Rosa J, Alastuey A, Querol X. Size distribution and chemical composition of metalliferous stack emissions in the San Roque petroleum refinery complex, southern Spain. Journal of Hazardous Materials 2011;190(1):713–22. https://doi.org/10.1016/j.jhazmat.2011.03.104.
[48] González Y, Rodríguez S. A comparative study on the ultrafine particle episodes induced by vehicle exhaust: a crude oil refinery and ship emissions. Atmospheric Research 2013;120:43–54.
[49] DiGuilio RM, Lee RJ, Schaeffer ST, Brasher LL, Teja AS. Densities and viscosities of the ethanolamines. Journal of Chemical & Engineering Data 1992;37(2):239–42.
[50] Li J, Chen B, de la Campa AMS, Alastuey A, Querol X, Jesus D. 2005–2014 trends of PM10 source contributions in an industrialized area of southern Spain. Environmental Pollution 2018;236:570–9.
[51] Rodriguez-Espinosa PF, Flores-Rangel RM, Mugica-Alvarez V, Morales-Garcia SS. Sources of trace metals in PM10 from a petrochemical industrial complex in Northern Mexico. Air Quality, Atmosphere and Health 2017;10(1):69–84.
[52] Yuan T-H, Shen Y-C, Shie R-H, Hung S-H, Chen C-F, Chan C-C. Increased cancers among residents living in the neighborhood of a petrochemical complex: a 12-year retrospective cohort study. International Journal of Hygiene and Environmental Health 2018;221(2):308–14.
[53] Yuan T-H, Chung M-K, Lin C-Y, Chen S-T, Wu K-Y, Chan C-C. Metabolic profiling of residents in the vicinity of a petrochemical complex. Science of the Total Environment 2016;548–549:260–9. https://doi.org/10.1016/j.scitotenv.2016.01.033.
[54] Cape JN. Interactions of forests with secondary air pollutants: some challenges for future research. Environmental Pollution 2008;155(3):391–7. https://doi.org/10.1016/j.envpol.2008.01.038.
[55] Rai PK. Impacts of particulate matter pollution on plants: implications for environmental biomonitoring. Ecotoxicology and Environmental Safety 2016;129:120–36. https://doi.org/10.1016/j.ecoenv.2016.03.012.

16

Environmental challenges of extracting unconventional petroleum reserves

Ali Behrad Vakylabad[1], Leila Zand[1] and Zohre Moravvej[2]

[1]*Department of Materials, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran;* [2]*Department of Chemical Engineering, Shiraz University, Shiraz, Iran*

1. Introduction

In the past, oil and gas production was only possible from fields and reservoirs that had a suitable permeability, but with the advancement advances in 3D seismic exploration technologies and the use of hydraulic fracturing (fracking technology along with advanced drilling technologies), production from unconventional shale resources has also been possible and has brought many benefits to the countries that hold. However, this technology is not limited to unconventional reservoirs and is also used in conventional tanks with normal permeability [1–4].

One of the environmental problems of this technology is methane leakage into the earth's atmosphere, whose greenhouse effect is more than 20 times more than carbon dioxide [5]. Another problem is the return water (flowback fluid) from hydraulic fracturing operations, which contains toxic materials and heavy metals imported from the reservoir [6]. The expansion of fractures and the possibility of connecting these reservoirs to underground water aquifers and their contamination are other adverse effects of this technology. Therefore, environmental activists and people in areas close to oil shale have warned against harvesting these resources that lead to global climate change (especially in the US, where environmental activists have a lot of power) despite the problems raised, many countries that own horizontal drilling technology and hydraulic fracturing, to exploit these unconventional sources of oil and gas, have invested heavily. Of course,

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00001-3

these countries have also regulated laws and regulations to reduce the negative effects of this technology [7–9]. In the United States, for example, a law has been passed requiring oil companies to use higher standards as well as providing chemical compounds used in water use that make their activities transparent. Even this has already become one of the positions of US presidential candidates in explaining their energy policies so that Democrats are willing to limit the increase in production from these resources due to environmental damage caused by hydraulic fracturing measures to extract from shale resources [10–14].

According to the US Environmental Protection Agency (EPA) report in 2015, some residents close to shale oil and gas wells reported changes in the quality of water resources, claiming that hydraulic fracturing was responsible for these changes and caused serious damage. These concerns are much higher, especially in areas facing water shortages, and require more detailed investigations. Therefore, considering the importance of this issue and the impact of the development of this technology on drinking water resources, this effect will be analyzed [14,15].

The statistics from the Canadian Petroleum Producers Association shows its resource triangle. At the summit of the pyramid is the conventional resources that have a small volume and are easy to develop. Then, there are unconventional resources that have a large volume, but they are difficult and expensive to develop and extract. They include tight sand gas, coal bed methane, shale gas, and gas hydrates. Tight gas sands are known as one of the most important unconventional reservoirs around the world, especially in Western Australia. These reservoirs have very low permeability and porosity. The investigation of the sands of the Vicherrange field in the Perth Basin shows that these sands, despite their high storage, do not have a stable and optimal production rate [16–18].

Coal bed methane (CBM) is a type of natural gas extracted from coal substrates. In recent decades, it has become an important source of energy in the United States, Canada, Australia, and other countries. The term refers to methane adsorbed into the solid coal matrix. Because of the lack of hydrogen sulfide, it is called “sweet gas.” Coal methane is distinct from a typical sandstone or other conventional gas tanks because methane is stored inside coal by a process called absorption. Shale gas is enclosed among hard rocks and shale structures, and its release requires the use of hydraulic fracturing technology. It is increasingly gaining more importance in the United States as a source of natural gas [19–21].

Gas hydrates are a combination of light gases such as methane, ethane, or carbon dioxide, which under certain temperatures and compressive conditions combined with water molecules and form an ice-like substance. This substance holds a large volume of gas [22,23]. Unconventional liquid fuel sources, most notably tar sands, are in Canada. In general, it can be said that extracting unconventional fuel sources is more expensive and has lower energy efficiency in investment than conventional sources. This means that unconventional fuels can never be produced at the same low price as conventional ones. The most valuable unconventional source is probably gas. Because of its low carbon content per energy, if we replace gas with coal in sustainable energy, we can consider gas as a transitional fuel source. Fig. 16.1 shows the fossil fuel resources in the triangle in which the closer we approach the base of the triangle, the higher the storage volume and the complexity of the extraction. Accordingly, the conventional oil and gas resources (Triangle Peak) have the lowest volume and easiest production path [23,26]. Fig. 16.2 shows the current situation and prediction of gas production from various conventional and unconventional sources in the USA. The increasing development of shale gas production has led to a significant increase in the share of these resources in the US for gas production in the future [24,28].

According to statistics, oil unconventional resources are the world's richest fossil fuel reserves. Table 16.1 summarizes the distribution of unconventional and conventional reserves in different countries of the world [29].

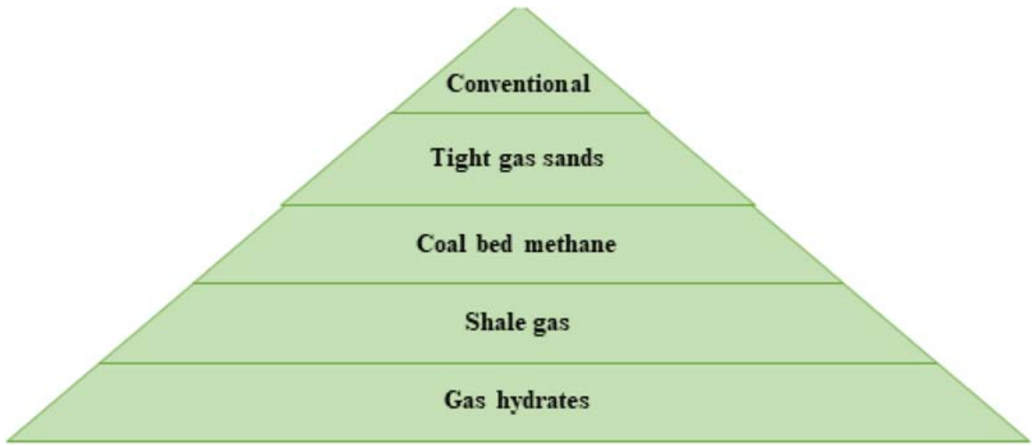


Figure 16.1 Resource triangle: conventional (small volumes-facile development) and unconventional (large volumes-difficult development) resources [16,24,25].

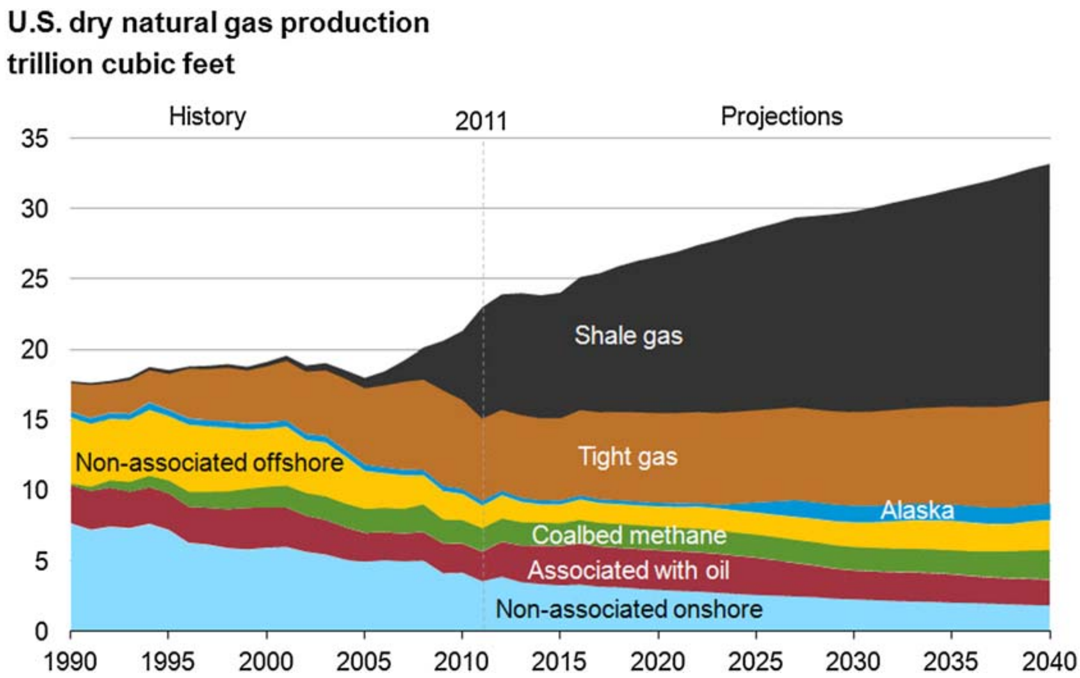


Figure 16.2 The current situation and prediction of gas production from various conventional and unconventional sources in the USA (The US energy information administration) [27].

Table 16.1 Comparison of the distribution of exploitable fossil fuel reserves by the end of 2018 [29].

	Reservoirs (billion barrels)		
Regional distribution	**Total reservoir**	**Conventional**	**Unconventional (tight oil, natural gas liquid, extra heavy oil and bitumen, kerosene oil)**
World	6165	2142	4024
North America	2364	244	2120
Central and South America	852	246	607
Europe	116	60	47
Africa	452	310	142
Middle East	1138	913	225
Eurasia	956	241	715
Asia Pacific	287	129	158

The increasing need for energy has led societies to produce energy in different ways. Energy production is one of the most important issues facing societies. Energy production through crude oil has long been considered. So, the oil industry is one of the most important industries today. Oil price fluctuations have significant changes in the economies of producing and consuming countries. Therefore, nowadays, the need for other ways of energy production seems inevitable. One of the methods of energy production is oil extraction from shale oil [30,31]. The US Energy Information Administration projects US gas production increases through 2040, due largely to the increased shale gas production. One of the main sources of oil production is called "shale oil." Shale oil is a group of rocks that contain enough organic matter (kerosene). This type of rock is in a wide range of nature from fresh waters to salt lakes and sedimentary swamps and so on. It can be found that they are formed between the geologic periods of Cambrian and tertiary (a widely used term for the period from 66 million to 2.6 million years ago). The use of these rocks goes back to ancient times. Most of the shale oil resources are in Colorado, the USA, which has a resource of over 3.3 trillion tons. There are two ways to extract shale oil, surface drilling, and in-situ drilling. In surface drilling, like the old methods, the bedrock is heated up to 500°C. In the new method, for further purification, crystal bitumen is used after the catalytic process is completed. In in-situ drilling, by electronic heaters located inside the bedrock, oil is heated over 2–3 years to 371°C to separate oil from them, and then extract through wells. To prevent the mixing of released oil with the groundwater aquifers and its contamination, the Shell company offers a shelling split in which the cooling technology of the ice dam is used. In this method, a large ice barrier is created inside the earth that prevents the mixing of oil with the groundwater aquifers. The use of the oil is economical only while the price of oil is continuously high, and the necessary technology for the processes is also available. The in-situ method includes lower environmental risks than others. Fig. 16.3 depicts various extraction methods (conventional mining vs. fracking technology) from the oil shale deposits [31,33,34].

On average, 15–20 e-heaters per 4000 m^2 are employed. Most of the required energy is spent on heating (about 250–300 kWh per barrel). Coal is often used to produce electricity. The pipes are insulated so that the heat transfer of the fluid inside it can be done only in the desired environment. The used fluid should have thermal capacity and high boiling point, low pressure, and pumping cost. To this end, liquid salt or liquid metal is chemically suitable. Salt is better than metal because it has more thermal

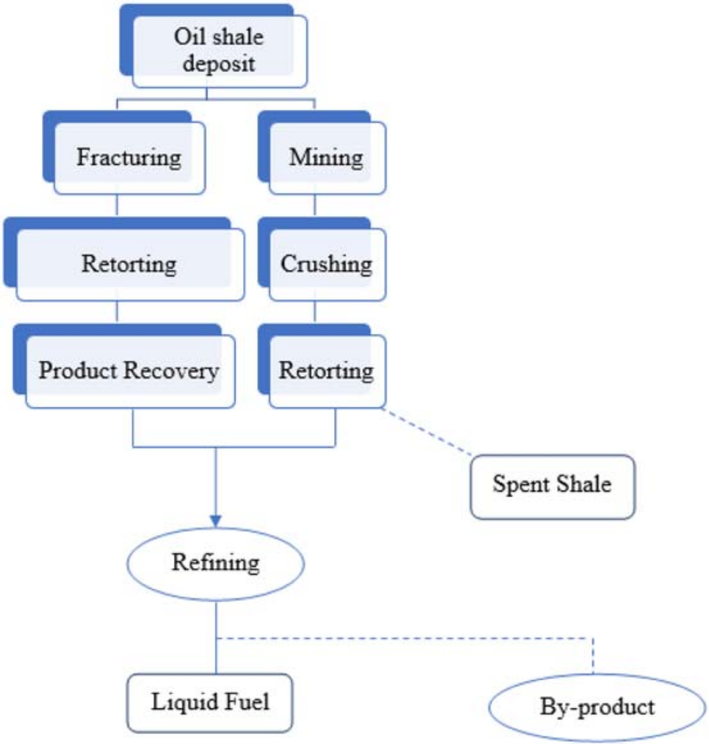


Figure 16.3 Fuel and by-products from oil shale deposits [32].

capacity and, unlike metal, does not react with the environmental media [35–38].

Shell Oil Company has a new method for this Mahogany Research Project technology, which is used to cool the earth and create an underground dam called an ice wall around the drilling environment (inside the ground) (Fig. 16.4). The ice wall is created by pumping frozen fluid into several wells drilled around the extraction site. This wall prevents groundwater from entering the drilling area and hydrocarbons and other products produced by this process remain. Shell's method has not yet been used on a commercial scale but is considered by the US Department of Energy to be a good-natured technology [40,41]. The alternative method for heating is the use of atomic reactors instead of electronic heaters, which reduces costs and produces fewer greenhouse gases. It is believed that the mentioned method is more economically and environmentally secure compared to the surface drilling method and includes two basic techniques: one is to control groundwater during production, and the other is to prevent subsurface environmental problems [42–44].

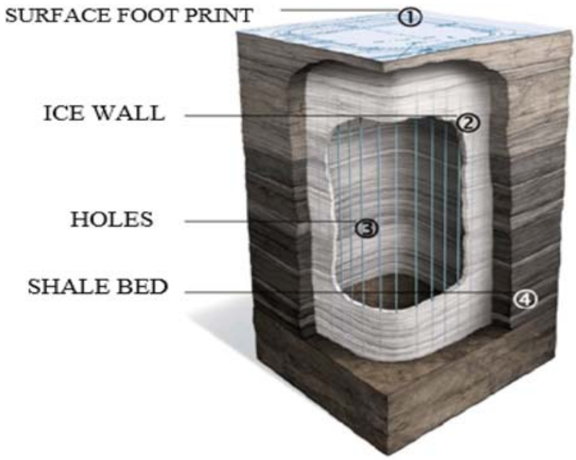


Figure 16.4 Freeze wall technology of Shell company for in-situ shale oil production [39].

This chapter aims to evaluate the environmental effects of unconventional petroleum resources such as petroleum rock (oil shale), oil sands, and super heavy crude oil. The use of unconventional hydrocarbon resources has significant environmental risks for the planet earth that should be recognized. These resources are of great importance in terms of economic and energy security. However, environmental issues are the most important challenges in the future of this industry. Land degradation, waste and hazardous effluent production, water consumption, air pollution, greenhouse gas emissions, ecological threats, and damage to biodiversity are among the most important problems. Sustainable development depends on the management of environmental costs. Establishing and enforcing efficient environmental laws and developing appropriate standards can be effective in reducing the destructive effects on ecosystems and in line with the sustainable development goals of the United Nations (UN) [45,46].

Sustainable Development Goals have been introduced by the UN in 2015. Due to major environmental and energy problems, these goals have been considered more than ever. As many countries with large reserves of oil and gas have invested in exploration, development, and production, securing the supply of crude oil has always faced challenges. Europe's growing dependence on Russian oil and gas in the medium to long term, along with the new Approach of the Middle East, particularly the five largest oil-producing countries to China's growing market, and the policies of these oil-rich countries such as Saudi Arabia and Qatar in the production and export of gas are important issues of the energy security [47,48].

1.1 Conventional sources

The US Energy Information Administration (EIA: The US Energy) defines conventional oil and natural gas reservoirs as crude oil and natural gas produced by a well drilled into the geological structure, allowing the flow characteristics to move smoothly in the well [49].

1.1.1 Conventional crude oil

Conventional oil, hydrogen-rich compounds with relatively short hydrocarbon chains, fewer carbon atoms C1 to C60, and molecular weight are lower than unconventional oils (200 C). There is no fixed formula for crude oil. They can have a great variety in this range, ranging from high-quality "light, sweet" crude oil to low-quality "heavy, sour" crude oil. Oil density is measured by the known American Petroleum Institute (API) viscosity scale (lighter oil, lower viscosity, and heavier oil have higher viscosity). Heavier oil extraction is difficult and requires gas injection and more advanced technologies. Lower API viscosity has made oil extraction and process more expensive, which will affect oil prices [50].

1.2 Unconventional resources

Unconventional oils are recognized by their characteristics. They are arrays of hydrocarbons that can be processed into petroleum products. These complex hydrocarbon and very heavy mixtures require a very high energy input for extraction (or processing), which is then refined with advanced technologies. Unconventional oils are much heavier, sourer, and generally of lower quality than conventional ones. They have more carbon as well as higher sulfur and are often full of toxic impurities. Since these resources are solid, they must be transferred to the refinery through mining or on-site heating until they flow. This group of hydrocarbons is not easily converted into petroleum products on the market by today's standards and requirements more advanced technologies. No unconventional oil sources are the same. By developing new methods for their rehabilitation from ultra-deep wells, oil can be extracted for miles under the sea by creating fractures in sandstone. Lighter and sweeter oil is less involved in the process and produces better and more valuable petroleum products, including gasoline, diesel, and jet fuel [51].

2. History of the emergence of oil shales

"Oil Shale" was also used in ancient times and was used directly like coal. The reuse of "Oil Shale" goes back to 1850 in Scotland. Between 1881 and 1955, about 1–4 million tons of oil was extracted from the Scottish mines, then production decreased, and stopped in 1962. The United States is the first country to begin exploiting Oil Shale on a massive scale. The distilled oil from the shale was first used for the flower breeding industry in the 19th century. But, no serious work was done in this area until 1900, when it was accompanied by extensive discoveries in the field of "Oil Shale." These resources were used as an emergency fuel source for marine power use. With the use of automobiles, the demand for "oil shales" increased as fuel, and many companies were established to utilize the sources of "Oil Shale" in the Green River. Common products obtained by then were paraffin, oil residue, light oil, lubricating oils, grease, and ammonium sulfate [52].

With 3.3 trillion tons of oil reserves, the United States owns the world's largest oil shale reserves [53]. US oil shale reserves are estimated at 5.1–8.1 trillion barrels of oil, not all of which can be used. Half of this amount is about three times the proven reserves of Saudi Arabia. There are two major sources in The Americas: east US resources known as "Devonian-Mississippian shale" with an area of Devonian-Mississippian shale (Devonian 250,000 square miles (650,000 km^2) and western resources in Green River Colorado in Utah, Wyoming are among the richest sources of shale oil globally. Other sources of shale oil reserves are located in Israel (15.4 billion tons) and Jordan (40 billion tons) [54].

Economic investigation of oil shale is closely related to the price of oil. If the price per barrel of oil is below US $40, the price of oil from shale oil is not comparable to that of crude oil. If the oil price is more than the US $40 per barrel, then oil companies will start exploiting shale oil. With the increase in oil prices in recent years, the use of shale oil has also increased. In general, the oil that must be extracted, transported, refined, and decomposed is at least 40% of the energy produced. Water is also required to add hydrogen to the oil before transferring it to the refinery. Three barrels of water are required to produce each barrel of the oil, which decreases in the in-situ method. Oil shale is a general word for a group of rocks that has enough rich organic matter (kerosene) in them. Oil shale is neither rock nor oil, but limestone soil, which includes compounds such as kerosene. When this material is heated to high temperatures, an oil-like material can be obtained that can be used. The useful components of oil shale are usually found above ground, and extracted as ex-situ processing. However, several advanced technologies may extract from underground with on-site or in-situ processing [55]. Both methods use the chemical process of pyrolysis to convert the kerosene in the oil shale to synthetic crude oil and oil-shale gas. The oxygen-free pyrolysis (450°C–500°C) decomposes the kerosene into gas, condensable oil, and a solid residue [56].

3. Hydraulic fracturing

Hydraulic fracturing has been used in oil and gas production since the late 1940s and in the first 50 years, it was the most widely used in vertical wells. Technological advances (including horizontal and directional drilling) have led to the use of this method in unconventional hydrocarbon formations (such as oil and gas shales). Thus, the use of this method has now made a significant contribution to oil and gas production around the world. In this method, first, the fluid with low viscosity and high pressure is inserted into the well to create cracks and fractures and spread it. Then, the main fluid with more viscosity is injected into the well. This fluid contains a good number of additives, and special sand that increases the size of the fractures, through which oil and gas flow and reach the surface [58,59].

The hydraulic fracturing process is usually investigated in a water cycle. The main component of most fluids used in the process is water, which accounts for about 94.6% of the volume of these fluids and this water is supplied from the surface or underground waters. Therefore, this cycle starts from the water supply as the most important injectable fluid (propulsive fluid). In most cases, chemicals are added to the water for different purposes. In some cases, the use of these materials for better water performance in terms of fracture and transport of proppant materials (retaining) will be in the depths of the reservoir rock. Furthermore, it is used to prevent corrosion of equipment, destruction of bacteria, and pH control. In the next step, the fluid is injected into the well to fracture the underground formation. Of course, by pumping water into the well, the entire length of the well will not be pressured. But, by placing the ducts, only the pressure will be applied to the desired area that receives all the pumping pressure. When the pressure in this area increases, the water creates fractures and the directed pressure expands them deep into the rock. When pumping stops, these fractures are quickly closed and the water used to open them is pushed back upward the drilling hole and collected at the surface. The water that returns to the surface is a compound of injected water and pore water that has been trapped in the underground layers for millions of years. This pore is usually saline water containing considerable amounts of dissolved solids. In the next step, the returned water can be transferred to the treatment and processing units. Fig. 16.5 shows the different stages of the water cycle in hydraulic fracturing [59–62].

4. Hydraulic fracturing in shale resources

In general, oil and gas extraction from unconventional oil and gas resources such as shales has high costs. Therefore, one of the factors that can make extracting from these resources economical

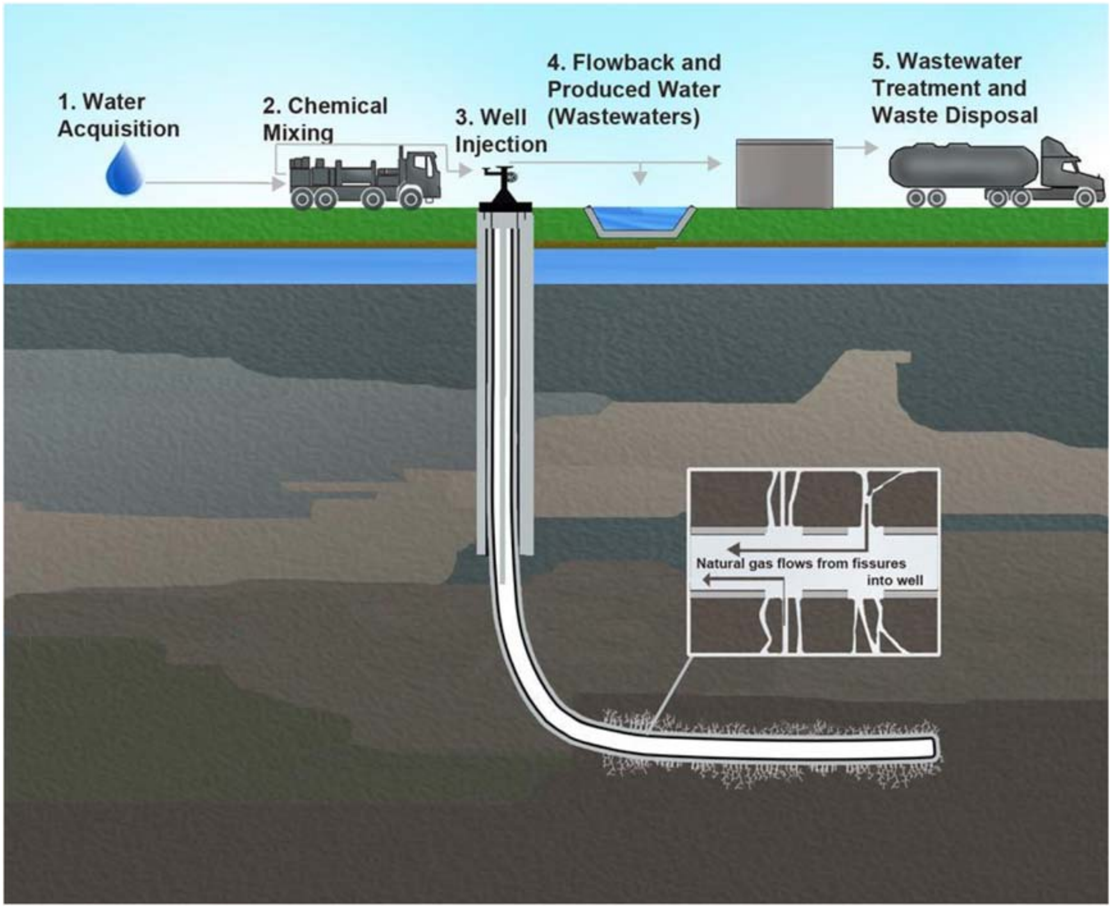


Figure 16.5 A schematic of the water cycle of hydraulic fracturing illustrated by environmental protection Agency (EPA) [57].

is the increase in oil prices. Advanced industrialized countries and major consumers of energy, especially the United States, which have always sought sustainable energy resources to maintain their economic growth rate and industrial authority, turned to the approach of developing the utilization of shale oil and gas resources in the past few years as crude oil prices rose above $100 per barrel. Therefore, the development of shale resource utilization in different parts of the world since 2003 disrupted the world's energy resources, which had previously relied on fossilized oil and gas. In particular, new technologies such as horizontal drilling in the depth of the earth and operationalization of hydraulic fracturing technology have made the use of these resources cost-effective. However, in the first few months of 2016, the decline in oil prices slowed oil and gas extraction from unconventional sources. But, the development of this technology of extraction from sources should be taken into consideration during the oil-expensive era.

The US Energy Department in its 2016 energy outlook (AEO 2016) shows that natural gas production from shale sources will grow slowly, while production from other sources remains relatively steady or declining. According to the report, natural gas production from unconventional shale and oil sand sources accounts for about half of all US natural gas production. Based on the reference scenario, gas production from these sources is expected to increase from about 14 trillion cubic meters in 2015 to 29 trillion cubic meters in 2040. This would equal 69% of the total natural gas production in the United States. Accordingly, the continuation of gas production from the shale resources can indicate the continuation of the use of hydraulic fracturing technology which can be reflected [63,64].

5. Environmental considerations

The potential for environmental effects of unconventional oil is very widespread. Because the environmental effects of the unconventional oil supply are larger than many conventional resources. To increase production from unconventional sources, technologies are needed in terms of the economic production of oil due to environmental limitations. There is often a great debate and confusion about the environmental effects of the unconventional oil supply. The refining process to produce "shale oil" produces soil and carcinogenic waste rocks that should be eliminated. According to the popcorn effect, about 30% of the oil shale is expanded after the process, which must be discarded. The energy required for transporting, crushing, and heating materials and then adding hydrogen is very high. Also, safe waste dumping, despite the high volume, is cost-stringing. These issues, along with the high costs of environmental protection, mean that the exploitation of the oil shale is economical only when the price of oil is high and remains stable. Although in-situ process, especially in its new method, has special environmental costs, environmental problems are reduced with this method. Creating an ice cover barrier to prevent oil flow into underground aqueous aquifers forces for its part endangers the environment [65]. Due to the high cost of oil, oil and gas extraction from unconventional shale resources has considerably improved. Therefore, many environmental hazards remain in force. Therefore, in this chapter, the damages and hazards of pollution of these resources are discussed and solutions are presented to reduce these effects.

5.1 Proximity to fracking and drinking water resources

In general, changes in oil and gas prices in the short term have been one of the factors causing fluctuations in the number of wells drilled using hydraulic fracturing. Although the drop in oil prices has caused a great slowdown in these activities due to the uneconomical oil extraction, especially from shale resources, technology has developed appropriately during the oil-expensive era. The EPA estimates that between 2011 and 2014, 25,000–30,000 new wells were drilled in which hydraulic fracturing was carried out [66–68]. The EPA also states that between 2000 and 03, almost 4.9 million people lived within a mile of these wells. Therefore, there is a high probability that these wells were located near residential areas and drinking water resources. Although the proximity of hydraulic fracturing activities with water resources by itself is not enough to have an effect, effectiveness potential is increased.

In general, the required water for hydraulic fracturing is supplied from surface, underground, or returned disposal waters. For example, in the Marcellus shale in Pennsylvania, the highest amount of water used in hydraulic fracturing is surface water, while in the Texas Barnett shale, surface and underground waters are used in nearly equal amounts. In areas facing a lack of surface water resources such as West Texas, underground waters are used for the fracturing. According to The NatGeo 2015, there has been serious damage to the underground aqueous aquifers, the main source of water for rivers and water needed by millions of people in the United States, by disrupting the area from which shale oil is extracted. Throughout the United States, most of the water used for hydraulic fracturing is the river and underground resources. Although some companies use lower quality water including disposal water, the number of them is very low. Half of the US shale oil resources are located in water-scarce areas that themselves are facing water-scarce problems and are in dire need of drinking water. The situation is so dire that the amount of water needed for shale oil production exceeds the total amount of water consumed for all human consumption in 2008 [69–71].

5.2 Impact of hydraulic fracturing on water resources

Fracking technology is very effective to increase oil and gas production from low permeable layers. This technology, with creating fractures and increasing the efficiency in hydrocarbon formations, leads to the economic cost of extracting oil from unconventional sources such as oil and gas shales. But this operation may have devastating bio-environmental effects and especially contaminate underground drinking water [72,73]. Accordingly, the as-created fractures and cracks may go in unwanted directions and establish connections between hydrocarbon tanks and drinking water layers. Therefore, with the entry of chemicals used in the hydraulic fracturing operations, the diffusion of saline waters and heavy metals and harmful hydrocarbon formations, or the entry of oil and gas fluids into the drinking water layers, the contamination of these resources will result in serious risks to human health. In this section, the effect of hydraulic fracturing operations on drinking water resources in the water cycle is investigated. The challenges of this technology are that usually, rock formation lies beneath drinking water aquifers. Therefore, the problem with the fracture is that these gaps reach the underground water tables and the gas can be mixed directly with the water or the cracks around the well allow the gas to enter the water supply. Fracking fluid is composed of 98% water and sand and 2% chemicals. These chemicals are not currently regulated and are usually used as trade secrets by companies that do fracking. For now, however, the EPA is drafting legislation that may need to be disclosed in the future. There is information about chemicals used in New York. Because if you use amounts greater than 4.5 tons, there must be material safety data sheets (MSDS) [74–76].

5.3 Water supply

Water harvesting to perform the hydraulic fracturing process changes the quality of the drinking water resources. Harvesting from underground water more than its standard rate reduces water reserves in the underground aquifers, and allows lower quality water penetration from the ground or adjacent formations into these aqueous deposits. Harvests can also reduce the discharge of basement waters into stream paths and potentially affect surface water quality. However, the areas exposed to drought and fed by the potential waters will be the most affected. Harvesting surface water also affects water quality. These harvests can reduce water levels and change flow paths and thus reduce the flow capacity to dilute pollutants. About 11.35 L of water is needed to produce 28.3 m^3 of shale gas [77]. This water consumption costs around US $1.00, based on 3.18–6.13 L for production of 28.3 m^3 along with 0–7.57 L for processing [77]. Despite paying 5 times the price of water by the oil and gas industry compared to the urban water consumption in the driest areas of southwest United States [78], the cost per liter of water is calculated at US$0.00008 per liter [79,80]. In comparison, only in the year 2007 around 172.7 billion m^3 of fresh water was irrigated 230,700 km^2 to produce $118.5 billion of crops. This amount of water is sufficient for fracking approximately 9,000,000 oil wells [10,81,82]. However, only 40,000–45,000 wells (0.5% of 9,000,000) are drilled each year in the United States. Technically, a horizontal shale gas well needs 11,400 m^3 to complete. In addition, some oil and gas wells with no need for fracking require much less water. Anyway, fracking water is about approximately 0.25% of that used for agricultural irrigation in the USA. The cost of water for agricultural purposes is $0.00071 per liter, while it is about $0.00162–$0.00649 per m^3 for fracking [83]. Also, compared to the water consumption for the production of an equivalent amount of combustion energy from conventional oil, the water needed to produce shale gas is much less [77]. Nevertheless, shale gas is facing strong opposition from environmental non-governmental organizations. Shale gas and shale oil impact less negatively than the greatly exaggerated potential claimed by these organizations. Despite methane leakage and contamination of groundwater and surface water by flow back and produced waters, these contamination pathways are not specific to the unconventional fuel sources. Furthermore, they are manageable. Some management strategies of the industry to reduce its water withdrawal are treating and reusing flowback water, recycling the treated produced water, using brackish water (not suitable for most other purposes), and researching and development on using new fracking fluids like gelled liquid propane, CO_2, and liquid nitrogen, foams, other multiphase fluids, etc. [10]. According to the US Environmental Protection Agency (EPA), 2010, the water used for each well depends on the formation specifications (depth, porosity, type of formation, etc.), design parameters of hydraulic fracturing (failure length, number of failures, and direction, number of failures per well, etc.), as well as the characteristics of the fluid used and its pressure. According to this study, an average of three–four million gallons (11–15 million liters) of water is required for each well. The report adds that over 10 years, about 13,600 hydraulic fracturing wells have been carried out and a total of about 200 billion liters of water have been consumed, which is equal to the amount of water consumed in a city with a population of about 6.2 million people in 1 year. Therefore, the amount of water used for this operation is very high and considerable. Also, according to another report from the EPA, 2013, the amount of water used to produce a barrel of crude oil is about 25 L, which, given the production of 5.3 million barrels of US shale oil this year, has increased significantly (more than 30 billion liters per year) while about 40% of shale oil and gas resources are located in areas with serious water shortages [84–86].

5.4 Chemicals

Chemicals make up a small percentage (usually 2% or less) of the total injectable fluid volume. The combination of chemicals and hydraulic fracturing fluids has the potential to accidently release and contaminate the site. The potential effects of chemicals on drinking water resources are due to hydraulic fracturing fluid leakage and chemicals leakage characteristics, transmission rate, and toxicity of the chemical leakage. Usually, equipment failure, human error, incomplete equipment prevent oil well eruption, corrosion, valve failure, and others (such as weather) cause leakage of chemicals and chemical flow from well to surface waters, soil pollution, transmission and penetration into surface waters, contamination of underground waters, and consequently contamination of drinking water resources [59,69,87,88].

5.5 Injection into the well

In the hydraulic fracturing process, fluids are injected into the wells at very high pressure. Fluid injection and fracturing can cause contamination of drinking water resources in two ways: (1) unwanted movement of liquid or gas fluids out of the production well toward the drinking water resources due to defects in the casing of the corrugated pipe and cement work, and (2) the unwanted movement of liquid or gas fluids from the production area and underground formations to the water sources. According to the EPA report in North Dakota, a part of the filament of a well during hydraulic fracturing operations broke up and disintegrated, causing oil and gas fluids to enter the surface and water resources near the Killdeer layer. In other cases, inappropriate cementing of the pipe has caused contamination of drinking water resources. In Ohio State, inappropriate cementing of the drill pipe during hydraulic fracturing has increased the pressure of natural gas in the basement layers around the production well, eventually leading to the movement of natural gas and entering the drinking water resources in these underground layers [89]. Hydraulic fracturing in old wells increases the likelihood of contamination of drinking water resources by moving gases and liquids into production wells. In addition, hydraulic fracturing operations in wells with long life may cause degradation and cracking of the casing pipe. Also, the proximity of the wall pipe with corrosive fluids such as hydrogen sulfide, carbon dioxide, and saline waters can speed up this degradation. Some basement layers contain both oil and gas resources and drinking water resources. Since some fluids tend to remain in the basement layers, the penetration of fluids used in hydraulic fracturing into the layer containing drinking water resources will directly affect the water quality. Also, if a marginal well does not tolerate the stresses caused by hydraulic fracturing of the adjacent wall, the components of the well may be fractured and as a result, fluids from the surface and by this well can reach the drinking water resources. Older wells or inactive wells (including oil and gas wells, injection wells, or drinking water wells) close to hydraulic fracturing operations have a higher potential for creating communication routes for contamination of drinking water resources [90].

5.6 Flowback fluid or production water

Variable quality water is a by-product of oil and gas production wells. After hydraulic fracturing and removing the pressure of fluid injection from the well, the return flow of water from the well is produced. At first, this water is the same fluid used in hydraulic fracturing, but over time its composition will be influenced by the fluid inside the shale formation and will be produced gradually inside the formation. (Sometimes in scientific references, the initial water produced after hydraulic fracturing is called flowback flow, also called hydraulic fracturing fluids and any water that returns from the formation to the surface, in sum, is called the produced water). Contaminating drinking water resources can occur by entering or leaking produced water into surface waters or underground waters. The environmental transport of the chemical compounds in the produced water depends on the leakage properties (such as the volume and duration of leakage), the composition of the leaked fluid, and the characteristics of the surrounding environment [91–93].

5.7 Waste residues

The extraction waste of this type of oil contains up to 125% of the original volume and must be disposed of. It affects large areas of the earth. The total volume of the waste due to the extraction of petroleum rocks is 180 million tons. Half a ton of waste is created in the process of enrichment of each ton of oil shale extraction. The main wastes planned for disposal in the land include water produced during distillation and subsequent separation from oil and the remaining waste rocks from the extraction. Distillation waters contain relatively high concentrations of complex soluble organic compounds and salt rocks that potentially leak and include pyrolytic organic products. In addition, the consumed rocks when excreted on the surface has corrosive potential. Considerable efforts have been made to manage the rock, with an emphasis on controlling corrosion as well as a rock as a growth environment and for plant replanting of halophile and drought-tolerant species [51,94].

5.8 Water consumption

There are five main stages of the water cycle in unconventional oil and gas development. These steps are water transfer, mixing chemicals, injection well (hydraulic fracturing), recursive flow process (flowback fluid), mobile water production, purification, and disposal. Various methods for water management have been proposed. The high volume of water consumed in the development of petroleum rocks can have significant detrimental effects on surface and groundwater resources. Nevertheless, the amount of these effects remains limited due to uncertainty about the technology and also due to the unknown future extent of the oil shale industry, limited knowledge of current water conditions, and groundwater flow. Developing oil ore and providing the power to carry out extractions and other related activities will require a considerable amount of water, which can pose problems, especially in arid regions such as the western United States where large populations are currently facing additional demands from water resources. For example, some analysts of major projects, oil ore development in Colorado, know that they need more water than the water consumed by more than one million residents of the Denver metropolitan area to extract from these types of resources. Furthermore, water supply for agricultural and urban development is also limited. Potential demand for water by decades-old drought and forecasting warm weather in the future has added to the complexities of this issue. Current assessments have significantly depended on assumptions about the amount of water needed to support the oil ore industry in the future. However, reports suggest that water needed for the initial development of the industry is likely to be available, but the final size of the industry may be limited due to the availability of water as well as the demand for water for other needs in the region. The possibility of competing for urban and industrial demands over water in the future, warm weather, future needs under existing contracts, and the need for additional water to protect endangered and exterminated fish may ultimately limit the size of the future oil shale industry [74,95,96].

5.9 Water quality and hazardous effluent production

While with the development of the oil ore industry, it is difficult to determine the effects of water volume quantitatively, researchers can determine more precisely the effects of water quality, which is likely to cause disturbances similar to the expected effects of oil ore development due to a variety of mining, construction, and development of oil and gas. In the absence of effective mitigation measures, the effects of oil rock development on water resources can be due to (1) disturbances at the ground level during road construction and production facilities, leading to the destruction of surface water quality, which itself is caused by runoff related to sediment, salt or may be due to the spilling of chemicals into rivers and streams, (2) harvesting water from rivers and aquifers for oil ore operations that reduce downstream flow and temporarily degrade downstream water quality by sedimentation during reduced flow, (3) underground extraction and surface mining that permanently affects aquifers and groundwater flow, and (4) discharge of wastewater from the oil ore operations that temporarily increase the flow of incoming water resulting in a change in water quality and temperature [97].

The US Environmental Impact Statement has stated that surface mining produces 8.4—42.3 liters per ton of waste from the oil ore processing. The oil ore industry's electricity has used 91% of all water consumed in Estonia. Depending on the type of technology, the high-level distillation consumes from one to five barrels of water per barrel of oil from the shale ore. The US Bureau of Land Management said surface mines and distillation operations produce approximately 1.9–9.1 gallons of effluent per tonne of oil ore processing [98]. According to estimates, about one-tenth of excess water is used in in-situ processing. Different groups of scientists have calculated that the process requires up to five barrels of water to control dust, cooling, and other targets, per barrel of petroleum rock produced [99].

5.10 Effluent and its management

Effluent disposal and management may affect drinking water resources in several different ways, including [100–102].

- **a** Lack of proper treatment of the effluent before discharge into the received source water
- **b** Accidental leakage or entry of effluent from storage pits during its transportation
- **c** Unauthorized discharge of the effluents
- **d** Migration of the effluent pollutant compounds through the soil
- **e** Inappropriate management of the residual materials in wastewater treatment
- **f** Accumulation of the effluent pollutant compounds in sediments of catchments close to the effluent treatment facilities
- **g** Using general methods of domestic wastewater treatment for the treatment of the effluents resulting from hydraulic fracturing.

However, due to the injection of the effluents from hydraulic fracturing into wells and their controlled transfer to the underground layers, the probability of the contamination of the drinking water resources by these effluents is almost zero (EPA 2015). If the effluent from hydraulic fracturing is discharged into surface waters after an inappropriate treatment, there is a possibility of contamination of drinking water resources. Lack of proper treatment of the effluent may increase the concentration of the total dissolved solids (TDS) concentrations of bromide, chloride, and iodine in the received water. It is necessary to supervise drinking water treatment units to control, and not form these substances properly, because some of them are toxic and can cause cancer. The effluents also contain other compounds such as barium, boron, and heavy metals. The presence of barium in the produced water with gas in clay layers has been proven. However, there is very little data on the concentration of metal and organic compounds in the treated and untreated effluents to assess whether the wastewater treatment and discharge operations are effective and have any effect on drinking water resources downstream or not [100,103,104].

5.11 Land degradation

In general, compared to the conventional oil supply, the unconventional oil development has more effects on the land. Surface degradation is done by mining for about 20% of the unconventional oil resources, in this case oil is very close to the surface and can be extracted (US oil shale and US oil sands and Canadian oil sands have great potential for mining, today the largest mineral resources are Canadian oil rocks in which the mining area is 1854 square miles, or about 0.7% of Alberta's area. For mining projects, materials on the surface including vegetation, surface soil or overburden are completely removed to bring the extracted resources through mining, which will be revitalized after mining. Although the modified land is not fully restored by mining, it returns the land to "balanced land capability." The goal of resuscitation or reclamation is a better (or acceptable) landscape, so it can protect native vegetation and wildlife. Depending on the type of land, the problems of achieving this goal vary. For example, pastures are easier to find than wetlands [105,106]. Earth fragmentation in some cases involves extraction from the unconventional sources such as Canadian oil shales and some hard oils, in a large area. During the oil production period, land use changes, for example drilling rigs (or platforms) and access roads can tear wildlife habitat apart, raising some concerns about the effects of this fledgling industry on wildlife habitats. Recently the industry has increased the use of Ecopads technology, allowing drilling from multiple wells with a much smaller surface area, thereby improving the situation by reducing the number of drilling areas and available roads [107,108].

5.12 Air pollution

Emissions of air pollutants from crude oil production wells are a complex mixture of hydrocarbons that generally produce from 5 to 40 carbon atoms per molecule, which has a variety of concerns. During production and due to various conditions, low-volatile hydrocarbons (with more carbon atoms) are unlikely to emit into the atmosphere. In unconventional oil and gas production, air pollutant emissions potentially arise as soon as subsurface hydrocarbons move. Despite the lack of leaks, the potential for emissions will start from the source and continue until the end of consumer use. Unconventional oil and gas emission sources are classified by air regulatory agencies as point sources (from a stack or pipe), mobile sources (from trucks, trains, well diggers), volatile sources (from equipment leaks, or external forces such as wind, natural or human errors, and fractures at ground level) and regional resources. In the United States, point sources, also known as fixed sources, are called large sources if their emissions exceed a certain amount. For example, for volatile hydrocarbons Volatile organic compounds (VOC) a value of 10 tons per year is needed to be called a large source. Regional Resources is a small point resource emitting complex of a particular category that does not include large point sources. Of course, releasing the number of volatile emissions is difficult because they can hardly be identified and may be intermittent or short-lived. An increase in methane has been reported in the soil around some active wells in Utah [109–111].

Emissions of point, mobile, volatile and regional resources will vary by type of oil and gas activity. There will be emissions of nitrogen oxides (NOx), particulate matter (PM), and volatile hydrocarbons in relation to the combustion of well drilling, compressors, production engines, as well as heaters and pumps. Mobile sources, especially in truck traffic, also contribute to the release of NOx, PM, and VOC, as well as the production of volatile dust on non-asphalted roads. Mobile water production management controls leakage from equipment and other sources of volatile emissions, including methane emissions and VOC. Exposure to soft and fine silica dust along with sand used in hydraulic fracturing processes is also well known as an influential factor in air quality. There are also VOC emissions resulting from the use and management of waste and drilling fluids [112]. Oil sands operations release large volumes of pollutants into the air. These pollutants in high amounts lead to respiratory, heart disease, bronchitis, headache, nausea, spontaneous miscarriage of the fetus, and weakening of nerve function [113,114]. Oil sand distillation produces waste and effluent, which may include rare metals, semi-volatile materials, polycyclic aromatic hydrocarbons (PAH), parts of oil, phenolic compounds, sulfides, etc. The potential risks and therapeutic measures of these cases need further investigation.

Effluent flows and heat discharge from oil sands processing may cause environmental problems. Semi-burning charcoal or ash residue from coal is harmful waste caused by oil sand distillation if its organic content is not fully burned during processing. The semi-burner coal can be partially recycled and burned in fluidized bed boilers. Organic content in the ash residue from the coal should be reduced through technological improvement initiatives. Semi-burning charcoal can also be used for construction products such as cement and rock wool. Some other environmental problems are explained, for example, in an in-situ distillation process at each distillation stage, oily rock distillation water is composed of the thermal decomposition of the kerosene, known as forming water. This untreated water is not suitable for safe discharge in lakes and rivers or use in other downstream oil ore processes. It contains a variety of pollutant materials like particulate matter, soluble pollutants, crude, distilled, and consumed oil shale particles, ammonia, phenol, sulfur, cyanide, lead, mercury, and arsenic. In addition, in a pulsed non-stationary thermal combustion system, cleansing distilled water can purify water, condense vapor or distill water. But, even when treated, it typically involves particles of oil ore, petroleum rock, ammonia, and organic carbon at 10 times more than the normal limit [115].

5.13 Greenhouse gas emission

Using current technology, the extraction and refining of heavy oil and oil sands produce more than three times as many greenhouse gases (total CO_2) as conventional oils, primarily due to the additional energy consumption of the extraction process. It may include the combustion of natural gas to heat and pressure the reservoir to stimulate the flow. Considering that all greenhouse gas emissions from one barrel of oil are 70%–80% of emissions due to the fuel combustion in a vehicle, the energy consumed in the extraction, refining, and transportation of this type of oil remains unknown and has not been calculated. When well-to-wheel emissions are taken into account (oil production emissions through fuel consumption in a vehicle), Canadian oil sands produce 5%–15% more greenhouse gases than the average crude oil consumed in the United States, and compared to some other conventional supply sources, including Nigerian, Venezuelan, and some other sources. Over time and gradual improvements in productivity as well as new technologies such as the use of solvents to move oil in situ (as an alternative to heating), the intensity of greenhouse gas emissions from unconventional operations is expected to decrease. Maybe, over a very long period, technologies such as carbon capture and storage (CCS) and low-polluting or non-polluting sources of energy such as nuclear power reduce the possibility of emissions [98]. Canada's oil sands are the fastest growing source of the greenhouse gas emissions in Canada. The average industrial emissions from the oil sands production and updating (well to pump) are 3.2–4.5 times of the condensed carbon and compressed conventional crude oil produced in North America. The greenhouse gas emissions for the extraction and preprocessing of Venezuelan bitumen in terms of the amount of CO_2 per barrel 95 kg CO_2 E/bbl (emission per barrel), While this amount for Canadian oil ore is about 110 kg of CO_2 E/bbl [116].

The average lifecycle of emissions associated with a barrel of sand crude oil is currently 17% more than the barrel of oil consumed in the United States. This phenomenon is due mainly to emissions from production and upgrades, which for the average emissions per barrel of consumed sand oil is nearly three times higher than the average oil emissions consumed in the United States. The actual emissions from oil sand projects alone are very different. The production and upgrading of oil sands emit about 70—130 kg of greenhouse gas per barrel. That is more than the greenhouse gas emissions from the life cycle of every barrel of oil consumed in the United States, averaging from 50 to 110 kg per barrel. Average greenhouse gas emissions from oil sands production can increase by switching from natural gas to the process of contaminated fuels such as coal or crude bitumen, or decrease with technological advances. The second trend has just prevailed [107].

5.14 Ecological threat and damage to biodiversity

Unconventional oil pollution has significant effects on the ecosystem of organisms. A study at the University of Alberta found that levels of cadmium, copper, zinc, mercury, nickel, and silver pollutants in melted snow, water collected from around the mine, and water flowing downstream from the river caused by oil sand extraction were above the level of the federal and regional guidelines for protecting aquatic life [117]. Oil spills and leakage can be a major source of water pollution in rivers, lakes, and oceanic environments. Oil spills on the ground have the potential to contaminate drinking water by directly leaking into rivers and streams, ultimately causing oil to leak into groundwater and polluting them [118]. Moreover, since the food ring cycle eventually leads to human species, the contamination caused by oil spills to fish and other wildlife creates serious health risks for humans. Water-soluble hydrocarbons have an immediate toxic effect on aquatic organisms like young fish [119]. Crude oil contains polycyclic aromatic hydrocarbons (PAH), which are very difficult to clean and have remained in sediment and marine environment for years. Although the effects of condensate leakage are now less known, gas condensate also includes PAHs. Marine species that are constantly exposed to PAHs can show growth problems, disease susceptibility, and abnormal reproductive cycles. The effects of these pollutants on salmon and other species of fish exposed to oil and other petroleum products include fatal and sub-lethal effects on growth, genes and defects in heart function, water collection in tissues, the curvature of the spine, reduction in jaw size, and other head and face structures. PAHs are the most toxic compounds for fish and invertebrates [94,120]. As a result of industrial development in northeastern Alberta, many species are endangered including Canadian deer, lynx, otters, fishers, and carnivorous mammals. Near in-situ steam refineries, Canadian deer, fish, and bears are in danger of being destroyed in a 400,000-hectare area, due to the fragmentation of their habitat [121]. A report from three oil-sands companies found that 27 black bears, 67 deer, 31 red foxes, and 21 jackals were killed. In addition, the oil sands belt is on track to migrate North American ducks and other birds. By 2070, about 166 million birds will be lost due to the loss of laying areas, staying, and landing in a garbage pond due to its similarity to a water corpus [122].

6. Costs and energy consumption

Investment costs and time for conventional oil ore production projects are also other major risks to the industry. Mining and upgrade projects require an investment of about three billion US dollars to produce 100,000 barrels per day for a high-quality refinery ready to produce synthetic crude oil. Operating costs are usually $10 per barrel. The time it takes for mining projects to be produced is about 6 years, which includes engineering feasibility, regulatory approval, equipment purchase, construction, and commissioning [123–125]. To enable reasonable exploitation of oil ore, it must be economically applicable. Any attempt to develop oil ore reserves can only be successful if the cost of producing ore oil is lower than the oil prices or other alternatives. The cost of producing a barrel of ore (shale) oil in a surface distillation model complex in the United States (including mining, distillery, upgrade plant, utilities support, and mine restoration and rehabilitation cost) is calculated between US$70–95. The measurement used to assess the viability of petroleum ore as an energy source is the ratio of energy generated by the oil ore to the energy used in its extraction and processing, i.e., the return of energy-to-energy investment (Energy Returned on Energy Invested). To increase the return of energy-to-energy investment (EROEI), numerous hybrid technologies have been proposed. These technologies include the use of wasted process heat (e.g., gas conversion or combustion of residual carbon (charcoal) and the use of the wasted heat from other industrial processes (e.g., converting coal into gas and nuclear power generation). Anyway, it is still not clear whether this calculation is considered or not for the energy consumed in creating water suitable for processes (e.g., desalination of seawater) as well as additional costs in arid countries. Assuming a gradual increase in output after the start of commercial production, an overall analysis shows a gradual reduction in process costs of up to US$30–40 per barrel after reaching the milestone. Royal Dutch Shell says that when crude oil prices are above US$30 per barrel, the technology makes it profitable [98]. Oil sands production requires energy and water. To produce a barrel of crude oil from the oil sands consumes between 700 and 1700 ft^3 of natural gas, which is as much fuel as it takes to heat an average Canadian home for 2.5–6 days. However, Canadian natural gas is unable to meet the gas needs of oil sands [94]. Recent oil sands production, which is approximately 1.2 million barrels per day, is responsible for producing about 40 million tons of CO_2 gas, which compares to conventional oil each year. That is roughly 5% of Canada's greenhouse gas emissions, 0.5% of US greenhouse gas emissions, and slightly less than 0.1% of global greenhouse gas emissions from energy consumption. The US carbon price is US$20 per tonne of CO_2. It is also the price that European companies are currently facing. Carbon prices are fixed in this range in the short term, but if the United States does not impose a system of restrictions on trade or carbon taxes, prices should rise toward US$50 per tonne of CO_2 within the 2020–2030-time frame. This increase will continue in the following decades. Forecasting carbon costs for oil-sands projects have little to do with the expected price of a barrel of oil. With coal-fired, the average cost, even for the price of carbon, rises sharply. Carbon costs can still affect production and pricing on margins, as well as a very high carbon price in the short term, can have much bigger effects. Some argue that since crude oil sands will also face carbon costs during the refining phase, the burden of carbon price pressure on oil sands will increase. The cost for Canadian resources is nearly double but in the short term, the cost increases for other sources including direct competitors (such as Venezuelan bitumen), which is often also a significant increase. Whether this additional cost will be absorbed by manufacturers (through lower production or lower profits) either by refining companies or by consumers (through higher prices) depends on the finer details of refining and market product, which is very difficult to predict [125,126].

7. Uncertainty about possible technologies

A major challenge in the development of oil ore is the uncertainty and feasibility of current technologies for extracting oil from the oil ore economically. To extract oil, the rock (shale, sand, etc.) must be heated to very high temperatures (about 343−538°C) during a well-known distillation process. Distillation can be done primarily in two ways. One method is to extract the oil ore by the mining method, which brings it to the surface and heats it in a piece of distillation equipment. Oil ore extraction and distillation have been observed in the United States and are also currently being carried out to a limited extent in Estonia, China, and Brazil. However, a commercial mining operation by surface distillation method has never been developed in the United States because the produced oil is directly compared to conventional crude oil, which has historically been cheaper to produce. Another method of the in-situ process involves drilling a borehole in the oil ore, placing heaters to heat the ore rock, and then collecting oil released from the rock formation. Some in-situ technologies are offered on a very small scale but other technologies have not yet been proven and none have been demonstrated economically or environmentally on a commercially feasible scale. According to some energy experts, the key to developing oil ore in the US is to develop an in-situ process because many of the rich oil ore reserves are buried hundreds of thousands of feet below the surface, and mining is difficult or impossible. In addition to this uncertainty, transporting oil produced from oil ore to refineries may face challenges, as no major pipelines or highways are located in remote areas where oil sands are located. Thus, special infrastructure is needed to provide power, where there are shortages on a large scale [127].

8. Environmental costs

The socioeconomic effects come from the imposed costs of oil ore development, which can bring additional pressure to the influx of workers' populations along with their families in local infrastructure such as roads, housing, urban water systems, and schools. The development and expansion of extractive industries, such as oil or oil and gas, typically follows a boom-and-go cycle that makes it difficult for local governments to plan for growth. In addition, traditional rural use is replaced by industrial use and negatively affects tourism areas relying on natural resources, such as hunting, fishing, and wildlife observation [128]. Many chemical and non-chemical stressors have been found in and around unconventional resource development sites that may affect both workers and communities. The negative mental health consequences of unconventional oil and gas production in the United States have been examined [129]. The overall effect of these stressors on community health depends on the risks of that stressful substance, its exposure path, time, and place of its arrival, which may have scaled from well to location, regional and global. The greatest potential public health effects are in the well itself, accidents, and injuries that may be inflicted on workers in the form of exposure to acute (e.g., H_2S) and chronic stresses (e.g., silica). Stressors whose effects are on a local scale include the risks of transporting chemicals out of places, such as volatile organic compounds (VOCs), diesel chimneys, fracture fluids, and hydraulic waste, which are leaking out of place, or migrating during accidents [130]. Despite some newly created steps in revitalization and reconstruction, the growth rate of these methods is very low compared to the speed and size of the degradation caused by mining in the oil sands. In addition, no drained lakes have been successfully restored and there is no long-term effective method for managing drainage fluids [94]. The long-term social, health, and environmental impacts will create more difficulties in the future [131–133].

9. Unconventional resource extraction: challenges

The development of unconventional energy sources poses significant environmental risks to water, air, land, and communities that need to be recognized. Real progress is in cost management of these environmental risks, which do not pose a threat to competition. Also, related technology is growing rapidly. Significant progress has also been made in improving regulatory standards in most energy-producing countries and conditions of continuous improvement between regulators and industry stakeholders have been formed. There is currently no relationship between environmental protection and company profitability. It is only by setting strong rules and compliances that allow companies to participate in the playing field of competitions. Failure to comply with these rules by some companies leads to significant environmental problems. Enacting and enforcing efficient environmental laws and developing appropriate standards can be effective in reducing the destructive effects on ecosystems and in line with the United Nations Sustainable Development Goals. Government, industry, and NGOs (non-governmental organizations) play a role. Therefore, strong regulatory standards are needed to fill gaps, accelerate leading industries, and encourage more innovations. Compliance with global regulations by industry and regulators is essential to strengthening regulatory enforcement and production compliance. For example, some industry players are pushing for economic policy while ignoring the negative environmental impacts and other consequences. Some environmental and climate advocates only use unspecified environmental events to generalize the performance of the entire industry without putting accidents in context. As a result, there is a lack of trust in the public which has caused them confusion [69,134,135].

10. Conclusion and future outlook

The use of technologies such as hydraulic fracturing, in the extraction operation of unconventional oil and gas resources, will result in many economic savings. However, in the field of the environmental degradation and pollution of groundwater resources as well as high consumption of water, there are many problems. Contamination of water resources can be done directly (overflowing pollutants into water resources) and indirectly (through soil pollution) and in addition to water pollution, it can cause social hazards. Anyway, it is necessary to consider the following in the use of this technology:

(i) In addition to hydraulic fracturing, many studies should be carried out on different underground layers and how they are located in the vicinity (layers containing oil, gas, and drinking water), and the exact effect of the hydraulic fracturing on the adjacent layers, reservoir rock coverings, the possibility of cap rock failure and oil and gas penetration into the layer containing drinking water and other related items should be thoroughly investigated. In other words, the design of the hydraulic fracturing operations should be carried out along with the investigation of all the possibilities in the field of chemical or backwater penetration, and oil and gas fluids into the underground drinking water layers, so that by conducting these studies, the relevant organizations will ensure that the underground water resources are not contaminated.

(ii) Due to the high pressure of the injected water to the well for hydraulic fracturing, it is necessary to investigate its impact on nearby wells, including oil and gas wells, injection wells, and drinking water wells, in addition to failure in the shale formation, this operation may cause other failure consequences, such as separation casing pipe failure, cement behind the casing pipe, and other equipment of the adjacent wells, creating a way to infiltrate polluting fluids into drinking water resources.

(iii) Due to the use of river water or underground waters (freshwater) for hydraulic fracturing, and also, due to the drilling of a large number of wells for the production of shale oil and hydraulic fracturing of most of them, the amount of water required for this number of wells is very high. Therefore, the mentioned companies must be forced to return to water treatment and reuse it for hydraulic fracturing in the next well (especially in low-water areas). By implementing this process in addition to saving water consumption and preventing irreparable damage to the underground water resources, the probability of surface water pollution and the general environment is also severely reduced.

Thus, although the decline in oil prices has slowed the extraction of unconventional oil and gas resources, extraction from these resources will continue to grow mildly, the main reason for which is the development of technologies such as hydraulic fracturing during the oil era. The use of these technologies in dry countries should be done with high precision and sensitivity because, in addition to the economic benefits resulting from it, we need to examine what damages it causes.

The emerging unconventional oil and gas industry, unlike conventional oil and gas, which with more than a century of experience has been able to create a legal and contractual structure to control its exploration and production risks, is at the beginning. The risks of exploration and production from the oil shale reserves are different from conventional reserves risks due to the use of advanced technologies of hydraulic fracturing (fracking) and horizontal drilling. Although some countries, such as France, Germany, Bulgaria, Romani, and the State of Canada, have largely banned the development of shale resources due to high environmental risks, this chapter concludes that the risks resulting from fracking and horizontal drilling operations in the shale projects by identifying the appropriate methods of this industry and enacting legal requirements in the application of those methods by oil companies and contractors are manageable and controllable. One of the ways to identify appropriate methods for the shale industry is to use the experiences of countries active in the industry and refer to the laws and regulations of the unconventional resources, especially the US regulations as the leading and successful country in this industry. The study of laws and regulations shows that legislative and regulatory institutions have managed the industry's risks through legislation and regulations in five parts of horizontal well drilling, hydraulic failure operations, water supply, environment, and responsibility. Therefore, the full prohibition on the development of the oil shale reserves in terms of the risks of this industry does not seem to be an appropriate approach, and must not be ignored by prohibiting the benefits of developing the invaluable shale reserves. Extraction of natural gas from the shale formation in the US has been an energy revolution. This revolution in its tracks will be a giant oil and gas industry in the future provided that the environmental risks posed are effectively managed.

Abbreviations

API	American Petroleum Institute
CBM	Coal bed methane
CBM	Coal bed methane
CCS	Carbon capture and storage
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EROEI	Energy-to-energy investment
NGOs	Non-governmental organization
NOx	Nitrogen oxides
PAH	Polycyclic aromatic hydrocarbons
PM	Particulate matter
TDS	Total dissolved solids
VOC	Volatile organic compounds

References

[1] Chen Z, et al. Application of high-precision 3D seismic technology to shale gas exploration: a case study of the large Jiaoshiba shale gas field in the Sichuan Basin. Natural Gas Industry B 2016;3(2):117–28.

[2] Suotang F, Daxing W, Zonghui Y. Progress of 3D seismic exploration technologies and oil and gas exploration and development performance in the loess tableland area of the Ordos Basin. China Petroleum Exploration 2020;25(1):67.

[3] Treadgold G, et al. Eagle Ford shale prospecting with 3D seismic data within a tectonic and depositional system framework. The Leading Edge 2011;30(1):48–53.

[4] Martineau DF. History of the Newark East Field and the Barnett shale as a gas reservoir. AAPG Bulletin 2007;91(4):399–403.

[5] Zhang D, Tingyun Y. Environmental impacts of hydraulic fracturing in shale gas development in the United States. Petroleum Exploration and Development 2015;42(6):876–83.

[6] Burnham A, et al. Life-cycle greenhouse gas emissions of shale gas, natural gas, coal, and petroleum. Environmental Science & Technology 2012;46(2):619–27.

[7] Wang C, et al. Is China really ready for shale gas revolution—Re-evaluating shale gas challenges. Environmental Science & Policy 2014;39: 49—55.
[8] Rabe BG. Shale play politics: the intergovernmental odyssey of American shale governance. Environmental Science & Technology 2014;48(15): 8369—75.
[9] Mauter MS, et al. Regional variation in water-related impacts of shale gas development and implications for emerging international plays. ACS Publications; 2014.
[10] Meakin P, et al. Shale gas: opportunities and challenges. Environmental Geosciences 2013;20(4):151—64.
[11] Umeozor EC, Jordaan SM, Gates ID. On methane emissions from shale gas development. Energy 2018;152:594—600.
[12] Wang J, et al. Environmental impacts of shale gas development in China: a hybrid life cycle analysis. Resources, Conservation and Recycling 2017; 120:38—45.
[13] Boothroyd IM, et al. Fugitive emissions of methane from abandoned, decommissioned oil and gas wells. Science of the Total Environment 2016;547:461—9.
[14] Rahm D. Regulating hydraulic fracturing in shale gas plays: the case of Texas. Energy Policy 2011;39(5):2974—81.
[15] Jackson RB, et al. Research and policy recommendations for hydraulic fracturing and shale-gas extraction. Durham, NC: Center on Global Change, Duke University; 2011.
[16] Holditch SA. The increasing role of unconventional reservoirs in the future of the oil and gas business. Journal of Petroleum Technology 2003; 55(11):34—79.
[17] Soeder DJ. The successful development of gas and oil resources from shales in North America. Journal of Petroleum Science and Engineering 2018;163:399—420.
[18] Masters JA. Deep basin gas trap, western Canada. AAPG Bulletin 1979; 63(2):152—81.
[19] Moore TA. Coalbed methane: a review. International Journal of Coal Geology 2012;101:36—81.
[20] Gayer R, Harris I. Coalbed methane and coal geologyvol 109. Geological Society London; 1996.
[21] Qin Y, et al. Resources and geology of coalbed methane in China: a review. International Geology Review 2018;60(5—6):777—812.
[22] Vedachalam N, et al. Review of unconventional hydrocarbon resources in major energy consuming countries and efforts in realizing natural gas hydrates as a future source of energy. Journal of Natural Gas Science and Engineering 2015;26:163—75.
[23] Bjørlykke K. Unconventional hydrocarbons: oil shales, heavy oil, tar sands, shale oil, shale gas and gas hydrates. In: Petroleum geoscience. Springer; 2015. p. 581—90.
[24] Matsumoto Ki, Voudouris V. Potential impact of unconventional oil resources on major oil-producing countries: scenario analysis with the ACEGES model. Natural Resources Research 2015;24(1):107—19.
[25] Scanlon BR, et al. Water issues related to transitioning from conventional to unconventional oil production in the Permian Basin. Environmental Science & Technology 2017;51(18):10903—12.
[26] Folger P. Gas hydrates: resource and hazard. Library of Congress, Congressional Research Service; 2010.

[27] https://en.wikipedia.org/wiki/Peak_gas#:~:text=World%20peak%20gas,-In%202002%2C%20R.W.&text=from%20about%202020.%22-,One%20forecast%20is%20for%20natural%20gas%20demand%20to%20peak%20in,even%20before%20the%20year%202020%22
[28] Hill LAL, et al. Temporal and spatial trends of conventional and unconventional oil and gas waste management in Pennsylvania, 1991–2017. Science of the Total Environment 2019;674:623–36.
[29] IEA. World energy outlook France: international energy agency. 2019.
[30] Brittingham MC, et al. Ecological risks of shale oil and gas development to wildlife, aquatic resources and their habitats. Environmental Science & Technology 2014;48(19):11034–47.
[31] Lechtenböhmer S, Zittel W. Impacts of shale gas and shale oil extraction on the environment and on human health. 2011.
[32] https://en.wikipedia.org/wiki/Oil_shale.
[33] Speight JG. Shale oil production processes. Gulf Professional Publishing; 2012.
[34] Lee S. Oil shale technology. CRC Press; 1990.
[35] Hascakir B, Babadagli T, Akin S. Experimental and numerical simulation of oil recovery from oil shales by electrical heating. Energy & Fuels 2008; 22(6):3976–85.
[36] Bridges JE. Wind power energy storage for in situ shale oil recovery with minimal CO_2 emissions. IEEE Transactions on Energy Conversion 2007; 22(1):103–9.
[37] Hascakir B, Babadagli T, Akin S. Experimental and numerical modeling of heavy-oil recovery by electrical heating. In: International thermal operations and heavy oil symposium. OnePetro; 2008.
[38] Hascakir B, Babadagli T, Akin S. Field-scale analysis of heavy-oil recovery by electrical heating. SPE Reservoir Evaluation and Engineering 2010; 13(01):131–42.
[39] https://en.wikipedia.org/wiki/Shell_in_situ_conversion_process.
[40] Crawford P, et al. Advances in world oil-shale production technologies. In: SPE annual technical conference and exhibition. OnePetro; 2008.
[41] Shen C, Mckinzie B, Arbabi S. A reservoir simulation model for ground freezing process. In: SPE annual technical conference and exhibition. OnePetro; 2010.
[42] Nazzal JM. Influence of heating rate on the pyrolysis of Jordan oil shale. Journal of Analytical and Applied Pyrolysis 2002;62(2):225–38.
[43] Forsberg CW. High-temperature nuclear reactors for in-situ recovery of oil from oil shale. La Grange Park, IL: American Nuclear Society; 2006.
[44] Curtis D, Forsberg C. A nuclear renewable oil shale system for economic dispatchable low-carbon electricity and liquid fuels. Nuclear Technology 2016;195(3):335–52.
[45] Ellafi A, et al. Future of hydraulic fracturing application in terms of water management and environmental issues: a critical review. In: SPE Canada unconventional resources conference. OnePetro; 2020.
[46] Neupane B, et al. Occurrence of unconventional hydrocarbon deposits and its structural relation in Nepal Himalaya: implication for future exploration. Arabian Journal of Geosciences 2020;13(2):1–8.
[47] Bravo O, Hernandez DF. Risk management strategies required for unconventional oil and gas exploration and development in Latin America. In: SPE international conference and exhibition on health, safety, environment, and sustainability. OnePetro; 2020.

[48] Gong B. Current situation, challenges and countermeasures of shale industry in China. In: Shale energy revolution. Springer; 2020. p. 53–75.
[49] Field RA, Soltis J, Murphy S. Air quality concerns of unconventional oil and natural gas production. Environmental Science: Processes & Impacts 2014;16(5):954–69.
[50] Ma YZ, Holditch S. Unconventional oil and gas resources handbook: evaluation and development. Gulf professional publishing; 2015.
[51] Kroepsch AC, et al. Environmental justice in unconventional oil and natural gas drilling and production: a critical review and research agenda. Environmental Science & Technology 2019;53(12):6601–15.
[52] Russell PL. Oil shales of the world, their origin, occurrence and exploitation. 1990.
[53] Andrews A. Oil shale: History, incentives, and policy. Washington DC: Library of Congress, Congressional Research Service; 2006.
[54] Knaus E, et al. An overview of oil shale resources. In: Oil shale: a solution to the liquid fuel Dilemma; 2010. p. 3–20.
[55] Burnham AK, McConaghy JR. Comparison of the acceptability of various oil shale processes. 2006.
[56] Youngquist W. Shale oil—the elusive energy. Hubbert Center Newsletter 1998;98(4):1–7.
[57] https://en.wikipedia.org/wiki/Hydraulic_fracturing_in_the_United_States.
[58] Barati R, Liang JT. A review of fracturing fluid systems used for hydraulic fracturing of oil and gas wells. Journal of Applied Polymer Science 2014;131(16).
[59] Ferrer I, Thurman EM. Chemical constituents and analytical approaches for hydraulic fracturing waters. Trends in Environmental Analytical Chemistry 2015;5:18–25.
[60] Li Q, et al. A review on hydraulic fracturing of unconventional reservoir. Petroleum 2015;1(1):8–15.
[61] Wu P-K, et al. Breakup processes of liquid jets in subsonic crossflows. Journal of Propulsion and Power 1997;13(1):64–73.
[62] He H, et al. Deep-hole directional fracturing of thick hard roof for rockburst prevention. Tunnelling and Underground Space Technology 2012;32:34–43.
[63] Morozov IV. Prospects for the development of the oil and gas industry in the regional and global economy. 2018.
[64] Melikoglu M. Shale gas: analysis of its role in the global energy market. Renewable and Sustainable Energy Reviews 2014;37:460–8.
[65] Seebach L. Shell's ingenious approach to oil shale is pretty slick. Rocky Mountain News; 2005.
[66] Sutton RP, Cox SA, Barree RD. Shale gas plays: a performance perspective. In: Tight gas completions conference. OnePetro; 2010.
[67] Warpinski NR, Du J, Zimmer U. Measurements of hydraulic-fracture-induced seismicity in gas shales. SPE Production & Operations 2012;27(03):240–52.
[68] Bland RG, et al. HPHT drilling fluid challenges. In: IADC/SPE Asia Pacific drilling technology conference and exhibition. OnePetro; 2006.
[69] Vengosh A, et al. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. Environmental Science & Technology 2014;48(15):8334–48.
[70] Butts KH. The strategic importance of water. Parameters 1997;27(1):1.
[71] Rosa L, Rulli MC, D'Odorico P. Water stranding in the energy and agriculture sectors: the case of hydraulic fracturing in water scarce

irrigated regions. In: Water resources and economic processes. Routledge; 2020. p. 98–114.
[72] Rules G. Golden age of gas. 2012.
[73] Kargbo DM, Wilhelm RG, Campbell DJ. Natural gas plays in the Marcellus shale: challenges and potential opportunities. ACS Publications; 2010.
[74] Zhong C, et al. Comparison of the hydraulic fracturing water cycle in China and North America: a critical review. Environmental Science & Technology 2021;55(11):7167–85.
[75] Liden T, et al. Unconventional oil and gas production: waste management and the water cycle. In: Advances in chemical pollution, environmental management and protection. Elsevier; 2017. p. 17–45.
[76] Boschee P. Produced and flowback water recycling and reuse: economics, limitations, and technology. Oil and Gas Facilities 2014;3(01):16–21.
[77] Mantell ME, Engineer PCE. Deep shale natural gas: abundant, affordable, and surprisingly water efficient. In: Water/energy sustainability symposium. Salt Lake City, UT: Groundwater Protection Council Annual Forum; 2009. Citeseer.
[78] Springer P. Industrial water in high demand in North Dakota. The forum of Fargo-Moorhead; 2012.
[79] Libecap GD. Water rights and markets in the US Semi Arid West: efficiency and equity issues. 2010.
[80] Brown FL. Market prices as measures of water scarcity in New Mexico and the West. In: Proceedings of the 52nd annual new Mexico water conference—beyond the year of water: living within our water limitations. Santa Fe La Fonda, New Mexico: New Mexico Water Resources Research Institute (New Mexico State University); 2007.
[81] Kenny JF, et al. Estimated use of water in the United States in 2005. US Geological Survey; 2009.
[82] Schaible G, Aillery M. Water conservation in irrigated agriculture: trends and challenges in the face of emerging demands. U. S. Department of Agriculture, Economic Research Service; 2012.
[83] Kurz B, et al. Evaluation of brackish ground water treatment for use in hydraulic fracturing of the Bakken play. North Dakota: Energy and Enviroment Research Center, University of North Dakota Grand Forks; 2011.
[84] Freyman M. Hydraulic fracturing & water stress: water demand by the numbers. Boston, MA: Ceres; 2014.
[85] Reig P, Luo T, Proctor JN. Global shale gas development: water availability & business risks. 2014.
[86] Wu X, et al. Water scarcity assessment based on estimated ultimate energy recovery and water footprint framework during shale gas production in the Changning play. Journal of Cleaner Production 2019; 241:118312.
[87] Shrestha N, et al. Potential water resource impacts of hydraulic fracturing from unconventional oil production in the Bakken shale. Water Research 2017;108:1–24.
[88] Elliott EG, et al. A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity. Journal of Exposure Science and Environmental Epidemiology 2017;27(1):90–9.
[89] Bair E, Freeman DC, Senko JM. Subsurface gas invasion, Bainbridge township, Geauga county, Ohio. Ohio Department of Natural Resources; 2010.

[90] Ajani A, Kelkar M. Interference study in shale plays. In: SPE hydraulic fracturing technology conference. OnePetro; 2012.
[91] Kahrilas GA, et al. Downhole transformation of the hydraulic fracturing fluid biocide glutaraldehyde: implications for flowback and produced water quality. Environmental Science & Technology 2016;50(20):11414–23.
[92] Thurman EM, et al. Analysis of hydraulic fracturing flowback and produced waters using accurate mass: identification of ethoxylated surfactants. Analytical Chemistry 2014;86(19):9653–61.
[93] Yost EE, et al. Overview of chronic oral toxicity values for chemicals present in hydraulic fracturing fluids, flowback, and produced waters. Environmental Science & Technology 2016;50(9):4788–97.
[94] Mech M. A comprehensive guide to the Alberta oil sands. Understanding the environmental and human impacts, export implications, and political, economic, and industry implications, and political, economic, and industry influences. Green Party of Canada; 2011.
[95] Kuwayama Y, Olmstead S, Krupnick A. Water quality and quantity impacts of hydraulic fracturing. Current Sustainable/Renewable Energy Reports 2015;2(1):17–24.
[96] Nicot J-P, et al. Source and fate of hydraulic fracturing water in the Barnett Shale: a historical perspective. Environmental Science & Technology 2014;48(4):2464–71.
[97] Torres L, Yadav OP, Khan E. A review on risk assessment techniques for hydraulic fracturing water and produced water management implemented in onshore unconventional oil and gas production. Science of the Total Environment 2016;539:478–93.
[98] Craig JH. Oil shales process and the environment. In: Proceedings of the international conference on environmental engineering. ICEE. Vilnius Gediminas Technical University, Department of Construction Economics; 2011.
[99] Horner RM, et al. Water use and management in the Bakken shale oil play in North Dakota. Environmental Science & Technology 2016;50(6): 3275–82.
[100] Estrada JM, Bhamidimarri R. A review of the issues and treatment options for wastewater from shale gas extraction by hydraulic fracturing. Fuel 2016;182:292–303.
[101] Olsson O, Weichgrebe D, Rosenwinkel K-H. Hydraulic fracturing wastewater in Germany: composition, treatment, concerns. Environmental Earth Sciences 2013;70(8):3895–906.
[102] Chen H, Carter KE. Water usage for natural gas production through hydraulic fracturing in the United States from 2008 to 2014. Journal of Environmental Management 2016;170:152–9.
[103] Rubinstein JL, Mahani AB. Myths and facts on wastewater injection, hydraulic fracturing, enhanced oil recovery, and induced seismicity. Seismological Research Letters 2015;86(4):1060–7.
[104] Lei X, et al. Fault reactivation and earthquakes with magnitudes of up to Mw4. 7 induced by shale-gas hydraulic fracturing in Sichuan Basin, China. Scientific Reports 2017;7(1):1–12.
[105] Brady WJ, Crannell JP. Hydraulic fracturing regulation in the United States: the laissez-faire approach of the federal government and varying state regulations. Vermont Journal of Environmental Law 2012;14:39.
[106] Lopez V. Oil sands extraction: lessons from Alberta can, and should, inform American policies. Pepperdine Policy Review 2013;6(1):7.

[107] Forrest J, et al. Working document of the NPC North American resource development study-unconventional oil. US National Petroleum Council (NPC); 2011. p. 1–6.
[108] Forrest J, et al. Working document of the NPC North American resource development study. 2011. Unconventional Oil, Tight Oil.
[109] Chang Y, et al. Shale-to-well energy use and air pollutant emissions of shale gas production in China. Applied Energy 2014;125:147–57.
[110] Webb E, et al. Potential hazards of air pollutant emissions from unconventional oil and natural gas operations on the respiratory health of children and infants. Reviews on Environmental Health 2016;31(2): 225–43.
[111] McKenzie LM, et al. Human health risk assessment of air emissions from development of unconventional natural gas resources. Science of the Total Environment 2012;424:79–87.
[112] Soeder DJ. Fracking and the environment: a scientific assessment of the environmental risks from hydraulic fracturing and fossil fuels. Springer; 2020.
[113] Blinn HN, et al. Exposure assessment of adults living near unconventional oil and natural gas development and reported health symptoms in southwest Pennsylvania, USA. PLoS One 2020;15(8):e0237325.
[114] Kerkvliet J, Morton P. Assessing the costs of air pollution from unconventional oil and natural gas activities. 2020.
[115] Poveda CA. The Canadian oil sands development: management of land, air and water resources. European Journal of Sustainable Development 2015;4(2):359.
[116] Venkatesh A, et al. Uncertainty analysis of life cycle greenhouse gas emissions from petroleum-based fuels and impacts on low carbon fuel policies. ACS Publications; 2011.
[117] Prabowo AR, Bae DM. Environmental risk of maritime territory subjected to accidental phenomena: correlation of oil spill and ship grounding in the Exxon Valdez's case. Results in Engineering 2019;4:100035.
[118] Maloney KO, et al. Unconventional oil and gas spills: materials, volumes, and risks to surface waters in four states of the US. Science of the Total Environment 2017;581:369–77.
[119] Patterson LA, et al. Unconventional oil and gas spills: risks, mitigation priorities, and state reporting requirements. Environmental Science & Technology 2017;51(5):2563–73.
[120] Patten DM. Intra-industry environmental disclosures in response to the Alaskan oil spill: a note on legitimacy theory. Accounting, Organizations and Society 1992;17(5):471–5.
[121] Nikiforuk A. Tar sands: dirty oil and the future of a continent. Greystone Books Ltd; 2010.
[122] Wells J, et al. Danger in the nursery: impact on birds of tar sands oil development in Canada's boreal forest. 2008.
[123] Greene DL, Hopson JL, Li J. Have we run out of oil yet? Oil peaking analysis from an optimist's perspective. Energy Policy 2006;34(5):515–31.
[124] de Klerk A, Gray MR, Zerpa N. Unconventional oil and gas: oilsands. In: Future energy. Elsevier; 2014. p. 95–116.
[125] Hosseini SH, Shakouri H, Kazemi A. Oil price future regarding unconventional oil production and its near-term deployment: a system dynamics approach. Energy 2021;222:119878.

[126] Charry-Sanchez J, Betancourt-Torcat A, Ricardez-Sandoval L. An optimization energy model for the upgrading processes of Canadian unconventional oil. Energy 2014;68:629–43.
[127] Gao W, et al. Industrial carbon dioxide capture and utilization: state of the art and future challenges. Chemical Society Reviews 2020;49(23): 8584–686.
[128] Mbaiwa JE. The socio-economic and environmental impacts of tourism development on the Okavango Delta, north-western Botswana. Journal of arid environments 2003;54(2):447–67.
[129] Malin SA. Depressed democracy, environmental injustice: exploring the negative mental health implications of unconventional oil and gas production in the United States. Energy Research & Social Science 2020; 70:101720.
[130] Adgate JL, Goldstein BD, McKenzie LM. Potential public health hazards, exposures and health effects from unconventional natural gas development. Environmental Science & Technology 2014;48(15):8307–20.
[131] Walsh KB, et al. Uneven impacts and uncoordinated studies: a systematic review of research on unconventional oil and gas development in the United States. Energy Research & Social Science 2020;66:101465.
[132] Kassotis CD, et al. Endocrine disrupting activities and geochemistry of water resources associated with unconventional oil and gas activity. Science of the Total Environment 2020;748:142236.
[133] Hinojosa R, et al. Unconventional oil and natural gas production, health, and social perspectives on fracking. Environmental Justice 2020;13(4): 127–43.
[134] Krupnick A, Wang Z, Wang Y. Environmental risks of shale gas development in China. Energy Policy 2014;75:117–25.
[135] Rabe BG, Borick C. Conventional politics for unconventional drilling? Lessons from Pennsylvania's early move into fracking policy development. The Review of Policy Research 2013;30(3):321–40.

17

Natural resources overusing in oil, gas, and petrochemical industries and challenges

Md. Jafar Hossain[1,2], Syed Istiyak Ahmed[3], Minhaj Uddin Monir[1,2], H.M. Salman[1], Kuaanan Techato[4] and Shahariar Chowdhury[4]

[1]*Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh;* [2]*Energy Conversion Laboratory, Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh;* [3]*Department of Civil, Environmental, and Geo- Engineering, University of Minnesota Twin Cities, Minnesota, MN, United States;* [4]*Faculty of Environmental Management, Prince of Songkla University, Songkhla, Thailand*

1. Introduction

The planet has been gifted with abundance of resources. Natural resources are components found on the globe that can be used and benefited by all living beings [1]. Scientists frequently separate them into various categories to examine them. Plants, animals, agricultural resources energy sources, landscapes, minerals, water forests, and atmospheric resources are among these categories [2]. Mankind has devised methods to boost as well as extend its power harvesting throughout thousands of years, initially by taming animals in the draft and subsequently by building devices to harness the force of water and wind. The extensive and intense use of fossil fuels permitted urbanization, that started the contemporary world's creation [3,4]. Finding and harnessing the earth's immense supplies of coal, oil, and natural gas, this discovery liberated modern civilization out from limits imposed by traditional flow of energy. These resources significantly increased the potential rate of energy consumption [5]. As a consequence of this, each of history's more significant societal revolutions occurred [6]. Population growth in various regions of the globe

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00013-X

is increasing a strain on the planet's limited resources. The increasing population and transportation automation are putting a strain on existing natural resources [7].

According to the World Energy Council, if the current economic development trend continues, global energy consumption would rise by 45%–60% (optimistic variation) or 35% (pessimistic variant) by 2030. The entire energy consumption in the European Union (EU) is expected to rise by 15%–20% by 2030. As per the International Energy Agency [8], energy is the primary resource that may increase to roughly 334 million barrels of crude oil equivalent per day in 2030, which is 1.5 times the amount used in 2000 (205 million barrels). At present, the three largest nations (the United States, China, and Russia) consume 41% of the total world's energy, although possessing just 38% of the basic sources of energy in the world.

For decades, there seems to be a raging discussion over energy status on different stages, possible future centuries' challenges owing to the dwindling accumulation of fossil-based energy supplies in the earth's crust, primary energy sources' huge, irresponsible, and overpowering consequences, as well as the massive growth in carbon dioxide emissions to the environment as well as the major intensity of such gases on global warming and climate change. Energy security is impeded by finite resources, especially in the coming, as well as their very unequal spatial pattern. Energy policy is now one of every state's most crucial public interests since public safety is based on it [9]. This chapter gives an outline of energy sources and their overusing problem in oil, gas, and petrochemical industries.

2. Natural resources

Natural resources are items that exist naturally on earth for human usage and therefore do not necessarily require human activity to generate or produce. Natural resources are important because it determines the development of people as well as other types of life on this planet. Rocks, land, woods (vegetation), minerals, waters (lakes, ocean, streams, rivers, and seas), fossil fuel, animals (wildlife, fish, and domesticated animals), sunshine, and air are among these resources. Natural resources include air, which gives energy from the wind, petroleum products, which also will provide an insight for power generation, woodlands, which can provide paper, timber, as well as varied medicinal products, steam, which can be used for drinking as well as generating hydropower electricity, daylight, used for drying clothes, photosynthetic activity, as well as renewable power. They are referred to as natural resources since they provide the foundation for life on earth. Every artificial product is created using natural resources. The materials can be utilized in their native state or converted into different forms. However, the majority of natural resources are vulnerable to depletion and deterioration, raising global concerns about their long-term use and management [7]. Natural resources are broadly classified into renewable energy sources and non-renewable energy sources.

2.1 Renewable energy resources

Renewable energy is the world's next energy field, and it has the potential to control energy issues [10]. Renewable energy is becoming a major global resource, delivering sustainable heat, electricity, and fuels from the smallest to the greatest requirements [11]. Renewable energy resources (RES) include bioenergy, hydropower, geothermal and aerothermal energy, wind energy, solar energy, and biomass (straw, biogas, landfill gas, energy crops, municipal waste, and so on) [12]. RES are utilized in three ways: to generate electricity, to generate heat, and to produce biofuel [9]. Renewable power is intrinsically linked to the objective of long-term development. It promotes energy supply security and is distinguished by almost clean technology. The utilization of renewable energy opens up possibilities for electrifying and heating rural locations. The worldwide accessibility of RES, particularly the sun and wind, is a good attribute [9]. The bulk of renewable energy comes from the sun, both direct and indirect. Sunshine, or renewable power, may be utilized directly to light and heat structures, to create electricity, and for warm boiling, sun cooling, and a variety of industrial and commercial purposes. The sun's heat also propels the wind, the energy of which is harnessed by wind turbines. Water evaporates as a result of the winds and light from the Sun. The stored energy in this water vapor may be captured using hydropower when it compresses into snow or rain and drops in streams and rivers. Because additional trees may be planted to provide more wood, wood is a renewable resource. Geothermal energy from within the earth is another type of renewable energy [6].

The world's renewable energy potential is limitless. In 2013, RES accounted for around 16% of overall global energy consumption. In 2012, the total estimated power of power stations was 1373 GW. Among them are wind energy production (283 GW), hydroelectric power (990 GW), wind energy production (283 GW), and solar Photovoltaic power (100 GW). RES generated around

19.5% of worldwide power [9]. According to a 2006 survey, global bioethanol output was 15 billion liters (126 million barrels), whereas biodiesel production was 4 billion liters (33 million barrels). Over the next 10 years, the output of both bioethanol and biodiesel is expected to rise more than tenfold [13,14]. Brazil and the United States are now the world leaders in bioethanol production. The global trend predicts a roughly five-fold growth in global output over the next 20 years. Corn and sugarcane are the principal bioethanol sources. Other sources include wheat, beet sugar, corn, barley, sunflower, potatoes, cassava, wood pulp, and brewers' waste.

Biodiesel is mostly manufactured in Europe (approximately 90% of overall bioethanol production). The other 10% is produced in the United States (8%) as well as other countries such as Malaysia, Canada, Brazil, Argentina, and India. In 2007, the US manufactured 632 million gallons (2392 million liters) of biodiesel. In 2004, Canada generated around 875,000 gallons (3.5 million liters) of biodiesel, with output estimated to reach 500 million liters (132 million gallons) in 2010 [15].

2.2 Non-renewable energy resources

Non-renewable sources are those that, once consumed or destroyed, cannot be easily restored or regenerated [7]. Examples include nuclear energy as well as coal, natural gas, and oil. With these sources, power becomes primarily an isolating power source, and additional action is necessary to begin the transmission of power for practical purposes [11]. Minerals are classified as non-renewable, while they are occurring naturally with the geological cycle, they require thousands of years to create [7]. Non-renewable energy sources, sometimes known as "conventional" energy resources, are limited, require huge time to refill, and are not uniformly distributed regionally. As previously noted, those resources have historically led the overall power situation, particularly when it comes to coal and oil. However, a "non-renewable" energy source is not automatically a "dirty" source of energy in terms of air pollution and greenhouse gas emissions. Nuclear energy is an exception; it's not regarded as sustainable, although its use emits significantly fewer greenhouse gases (GHGs) compared to carbon fuels, however, there are restrictions on radioactive waste produced as part of using it [16]. The outcome of this process might be liquids (oil), solid (coal), or gaseous (natural gas) hydrocarbon, based on the options of the production state or beginning to learn.

2.2.1 Coal

Coal is possibly the most complicated geologic substance. In addition to biological matter, which is important for its potential energy, all coals include minerals, water, the majority, if not all, of the Periodic Table component, oil, gas, rock fragments, and fossils [17,18]. Coal comes in a variety of forms, based on its overall condition of formation [19]. Lignite is the most recent kind of coal and has the smallest energy content value. Sub-bituminous coal is created when lignite is exposed to greater pressures and temperatures. With more pressure and heat, the most common type of bituminous coal is generated. Finally, anthracite coal is more difficult to get, and it has a higher heating value. Because of their availability, these coals can create energy when burned and remain one of the most economical sources of fuel [16].

The most important use of coal would be as input energy for ignition processes that create electricity generation as well as power and heat factories, cement factories, and many other manufacturing and industrial amenities; and the most significant environmental effect of ignition is connected to emissions in the world. During combustion, constituents of coals are converted to oxides. Gaseous emissions include water vapor, nitrogen oxides (NOx), sulfur oxides (SOx), carbon dioxide (CO_2), and other compounds and elements known as major air pollutants (HAPs) including mercury [20]. Due to tight air quality rules in metropolitan areas, most industrialized countries have replaced coal as a home fuel with gas and fuel oil. Nevertheless, in the less or destitute countries, coal is still widely used as a source of heat in workplaces and homes, as well as for meals, resulting in significant air pollution [20,21].

Coal's future as a source of energy is quite questionable. Since 2013, there has been a modest reduction in global coal usage, owing to reduced gas costs, an increase in renewables, improvements in energy efficiency, and rigorous rules governing emissions that contribute to greenhouse gas emissions, among other factors. The majority of coal-related operations have a significant effect on the environment and people's life, involving mining, refinement and manufacturing, transportation as well as consumption [4]. As a result, while coal continues to be a significant component of the socioeconomic development of several countries, there's also an urgent need for us to minimize and minimize the adverse repercussions associated with coal-related operations [21].

2.2.2 Natural gas

Natural gas contains rich hydrocarbon that is found in oil and gas fields, as well as coal seams; this is a gaseous source of fuel located in oil and gas fields, as well as coal seams [22,23]. In 1821, William Hart, recognized as America's "Founder of Natural Gas," drilled the first documented oil and gas well in Fredonia, New York. Natural gas had recently discovered while exploring petroleum oil exploration. Natural gas was used primarily as a lighting source throughout the 19th century due to the absence of a stable framework for lengthy gas delivery. Natural gas was widely used after World War II as a result of technological improvements that enabled the building of safe, dependable, transmission of gas in long-distance pipes [23]. It is recognized as an environmentally friendly clean fuel particularly compared to all other fossil energy (crude oil and coal). Apart from natural gas, the use of fossil energy emits massive amounts of chemicals and particles that are harmful to human health. However, during natural gas burning, SO_2 emissions are insignificant, and N_2O and CO_2 emissions are reduced, which assists to alleviate problems related to greenhouse gases, acid rain, and the ozone layer [24].

When transported, stored, and utilized properly, natural gas seems to be a very efficient energy source. It has been used to heat homes, businesses, and industries. In addition, it is utilized to generate heat and power. It's being used as feedstock or primary ingredient in the petroleum industry, such as in the production of ethylene. It is used in the fertilizer business to produce ammonia. Natural gas may be used to generate sulfur, hydrogen, and black carbon [25,26]. However, while natural gas is less costly and deemed "cleaner" than coal and oil, it nonetheless emits significant volumes of CO_2 when burned. Furthermore, natural gas extraction contributes to environmental issues. Collapsing rocks, for example, can cause mini-earthquakes, and excessive chemicals and water pushed underground may leak into other sources of water, contaminating ground and drinking water resources [16].

2.2.3 Petroleum

Petroleum is a naturally occurring hydrocarbon mixture, often in a fluid state, which could also include nitrogen, oxygen, sulfur, metals, and many other components [23]. This combination was generated over millions of years by the breakdown of organic materials from marine creatures when subjected to high temperatures and pressures as a result of deeply burying [16]. Petroleum is discovered beneath at varied pressures based on depths. Along with the stress, it includes a significant amount of natural gas in the solution. Because increasing temperatures (the geological gradients) in underground formations reduce stiffness, petroleum underneath is much more liquid than with the ground and is often transportable below isothermal conditions. Although the hydraulic gradient varies by location, it is often in the range of 25–30°C/km (15°F/1000 ft or 120°C/1000 ft, i.e., 0.015°C per foot of depth or 0.012°C per foot of depth).

The main components of petroleum are hydrocarbons, which are hydrogen and carbon molecules with a wide range of molecular structures. Paraffins are a wide collection of chain-shaped molecules that are the most basic hydrocarbons. This vast series includes methane, which generates natural gas, liquids processed into gasoline, and crystalline waxes. The naphthalene is a class of hexagonal hydrocarbons that range between gases and vapors such as naphtha to large molecular weight molecules that are isolated as the asphaltene fractions. Aromatics are another type of hexagonal hydrocarbon; the most important component in this class is benzene, which is used to make petrochemicals [23]. Fig. 17.1 shows the world's current energy sources.

3. Non-renewable energy-based industries

3.1 Oil industry

The 19th century was a period of rapid industrialization and profound changes. The iron and steel industry developed numerous construction equipment, railways connected the region, and oil exploration provided a new supply of energy. The 1901 finding of the Spindletop geyser catapulted the oil industry to the next level. Within a year, over 1500 oil companies had been

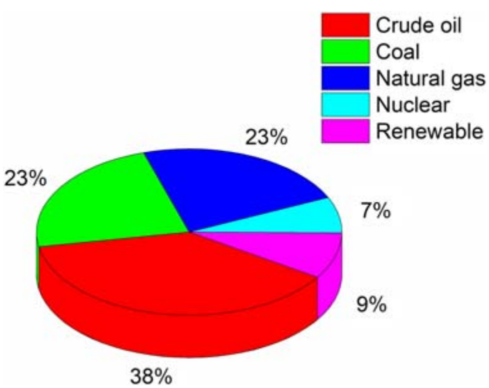


Figure 17.1 World's current energy sources [27].

formed, and oil had emerged as the dominant energy of the 20th century, as well as a vital component of the American economy. Oil has a large and crucial part in modern civilization as it is presently structured. Oil is considerably more than simply one of humanity's primary sources of energy. Petroleum products, proven to be an important source of energy, serve as fuel for a wide range of customer products, playing a significant role in human life [28]. The oil-based industry is shown in Fig. 17.2.

Currently, the global expansion of gas and oil fields are entirely dependent on the amount of accessible (reserve) liquids discovered in subsurface formations (reservoirs). The world's greatest oil reserves are shown in Table 17.1 by nation. Both conventional and unconventional oil resources are included in hydrocarbon reserves. Nonconventional deposits are typically found in the United States and are hard to retrieve; however, it is now possible to fracture shale oil (nonconventional) reserves, thanks to recent technological advances in Canada, the United States, and other regions.

Figure 17.2 Oil-based industry in Bangladesh [29].

Table 17.1 Global oil reserves distribution by country [30–32].

S. N.	Country	Oil reserves (billion barrels)	World share (%)
1	Venezuela	2.984×10^2	18.2
2	Saudi Arabia	2.683×10^2	16.2
3	Canada	1.71×10^2	10.4
4	Iran	1.578×10^2	9.5
5	Iraq	1.442×10^2	8.7
6	Kuwait	1.04×10^2	6.1
7	Russia	1.032×10^2	5.9
8	United Arab Emirates	9.78×10^1	4.8
9	Libya	4.836×10^1	2.9
10	Nigeria	3.707×10^1	2.2
11	United States	3.652×10^1	2.1
12	Kazakhstan	3.00×10^1	1.8
13	Qatar	2.524×10^1	1.5
14	China	2.465×10^1	1.5
15	Brazil	1.532×10^1	1

Since its start in the late 1800s, the sector has contributed oil of 1.063 trillion barrels (bbl). In 2000, world oil demand was 76 million barrels per day (27.74 billion barrels per year). World oil consumption is expected to range between 37.6 and 50.4 billion barrels per year in 2030 [33]. The top five crude-oil producing countries in the world, according to the US Department of Energy, are [6]

- Saudi Arabia
- Russia
- United States
- Iran
- China

3.2 Gas industry

The oil and gas industry is one of the businesses that has had a beneficial influence on the environment for a lot of reasons. In 2012, 40.7% of oil and 15.2% of natural gas contributed to global energy consumption, as per the International Energy Agency (IEA) [34]. Over the last two centuries, the gas business has matured and intends to increase. This chapter presents a brief overview of the oil industry in order for us to comprehend its scale, extent, wealth, breadth, and impact [35]. They provide energy for motor vehicles, planes, and ships, as well as for the operation of various manufacturing machines. They are used to heat our houses, cook our meals, and generate energy to power our daily activities and other human undertakings which improve the quality of life. Moreover, crude oil byproducts are utilized as raw materials in a wide range of industries, such as pharmaceuticals, petrochemicals, solvents, pesticides, fertilizers, and polymers [34]. The gas-based industry is shown in Fig. 17.3.

According to several recent estimates, the world's total natural gas reserves are around 212.09 trillion m^3, 203.63 trillion m^3, and 196.85 trillion m^3 [8,32]. Russia leads the world in proved natural gas reserves, with 47.8 trillion m^3, followed by Iran, which has 33.72 trillion m^3 of confirmed natural gas reserves. Table 17.3 depicts a graphical depiction of the world's top 10 natural gas-rich nations. 3000 TCF [85 TCM] of gas have also been generated by the industry [31]. The global natural gas demand in 2000 was 88.7 TCF (2.51 TCM) per year. In 2030, gas consumption is estimated to be 130–212 TCF per year (3.7–6.0 TCM per year) [35]. Table 17.2 shows the world's top gas-producing countries.

Figure 17.3 Gas-based industry in Bangladesh [29].

Table 17.2 World's top gas-producing countries [30–32].

S. N.	Country	Gas reserves (MMcf)	World share (%)
1	Russia	1.688228×10^9	24.3
2	Iran	1.201382×10^9	17.3
3	Qatar	8.71585×10^8	12.5
4	United States	3.68704×10^8	5.3
5	Saudi Arabia	2.94205×10^8	4.2
6	Turkmenistan	2.65×10^8	3.8
7	United Arab Emirates	2.15098×10^8	3.1
8	Venezuela	1.97087×10^8	2.8
9	Nigeria	1.8049×10^8	2.6
10	China	1.63959×10^8	2.4

Table 17.3 The three principal petrochemical product categories [36].

Petrochemical types	Remarks
Olefins (C_nH_{2n})	Examples: Ethylene ($CH_2{=}CH_2$) and propylene ($CH_3CH_2 = CH$). Butadiene ($CH_2{=}CHCH{=}CH_2$) is utilized in the production of synthetic plastic and is an important source of industrial chemicals and polymers.
Aromatics ($C_{4r+2}H_{2r+4}$)	Toluene, benzene, and the isomers of xylene are among the examples. Benzene is an unprocessed chemical used in the production of colors and synthetic detergents. Isocyanates are made from benzene and toluene as basic ingredients. Xylenes are chemicals that are used to make synthetic and textile materials.
Synthesis gas ($CO + H_2$)	A hydrogen/carbon monoxide combination. In the Fischer–Tropsch method, it is used to generate hydrocarbons in the gasoline and diesel ranges. It is also utilized in the production a mixture of dimethyl ether and methanol.

3.3 Petrochemical industry

Petrochemicals are organic polymers derived from crude oil; however, most of the same organic molecules may be produced using alternative energy sources such as natural gas and coal, as well as renewable sources such as sugar cane, wheat, and other kinds of biomass [37,38]. The petrochemicals industry emerged with refineries, and so as a reason, refining and petrochemical operations are quite similar to refinery projects. The fundamental goal of a refiner is to ensure that the production of purified items of a certain refinery roughly fulfills consumer needs. Energy companies are especially concerned with satisfying consumer demands for the three main transportation fuels, including gasoline, diesel, jet fuel, and gasoline [39]. The basic purpose of the petroleum business is to identify and transfer above-ground crude oil and natural gas, refine this into goods, and deliver them to consumers. The properties of crude oils and, especially, natural gas are a critical factor in determining the relevance, efficiency of treatment, end-product quality, and environmental impact of the petroleum industry [40]. The petrochemical-based industry in Bangladesh is shown in Fig. 17.4.

Petrochemical production is based on the multistage refining of petroleum products and related gas. Crude oil refining byproducts are key raw components in the petrochemical industry (mainly naphtha and gases). Propylene, ethylene, as well as

Figure 17.4 Petrochemical-based industry in Bangladesh [29].

benzene are examples of petrochemical products, as are primary molecules for synthetic plastics and technical carbon sources. Petrochemicals are being used to produce a wide range of feedstocks, monomers, and monomers predecessors. Polymerization of molecules produces a variety of polymers, which are subsequently used to generate lubricants, gels, elastomers, plastic, and fabrics. Petrochemical and petroleum derivatives are the secondary byproducts derived from crude oil after different refining activities. Crude oil is the fundamental component utilized to manufacture all petrochemical and crude oil products after just a lengthy refinement process in petroleum refining [41,42]. Based on their chemical structure, petrochemicals are categorized into three types: (i) olefin compounds, (ii) aromatic derived products, and (iii) syngas.

The raw ingredients for the petrochemical industry are obtained in one of two main methods from crude oil. They could be found in crude oil and must be separated using various methods like solvent extraction or distillation. They may, from the other side, be present in trace amounts, if at all, and are generated during the purification process. Indeed, unstructured (olefin) hydrocarbons compounds are virtually always created as intermediate during various processing phases, despite the fact that they are not typically occurring in crude oil. The facile responsiveness of numerous compound types to fundamental chemical processes like halogenation, oxidation, nitration, polymerization, dehydrogenation addition, and alkylation underpins the chemicals production from crude oil. Because they are readily separated and handled, low molecular olefin and paraffin compounds found in natural gas and refinery gases, as well as simple aromatics compounds, have generated the most interest thus far [36].

Ethylene and propylene, which make up the majority of olefin derivatives, are used to make a variety of plastics and chemical products. Butadiene, on the other hand, is used to manufacture synthetic materials. Aromatic compounds are mostly composed of benzene, toluene, and xylene isomers. Those aromatic petrochemicals are utilized in the production of secondary products like laundry detergents, plastic, synthetic fabrics, and polyurethanes. Synthetic gas is composed of hydrogen and carbon monoxide, which are combined to produce methanol as well as ammonia, which are subsequently used to produce a variety of organic and synthesis compounds [42,43].

The petrochemicals sector is driven by industry participants looking for economic possibilities to distressed stream both petroleum and natural gas refining are sourced and converted into value through new chemical treatment. Non-fuel uses, notably the production of synthetic fibers, have historically given effective advertising opportunities for petroleum products. Such elements become less costly to produce and perform better than many natural materials. Currently, the yearly output of petrochemical materials and products is over 500 million tons, with more essential goods including [39]

- Polymers, such as bottles and bags, are utilized for wrapping.
- Rubber is used in car tires and other similar products.
- Fertilizers and agricultural goods: Fertilizers and agricultural materials used in the food industry.
- Synthetic fibers are used in textiles, clothing, rope, and other products.
- Surfactants and detergents: These are used in cleaning applications.

4. Overusing of oil, gas, and petrochemical in industries

As the human population continues to rise, there is increasing strain on the use of practically all land and resources. That frequently results in the overharvesting of natural assets. To make the problem worse, finite land and resources such as agricultural land, fossil fuels, coral reefs, freshwater, and diverse flora in forests are rapidly depleting as a result of overexploitation to fulfill the demands of an ever-increasing population. This places a strain on essential existence elements and leads to a precipitous deterioration in the popularity of lives. Natural water, food, timber, fish, clothes, leather, gas, and other natural resources are depleted as a result of overpopulation [7]. The nuclear and renewable energy sources might expand significantly, while hydrocarbon and coal-based energies would still account for up to 80% of total energy consumption [44].

Since the beginning of 2015, the world has collected over 99 billion barrels of oil, almost 25 billion tons of coal, and more than 10.6 trillion cubic meters of natural gas, including an animated chart made by Guardian [44]. Fossil fuels now meet the vast bulk of the world's largest power needs, and they will continue to do so in the near future. The combustion of fossil-based fuels causes air pollution, which is projected to kill 6.5 million people each year. Oil production may cause significant spillage in maritime regions, coal mining can devastate woodlands as well as other ecosystems, and oil and gas extraction can poison streams and cause earthquakes [7].

The global usage of energy is continually changing. The majority of the world's energy is derived from fossil fuels. As previously stated, their supplies are limited and will eventually run out. Alternative energy generation methods are quickly evolving across the world. As a result, in the longer term, renewable energy will replace fossil fuels. Compared to world Energy Council (2013) publications claiming that coal and oil have such a greater degree of exploitation, oil and gas prices will increase in the coming years due to limited access to reserves. The world's easily available resources have already been depleted through constant exploitation [9]. Fig. 17.5 represents historical GHG emissions from the use of fossil fuels during the 1990s, as well as projected forecasts for a large increase over the following decades.

Environmental issues have grown worldwide in terms of their physical presence and consequences, in addition to the financial factors that cause them, in recent decades. Following a brief discussion of the increasing worldwide concern about the environment, the above entrance looks at the nature of environmental issues as well as their international network, proof that people are progressively trying to force against worldwide environmental restrictions, international politico-economic powers which create and exacerbate pollution problems on a worldwide scale, and lastly concludes the study [45]. The petrochemicals business, like the various oil and gas industry sectors, poses major environmental dangers to society as a whole. Furthermore, most chemical methods used by industries and so many petroleum-based products are hazardous, posing serious health risks to the general people. The industry seems to have a history of serious catastrophes which has led to severe casualties and contamination. As a result,

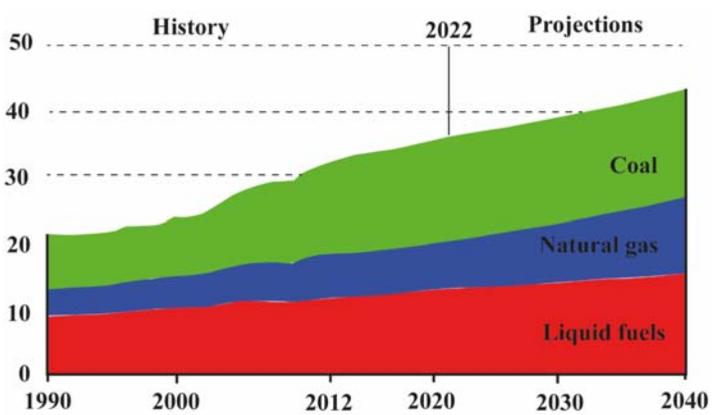


Figure 17.5 CO_2 emissions from the usage of fossil fuels in the world, by fuel type, 1990–2014, in billions of tons [16].

assessing the environment, and healthcare, including safety considerations regarding activities within that area, is just as important as it is for efforts in other sectors of the organization [39]. Humans make "waste" products as a result of resource use; moreover, we produce a considerably higher number and waste types than any other animals [45].

5. Overusing challenges and solutions

Fossil fuels have been and continue to be important components of our energy generation throughout the last 150 years. During this time, a significant portion of these deposits was extracted. Human reliance on fossil fuels, as well as their loss and enormous environmental impact, underline the vital necessity for installing renewable sources of energy as well as expanding the global energy system. The use of these sources has been a substantial contributor to human GHGs emissions in recent decades and has been implicated in climate change and global warming [16]. The oil, gas, and petrochemical industries pose significant environmental risks and may have an influence on the environment at several levels, including soil, air, water, and, as a result, all breathing species on the earth. Pollution is the most common and hazardous result of petroleum and natural gas sector operations in this environment. Pollution is present at practically every stage of the natural gas production process, from exploring to purification. Industrial effluents, greenhouse gases, waste materials, as well as aerosol created while drilling, producing, refining (the source of the most pollutants), and shipping constitute over 800 different compounds, the vast majority of those being petroleum products compounds.

Within maximum, utilizing the entire environment as a trash dump for greenhouse gases generates climate changes that jeopardize people's environments and maintain global activities. Second, in accordance with a consensus view that perhaps the maximum weight of human groups—as evaluated by ecological impact as well as other factors—would seem unaffordable, the multiple elite circles denoting living things use of its ecological system have now surpassed the boundary lines of the outermost ring signifying the Earth's lengthy load bearing capacity [46]. The potential environmental implications of the oil, gas, and petrochemical industries, as well as some potential mitigation strategies, are described below.

5.1 Potential environmental implications

Oil and gas are produced and used in a way that is intrinsically tied to water. Large amounts of water are used in the extraction and processing of oil and gas, which also produces wastewater and may unintentionally contaminate water sources. Water supply, human health, and natural resources are all impacted by these consequences [47]. Effluent, wash water, and cooling water discharges, as well as seepage from storage and waste tanks, all contribute to water pollution. Water contamination is caused by untreated discharges of inorganic salt-rich water effluents (saline pollution). Thermal pollution is caused by the discharge of effluents with temperatures greater than those of the recipient water bodies, as well as water contamination caused by oil spills. Particulate emissions into the atmosphere are caused by operations in manufacturing and refining plants. Large oil spills, leaks, fires, and explosions in factories are examples of accidents that have a negative influence on the environment [28]. Refineries are subject to a series of environmental rules pertaining to air, land, and water since they are typically regarded as major sources of pollution in the regions where they are located. Here is a description of the risks that refineries bring to the air, water, and soil [48].

5.2 Air pollution hazards

A significant source of dangerous and harmful air pollutants, like chemicals, is petroleum refineries (benzene, toluene, ethylbenzene, and xylene). They are also a significant producer of the following air pollutants: sulfur dioxide, nitrogen oxides, carbon monoxide, hydrogen sulfide, and particle matter (PM) [49]. Less hazardous hydrocarbons like natural gas (methane) as well as other volatile organic fuels and oils are also released by refineries. A few of the chemicals emitted are recognized or suspected to be carcinogens and to be the cause of reproductive and developmental issues. Additionally, they could make respiratory disorders such kid asthma worse. The consumption of these chemicals may have negative health impacts, but it’s also probable that it may alarm and frighten locals [50]. In a petroleum refinery, air emissions can arise from a variety of places, such as equipment leakage, high-temperature combustion processes during the actual burning of fuels for power production, heating of steam and process fluids, and product transfer [51].

5.3 Water pollution hazards

Additionally, refineries have the potential to significantly contribute to the polluting of surface and groundwater. Some refineries dispose of the wastewater produced inside the facilities via deep injection wells, and many of these pollutants wind up in aquifers and groundwater. Given the variety of sources wastewater in refineries might come into touch with during the refining process wastewater in refineries may be highly polluted [52]. This polluted water may be storm water, distillate, desalting process wastewaters, cooling tower water, or cracking wastewaters. It could include hazardous pollutants like oil residues and many others. Before being discharged into surface waterways, this water undergoes many treatment procedures, along with a wastewater treatment facility, throughout the refining process [53]. These discharge standards set limits on the concentrations of components such as sulfides, ammonia, suspended particles, and other substances that may be present in wastewater. Despite the existence of these regulations, it is occasionally possible for surface water basins to still have considerable pollution from prior releases [51].

5.4 Soil pollution hazards

In comparison to air and water pollution, soil contamination from refining operations is often a less serious issue. It's possible that previous manufacturing procedures caused leaks on the refinery's premises that need to be cleaned. In contrast to many other contaminants, naturally occurring microorganisms that may utilize petroleum as food are frequently efficient at clearing up petroleum spillage and leaks [54]. During the refining operations, a lot of residuals are created, and some of them are recycled at different phases of the procedure. Other leftovers are gathered and dumped in landfills, or they might be salvaged by further operations. Leaks, accidents, or spillage inside or outside the site during the shipping process can cause soil contamination, which can include some hazardous wastes, used catalysts as well as coke dust, the bottoms of storage tanks, and slurries from the treatment operations [55].

5.5 Potential mitigation strategies

The problem of lack of engagement was the biggest obstacle to the efficiency of the mitigating measures. According to certain key informants, there is a high level of indifference toward supporting mitigation measures because the majority of people do not see any significant improvements in their possibilities for a better quality of life as a result of the adoption of the measures. The lack of regard for the problem pertaining to the adoption of mitigation strategies to solve environmental difficulties linked with the oil and gas industry was the least significant obstacle [56]. Here are some key factors of potential mitigation strategies for oil and gas industries [28]:

- No wastewater should be dumped into rivers or other sites where infiltration may occur unless properly treated.
- Depending on the pollutant to be eliminated, water effluents may be treated using the following methods: neutralization, evaporation, aeration, flocculation, oil and grease separation, carbon adsorption, reverse osmosis, ion exchange, biotreating, and so on.
- No wastewater should be dumped into rivers or other sites where infiltration may occur unless properly treated.
- Discharges of liquid effluent into recipient water bodies must adhere to norms set by laws and regulations in each nation.
- To prevent contaminating rainfall, substances that may infiltrate torrential rain should be stored in closed warehouses with drainage facilities.
- Waterproofing and drainage systems should be installed in areas where raw materials and products are stored and handled, so that spillage, as well as wastewaters, may be sent to a rehab center.
- Particle emissions could be minimized with the use of technologies like as electrostatic precipitators, cyclones, bag filters, and purifiers.
- Wet scrubbers can be used to manage acidic pollutants such as sulfur and nitrogen oxides.
- Wet scrubbers and carbon adsorption, among other approaches, can be used to reduce gas emissions.
- Acoustic treatments include the encapsulation of equipment or the soundproofing of houses that hold loud equipment and/or unit which run with high levels of noise.
- If these treatments are not available on-site, the garbage could be handled at other factories that have the appropriate infrastructure, in whose situation special measures should be undertaken while trashing movement.

For example, gasoline yields are sacrificed for deep catalytic cracking yields. The big petrochemical companies' competitive edge in the future depends on improved efficiency of all kinds, which will reduce GHG emissions. The 12 concepts of Green Chemistry summarize improvements to such environmental performance of the methyl methacrylate facility (Table 17.4). A method of chemical manufacturing known as "green chemistry" emphasizes how every operation affects the environment [58].

5.6 Disaster management in the oil and gas industry

These days, the majority of oil and gas installations and refineries view "Catastrophe Management" as a component of any disaster brought on by internal factors, such as any operation failures or uncontrolled conditions within the plant, and if it exceeds the limit. A significant emergency can arise as a result of natural disasters such as storms, earthquakes, floods, lightning, etc., or as a result of functioning and containing systems failing. There is currently a consensus that nothing can be done to prevent the occurrence of natural disasters [59]. The industry considers some of its prior experiences while creating such a paper. There were sad, out-of-the-ordinary events that the specific industry had to deal with, and they are noted in the "Disaster Management" documentation. Examples of such events include fire explosions, toxic releases, oil spills on land or in bodies of water, and natural disasters like unusually heavy rain [60]. Utilizing both internal resources at the facility and external assistance,

Table 17.4 Twelve green chemistry concepts [57].

S. N.	Green chemistry concepts
I	Avoid wasting
II	Create chemicals and products that are safer
III	Create safer chemical synthesis processes
IV	Use renewable sources of fuel
V	Instead of stoichiometric reagents, use catalysts.
VI	Keep clear of chemical derivatives
VII	Enhance atom economy
VIII	Put reaction conditions and safer solvents to use
IX	Enhance energy effectiveness
X	Develop products and substances that disintegrate after usage
XI	Real-time analysis to stop pollution
XII	Reduce the possibility of accidents

the disaster management strategy seeks to accomplish the following goals [60]:

- Rescue and provide medical care for victims
- Protect others
- Minimize harm to the environment and property
- Contain the problem at first and finally put it under control
- Identify any deceased individuals
- Attend to the requirements of kin
- Provide reliable information to the media
- Ensure the safe restoration of the affected region
- Preserve pertinent documents and equipment for the ensuing investigation into the emergency's cause and circumstances

5.7 Crisis management in the oil and gas industry

One of the riskiest occupational areas in the world is the oil and gas industry. Infrastructure, employee, and process safety must be prioritized, and each occurrence requires a significant commitment. As a result, company integrity and reputation in the oil and gas industry depend greatly on emergency response management [61]. The number of possible catastrophes and crises that might influence, disrupt, or stress out production has increased. Not all of these occurrences, if handled well, will be serious or qualify as crises, but those that cause significant losses or raise organizational demands will have negative effects on the firm, its stakeholders, the nation, and the reputations of everyone engaged in the response [62]. Some objectives of crisis management of the oil and gas industry are given below [63,64]:

- There is no time wasted during a crisis. It is essential that communications be simplified, simple, and quick. Additionally, it should provide two-way communication with outreach and response capabilities, allowing leaders to assign jobs swiftly and get updates on the state of the problem [65].
- To establish operational resiliency, enable an efficient crisis response, to restore law and order in an industrial setting-all crucial component to prevent loss of life account for all of your staff.
- It may send updated information to staff members and outside parties via a variety of devices and communication channels with just one click. These consist of land mobile radios, outdoor and indoor speakers, accessing, cellphones, text messaging, email, social media, and more. Communication can contain material like HTML, video, maps of escape routes, and links.

- Alert receivers can reply to acknowledge receipt of a text along with their status via several choices. Managers may generate reports from many sources, including individuals, contact centers, and persons answering on behalf of others, and alerts are measured in real-time with complete delivery information for each receiver. Managers can evaluate a response effort after the crisis has passed thanks to this useful information.
- The risk manager might contact pertinent outside groups to work with them on their response and help it succeed. An organization won't have to handle contact details for external organizations with a simpler approach, helping to ensure you don't miss any crucial interactions.
- Oil and gas firms may keep total control over employee information, and message content, including delivery methods thanks to the solution's ability to be placed behind a firewall and other network security features. The system can also be implemented using a customized hybrid option or a public cloud.
- A correct understanding of the operation of an emergency plan.
- Accurately identifying relevant risks, challenges, and hazards.
- Resources at your facility should be evaluated and upgraded.
- Reviewing, testing, and modifying the emergency response plan for your oil and gas facility.

6. Conclusion

Because of the global impact and influence of humans, it is essential to know our resources, protect them, utilize them wisely, as well as plan for potential generations. One of the most obvious solutions to the problem of excess consumption is to just slow the rate at which supplies deplete. Lower consumption seems to have a natural negative influence on the economy; consequently, countries must aim to lower consumption rates and enable new enterprises to develop and alleviate some of the economic burden, like sustainable power and recyclable technology. The significance of natural resources in meeting the world's expanding energy demands cannot be overstated, however, the load may be shared by employing alternate energy choices such as renewables. Synthesis method, recycling of waste materials as well as bioengineering, processing science and technology, and computation technologies are all areas of study, and materials are all being researched in the petrochemical industry. Energy conservation and method advancements in timber processing and materials, pulping, cleaning, chemical recovery, paper manufacturing, regeneration, recovering, and emissions regulations are being studied in the case of forest products. In the future, biomass energy sources will be more beneficial as energy sources other than fossil fuels.

Abbreviations

GHG Green House Gas
IEA International Energy Agency
MMcf Million Cubic Feet
RES Renewable Energy Resources
TCF Trillion Cubic Feet
TCM Trillion Cubic Meter

References

[1] Swain SS, Mishra P. How does cleaner energy transition influence standard of living and natural resources conservation? A study of households' perceptions in rural Odisha, India. Energy 2021;215:119135. https://doi.org/10.1016/j.energy.2020.119135.
[2] Kremsa VŠ. Sustainable management of agricultural resources (agricultural crops and animals). In: Hussain CM, Velasco-Muñoz JF, editors. Sustainable resource management. Elsevier; 2021. p. 99–145.
[3] Abbasi KR, Shahbaz M, Zhang J, Irfan M, Alvarado R. Analyze the environmental sustainability factors of China: the role of fossil fuel energy and renewable energy. Renewable Energy 2022;187:390–402. https://doi.org/10.1016/j.renene.2022.01.066.
[4] Monir MMU, Hossain HZ. Coal mine accidents in Bangladesh: its causes and remedial measures. International Journal of Economic and Environmental Geology 2012;3:33–40.
[5] Khatun F, Monir MMU, Arham SMN, Wahid ZA. Implementation of carbon dioxide gas injection method for gas recovery at Rashidpur gas field, Bangladesh. International Journal of Engineering Technology and Sciences (IJETS) 2016;5(1):52–61. https://doi.org/10.15282/ijets.5.2016.1.7.1046.
[6] Casper JK. Energy: Powering the Past, present, and future. Infobase Publishing; 2007.
[7] Subramanian K. The crisis of consumption of natural resources. International Journal of Recent Innovations in Academic Research 2018; 2(4):8–19.
[8] IEA. World energy outlook. 2020. Available from, https://www.iea.org/reports/world-energy-outlook-2020.
[9] Tvaronavičienė M, Baublys J, Raudeliūnienė J, Jatautaitė D. Chapter 1 – global energy consumption peculiarities and energy sources: role of renewables. In: Tvaronavičienė M, Ślusarczyk B, editors. Energy transformation towards sustainability. Elsevier; 2020. p. 1–49.
[10] Zakir Hossain HM, Hasna Hossain Q, Uddin Monir MM, Ahmed MT. Municipal solid waste (MSW) as a source of renewable energy in Bangladesh: revisited. Renewable and Sustainable Energy Reviews 2014;39: 35–41. https://doi.org/10.1016/j.rser.2014.07.007.
[11] Twidell J. Renewable energy resources. Routledge; 2021.

[12] Hasan MY, Monir MU, Ahmed MT, Aziz AA, Shovon SM, Ahamed Akash F, et al. Sustainable energy sources in Bangladesh: a review on present and future prospect. Renewable and Sustainable Energy Reviews 2022;155: 111870. https://doi.org/10.1016/j.rser.2021.111870.

[13] Monir MU, Abd Aziz A, Yousuf A, Alam MZ. Hydrogen-rich syngas fermentation for bioethanol production using *Sacharomyces cerevisiea*. International Journal of Hydrogen Energy 2020a;45:18241–9. https://doi.org/10.1016/j.ijhydene.2019.07.246.

[14] Monir MU, Aziz AA, Khatun F, Yousuf A. Bioethanol production through syngas fermentation in a tar free bioreactor using *Clostridium butyricum*. Renewable Energy 2020b;157:1116–23. https://doi.org/10.1016/j.renene.2020.05.099.

[15] Arunachalam S, Fleischer E. MRS bulletin April 2008 volume 33 No. 4; harnessing materials for energy. MRS Bulletin 2008;33:261. https://doi.org/10.1557/mrs2008.60.

[16] Oliveira JFG, Trindade TCG. World energy matrix. In: Sustainability performance evaluation of renewable energy sources: the case of Brazil. Springer; 2018. p. 1–17.

[17] Finkelman RB, Dai S, French D. The importance of minerals in coal as the hosts of chemical elements: a review. International Journal of Coal Geology 2019;212:103251. https://doi.org/10.1016/j.coal.2019.103251.

[18] Wert CA, Hsieh K-C, Tseng B-H, Ge Y-P. Applications of transmission electron microscopy to coal chemistry. Fuel 1987;66(7):914–20. https://doi.org/10.1016/0016-2361(87)90329-2.

[19] Ahamed S, Monir MU, Biswas PK, Khan AA. Investigation the risk of spontaneous combustion in Barapukuria coal mine, Dinajpur, Bangladesh. Journal of Geoscience and Environment Protection 2016;4(04):74.

[20] Suárez-Ruiz I, Crelling JC. Applied coal petrology: the role of petrology in coal utilization. Academic press; 2008.

[21] Suárez-Ruiz I, Diez MA, Rubiera F. Chapter 1 – coal. In: Suárez-Ruiz I, Diez MA, Rubiera F, editors. New trends in coal conversion. Woodhead Publishing; 2019. p. 1–30.

[22] Carroll JJ. Acid gas injection and carbon dioxide sequestration. John Wiley & Sons; 2010.

[23] Speight JG. Natural gas: a basic handbook. Gulf Professional Publishing; 2018.

[24] Faramawy S, Zaki T, Sakr AAE. Natural gas origin, composition, and processing: a review. Journal of Natural Gas Science and Engineering 2016; 34:34–54. https://doi.org/10.1016/j.jngse.2016.06.030.

[25] Mokhatab S, Poe WA, Mak JY. Handbook of natural gas transmission and processing: principles and practices. Gulf professional publishing; 2018.

[26] Schoell M. Isotope techniques for tracing migration of gases in sedimentary basins. Journal of the Geological Society 1983;140(3):415–22.

[27] Papavinasam S. Corrosion control in the oil and gas industry. Elsevier; 2013.

[28] Mariano J, La Rovere E. Environmental impacts of the oil industry. LAP Lambert Academic Publishing; 2017.

[29] PETROBANGLA. Annual Report 2020. 2020. Available from: http://petrobangla.org.bd/sites/default/files/files/petrobangla.portal.gov.bd/annual_reports/b01f8121_46b5_4cd0_96be_bc5b43cb2010/2022-03-27-10-27-5bf851d9f53edf0db83f223675765243.pdf.

[30] Capuano L. International energy outlook 2020. US Energy Information Administration (EIA); 2020. Available from, https://www.eia.gov/outlooks/ieo/.

[31] Haider WH. Estimates of total oil & gas reserves in the world, future of oil and gas companies and smart investments by E & P companies in renewable energy sources for future energy needs. In: Paper presented at the international petroleum technology conference; 2020.
[32] British Petroleum Statistical Review. Statistical review of world energy. 2021. Available from: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf.
[33] Koch GH, Brongers M, Thompson NG, Virmani YP, Payer JH. Corrosion cost and preventive strategies in the United States. 2002.
[34] Okotie S, Ogbarode NO, Ikporo B. Chapter 4 — the oil and gas industry and the Nigerian environment. In: Ndimele PE, editor. The political ecology of oil and gas activities in the Nigerian aquatic ecosystem. Academic Press; 2018. p. 47—69.
[35] Papavinasam S. Chapter 1 — the oil and gas industry. In: Papavinasam S, editor. Corrosion control in the oil and gas industry. Boston: Gulf Professional Publishing; 2014. p. 1—39.
[36] Speight JG. Chapter 12 — petrochemicals. In: Speight JG, editor. Handbook of industrial hydrocarbon processes. 2nd ed. Boston: Gulf Professional Publishing; 2020. p. 511—52.
[37] Matar S, Hatch LF. Chemistry of petrochemical processes. Elsevier; 2001.
[38] Speight JG. The biofuels handbook. Royal Society of Chemistry; 2011.
[39] Clews RJ. Chapter 11 — the petrochemicals industry. In: Clews RJ, editor. Project finance for the international petroleum industry. San Diego: Academic Press; 2016. p. 187—203.
[40] Cholakov GS. Control of pollution in the petroleum industry. Pollution Control Technologies 2010;3:1—10.
[41] Hsu CS, Robinson PR. Springer handbook of petroleum technology. Springer; 2017.
[42] Speight J. Handbook of crude oil refining. Boca Raton, Florida: CRC Press, Taylor & Francis Group; 2017.
[43] Gary JH, Handwerk JH, Kaiser MJ, Geddes D. Petroleum refining: technology and economics. CRC press; 2007.
[44] Holditch S, Chianelli R. Factors that will influence oil and gas supply and demand in the 21st century. Mrs Bulletin 2008;33:317—23. https://doi.org/10.1557/mrs2008.65.
[45] Dunlap RE, Jorgenson AK. Globalization of environmental problems. In: Ritzer G, editor. The Wiley-Blackwell encyclopedia of globalization. Blackwell; 2012. https://doi.org/10.1002/9780470670590.wbeog174.
[46] Haberl H, Wackernagel M, Krausmann F, Erb K-H, Monfreda C. Ecological footprints and human appropriation of net primary production: a comparison. Land Use Policy 2004;21(3):279—88.
[47] Liu Y, Lu H, Li Y, Xu H, Pan Z, Dai P, et al. A review of treatment technologies for produced water in offshore oil and gas fields. Science of the Total Environment 2021;775:145485.
[48] Odeyemi O, Ogunseitan OA. Petroleum industry and its pollution potential in Nigeria. Oil and Petrochemical Pollution 1985;2(3):223—9.
[49] Naik B, Mohanta KL. Air pollutants and health effects at different locations in Dhaka City. European Journal of Molecular & Clinical Medicine 2020;7(6):860—8.
[50] Lewtas J. Air pollution combustion emissions: characterization of causative agents and mechanisms associated with cancer, reproductive, and cardiovascular effects. Mutat Res 2007;636(1—3):95—133.

[51] Emam EA. Gas flaring in industry: an overview. Petroleum & Coal 2015; 57(5):532–55.
[52] Ashour I, Abu Al-Rub F, Sheikha D, Volesky B. Biosorption of naphthalene from refinery simulated waste-water on blank alginate beads and immobilized dead algal cells. Separation Science and Technology 2008; 43(8):2208–24.
[53] Sonune A, Ghate RJD. Developments in wastewater treatment methods 2004;167:55–63.
[54] Silva RDCF, Almeida DG, Rufino RD, Luna JM, Santos VA, Sarubbo LA. Applications of biosurfactants in the petroleum industry and the remediation of oil spills. International Journal of Molecular Sciences 2014; 15(7):12523–42.
[55] Barbooti MM, Hamadi AS, Abdul-Razzaq A, Hussain JJE, Technology. Environmental site assessment of Al-Daura refinery-evaluation of soil pollution with petroleum products. Engineering and Technology Journal 2010;28:6016–28.
[56] Arthur JL. Mitigating the environmental effects of oil and gas exploitation: issues of compliance, Cost of Production, and Community Awareness. Journal of Power and Energy Engineering 2020;8(9):51–64.
[57] Cannon AS, Warner JC. Noncovalent derivatization: green chemistry applications of crystal engineering. Crystal Growth & Design 2002;2(4): 255–7.
[58] Bennett SJ. Implications of climate change for the petrochemical industry: mitigation measures and feedstock transitions. In: Chen W-Y, Seiner J, Suzuki T, Lackner M, editors. Handbook of climate change mitigation. Springer US; 2012. p. 319–57.
[59] Cruz AM, Steinberg LJ, Vetere Arellano A, Nordvik J-P, Pisano F. State of the art in Natech risk management. 2004.
[60] Coppola DP. Introduction to international disaster management. Elsevier; 2006.
[61] Sakib N, Hossain NUI, Nur F, Talluri S, Jaradat R, Lawrence JM. An assessment of probabilistic disaster in the oil and gas supply chain leveraging Bayesian belief network. International Journal of Production Economics 2021;235:108107.
[62] Flannery RB, Everly GS. Critical Incident Stress Management (CISM): updated review of findings, 1998–2002. Aggression and Violent Behavior 2004;9(4):319–29. https://doi.org/10.1016/S1359-1789(03)00030-2.
[63] BlackBerry. Crisis management for the oil and gas industry. 2019. Available from: https://www.blackberry.com/content/dam/blackberry-com/asset/enterprise/pdf/br-athoc-crisis-management-oil-gas-industry.pdf.
[64] petroEDGE. Crisis management & emergency response planning for the oil & gas industry. 2021. Available from: https://petroedgeasia.net/training/crisis-management-emergency-response-planning-for-the-oil-gas-industry-vilt/.
[65] Rud OP. Business intelligence success factors: tools for aligning your business in the global economyvol 18. John Wiley & Sons; 2009.

18

Noise pollution from oil, gas, and petrochemical industries

Priyanka Saha[1], Minhaj Uddin Monir[1,2,*], Shaheen M. Sarkar[3] and Azrina Abd Aziz[4]

[1]*Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh;* [2]*Energy Conversion Laboratory, Department of Petroleum and Mining Engineering, Jashore University of Science and Technology, Jashore, Bangladesh;* [3]*Department of Applied Science, Technological University of the Shannon: Midlands Midwest, Limerick, Ireland;* [4]*Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Gambang, Malaysia*

**Dr. Minhaj Uddin Monir (monir_pme@just.edu.bd)*

1. Introduction

Noise pollution is increasing globally as a consequence of industrialization, urbanization, and excessive use of vehicles [1]. It is defined any unwanted sound from the environment that is harmful to human health, animals, and plants. Environmental noise is defined in the European Union (EU) directive 2002/49/EC on the regulation of environmental noise as, "unwanted or hazardous outdoor sound caused by human activities, including noise from roads, airports, rails and industrial sites" [2]. The world health organization (WHO) on the other hand, specifies that "noise emitted from all sources except noise at the industrial workplace" (WHO, 1999) is not considered to be harmful. The European statement, however, is broader than the WHO standard since it includes industrial noise. People may develop psychological and physical illnesses as a result of disturbing loud noises and unwelcome exposure, especially if exposed continuously from multiple sources for an extended period of time [3]. It has also grown steadily as a result of modern urbanization, rapid population growth, globalization of transportation and communication networks, and the expansion of resource extraction [4–6]. Motor vehicles, which account for roughly 55% of all noise in metropolitan areas, are the main source of this pollution [7,8]. Moreover,

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00012-8

these activities are related to highway traffic contribute to this increase. Noise pollution is rapidly increasing in comparison to the previous year, owing to the increased use of various machinery in oil and gas production. It is extremely hazardous to both industrial workers and the environment. The levels of human noise exposure have been described in the literature. WHO estimates that, 10% of the world population is subjected to sound pressure levels that may cause noise-induced hearing damage [9,10]. Approximately, 10 million people in the United States have already suffered irreparable hearing impairment as a result of noise pollution, and 30–50 million peoples are badly affected on a regular basis [9]. This chapter describes various noise sources from the oil and gas industry, as well as their effects on human health and the environment with techniques for successful noise pollution prevention.

2. Parameters for measuring noise pollution

2.1 Decibel

Decibel is the most commonly used unit of measurement for noise. The word "decibel" is made up of two parts where deci comes from the "Decimus," a Latin word, which means "tenth" and the other part is bel, which honors Alexander Graham Bell, the inventor of the telephone and also concerned about deaf people's difficulties [11]. A decibel is defined by a ratio that represents a logarithmic scale in respect to a reference pressure level. On the decibel scale, near absolute silence is designated as 0 dB while a sound 15 times louder is labeled as 15 dB [11]. People may hear distinct sounds at varying frequencies ranging from 20 to 20,000 cycles per second. Infrasound refers to frequencies less than 20, whereas ultrasound refers to frequencies greater than 20,000 [11]. Human voice typically has a volume of 60 dB [3].

2.2 The pressure of sound

Sound pressure is typically expressed on a decibel scale [11,12]. It can be described using the pressure measurement unit "newton/m^2." The noise level will rise by 6 dB when it is doubled [3]. According to the Federal Highway Administration, a 1 dB change in sound intensity is scarcely detectable by humans, while fluctuations of 2–3 dB are barely noticeable. Furthermore, a 5 dB difference is easily discernible; a 10 dB difference is regarded as doubling in loudness; a 20 dB difference is regarded as dramatic; and a 40 dB difference indicates the difference between a

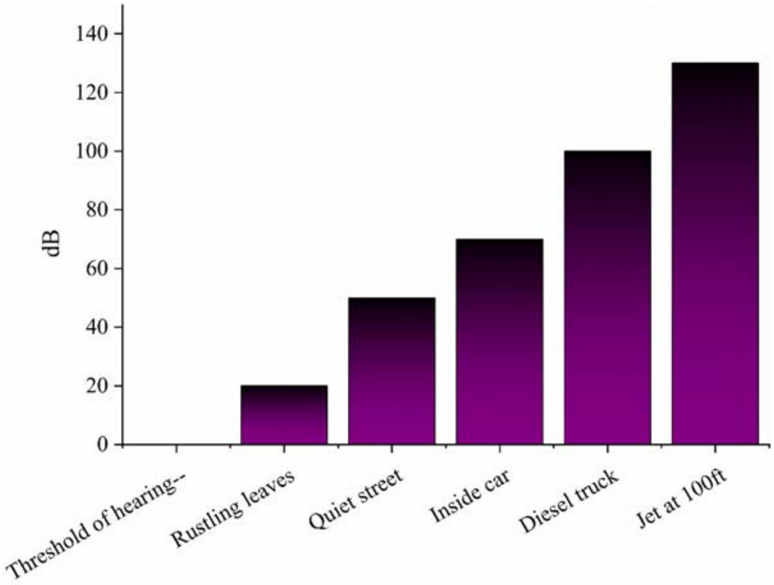


Figure 18.1 Sound pressure in decibels [11].

barely audible sound and a very loud one. As a result, it may continue to be exposed to higher sound levels that can harm our hearing distance without realizing it [13]. Fig. 18.1 represents the sound pressure in decibels from different sources.

2.3 Sound intensity

Sound intensity is defined as the quantity of acoustic energy that passes through the unit of distance from the medium to the unit of time [14]. It represents the depth of the acoustic router's and its effect on hearing sensation. Both compression and permutation waves rise when the initial "acoustic wave depth" increases and it is expressed as Watt/M^2 unit. Doubling it results in a 3 dB increase on the noise scale. It is one of the most powerful noises between 75 and 100 dB and the louder it gets, the more irritating it becomes [3].

3. Types of noise pollution

Physiological damage with some temporary contamination, chronic contamination, and temporary pollution without damage are the several types of noise pollution. It is classified by its genesis of source and its durability criteria [11,15].

3.1 Based on genesis

It is classified into two types:

- Some natural sources of noise pollution include explosions, volcanoes, and the sound of explosives.
- Human noise pollution is caused by various human-created incidents such as traffic, the sound of automobiles, and the sound of machinery from industries among others.

3.2 Based on the durability criteria

It is divided into two types:

- Chronic noise pollution: This sort of noise is more impactful than the other part since it produces permanent hearing damage.
- Temporary noise pollution: It happens in a limited time without create a permanent problem because it occurs unexpectedly [3].

4. Fundamental sources of noise pollution

Different noise sources have different directions in which their noise propagates [16]. Numerous methods of noise reduction control exist due to the variety of noise sources. First and foremost, the primary source of noise is the noise made by tens of thousands or hundreds of thousands of cars and airplanes as they take off and land, as well as other forms of transportation like trains, buses, and other vehicles that run continuously throughout the day and night on city streets [17]. Furthermore, the noise from factories affects the industrial or construction workers, which is a problem for the nearby residential area. Numerous other occupations are also characterized by excessive noise exposure, including the teaching of machinery, military personnel training in shooting and strategy, airport pilots and ground crews, traffic police, restaurant and cafe service, and military personnel. Since everyone has adapted to modern lifestyles, our houses and apartments generate a lot of noise.

Modern homes are populated with noise from appliances like washing machines, air conditioners, vacuum cleaners, dryers, audio equipment, televisions, sound recorders, and other devices. There are other external sources of noise in a house besides these internal sources. As previously stated, a significant amount of noise that enters homes is caused by street traffic, nearby businesses or offices, pedestrian walkways, construction or maintenance systems, and other factors.

Playgrounds are vital places for social interaction, but they can be noisy for the nearby homes. Finally, a number of governmental activities, such as garbage collection and street cleaning, which frequently take place at night or early the next morning, are also sources of noise. Unwanted noises are referred to as noise pollution and include singing, music, crying children, and revving engines. As a result, loud volume settings may make even enjoyable music irritating. Air conditioning units, mixers, washing machines, and drying machines are examples of native and general noise sources in cities and villages. The main fundamental sources are categorized into three ways as point source, linear source, and surface source. Table 18.1 depicts the primary fundamental sources of noise pollution.

Table 18.1 Main fundamental sources of noise pollution and their characteristics [3].

Category of sources	Pollution from individual sources	Characteristics
Point source	Machines which generated a large amount of noise. Generators and cooling machine. Object that emits sound waves in all direction.	Location of this source for adjacent surfaces. Affecting acoustic energy density values, acoustic energy levels. The levels of noise released from it.
Linear source	A busy route like a train traffic line.	The linear source, which is a collection of points that keeps traveling in a straight line, separating one another at regular intervals of equal distance. It travels at a different speed and emits.
Surface source	Noise from the explosion, drill machines, other machinery used in construction and mining. Generators. Explosive materials. Hammer sounds, tractors, and bulldozers and cement mixers.	Transmitted through this surface to adjacent areas. The noise-generating surface is the surface source if the recipient is far from the interface.

5. Overview of industrial and commercial sources of noise pollution

As it has been stated earlier, sound is defined in the medical profession as detectable energy of sound that can affect human physical and mental health without being distinguished from noise level by physical or other measuring equipment. On the basis of most developed nations have adopted laws and regulations to limit human exposure noise or sound, particularly in the industrial environment. The amount of noise exposure and the amount of time spent at work vary by industry depending on the nature of the task and the role of each individual. According to the Occupational Health and Safety Code, occupational exposure limits (OELs) are expressed by a worker's maximum allowable daily noise exposure without hearing protection in different countries [11]. OELs are calculated by using the noise exposure time in hours per day which is function of noise loudness levels measured in decibels. In that case, the most hazardous sources of noise for both site workers and residents of nearby homes are construction activities. The intensive uses of cranes, drilling machines, mixers, roads, welding, as well as the movement of tracks, equipment, and machinery from the worksite are all factors in the production of industrial noise. The engine accessories, cooling fans, handheld circular saw, brakes, and exhaust systems of a vehicle, as well as the surrounding air environment, all contribute to commercial noise. Fig. 18.2 has shown the typical noise level at commercial sites using different types of equipment, machinery, and transportation.

6. Noise emission from oil, gas, and petrochemical industries

Each stage of the oil and gas development process generates its own set of noise sources. Engines power, large air compressors, generators, the drilling rig, and hydraulic fracturing equipment during drilling and hydraulic fracturing operations all are the sources of noise [18]. These compressors, generators, and engines produce the most noise at drilling and hydraulic fracturing sites. Mud pumps are also used to circulate drilling fluid during drilling operations. It has the potential to be a significant source of noise. Traffic can create a lot of noise at all stages of an oil and gas production company, as well as in the petrochemical industry. In order to reduce noise, oil and gas companies typically

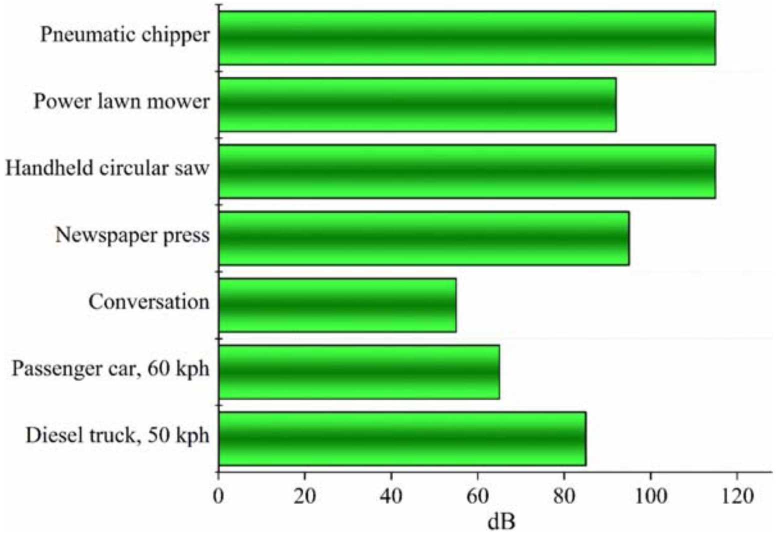


Figure 18.2 Typical noise level at commercial site [11].

erect noise barriers or noise walls to limit noise produced by drilling and fracturing activities. The height of these barriers ranges from 16 to 32 feet which means 4.9–9.8 m [19]. Production facilities for oil and gas wells can be found in a variety of zone. Residential, commercial, rural, agricultural, light industrial, and industrial zones are available in that zone [20].

6.1 Noise pollution from different oil and petrochemical industries

According to Kaduna Refining and Petrochemical Company (KRPC) which is a Nigerian petrochemical industry, the average noise level exceeded 90 dB in operational areas. At the steam let down section, the vibration signal exceeded the peak sound level of 140 dB sound pressure level [21]. 141.1 dB was the highest-level measurement that recorded from the steam let down section. As well as the Compressor Unit, which recorded the single event level of 137.8 dB and the highest measured signal of 105.8 dB. The noise level in the turbine generator room averaged 93.1 dB. 126.8 dB was the highest recorded level for a single event measurement. For this level of noise, the production process is hampered by this hazardous environment [22]. Petrochemical industries produce and use potentially hazardous compounds, some of which are poisonous, offensive-smelling, or combustible. A total of 108 noise sources were discovered, according to the Eleme

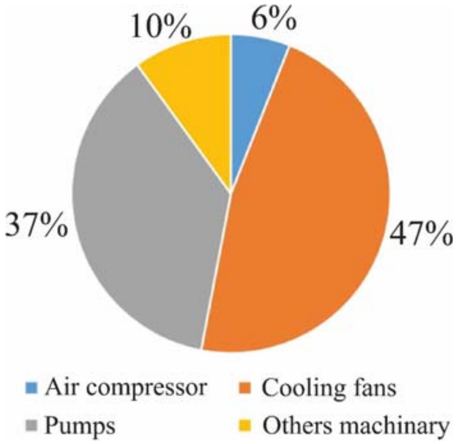


Figure 18.3 Percentage of noise from EPCL [24].

Petrochemical Company Limited (EPCL), a subsidiary of the Nigerian national petroleum corporation [23]. These sources were later divided into four categories based on the type of equipment they used: air coolers/fans (47%), pumps (37%), compressors (6%), and office spaces and other miscellaneous (10%) [24]. Fig. 18.3 shows a pie chart illustrating this percentage.

People who live or work close to petrochemical or oil-related industrial facilities as well as the accompanying transportation (heavy vehicles, tank trucks, trains, ships) may have chronic noise exposure [25]. The periodic peaks in noise levels caused by the combustion of extra gases may be heard by nearby residents. There are few field investigations of the irritation caused by fixed sources of communal noise. A petrochemical company was divided into three zones based on the volume of their noise: a safe zone (16.7%), a caution zone (74.5%), and a danger zone (8.8%) [26]. The major source of noise was discovered to be dryer machines, and the compression section of the air plant was determined to be the top priority for the implementation of noise abatement measures.

6.2 Noise pollution from gas industries

Noise is a serious issue in natural gas production. The gas compression process generates a significant amount of noise [27,28]. Natural gas must be cleaned and compressed before it can enter pipelines, and the compression process generates a lot of noise. Because these compression systems are operating continuously on site for many years, noise reduction is a top concern for landowners and manufacturing companies. Common noise sources are frequently the result of poor design. This may include the bellows or transition pieces in the air intake duct, exhaust ducts, uninsulated piping, noisy valves (with improperly chosen valve-trim), and cooling fans [27]. As an alternative, strange noise sources can also be produced by various gas production systems such as roof enclosures, booster fan, surfaces making mechanical contact, fan belts, and others. Conducting a noise evaluation early in the design process and incorporating appropriate controls into package selection is the best way to addressing noise hazards while avoiding costly revisions later. It may be challenging to comply with environmental and occupational health regulations if excessive noise levels are not taken into consideration during design, even after identifying acoustic weak points and adding appropriate controls.

7. Effect of noise pollution on human health

Numerous harmful effects on health are caused by noise. Long-term noise exposure causes hearing loss, high blood pressure and hypertension, headache, dry skin, poor vision, and an abnormal state of mind [11,29]. Furthermore, noise has both physiological as well as behavioral consequences. Unwanted sound has little effect on physiology and psychology. Noise pollution can cause annoyance and hostility, high stress levels, tinnitus, hearing loss, sleep disruptions, difficulty conversing, and productivity losses owing to poor attention. Noise pollution has an impact on human behavior, cognition, mental performance and alertness, proper sleep patterns, and student studies. Apart from these, it may have an unusual effect on the human neurological system, causing widespread harm to our health. It undoubtedly has an impact on our identity and charm, as well as our public and private behavior. Even while we sleep, many external sounds enter our brains like bullets, becoming registered on the mind's hard drive and causing superfluous mental activity. Noise in the surroundings is a major contributor to increased systolic/diastolic blood pressure, pulse rate, blood glucose levels, sweating rate, and oxygen consumption in humans [30,31].

7.1 Hearing loss

The human is heard when sound or noise enters the hearing stream through the outer ear and the ear drum membrane, and then into the hearing magnificence. The inner ear and auditory snail are made up of soft tissue that containing small beams linked with neurons that connect to the brain via the auditory nerve [32]. Sound vibrations frequently move when they reach minuscule beams. As a result, complex electrical—neuroelectric impulses connect with the brain. It analyses the beams and detects the logical noises that humans miss, but not inconsistent noises. The brain then becomes blocked. Exposure to the highly bothersome class of noise for an extended period of time can harm the brain, ears, and nervous system. Tinkers are the localized deaths of living tissue that occur as microscopic beams deteriorate over time, internal auditory targets deteriorate, and so on. Finally, hearing is harmed due to damage to the ear-forming cells [33].

There are three phases of hearing loss on the ear because of noise pollution:

- People who work in offices, labs, or crowded areas have temporary hearing loss. After a few minutes or hours, the hearing returns to normal.
- An individual reason has persistent hearing loss, which causes them to be unable to hear light or quiet conversation. As a result, they are constantly exposed to loud noises on a regular basis.
- Lifelong deafness is caused by daily and continuous exposure to extremely loud and unexpected sounds of incidents such as cannons and bomb explosions. In some cases, the eardrum is punctured, bones are broken, or sensory nerves are damaged. The inner ear balancing device is sometimes influenced by dizziness or vomiting [34].

7.2 Neurological and psychological effects

Noise places a heavy burden on the nerves, causing harm. Noise levels of 50—80 dB have an effect on the nervous system and raise the screening level of adrenal hormones in the adrenal gland, which is located on top of the kidney [31,35]. If it enters the bloodstream, it will cause even more neurodegeneration. Changes of deep sleep patterns are caused by the influences on the upper regions of the brain, especially in older people who suffer from insomnia and difficulty falling asleep again. One needs between 7 and 9 h of sleep per day for optimal physiological and mental health. It also turns out that 25 dB noise is the ideal threshold for peaceful sleep. In 2007, Russian researchers conducted a field study in the state of Zubair, Basra province. They discovered that 74.5% of respondents reported hearing noise at night and 83.9% indicated it interfered with their ability to sleep [32].

8. Preventive action to reduce noise pollution

Noise is one of the most common reasons for criticism all over the world, particularly in residential areas near highways and transit networks as well as in densely populated metropolitan regions [3]. People prefer to live away from noisy metropolitan areas, therefore homes near minor roads and away from noise sources are typically in high demand [36]. As a noise control measurement, building insulation materials such as double-window glazing and also some technical materials that absorbed noise in building walls have been utilized to prevent noise pollution [37]. Moreover, the road noise produced when an automobile's tires interact with the road surface and the amount of noise is dependent on the type of tire, tire tread designs, and the asphalt surface. Road noise can also be created by bridge decks extension joints and concrete surfaces. Vehicles driven on hilly roadways with tight curves make greater noise. Roadside vegetation, on the other hand, absorbs and moderates noise and well-kept, smooth-surfaced roadways produced less loud than fractured, broken, or patched surfaces [38]. With 10%—15% drainage asphalt porosity, 0.1—0.4 dB would be the peak noise reduction. But peak noise levels would be reduced by 0.1—1.0 dB when porosity is 20% —25% [39].

8.1 Control noise pollution of air compressor

Mufflers, silencing tunnels, and sound insulation technology are the three main methods used to reduce air compressor noise.

Install the air compressor's exhaust system:

The air compressor has a high air flow velocity and a high exhaust air pressure which creates noise. It should have a tiny hole muffler which act as a noise preventor. It is installed in the air compressor exhaust port [40].

Construct an air compressor silencing tunnel:

This tunnel is either underground or semi-underground, and its brick walls absorb sound effectively. Connect the air compressor's intake pipe to the silencing tunnel to ensure that air reaches the compressor through the silencing tunnel. Muffler tunnels are more durable than conventional mufflers and can significantly reduce the air compressor's intake noise [41,42].

Establish a sound insulation cover:

The air compressor's mechanical noise and motor noise are still quite loud, but mufflers or silencing tunnels at the intake and exhaust ports can reduce airflow noise about 80 dB. A soundproof cover should be placed over the machine's unit [43].

8.2 Control noise pollution of blasting operation

Blasting produces a lot of noise, which might bother nearby residents or other workers. The air blast overpressure needs to be controlled if blasting noise does enter a noise-sensitive area [44].

- No matter how long the gap between blows, to control the noise from any blasting operations, sound level never exceeds 115 dB peak for 9 out of every 10 consecutive explosion [45].
- For any explosion, it doesn't go beyond 120 dB peak [45].

Noise can be controlled from blasting operation is possible if the sound level can be maintained in this way.

8.3 Control noise from transportation system

Noise from traffic on the roads is caused by the kind of vehicles [46,47]. Therefore,

- Large vehicles typically make more noise than light vehicles since they have more wheels in contact with the ground and frequently employ engine brakes while slowing down. To control the noise pollution, it is essential to use light vehicles in different industry and commercial sites.
- Vehicles in poor condition, with poorly maintained brakes or incomplete exhaust systems, make more noise than properly maintained vehicles. So, it is important to using a properly manufactured transportation system in all sector [48].
- The consistency of traffic flow with regard to roundabouts, traffic signals, and stop signs. This total system should be done by a systematic way with proper administrative rules of a country.
- There should be posted speed restrictions. Because noise becomes louder at high speeds, reducing speed by half results in a 6 dB reduction in noise [11].

Improper human activities include excessive uses of vehicle horns, shouting, playing loud music and causing the squeal tires due to acceleration or sudden braking. According to WHO, a standard range of sound is proposed along with time duration in different sector (Table 18.2).

Table 18.2 Proposed range of sound in different sector [49].

Environmental noise sources	Proposed ranges of sound level (dB)	Time duration (h)
Commercial and heavy traffic zones	70	24
Services	100	40
Outdoor active zones	50—55	16
Indoor houses	35	16

9. Conclusion

Noise has been identified as a significant issue for human well-being in industrial environment. The noise level is determined by sound pressure and intensity. Noise pollution is becoming more prevalent as a result of increased traffic, commercial activities, air transportation, and the use of various machinery in industry and industrial equipment. It has a negative impact on people's neurological, mental and physical health and it increases risk of heart disease, blood pressure, sleep and thinking issues with anger levels along with other difficulties. There are some preventive actions that can be taken to reduce noise pollution, such as using sound-insulating materials in industry, maintaining machinery on a regular basis, limiting the use of explosive materials in the oil and petrochemical industries, attempting to create a limited sound that is acceptable for human health, and raising public awareness. Therefore, many research works are required to prevent noise pollution from the oil, gas, and petrochemical industries.

References

[1] Hener T. Noise pollution and violent crime. Journal of Public Economics 2022;215(1—17):104748. https://doi.org/10.1016/j.jpubeco.2022.104748.
[2] Senetra A, Szczepańska A, Wasilewicz-Pszczółkowska M. Traffic noise as a factor driving apartment prices—a case study of a large European urban agglomeration. Acoustics Australia 2014;42(1):47—50.
[3] Al-Taai SHH. Noise and its impact on environmental pollution. Materials Today: Proceedings 2021. https://doi.org/10.1016/j.matpr.2021.05.013.
[4] Francis CD, Barber JR. A framework for understanding noise impacts on wildlife: an urgent conservation priority. Frontiers in Ecology and the Environment 2013;11(6):305—13.

[5] Shannon G, McKenna MF, Angeloni LM, Crooks KR, Fristrup KM, Brown E, et al. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews 2016;91(4):982−1005.
[6] Swaddle JP, Francis CD, Barber JR, Cooper CB, Kyba CC, Dominoni DM, et al. A framework to assess evolutionary responses to anthropogenic light and sound. Trends in Ecology & Evolution 2015;30(9):550−60.
[7] Banerjee D, Chakraborty S, Bhattacharyya S, Gangopadhyay A. Evaluation and analysis of road traffic noise in Asansol: an industrial town of eastern India. International Journal of Environmental Research and Public Health 2008;5(3):165−71.
[8] Sinha S, Sridharan P. Present and future assessment of noise level in the Neyveli region. Journal of Environmental Studies and Policy 1999;2(1):1−14.
[9] Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S. Auditory and non-auditory effects of noise on health. The Lancet 2014; 383(9925):1325−32.
[10] Oishi N, Shinden S, Kanzaki S, Saito H, Inoue Y, Ogawa K. Influence of depressive symptoms, state anxiety, and pure-tone thresholds on the tinnitus handicap inventory in Japan. International Journal of Audiology 2011;50(7):491−5.
[11] Mohamed A-MO, Paleologos EK, Howari FM. Chapter 19—noise pollution and its impact on human health and the environment. In: Pollution assessment for sustainable practices in applied sciences and engineering. Butterworth-Heinemann; 2021. p. 975−1026.
[12] Svoreň J, Naščák Ľ, Koleda P, Barcík Š, Němec M. The circular saw blade body modification by elastic material layer effecting circular saws sound pressure level when idling and cutting. Applied Acoustics 2021;179:108028.
[13] FHWA. Roadway construction noise model user's guide. Federal Highway Administration; 2006. Retrieved from, www.fhwa.dot.gov/environment/noise/rcnm/rcnm.pdf.
[14] Yang X, Zhu G, Miao Y. Calibration of sound intensity instruments based on the double coupler technology. Applied Acoustics 2022;199:109008. https://doi.org/10.1016/j.apacoust.2022.109008.
[15] D'Agosto MDA. Chapter 7—noise pollution, vibration, visual intrusion, and emission of solid and liquid waste. In: Transportation, energy use and environmental impacts. Elsevier; 2019. p. 259−80.
[16] Mir M, Nasirzadeh F, Lee S, Cabrera D, Mills A. Construction noise management: A systematic review and directions for future research. Applied Acoustics 2022;197:108936. https://doi.org/10.1016/j.apacoust.2022.108936.
[17] Sheikh PA, Uhl C. Airplane noise: a pervasive disturbance in Pennsylvania Parks, USA. Journal of Sound and Vibration 2004;274(1):411−20. https://doi.org/10.1016/j.jsv.2003.09.014.
[18] Han Y, Wu H, Geng Z, Zhu Q, Gu X, Yu B. Review: energy efficiency evaluation of complex petrochemical industries. Energy 2020;203:117893. https://doi.org/10.1016/j.energy.2020.117893.
[19] Radtke C, Autenrieth DA, Lipsey T, Brazile WJ. Noise characterization of oil and gas operations. Journal of Occupational and Environmental Hygiene 2017;14(8):659−67. https://doi.org/10.1080/15459624.2017.1316386.
[20] Ferreira NN, Martins MR, Gaya de Figueiredo MA, Gagno VH. Guidelines for life extension process management in oil and gas facilities. Journal of Loss Prevention in the Process Industries 2020;68:104290. https://doi.org/10.1016/j.jlp.2020.104290.

[21] Aliyu A, Saidu S. Pattern of occupational hazards and provisions of occupational health services and safety among workers of Kaduna Refinery and Petrochemical Company LTD (KRPC), Kaduna, Nigeria. Continental Journal of Tropical Medicine 2011;5(1):1–5.
[22] Olayinka OS, Abdullahi SA. An overview of industrial employees' exposure to noise in sundry processing and manufacturing industries in Ilorin metropolis, Nigeria. Industrial Health 2009;47(2):123–33.
[23] Numbere A. Impact of natural gas project on mangrove forest in coastal communities in the Niger Delta, Nigeria: evaluation, mitigation and management strategies. Nigeria: Evaluation, Mitigation and Management Strategies 2019.
[24] Nwali E, Agunwamba J. Analysis of the environmental and socio-economic impact of noise pollution in ELEME petrochemical company limited. Nigerian Journal of Technology 2005;24(1):67–78.
[25] Álvarez Pelegry E, Bravo López M. The oil industry: challenges and strategic responses. 2018.
[26] Dehghan SF, Nassiri P, Monazzam MR, Aghaei HA, Moradirad R, Kafash ZH, Asghari M. Study on the noise assessment and control at a petrochemical company. Noise & Vibration Worldwide 2013;44(1):10–8.
[27] McCarthy E. International regulation of underwater sound: establishing rules and standards to address ocean noise pollution. Springer Science & Business Media; 2007.
[28] Son Y, Choi J, Lee S. Noise source identification of the hermetic reciprocating compressor for refrigerator. Journal of Mechanical Science and Technology 2021;35(11):4849–58.
[29] Thompson R, Smith RB, Karim YB, Shen C, Drummond K, Teng C, Toledano MB. Noise pollution and human cognition: an updated systematic review and meta-analysis of recent evidence. Environment International 2022;158:106905.
[30] Chahyadhi B, Widjanarti MP, Ada YR, Suratna FSN, Wijayanti R. Noise intensity, blood pressure, and pulse rate in textile industry workers. PLACENTUM: Jurnal Ilmiah Kesehatan dan Aplikasinya 2022;10(1):73–80.
[31] Dolan TG, Maurer JF. Noise exposure associated with hearing aid use in industry. Journal of Speech, Language, and Hearing Research 1996;39(2): 251–60.
[32] Alqatrani FSA. The old city of al Zubair. The emergence and physical reality (1571–1882 Iraq). Bulletin of Geography. Socio-economic Series 2015;(27): 17–32.
[33] Vartan ALSA, Abdallah ALYN. Noise pollution in Governoate Basrah (its sources, effects and treatment) THE. AL GHAREE for Economics and Administration Sciences 2013;9(26).
[34] Taher NH. The relationship of noise pollution to the mental health of among university students. Journal of Educational and Psychological Researches 2019;16(63).
[35] Themann CL, Masterson EA. Occupational noise exposure: a review of its effects, epidemiology, and impact with recommendations for reducing its burden. The Journal of the Acoustical Society of America 2019;146(5): 3879–905.
[36] Serkan O, Hasan Y, Murat Y, Pervin Y. Evaluation of noise pollution caused by vehicles in the city of Tokat, Turkey. Scientific Research and Essays 2009; 4(11):1205–12.

[37] Mehravaran H, Zabani S, Nabi BGR, Ghousi R, Keshavarzi SH. Noise pollution evaluation method for identification of the critical zones in Tehran. 2011.
[38] Xu D, Mohamed A, Yong R, Caporuscio F. Development of a criterion for road surface roughness based on power spectral density function. Journal of Terramechanics 1992;29(4–5):477–86.
[39] Meiarashi S, Ishida M, Fujiwara T, Hasebe M, Nakatsuji T. Noise reduction characteristics of porous elastic road surfaces. Applied Acoustics 1996;47(3): 239–50.
[40] Dandsena J, Mohapatra K, Satapathy A, Jena D. Noise control of outdoor unit of split type air-conditioner using periodic scatterers made with array of Helmholtz resonators. Applied Acoustics 2021;179:108054.
[41] Leng J, Wen Y. Environmental standards for healthy ventilation in metros: Status, problems and prospects. Energy and Buildings 2021;245:111068.
[42] Liu X, Zhao D, Guan D, Becker S, Sun D, Sun X. Development and progress in aeroacoustic noise reduction on turbofan aeroengines. Progress in Aerospace Sciences 2022;130:100796.
[43] Forouharmajd F, Nassiri P, Monazzam MR. Noise pollution of air compressor and its noise reduction procedures by using an enclosure. International Journal of Environmental Health Engineering 2012;1(1):20.
[44] Kosała K, Stepień B. Analysis of noise pollution in an andesite quarry with the use of simulation studies and evaluation indices. International Journal of Occupational Safety and Ergonomics 2016;22(1):92–101.
[45] Minimising Noise. Queensland government. 2018. Retrieved from, https://www.business.qld.gov.au/industries/mining-energy-water/explosives-fireworks/requirements/blasting/minimising-noise.
[46] Agudelo OEA, Marín CEM, Crespo RG. Sound measurement and automatic vehicle classification and counting applied to road traffic noise characterization. Soft Computing 2021;25(18):12075–87.
[47] Özen ZÜ, Tosun M, Yasa E. Investigation of the effect of traffic noise in inspection of urban-level noise: a noise analysis in Konya-Nalcaci street. Athens Journal of Technology and Engineering 2021;8(1):91–112.
[48] Münzel T, Sørensen M, Daiber A. Transportation noise pollution and cardiovascular disease. Nature Reviews Cardiology 2021;18(9):619–36.
[49] WHO. Guidelines for Community Noise. https://www.who.int/. [Accessed 29 April 2023].

19

Environmental benefits and challenges of fossil fuel replacement with clean energy

A.R. Karbassi
Department of Environmental Engineering, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

1. Introduction

In many parts of the world, a great portion of electricity supply comes from coal, oil, and natural gas-fired power plants. It should be noted that global fossil fuel emissions are mainly derived from coal, oil, and natural gas combustion. The respective global share of coal, oil, and natural gas in CO_2 emission is about 38%, 47%, and 15% [1]. Subsequently, atmospheric CO_2 content reached about 415 ppmv in 2022. The rate of increase in CO_2 emission is far behind the targets for keeping warming limits of 1.5−2°C.

Many studies have shown that the health of citizens and the associated external costs depend on the kind of power plants [2−7]. Generally, the health burdens of various power plants might be summarized as

Coal > **Oil** > **Gas** > **Hydropower** > **Nuclear** > **Solar** > **Wind**

Higher Health Risk ⟷ Lower Health Risk

Thus, the utilization of cleaner energies is inevitable to reduce global emissions of greenhouse gases (GHGs) for the improvement of health as well as combating climate change. However, cleaner technologies such as nuclear, wind, and solar are not able to address the above-mentioned issues in a short period. In many developing countries, access to reliable and cheap electricity from sources with higher greenhouse gas emissions is preferred. Thus, the attitude might vary among developed and

Crises in Oil, Gas and Petrochemical Industries. https://doi.org/10.1016/B978-0-323-95154-8.00016-5

developing countries toward the utilization of cleaner technologies (such as wind, solar, nuclear, etc.) and traditional fossil fuels (such as coal, oil, and natural gas). It should be pointed out that natural gas might be considered a good means for the transition period from fossil fuels to cleaner energies [8].

2. Low energy prices versus clean energies

As an example, Iran's electricity production could be overviewed in the context of electricity production. Iran benefits from plentiful solar radiation [9] and thus can use cleaner energies conveniently [10]. However, due to the very low fossil fuel prices [8], the development of cleaner electricity production is hindered. On the other hand, among the cleaner electricity production technologies, it might be noticed that hydropower dams are rather well developed [11] due to water scarcity in the country. Table 19.1 depicts the share of electricity generation from various sources within Iran. Though fossil-fueled power plants account for over 72% of electricity generation 60% of total fuel consumption is gas that emits about half as much CO_2 as a coal-fired power plant. It might be possible for oil-producing countries to further reduce emissions from fossil fuels by capturing the carbon dioxide and storing it in oil reservoirs. Carbon capture and sequestration could be carried out in oil-producing countries much easier than in other countries since the oil reservoirs are suitable for

Table 19.1 Share of installed capacity for electricity production in Iran (2021) [12].

Power plant type	Installed capacity (MW)	Electricity production share (%)
Gas fired	20,960	23.8
Combined cycle	34,246	38.8
Steam	15,829	18.0
Hydropower	12,442	14.1
Nuclear	1020	1.2
Scattered productions	2168	2.5
Diesel	407	0.5
Renewables (wind, solar, and small hydro turbine)	939	1.1
Total	88,011	100

underground storage. On the other hand, carbon storage might increase the efficiency of oil reservoirs in terms of reducing oil well depth. Thus lesser electricity would be consumed to pump out the oil for export and thus enhances oil recovery too [13–15].

It is therefore vital to substitute fossil fuels with cleaner energies based on the various economic conditions prevailing in developing and developed countries. The main aim would remain as stated in the context of sustainable development. There is not any doubt that developed countries such as the European community would prefer to cut their dependency on fossil fuels at a much faster rate than other countries. On the other hand, oil-producing countries may somehow stick to the traditional use of fossil fuels (the example of Iran is given in Figs. 19.1 and 19.2). Fig. 19.2 shows the gradual shift from oil to gas consumption.

2.1 Incentives

The recent reductions in the prices of wind and solar technologies will certainly leave ample incentives for oil-producing countries to supply electricity at the local level and meet oil market demand as before. Good examples are Saudi Arabia and the

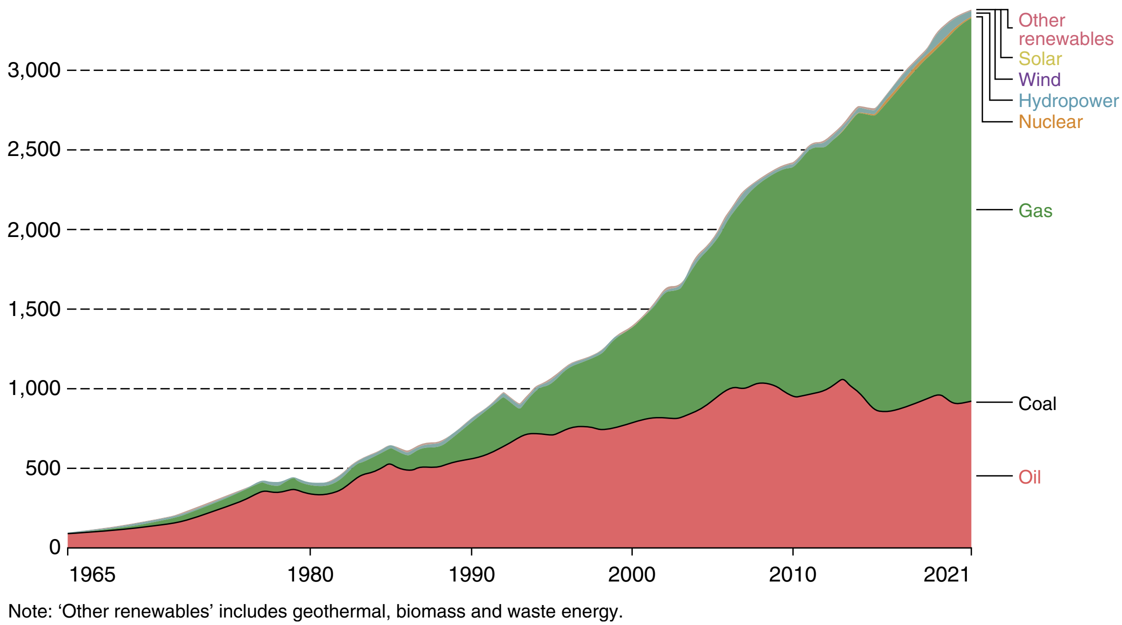


Figure 19.1 Energy consumption by source in Iran; primary energy consumption is measured in terawatt-hours (TWh) [16].

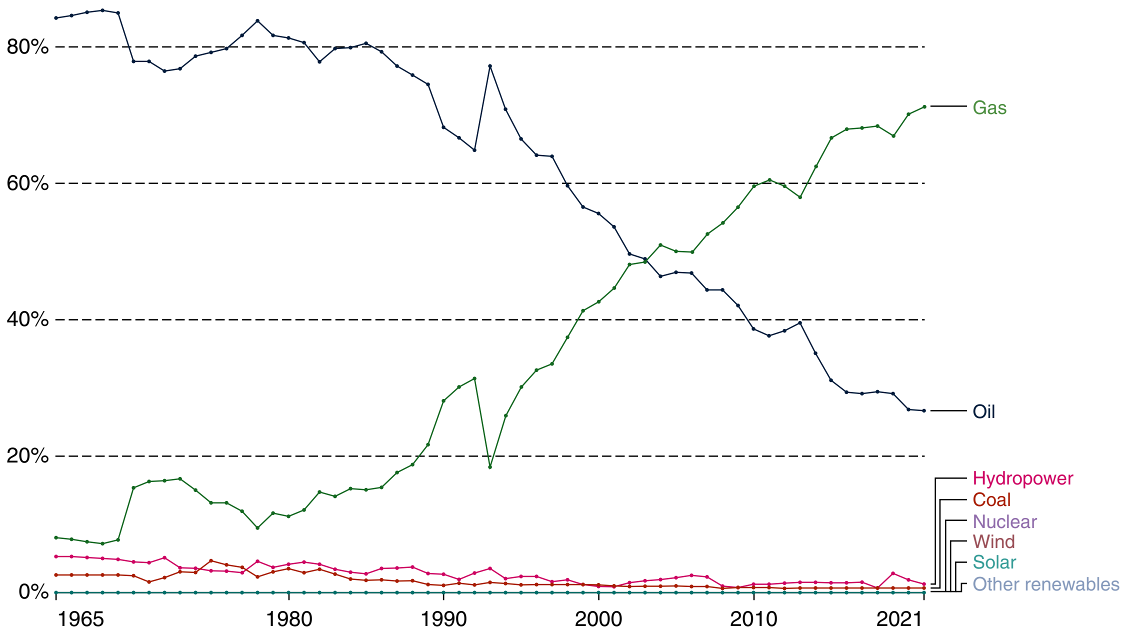


Figure 19.2 Energy consumption by source in Iran and gradual shift from oil to gas use [16].

United Arab Emirates. Saudi Arabia plans to produce 50% of the country's electricity with gas and the other 50% by renewables in the next 8 years. This would replace about one million barrels of oil equivalent to liquid fuels [17]. This huge increase in capacity will help in diversifying UAE's energy mix. The energy mix in the United Arab Emirates would significantly change by the year 2050 as follows [18]:

- 44% clean energy
- 38% gas
- 12% clean coal
- 6% nuclear.

from 7% in 2020 to 21% in 2030, and 44% by 2050. Thus, it is expected that the United Arab Emirates to significantly increase the clean energy share by 2050 (mainly by nuclear and solar energy).

2.2 Cheaper clean technologies

It should be pointed out that continuous progress in advanced technologies would result in more confidence from developing economies and even oil-producing countries for changing their energy mixes in to a cleaner one. One might conclude that the key for the final initiative would progress in storage capacity for saving renewable energies during day time so that reliable electricity could be supplied during the night times. Utilization of cleaner energies along with proper carbon capture would be the best practice for the next 25 years. By then, many fossil fuel power plants will be old enough for decommission.

It is interesting to know that utilizing cleaner energies such as solar and wind is most suitable for arid regions like Iran that are faced with water scarcity. Water is a common coolant for power plants but steam-operated power plants consume significant amounts of water. In arid regions where most rivers are seasonal, power plants cannot benefit from once-through cooling techniques, too. Though the share of biomass for heating and cooking is rather small their use will be greatly decreased as the new portable technologies advance.

3. Energy efficiency

In recent years much research has been carried out to enhance the absorption of atmospheric CO_2 by various means and at different places. These researches encompass technology and economic aspects [19—22]. However, the consequence of many methods for reducing atmospheric CO_2 is rather unknown to man [23—26]. Thus, more studies ought to be carried out to know the ecological effects of carbon capture by various means. Though such studies are long time consuming but advanced clean energy technologies are more promising.

The energy intensity in many developed countries has reached a certain level and increasing the energy efficiency of equipment is more expensive than the utilization of new renewable energy technologies. On the other hand, the energy intensity in many developing countries is so low that energy efficiency practices would be more cost-effective than the utilization of new renewable technologies. Also, subsidized energy prices do not provide enough incentives for the implementation of energy-efficient technologies. For the utilization of clean energies, the energy sector should be outsourced to the private sector in oil-producing countries as well as other developing countries. The private sector would much faster move toward the implementation of energy-efficient practices that subsequently arrives at cleaner energy technologies. If the present practices continue in developing countries, the carbon emissions will far pass the set amount and eventually, the global average temperature rises to 2°C. That level of emissions would have disastrous climate consequences for the planet [27]. There are several emission reduction opportunities for the energy sector, notably reducing the amount of energy consumed and reducing the net carbon intensity of the energy sector by fuel switching and by controlling CO_2 emissions. Thus, it might be concluded that privatization, energy efficiency practices, and cleaner energy technologies should be backed up by the right governance and peoples' attitudes toward lesser energy consumption. These should be followed by green industrial processes too.

The use of cleaner energy technology should not be confined to the electricity-producing sector. The transport sector emits more pollutants at least in developing countries where public transport is also not very active [28].

In many oil-producing countries, the majority of urban trips are made by private cars. The public buses as well as other means of transport such as the metro are not functioning well or there is a serious shortage of such means within the developing countries. The consumption of gasoline by private cars is very high due to old car-producing technologies in the absence of adequate public transport [29–32].

In developing and oil-producing countries such as Iran, the very cheap fuel in the transport sector as well low efficient cars have led to enormous air pollution and higher consumption of fuels. Presently (the year 2022), the gasoline consumption in Iran is around 100 million liters/day which reaches 153 million liters/day. The price of gasoline is around 5 US cents/liter for low octane ones and around 10 US cents/liter for high octanes. On the other hand, the fuel consumption of cars manufactured in Iran does not meet European standards and ranges from 6 to 10 L/100 km. It is predicted that gasoline consumption reaches 213 million liter/day in the year 2045 [33]. This clearly shows the necessity for the utilization of cleaner energy in the transport sector, especially in the metropolitan city of Tehran. A gradual shift from gasoline-based engines to electrical cars should be considered. The replacement of gasoline with other fuels such as methanol and ethanol could on one hand result in a decrease in CO_2 emissions and on the other hand decrease air pollution [34–36]. Alternative fuels such as methanol and ethanol cannot be considered a suitable option in arid areas like Iran where agriculture is limited due to water scarcity. Therefore, cleaner energies for the transport sector in arid regions should not be based on water consumption.

4. Climate change and policies

The natural gas that is known as the cleanest fossil fuel leaves adverse effects on the environment and possess various health problems [37–40]. It should be noted that methane in natural gas does not burn completely and some parts would be released into the atmosphere.

The proper implementation of policies toward the utilization of cleaner energies is in the need of external costs computations and enforcement. Externalities encompass uncompensated environmental or social adverse effects. In many developing countries, consumers pay for the production costs only. This might hardly be called an internal cost since some governments provide subsidies on energy costs. Table 19.2 depicts the number of subsidies on various fuel types in Iran. The first place for fuel subsidy at the world level goes to Iran (16.33% of total energy subsidy around the world) and China with 16 times the population more than Iran, stands in second place. The external cost of electricity depends on the production technology. Many studies have been carried out on the externalities of electricity production [42–45]. It might not be possible to provide a general trend on externalities since some costs in a particular place might have been incurred due to an accident.

Also, some externalities may occur due to air pollution and some others due to water and soil pollution. However, previous works show that externalities of cleaner energies (wind, solar, hydro, nuclear) are considerably lower than fossil fuels (coal, peat, oil, gas). The other important issue is the internalization of externalities that highly depends on the social, economic, and political situation prevailing in a particular country. In

Table 19.2 Fossil fuel subsidies in energy sector of Iran from the years 2010 to 2020 [41].

	Years (units: real 2020 million USD)										
Fuel	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Oil	48,057	39,866	64,051	65,035	58,832	27,576	16,771	26,988	43,171	14,785	4973
Electricity	19,062	19,073	26,316	22,656	22,040	18,788	7289	22,184	25,811	56,119	12,483
Gas	38,359	23,312	46,522	39,841	34,770	28,460	22,737	26,037	35,212	17,040	12,180
Coal	—	—	—	—	—	—	—	—	—	—	—
Total	105,478	82,252	136,889	127,533	115,644	74,824	46,797	75,209	104,194.5	87,944	29,636

many developing countries and oil-producing ones, the removal of energy subsidies provides ample revenue for government expenditures. The effect of subsidy removal vanished within a short period [46]. Thus, energy subsidy removal is not channelized into specific directions such as cleaner energy technologies or pollution control equipment. Therefore, it might be concluded that if externalities are internalized in such countries, the revenue would be spent as governments' expenditures. Internalization should have a specific aim of achieving sustainable development through the preservation of natural resources and improving the health of citizens [47–50]. Table 19.3 shows a rough average of external costs by various electricity generation techniques.

Paris climate goals might eventually lead to the phasing out of the old coal, oil, and gas power plants. To achieve the Paris climate goals many actions must be considered at a time. These actions may include energy efficiency practice, carbon capture, utilization of cleaner energy technologies, and so on. The era of phasing out dirty energies has already arrived. Unfortunately, IEA reports show that coal, oil, and gas production are growing by about 2% per year [41]. Many developing nations should be supported by wealthy oil and gas producers to replace dirty energy with cleaner ones. The costs of cleaner technologies should further be reduced to encourage widespread use of cleaner energies as well as more efficient equipment. In developing countries, energy efficiency measures should be adopted before the utilization of cleaner energy. For instance, while the transmission loss of electricity is around 8%–9% in developed countries but it may reach as high as 22%–40% in some developing countries

Table 19.3 Rough external costs of electricity generation [51].

Electricity generation technology	External cost (US$/kwh)
Various types of coal	0.03–0.14
Liquid fuel (fuel oil)	0.04–0.09
Natural gas	0.015–0.035
Various types of biomass	0.012–0.035
Electricity from hydropower dams	0.0012–0.010
Nuclear	0.0025–0.0075
Photo voltaic	0.45–0.67
Wind mills	0.06–0.30

[52,53]. The inefficient home appliances are also another area of concern. The potentials for energy saving in home appliances are many and very large [8].

Thus, one cannot expect to install valuable cleaner energy technologies and transmit the electricity with great loss. In other words, the utilization of cleaner energy technologies needs some infrastructure in terms of efficiency. Energy efficiency can be considered as free-of-cost fuel. However, the improvements in energy efficiency measures in developing countries are not fast enough to meet the climate goals (Table 19.4). It should be pointed out that energy importing countries spend a significant amount of funds on very logical energy efficiency. Energy efficiency policies ought to be mandatory in developing countries too. Unfortunately, and due to inadequate energy efficiency policy in some major economies and also higher demand growth in weaker economies, a decreasing rate of improvement in overall energy intensity has been observed in recent years [54].

4.1 Cleaner energies implementation

There are many benefits to the utilization of cleaner energies. Some of these benefits might be shortened as

- Achieving sustainable goals,
- Combating global warming,
- Improving air quality,

Table 19.4 Comparison of energy intensity as a measure of total energy supply among some selected countries/regions [54].

Country	TES/GDP (MJ/2017 USD PPP)[a]
Iran	11.12
World	4.69
Germany	2.76
Japan	3.33
Italy	2.45
Kuwait	7.4
Malaysia	4.25
Mexico	3.06
India	4.28

[a]Total energy supply/gross domestic product based on purchasing power parity.

- Saving water (especially in arid regions) when compared with steam power plants,
- Employing more labor when compared with equal investment in traditional electricity generation,
- Improving public health,
- Cheaper for importing oil countries,
- Low-cost operation,
- Higher safety during operation,
- Preservation of natural resources such as oil and gas for more useful by-products,
- Lesser external costs, and
- Reducing the costs of energy transport to conventional power plants.

It is very much obvious that the benefits mentioned above encompass many organizations' duties. For instance, the Department of Environment, the Ministry of Health and Medical Education, and the Municipality of metropolitan cities are responsible for reducing air pollution and improving the health of citizens. Thus, such organizations can fulfill their duties by allocating financial support for the implementation of cleaner energies. Employment of more labor that leads to the welfare of citizens must be supported by the Ministry of Labor and Social Affairs. Also, the government's expenditure would be reduced in many ways. Therefore, stakeholders should put a hand to hand to furnish suitable ground for the implementation of cleaner energies. Other organizations should not opine that the production of electricity is the sole duty of the Ministry of Energy. At the same time, Government should take appropriate actions such as

- Lifting the energy subsidy at a much faster rate than before,
- Implement energy efficiency measures in residential and industrial sectors,
- Privatization of the energy sector of the country,
- Improving international ties up for foreign investment and technology transfer,
- Outsourcing the cleaner energy technologies to the private sector,
- Imposing higher penalties on polluters to provide enough funds for the development of cleaner energies,
- Incorporating externalities into the energy prices,
- Developing and adequate implementation of a consistent national energy policy,
- Developing the necessary infrastructures through private sector cooperation,
- Providing adequate training to address the clean energy technology transfer,

- Allocating a specific portion of oil export revenues for the promotion of cleaner energies,
- Improving efficiencies on demand and supply sides,
- The government should work for better coordination among stakeholders,
- Renovating power transmission and distribution systems to avoid electricity losses, and
- Promotion of people's attitude toward cleaner energy use.

A general scheme of action is given in Fig. 19.3. This scheme needs to be elaborated further to include the following groups for adequate implementation of cleaner energy within the country:

- Government including concerned ministries such as
  - Ministry of Energy
  - Ministry of Oil
  - Ministry of Health and Medical Education
  - Ministry of Labor and Social Affairs
  - Department of Environment
  - Mayors of metropolitan municipalities

The barriers to the implementation of cleaner energy technologies are many and on the other hand, ample strategies and tools are available. For instance, the Government of Iran as an oil-producing country can benefit from constitutional laws and also drawing regulations (Fig. 19.4). Article 50 of the constitution law [55] states that *"The preservation of the environment, in which the present as well as the future generations have a right to flourishing social existence, is regarded as a public duty in the Islamic Republic. Economic and other activities that inevitably involve*

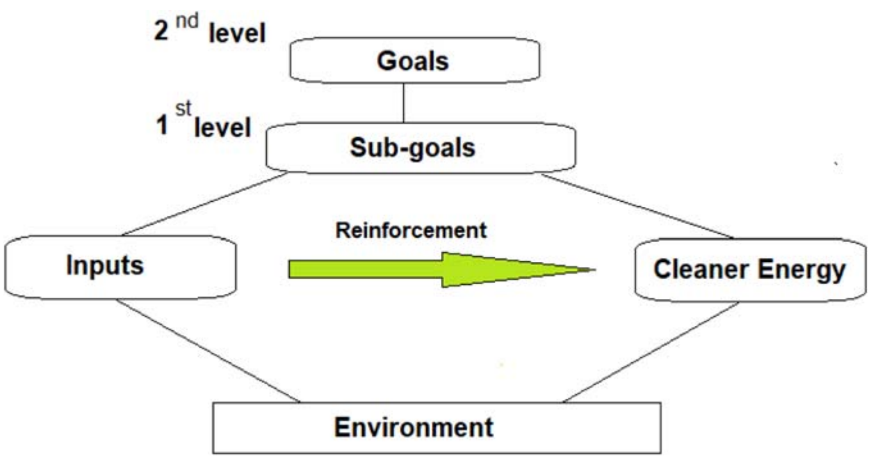


Figure 19.3 General scheme of action for implementation of cleaner energy.

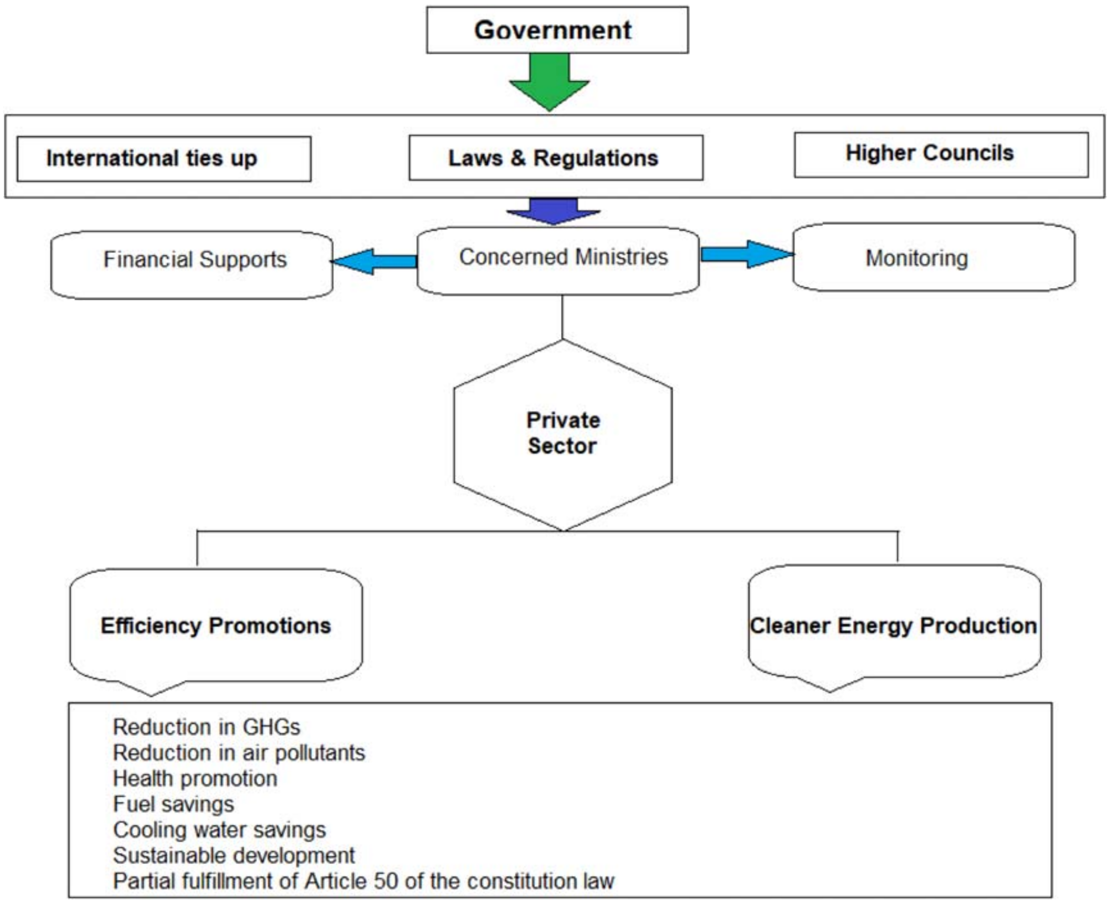


Figure 19.4 Inter-relationship among stakeholders to promote energy efficiency and cleaner energy production.

pollution of the environment or cause irreparable damage to it are therefore forbidden."

Though article 44 [55] states that "*The economy of the Islamic Republic of Iran is to consist of three sectors: state, cooperative, and private, and is to be based on systematic and sound planning. The state sector is to include all large-scale and mother industries, foreign trade, major minerals, banking, insurance, power generation, dams and large-scale irrigation networks, radio and television, post, telegraph and telephone services, aviation, shipping, roads, railroads and the like; all these will be publicly owned and administered by the State. The cooperative sector is to include cooperative companies and enterprises concerned with production and distribution, in urban and rural areas, in accordance with Islamic* *criteria. The private sector consists of those activities concerned with agriculture, animal husbandry, industry, trade, and services that supplement the economic activities of the state and cooperative sectors. Ownership in each of these three sectors is protected by the laws of the Islamic Republic, in so far as this ownership is in conformity with the other articles of this chapter, does not go beyond the bounds of Islamic law, contributes to the economic growth and progress of the country, and does not harm society. The [precise] scope of each of these sectors, as well as the regulations and conditions governing their operation, will be specified by law*"; but privatization of power plants is successfully continued in the past 2 decades. Before the year 2003, nationwide electricity was produced by the Ministry of Energy and also some large industries such as petrochemicals as well as refineries. As a result of restructuring measures in the power generation industries over 55% of installed capacity was shifted to the private sector [56]. It should be pointed out that the efficiency of electricity production was promoted after the privatization act [57].

5. Conclusion

Responsible organizations ought to allocate financial support for the implementation of cleaner energies. Stakeholders should cooperate with each other to furnish suitable ground for the implementation of cleaner energies. Production of cleaner energies should not be confined to the Ministry of Energy. Government should regulate the activities by lifting the energy subsidy and implementing energy efficiency measures in residential and industrial sectors. In this direction, Government should move toward privatization of the energy sector of the country and outsource the cleaner energy implementation to the private sector. Ample capital investment might be derived by imposing higher penalties on polluters to provide enough funds for the development of cleaner energies. Thus, externalities of the fossil fuel power plants should be internalized. The other financial aid could be mobilized by allocation of a specific portion of oil export revenues for the promotion of cleaner energies.

References

[1] IEA. Global energy review: CO_2 emissions in 2021. Paris: IEA; 2022. https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2.

[2] Cropper M, Gamkhar S, Malik K, Limonov A, Partridge I. The health effects of coal electricity generation in India. Resources for the Future Discussion Paper 2012:12–25.

[3] Lave LB, Freeburgt LC. Health effects of electricity generation. Nuclear Safety 1973;14(5):409.
[4] Lu J, Zhang C, Ren L, Liang M, Strielkowski W, Streimikis J. Evolution of external health costs of electricity generation in the Baltic States. International Journal of Environmental Research and Public Health 2020; 17(15):5265.
[5] Markandya A, Armstrong BG, Hales S, Chiabai A, Criqui P, Mima S, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: low-carbon electricity generation. The Lancet 2009;374(9706):2006–15.
[6] Markandya A, Wilkinson P. Electricity generation and health. The Lancet 2007;370(9591):979–90.
[7] Sovacool BK, Heffron RJ, McCauley D, Goldthau A. Energy decisions reframed as justice and ethical concerns. Nature Energy 2016;1(5):1–6.
[8] Karbassi AR, Abduli MA, Abdollahzadeh EM. Sustainability of energy production and use in Iran. Energy Policy 2007;35(10):5171–80.
[9] Shahsavari A, Yazdi FT, Yazdi HT. Potential of solar energy in Iran for carbon dioxide mitigation. International Journal of Environmental Science and Technology 2019;16(1):507–24.
[10] Ifaei P, Karbassi A, Lee S, Yoo C. A renewable energies-assisted sustainable development plan for Iran using techno-econo-socio-environmental multivariate analysis and big data. Energy Conversion and Management 2017;153:257–77.
[11] Tajziehchi S, Karbassi A, Nabi G, Yoo C, Ifaei P. A cost-benefit analysis of Bakhtiari hydropower dam considering the nexus between energy and water. Energies 2022;15(3):871.
[12] Bargh News. Share of installed capacity for electricity production in Iran for the year 2021. 2022. https://barghnews.com/fa/news/50599/.
[13] Plasynski SI, Litynski JT, McIlvried HG, Srivastava RD. Progress and new developments in carbon capture and storage. Critical Reviews in Plant Science 2009;28(3):123–38.
[14] Raza A, Gholami R, Rezaee R, Rasouli V, Rabiei M. Significant aspects of carbon capture and storage—a review. Petroleum 2019;5(4):335–40.
[15] Wilberforce T, Olabi AG, Sayed ET, Elsaid K, Abdelkareem MA. Progress in carbon capture technologies. Science of the Total Environment 2021;761: 143203.
[16] Our world in data; 2021. https://ourworldindata.org/energy/country/iran.ourworldindata.org.
[17] Arab News. Saudi Arabia aims to generate 50% of power from renewables by 2030. Arab News; 2022.
[18] The Information and eGovernment Sector of UAE. UAE energy strategy 2050—the official portal of the UAE government. 2022. Retrieved from, https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/federal-governments-strategies-and-plans/uae-energy-strategy-2050. [Accessed October 2022].
[19] Nocito F, Dibenedetto A. Atmospheric CO_2 mitigation technologies: carbon capture utilization and storage. Current Opinion in Green and Sustainable Chemistry 2020;21:34–43.
[20] Park JM, Yoo DK, Jhung SH. Selective CO_2 adsorption over functionalized Zr-based metal organic framework under atmospheric or lower pressure: contribution of functional groups to adsorption. Chemical Engineering Journal 2020;402:126254.

[21] Sattari A, Ramazani A, Aghahosseini H, Aroua MK. The application of polymer containing materials in CO_2 capturing via absorption and adsorption methods. Journal of CO_2 Utilization 2021;48:101526.
[22] Younas M, Sohail M, Leong LK, Bashir M, Sumathi S. Feasibility of CO_2 adsorption by solid adsorbents: a review on low-temperature systems. International Journal of Environmental Science and Technology 2016;13(7): 1839–60.
[23] Cuéllar-Franca RM, Azapagic A. Carbon capture, storage and utilisation technologies: a critical analysis and comparison of their life cycle environmental impacts. Journal of CO_2 Utilization 2015;9:82–102.
[24] Jones DG, Beaubien SE, Blackford JC, Foekema EM, Lions J, De Vittor C, et al. Developments since 2005 in understanding potential environmental impacts of CO_2 leakage from geological storage. International Journal of Greenhouse Gas Control 2015;40:350–77.
[25] Lackner KS. A guide to CO_2 sequestration. Science 2003;300(5626):1677–8.
[26] Pörtner HO. Ecosystem effects of ocean acidification in times of ocean warming: a physiologist's view. Marine Ecology Progress Series 2008;373: 203–17.
[27] Leiserowitz AA. American risk perceptions: is climate change dangerous? Risk Analysis: An International Journal 2005;25(6):1433–42.
[28] Colvile RN, Hutchinson EJ, Mindell JS, Warren RF. The transport sector as a source of air pollution. Atmospheric Environment 2001;35(9):1537–65.
[29] Atash F. The deterioration of urban environments in developing countries: mitigating the air pollution crisis in Tehran, Iran. Cities 2007;24(6):399–409.
[30] Badami MG. Transport and urban air pollution in India. Environmental Management 2005;36(2):195–204.
[31] McGranahan G, Murray F, editors. Air pollution and health in rapidly developing countries. Earthscan; 2012.
[32] Romero Y, Chicchon N, Duarte F, Noel J, Ratti C, Nyhan M. Quantifying and spatial disaggregation of air pollution emissions from ground transportation in a developing country context: case study for the Lima Metropolitan Area in Peru. Science of the Total Environment 2020;698: 134313.
[33] Karbassi AR, Abbasspour M, Sekhavatjou MS, Ziviyar F, Saeedi M. Potential for reducing air pollution from oil refineries. Environmental Monitoring and Assessment 2008;145:159–66. https://doi.org/10.1007/s10661-007-0025-4.
[34] Masuk NI, Mostakim K, Kanka SD. Performance and emission characteristic analysis of a gasoline engine utilizing different types of alternative fuels: a comprehensive review. Energy & Fuels 2021;35(6):4644–69.
[35] Vinoth Kanna I, Paturu P. A study of hydrogen as an alternative fuel. International Journal of Ambient Energy 2020;41(12):1433–6.
[36] Zhen X, Wang Y, Liu D. Bio-butanol as a new generation of clean alternative fuel for SI (spark ignition) and CI (compression ignition) engines. Renewable Energy 2020;147:2494–521.
[37] Adgate JL, Goldstein BD, McKenzie LM. Potential public health hazards, exposures and health effects from unconventional natural gas development. Environmental Science & Technology 2014;48(15):8307–20.
[38] Khan MI, Yasmin T, Shakoor A. Technical overview of compressed natural gas (CNG) as a transportation fuel. Renewable and Sustainable Energy Reviews 2015;51:785–97.
[39] Lueken R, Klima K, Griffin WM, Apt J. The climate and health effects of a USA switch from coal to gas electricity generation. Energy 2016;109:1160–6.

[40] Mouette D, Machado PG, Fraga D, Peyerl D, Borges RR, Brito TLF, et al. Costs and emissions assessment of a Blue Corridor in a Brazilian reality: the use of liquefied natural gas in the transport sector. Science of the Total Environment 2019;668:1104–16.
[41] IEA. World energy outlook 2021. Paris: IEA; 2021. https://www.iea.org/reports/world-energy-outlook-2021.
[42] Adusumilli N, Lee T, Rister ME, Lacewell RD. The economics of mitigation of water pollution externalities from biomass production for energy. Resources 2014;3(4):721–33.
[43] Bielecki A, Ernst S, Skrodzka W, Wojnicki I. The externalities of energy production in the context of development of clean energy generation. Environmental Science and Pollution Research 2020;27(11):11506–30.
[44] Brandt J, Frohn LM, Christensen JH, Andersen MS, Hertel O, Geels C, et al. Assessment of health-cost externalities of air pollution at the national level using the EVA model system. In: EGU general assembly conference abstracts; 2009, April. p. 4196.
[45] Jaramillo P, Muller NZ. Air pollution emissions and damages from energy production in the US: 2002–2011. Energy Policy 2016;90:202–11.
[46] Solaymani S. Energy subsidy reform evaluation research–reviews in Iran. Greenhouse Gases: Science and Technology 2021;11(3):520–38.
[47] Berta N, Bertrand E. Market internalization of externalities: what is failing? Journal of the History of Economic Thought 2014;36(3):331–57.
[48] Bithas K. Sustainability and externalities: is the internalization of externalities a sufficient condition for sustainability? Ecological Economics 2011;70(10):1703–6.
[49] Máca V, Melichar J, Ščasný M. Internalization of external costs of energy generation in central and eastern European countries. The Journal of Environment & Development 2012;21(2):181–97.
[50] Štreimikienė D. Review of internalization of externalities and dynamics of atmospheric emissions in energy sector of Baltic States. Renewable and Sustainable Energy Reviews 2017;70:1131–41.
[51] Saeedi M, Karbassi AR, Sohrab T, Samadi R. Power plants' environmental management. Iran organization for energy efficiency. Iran: Ministry of Energy; 2005, ISBN 964-6553-25-7. p. 331 (in Persian).
[52] Anumaka MC. Analysis of technical losses in electrical power system (Nigerian 330 kV network as a case study). International Journal of Research and Reviews in Applied Sciences 2012;12(2):320–7.
[53] Bhatti SS, Lodhi MUU, ul Haq S, Gardezi SNM, Javaid EMA, Raza MZ, Lodhi MIU. Electric power transmission and distribution losses overview and minimization in Pakistan. International Journal of Scientific & Engineering Research 2015;6(4):1108–12.
[54] IEA. SDG7: data and projections. Paris: IEA; 2022. https://www.iea.org/reports/sdg7-data-and-projections.
[55] Constitution of the Islamic Republic of Iran. Constitution of the Islamic Republic of Iran. 2021 (shora-gc.ir).
[56] Yousefi GR, Kaviri SM, Latify MA, Rahmati I. Electricity industry restructuring in Iran. Energy Policy 2017;108:212–26.
[57] Kouyakhi NR, Shavvalpour S. The driving forces of energy consumption and carbon dioxide emissions in Iran's electricity sector: a decomposition analysis based on types of ownership. Cleaner Environmental Systems 2021;2:100012.

Index

'*Note:* Page numbers followed by "f" indicate figures and "t" indicate tables.'

This page intentionally left blank

Crises in Oil, Gas, and Petrochemical Industries
Disasters and Environmental Challenges
VOLUME 1

Edited by

Mohammad Reza Rahimpour, Department of Chemical Engineering, Shiraz University, Shiraz, Iran

Babak Omidvar, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Nazanin Abrishami Shirazi, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

Mohammad Amin Makarem, Department of Chemical Engineering, Shiraz University, Shiraz, Iran

Volume 1 of the two-volume set categorizing various disasters in oil, gas, and petrochemical industries and discussing how to manage them.

Crises in Oil, Gas, and Petrochemical Industries provides an overview of both natural and manmade disasters occurring in oil, gas, and petrochemical industries and prepares special solutions based on their types.

Volume 1 on disasters and environmental challenges is a collection of chapters illustrating various disasters in oil, gas, and petrochemical industries. This includes the effects of natural disasters such as floods and hurricanes as well as manmade incidents including fire events, explosions, and release of dust and toxic substances on various related units and plants. Besides, the side effects on both humans and the environment resulting from these industries are presented. Problems such as releasing wastes and venting gases into the environment and challenges from overusing the natural resources and producing noise pollutants are discussed in detail.

Key Features

- Introduces the effect of natural disasters on oil, gas, and petrochemical industries
- Describes the effect of manmade disasters on oil, gas, and petrochemical industries
- Discusses about the long-term side effects of oil, gas, and petrochemical units on humans and the environments

Related Titles:
Rahimpour et al., Crises in Oil, Gas, and Petrochemical Industries. Loss Prevention and Disaster Management, 9780323951548

ISBN 978-0-323-95154-8

9 780323 951548

ELSEVIER elsevier.com/books-and-journals