الجمهورية الجزائرية الديمقراطية الشعبية
République Algérienne Démocratique et Populaire
وزارة التعليم العالي والبحث العلمي
Ministère de l'Enseignement Supérieure et de la Recherche Scientifique

جامعة وهران 2 محمد بن أ حمد
Universitéd'Oran 2 Mohamed Ben Ahmed

معهد الصيانة و الأمن الصناعي
Institut de Maintenance et de Sécurité Industrielle

Département de sécurité industrielle et environnement

MÉMOIRE

Pour l'obtention du diplôme de Master

Filière : Hygiène et Sécurité industrielle
Spécialité : Prévention / Intervention

Thème

Application of the Bayesian approach in the safety of a hydrogen process

Présenté et soutenu publiquement par :

ACHOUR AYMEN et **AIT-OUFEROUKH YOUNES**

Devant le jury composé de :

Nom et Prénom	Grade	Etablissement	Qualité
LOUNIS Zoubida	Professeur	IMSI	**Président**
AISSANI Nassima	MCA	IMSI	**Encadreur**
ZOUAIRI Saim	MAA	IMSI	**Examinateur**

Année 2022/2023

Remerciement

Nous remercions tout d'abord "Allah" pour nous avoir donné la force et la volonté d'élaborer ce modeste travail.

Nos remerciements spéciaux et chaleureux à nos parents qui nous ont donné tout l'encouragement et tous les moyens pendant toute la durée de nos études.

Nous voulons exprimer nos sincères remerciements à notre encadreur ***Mme. Aissani nassima*** *pour son encadrement, son soutien, ses remarques pertinentes et ses conseils judicieux qui nous ont apportés et sans oublier son encouragement et son aide précieux pour finaliser notre travail (Projet de fin d'étude).*

Nos remerciements s'adressent à toutes les personnes qui ont contribuées de près ou de loin à la réalisation de ce projet.

Nous remercions aussi tous les enseignants du département d'Hygiène et sécurité industrielle pour l'enseignement qu'ils nous ont inculqué au cours de notre cursus universitaire.

Dédicace

A mes chers parents, pour tous leurs sacrifices, leur amour, leur tendresse, leurs prières et leurs soutien moral est financière tout au long de mes études,

A toute ma famille pour leur soutien tout au long de mon parcours éducatif,

A Ait-ouferoukh younes, cher ami avant d'être binôme,

A Azzouz Mohammed et Bougouffa Mohamed

mes amis qui m'ont encouragé pendant cette difficile année.

Achour aymen

Dédicace

Je dédie ce modeste travail :

A mes chers parents. Aucun hommage ne pourrait être à la hauteur de l'amour Dont ils ne cessent de me combler. Que Dieu leurs procure une bonne santé et une longue vie.

A toute ma famille, et mes amis, A mon binôme

Achour aymen. Et tous ceux qui ont contribué de près ou de loin pour finir ce projet, je vous dis Merci.

Ait-ouferoukh younes

مُلَخَّص

تلعب وحدة التكرير بالهيدروجين دورًا حاسمًا في عملية تكرير البترول، حيث يعتمد جودة المنتجات النهائية بشكل كبير على تشغيلها الفعال. ومع ذلك، فإن الطبيعة المعقدة للوحدة وترابطها مع عوامل متنوعة تجعلها عرضة للمخاطر، بما في ذلك فشل المعدات والمخاطر الأمنية والحوادث البيئية. للحد من هذه المخاطر وضمان سير عمليات سلسة، فإن منهجية تقييم المخاطر الفعالة أمر ضروري.توفر الشبكات البايزية إطارًا قويًا لنمذجة وتحليل مثل هذه الأنظمة عن طريق تمثيل المتغيرات كعقد والعلاقات السببية كحواف موجهة. من خلال الاستدلال الاحتمالي، تُسهِّل الشبكات البايزية تقييم مخاطر النظام في الوقت الحقيقي، مع مراعاة الحالة الحالية للمتغيرات وترابطها. يتيح ذلك لصناع القرار تحديد المخاطر المحتملة بسرعة، وتوزيع الموارد بكفاءة، وتنفيذ استراتيجيات التخفيف المناسبة

Résumé

L'unité d'hydrofinissage joue un rôle crucial dans le processus de raffinage du pétrole, où la qualité des produits finaux dépend grandement de son fonctionnement efficace. Cependant, la nature complexe de l'unité et ses interdépendances avec divers facteurs la rendent sujette à des risques, notamment les pannes d'équipement, les dangers pour la sécurité et les incidents environnementaux. Pour atténuer ces risques et garantir des opérations fluides, une méthodologie d'évaluation des risques efficace est essentielle.

Les réseaux bayésiens offrent un cadre puissant pour la modélisation et l'analyse de tels systèmes en représentant les variables sous forme de nœuds et les relations de causalité sous forme d'arêtes dirigées. Grâce à l'inférence probabiliste, les réseaux bayésiens facilitent l'évaluation des risques du système en temps réel, en tenant compte de l'état actuel des variables et de leurs interdépendances. Cela permet aux décideurs d'identifier rapidement les risques potentiels, d'allouer efficacement les ressources et de mettre en œuvre des stratégies d'atténuation appropriées.

Abstract

The hydrofinishing unit plays a critical role in the petroleum refining process, where the quality of the final products greatly depends on its efficient operation. However, the complex nature of the unit and its interdependencies with various factors make it prone to risks, including equipment failures, safety hazards, and environmental incidents. To mitigate these risks and ensure smooth operations, an effective risk assessment methodology is essential.

Bayesian networks offer a powerful framework for modeling and analyzing such systems by representing variables as nodes and causal relationships as directed edges. Through probabilistic inference, Bayesian networks facilitate the assessment of system risks in real-time, taking into account the current state of the variables and their interdependencies. This enables decision-makers to identify potential risks promptly, allocate resources efficiently, and implement appropriate mitigation strategies.

Table of contents

List of figures

Chapitre I :

Chapitre II :

Chapitre III :

Chapitre IV :

List of tables

Chapitre I :

Chapitre II :

Chapitre III :

Chapitre IV :

Abbreviations list

GDP: Gross domestic product

BTU: British thermal units

UNFCCC: United Nations Framework Convention on Climate Change.

NDC: Nationally Determined Contributions

RES: renewable energy sources

LCOE: The levelized cost of energy

SEGS: The Solar Energy Generating Systems

GE: General Electric

HFI: Hydrogen Fuel Initiative

SMR: Steam methane reforming

PSA: pressure swing adsorption

POX: Partial oxidation

ATR: Autothermal reforming

PEM: Polymer electrolyte membrane

SOECT: solid oxide electrolyser cell

SOFC: solid oxide fuel cell

R&D: esearch and Development

PEC: photoelectrochemical cells

IEA: International Energy Agency

PEMFC: Proton exchange membrane fuel cells

AFC: Alkaline fuel cells

SOFC: Solid oxide fuel cells

DMFC: Direct methanol fuel cells

MCFC: Molten carbonate fuel cells

PAFC: Phosphoric acid fuel cells

EAF: Electric Arc Furnace

BLEVE: boiling liquid expanding vapor explosion

VNG: Verbundnetz Gas

HSE: Health, Safety, and Environment

PMI: Project Management Institute

ISO: International Organization for Standardization

HAZOP: Hazard and Operability

ALARP: As Low as Reasonably Practical

SFAIRP: so far as is reasonably practicable.

UK: United Kingdom

NZ: New Zealand

FMEA: failure modes and effects analysis

SWOT: Strengths, Weaknesses, Opportunities, and Threats

PHA: Preliminary Hazard Analysis

FTA: Fault Tree Analysis

P&ID: Piping and Instrumentation Diagram

PFD: Process Flow Diagram

QRA: Quantitative Risk Assessment

BN: Bayesian network

LUP: Land Use Planning

DBN: Dynamic Bayesian network

ROV: ratio of variation

MCMC: Markov Chain Monte Carlo

ETA: event tree analysis

ESD: event sequence diagrams

LFL: lower flammability limit

UFL: upper flammability limit

XFTA: extended Fault Tree Analysis

PSA: Probabilistic Safety Assessment

GUI: graphical user interface

MAU: multi-attribute utility

MS Excel: Microsoft Excel

OREDA: Offshore Reliability Data

General Introduction

General introduction

Since Henry Cavendish's recognize of hydrogen gas as a discrete substance in 1766, the history of hydrogen production has been both lengthy and fascinating. Hydrogen wasn't used as a fuel source until the early 1800s, mostly for illumination. Numerous techniques for producing hydrogen have been developed over time, including electrolysis of water, steam reforming of natural gas, and gasification of biomass.With the increased environmental awareness around the world, hydrogen has regained popularity as a clean energy substitute for conventional fossil fuels. Hydrogen is a significantly cleaner alternative that can help lower greenhouse gas emissions and mitigate the consequences of climate change because burning it only produces water.

However, when it comes to generating, storing, and distributing hydrogen, safety is a top priority. Since hydrogen is highly combustible, improper handling might result in serious risks. Due to this, there is now more interest in applying Bayesian methods to guarantee the security of hydrogen generation.

The complexity and dynamism of hydrogen safety procedures make Bayesian algorithms an excellent choice for modeling and interpreting uncertain data. By using these methods, we may develop safer precautions and more precisely assess the dangers associated with the production, storage, and transport of hydrogen.

This study aims to examine the potential of Bayesian techniques in enhancing hydrogen safety by: (1) examining the state of hydrogen safety processes at present and the difficulties in ensuring their reliability; (2) analyzing the advantages of Bayesian methods in modeling and analyzing hydrogen safety data; (3) developing a Bayesian model for hydrogen safety assessment; (4) evaluating the efficacy of the Bayesian model in improving hydrogen safety processes.

It's important to remember that hydrogen has been used for a variety of things throughout history, including as rocket fuel and in industrial activities. But it wasn't until recently that its potential as a clean energy source became clear, spurring more funding and study of hydrogen technologies.

In conclusion, this study has the potential to influence how hydrogen technology develops in the future. Our goal is to enhance the subject and offer insightful information for ongoing research by investigating the possibilities of Bayesian approaches in boosting hydrogen safety. If hydrogen is to become a practical replacement for fossil fuels, it must be produced, stored, and distributed safely. Using Bayesian approaches offers a possible option

Chapter I : Global Renewable Energy Industry And Algeria Overview

1 Introduction :

Energy is ubiquitous and propels everything. Our modern existence, both individually and collectively, have become reliant on its availability, utility, and potential. It is the driving force within our bodies that propels our vehicles and illuminates the universe. Consider a power outage or a deceased cell phone battery; even ten minutes without energy demonstrates the indelible mark it leaves on daily activities. At the same time, we inhabit a remarkable ecosystem that is both resilient and fragile. Our energy is derived from and returned to a global ecosystem **[1]**.

Biomass, which is derived from vegetation, was the sole source of energy for human evolution on Earth. The average power consumed by a human body at repose is 0.1 kW, and the average power delivered by a hard-working body is 0.4 kW. The carbon dioxide released by humans and animals was reabsorbed by plants during photosynthesis, so the consumption of plants by humans and animals had no effect on the atmosphere. The only nonliving systems that could perform mechanical work were windmills and waterwheels, which converted wind energy and hydro-power into mechanical power. Thomas Newcomen's discovery of the steam engine in 1712 gave humanity its first access to a nonliving mechanism consuming carbon or hydrocarbons and delivering mechanical power on demand. This initiated the industrialization process and completely transformed society, particularly the demand for ever-increasing amounts of energy. The energy for the steam engine was discovered in the form of mineral coal, solar energy conserved for millions of years in the Earth's crust. **[2]**

In 1860, the global energy consumption was 5×10^{12} kWh/year, whereas it is now 1.2×10^{14} kWh/year. More than 80 percent is derived from fossil fuels, such as coal, oil, and natural gas. **[3]**

Human population has increased by a factor of four over the past century, while energy demand has increased by a factor of twenty-four. The global average continuous power demand is 2 kW per person. In the United States, the average power consumption per capita is 10 kW, while in Europe it is about 5 kW **[4]**.Currently, two billion individuals on Earth do not use any fossil fuels. However, Earth's crude oil reserves are limited, and projections based on the extrapolation of energy consumption indicate that demand will soon exceed supply **[5]**.

Since 1750, as a consequence of human activities and needs, global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased significantly and now far exceed pre-industrial values determined from ice cores spanning thousands of years.

We've never had the opportunity to balance energy and the environment until now, due to a key component of what we call technology. However, is it really that simple and does it really work? And could satisfy human needs, is it safe ? asking the correct question can lead to further questions.

2 Energy :

There are numerous forms of energy. Kinetic energy is the energy available in the motion of particles (e.g., air or water in motion). Potential energy is the energy available because of the position between particles, such as water contained in a dam, spring energy, and the energy stored in molecules (gasoline). There are numerous types of energy, including mechanical, electrical, thermal, chemical, magnetic, nuclear, biological, tidal, and geothermal **[6]**. In reality, the universe contains only four generalized interactions (forces between particles): nuclear, electromagnetic, weak, and gravitational **[7]**. In other words, all forms of energy in the universe can be traced back to one of the four interactions listed in **Table 1**. This force or interaction is transmitted via an exchange particle. The exchange particles for electromagnetic and gravitational interactions have zero rest mass, so energy and information are transferred at the speed of light, $3 * 10^8$ m/s (186,000 mi/s). Even though the gravitational interaction is incredibly feeble, it is observable when large masses are present. The four interactions are an excellent illustration of how a scientific principle can be applied to a vast array of phenomena **[6]**.

Table 1 : *Information for Generalized Interactions [6].*

Interaction	Particle	Strength	Range (m)	Exchange Particle
Nuclear (strong)	Quarks	1	10^{-15}	Gluons
Electromagnetic	Charge	10^{-2}	Infinite	Photon
Weak	Leptons	10^{-6}	10^{-18}	Weakons[a]
Gravitational	Mass	10^{-39}	Infinite	Gravitons

The conversion of hydrogen nuclei into helium nuclei is the source of solar energy, which is produced by nuclear interactions at the centre of the sun. This energy is transmitted to Earth primarily by electromagnetic waves, which are also represented by particles (photons). Hydro and tides are energy caused by gravitational interaction, and geothermal energy is the result of nuclear decay and gravitational interaction.

Exponents are used to denote significant and small numbers. The exponent signifies the number of times the number is multiplied by itself or the number of places in which the decimal point must be moved. Order-of-magnitude problems, which involve approximations, benefit from powers of ten **[6]**.

$$10^3 = 10 * 10 * 10 = 1000$$

$$10^{-3} = 1/10^3 = 0.001$$

Note that the use of billions in the United States (10^9) and England (10^{12}) differs. If there is uncertainty, we use exponents or the notation for prefixes shown below:

nano	10^{-9}	**mega**	10^6
micro	10^{-6}	**giga**	10^{12}
milli	10^{-3}	**peta**	10^{15}
exa	10^{18}	**quad**	10^{15}
kilo	10^3		

1 quad = 1.055 exajoules .

3 Old school energy : struggling viewpoint

The majority of today's energy consumption is for fossil fuels, coal, and gas; whether for fundamental or industrial daily activities, they all rely on them.

However, regardless of how long fossil fuels last, their supply is finite. Demand for fossil fuels has a significant effect on the social, political, and economic interactions between nations. For instance, two-thirds of crude oil reserves are located in the Near East, but the majority of gasoline is consumed in the United States, Europe, and Japan. Long-distance transportation by means such as pipelines and tankers causes significant environmental damage **[5]**. The disparity in the distribution of resources is one of the primary causes of political instability that leads to conflict and terrorism. This is the first significant fact that compels the world to seek an energy solution that does not rely on fossil fuels but rather on limitless renewable energy.

Industrialized societies rely on energy, which is a tautology in the sense that it is self-evident. Population, gross domestic product (GDP), consumption, energy production, and pollution production are interconnected for the world and the United States. Despite having less than 5% of the world's population, the United States generates approximately 25% of the gross production, 22% of the carbon dioxide emissions, and consumes 22% of the world's energy **(Figure 1)** . The countries depicted in Figure 1 consume approximately 75% of the world's energy and generate 75% of the world's GDP and carbon emissions. The developed nations consume the most energy and generate the most pollution, primarily as a result of the rise in energy per capita. The United States has the highest energy consumption and carbon dioxide emissions per capita. The United States' energy consumption increased from 32 quads in 1950 to 101 quads in 2009. The equivalent of one quad in British thermal units (Btu) is 1015 Btu. Primarily as a result of the 1973 oil crisis, there was an increase in industrial sector efficiency. However, keep in mind that the correlation between GDP and energy consumption does not imply causation. The 1973 oil crisis demonstrated that energy consumption and gross domestic product rely heavily on efficiency. It is illuminating to contemplate how the United States' energy consumption has changed since World War II. Ask elderly people about their circumstances in the 1950s, and then compare the following to the present day **[6]** :

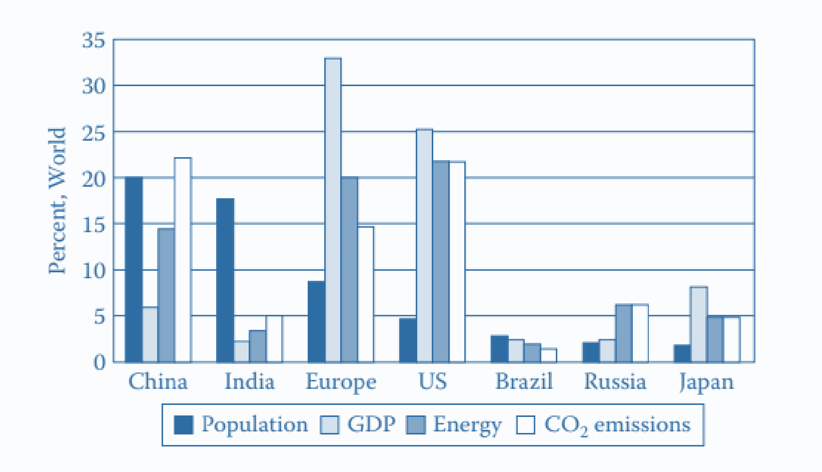


Figure 1 : *Comparisons, percentage of world, for population (rank in world), gross domestic product, energy consumption, and carbon dioxide emission. [9]*

Now, the underdeveloped portion of the world, specifically the two largest countries by population (China $1,3 * 10^9$ and India $1,1 * 10^9$), are beginning to imitate the developed countries in terms of energy consumption, material resource consumption, and greenhouse gas emissions. A significant number of villages and other rural areas in the developing world do not have electricity **[6]** .

4 Clean energy :

Solar energy is considered renewable or sustainable energy because it will continue to be available as long as the sun shines. The remaining lifespan of the sun's main stage is estimated to be between 4 and 5 billion years. Insolation refers to the electromagnetic radiation emitted by the sun. Wind, bioenergy, geothermal, hydro, tidal, and waves are the other major renewable energies. Wind energy is derived from the unequal heating of the Earth's surface due to greater heat input at the equator, accompanied by the transfer of water and thermal energy through evaporation and precipitation. In this sense, hydroelectric rivers and dams store solar energy. The third main aspect of solar energy is photosynthesis, which converts solar energy into biomass. Solar energy produces animal products such as oil from lard and biogas from manure. Geothermal energy is another form of renewable energy that derives from the decay of radioactive particles and remnant heat from the formation of the

Earth. Volcanoes are fiery manifestations of geothermal energy reaching the surface from a heated interior. The primary source of tidal energy is the gravitational interaction between the Earth and the moon. Overall, 14% of the world's energy is derived from bioenergy, predominantly wood and charcoal but also crop residue and animal dung for cooking and heating. This contributes to deforestation and soil erosion in developing nations. The production of ethanol from biomass is currently a contributor to transportation liquid fuels, particularly in Brazil and the United States. In contrast, fossil fuels are solar energy stored over geological eons. Even though the quantities of oil, natural gas, and coal are substantial, they are limited and cannot be sustained over hundreds of years **[6]**.

4.1 Net zero and hard net zero, gross zero emissions and so negative:

Net Zero emissions are the condition in which the amount of greenhouse gases released into the atmosphere is equal to the amount removed from the atmosphere. With Hard Net Zero, the balance is maintained indefinitely or for the same time period. In addition, net zero emissions still permit residual emissions in regions where reducing emissions is prohibitively expensive.

Gross Zero Emissions or Absolute Zero refers to a condition in which there are neither offsets nor removals to balance out emissions. Similar to net zero and zero emissions, Negative Emissions refers to the removal of carbon dioxide from the atmosphere, as well as its storage on land, underground, or in the oceans **[8]**.

4.2 The paris pact :

The United Nations Framework Convention on Climate Change (UNFCCC) was responsible for the creation of a legally enforceable international accord known as the Paris Pact. Its primary goals are to lower emissions of greenhouse gases and maintain a global temperature rise of no more than 1.5 degrees Celsius over pre-industrial levels. This adds new information to the body of knowledge that currently exists regarding the effects of climate change and the necessity of reducing emissions. The United governments Framework Convention on Climate Change requires that all governments provide what are known as "Nationally Determined Contributions," or NDCs. These contributions outline the actions that each nation will take to reduce emissions and adapt to the effects of climate change. The accord also recognizes the concept of "shared but differentiated duties," which states that the developed nations, which are primarily to blame for climate change and have the resources to combat it, must take responsibility while also adopting measures to reduce their own emissions taking into consideration the requirements of less developed and developing nations.The agreement also sets a system of routine assessments and modifications to ensure that national climate commitments are in line with the aim of limiting global warming to 2 degrees Celsius **[9]** .

Recent years have seen a rise in the use of renewable energy sources, also known as RES, in an effort to reduce the amount of reliance the world has on fossil fuels. **Figure 2**, which is taken from the 70th edition of the World Energy Statistical Review and depicts the rise in the production of renewable energy since 1965:

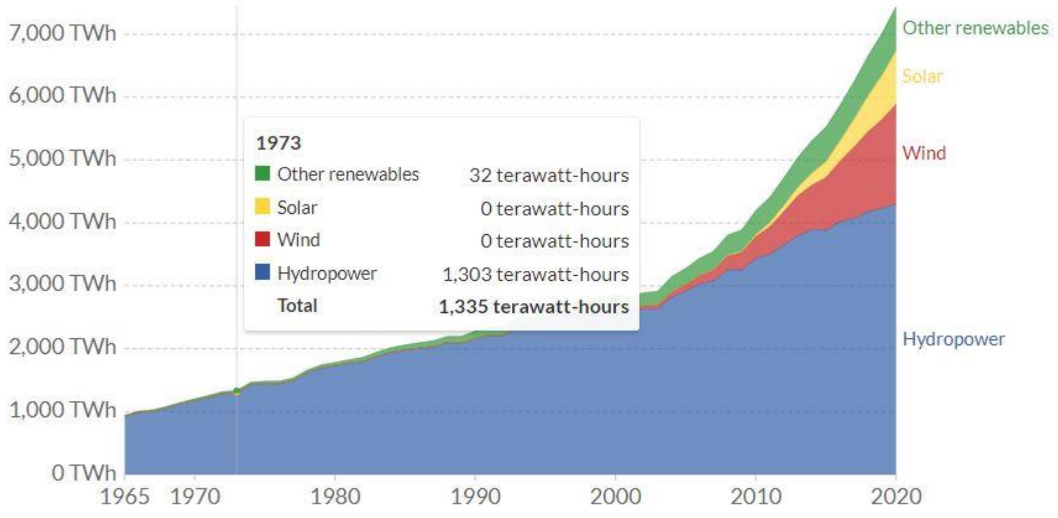


Figure 2 : *renewable energy generation around the world. [70th edition of the World Energy Statistical].*

Is placed next to **Figure 3**, which is also taken from the 70th edition of the World Energy Statistical Review and discusses the use of renewable energy around the world. Along with a growth in the use of hydro, solar, and wind power, the utilization of biomass and geothermal energy has also grown.

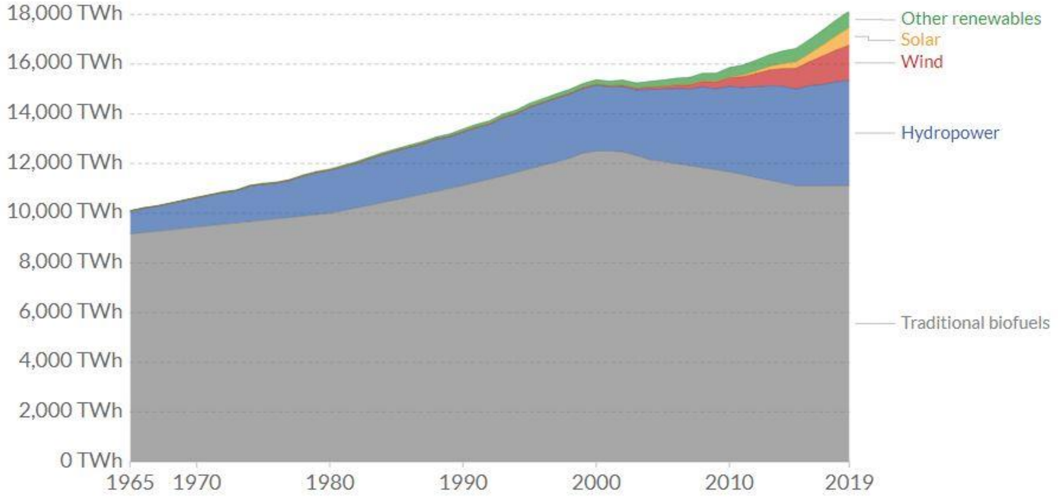


Figure 3 : *renewable energy consumption around the world. [70th edition of the World Energy Statistical].*

This increase in the use of renewable energy can be attributed to a number of factors, including governmental initiatives, technological advancements, increased public awareness of the issue, and financial incentives. All of these factors have contributed to the rise in the use of renewable energy and have helped to establish it as a viable alternative to the traditional fuels **[10]**. A significant source of clean energy such as hydropower, and during the course of the last ten years, there has been a considerable increase in the utilization of wind and solar power. Research has been done to increase the effectiveness, profitability, and long-term viability of this renewable energy source in order to make it more competitive with traditional sources of energy such as coal and oil. Governments have enacted regulations to encourage the use of renewable energy at the same time that technology breakthroughs have made it possible to generate renewable energy on a larger scale and at a lower cost. The increasing awareness among people of the environmental damage caused by fossil fuels has been another factor that has facilitated the shift toward the use of renewable energy sources.

4.3 The benefit and economic value of renewable energy:

Renewable energy has the advantages of being sustainable (nondepletable), ubiquitous (found everywhere in the world, as opposed to fossil fuels and minerals), and fundamentally nonpolluting. Note that wind turbines and photovoltaic panels do not require water for electricity generation, in contrast to fossil fuel and nuclear power facilities **[6].**

Table 2 : *Availability of Global Renewable Energy [Jacobson and Delucchi (2011)] [10]*

Energy Source	Total Global Availability (trillion watts)	Availability in Likely-Developable Locations (trillion watts)
Wind	1700	40 – 85
Wave	> 2.7	0.5
Geothermal	45	0.07 – 0.14
Hydroelectric	1.9	1.6
Tidal	3.7	0.02
Solar photovoltaic	6500	340
Concentrated solar power	4600	240

The concerns of business entities are always couched in terms of economics (money), as in "We cannot have a clean environment because it is uneconomical." The argument here is that renewable energy is not as cost-effective as coal, oil, or natural gas. We must be permitted to continue operating as we have in the past because if we are required to implement new equipment to reduce greenhouse gas emissions, we will be unable to compete with other energy sources and will be forced to reduce employment, export jobs, etc. There are three distinct categories of economics to consider: financial, social, and physical. Money is what most people consider to be economics. In light of this, we should consider life-cycle costs rather than our customary focus on reduced initial costs. Life-cycle costs refer to all expenses incurred throughout the system's lifecycle. Social economics are those endured by everyone, and many companies want the public to pay for their environmental costs. An excellent example is the use of coal in China, where social regulations for clean air are in place but not enforced. The cost will be borne in the future in the form of health issues, particularly for the children of today. Who pays if environmental issues affect someone else today or in the future? The estimated pollution costs for coal-generated electricity range from $0.005 to $0.10 per kilowatt-hour **[6]**.

In recent years, the cost advantage of fossil fuels over renewable energy sources has decreased, and certain renewable energy sources can now compete with fossil fuels solely on a financial basis. The costs of renewable energy are anticipated to decrease further in the future, while fossil fuel prices are anticipated to increase. Thus, even without policies to promote a transition to renewable energy, we are currently moving in that direction due to economic factors. The levelized cost of energy (LCOE) is calculated in order to compare the costs of various energy sources. Levelized costs are the present value of constructing and operating a facility over its assumed lifetime, expressed in real terms to eliminate the effect of inflation. For energy sources that require fuel, assumptions are made about future fuel costs. The levelized construction and operations costs are then divided by the total energy produced to facilitate direct comparisons between various energy sources. Wind and geothermal are nearly cost-competitive with conventional energy sources. Solar is more expensive, but since individual consumers can install solar photovoltaic, the price of PV need only decline to the retail power price that consumers pay, which is higher than the wholesale price **[11]**.

Among the economic benefits of investing in renewable energy mentioned in the report is the reduction of utility expenditures for individuals, businesses, and communities **[12]:**

- Generates more employment per dollar invested compared to conventional electricity generation technologies.
- Utilize predominantly indigenous resources so that the majority of energy dollars can be retained domestically.
- Strengthening the region's economic foundation, thereby reducing the tax burden on individual taxpayers.
- Contribution of greater tax revenue than conventional energy sources for producing the same quantity of energy.
- Paying salaries to employees and contributing to local economies are also included.
- Injecting income and employment opportunities into rural communities.
- Landowners can generate additional income through lease agreements.
- Rejuvenation of rural America through biomass energy initiatives.
- The development of dedicated energy crops for biomass power plants over the next 15 years, resulting in the creation of new employment.

- The rising demand for electricity in developing nations can continue to generate employment opportunities for American workers.

Through this report, which examines the United States of America, we can project numerous facets of Algeria's experience and accomplish a great deal within this context. Algeria is rich in many climatic and economic conditions, which can be viewed as a vibrant youthful experience and a genuine opportunity to lead in this door. And can be sited in this a number of reasons:

- Algeria has abundant natural resources for renewable energy, including a long coastline spanning the Mediterranean Sea and Greater Sahara. These natural resources are optimal for wind and solar power generation.
- Algeria has one of the greatest rates of solar availability in the world, with over 3,000 hours of solar light per year. In addition, the country features intense winds in various regions, particularly along the coast and in mountainous regions. These natural resources can be utilized to generate sustainable and environmentally friendly electricity.
- The Algerian government places a high priority on the development of the renewable energy sector in an effort to diversify energy sources and reduce reliance on fossil fuels. In order to generate approximately 27% of electricity from renewable sources by 2030, a national renewable energy strategy has been developed.
- Large market: Algeria's energy market is large and expanding. Due to economic and population growth, there is a rising demand for electricity in the country, which necessitates substantial investments in the renewable energy sector.
- Algeria is currently undergoing extensive economic reforms intended to improve the investment climate and encourage the formation of new businesses. Efforts have been made to streamline bureaucratic procedures and enhance tax and renewable energy legislation. These reforms create an environment conducive to investment and mitigate trade and legal risks.
- The increasing demand for electricity in Algeria, as a result of population growth and economic development, creates export opportunities. In addition, Algeria could benefit from exporting renewable electricity to neighboring nations, particularly Europe. Algeria participates in the "Mediterranean Rena +" initiative, which promotes regional cooperation in the field of renewable energy.
- Investing in renewable energies in Algeria is an opportunity to contribute to environmental preservation and the reduction of carbon emissions. Rather than relying on fossil fuels, electricity can be generated from renewable and pure sources, contributing to an improvement in air quality and a decrease in pollution.

On the basis of these factors, Algeria can be said to offer significant investment opportunities in the renewable energy sector and to foster the development and implementation of sustainable energy projects.

Algeria requires ever-increasing amounts of electricity due to rising demand and an expanding population. Not only to cover its daily power deficits, but also to foster economic growth. According to a previous report, Algeria's energy consumption is divided among three sectors: industrial (24%), transportation (33%), and residential and services (43%) **[13]**.

The residential sector (including agriculture) utilizes the greatest amount of energy (43%), followed by the transportation sector (36%) and the industry sector (21%). The following table provides more specific numbers.

Table 3 : *Final energy consumption in Algeria in 2012 and 2013 by sector (ktoe) [14].*

Sector	2012	2013	Change in %
Industry	7,939	8,229	+3.7
Transport	13,371	13,889	+3.9
Residential	15,068	16,425	+9.0
Total	36,377	38,543	+6.0

Additionally, Algeria has established a green momentum by initiating an ambitious program to develop renewable energies and promote energy efficiency. This program relies on a strategy centered on the development and expansion of the use of nonrenewable resources, such as solar energy, to diversify Algeria's energy sources and prepare it for the future. Between 2011 and 2030, the program will construct up to 22,000 mW of power-generating capacity from renewable sources, of which 12,000 mW will be used to meet domestic electricity demand and 10,000 mW will be exported **[14]**.

4.4 Types of renewable energies:

4.4.1 Solar Energy:

The energy we receive from the sun can be a thousand times greater than what is required to power the entire planet. Today, we have access to everything that can be powered by photovoltaic cells **[15]**.

There is a strong likelihood that we will be driving and strolling on solar roads in the future. All of this, however, is only feasible if the solar panels receive sufficient sunlight or at least daylight. Therefore, it may not be applicable in all regions of the globe **[15]**.

Now that we have the technology to efficiently harness solar energy, it can significantly reduce our reliance on fossil fuels. Looking at it in terms of utilization, it is environmentally friendly and reduces energy costs in the long run. In the short term, it drastically reduces your energy costs **[15]**.

Nonetheless, solar energy is highly utilized in many regions of the globe. In 2018, solar photovoltaics produced slightly more than 2% of the world's electricity, or approximately 505 gigawatts of power **[15]**.

Figure 4 : *The Solar Energy Generating Systems (SEGS) solar trough farm at Kramer Junction, California.*

Solar energy sources are prohibitively expensive, which is a drawback of their immediate implementation. Despite the long-term benefits, the costs appear unrealistic **[15]**.

Installed Solar PV Capacity:

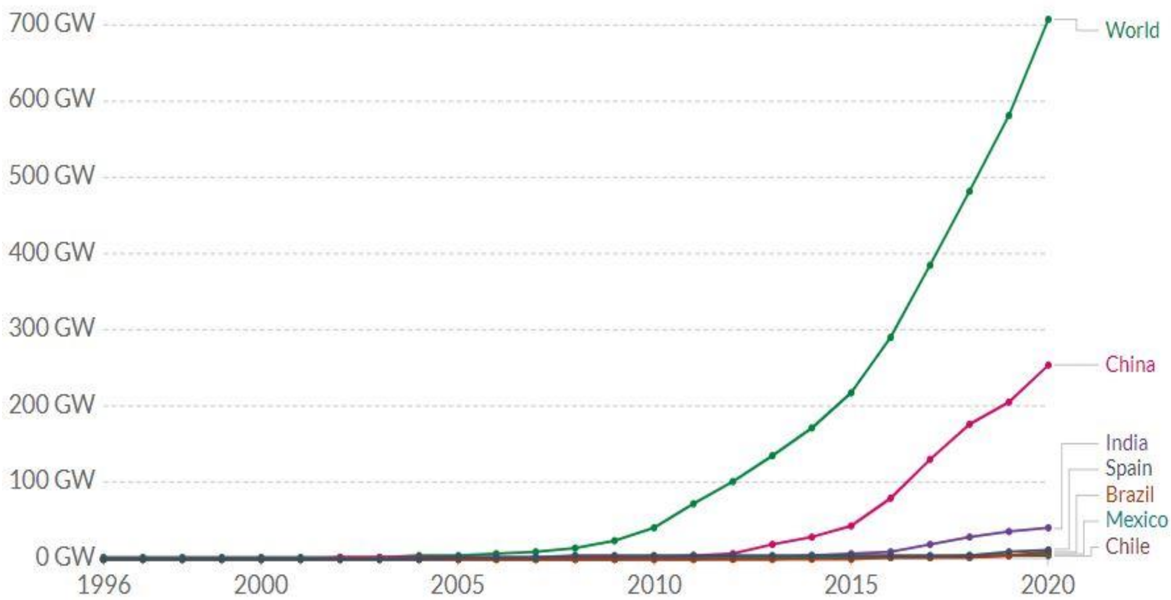


Figure 5 : *Cumulative installed solar capacity from 2008 to 2020, measured in gigawatts (GW). Sources: Our World in Data and BP Statistical Review of Global Data (2021).*

Solar PV Consumption:

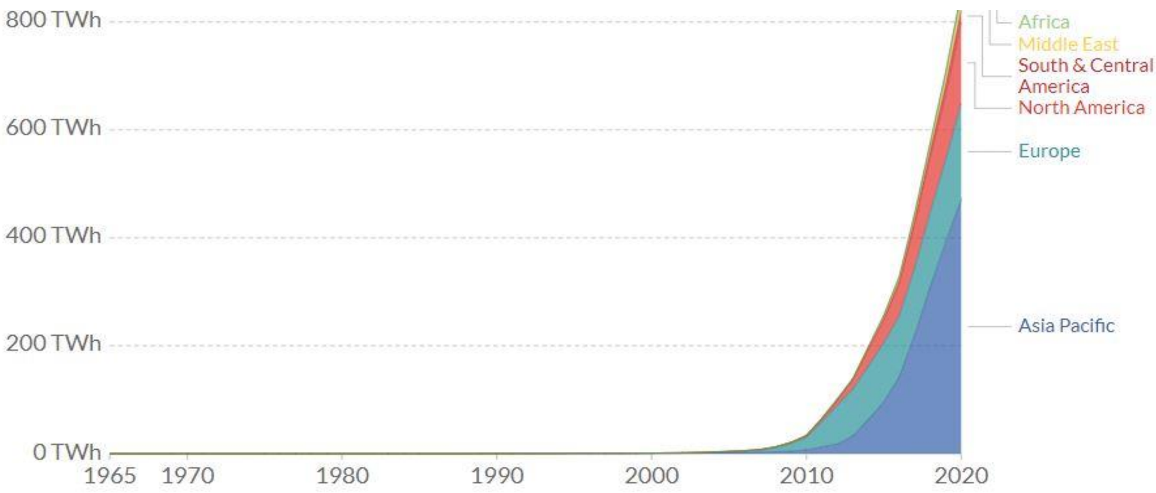


Figure 6 : *Solar energy generation by region from 1980 to 2020, measured in terawatt-hours (TWh) per year. Sources: Our World in Data and BP Statistical Review of Global Energy (2021).*

Solar capacity in Algeria:

Two primary technologies comprise solar energy: solar thermal and photovoltaics (or PV). The use of solar thermal technology can generate both heat and electricity. Approximately 169,440TWh/year, which is equivalent to 5000 times the country's current energy consumption, could be captured and used to support various applications **[16]**.

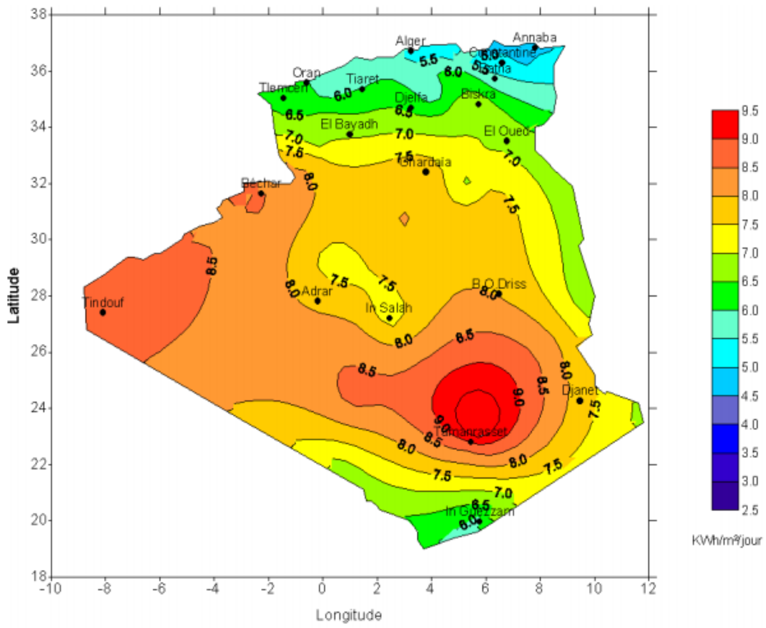


Figure 7 : *Monthly mean direct solar radiation in Algeria (for the monthly mean direct solar radiation in Algeria (for the month of April), [19].*

Solar panels convert solar radiation directly into electricity. This technology is utilized globally and is regarded as a well-developed and mature technology. Algeria's PV capacity is estimated to be 13,900TWh/year **[16]**. The annual average amount of solar in Algeria is estimated to be 2,000 hours, or 6.57 kWh/m2/day, Algeria, with a territory consisting of 86% of the Sahara Desert and due to its geographical location, is the area with the most sunshine and is endowed with an abundance of solar energy. Algeria has the opportunity to effectively utilize this natural resource, promoting a clean environment and developing renewable energy technologies in the region**[17]**. In comparison to natural gas, the energy capacity of the Algerian sun is equivalent to 37,000 billion cubic meters, or eight times the country's natural gas reserves **[18]**, with the difference that solar capacity is renewable. The accompanying table and graph illustrate the capacity of solar energy in Algeria, broken down by region.

4.4.2 Wind Energy :

Wind, like the sun, is a formidable source of energy. Essentially, it is a form of photovoltaic energy. It is the second-largest source of energy for generating electricity. Wind energy is generated by wind turbines that power generators that supply the grid with electricity. In addition, there are also turbines for private use that are not connected to the grid **[15]**.

Wind energy is the most environmentally friendly option. It is a clean energy source, meaning it does not contaminate the atmosphere. It does not emit pollutants or hazardous substances that have the potential to harm the environment or human lives **[15]**.

Numerous governments have already begun investing in wind energy. In addition to the benefits of utilizing this energy source, it also generates numerous employment opportunities over time. Wind turbines necessitate service and maintenance, thereby creating jobs and possibly training for those positions **[15]**.

To install a private wind turbine, you must be situated in an area with sufficient wind to turn the turbine's rotor. Wind is a reliable source of energy that can even be used as a substitute for solar energy because it is readily available everywhere **[15]**.

Global wind energy production capacity is 591 GW, of which 5% was generated in 2018. The scale and capacity of wind turbines have steadily increased over time. Numerous onshore turbines can generate between 2 and 5 MW of power **[15]**.

Meanwhile, offshore variants are capable of producing 12 MW. In the future, it is anticipated that some turbine models will generate more than 14 MW of electricity in offshore projects **[15]**.

In addition, offshore wind energy is expected to continue to grow strongly over the coming years, with estimates of 130-140 GW of capacity by 2035.

Installed Wind Capacity:

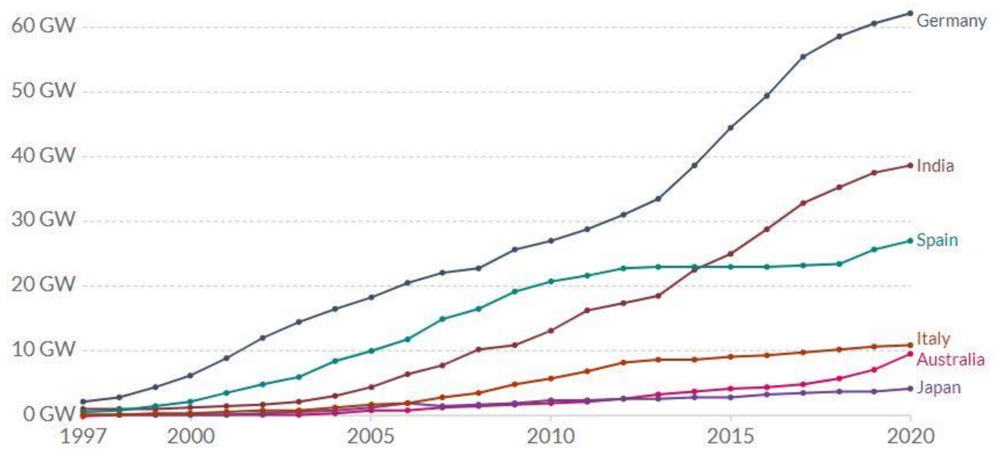


Figure 8 : *Installed wind energy capacity from 1997 to 2020, measured in gigawatts (GW). Sources: Our World in Data and BP Statistical Review of Global Energy (2021).*

Wind power capacity in Algeria:

Algeria's wind capacity is moderate, with velocities ranging between 2 and 6 meters per second.This energy capacity is optimal for pumping water to the plains but inadequate for large commercial endeavors. The most promising sites are located in the southern region of Adrar, north-west of Oran, between the Meghres in Biskra and El Kheiter in Tiaret. A number of coastal locations have average wind velocities above 5 m/s, which increase to more than 8.5 m/s at 80m **[14]**.

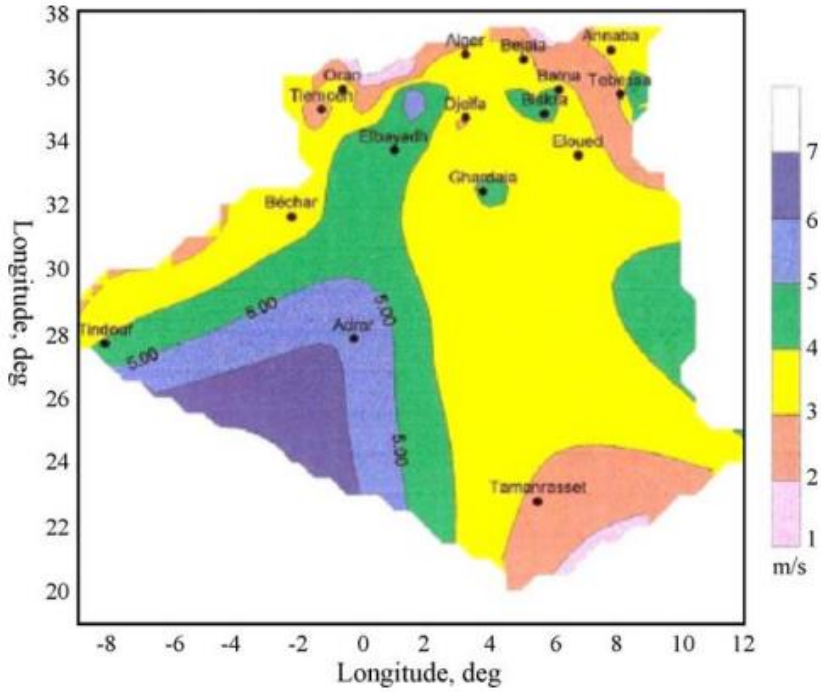


Figure 9 : *Wind map evaluation in Algeria [20].*

4.4.3 Hydro Energy:

Among all renewable energy sources, hydropower is unquestionably the most popular and widely employed **[15]**.

Both large-scale and small-scale hydropower initiatives can generate electricity. While hydropower is non-polluting, highly dependable, and capable of producing potent and useful energy, it may disrupt aquatic biodiversity **[15]**.

However, it is extremely reliant on cascading water, where there is little aquatic life. It is an excellent option for remote locations where other power sources cannot be utilized **[15]**.

In 2018, hydropower accounted for 4,210TWh of the total 26,700TWh of global electricity production **[15]**.

Hydro-electric Capacity in Algeria:

In Algeria, there is limited unused capacity. However, there is a modest capacity that could be expanded. In addition, there are several wind barriers on Algerian rivers, but they are primarily used for irrigation and potable water, and electricity production is limited. The ratio of hydraulic capacity to electric capacity **[14]**.

Hydroelectric Power Consumption:

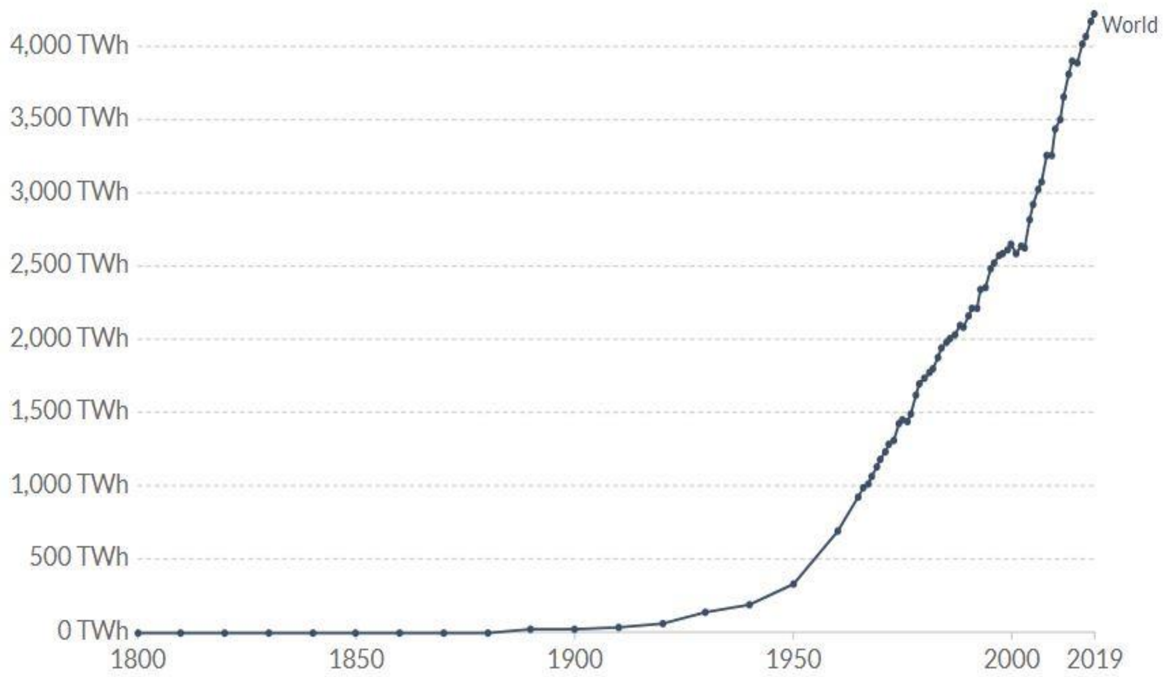


Figure 10 : *Global hydroelectric power consumption from 1900 to 2019, measured in terawatt-hours (TWh). Sources: Our World in Data, BP Statistical Review of Global Energy (2020).*

Hydropower Generation by Region:

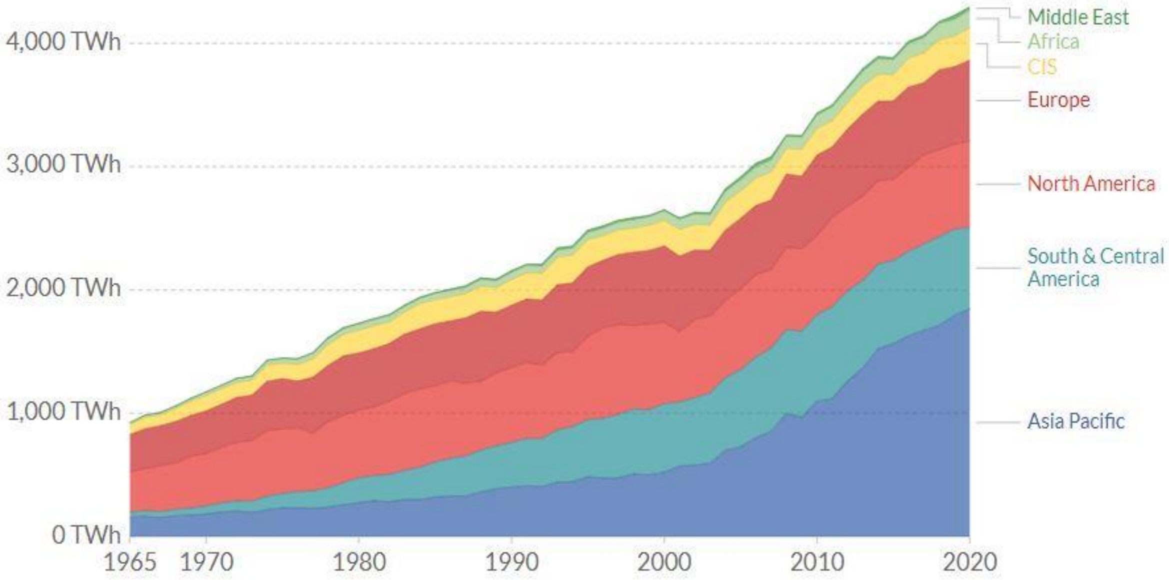


Figure 11 : *Hydropower generation by region from 1965 to 2020, measured in terawatt-hours (TWh). Sources: Our World in Data and BP Statistical Review of Global Energy (2021).*

4.4.4 Geothermal Energy :

Geothermal energy refers to the heat energy that is derived from the Earth's interior. Geothermal energy is derived from shallow ground, heated water, hot rock buried deep within the Earth, and molten rock called magma **[15]**.

Through the fissures in the earth, steam or heated water is naturally produced. When this form of steam or hot water cannot escape, it is gushed out through holes drilled in it. Due to the high supressed pressure, the connected generators' turbines rotate, resulting in the production of electricity **[15]**.

In 2018, geothermal energy generated an estimated 175 TWh of electricity. Half was in the form of electricity and half was in the form of heat. The former had a capacity of 13.3 GW, while the latter had a capacity of 26,700TWh **[15]**.

Geothermal energy is derived from the Earth's interior and can be obtained from the following sources :

- Shallow ground
- Heated water
- Hot rock buried deep within the Earth
- Molten rock called magma

Geothermal energy is an important source of renewable energy that can be used to reduce greenhouse gas emissions.

Installed Geothermal Capacity:

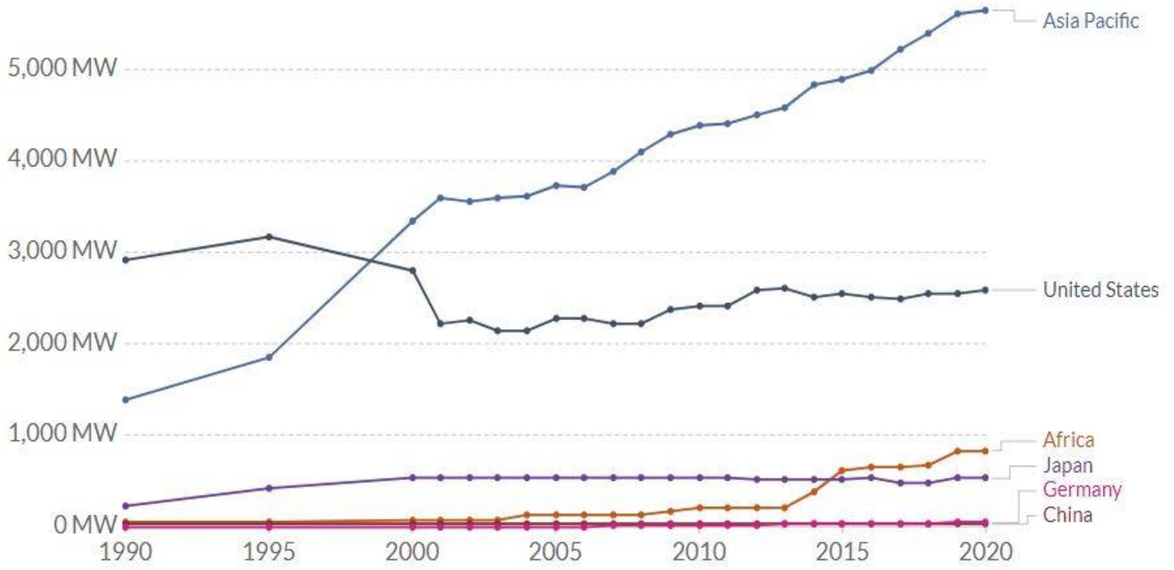


Figure 12 : *Installed geothermal energy capacity from 1990 to 2020, measured in megawatts (MW). Sources: Our World in Data and BP Statistical Review of Global Energy (2021).*

Geothermic Capacity In Algeria:

Algeria has a substantial geothermal capacity, estimated at 700MW in terms of electricity production. More than 200 heat sources have been identified in the country's north, of which nearly a third (33%) have a temperature above 45° C. Some Hamman Meskoutine sources have temperatures that can reach 96 degrees Celsius. Further south, the nation possesses a vast geothermal reservoir that spans several thousand square kilometers. This reservoir is referred to as the "Albian Water Table" and has an average temperature of 57 degrees Celsius **[14]**.

4.4.5 Biomass Energy :

Biomass energy is a type of energy derived from solid vegetative matter. Biomass generates electricity through the combustion of organic matter. However, it doesn't include burning wood. Consequently, it is considerably less polluting than using nonrenewable resources **[15]**.

Biomass converts agricultural, industrial, and domestic waste into fuels in all three forms of matter and provides energy at a much lower cost and without harming the environment. Biomass energy production creates carbon dioxide. However, plants consume the same quantity of carbon dioxide, resulting in an atmosphere that is balanced **[15]**.

In 2017, biomass accounted for 5% of the total energy used in the United States. Therefore, not only is biomass optimal for personal use, but it is also effective for commercial use. However, biomass energy has both advantages and disadvantages **[15]**.

In 2017, biomass accounted for 5% of the total energy used in the United States. Therefore, not only is biomass optimal for personal use, but it is also effective for commercial use. However, biomass energy has both advantages and disadvantages **[15]**.

Figure 13 : *Biomass Energy [15].*

In 2017, biomass accounted for 5% of the total energy used in the United States. Therefore, not only is biomass optimal for personal use, but it is also effective for commercial use. However, biomass energy has both advantages and disadvantages **[15]**.

Typically, one ton of trash can generate between 550 and 750 kWh of electricity. According to 2018 data, biomass was capable of producing 130GW worldwide. In the same year, the United States had the capacity to generate 16 GW of electricity from biomass **[15]**.

Biomass Capacity IN ALGERIA:

Forest areas cover about 250 million hectares in Algeria, which is less than 10% of the country's total area. The total capacity of biomass is estimated to be 37 mtep, of which approximately 10% could be recovered. 5 million tons of agricultural and municipal waste **[14]**.

Barriers to renewable energy development in Algeria:

The full potential and benefits of renewables are presently hampered in Algeria due to the existence of numerous barriers, such as institutional barriers and the subsidised price of fossil fuels. The "externalities" associated with the use of such resources, including additional health and environmental costs, are not taken into account **[21]**:

- Weak intersectoral coordination and communication, which not only tends to slow the promotion of such initiatives, but also leads to duplication of efforts and impedes the development of human capital.

- Implementation of Decrees of Application is sluggish, time-consuming, and prevents the implementation of necessary measures for the promotion of such initiatives.
- Human resources. Rotation of staff precludes the accumulation of long-term experience and makes the process overly dependent on individual participation, or lack thereof.
- Insufficient knowledge networks. Due to a lack of information dissemination, seminars on building capacity on a topic of interest to diverse stakeholders may only benefit a subset of participants.

5 Hydrogen as a Renewable Energy: A Promising Option

Hydrogen is a versatile and environmentally friendly energy carrier that can be derived from a variety of domestic resources, including renewable sources such as solar, wind, and biomass. It is a promising option for storing renewable energy and appears to be the least expensive option for storing electricity for days **[22]**. Hydrogen can contribute to the decarbonization of multiple sectors, such as long-distance transportation, structures, and power generation **[23]**.

Figure 14 : *Green Hydrogen [Indiatoday.in].*

5.1 Hydrogen Time line:

- Hydrogen has a lengthy and fascinating history, marked by numerous significant events. The following is a timeline of significant occurrences in the history of hydrogen.
- 1671: British chemist Robert Boyle discovers hydrogen for the first time.
- Antoine Lavoisier, a French chemist, gives hydrogen its name in 1788, which is derived from the Greek words "hydro" and "genes," meaning "water" and "born of"

- William Nicholson and Sir Anthony Carlisle discover in 1800 that applying an electric current to water produces hydrogen and oxygen molecules. This procedure was later dubbed "electrolysis"
- Christian Friedrich Schoenbein, a Swiss chemist, developed the fuel cell effect in 1839 by combining hydrogen and oxygen gases to generate water and an electric current.
- Niels Bohr explains the Rydberg formula for the hydrogen spectrum in 1913 by imposing a quantization condition on the classical orbits of the hydrogen electron.
- Rudolf Erren converts the internal combustion engines of vehicles, buses, and submarines to use hydrogen or mixtures of hydrogen in the 1920s.
- Ohio State University tests liquid hydrogen as a rocket propellant in 1943.
- 1960: General Electric (GE) develops hydrogen fuel cells for electricity generation
- 1996: The Hydrogen Future Act is enacted to facilitate the expansion of hydrogen energy development.
- 2003: President Bush introduces the Hydrogen Fuel Initiative (HFI) to promote the development of hydrogen fuel cells.

Hydrogen is primarily used as a feedstock for industrial processing in 2019, particularly in the production of ammonia for fertilizers (around 50 percent), refining (35 percent), and the food, electronics, glass, and metal industries. The use of hydrogen as an energy vector is gaining traction, however, as global energy industry leaders seek solutions to help achieve decarbonization or improve energy security.

This timeline illustrates that hydrogen has been studied and utilized for centuries, with numerous significant discoveries and advancements. Hydrogen has played a significant role in science and technology, from its discovery by Robert Boyle to its use as rocket propellant and beyond. As we continue to seek out new sources of renewable energy, hydrogen will likely play an increasingly vital role in our lives.

5.2 Advantages of Hydrogen :

Hydrogen's numerous benefits make it an attractive fuel option for transportation and electricity generation. It is a pure fuel that produces only water when burned in a fuel cell. It can be stored, has a high energy density, and emits no direct contaminants or greenhouse gases. Additionally, it is simple to store, allowing it to be utilized for other purposes and at periods other than immediately after its production **[24]**.

5.3 Challenges of Hydrogen :

The high energy consumption required for hydrogen synthesis is the greatest obstacle to its production. Since hydrogen is extremely volatile and combustible, there are also safety concerns **[25]**. However, efforts are being made to optimize environmental protection, enhance energy security, transform global industries, and accelerate the implementation and widespread use of hydrogen in the areas of production, storage, distribution, power, heating, transportation, and industry **[23]**.

6 Conclusion :

Hydrogen has emerged as an essential component of the mix of renewable energy sources required to assure a sustainable future. The declining cost of hydrogen produced with renewable energy has provided pure hydrogen with unprecedented political and commercial momentum. The potential of hydrogen fuel for energy applications that are difficult to decarbonize is being thoroughly examined. Hydrogen is a promising option for storing renewable energy and decarbonizing multiple industries. Hydrogen can become an integral element of the contemporary energy system through continued research and development.

Chapter II : Hydrogen as renewable energy

1 Introduction

With an atomic number of 1, hydrogen is the first element in the periodic table. It makes up 90% of all the atoms in the universe, making it the lightest and most prevalent element. It is primarily discovered on Earth in combinations with practically every other element. This highly flammable, colorless, odorless and tasteless gas has considerable energy potential and offers many possibilities in the field of clean energy **[26]-[27].** In this chapter we have explored the different methods of hydrogen production, its various uses, the challenges related to its storage, the associated risks, and hydrogen in Algeria.

There are numerous feedstocks from which hydrogen can be produced. Along with renewable resources like biomass and water that receive energy from renewable energy sources (such sunshine, wind, wave, or hydropower), these include fossil resources like natural gas and coal. Process technologies can be chemical, biological, electrolytic, photolytic, and thermo-chemical, among others. Every technology is at a different level of development and has its own chances, advantages, and difficulties **[28].**

The uses for hydrogen are diverse. It can be utilized as fuel in automobiles with fuel cells. It is used in the chemical industry to produce cyclohexane and methanol, which are intermediates in the formation of polymers and medicines, as well as ammonia for agricultural fertilizer (the Haber process). In the course of the oil-refining process, it is also employed to remove sulfur from fuels. Hydrogenation of oils to produce fats requires a lot of hydrogen. For the purpose of producing flat glass sheets, hydrogen is employed in the glass industry as a protective atmosphere. It is utilized as a cleansing gas in the electronics sector during the production of silicon chips **[29].**

However, hydrogen storage is an important obstacle to the widespread use of hydrogen as a clean energy carrier. Hydrogen has a poor energy density, thus in order to store energy efficiently, it must be compressed or liquefied. These storage techniques call for particular infrastructures and carry a danger of leakage, explosions, or burns. The safe and cost-effective storage of hydrogen therefore remains a major concern for its large-scale use **[30].**

Algeria has large reserves of natural gas, which is an important source for making hydrogen. The country has always produced and exported natural gas, and now it wants to use this resource to produce blue hydrogen. In addition to the existing infrastructure of the oil and gas industry in Algeria. Along with its exceptional potential for wind and solar energy which is used to produce green hydrogen, what helps Algeria achieve its goal, and make itself a major exporter for green hydrogen to the European market **[31]-[32]-[33].**

In the end, hydrogen's issues are essential for the international and domestic energy transformation. Despite the fact that hydrogen is regarded as a clean and renewable energy source **[28],** there are still obstacles to be cleared before this technology can compete effectively with fossil fuels **[34].** Is Algeria prepared to transition from an economy powered by fossil fuels to one that uses renewable energy sources?

2 Hydrogen properties

Table 1 : *Hydrogen properties [35].*

Property	Numerical value
Lower calorific value (LCV)	10,800 KJ/Nm3 119,930 KJ/Kg 3,00 KWh/Nm3 33,33 KWh/Kg
Higher calorific value: includes water vapor energy (HCV)	12,770 KJ/Nm3 141 860 KJ/Kg 3,55 KWh/Nm3 39,41 KWh/KG
Gas density at 20.3K	1,34 Kg/m3
Gas density at 273K	0,08988 Kg/Nm3
Liquid density at 20.3K	70,79 Kg/Nm3
Specific heat (Cp)	14 266J/Kg. K (293K)
Specific heat (Cv)	10 300 J/Kg. K
Thermal conductivity of gas	0,1897 W/(mK)
Heat of evaporation	445,4 KJ/Kg
Theoretical liquefaction energy	14 112 J/G (3,92 KWH/Kg)
Electronegativity (Pauling scale)	2,2
Atomic mass	1,0079
Gas constant	4 124,5 J/Kg.K
Solidification temperature	14,01K
Boiling temperature (at 1013 mbar abs.)	20,268K
Critical temperature	33,30K
Autoignition temperature in Air	858K
Flame temperature in Air at 300K°	2318K
Flammability limits in Air (vol%)	4-75
Detonation limits in Air (vol%)	13-65
Minimum ignition energy (J)	20
Theorical explosive energy (kg of TNT/ m3 gas)	2,02
Detonation overpressure (mixture stoichiometry)	14,7 bar
Air diffusion coefficient	0,61 cm/s
Flame velocity in Air	260 cm/s
Detonation velocity in Air	2,0 Km/s
Stoichiometric mixture in Air (vol%)	29,53%

3 Types of hydrogen

3.1 Gray hydrogen

Most hydrogen today is referred to as "gray" hydrogen. It is produced from natural gas through a process that consumes a lot of energy and emits a lot of carbon dioxide **[36].**

3.2 Blue hydrogen

Sometimes referred to as a clean alternative, blue hydrogen. The carbon dioxide emissions are essentially collected throughout production, so they don't enter the atmosphere like they would with gray hydrogen **[36].**

3.3 Green hydrogen

In the case of green hydrogen, electrolysis necessitates the use of electrical energy produced by renewable sources, such as wind and solar energy. Green hydrogen can also be made through pyrolysis of biogenic feedstocks and steam reforming of biomethane in addition to electrolysis **[37].**

4 Hydrogen production

4.1 Hydrogen from fossil fuels

4.1.1 Production from natural gas

Currently, three distinct chemical methods can product hydrogen from natural gas:

Steam methane reforming (SMR)

Steam methane reforming (SMR) has long been the preferred method for producing hydrogen in petrochemical and refining complexes.

There are four main sections in the steam reforming plant. Sulfur and other impurities are removed from the feedstock in the first step, and syngas (mostly hydrogen and carbon monoxide) are produced by converting feedstock and steam in the steam methane reformer at high temperature and moderate pressure. An adiabatic, catalytic pre-reforming step is anticipated upstream the SMR in the event of multiple or heavy feeds and/or for large capacities. The syngas heat recovery is the third section, and it includes one or more CO shift reactors to boost the hydrogen production. The raw hydrogen purification process is the last step, and in this stage, contemporary factories use a pressure swing adsorption (PSA) unit to achieve the purity of the finished product **[38].**

The endothermic transformation of methane and water vapor into hydrogen and carbon monoxide occurs during steam reforming (2.1). Combustion of some of the methane feed gas frequently provides the heat. Typically, the process takes place between 700 and

850°C and 3 and 25 bar pressure. The water-gas shift reaction (2.2) can further convert the CO content of about 12% of the resulting gas to CO2 and H2 by this process **[39].**

$$CH_4 + H_2O + heat \rightarrow CO + 3H_2 \quad (2.1)$$

$$CO + H_2O \rightarrow CO_2 + H_2 + heat \quad (2.2)$$

In this instance, the ad hoc hydrogen production utilizing SMR accounts for around 15% of the present emissions related with the refining business and about 30% of the overall hydrogen produced by the refinery **[40].**

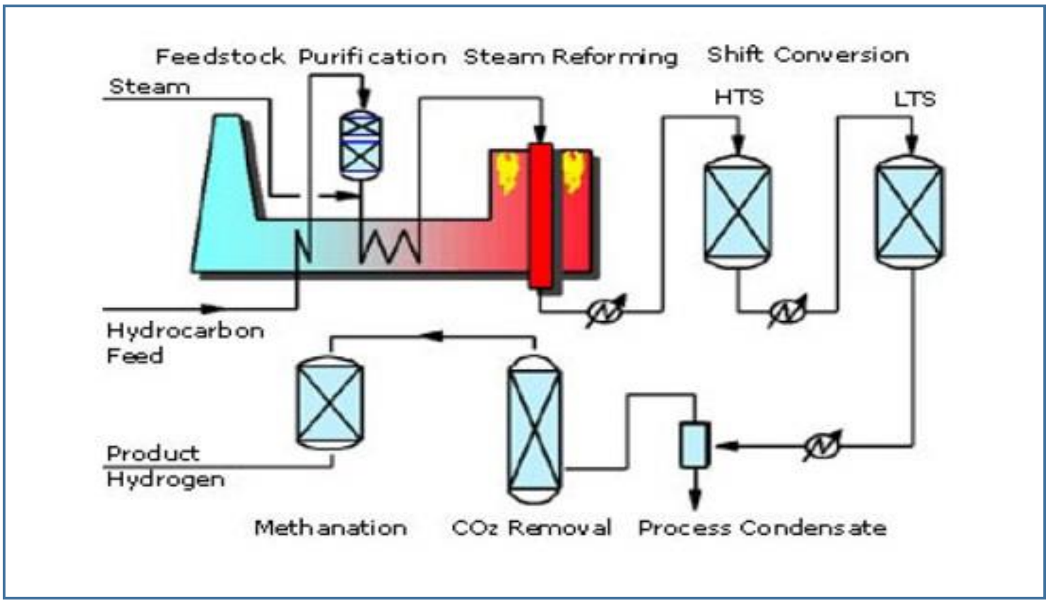


Figure 1 : *Process diagram of steam methan reforming [41].*

Partial oxidation (POX)

When methane is partially burned with oxygen gas to form carbon monoxide and hydrogen, this process is known as partial oxidation of natural gas (2.3). This process does not require any external heating of the reactor because heat is generated during an exothermic reaction, allowing for a more compact design. According to equation (2.2), the CO generated is further transformed to H2 **[39]**.

$$CH_4 + 1/2O_2 \rightarrow CO + 2H_2 + heat \quad (2.3)$$

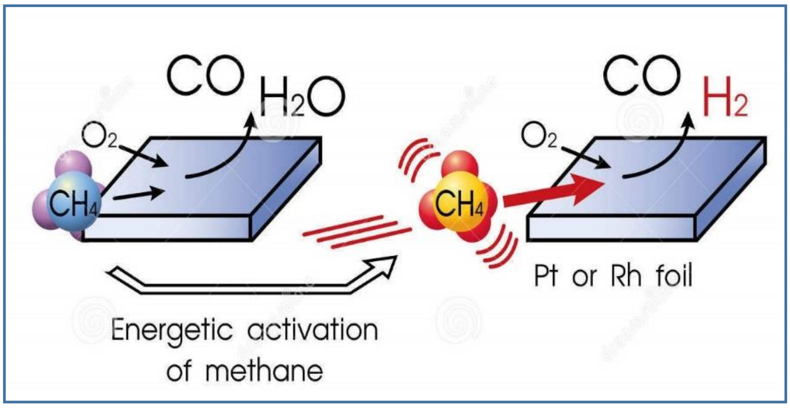


Figure 2 : *Process diagram of partial oxidation [42].*

Autothermal reforming (ATR)

Steam reforming (2.1) and partial oxidation (2.3) are both components of autothermal reforming.

Since the entire reaction is exothermic, heat is released. The reactor's outlet temperature is between 950 and 1100 °C, and the gas pressure can reach 100 bar. Again, the water-gas shift process (2.2) converts the CO generated to H2. The requirement for output gas purification greatly raises plant expenses and lowers overall plant efficiency **[39]**.

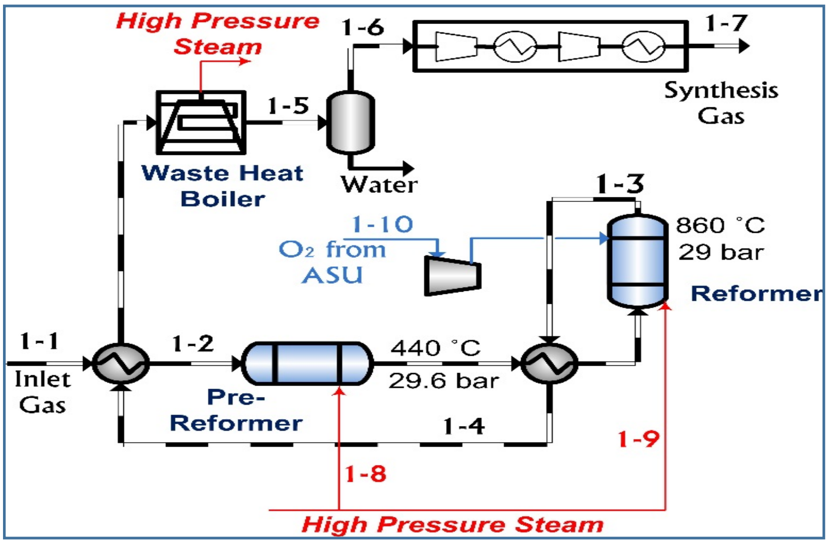


Figure 3 : *Diagram process of autothermal reforming [43].*

4.1.2 Production from coal

Using several gasification methods (such as fixed bed, fluidized bed, or entrained flow), hydrogen can be produced from coal. In order to increase the conversion of carbon to gas and to minimize the development of char, tars and phenols, high temperature entrained flow techniques are generally preferred. Equation (2.4) describes a typical reaction for the process in which carbon is transformed into carbon monoxide and hydrogen.

$$C(s) + H2O + heat \rightarrow CO + H2 \qquad (2.4)$$

Similar to when methane reforms, more heat is needed for this endothermic reaction. Equation (2.2)'s description of the water-gas shift process shows how the CO is further transformed into CO2 and H2.

Although commercially viable, the production of hydrogen from coal is more complicated than that of hydrogen from natural gas. The resultant hydrogen is likewise more expensive. However, considering that coal is widely available around the world and will probably continue to be used as an energy source. Looking into the development of clean technology for its application is worthwhile **[39]**.

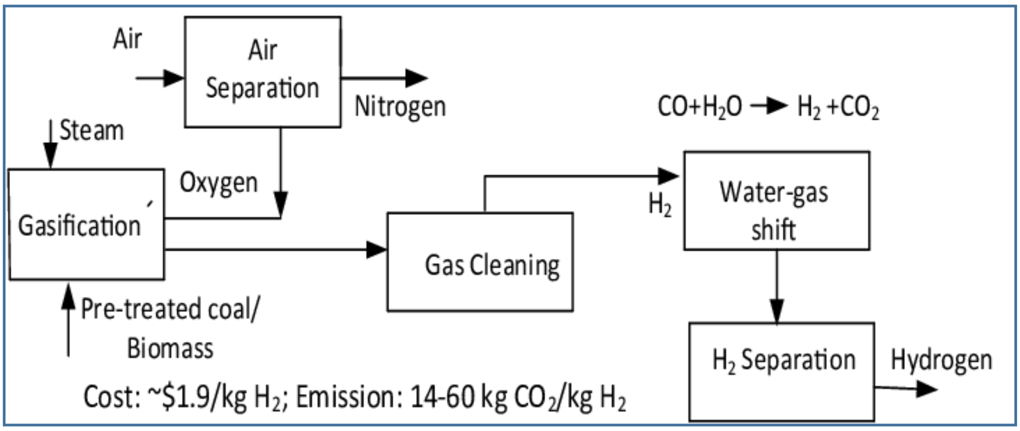


Figure 4 : *Diagram process of coal gasification [44].*

4.2 Hydrogen from splitting of water

4.2.1 Water electrolysis

Electrolysis of water to produce hydrogen is one of the worst energy-intensive ways to produce the fuel. As long as the electricity is generated from a clean source, the process is clean. However, electrolysis leads to losses. A higher voltage is required by electrolyzers to split water into hydrogen and oxygen. In practical circumstances, the surge is needed to compensate for bias and ohmic losses caused by electric current flow **[45]**.

According to equation (3.1), water electrolysis is the process by which water is split into hydrogen and oxygen using electrical energy. While the required electrical energy reduces with temperature, the overall energy needed for water electrolysis somewhat increases.

When high-temperature heat is available as waste heat from other operations, a high-temperature electrolysis process may therefore be preferred. This is particularly significant because the majority of the electricity producted by fossil fuels, which have relatively low efficiency and have the potential to significantly lower production costs **[39]**.

$$H_2O + Electricity \rightarrow H_2 + 1/2O_2 \quad (3.1)$$

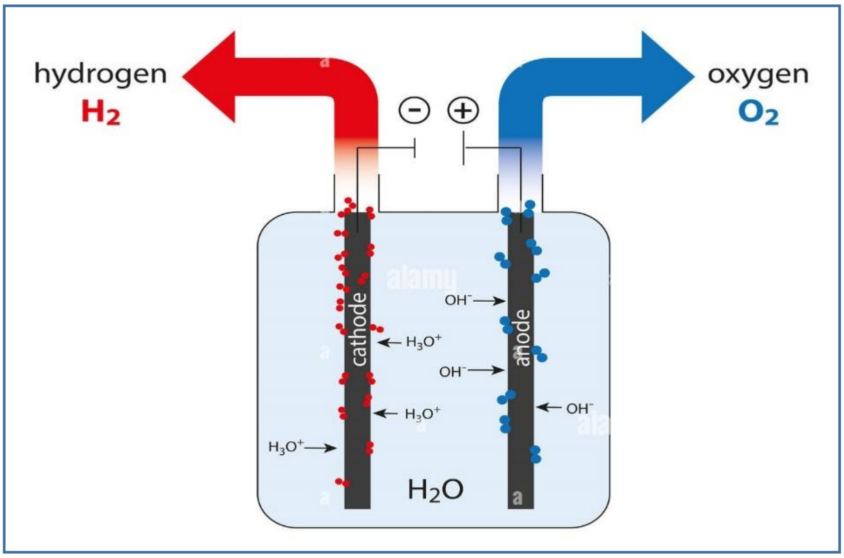


Figure 5 : *Diagram process of water electrolysis [46].*

4.2.2 Alkaline electrolysis

An aqueous KOH solution (caustic) is used in alkaline electrolysers as the electrolyte, which typically flows through the electrolytic cells. Alkaline electrolysers are available at operating pressures up to 25 bar and are suitable for stationary applications. Alkaline electrolysis is a well-established technology that enables remote operation and has a long history of use in industrial applications.

Inside the alkaline electrolysis cell, the following reactions happen:

$$\text{Electrolyte: } 4H_2O \rightarrow 4H^+ + 4OH^- \quad (3.1)$$

$$\text{Cathode: } 4H^+ + 4e^- \rightarrow 2H_2 \quad (3.2)$$

$$\text{Anode: } 4OH^- \rightarrow O_2 + 2H_2O + 4e^- \quad (3.3)$$

$$\text{Sum: } 2H_2O \rightarrow O_2 + 2H_2 \quad (3.4)$$

Most commercial electrolysers are constructed from a number of stacked electrolytic cells **[39]**.

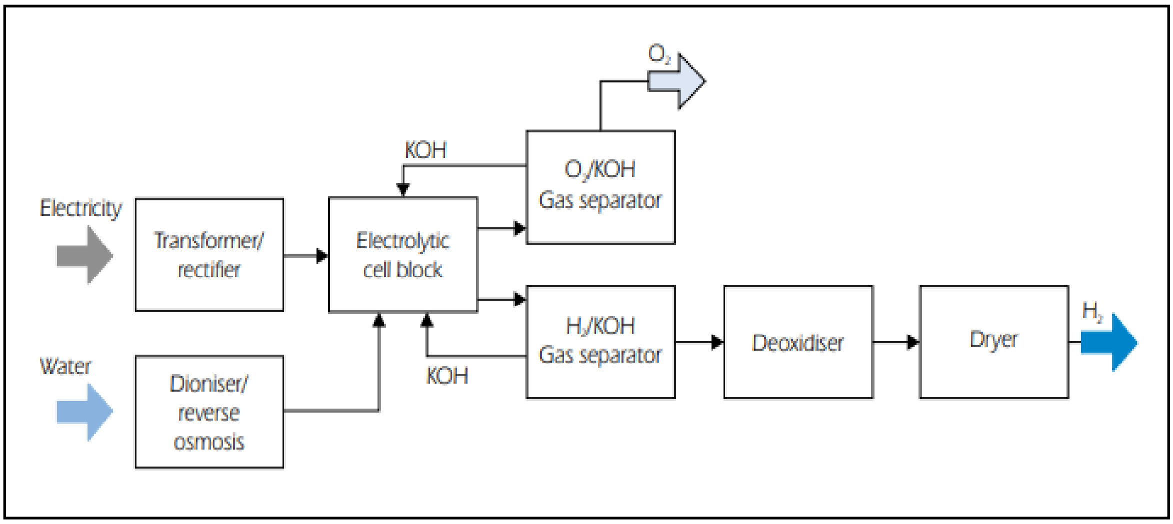


Figure 6 : *Process Diagram of alkaline electrolysis [47].*

4.2.3 Polymer electrolyte membrane (PEM) electrolysis

The PEM electrolysis principle is described in equations (3.6) and (3.7). PEM electrolysers have a substantially simpler design because they don't need liquid electrolytes. Membrane made of acidic polymer serves as the electrolyte. PEM electrolysers are appropriate for both stationary and mobile applications and may be built at operating pressures up to several hundred bar. The membranes' finite lifespan is this technology's primary flaw. The higher turndown ratio, increased safety from the lack of KOH electrolytes, more compact design made possible by higher densities, and higher operating pressures are the main benefits of PEM over alkaline electrolysers.

$$\text{anode: } H2O \rightarrow 1/2O2 + 2\,H+ + 2e– \quad (3.6)$$

$$\text{cathode: } 2H+ + 2e– \rightarrow H2 \quad (3.7)$$

The PEM electrolysers that are now on the market are not as developed as alkaline electrolysers due to their comparatively high cost, low capacity, poor efficiency, and short lifespan. Additional research in material development and cell stack design is anticipated to considerably enhance the performance of PEM electrolysers **[48]**.

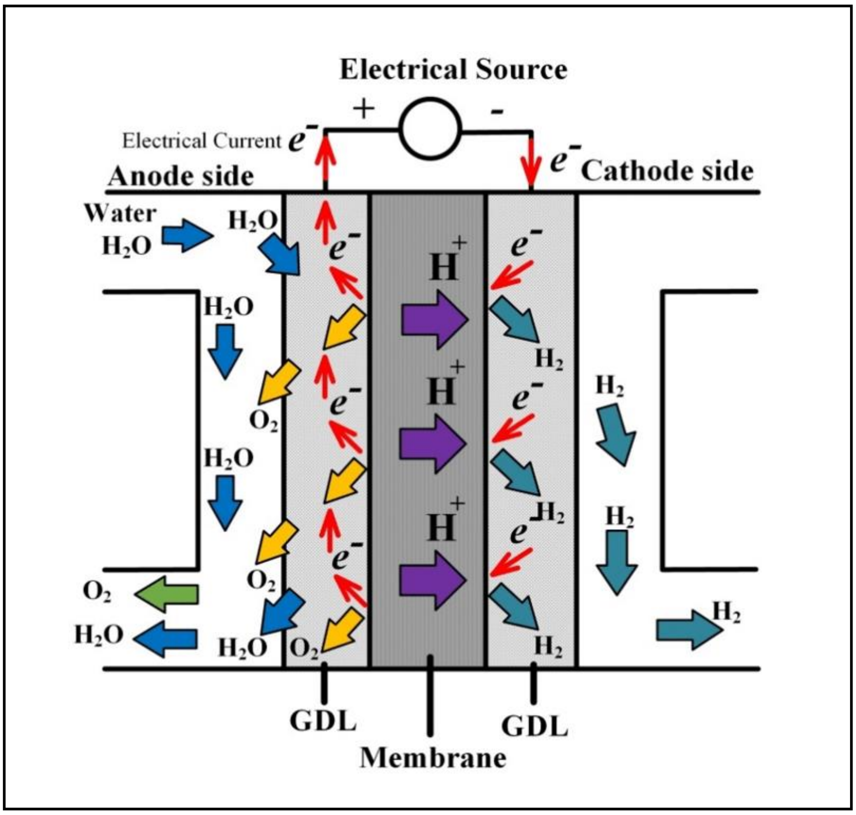


Figure 7 : *principle of operation of proton exchange membrane (PEM) electrolysis [49].*

4.2.4 High-temperature electrolysis

The technology behind high-temperature fuel cells is the foundation for high-temperature electrolysis. Compared to electrolysis at 100 °C, splitting water at 1000 °C requires a lot less electrical energy. This indicates that compared to standard low-temperature electrolysers, a high-temperature electrolyser can operate at much greater overall process efficiency.

The solid oxide electrolyser cell (SOEC) is a common technology. The solid oxide fuel cell (SOFC), which is used in this electrolyser, typically runs between 700 and 1000 °C. These temperatures make the electrode reactions more reversible, making it simpler to convert a fuel cell reaction to an electrolysis reaction. There are also efforts being made to product systems in which some of the power used by the electrolyser can be swapped out for the heat produced by geothermal, solar, or natural gas sources, considerably reducing the amount of electricity used.

The primary R&D demands for SOECs are related to material development and thermo-mechanical stress inside functional ceramic materials, much like the primary problems for SOFCs **[39]**.

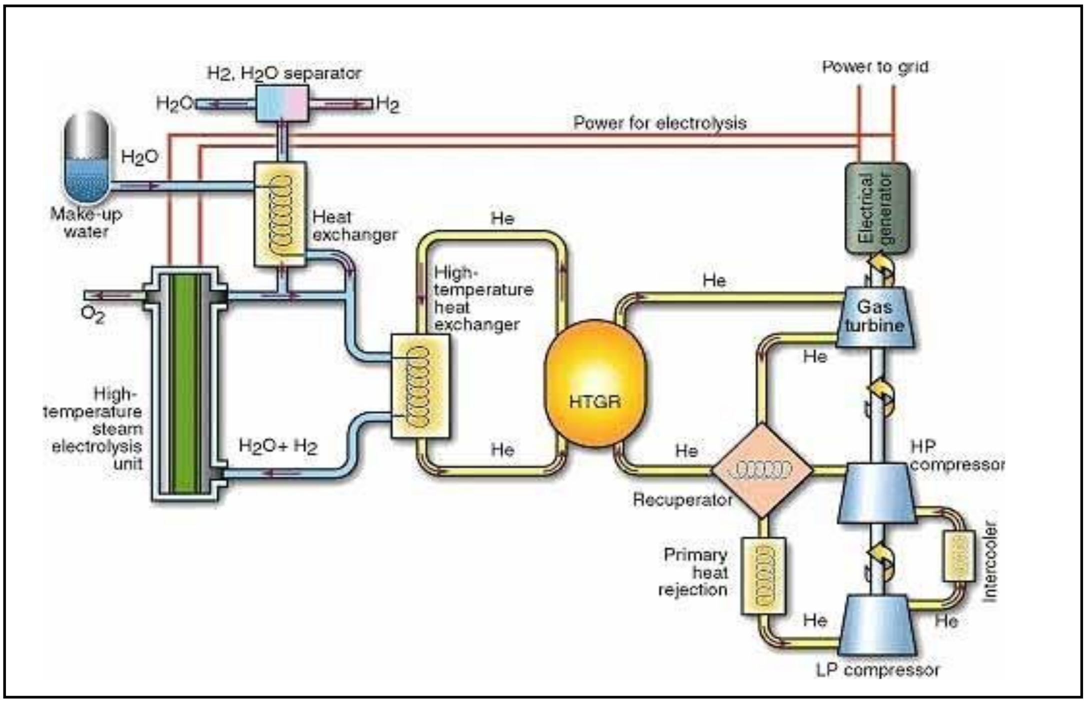


Figure 8 : *Diagram process of high temperature electrolysis [50].*

4.2.5 Photo-electrolysis (photolysis)

The dissociation of water caused by the electric current generated by the lighting of a semiconductor photocatalyst is known as photo-electrolysis. When submerged in an aqueous electrolyte or in water and exposed to sunlight, photoelectrochemical cells (PECs) (photoactive electrodes) can convert water into hydrogen and oxygen. They can be **categorized as integrated or** monolithic photovoltaic/electrolytic devices in their most basic form. Around the world, numerous PEC and photocatalysis techniques that can separate water are being researched. In particular, the International Energy Agency (IEA) has conducted studies.

Even though they are fundamentally straightforward, cell materials PECs for hydrogen production are still in the early stages of basic research **[51]**.

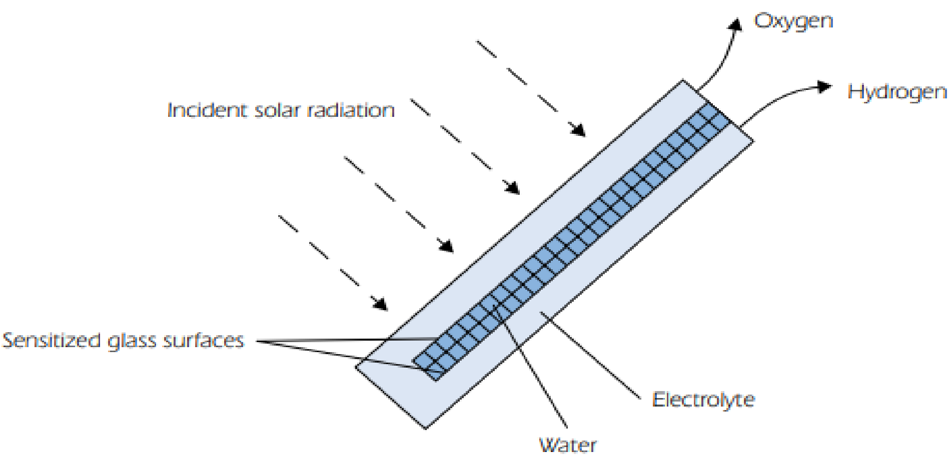


Figure 9 : *Principle of photo-electrolytic cell [39].*

4.2.6 Photo-biological production (biophotolysis)

The two processes that make up photo-biological hydrogen production are photosynthesis (3.8) and hydrogen production catalyzed by hydrogenases (3.9) **[39]**. for example, microalgae and cyanobacteria.

Microalgae produce photo-biological hydrogen, this method has been used since the early 1970s and has received much attention from scientists in recent years. In order to convert solar energy and water into hydrogen with oxygen as a byproduct, microorganisms act as a catalyst in the photolysis process **[52]**.

Photosynthesis: $2H_2O \rightarrow 4H^+ + 4e^- + O_2$ (3.8)

Hydrogen Production: $4H^+ + 4e^- \rightarrow 2H_2$ (3.9)

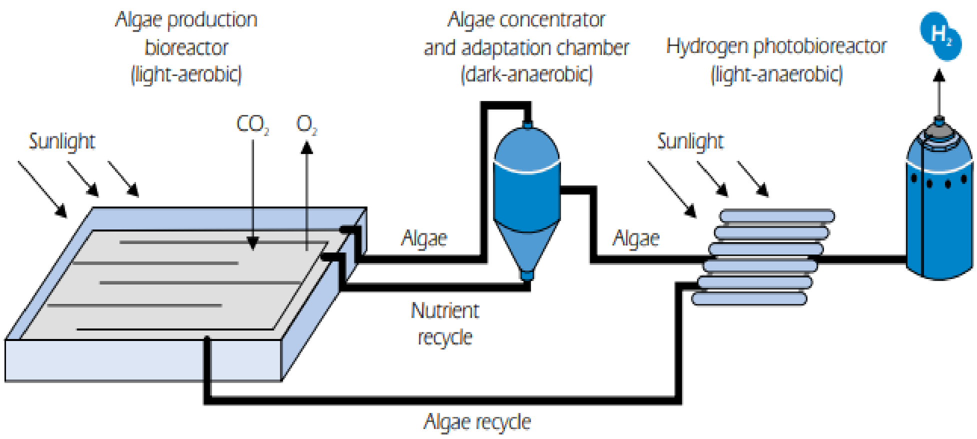


Figure 10 : *Principle of photo-biological hydrogen production [39].*

4.2.7 High-temperature decomposition

At high temperatures, water splits at a temperature of about 3000 °C. At this temperature, 10% of the water decomposes, while the remaining 90% can be recycled. Other approaches to reduce the temperature of water split at high temperatures include:

- Thermo-chemical cycles.
- Hybrid systems coupling thermal decomposition and electrolytic decomposition.
- Direct catalytic decomposition of water with separation via a ceramic membrane ("thermo-physic cycle").
- Plasma-chemical decomposition of water in a double-stage CO2 cycle.

Efficiency levels of 50% are anticipated for these technologies, which may result in a significant drop in the price of hydrogen generation. The development of materials for high temperature corrosion resistance, high temperature membrane and separation processes, heat exchangers, and heat storage medium are the key technical challenges for these high temperature processes. Safety and design considerations are equally crucial for high-temperature procedures **[39]**.

4.2.8 Thermo-chemical water splitting

The process of splitting water into hydrogen and oxygen by a sequence of chemical reactions that are fueled by heat. Since 35 years ago, thermo-chemical water-splitting cycles have been understood. Equations (3.10), (3.11), and (3.12) describe the iodine/sulphur cycle as an illustration of a thermochemical process **[39]**.

(850 °C): $H_2SO_4 \rightarrow SO_2 + H_2O + 1/2O_2$ (3.10)

(120 °C): $I_2 + SO_2 + 2H_2O \rightarrow H_2SO_4 + 2HI$ (3.11)

(450 °C): $2HI \rightarrow I_2 + H_2$ (3.12)

SUM: $H_2O \rightarrow H_2 + 1/2O_2$

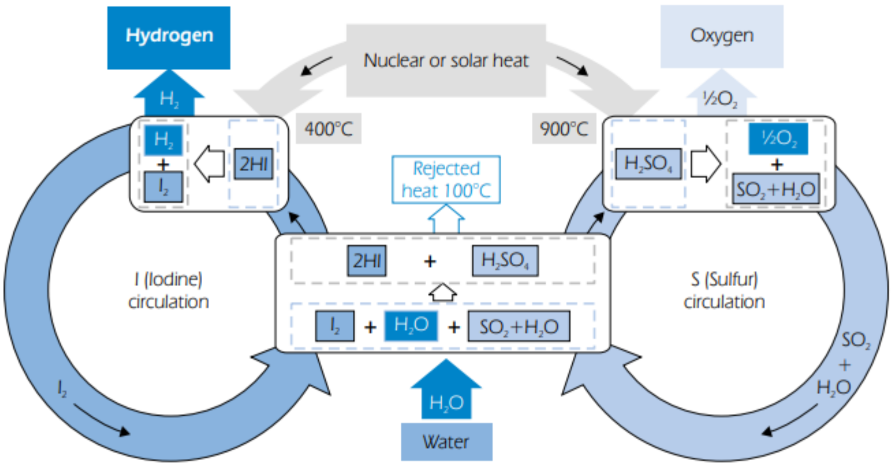


Figure 8 : *Principle drawing of iodine/sulfur thermo-chemical process [39].*

4.3 Biomass to hydrogen:

Biomass gasification is a well-established technological approach that converts biomass into hydrogen and other products without burning through a controlled process including heat, steam, and oxygen **[53]**.

Agro-industrial, residential, and agricultural waste make up the majority of the biomass that is exploitable. It can be considered a renewable primary energy source if its exploitation protects agricultural and forestry resources **[54]**.

Carbon monoxide, hydrogen, and carbon dioxide are produced when organic or fossil-based carbonaceous materials are gasified at high temperatures (>700°C). The carbon monoxide then undergoes a water-gas shift reaction with water to produce carbon dioxide and additional hydrogen. The hydrogen in this gas stream can be extracted using adsorbers or certain membranes **[53]**.

$C_6H_9O_4$ (biomass) + 2 H_2O → 6 CO + 6,5 H_2 (900 - 1 200°C) **[11]**

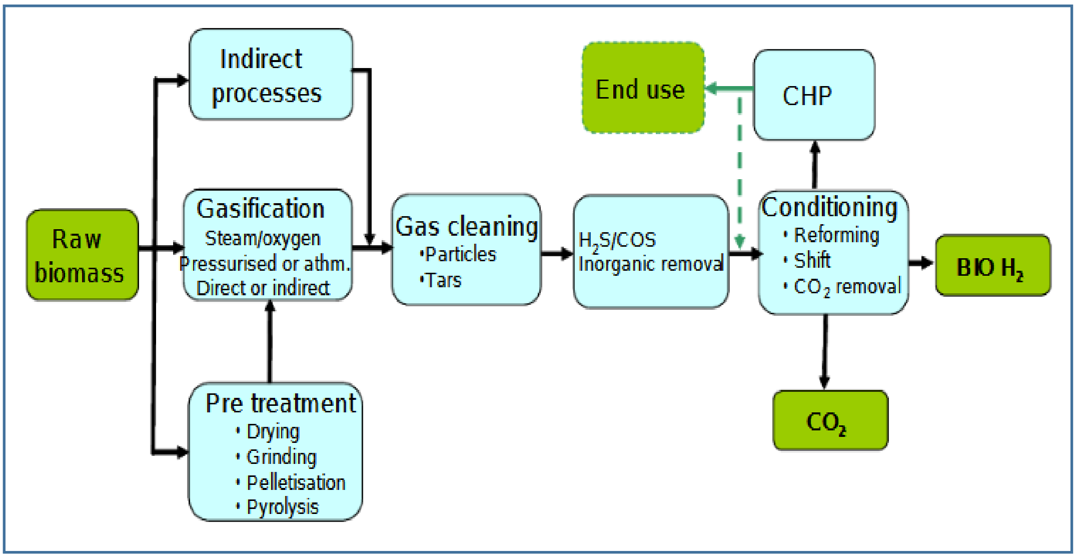


Figure 12 : *Biomass to hidrogen through gasification pathway [55].*

5 Hydrogen storage

5.1 Gaseous state storage

The most developed storage technology at the moment is the storage of hydrogen as a gas in tanks.At 5,000 psi, composite gas storage tanks are already accessible. Recently, 10,000-psi tanks were shown off. New lightweight tank materials, like carbon-fiber reinforced composites, are used in these high-pressure tanks. The limited amount of hydrogen that can be kept in a practical volume is the main disadvantage of gaseous storage for transportation purposes. Even at pressures of 10,000 psi, hydrogen has a much lower energy content than gasoline for the same volume — 4.4 MJ/L (10,000 psi) for hydrogen versus 31.6 MJ/L for gasoline. Another factor is the significant pressure drop that occurs during use, which focuses on both the beginning and final pressures utilized to compress the gas.

The development of novel materials that are powerful, and affordable is one of the main areas that require research for improved compressed gas storage. For instance, new fiber synthesis methods that consistently yield high-quality fibers and novel binders that are durable and impermeable to hydrogen are needed for fiber-reinforced composites for storage containers. Additionally, a deeper comprehension of the processes underlying the failure of storage container materials is required. In order to develop methods to minimize failure brought on by prolonged exposure to hydrogen, researchers require a better knowledge of the atomic-level mechanisms responsible for hydrogen embrittlement in candidate materials. This is because many of the system components exposed to hydrogen will be metallic. To enable their practical application to pressurized gas storage, embrittlement-resistant materials will need to be developed. This will require well-coordinated basic and applied research. for the safe application of gaseous hydrogen storage, smart sensors that can detect hydrogen leakage and the associated safety feedback systems must also be thoroughly developed.

5.2 Liquid state Storage

A significant benefit of storing liquid hydrogen in cryogenic containers is that more hydrogen may be stored as a liquid in a given volume than can be stored as gas. Researchers calculate 8.4 MJ/L for liquid hydrogen against 4.4 MJ/L for compressed gas (at 10,000 pressure). Liquid hydrogen has a density of 70.8 kg/m3 at standard pressure and temperature.

The significant amount of energy needed for liquefaction, which is now around one-third of the energy value of the hydrogen stored, is a major disadvantage of liquid storage. Evaporative hydrogen loss is another problem, particularly with tiny tanks. The use of high-pressure cryogenic tanks is also being investigated to reduce the need for extremely low temperature storage.

The development of novel light weight, low volume, low cost, and low heat transfer materials is one of the fundamental research goals connected to liquid hydrogen storage. These materials must exhibit endurance, toughness (no leaks) and strength. Additionally, new, resistant substances that reduce heat transmission and are suitable for mass production are required. These materials should be developed through experiments and computer simulations. New methods are also required to lower the cost and increase the energy efficiency of liquefaction. The development and deployment of novel methods for managing cryogenic liquids must also proceed quickly.

5.3 Solid-state Storage

Storage of hydrogen in chemical storage materials, metal hydrides, and nanostructured materials are all examples of solid-state storage. Perhaps the best opportunities for fulfilling the needs for internal storage are provided by this approach of hydrogen storage. Hydrogen can be irreversibly and reversibly stored in these materials. Reversible storage refers to the process whereby hydrogen is first replenished (stored) by controlling temperature and hydrogen pressure before being released by increasing the temperature of, say, a metal hydride at an appropriate pressure. Although pressure and temperature are the two thermodynamic variables that are most frequently adjusted, additional forms of energy (such as mechanical and acoustic) can be used to regulate both the release and uptake of hydrogen. The ideal conditions for hydrogen storage and release are between 0°C and 100°C, 1–10 bar pressures, and timescales appropriate for transportation uses. Some substances have hydrogen that is tightly chemically bonded and difficult to extract. The needs for hydrogen storage for transportation applications can only be met by hydrogen that can be made readily available **[56].**

6 Hydrogen uses

6.1 Fuel cell technologie

Similar to ordinary batteries, fuel cells use an electrochemical process to continually produce electricity in the form of current. An oxidant and a reducer are separated by an electrolyte in the same way that an ordinary battery operates.

The oxidant and reductant, which are typically provided in gaseous (occasionally liquid) form, are continually supplied to a fuel cell, unlike a normal fuel cell where they are gradually consumed. The battery will operate steadily as long as this supply is maintained.

The temperatures in the fuel cell are lower than in turbines or combustion engines, which is one of its benefits. Among other things, this enables the prevention of NOx production. However, the majority of conventional carbonaceous fuels are insufficiently reactive at this temperature, and hydrogen on its own is acceptable.

The following describes the regulated electrochemical combustion reaction in typical fuel cells:

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$$

Intriguingly, the production of the hydrogen (H+) and hydroxyl (OH-) ions that make up water results in the release of electrons that are converted into electricity. Hydrogen and oxygen are combined to produce water, heat, and energy. Battery fuel, which primarily

consists of an electrolyte, an acidic or basic ionic conducting medium, separating an anode supplied with hydrogen and a cathode supplied with oxygen, is the device that permits this process. As a result, the battery fuel works on the exact opposite principle from electrolysis, producing hydrogen and oxygen from water by applying an electric current to it **[57]**.

Many companies apply this technology, with NASA being one of the pioneers in doing so **[58].**

There are several types of fuel cells that use hydrogen as a fuel. here are some of the most common ones **[57]**:

- Proton exchange membrane fuel cells (PEMFC)
- Alkaline fuel cells (AFC)
- Solid oxide fuel cells (SOFC)
- Direct methanol fuel cells (DMFC)
- Molten carbonate fuel cells (MCFC)

- Phosphoric acid fuel cells (PAFC)

Figure 13 : *Hydrogen fuel cell [59].*

6.2 Hydrogen heat engines

Internal combustion or "explosion" engines, also called heat engines, burn fuels such as light petroleum, alcohol, diesel, coal gas, natural gas, more or less heavy petroleum distillates, or fermentations of organic matter. All of these combustion engines can run on hydrogen with little modification to generate mechanical energy, emitting only water vapor and a very small amount of nitrogen oxides. Steam turbines are only used for very high powers, whereas the very rare gas turbines used today in aviation totally dominate the field. All these engines, including those using the Diesel cycle, are capable of being converted to hydrogen from a purely thermodynamic point of view **[57]**.

Despite having an excellent energy to mass ratio, hydrogen has a bad energy to volume ratio. As a result, smaller vehicles like cars will need to run on liquid hydrogen, whereas buses have enough tank space to run on hydrogen gas.

- It is possible to convert gasoline engines to run on hydrogen **[60].**
- Engines powered by hydrogen may operate more efficiently than those running on fossil fuels **[61].**
- Because they don't require pollution control equipment, hydrogen-fueled engines use less energy **[61].**
- Hydrogen reduces take-off weight because it is so much lighter than jet fuel **[61]-[62].**
- The capacity to currently build combustion engines within the automotive sector is a substantial economic resource advantage over electric vehicles **[63]**.

Figure 14*: internal heat engines [64].*

6.3 Refining and petrochemicals

One of the primary intermediate products that is frequently employed in the petrochemical and petroleum industries is hydrogen. Her use in contemporary refineries, chemical complexes, and petrochemicals to process heavier oil feedstocks has progressively expanded. Hydrogen is sometimes utilized as a raw material in refining processes and is also occasionally produced as a byproduct of other processes. Off-gas streams from refineries or petrochemical complexes typically contain a significant amount of hydrogen, which is primarily burned as waste gas in refinery flares!"). In reformers, valuable hydrocarbons are simultaneously transformed into hydrogen to provide the process's hydrogen consumers. Due to increasingly stringent environmental laws, the refineries' need for hydrogen is rising. This raises the investment costs necessary to construct new hydrogen production facilities or expand current factories.

Figure 15: *Hydrogen in oil rafineries [67].*

The recovered hydrogen can either be sold to downstream businesses as a new product or utilized as a feedstock in a refinery **[65]-[66]**.

6.4 Metal production

In the current industrial decarbonization endeavor, hydrogen serves as a reducing agent for the manufacture of metals in addition to being a source of clean fuel energy. Hydrogen is still not frequently used in the manufacture of several metals at this time. Only a small number of refractory metals are used economically, and the manufacturing of Ni and Co metals uses hydrogen to some extent. The hydrogen reduction of metal oxides has recently seen advancements in experimental methods, modern uses, and technological developments. The utilization of hydrogen has the potential to recover valuable metal from secondary resources (such as Pb from slag and Zn from EAF dust) **[68]**.

Figure 16: *H2 green steel industry in stockholm [69].*

6.5 Energy Storage

Chemical energy storage that involves converting electrical power into hydrogen is known as hydrogen energy storage. It helps to balance peak electricity demand charges by storing and supplying extra energy as needed, which is similar in concept to battery energy storage.

This kind of energy storage utilises extra energy generated by renewable energy sources like solar panels and wind turbines during times of low demand. Hydrogen is produced through electrolysis, which is powered by the excess energy. When an electrical current flows through a chemical solution, electrolysis generates hydrogen. Fuel cells are able to re-electrify stored hydrogen with up to 50% efficiency. Instead of using combustion to produce power.

Additional benefits of this technology include its capacity to store more energy for longer periods of time. In contrast to other technologies like battery energy storage, this is. In contrast to other energy storage technologies, which have discharge times of four hours or fewer, hydrogen technology may store energy for weeks at a time **[70]**.

Figure 17 : *Hydrogen storage [70].*

7 Hydrogen risks

7.1 Fire and explosion

Hydrogen is highly flammable and can cause fires and explosions if not handled properly. Nevertheless, hydrogen fires differ significantly from fires caused by other fuels. Diesel and other heavy fuels leak more frequently and collect nearby the ground. However, hydrogen, one of the lightest elements on earth, quickly disperses upwards. The increased reactivity of hydrogen—which ignites and burns considerably more readily than other fuels—increases the risks connected with this. Furthermore, because hydrogen flames are invisible, it is difficult to identify the fire **[71]-[72]**.

7.2 Asphyxiation

Because hydrogen has no taste, color, or odor, it can be difficult for humans to detect leaks using only their senses. Although hydrogen is not dangerous, it can build up indoors and replace oxygen, leading to asphyxiation in places like battery storage rooms **[73]**.

7.3 Hydrogen is buoyant

Because hydrogen gas is much more buoyant than other gases, it will rise rapidly if it spills into the atmosphere. this is advantageous for hydrogen systems placed outdoors. but in enclosed spaces leaking hydrogen will accumulate, eventually forming an explosive mixture **[74]**.

7.4 Hydrogen embrittlement

Metals become brittle due to the entrance and diffusion of hydrogen into the substance, which is known as embrittlement. The amount of hydrogen absorbed and the material's microstructure both have an impact on the degree of embrittlement. High strength microstructures, which are frequently measured by hardness level, or those with particular grain boundary particle or inclusion distributions might lead to higher vulnerability to embrittlement. When the problem causes cracking, it typically becomes substantial **[75]**.

7.5 Hydrogen leaks

Little leaks are frequent in gaseous hydrogen because the molecule that makes it up is so tiny. These extremely minor leaks are not an issue in correctly constructed systems since the little hydrogen released won't be enough to produce a combustible air combination. Only when hydrogen gas can accumulate up over time in a small space will there be a danger of an ignitable combination or asphyxiation **[76]**.

7.6 Damages by low temperature releases

Hydrogen gas or liquid contact with the skin can result in severe cold burns similar to those brought on by boiling water. Unprotected skin may freeze on liquid-cooled surfaces and cause significant injury when removed. Frostbite can happen if your skin is exposed to cold hydrogen for a long time. Local pain is one sign, and while it typically serves as a warning before freezing, it can also occasionally go unnoticed or last just briefly. Tissues that have been frozen don't hurt and have a waxy appearance in a light whitish or yellowish tint. Painful thawing of the frozen tissue is possible. Shock could also happen. The eyes are especially vulnerable; even little drops of liquid hydrogen or brief contact with a cold vapor or gas can instantly freeze the tissues of the eyes and cause lasting harm.

People who are sensitive suffer breathing pain and may experience an asthma attack after a brief exposure to extremely cold gas. Long-term exposure to cold vapor or gas can seriously harm the lungs. Hypothermia can happen when the entire body is exposed to cold for a long time **[77]**.

7.7 LH2 BLEVE

Liquid hydrogen (LH2) boiling liquid expanding vapor explosion (BLEVE) is a possible mishap scenario for its storage and delivery. A BLEVE is a physical explosion that happens when a liquid tank ruptures catastrophically at a temperature higher than its boiling point at atmospheric pressure. Its effects include a pressure wave, missiles made of tank debris scattered by the explosion, and, in the case of an ignition source, a blaze **[78]**.

8 Hydrogen in Algeria

Although Algeria has large hydrocarbon reserves, it also wants to contribute to Africa's energy transition. The nation has abundant renewable energy resources, including wind and solar power (Algeria is the largest African country by area and receives 2,000 to 3,000 hours of sunshine annually in its desert, which makes up 80% of the country and has the highest surface temperature in the world **[79]**), wind and water, which can be used to produce green hydrogen **[80]** with blue hydrogen, produced from gas **[81].**

Using data gathered during a workshop held by the ministry to outline the development plan for hydrogen. By exploiting its technical prowess and competitive advantages, Algeria hopes to manufacture and export between 30 and 40 billion kilowatts of gaseous, liquid, and derived hydrogen by 2040, meeting up to 10% of the European market's need at extremely competitive selling costs. A roadmap for hydrogen development is being put into action by Algeria at a time when the European Union is ramping up efforts to decarbonize its economy **[82].**

For the purpose of producing green hydrogen, Algeria proposes to invest 20 to 25 billion US dollars **[79]**. The construction of experimental projects and global alliances targeted at advancing the production of hydrogen, storage, and utilization **[81]-[82]** is evidence of Algeria's investment in this field. With a focus on utilizing the country's huge potential for renewable energies, the Algerian oil giant Sonatrach and the German energy company VNG AG inked a contract in December 2022 to build green hydrogen and ammonia reactors there **[79]**. These programs include construction of centers for hydrogen research, development, and training; accelerating the energy transition and lowering carbon emissions; building a hydrogen economy and its derivatives; and even cutting back on the use of fossil fuels. **[81].**

Algeria's existing infrastructure in the oil and gas sector (pipelines, liquified gas terminals etc.), its industrial gas industry, in addition to the availability of wind and solar energy and its proximity to European markets, make it a potential supplier of green hydrogen. A domestic production of green hydrogen would represent for Algeria an interesting opportunity to diversify its traditional markets, in line with the government's diversification strategy **[83].**

9 Conclusion

In conclusion, hydrogen offers considerable possibilities as a clean and versatile energy carrier. However, addressing the challenges associated with its production, storage and safety is key to maximizing its benefits while minimizing potential risks **[30]**. Algeria, while capitalizing on its natural assets, can play a key role in the transition to a sustainable hydrogen economy **[58]**. Therefore, Algeria must make investments and work to break down technological barriers in order to develop hydrogen as a source of energy **[84]**.

Chapter III : Hazard Analysis and Risk Management in Industrial Processes for Hydrogen

1 Introduction

The purpose of this chapter is to provide a comprehensive discussion on the topic of Hazard Analysis and Risk Management in Hydrogen Industrial Processes. The chapter aims to serve as a complete reference for theoretical background and practical activities required to ensure worker and environmental safety in hydrogen-based industrial processes. It is intended to be read in conjunction with the other chapters in this thesis. Hydrogen is an extremely flammable gas that is used in a wide range of industrial operations, including the manufacturing of chemicals, the operation of fuel cells, and the storage of energy. While hydrogen has many positive applications, it also has negative safety implications due to its flammability and explosive potential. Therefore, it is essential to implement efficient hazard analysis and risk management procedures to reduce the occurrence of accidents, injuries, and damage to the environment.

The chapter begins with a general discussion on the significance of risk assessment and management in the context of industrial processes. In addition to laying a theoretical groundwork for hazard analysis and risk management, it stresses the importance of making safety a top priority for organizations. The chapter then moves on to a discussion of the fundamental steps involved in the process of risk assessment and management for industrial processes. It provides an in-depth guide to the process of risk assessment, which covers hazard identification as well as risk analysis and risk evaluation. In addition to this, it delves into the significance of risk communication as well as the part that stakeholders play in the process of risk management.

Furthermore, this chapter examines a variety of tools and methods that can be applied to evaluate and manage the risks associated with operations that involve hydrogen. It offers a summary of quantitative and qualitative risk assessment methodologies, as well as the implementation of safety barriers and tactics for risk reduction. The Hazard Analysis and Risk Assessment process should include members of the project and/or safety teams that have expertise in the various aspects of the project. The approach is specific to hydrogen and analyzes the probability of operations and failure modes that can lead to combustible mixtures and ignition events or even a leakage. From high-level system analysis to detailed component-level risk assessments, the methodology enables a simple, data-driven, step-by-step approach. Facilities that produce or use hydrogen shall carry out robust hazard analyses, involving multidisciplinary teams, to consider what process deviations or failures could lead to hazardous conditions. A hydrogen hazards analysis is a useful tool for hydrogen-system designers, system and safety engineers, and facility managers.

And how to involve the Bayesian approach in the hazard analysis and risk management in hydrogen industrial processes, one can use Bayesian networks to model the relationships between different variables and their impact on the overall risk of the system. Bayesian networks are a probabilistic graphical model that can be used to represent and understand potential hazards and risks, and how it is distinct from other approaches, as well as an in-depth discussion of the benefits that it offers.

2 The Theoretical Background

When it comes to manufacturing operations, conducting risk assessments and managing potential dangers are absolutely necessary to protect both workers and the surrounding environment. Hazard analysis is a procedure that involves detecting potential dangers that could be harmful to workers, the environment, or the general population as a whole. The process of evaluating potential dangers and taking preventative measures against them is what we mean when we talk about risk management. By anticipatorily identifying and mitigating potential hazards, the goals of hazard analysis and risk management are to reduce the likelihood of adverse events, such as accidents, injuries, and damage to the environment.In other word , Risk assessment refers to the overarching procedure or method in which you:

- ✓ Identify prospective hazards and risk factors that could cause harm (hazard identification).
- ✓ Analyze and assess the risk posed by this hazard (risk analysis and risk assessment).
- ✓ Determine appropriate methods for eliminating the hazard, or for mitigating the risk (risk control) if the hazard cannot be eliminated.

A risk assessment is a detailed evaluation of the workplace that identifies the elements, circumstances, and procedures, among other elements, that constitute a hazard, in particular, to employees. After a danger has been identified, it must then be analyzed and its likelihood and severity evaluated. After you have made this judgment, you will be able to decide the steps that need to be taken in order to either repair the damage or prevent more damage **[85].**

2.1 The Concept of Risk

When discussing risks, there is an imminent risk that each person will express a different perspective.Risk is defined in a variety of ways, and providing a universal definition of "Risk" is difficult. There are numerous definitions in various literatures, each of which varies according to the problem domain. For instance, if the risk is based on an economic view, engineering or technical view, environment or human health concerns, or a broader view of risks in project objectives.

In general, risk is defined as the combination of an undesirable event's probability and its consequence. In other word, to answer the question “what is risk?” we need to answerthree questions: What can happen? What are the consequences? And how likely is this?

Risk, from the perspective of the environment, is the combination of probability and consequence. Consequences typically refer to various aspects of HSE, such as loss of life, injuries, environmental and social factors. Environmental risk comprises ecological risk, human risk, social risk, and cultural risk, in accordance with the United States Environmental Protection Agency's definition of risk.

Risk is defined by Chapman et al. (2003), PMI (2009), and Young (2010) as "an uncertain event or condition that, if it occurs, has a positive or negative impact on a project's objectives." In this definition, probability is referred to as uncertainty, and the consequence is referred to as the impact on project objectives. Aven (2010) argues that uncertainty is a crucial component of risk that must be accounted for in all aspects of risk assessment and decision analysis. The objectives of a project are scope, schedule, cost, and quality **[86] [87] [88]**.

In contrast to other definitions of risk, which emphasize only the negative effects, this definition includes both negative and positive outcomes. Chapman et al. (2003) and PMI (2009) argue that in any decision situation, both hazards and opportunities should be managed. Never permit a singular focus to eliminate concern for others.Consequently, the risk concept encompasses both uncertain events that could have a negative impact on a project's objectives and those that could have a positive impact.

2.2 Hazard :

It is important to remember hazard is different to risk. A hazard is a situation that has thepotential to cause harm, including human injury, damage to property, damage to the environment, or some combination of them **[89]**.

As previously stated, a hazard exists when a situation has the potential to cause an adverse outcome.In contrast, risk is the likelihood that such effects will occur.

2.3 Probability/likelihood

A probability is a means of conveying the likelihood of an event or consequence. There are basically two ways ofinterpreting a probability:

A) Risk exists objectively within the classical statistical approach, and specialists should calculate the most accurate estimate of this risk based on empirical data. This approach interprets probability as the proportion of times an event would occur if the investigated situation were repeated an infinite number of times. According to this definition, each event has an occurrence probability, such as once every 100 years **[88]**.
B) Probability, from a Bayesian perspective, is a subjective measure of uncertainty.Probability is a measure of uncertainty regarding an event's occurrence and its outcomes, based on the evolving expertise and body of knowledge of experts **[88]**.

As an example, as an illustration, the probability of a process facility exploding within one year. In accordance with definition (A), if sufficient experience data are available, estimates are derived by analyzing the data using the traditional statistical method. These estimates are dubious, as there may be a significant discrepancy between them and the actual values in the future. In accordance with definition (B), we use engineering judgments to establish subjective uncertainty measures in order to estimate the true value of probability if the required data are unavailable **[88]**.

2.4 Uncertainty

Every decision-making circumstance involves some degree of uncertainty; without uncertainty, decisions would be simple. In contrast, reality is more complex, and decisions necessitate uncertainty-based judgments. Uncertainty exists when we lack certain knowledge that is assumed to be essential for making a decision.

For example, capital investment decision making in oilfield exploration projects involves a great number of uncertainties in terms of oil price and demand, geological and operationaluncertainties, political issues, etc., all of which have an impact on their investment plan in this industry.

In other words, uncertainty exists when all potential outcomes of an event are unknown, the probability of hazards and/or their associated outcomes is uncertain, or both the outcomes and the probabilities are unknown.

2.5 Risk Vs Uncertainty

It is necessary to make a distinction between risk and uncertainty. There is a variety of written material available that discusses uncertainty, risk, and the differences between the two.

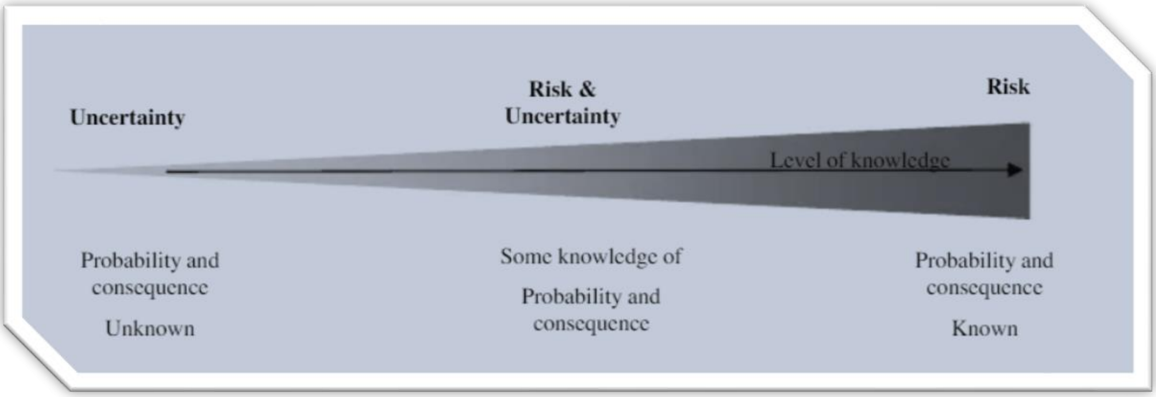


Figure 1 : *The level of knowledge about Risk and Uncertainty*

From an economic point of view, Frank Knight is responsible for the introduction of the most well-known theory. In this theory, quantifiable uncertainties are defined as risk, whereas non-quantifiable uncertainties are defined as uncertainty. This means that risk is present if you are able to assign a probability to future events, whereas uncertainty is present if the probability of future events is either indefinite or incalculable.

Risk and uncertainty are defined as follows :

• Uncertainty exists where you don't know the all possible consequences, the possibility ofsubsequences are completely unknown or you don't know what the underlyingdistribution look like, or both consequences and probabilities are unknown (Rodger et al.,1999; Kaliprasad, 2006; Sackmann, 2007; Migilinskaset al.,2008).

• Risk exits where we know the all possible consequences but we don't know whichconsequences will occur for sure; in addition the probability of outcomes or theunderlying outcome distribution is known by decision makers (Sackmann, 2007;Migilinskas et al., 2008).

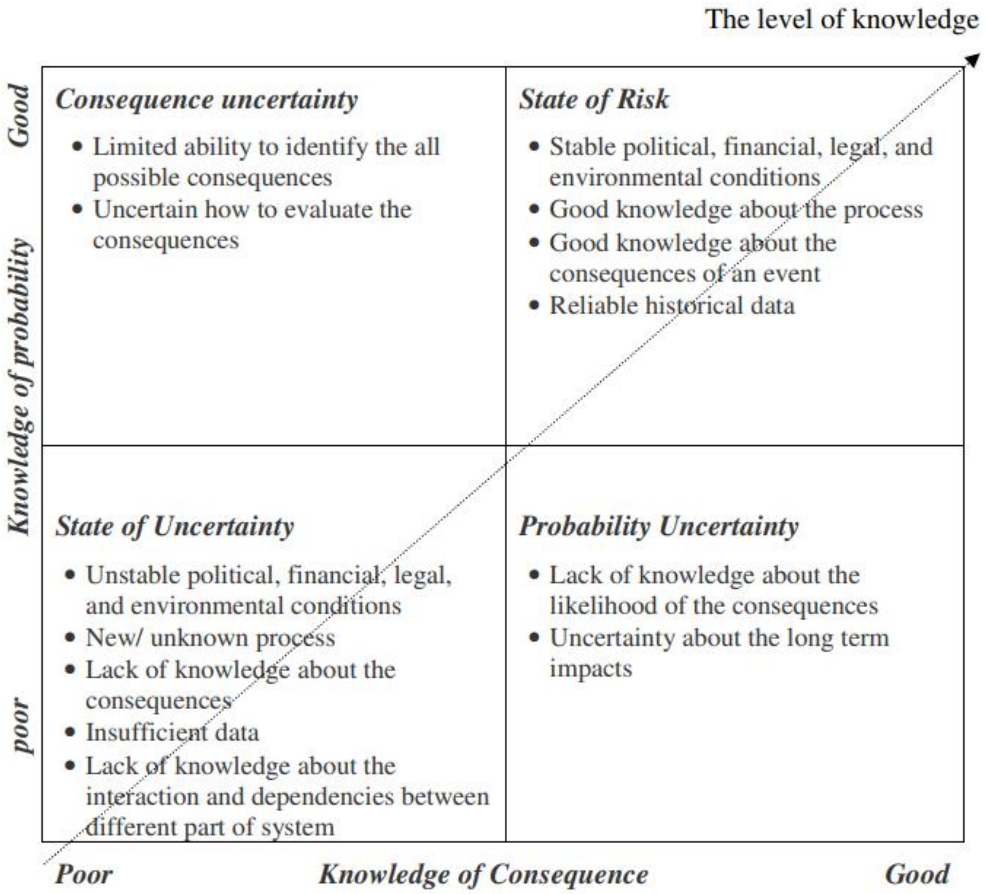


Figure 2 : *the relation between the level of knowledge about probability and consequence and distinction between risk and uncertainty*

2.6 Variables

Variables are the fundamental constituents that must be identified for the risk assessment. A variable is any entity that can take on different values depending on the situation.

In financial modeling, variables may include sales, costs, revenues, and profits, among others. In contrast, variables in modeling a risk analysis of a process facility may include pressure, temperature, flow, or chemical composition of the material.

3 Risk Management Methodology

All companies must implement an effective management system to resolve the health and safety aspects of their operations. This management system should be applied to all phases of a project's life cycle and all associated activities. A key component of an effective management system is a systematic approach to the identification of hazards and assessment of associated risk in order to provide information to facilitate decision-making regarding the need to implement risk reduction measures.

In recent years, there has been a significant interest in managing project risks and uncertainties to improve project success. The term "Risk Management" encompasses a vast assortment of tools, techniques, processes, and methodologies. The distinction between "Management of Business Risk" and "Operational Risk Management" is crucial. Uncertainty in terms of finance and insurance refers to the management of business risks. The genesis of Operational Risk Management focuses primarily on the physical damage that may result from faulty equipment or operator performance.

3.1 Risk Management Processes

According to Figure 3, which was adopted from the Australian and New Zealand standard (2004), the risk management process consists of establishing the context, risk assessment (including hazard identification, risk analysis, and risk evaluation), risk management, communication and consultation, and monitoring. Figure 3 depicts the risk management process phases as well as the control and information flow between each step.

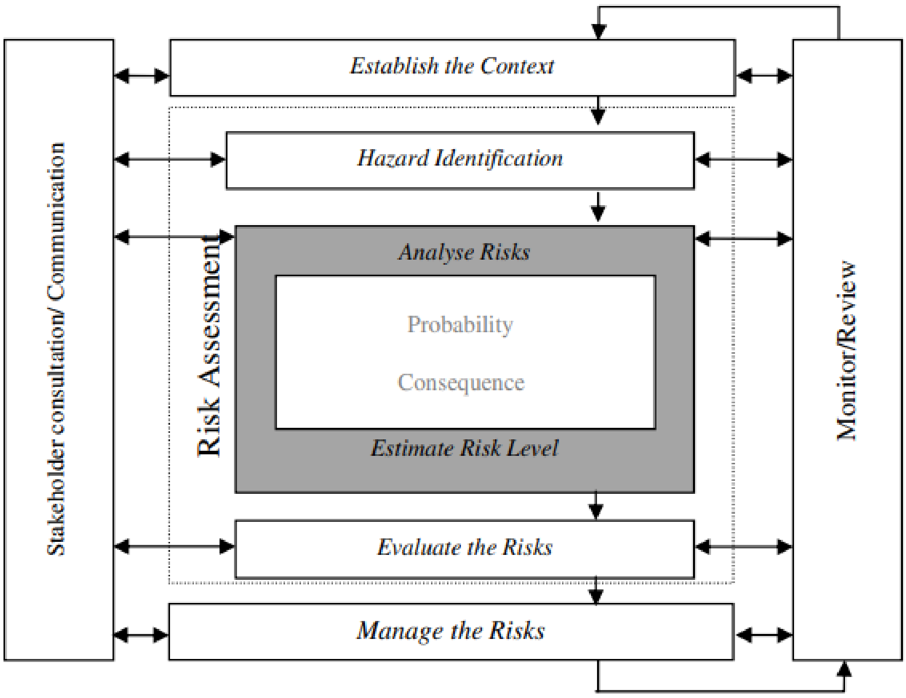


Figure 3 : *Risk Management Process*

3.1.1 Establish the Context

Establishing the context is the first step in the project risk management process, which involves defining suitable decision criteria and structures for carrying out the risk assessment process. The context includes determining risk assessment objectives, risk criteria, and risk assessment programs agreed upon by all stakeholders. It is important to consider external and internal contexts, as well as the risk management context, when establishing the context. The purpose of establishing the scope, context, and criteria is to customize the risk management process and enable effective risk assessment and appropriate risk treatment **[89]**.

3.1.2 Risk Assessment

Risk assessment encompasses hazard identification, risk evaluation, and risk analysis. After identifying the hazards, the associated risks are analyzed in terms of their probability and consequences, and unacceptable risks are identified by comparing them to risk acceptability criteria. On the basis of the results of the risk assessment process, decision makers can determine whether an activity should be undertaken, the most appropriate risk treatment strategies, and whether hazards need to be reduced or eliminated **[90]**.

Risk assessments are crucial because they are an integral component of a health and safety management plan. They aid in **[85]**:

- Create awareness of risks and hazards.
- Determine who may be at risk (employees, caretakers, visitors, contractors, the general public, etc.).
- Determine if a control program is necessary for a specific hazard.
- Determine if the current control measures are sufficient or if more needs to be done.
- Prevent injuries and ailments, particularly during the design and planning phases.
- Prioritize risks and preventative measures.
- Conform to applicable legal requirements.

There may be numerous reasons why a risk assessment is necessary, such as:

- Before introducing new processes or activities.
- Before introducing alterations to existing processes or activities, such as when products, machinery, tools, or equipment change or when new information regarding potential harm becomes available.
- When risk factors are identified.

3.1.3 Managing the Risk

According to ISO 17776:2000, AS/NZS: 4360, 2004, the appropriate strategy to reduce unacceptable risk to a tolerable level should be developed based on hazard and risk assessment. The strategies can be based on expert judgment or criteria adopted by the company. The possible strategies include avoiding the activity that generates the risk, reducing the likelihood, reducing the consequence or both, transferring the risk, and retaining the risk. Decision-makers should select the most suitable strategy among the possible response strategies. They should ensure that the selected response is achievable, affordable, cost-effective, and appropriate **[90] [91]**.

3.1.4 Monitoring and Review

To ensure the efficacy of the Risk Management Process, it is necessary to regularly review, monitor, and update it. This includes reevaluating previously identified hazards and associated risks, identifying new risks, managing them appropriately, and evaluating and monitoring the efficacy of implemented strategies throughout the life cycle of the project. The progress of risk management should be reported to the risk proprietors so that they can determine whether the risk management was effective or if additional action is required. As the project progresses, additional information becomes available, the environment changes, and/or new information is acquired, all of which can have an impact on the activities of each phase. Consequently, it is essential that the Risk Management Process be repeated frequently throughout the project's life cycle **[90] [91]**.

3.1.5 Communication and Consultation

Effective communication and consultation with stakeholders are crucial for success in risk management. All stakeholders who need to be involved in the process should be kept informed about the progress of the process. Involving stakeholders in the risk management process is necessary for developing a communication plan, meeting the interests of stakeholders, considering different views in evaluating risks, and supporting risk management strategies **[92] [93]**.

There are several best practices for involving stakeholders in risk management. First, it is important to identify all stakeholders who may be affected by the risks and who may have an interest in the outcome of the risk management process. Second, stakeholders should be engaged throughout the project and risk management process to ensure that they are aware of the potential risks, their outcomes, and provide information about the risk. Third, managing stakeholder expectations and interests is a crucial part of any project, especially when it comes to identifying and addressing potential risks **[92] [93].**

By engaging stakeholders, there are opportunities for the project team and manager to understand different perspectives, obtain expertise, and develop appropriate risk mitigation or treatment responses. Organizations should continually identify, manage, and communicate risks to key stakeholders during the different phases of crisis management. A stakeholder orientation demands that organizations seek and involve risk stakeholders in the risk management process. The level of involvement will depend on both the identified risks and how stakeholders are expected to be affected by the proposed solutions and decision-making processes **[92] [93]**.

3.2 Risk Assessment Process

Hazard and risk assessment is a process that involves hazard identification, risk analysis, and risk evaluation (Figure 3). Risk analysis estimates the characteristics of the risk, while risk evaluation uses information from risk analysis and risk acceptance criteria to identify unacceptable risks and take necessary actions to eliminate or control the harm from happening. The process of hazard and risk assessment is a systematic examination of a task, job, or process that a risk professional carries out at work to identify significant hazards. The process involves identifying hazards and risk factors that have the potential to cause harm, analyzing and evaluating the risk associated with that hazard, determining appropriate ways to eliminate the hazard or control the risk when the hazard cannot be eliminated, documenting the risks, taking action, and reviewing the results. The results provide insight for decisions, where choices are being made, and the options **[85] [94]**.

3.2.1 Hazard Identification

According to ISO 17776:2000, hazard identification is a crucial step in assessing the risk associated with a particular activity. Without identifying hazards, it is impossible to estimate the consequences and probabilities of an operation, and subsequently, implement risk reduction strategies. The standard describes various tools and techniques that are commonly used to identify and assess hazards in the petroleum and natural gas industries, particularly in offshore production installations **[90]**.

Therefore, before undertaking any activity, it is important to identify the hazards that may arise from it to ensure the safety of all involved.

3.2.2 Risk Analysis

Risk analysis is a process that involves identifying hazards and determining the probability and consequences of risks arising from the identified hazard. The consequences and probabilities are then combined to determine the level of risk. These analyses provide decision-makers with characteristics of the risks associated with personnel, environment, and facilities **[95] [96]**.

Risk analysis can be carried out qualitatively or quantitatively. Qualitative techniques involve defining the probability and consequences of risk in terms of high, medium, and low. Then, the level of risk is determined by the combination of probabilities and consequences. In qualitative analysis, there should be a clear description of employed terms. Semi-quantitative techniques use a numerical rating scale instead of subjective rating for probabilities and consequences. The probabilities and consequences are combined to estimate the level of risk. Quantitative techniques allow estimating the realistic value for consequences and probabilities rather than in relative terms such as low, medium, and high. However, lack of sufficient and detailed information about activities in the project causes that quantitative techniques be not possible all the time. A quantitative risk analysis can be carried out either deterministic or stochastic. In deterministic approach, a single-point value is used to estimate the likelihood and consequences. In stochastic approach such as Monte Carlo simulation, uncertain inputs are represented by a range of possible values which is known as probability distributions. Describing uncertainty in variables is more realistic by using probability distributions **[95] [96]**.

Consequence analysis

The consequence analysis estimates the impact of particular events or circumstances on the project's objectives. In general, consequences are divided into four categories: health, safety, environmental, and economic. Safety consequences pertain to the potential for human injury or death as a result of hazardous situations. Some hazards can cause health issues, such as H2S's long-term health effects. Some hazards do not result in human injury or death, but they do have environmental consequences, such as an oil discharge in a river. All hazards have economic repercussions, including production loss, asset loss, and increased maintenance costs.

Probability Estimation

There are various techniques for estimating the probability of the outcomes of an event or circumstance identified during the risk identification phase. Using historical data about the typical event or situation that has occurred in the past to estimate the probability of an event occurring in the future is a common method.

When historical data is unavailable, probabilities are predicted using predictive techniques such as fault tree analysis and event tree analysis. By analyzing a system, activity, piece of equipment, or organization, the necessary data for estimating the probability of consequences is identified. This method determines the numerical data for equipment, individuals, and system based on operational experience or published data, and then combines these numbers to calculate the probability of the top event. Simulation techniques may be required to calculate the influence of uncertainties on the probability of equipment and structural failure in order to generate failure probabilities **[97] [98]**.

Subjective methods employing expert opinion in a structured and systematic manner are another method for estimating probability. There are numerous formal methods, including what-if analysis, HAZOP, the Delphi method, etc.

Prioritizing risks:

A risk matrix is a tool used to prioritize risks based on their likelihood of occurrence and potential impact on the project or organization. The matrix works by combining the probability and consequences of each risk to determine its level of risk. Once the risks are identified and categorized, decision-makers can use the prioritization to decide whether to treat risks without further assessment or proceed with more detailed risk assessment. The risk matrix is a crucial tool in risk management for easy prioritization of risks and risk-informed decision-making. The risk assessment matrix methodology should be formally documented in policy and procedure documents, including any weighting and any changes to the risk process or approach. The prioritization of risks should be based on the likelihood of a risk and the potential harm it poses to the organization. A risk matrix is an effective tool for prioritization; it lets you chart each risk by likelihood and severity **[99]**.

3.2.3 Risk Evaluation

Based on the results of risk analysis and risk criteria, risk evaluation serves as the foundation for risk management decision making. The objective of risk criteria is to assess the acceptability of an identified hazard or its consequences. During the conceptualization phase, the risk criteria are defined, but they should be refined in the risk evaluation phase based on the additional information obtained by analyzing risks. In addition to the outcome of risk analysis, political, economic, social, and technical considerations are taken into account during risk evaluation. Decision-makers must determine whether a risk must be mitigated or eliminated, and whether a given activity should be pursued.

Typically, risk criteria are defined using national and international protocols, standards, and environmental regulations. Additionally, the company's policies defining maximal acceptable risk levels must be taken into account **[90]**.

Standards for engineering and other professional documents can provide direction. But ultimately, the manager or any conducting resposible must make a decision based on risk.

Various terms are used to determine the level of acceptable risk; ALARP is discussed in greater detail here:

ALARP (As Low As Reasonably Practical)

ALARP is a principle used to regulate and manage safety-critical and safety-involved systems. It stands for "As Low As Reasonably Practicable" or "As Low As Reasonably Achievable." The principle is that the residual risk shall be reduced as far as reasonably practicable. In the UK and NZ Health and Safety law, it is equivalent to SFAIRP ("so far as is reasonably practicable"). The ALARP principle can be used to define two sets of risk tolerance criteria: a minimum requirement and a target value. Between the two sets of criteria, the range of risks is tolerable. The residual risk should fall either in the broadly acceptable region, or near the bottom of the tolerable region.

The ALARP region lies between unacceptably high and negligible risk levels. For a risk to be ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. The ALARP principle originated within a legal and regulatory framework and is used by regulators and companies around the world as it provides a way to provide higher levels of safety where it is feasible **[100] [101]**.

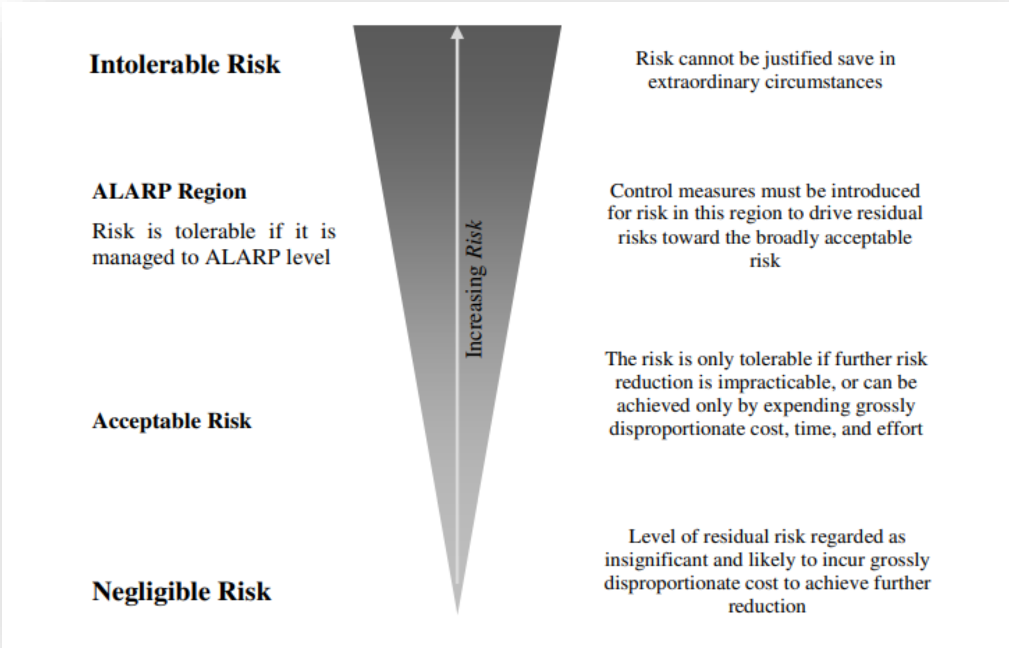


Figure 4 : *Level of risk and ALARP*

It is difficult to precisely define the term "As Low As Reasonably Practical" (ALARP), but some guidelines have been developed to determine its meaning. These recommendations are founded primarily on engineering judgments and codes.

Some guidelines to identify the level of ALARP are:

- The use of best available technology which is adopted to install, operate and maintain in the work environment by the people prepared to work in that environment;
- The best operations and maintenance management systems relevant to safety;
- High level of standard for maintenance of the equipment and management systems;
- The trust of employee to the low level of risk.

The difficulty with this concept is that it is impossible to define terms such as best available technology, best operation, or high standard objectively.

3.2.4 Selection of methods for hazard identification and risk assessment

Hazard identification and risk assessment in a project require the selection of appropriate tools and techniques based on various factors such as the level of complexity, type and level of risk, potential magnitude of the consequence, available information and resources, regulation or contractual requirement, and the stage of the project life cycle. The appropriate tools vary depending on the level of complexity of the project. For instance, in large production plants with complex facilities, detailed studies are required to address all hazardous scenarios, while in simpler projects with limited process facilities, it may be possible to rely on application of codes and standards. The nature and degree of uncertainty should be taken into account through the selection of hazard identification and risk assessment method. Poor quality data or the lack of essential and reliable data is one of the sources of uncertainty. Some of the common risk assessment tools and techniques include risk matrix, decision tree, failure modes and effects analysis (FMEA), bowtie model, documentation reviews, brainstorming, Delphi technique, root cause analysis, SWOT analysis, hazard and operability study (HAZOP), fault tree analysis, and probability and impact matrix **[102]**.

3.2.5 Classification of Hazard Identification and Risk Assessment Techniques

SA: Strongly Applicable **A:** Applicable **NA:** Not Applicable

Table 1 : *Selection of tools for risk Assessment Process*

Techniques	Hazard and Risk assessment Process				
	Hazard Identification	Risk Analysis			Risk Evaluation
		Consequence	Probability	Level	
Checklists	SA	NA	NA	NA	NA
SWIFT	SA	SA	SA	SA	SA
Fault Tree Analysis	NA	A	A	A	A
Event Tree Analysis	NA	SA	SA	A	NA
Cause & Consequence Analysis	A	SA	NA	A	A
FMEA	SA	NA	NA	NA	NA
FMECA	SA	SA	SA	SA	SA
HAZOP	SA	SA	NA	NA	SA
Monte Carlo	SA	SA	SA	SA	SA
Consequence/Likelihood Matrix	SA	SA	SA	SA	A

Methods for identifying hazards and assessing risks can be classified in various ways to determine their strengths and weaknesses within each category. Two classification approaches for risk assessment methodologies are presented here. The first classification illustrates how various methods pertain to each phase of the hazard and risk assessment procedure. Based on this perspective, risk and hazard assessment methods are categorized into the five categories shown in Table 1 above:

- Hazard identification,
- Consequence analysis,
- Qualitative, semi-quantitative, and quantitative probability analysis
- Estimation the level of risk
- Risk Evaluation

3.3 Hazard Identification and Risk Assessment Techniques

3.3.1 Check lists

Checklists are a straightforward method of hazard identification. Based on previously developed lists, regulations, or standards, they provide a list of typical hazards that must be taken into account during the process. Checklists are appropriate for situations with minimal levels of uncertainty and straightforward processes. Checklists are applicable at all phases of the project life cycle.

In addition, they can be incorporated into other hazard and risk assessment techniques to ensure that everything has been accounted for.

3.3.2 Preliminary Hazard Analysis (PHA)

PHA is an analytical technique used to identify hazards that will lead to dangerous scenarios. Typical sources of hazardous events include pressurized oil and gas, fluids at high temperatures, toxic, explosive, combustible, and radioactive materials, etc **[90]**.

PHA is frequently performed at the conceptual and fundamental design phases of a project, when little is known about the detailed design and operational procedures. This technique permits the identification of potential risks early in the project's life cycle, thereby facilitating the selection of the optimal arrangement of facilities and equipment.

The process of PHA involves the following steps **[90]**:

- Definition of operational modes and subsystems.
- Identification of hazards associated with each subsystem.
- Definition of hazardous scenarios arises from the identified hazard.
- Estimation of the probabilities and potential consequences of the hazardous scenarios and the level of risk.

- Identify the safeguards and appropriate actions which should be taken to reduce the probability, impact of consequences or both.
- Identify the interaction of hazardous scenarios.

3.3.3 Fault Tree Analysis (FTA)

Fault Tree Analysis is a graphical, deductive technique for identifying the combination of factors, such as equipment failure and human error that can lead to the occurrence of dangerous scenarios (top event).

In addition, the probability of the top event can be estimated by calculating the failure rate of each component. FTA is an effective technique for analyzing complex systems. This method is frequently used in conjunction with other hazard analysis methods, such as HAZOP, when a hazardous scenario requiring further investigation has been identified **[103]**.

The Fault Tree is composed of gates and events. Or Gate yields a positive output if one or more of the inputs are positive. In contrast, all inputs to an And Gate must be positive for the output to be positive. The Voting Gate requires at least three positive inputs for a positive output **[103]**.

In Fault Tree Analysis, there are three events: the Top Event, Intermediate vents, and Basic events. As previously stated, Fault Tree Analysis is utilized to determine how a hazardous scenario is caused; this undesirable occurrence is known as the Top Event. The following topics should be added to the definition of top event: how much? How long? What is the impact on safety? What is the impact on the environment? What is the effect on production? What are the regulatory consequences? The intermediate event is defined to advance the analysis of the primary event. Through the OR and AND Gates, intermediate events are developed to become the fundamental event. The Base Event cannot be further developed. After the tree is constructed, it can be measured **[103]**.

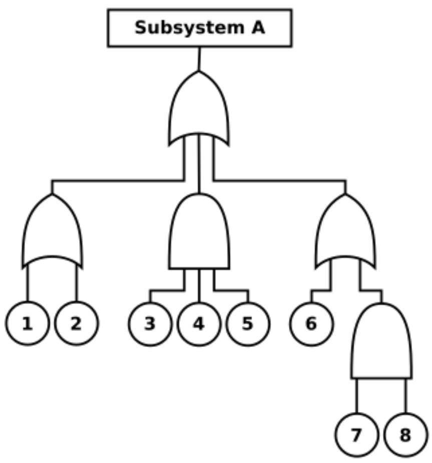


Figure 5 : *Fault Tree Analysis (FTA) Example.*

Once the fault tree has been constructed, the failure rate for each individual component can be inputted, and then the probability of an undesirable event can be calculated. The primary source of uncertainty in this method is the estimated failure rate, also known as measurement uncertainty **[103]**.

After the fault tree model and its associated estimation have been created, additional safeguards can be implemented as mitigation measures.

3.3.4 The HAZOP Study Method

HAZOP (Hazard and Operatability Analysis) is the most popular technique for identifying hazards or dangerous situations. The organization of HAZOP is its greatest asset. The HAZOP meeting begins with the selection of nodes. A node represents a section of the process in which the pressure, temperature, or chemical composition changes significantly. In practice, a single node can encompass multiple process changes.

Table 2 : *Examples of possible parameters for process operations.*

Examples of possible parameters for process operations	
• Flow • Pressure • Temperature • Mixing • Stirring • Transfer • Level • Viscosity • Reaction • Composition • Addition • Monitoring • Separation • Time • Aging	• Phase • Speed • Particle size • Measure • Control • pH • Sequence • Signal • Start/stop • Operate • Maintain • Diagnostics • Services • Communication

HAZOP is primarily concerned with identifying deviations from design or secure process conditions. Therefore, the process parameter to be discussed must be identified. Flow Rate, Flow Quantity (for batch operations), Pressure, Temperature, Level (when vessels and containers are part of the node), Composition, and Phase are the general process parameters. Whenever feasible, the safe limit values for each parameter should be determined. It is important to note that the HAZOP study must examine the whole envelope of the process parameters, including the low flow mode which may require special attention.

Table 3 : *Examples of meaningful combinations of parameters and guidewords.*

Parameter	Guidewords That Can Give a Meaningful Combination
Flow	None; more of; less of; reverse; elsewhere; as well as
Temperature	Higher; lower
Pressure	Higher; lower; reverse
Level	Higher; lower; none
Mixing	Less; more; none
Reaction	Higher (rate of); lower (rate of); none; reverse; as well as/other than; part of
Phase	Other; reverse; as well as
Composition	Part of; as well as; other than
Communication	None; part of; more of; less of; other; as well as

After identifying the nodes and safe operating limits, the danger is determined. High, Low, No, Reverse, Misdirected, and Wrong are typically the guidewords for deviations from the safe operating limits. The HAZOP Matrix is utilized to organize process and deviation directives. The deviation from the secure limits must be communicated to the operator. These alarms notify the operator of a potentially hazardous condition. If the HAZARD team determines that there is no obvious method to alert the operator of the hazardous condition, they should recommend the installation of additional instrumentation to provide alarms.

The next stage is to determine the consequences of the hazard in terms of safety, the environment, and economics. Additionally, the incidence of each risk should be evaluated. In addition, the team should assess the risk associated with each identified hazard scenario. Risk Matrix is the correct method for ranking hazards. Finally, a recommendation should be generated for those hazards whose risk level exceeds the acceptable risk level.

The HAZOP implementation may be slower than other methods. However, the primary benefit of the HAZOP method is its systematic and logical approach. The HAZOP team should adhere to a standard format that includes special directives and deviations that must be addressed. The team supervisor is responsible for directing the meeting throughout the process. In addition, HAZOP can analyze a combination of failures by resolving sequential failures that continue to occur. When the process is straightforward, the specific HAZOP is not required; instead, the team can assess the items using What-If questions.

HAZOP can be performed at any project stage, from the conceptual to the modification stage. During the execution phase, however, it may not be economically practicable to implement the HAZOP study's recommendation to control the assessed hazards. Therefore, the optimal time to apply HAZOP is when the recommendations can be readily implemented by alerting the design, processes, and operational procedures.

Therefore, the optimal time for the HAZOP study is just after the fundamental design and before any decisions are made regarding fabrication or installation; the implementation of suggested modifications will be most cost-effective at this stage. In addition, the information required for conducting an effective HAZOP study, such as P&IDs, PFDs, material data sheets, and operational procedures, should be accessible at this stage.

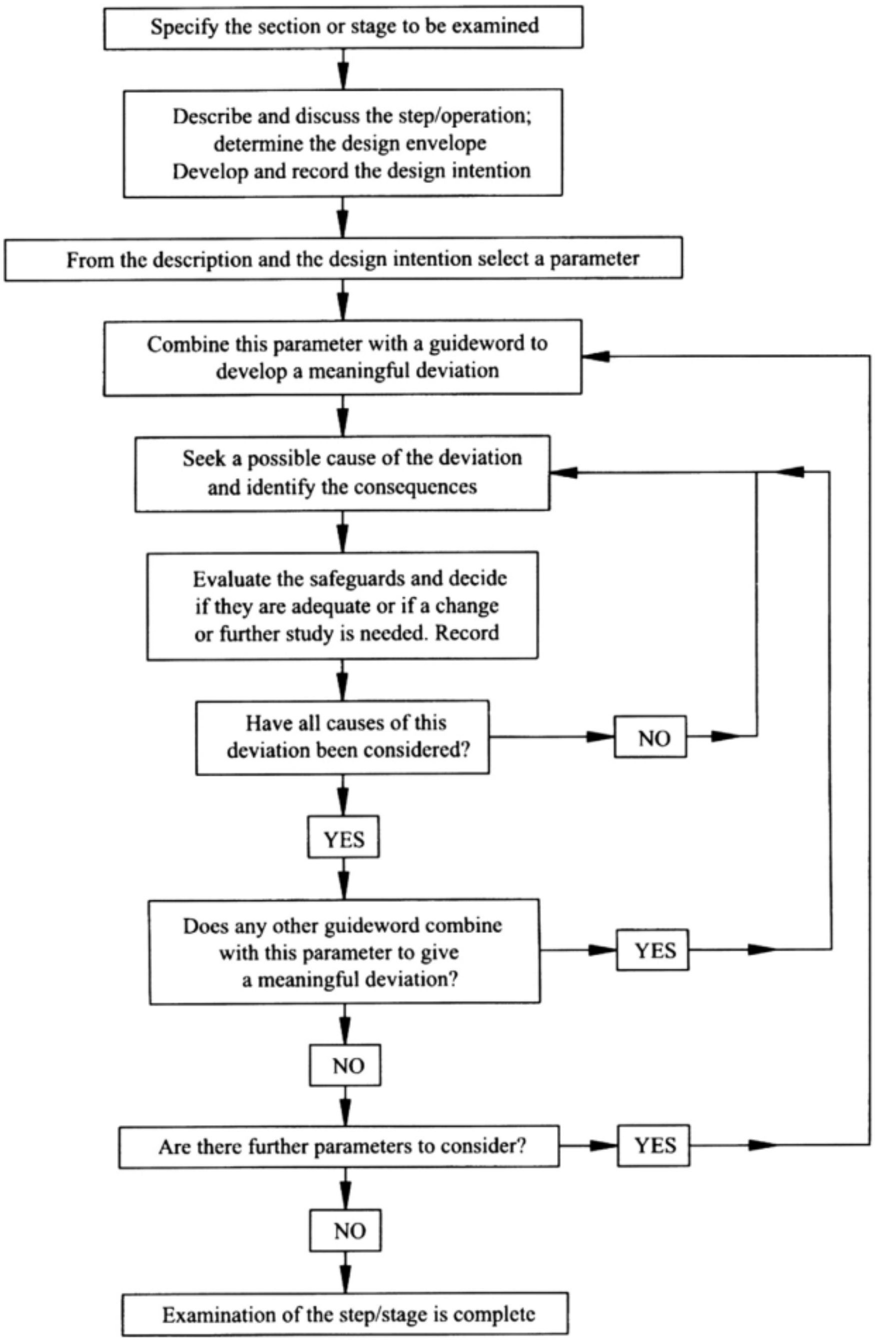


Figure 6 : *Flow diagram for the HAZOP analysis of a section or stage of an operation —the parameter-first approach.*

While HAZOP is one of the most versatile techniques for hazard identification, other identification and assessment techniques can be used to supplement HAZOP during the detailed design phase (As example of a use).

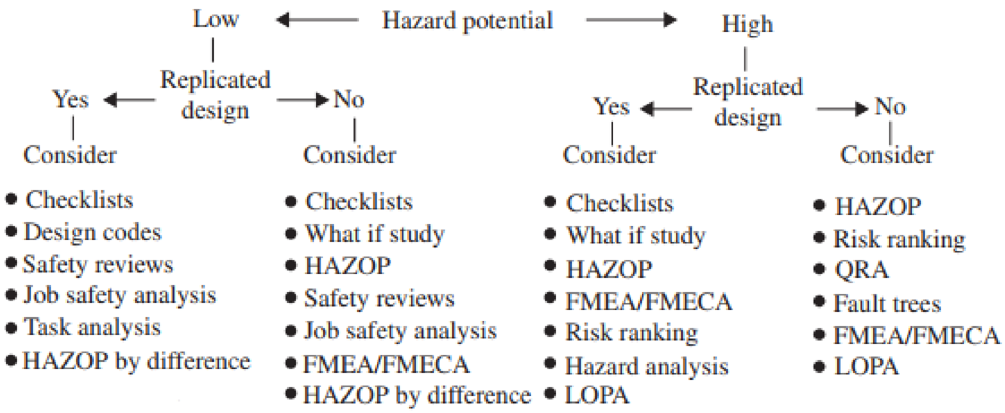


Figure 7 :*Possible alternatives to replace or supplement HAZOP study as a detailed design hazard study.*

3.3.5 Risk Ranking Matrix

The Risk Ranking Matrix is used to evaluate the risk level by combining qualitative or semi-quantitative ratings of consequence and likelihood. When many risks have been identified, this matrix is typically used as a screening tool to determine which risks require more detailed analysis, or which risks must be managed first **[106]**.

The consequence scale should encompass the spectrum of consequences to be considered (financial loss, safety, the environment, and other dependent parameters).

Likelihood rating							
	E	IV	III	II	I	I	I
	D	IV	III	III	II	I	I
	C	V	IV	III	II	II	I
	B	V	IV	III	III	II	I
	A	V	V	IV	III	II	II
		1	2	3	4	5	6
		Consequence rating					

Figure 8 : *Risk matrix.*

The likelihood scale may have any number of points; it must span the pertinent range for the current study **[106]**.

Figure 7 depicts a matrix with a six-point scale on the consequence axis and a five-point scale on the probability axis. To rank risks, first the consequence descriptor that best fits the situation is identified, followed by the probability that the consequences will occur. Numerous risk events have multiple repercussions. Therefore, it is possible to address either the most frequent or most severe outcomes, or some other combination.

3.4 Bayesian Networks

The concept of "Bayesian statistics" is derived from the "Bayesian" neologism, which was named after Thomas Bayes, who introduced the theorem in a posthumous article published in 1763, 250 years ago. This theorem expresses conditional probabilities in terms of their inverses **[107]**.

The Bayesian method makes it possible to infer the probability of an event based on the probabilities of previously evaluated events. It is based on the formula for conditional probability **[107]**:

$$p(B_i / A) = \frac{p(A / B_i)p(B_i)}{\sum_{i=1}^{n} p(A / B_i)p(B_i)} \quad (1)$$

Where P (A | B_i) is the conditional probability of obtaining event A given that B_i is the i^{th} cause, P (Bi) is the "a priori Probability of B_i", P (A | B_i) is the likelihood function, and P (Bi | A) is the "a posteriori Probability of Bi." i ranges between 1 and n, the number of potential causes **[107]**.

3.4.1 Major Limitations of QRA

QRA is thoroughly integrated into process safety studies as a tool for land use planning and spacing of critical units in oil and gas facilities. The preponderance of QRAs conducted during the design phase of a facility, however, are typically stored in the records section or on library shelves. During the operational phase, very few or no attempts are made to update these QRAs.When changes are made to the facilities, QRAs are typically conducted only on the portion that is altered, which has proved to be fundamentally flawed **[108]**.

Executing QRAs provided direct evidence of these limitations. They are summarized as follows **[108]**:

- Uncertainties in data for failure frequencies, lack of precision in models and difficulties in identifying common cause failures.

- Assumptions are not visible to all concerned.
- Models are static, difficulties in capturing variations/changes to the facility
- Requires considerable specialist efforts and time
- Software is costly, calculations are not transparent and limit flexibility
- The causes of loss of containment are not investigated in detail

3.4.2 BN and Its Advantages

BN is viewed as a viable alternative to and/or a supplement to the QRA method. BN is being widely applied to computer science, ecology, finance and chemical industries. So, the main advantages of BN are as follows **[108]**:

- It presents the risk in a visually and easily understandable manner
- The methodology is transparent.
- Failure data and thereby the risk profile can be easily updated in line with changes/updates of the facility
- Site-specific data (even if it is sparse) and experts' opinion can be incorporated.
- Layers of interconnecting causes of loss of containment can be fully explored.
- BN can be simulated in predictive and diagnostic mode since causes and effects with their relationships are represented in a transparent model

In conclusion, although QRA has a role in Land Use Planning (LUP) and safe distances, Bayesian techniques provide models that can represent a version of cause and effect.

3.4.3 Probability Basics

Probability is a numerical measure of the likelihood of an event occurring relative to a set of alternative events that do not occur. The set of all possible events must be known. Probability is always a number between 0 and 1, where 0 means an event is impossible and 1 means an event is certain. The probabilities in a probability model must sum to 1. When the outcomes of an experiment are all equally likely, we can find the probability of an event by dividing the number of outcomes in the event by the total number of outcomes in the sample space for the experiment. To find the probability of the union of two events, we add the probabilities of the two events and subtract the probability that both events occur simultaneously. The probability of the complement of an event is the difference between 1 and the probability that the event occurs **[109].** Here are some of the basic rules of probability **[109]**:

- Addition Rule: Whenever an event is the union of two other events, say A and B, then $P(A \text{ or } B)=P(A)+P(B)-P(A\cap B)$.
- Complementary Rule: Whenever an event is the complement of another event, specifically, if A is an event, then $P(\text{not } A)=1-P(A)$ or $P(A') = 1 - P(A')$.

- Conditional Rule: When event A is already known to have occurred and probability of event B is desired, then P(B, given A)=P(A and B)P(A, given B). It can be vice versa in the case of event B.
- Multiplication Rule: Whenever an event is the intersection of two other events, that is, events A and B need to occur simultaneously.
- Then P(A and B)=P(A)·P(B) .
- The probability of an impossible event is zero; the probability of a certain
- For S the sample space of all possibilities, P(S) = 1
- For any event A, P(Ac) = 1 - P(A) .
- This is the probability that either one or both events occur.
- P(A or B) = P(A) + P(B) - P(A and B) .
- P(A or B) = P(A) + P(B) if A and B are mutually exclusive.

3.4.4 The Basis For The BN

A Bayesian belief network or Bayesian network (BN) is a graphical model that can be used as an alternative to FTA and ETA to depict the relationships between a system failure or accident and its contributing factors (causes), as well as one or more outcomes (consequences), in an industrial system **[110]**. BN analysis is more general than FTA and ETA analysis because causes and effects do not need to be binary events and can be qualitative or quantitative; the combination of the two approaches depends on what is being analyzed **[111]**.

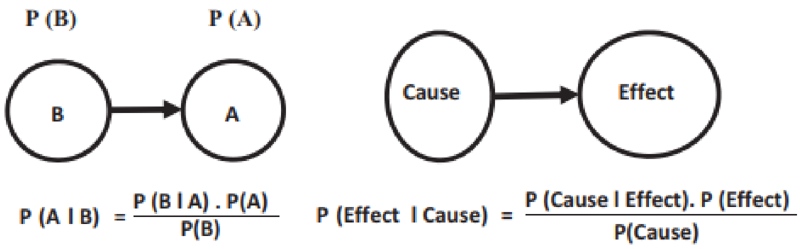


Figure 1 *Bayes theorem for cause and effect.*

Nodes and directed arcs constitute the network. Each node represents a component, state, or condition, while each arc represents a direct relationship between nodes.

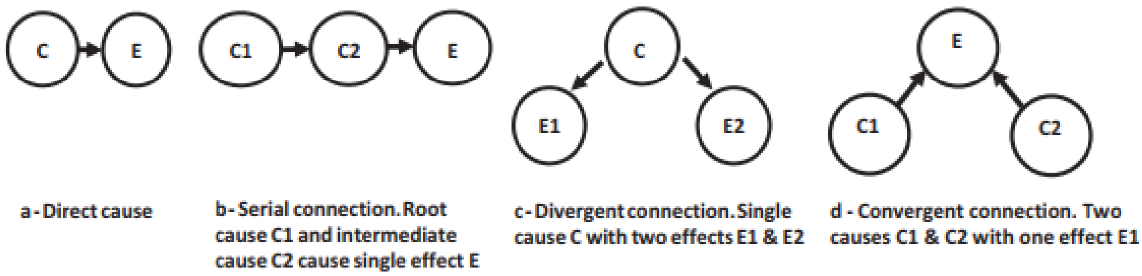


Figure 10 : *Types of cause and effects relationships and their Bayesian representation.*

A BN indicates the joint probability distribution P(X) of variables U $=\{X_1, X_2 \ldots X_n\}$ included in the network:

$$P(U) = \prod_{i=1}^{n} P(Xi/Pa(Xi)) \quad (2)$$

Where Pa (X_i) is the parent set of the variable X_i; the probability of X_i is then calculated as follows:

$$P(Xi) = \sum_{Xi} P(U) \quad (3)$$

A BN utilizes Bayes' theorem to revise the prior probability of events given new observations, also known as evidence E, thereby producing the updated or posterior probabilities:

$$P(U / E) = \frac{P(U,E)}{P(E)} = \frac{P(U,E)}{\sum_{U} P(U,E)} \quad (4)$$

The unavailability of each parent node can be calculated using the exponential distribution by determining the probability density function of the time between failures of each parent node

$$U(t) = \frac{\lambda}{\lambda + \mu} - \frac{\lambda}{\lambda + \mu} e^{(-\lambda+\mu)t} \quad (5)$$

$$U(\infty) = \frac{\lambda}{\lambda + \mu} \quad (6)$$

3.4.5 The Dynamic BN (DBN)

Dynamic Bayesian network is a type of Bayesian network used to dynamically process time series data. In general, natural phenomena such as the toss of a coin do not alter the current probabilistic distribution based on the preceding outcome. Some phenomena, such as natural language processing and earthquakes, have causal relationships between the present state at time t and the previous state at time t-1. The standard Bayesian network does not take temporal causality into account.

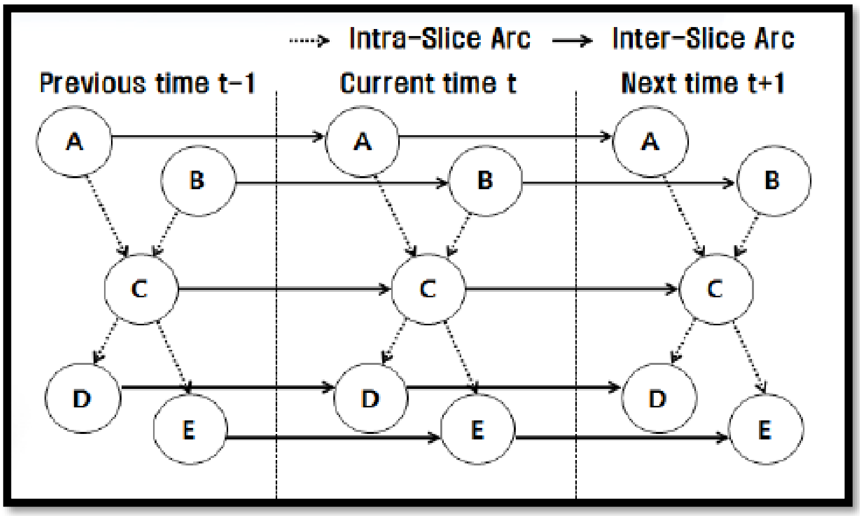


Figure 2 *A structure of dynamic Bayesian network.*

Utilizing a dynamic Bayesian network to depict the temporal relationship between nodes. This dynamic Bayesian network is valuable for monitoring, diagnosis, and prediction, among other tasks.

The majority of the events we encounter in our daily lives are not detected at a single point in time, but can be described through multiple phases of observations that result in a judgment of a single complete event. Numerous methods for reasoning about temporal relationships between various entities in the world have been devised by statisticians. This discipline is commonly referred to as time-series analysis.

Time is also an essential factor in the field. However, there is no direct mechanism for representing temporal dependencies in BNs. In an effort to introduce temporal dimension to the BN model, numerous strategies have been proposed. This novel dimension in BN models is frequently referred to as "temporal" or "dynamic" Nonetheless, the distinction between these models and their designation cannot refer to a single typical model. Sterritt et al. **[112]** attempted to differentiate between these categories in the manner described below:

Dynamic Belief Networks (DBN) should be the term of a model describing a system that changes or evolves dynamically over time. This model will allow users to monitor and upgrade the system over time, as well as predict the system's future behavior. In such models, the term "dynamic" is associated with "motive force." Changing the essence of the static BN to represent "motive forces" can be considered an adaptation to a dynamic model. Despite the fact that every system that changes its state involves time, authors distinguish between the terms dynamic and temporal in that temporal models explicitly model time as a continuous, permanent category as opposed to other system changes, such as a system's state change. Temporal models would therefore be a subclass of dynamic. If each time slice of a temporal model corresponds to a specific state of a system, and if the movement between the segments reflects a change in state rather than time, then the model is typically categorized as a dynamic model.

Regarding time representation, according to the same authors, temporal approaches can be divided into two primary categories: models that represent time as points (instances) or as time intervals. Nevertheless, time intervals can be viewed as a series of consecutive time points. Therefore, time-point representation appears more suitable and expressive.

3.4.6 Sensitivity Analysis

Given the occurrence of the initiating event, the most efficient characteristics of the BN are centered on the event likelihood updating (posterior) of each event. They depict the accident characteristics more accurately than prior probabilities and are therefore less uncertain **[111]**.

In any system failure and sensitivity analysis, the ratio of variation (RoV) in Equation (7) can represent a reliable proportion of importance **[111].**

$$RoV(Xi) = \frac{\pi(Xi) - \theta(Xi)}{\theta(Xi)} \qquad (7)$$

Where π (X_i) and θ (X_i) denote, respectively, the posterior and prior probabilities of X_i.

3.5 Petri nets

3.5.1 Definition

Petri nets are a mathematical and graphical tool for simulating and modeling systems where the ideas of events and evolution are significant. This formalism was developed in 1962 by Carl Adam Petri **[113]**.

3.5.2 The basic concepts of petri net

3.5.3.1 Places

These are nodes of the graph which represent states of the system. Places can contain tokens, which usually represent available resources **[114]-[113] - [115]**.

3.5.3.2 Transitions

These are the nodes in the graph that reflect the events that are possible to take place if all of the prerequisites are satisfied. The execution of a transition is an indivisible action that is decided by the existence of the token on the input spot. This presence is what determines whether or not the transition will be executed. **[114]- [113]-[115]**.

3.5.3.3 Arcs

These are oriented links that connect places to transitions and transitions to places. The arcs represent the conditions necessary for the transitions to be executed **[114]-[113]-[115]**.

3.5.3.4 Tokens

These are markers that are placed in places to represent available resources or system states **[114]-[113]-[115]**.

3.5.3.5 Bipartite net

The Petri net is a bipartite graph, composed of two types of nodes (places and transitions) and of which no arc connects two nodes of the same type **[114]-[113]**.

3.5.3.6 Label on arrows

In a Petri net, the label on the arrows represents the conditions necessary for the transition to be executed. The labels on the arrows can be used to represent weights, which indicate the number of tokens needed for the transition to run. Weights can be represented by integers or algebraic expressions **[116]-[113]**.

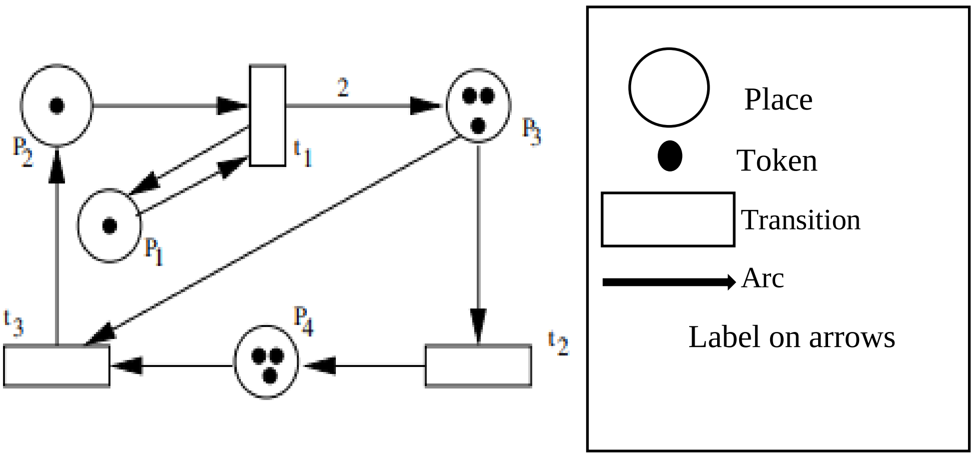


Figure 3 *petri net [113].*

3.6 Markov Chains

3.6.1 Definition

According to specific probabilistic laws, a Markov chain is a mathematical system invented by Andrey Markov that goes through transitions from one state to another. The defining characteristic of a Markov chain is that the probability of transitioning to any particular state is influenced solely by the current state and time elapsed **[117] - [118]**.

The probability of transitioning from one state to another can be described using something called a transition matrix, which can be used to depict a Markov chain. A square matrix is used to represent the transition matrix, and its rows and columns correspond to the states in the state space **[118]**.

Markov chains can be used in various applications, such as the probability of a sequence of events occurring based on the state in the previous event, modeling real-world phenomena in computer simulations, and performing Bayesian inference using Markov Chain Monte Carlo (MCMC) methods **[118]- [119]**. It's a widely utilized model that's simple to understand and is regularly employed in fields that work with sequential data. Even Google uses a type of Markov chain in its page rank algorithm, which decides which links to display first in its search engine **[118]**.

3.6.2 Basic concepts of Markov chains:

3.6.2.1 States

A finite set of possible states, called a state space **[120]-[121]**.

3.6.2.2 Transition matrix:

A transition matrix, which describes the probabilities of moving from one state to another. This matrix is called a stochastic matrix and must satisfy certain properties, in particular that the sum of the elements of each row must be equal to 1 **[120]-[121]-[122]**.

3.6.2.3 Markov property

The Markov property, which states that the probability of moving from one state to another depends only on the present state and not on past states **[123]**.

3.6.2.4 The initial distribution

The initial distribution, which describes the probability that the system is in each state at the start of the process **[120]-[121]**.

3.6.2.5 The stationary distribution

The stationary distribution, which describes the probability that the system is in each long-term state, after a large number of transitions **[121]**.

4 Hydro finishing:

4.1 Definition

The process of hydro finishing is a catalytic treating process that is carried out in the presence of hydrogen to improve the properties of low viscosity-index naphthenic and medium viscosity-index paraffinic base oils **[124]**. It is used to remove non-hydrocarbon constituents and to improve the physicochemical properties of oils such as color, viscosity, and stability **[125]**.

Hydro finishing involves several reactions, including hydrodesulphurization (HDS), hydrodenitrogenation (HDN), hydrodeoxygenation (HDO), and hydrodemetallization (HDM). Hydrocracking and hydrogenation of aromatic rings also occur during the removal of heteroatoms and metals. The combination of Co/Mo is normally more active in hydrodesulphurization reactions, while the Ni/Mo combination is responsible for hydrodenitrogenation and aromatics saturation reactions. A typical atmospheric residue hydrodesulphurization unit can achieve 95% conversion in hydrodesulphurization reactions and 98% in hydrodemetallization reactions **[126]**.

4.2 The reason For Hydro finishing

Here are some reasons why Hydro finishing is used:

4.2.1 To improve color and oxidation stability

Hydro finishing removes color bodies and improves the color and oxidation stability of oils **[127]**.

4.2.2 Olefin Saturation

Olefins are unsaturated hydrocarbons with the general formula CnH2n, also known as alkenes. Due to their non-cyclic carbon structure, they belong to the aliphatic series **[128]**. Hydro finishing can selectively saturate or convert olefins to more stable and less reactive compounds **[129]**.

4.2.3 Oil quality improvement

Hydro finishing is also typical to improve the properties of the resulting lube base stock by reducing impurities and increasing their performance **[130]**.

4.2.4 Nitrogen Removal

Nitrogen compounds can also be present in crude oil and its derived products. These compounds can contribute to the formation of pollutants, such as nitrogen oxides (NOx), when fuels are burned. Hydro finishing helps to remove nitrogen from petroleum products, thus reducing the potential environmental impact **[131]-[132]-[130]**.

4.2.5 Oxygen Removal

HDO process typically occurs in a reactor where the oxygen-containing compounds react with hydrogen in the presence of a catalyst. The oxygen is effectively removed as water, which is a desirable product that can be easily separated **[132]**.

4.2.6 Sulfur removal

Removal of organic sulfur compounds from a petroleum fraction and conversion to hydrogen sulfide (H2S) **[129]-[132]-[130].** Sulfur is a major impurity found in crude oil, and its presence in fuels leads to harmful emissions when burned, contributing to air pollution and acid rain.

4.2.7 Contaminant Removal

Hydro finishing is an excellent method for removing a wide variety of pollutants, including oxygenates, organometallic compounds, and metals (such as nickel and vanadium, among others). These pollutants have the potential to have a negative impact on the catalysts and equipment used farther down the production line **[130]**.

4.3 Factors affecting the process of Hydro finishing

4.3.1 Catalyst Selection

Catalysts are essential in hydro finishing processes as they facilitate the desired chemical reactions. The selection of an appropriate catalyst depends on the target impurities to be removed. Typically, catalysts based on metals such as nickel, cobalt, and molybdenum supported on alumina or silica-alumina are used **[132]**.

4.3.2 Temperature

Temperature is really the factor that has the biggest impact on the processes. It should be high enough to produce a product of the right grade but not too high to raise the proportion of unfavorable reactions that cause the catalyst to become inactive **[132]**.

4.3.3 Pressure

Hydro finishing works under high pressure conditions. Specific pressure levels depend on feedstock composition and desired product specifications. Higher pressures generally promote desired reactions, such as desulfurization and denitrogenation **[132]**.

4.3.4 Residence time

The more time the load spends in the reactor, the better its chances are of producing the raffinate with the desired qualities **[132]**.

4.3.5 Hydrogen Supply

Hydrogen is a critical reactant in hydro finishing processes, as it reacts with impurities to form volatile compounds that can be separated from the product stream. Sufficient and high-quality hydrogen supply is necessary to achieve the desired conversion of impurities **[132]**.

4.3.6 Feedstock Quality

Feedstock quality can have a significant impact on hydro finishing **[133]**. The feedstock's sulfur, nitrogen, and metal content can impact the process's performance. Higher levels of impurities may require more severe process conditions or longer residence time to achieve the desired product quality **[130]**.

4.4 Hydro finishing risks:

4.4.1 Fire and explosions hazards

The process, which is carried out by the units, calls for the utilization of hydrogen gas and normally takes place at high temperatures and pressures. Hydrogen is extremely combustible, and if it is not kept under adequate control, it might provide a risk of fire or explosion **[124]**.

4.4.2 H2S exposure

Workers involved in Hydro finishing operations may be exposed to various hazardous substances, such as hydrogen sulfide (H2S), which is a toxic gas with a distinct rotten egg smell. Prolonged exposure to H2S can be harmful and even fatal **[124]-[134]**.

4.4.3 Process upsets and equipment failures

Hydro finishing units are complex systems with various components, such as reactors, heat exchangers, and pumps. Can fail due to high pressure and temperature. This can result in leaks, fires, and explosions **[124].**

4.4.4 Toxic releases

The process can also produce toxic waste and emissions, which can pose a risk to human health and the environment if not properly handled and disposed of **[135]-[134]**.

5 Case study:

5.1 Description of the U25 unit:

Base oils are the starting material for producing lubricants, and their properties greatly influence the performance and characteristics of the finished lubricant. They are typically derived from crude oil but can also be made from synthetic or bio-based sources. The American Petroleum Institute classifies them into five base oil groups. The base oil category defines what the oil is made of, how it is manufactured, and how the lubricant handles certain environments such as extreme heat. The base oil groups are as follows:

- Group I: These base oils are the least refined and are generally used in less demanding applications.
- Group II: These base oils are produced using hydrogen in a process called hydrogenation or hydrotreating. They have better performance characteristics than Group I oils and are used in a wide range of applications.
- Group III: These base oils are made in much the same way as Group II oils, but they undergo more severe hydrocracking to further refine them. They have even better performance characteristics than Group II oils and are used in high-performance applications.
- Group IV: These base oils are synthetic oils made from polyalphaolefins (PAOs) and have excellent performance characteristics, particularly at high temperatures.
- Group V: These base oils include all other base oils not included in Groups I-IV, such as esters, polyalkylene glycols (PAGs), and biolubricants. They are used in a variety of specialty applications.

In our endeavor to obtain base oil with the desired characteristics, it is essential to approach the treatment process with a comprehensive perspective. By subjecting the load to specific procedures, we aim to achieve a base oil that exhibits the following key attributes related to quality and safety:

- **Color**: The treatment process should aim to attain the desired color profile of the base oil, ensuring it meets the specified requirements for its intended application.
- **Odor**: Through meticulous treatment techniques, we seek to modify the odor properties of the base oil, aligning it with the expected sensory perception in accordance with the desired standards.
- **Oxidation stability**: The treatment process should target enhancing the base oil's ability to resist oxidation, thus ensuring improved longevity and maintaining its performance over an extended period.
- **High viscosity index**: By employing appropriate treatment methods, we strive to achieve a base oil with a high viscosity index, minimizing viscosity variations across different temperatures. This outcome ensures consistent lubrication performance and optimal functionality across diverse operating conditions.
- **Clarity**: The treatment procedure should effectively eliminate impurities such as paraffin particles and water, resulting in a base oil that possesses exceptional clarity. This outcome guarantees the absence of obstructive elements and enhances the oil's purity and suitability for its intended applications.
- **Low volatility**: By employing suitable treatment protocols, we aim to reduce the volatility of the base oil, ensuring minimal evaporation and maintaining the stability and reliability of the oil during operational usage.
- **Good fluidity at low temperatures**: The treatment process should enable the base oil to exhibit favorable fluidity even at lower temperatures. This achievement ensures optimal lubrication performance and smooth operational efficiency, even in cold environments.
- **Low flammability and high flash point**: With a focus on safety, the treatment procedures should aim to reduce the base oil's flammability, resulting in a higher flash point. This characteristic enhances workplace safety during handling, storage, and application, minimizing the risk of fire hazards.

The production of lubricant base oils involves several steps, including dewaxing and hydro-finishing. However, some of the filtrates from the dewaxing units may lack the color and stability qualities required for base oils used in lubricant synthesis. To remove any leftover contaminants, these filtrates must undergo an extra hydro-finishing process using the U25 unit.

The hydrofinishing process commences by introducing a gas rich in hydrogen into the unit. The decision to use a hydrogen-rich gas instead of pure hydrogen alone is driven by its high reactivity, which can lead to undesired side reactions. Consequently, the hydrofinishing process utilizes a gas mixture containing hydrogen along with other gases such as nitrogen, methane, and ethane. This gas mixture undergoes pressure indication and control (PIC) through a pressure indicator and controller, which monitors and regulates the pressure via a controlling pressure valve (PIC6) **[136]**.

Subsequently, the gas mixture passes through separator drum 25-D5 to eliminate any liquid or solid contaminants present in the gas stream that may cause fouling and damage to the subsequent compressors. These compressors, 25-G3 A and B, compress the gas mixture. To monitor and control the flow of the hydrogen-rich gas throughout the system, an FRC3 valve is employed **[136]**.

Simultaneously, pump 25-G1 A/B is employed to unload the tanks and pre-heat the contents within the 25-E1 exchanger. Following this step, the charge is mixed with the hydrogen-rich gas and flows through an FRC7 valve to monitor and control the combined flow through the system. The resulting mixture, referred to as the oil/gas mixture, undergoes sequential heating by passing through exchanger's 25-E2A, B, and C **[136]**.

If the desired temperature has not yet been reached, the oil/gas mixture is directly introduced into furnace 25-F1, which facilitates heating the mixture to the appropriate treatment temperature. A temperature regulating controller (TRC1) is present to monitor and control the oil/gas mixture within the system **[136]**.

Once the mixture reaches the required temperature, it enters the catalytic reactor 25-C1, where a catalyst consisting of metal oxides placed on alumina spheres accelerates the transformation of various contaminants present in the oil. Due to the exothermic nature of the reaction, it is essential to prevent excessive temperature rise within a single catalyst bed. To manage this, commercial units employ multiple catalyst beds with cooling intervals in between. These beds can be arranged either as one bed per reactor or with multiple beds per reactor separated by quench zones **[136]**.

Upon exiting the reactor, the mixture enters the high-pressure separator drum 25-D1, where the majority of unreacted hydrogen is eliminated. The resulting stream, comprising products and gases, is removed as a vapor stream overhead. This hydrogen-rich vapor stream, containing equilibrium quantities of hydrocarbon reaction products, undergoes cooling in exchanger 25-E3 through PRC3. Subsequently, it enters separator drum 25-D3 to separate any valuable liquid (filtrate), while any ineffective treating and unnecessary gases are sent to the torch for combustion. The separated filtrate from drum 25-D3 is then directly received by the column 25-C2 for further treatment **[136]**.

Returning to separator drum 25-D1, the filtrate obtained from it is still hot. This heat is utilized within exchangers 25-E2A, B, and C to warm up the oil/gas mixture mentioned earlier. Simultaneously, the filtrate is cooled by incoming unheated oil/gas mixture, resulting in pressure reduction according to the principles of thermodynamics ($PV = NRT$). The cooled filtrate then passes through temperature regulating controller TRC2 and enters LIC1 before reaching drum D-2. Any gases separated from the liquid in D-2 are directed to D-3 for further treatment and the liquid continues its path towards LIC2. The LIC valves (LIC1 and LIC2) operate in a mutually exclusive manner, such that when one is closed, the other is open, depending on the status of D-2, which is full and undergoing treatment **[136]**.

Subsequently, the filtrate exiting from drum 25-D2, with LIC2 open, proceeds directly to the stripper. On its way to the stripper, it encounters the filtrate from drum D-3, which prompts LIC4 to open, allowing the mixture to reach the stripper once drum D-3 is filled. The stripper eliminates residual hydrogen as using steam regulated and controlled by FIC 9 and TIC 3.

The stripped oil then passes through the LIC 5, which indicates and controls the levels, before entering the 25-C3 dryer in order to eliminate any trace of humidity in the oil.

The waste produced by the stripper and dryer is delivered to another sub-unit so that the steam can be used to remove the gases and recover the oil. To change it into a liquid condition, the dryer discharges into a K-1 condenser. The emissions from the dryer and the stripper enter an E-5 exchanger for water cooling after leaving the condenser. In order to separate the gases from the liquid emissions once more, the gases enter the exchanger E-6 and condenser K-2. The liquids enter D-4 for separation, and the gases are evacuated towards the torch in order to burn them.

The bottoms product obtained from the stripper 25-C3 represents the final desulfurized liquid product. Pumped by 25-G2 A/B, this product is transferred out of 25-C3 and directed to the 25-E1 exchanger for preheating the initial charge **[136]**.

The hydrogen sulfide present above 25-C2 and 25-C3 is further treated. To cool down the final product, it undergoes cooling using an exchanger with cold water. Additionally, the final product undergoes a final filtration step in 25-K4 A/B to ensure it meets the required specifications for base oil before being transported to the base oil tank **[136]**.

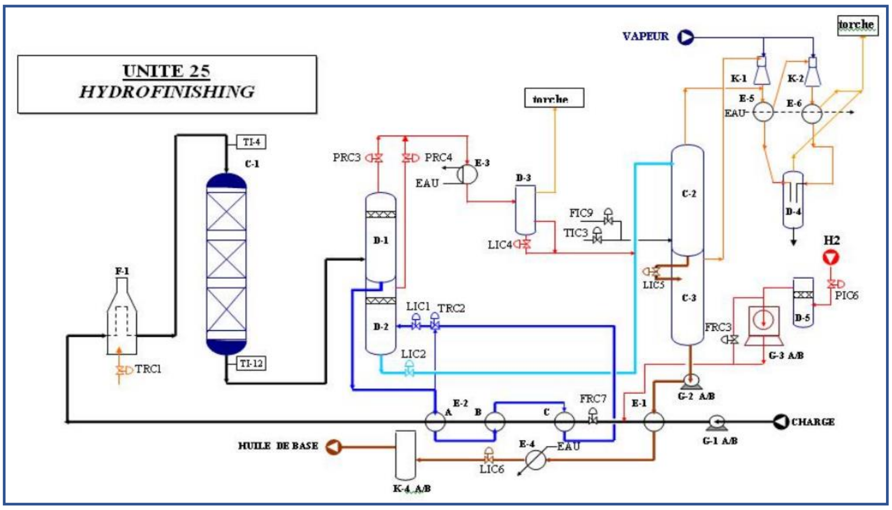
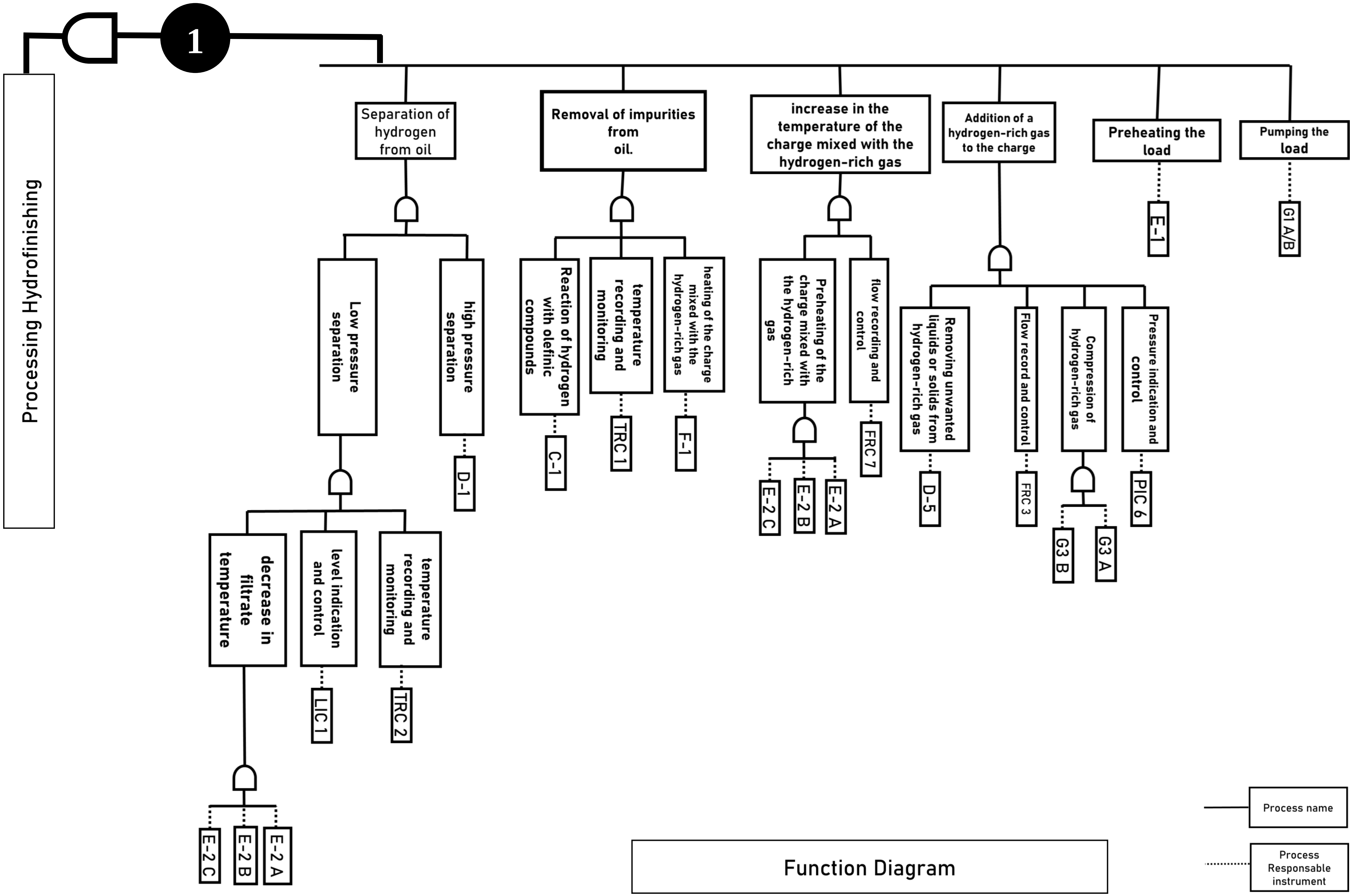
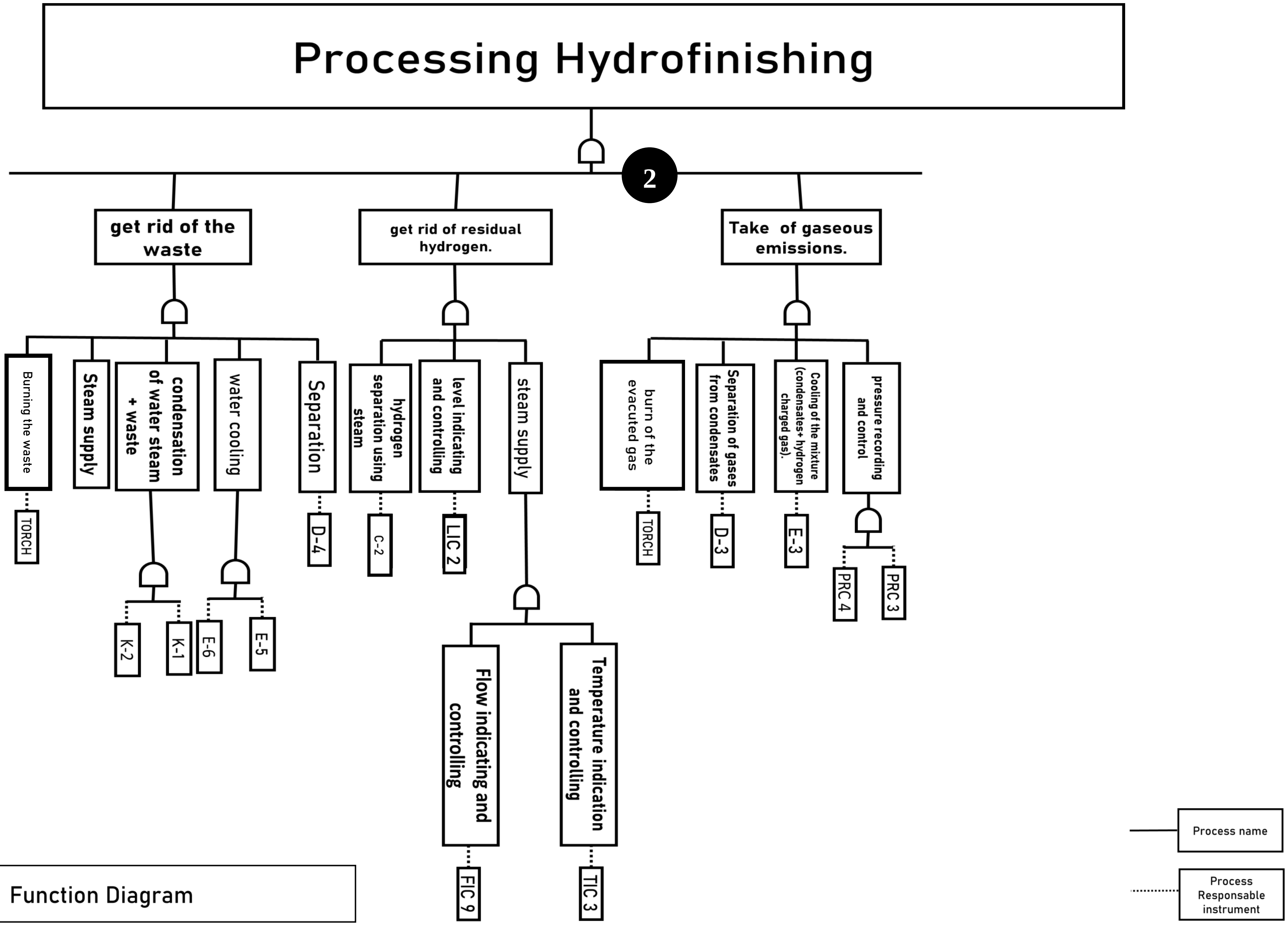


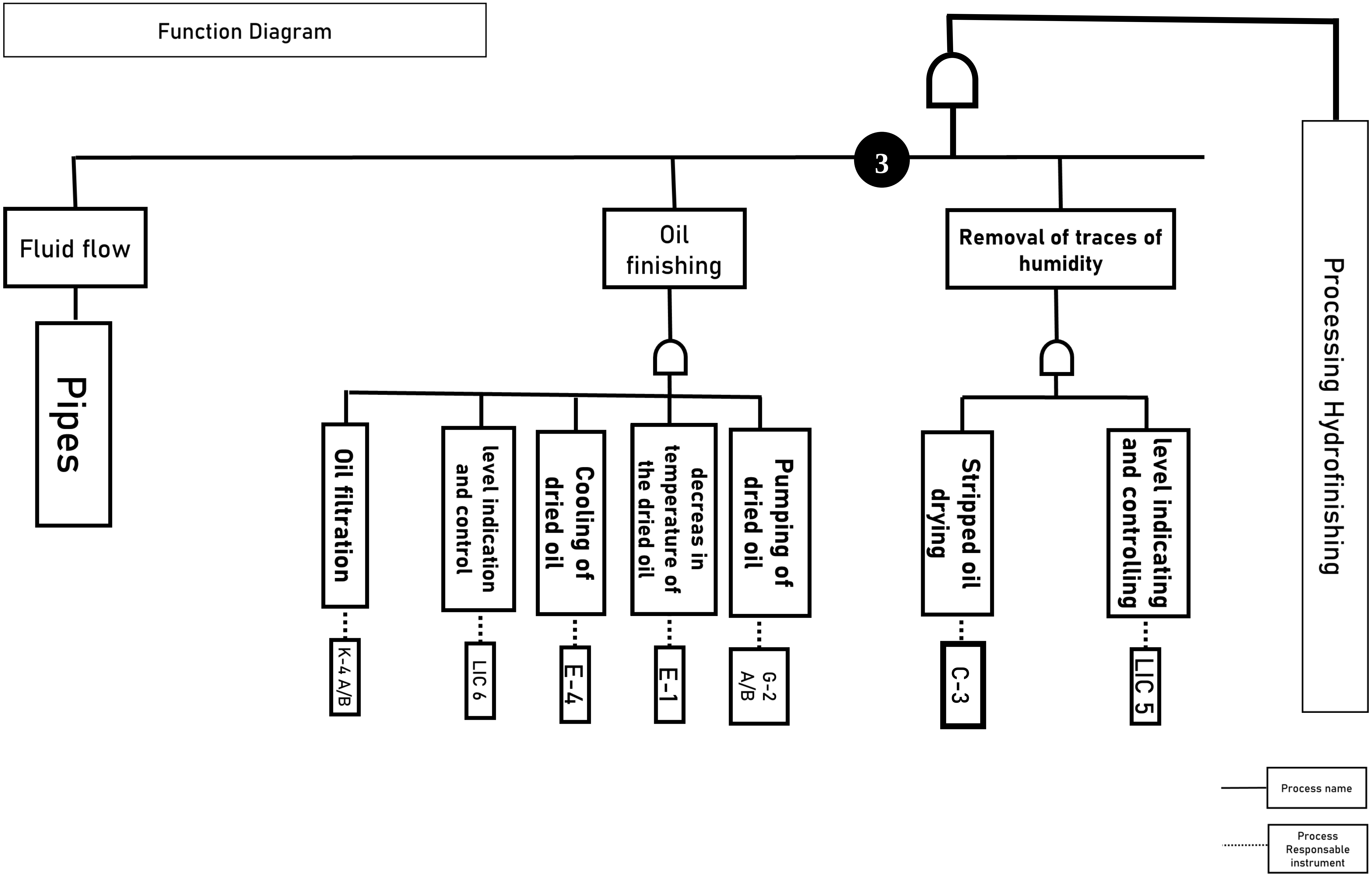
Figure 43 : *Process diagram of unite 25 [136].*



Function Diagram



Function Diagram


Function Diagram
3
Fluid flow
Pipes
Oil finishing
Removal of traces of humidity
Processing Hydrofinishing
Oil filtration
level indication and control
Cooling of dried oil
decreas in temperature of the dried oil
Pumping of dried oil
Stripped oil drying
level indicating and controlling
K-4 A/B
LIC 6
E-4
E-1
G-2 A/B
C-3
LIC 5
Process name
Process Responsable instrument

6 Conclusion

In conclusion, hazard analysis and risk management are essential for guaranteeing the safety of workers and the environment in hydrogen-based industrial processes. By identifying potential dangers and evaluating their risks, it is possible to prevent accidents, injuries, and environmental damage. Using Bayesian networks and other analytical tools can facilitate this process by providing a comprehensive comprehension of the relationships between various factors and their possible outcomes. It is essential to perpetually monitor and update risk assessments as new information becomes available, as well as to prioritize the most severe or frequent threats. With appropriate hazard analysis and risk management, hydrogen-based industrial processes can be conducted efficiently and safely.

Chapter IV: Modeling and Mitigating Hazards in Industrial Processes for Hydrogen

1 Introduction:

In the process of refining petroleum, a catalytic conversion known as hydro treating is employed to remove contaminants from the fuel. These contaminants include sulfur, nitrogen, and olefins. It is vital to carry out the procedure in order to generate high-quality fuel products that are both safe to use and efficient, as required by environmental rules. The upgrading of refinery streams via the utilization of hydrogen gas and a catalyst is an example of the hydro processing technique known as hydro treating. The flexibility of the hydro treating process is related to the fact that the catalyst that is employed can be adapted to the particular feedstocks and products that are sought. The potential for hydrogen (H2) leakage during the hydro treating process is one of the obstacles that must be overcome. This leakage poses a threat to worker safety and reduces the overall efficiency of the operation. Bayesian network analysis is a tool that can be used to simulate the elements that contribute to H2 leakage and estimate the chance of a leak occurring. This tool can be used to help fix the problem that has been identified. Bayesian networks are a sort of probabilistic graphical model that may be used to represent complicated systems as well as the relationships that exist between the variables in those systems. They have been put to productive use in a wide number of sectors, including diagnostic medicine and proteomics, amongst others.

In addition to using Bayesian network analysis, quantitative risk assessment (QRA) can be used to identify the probable sources of H2 leakage, evaluate the likelihood and effects of a leak, and devise methods to minimize or mitigate the risk. Bayesian network analysis is employed. The Environmental, Health, and Safety Guidelines for Petroleum Refining provide guidance on how to manage the risks that are associated with the refining process. These guidelines emphasize the importance of implementing a systematic approach to risk management, which includes hazard identification, risk assessment, and risk mitigation. In addition, these guidelines provide information on how to manage the risks that are associated with the refining process.

It is possible to establish a full understanding of the components that lead to H2 leakage in the hydro treatment process and devise methods to limit the risk by utilizing Bayesian network analysis and QRA. Both of these analyses can be performed in conjunction with one another. This can help to ensure the safety and efficiency of the process, as well as fulfill environmental laws and produce high-quality fuel products. It can also help to assure compliance with the regulations.

Leaks:

The characteristics of hydrogen that contribute to the risk of leakage include:

- It has the tiniest molecules and the lowest molecular weight of any element. The small size of hydrogen molecules makes them more difficult to contain than the molecules of other gases.
- It has the highest buoyancy and lowest density of any element.
- It can weaken some materials.
- It is tasteless, colorless, and odorless. Its presence cannot be detected by humans, and there are no warning symptoms before unconsciousness results.
- When present in concentrations high enough to significantly lower the oxygen level, it functions as a simple asphyxiator **[137]**.

Hydrogen fires/explosions:

Leaks of hydrogen combine with air and catch fire in a variety of amounts. This explosive mixture burns hotly and quickly once it ignites. The flame is practically unnoticeable in broad daylight. If hydrogen leaks into an enclosed environment, the likelihood of combustion and explosion increases.

Most mixtures of hydrogen and air are potentially flammable and explosive, and can be easily ignited by a spark or hot surface.

The characteristics of hydrogen that contribute to its flammability hazard are:

- It has the widest flammability range of any fuel, the lower flammability limit (LFL) of hydrogen in air is approximately 4% by volume, and the upper flammability limit (UFL) of hydrogen in air is about 75% by volume.
- It has the lowest ignition energy of any fuel
- It has the biggest energy per weight of any fuel, with a value of approximately 120 MJ/kg.
- It burns invisibly and without smoke
- It can potentially generate electrostatic charges that result in sparks through flow or agitation **[137]**.

2 The Proposed Methodology:

The proposed work methodology, illustrated in the Figure below, comprises three main steps: risk analysis, risk assessment, and risk evaluation. The risk analysis phase employs the AMDE technique to identify failure modes of each component. In the risk assessment phase, a FTA diagram is constructed by identifying cause relationships, and then a mapping algorithm is used to convert the FTA diagram to BN by assessing the occurrence probability or failure frequency of the top event (causes) and assessing all possible consequences. Finally, in the risk evaluation phase, a sensitivity analysis is conducted to identify the most sensitive indicators for risk, and a recommendation is presented to improve the process safety level. Sensitivity analysis is a crucial part of risk management that examines how changes in inputs affect outputs, and it helps with long-term decision-making. It is important to use the best sensitivity and risk analysis techniques possible to get a clear overview of all future possibilities. Quantitative tools rely on numbers to express the level of risk, while qualitative assessments produce non-numerical estimates of risk.

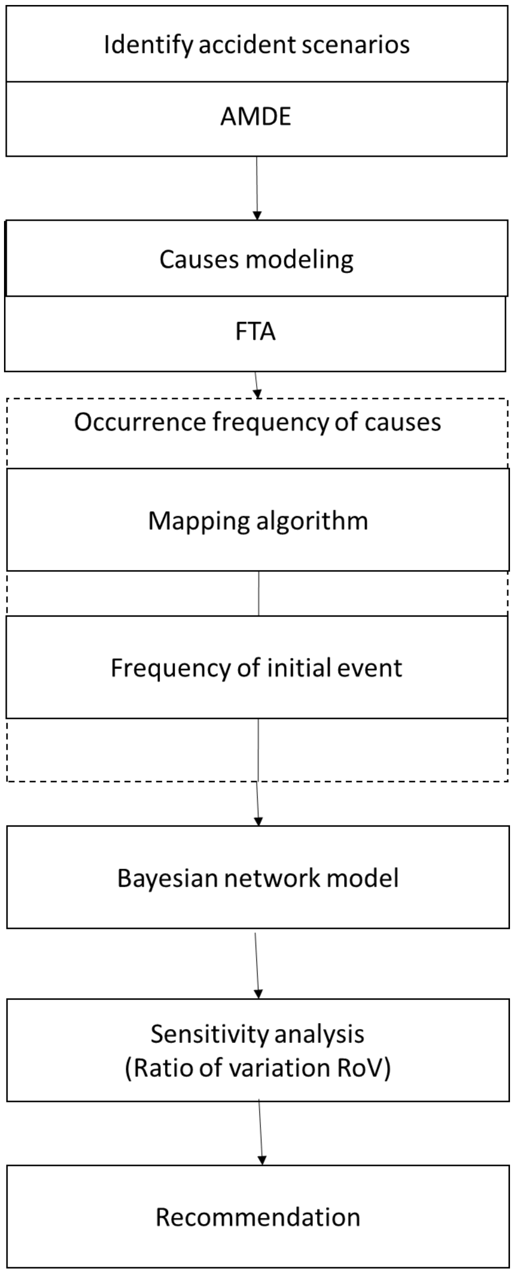


Figure 1 : *The Proposed Methodology*

2.1 Fault Tree Analysis (FTA):

Fault tree analysis is an engineering technique widely used in system safety studies. This method consists of graphically representing the possible combinations of events that allow an undesirable event to occur. It is a deductive technique that offers a way to determine the cause or combination of causes that may result in the most significant event and to calculate the likelihood of this event **[138]**. Using arbre analyste software, we used FTA in our case study to identify the root causes and calculate the probability of hydrogen leakage in a hydro-finishing unit U25 with a lifetime of 8760 running hours, which is equivalent to one year.

Arbre analyste:

Arbre Analyste is a fault tree software for a system safety study, it is designed to meet the needs of fault tree or cause tree studies. Tree Analyst allows you to build fault trees using basic symbols to describe various points, causes and effects in a process **[138]**.

Why Arbre analyste?

- Arbre Analyste is a software tool designed by engineers who specialize in the field of functional safety to provide a tool that best meets the needs of studies.
- Interoperability is essential if you want to capitalize on your functional safety studies. Arbre Analyste respects the Open-PSA standard, providing the best interoperability.
- Arbre Analyste uses the XFTA engine, allowing it to take advantage of the latest developments in the field.
- Arbre Analyste is a professional Fault Tree assessment software that is free to use.
- Arbre Analyste is designed by a team of French engineers specialized in safety analysis **[1]**.

2.2 List of failure modes and mean failure rate (per 10^6 hours) of U25 equipment:

Valves:

- FTC: fail to close on demand
- FTO: fail to open on demand
- FTR: fail to regulate
- HIO: high output

Table 1 : *The table represents failure mode and mean failure rate of the valves by OREDA.*

Failure mode	Mean failure rate (per 10^6 hours)
FTC	2,31
FTR	0,55
FTO	2,81
HIO	0,03

Compressors:

- ELP: external leakage – process medium
- VIB: vibration
- STD: structural deficiency

Table 2 : *The table represents failure mode and mean failure rate of the compressors by OREDA.*

Failure mode	Mean failure rate (per 10^6 hours)
ELP	10,26
VIB	3,14
STD	2,29

Heat exchangers:

- ELP: external leakage – process medium
- INL: internal leakage

Table 3 : *Table 2 the table represents failure mode and mean failure rate of the compressors by OREDA.*

Failure mode	Mean failure rate (per 10^6 hours)
ELP	4,30
INL	1,00

Heaters and boilers:

- ELP: external leakage – process medium
- OHE: over heating

Table 4 : *the table represents failure mode and mean failure rate of the heaters and boilers by OREDA.*

Failure mode	Mean failure rate (per 10^6 hours)
ELP	7,88
OHE	3,94

Pipe:

Burning torch is also considered as a pipe.

- ELP: external leakage – process medium

Table 5 : *The table represents failure mode and mean failure rate of the pipes by OREDA.*

Failure mode	Mean failure rate (per 10^6 hours)
ELP	0,4402
STD	5,96

Separator drum and catalytic reactor:

A separator drum and catalytic reactor can be considered a vessel from the OREDA component.

- ELP: external leakage – process medium

Table 6 : *The table represents failure mode and mean failure rate of the vessels by OREDA.*

Failure mode	Mean failure rate (per 10^6 hours)
ELP	2,87
PDE	1,33

2.3 AMDE:

Table 7 : *The table represents AMDE of the system.*

Component	**failure mode**	**Consequences**
PIC 6	• External leakage – process medium • Fail to regulate • High output	• Deterioration of pipes • Deterioration of equipment • H_2 Leakage • fire/explosion
D-5	• External leakage – process medium • Parameter deviation	• H_2 Leakage • fire/explosion • Pool fire • jet fire • UVCE Blast • Confined explosion
G-3 A/B	• External leakage – process medium • Vibration	• H_2 Leakage • fire/explosion • Pool fire • jet fire • UVCE Blast • Confined explosion
FRC 3	• External leakage – process medium • Fail to close on demand • Fail to regulate • High output	• Deterioration of pipes • Deterioration of equipment • H_2 Leakage • fire/explosion

FRC 7	• External leakage – process medium • Fail to close on demand • Fail to regulate • High output	• Deterioration of pipes • Deterioration of equipment • H_2 Leakage • fire/explosion
E-2 A, B, C	• External leakage – process medium • Internal leakage	• H_2 Leakage • fire/explosion
F-1	• External leakage – process medium • Over heating	• H_2 Leakage • fire/explosion • Start of fire in the furnace • Confined explosion
TRC 1	• Fail to close on demand • Fail to regulate	• Deterioration of pipes • Deterioration of equipment • H_2 Leakage • fire/explosion • Feu de jet • UVCE Blast
C-1	• External leakage – process medium • Parameter deviation	• H_2 Leakage • fire/explosion • Pool fire • jet fire • UVCE Blast

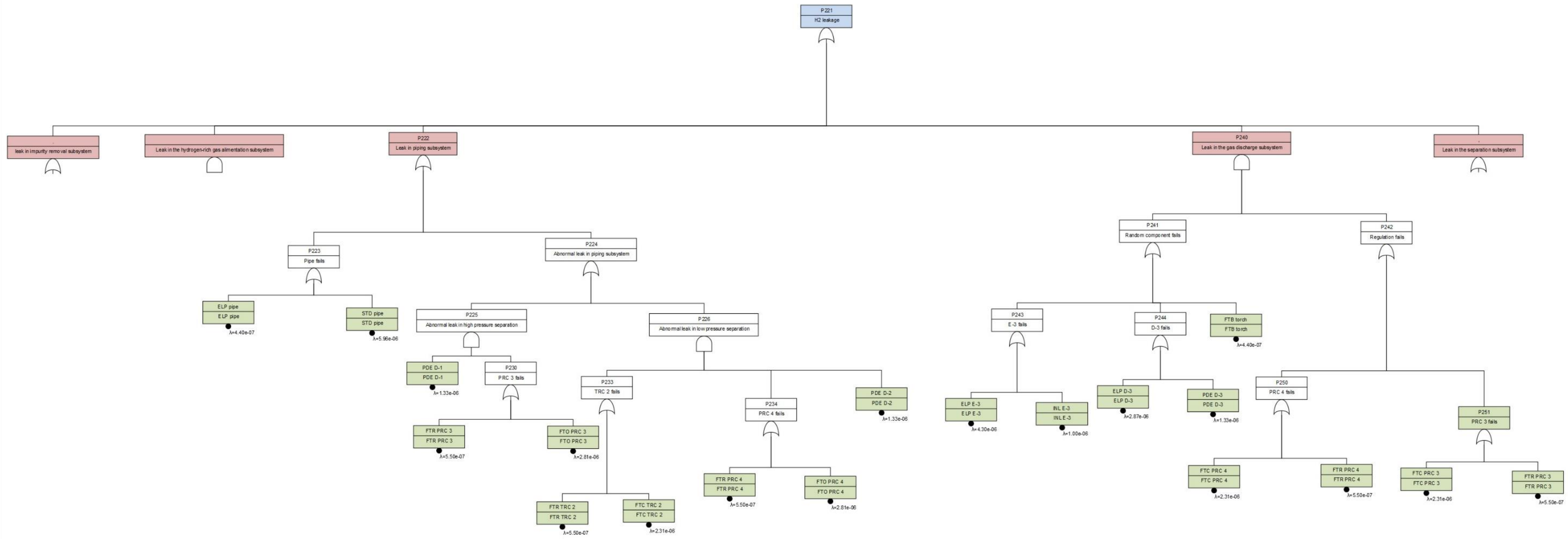
D-1	• External leakage – process medium • Parameter deviation	• H_2 Leakage • fire/explosion • Pool fire • jet fire • UVCE Blast • Confined explosion
D-2	• External leakage – process medium • Parameter deviation	• H_2 Leakage • fire/explosion • Pool fire • jet fire • UVCE Blast
LIC 1	• Fail to regulate • High output	• Deterioration of pipes • Deterioration of equipment • H_2 Leakage • fire/explosion
TRC 2	• External leakage – process medium • Fail to close on demand • Fail to regulate • High output	• Deterioration of pipes • Deterioration of equipment • H_2 Leakage • fire/explosion
PRC 3	• Fail to close on demand • Fail to regulate	• Deterioration of pipes • Deterioration of equipment

		• H_2 Leakage • fire/explosion
PRC 4	• Fail to close on demand • Fail to regulate	• Deterioration of pipes • Deterioration of equipment • H_2 Leakage • fire/explosion
E-3	• External leakage – process medium • Internal leakage	• H_2 Leakage • fire/explosion
D-3	• External leakage – process medium • Parameter deviation	• H_2 Leakage • fire/explosion
Torch	• External leakage – process medium	• H_2 Leakage
Pipe	• External leakage – process medium • Structural deficiency	• H_2 Leakage • fire/explosion

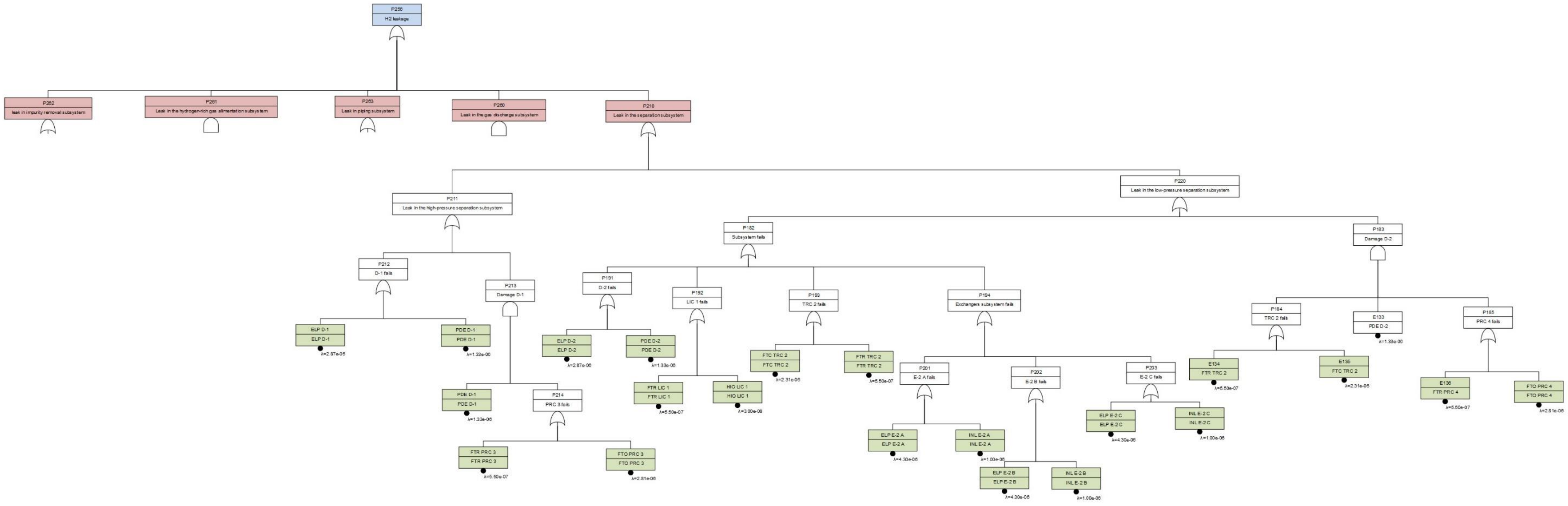
H2 leakage as a top event:

Fault tree analysis is a technique that can be used to determine all of the conceivable events and problems that could culminate in a top event. In this particular instance, the most important event is a hydrogen leak in unit 25, which is a significant threat to the unit's overall safety throughout the Hydro finishing process. The reasons of hydrogen leaks that have been identified can be used to assist prevent mishaps and assure the safety of the unit and the people working inside it. Fault tree analysis has been utilized in a number of studies to assess the dependability and resiliency of various hydrogen-based systems.

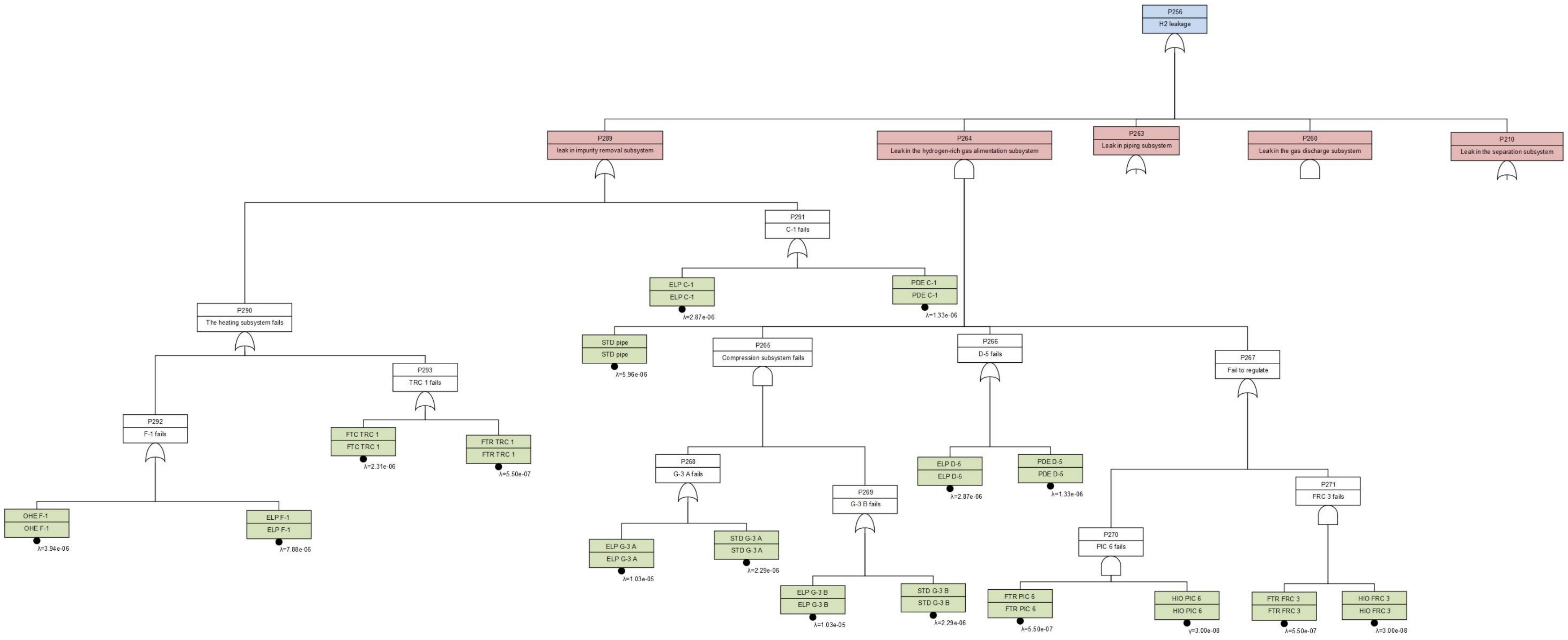
Project: Leakage In The Gas Discharge Subsystem And In Piping Subsystem		Company: IMSI	Author: ACHOUR AYMEN / AIT-OUFEROUKH YOUNES / IN CHARGE : AISSANI NASSIMA
Name: Leakage In The Gas Discharge Subsystem And In Piping Subsystem	Page 1/4	Version: FINAL	Created on: 16/05/16 at 16:18 — Last changed: 23/06/18 at 00:54
Arbre Analyste - version 2.3.2 - 2014-19			



Project: Leakage In Separation Subsystem	Company: IMSI — Author: ACHOUR AYMEN / AIT-OUFEROUKH YOUNES / IN CHARGE : AISSANI NASSIMA
Name: leakage in separation subsystem — Page 4/4	Version: FINAL — Created on: 16/05/16 at 16:18 — Last changed: 23/06/18 at 00:54
Arbre Analyste - version 2.3.2 - 2014-19	



Project: Leakage In Impurity Removal Subsystem / Leakage In The Hydrogen-Rich Gas Alimentation Subsystem		Company: IMSI	Author: ACHOUR AYMEN / AIT-OUFEROUKH YOUNES / IN CHARGE : AISSANI NASSIMA
Name: Leakage In Impurity Removal Subsystem / Leakage In The Hydrogen-Rich Gas Alimentation Subsystem	Page 1/4	Version: FINAL	Created on: 16/05/16 at 16:18 Last changed: 23/06/18 at 00:54
Arbre Analyste - version 2.3.2 - 2014-19			



The top event:

The top event refers to the undesired or critical event that is being analyzed. In this work, an FTA is performed on the H2 leak which represents the top event in the U25 unit of hydrofinishing, and the results obtained are presented in the following table:

Table 8 : *The table represents the results of FTA made by arbre analyst.*

Results	
Probability	0.374
Lambda system	9.67e-05
Number of failures	0.458
System MTTR	8806

Basic events:

In Fault Tree Analysis (FTA), the basic events are considered to be the lowest-level events or failure modes that contribute to the occurrence of the top event. The probabilities of each basic event were calculated in this study using the exponential law, specifically:

$$P(t) = 1 - e^{-(\lambda . t)}$$

The lambdas for each failure mode were obtained from the OREDA database.

The following table contains the settings for each of the basic events involved in the dreaded event:

Table 9 : *The table represents the settings for each of the basic events involved in the dreaded event.*

Event	**Law**	**Lambda**	**Probability**
ELP D-2	Exponential	2.87e-6	0.025
PDE D-2	Exponential	1.33e-6	0.012
FTR TRC 2	Exponential	0.55e-6	0.0048
FTC TRC 2	Exponential	2.31e-6	0.02
HIO LIC 1	Exponential	0.03e-6	0.00026
FTR LIC 1	Exponential	0.55e-6	0.0048
INL E-2 C	Exponential	1e-6	0.0087
ELP E-2 C	Exponential	4.30e-6	0.037
ELP E-2 A	Exponential	4.30e-6	0.037

INL E-2 A	Exponential	1e-6	0.0087
INL E-2 B	Exponential	1e-6	0.0087
ELP E-2 B	Exponential	4.30e-6	0.037
PDE D-2	Exponential	1.33e-6	0.012
FTR TRC 2	Exponential	0.55e-6	0.0048
FTC TRC 2	Exponential	2.31e-6	0.02
FTO PRC 4	Exponential	2.81e-6	0.024
FTR PRC 4	Exponential	0.55e-6	0.0048
PDE D-1	Exponential	1.33e-6	0.012
ELP D-1	Exponential	2.87e-6	0.025
FTO PRC 3	Exponential	2.81e-6	0.024
FTR PRC 3	Exponential	0.55e-6	0.0048
STD pipe	Exponential	5.96e-6	0.051
ELP pipe	Exponential	0.4402e-6	0.0038
FTR PRC 3	Exponential	0.55e-6	0.0048
FTR PRC 4	Exponential	0.55e-6	0.0048
FTO PRC 4	Exponential	2.81e-6	0.024
FTB torch	Exponential	0.4402e-6	0.0038
PDE D-3	Exponential	1.33e-6	0.012
ELP D-3	Exponential	2.87e-6	0.025
ELP E-3	Exponential	4.3e-6	0.037
INL E-3	Exponential	1e-6	0.0087
FTC PRC 3	Exponential	2.31e-6	0.02
FTC PRC 4	Exponential	2.31e-6	0.02
FTR PRC 4	Exponential	0.55e-6	0.0048
ELP D-5	Exponential	2.87e-6	0.025
PDE D-5	Exponential	1.33e-6	0.012
HIO PRC 3	Exponential	0.03e-6	0.00026
FTR PRC 3	Exponential	0.55e-6	0.0048

HIO PIC 6	Exponential	0.33e-6	3e-8
FTR PIC 6	Exponential	0.55e-6	0.0048
ELP G-3 A	Exponential	10.26e-6	0.086
STD G-3 A	Exponential	2.29e-6	0.02
STD G-3 B	Exponential	2.29e-6	0.02
ELP G-3 B	Exponential	10.26e-6	0.086
PDE C-1	Exponential	1.33e-6	0.012
ELP C-1	Exponential	2.87e-6	0.025
OHE F-1	Exponential	3.94e-6	0.034
ELP F-1	Exponential	7.88e-6	0.067
FTR TRC 1	Exponential	0.55e-6	0.0048
FTC TRC 1	Exponential	2.31e-6	0.02

Cut sets:

The following table contains the total number of min cuts per order

Table 10 : *The table represents the total number of min cuts per order.*

Order	Quantity
1	22
2	20
3	4

Minimal cut sets:

The minimal cut sets in FTA are concepts that can help in determining the base event combinations that may result in the top event.

Table 11 : *The table represents the minimal cut sets.*

Order	Probability	Event
1	0.0667	ELP F-1
1	0.0509	STD pipe
1	0.037	ELP E-2 C

1	0.037	ELP E-2 B
1	0.037	ELP E-2 A
1	0.0339	OHE F-1
1	0.0248	ELP D-2
1	0.0248	ELP D-1
1	0.0248	ELP C-1
1	0.02	FTC TRC 2
1	0.02	FTC TRC 1
1	0.0116	PDE D-2
1	0.0116	PDE D-1
1	0.0116	PDE C-1
1	0.00872	INL E-2 C
1	0.00872	INL E-2 B
1	0.00872	INL E-2 A
1	0.00481	FTR TRC 2
1	0.00481	FTR LIC 1
1	0.00481	FTR TRC 1
1	0.00385	ELP pipe
2	0.000741	ELP E-3.FTC PRC 3
2	0.000741	ELP E-3.FTC PRC 4
2	0.000497	ELP D-3.FTC PRC 3
2	0.000497	ELP D-3.FTC PRC 4
1	0.000263	HIO LIC 1
2	0.000232	FTC PRC 3.PDE D-3
2	0.000232	FTC PRC 4.PDE D-3
2	0.000178	ELP E-3.FTR PRC 3
2	0.000178	ELP E-3.FTR PRC 4
2	0.000175	FTC PRC 3.INL E-3
2	0.000175	FTC PRC 4.INL E-3

2	0.000119	ELP D-3.FTR PRC 3
2	0.000119	ELP D-3.FTR PRC 4
2	7.71e-05	FTB torch. FTC PRC 3
2	7.71e-05	FTB torch. FTC PRC 4
2	5.57e-05	FTR PRC 3.PDE D-3
2	5.57e-05	FTR PRC 4.PDE D-3
2	4.19e-05	FTR PRC 3.INL E-3
2	4.19e-05	FTR PRC 4. INL E-3
2	1.85e-05	FTB torch. FTRNPRC 3
2	1.85e-05	FTB torch. FTR PRC 4
3	5.64e-06	PDE D-2.FTC TRC 2.FTO PRC 4
3	1.35e-06	PDE D-2.FTR TRC 2.FTO PRC 4
3	1.12e-06	PDE D-2.FTC TRC 2.FTR PRC 4
3	2.68e-07	PDE D-2.FTR TRC 2.FTR PRC 4

2.3.1 Table discussion:

The table represents the minimal cuts of a fault tree analysis, which shows the probability of each event occurring in the system. The events are listed in order of probability, with the most likely event at the top. It also shows that the probability of the top event can be calculated by using the probability of the basic events. The table can be used to prioritize the contributors leading to the top event and make critical equipment/parts/events lists for different importance measures. The results can be used to improve system design and reduce the likelihood of failure. This information is crucial in understanding the potential causes of hydrogen leakage and the equipment that requires the most attention in terms of maintenance and monitoring. By identifying the minimal cut sets, the analysis enables the calculation of the top event's probability or frequency, which is essential in developing effective risk management strategies.

2.4 QRA limitation:

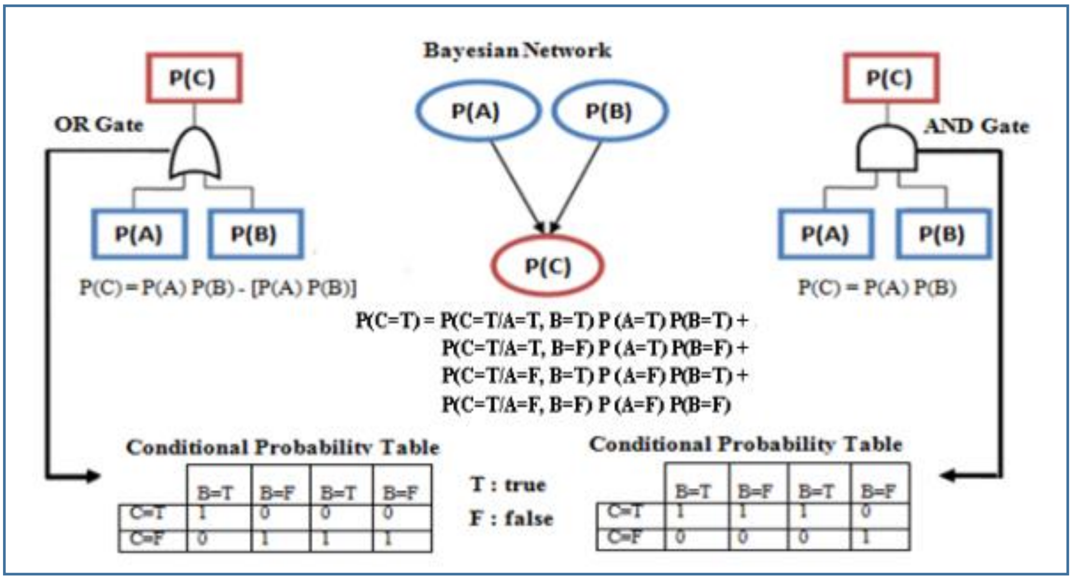
Bayesian networks and quantitative risk analysis (QRA) share some commonalities in risk assessment. For instance, both approaches evaluate the likelihood, impacts, and risk of adverse events. However, Bayesian networks have some advantages over QRA. Bayesian networks can integrate human factors into risk analysis, which is not sufficiently represented in QRA. Additionally, Bayesian networks can handle complex systems with multiple interrelated variables and dependencies, which is challenging for QRA.

The advantages of Bayesian networks over QRA are:

- Integration of human factors: Bayesian networks can integrate human factors into risk analysis, which is not sufficiently represented in QRA. This means that Bayesian networks can provide a more comprehensive and accurate risk assessment by considering the impact of human error and behavior on the system.
- Handling complex systems: Bayesian networks can handle complex systems with multiple interrelated variables and dependencies, which is challenging for QRA. This means that Bayesian networks can provide a more accurate risk assessment for complex systems, such as healthcare systems or industrial processes.
- Causal relationships: Bayesian networks provide a framework for presenting causal relationships between variables, which enables a better understanding of the system and its behavior. This means that Bayesian networks can help identify the root causes of risks and provide insights into how to mitigate them.
- Real-time risk assessment: Bayesian networks can be used for real-time risk assessment and decision support. This means that Bayesian networks can provide timely and accurate risk information to decision-makers, enabling them to make informed decisions quickly.

2.5 Transformation of fault tree into Bayesian network methodology:

To transform a Fault Tree into a Bayesian Network, the graphical representation of the Fault Tree is transformed into a Bayesian Network using a set of rules based on the Conditional Probability Tables to decide the nature of gates in the Fault Tree. The transformation is performed in two steps: the quantitative step, which involves estimating the probability distribution tables, and the qualitative step, which involves modeling using the Bayesian Network. The set of rules is applied to translate the Fault Tree into a Bayesian Network, and the Conditional Probability Tables are used to decide the nature of gates in the Fault Tree. The resulting Bayesian Network can be used for fault diagnosis and system risk importance analysis **[139].**



	B=T	B=F	B=T	B=F
C=T	1	0	0	0
C=F	0	1	1	1

	B=T	B=F	B=T	B=F
C=T	1	1	1	0
C=F	0	0	0	1

Figure 2 : *graphical and digital transformation of fault tree into Bayesians network [139].*

Genie Bayesian Modeler:

GeNIe Modeler is a graphical user interface (GUI) to SMILE Engine and allows for interactive model building and learning. It is written for the Windows environment but can be also used on macOS and Linux under Wine. It has been thoroughly tested in the field since 1998, has received a wide acceptance within both academia and industry, and has thousands of users world-wide.

An important design criterion for all products of GeNIe has been from the very start that they should allow for a complete modeling freedom. GeNIe models do not bend reality to available modeling tools. Whatever the domain demands, can be modeled in the software. Because no exact algorithms exist for some type of models, the software is equipped with a suite of approximate stochastic sampling algorithms, capable of solving any models created by the users.

Genie Features:

The primary features of GeNIe, a network modeling software, include a graphical editor to create, learn, and refine network models, complete integration with MS Excel, flexible data handling, structure and parameter learning algorithms, and influence diagrams with decision, utility, and multi-attribute utility (MAU) nodes with arbitrary MAU functions. It also includes powerful diagnostic functionality, saving and retrieving multiple evidence sets with case manager window, full Unicode support, and cross-compatibility with other software. The software uses the SMILE Engine and allows for the development of models in GeNIe and creating a custom interface for them using SMILE

2.5.1 Real world example from component of the unit:

AND GATE:

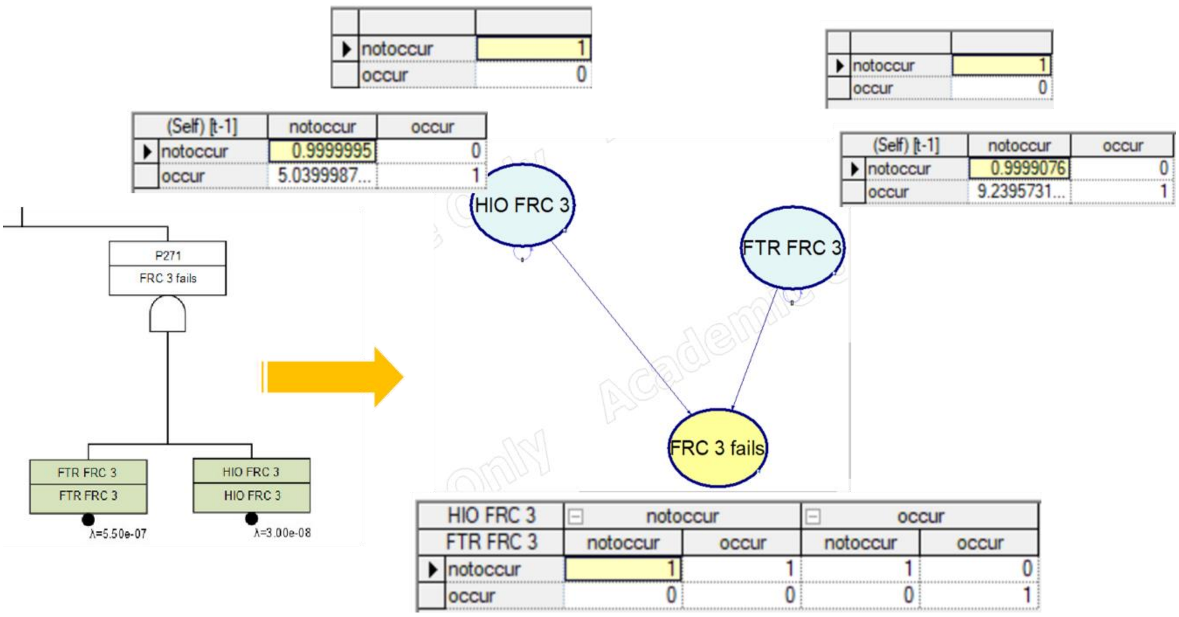


Figure 3 : *AND GATE transformation from FTA to Bayesian Network*

OR GATE:

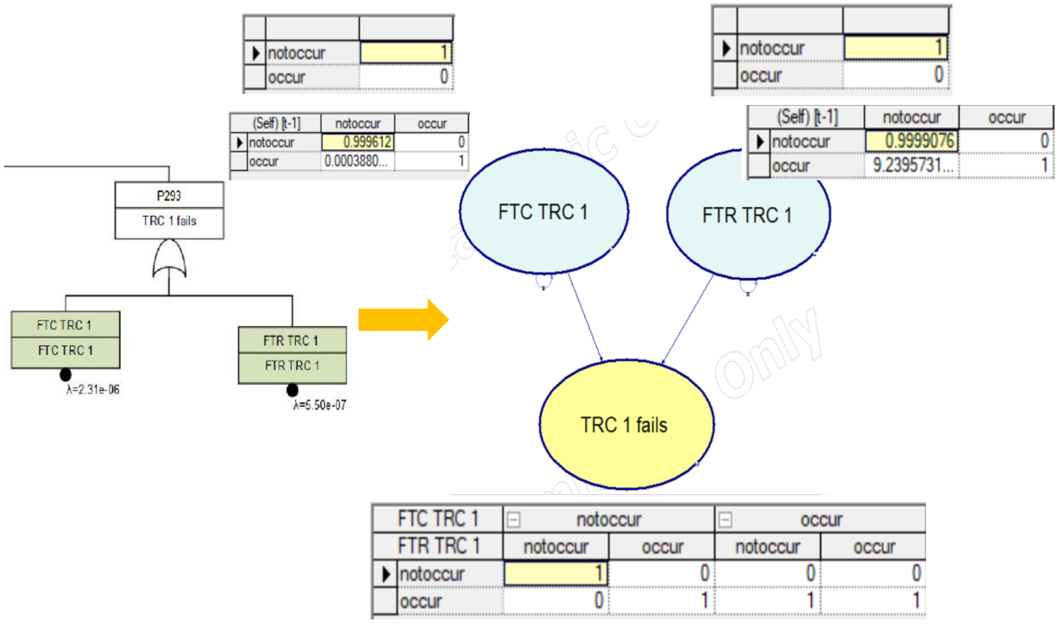


Figure 4 : *Figure 3 OR GATE transformation from FTA to Bayesian Network*

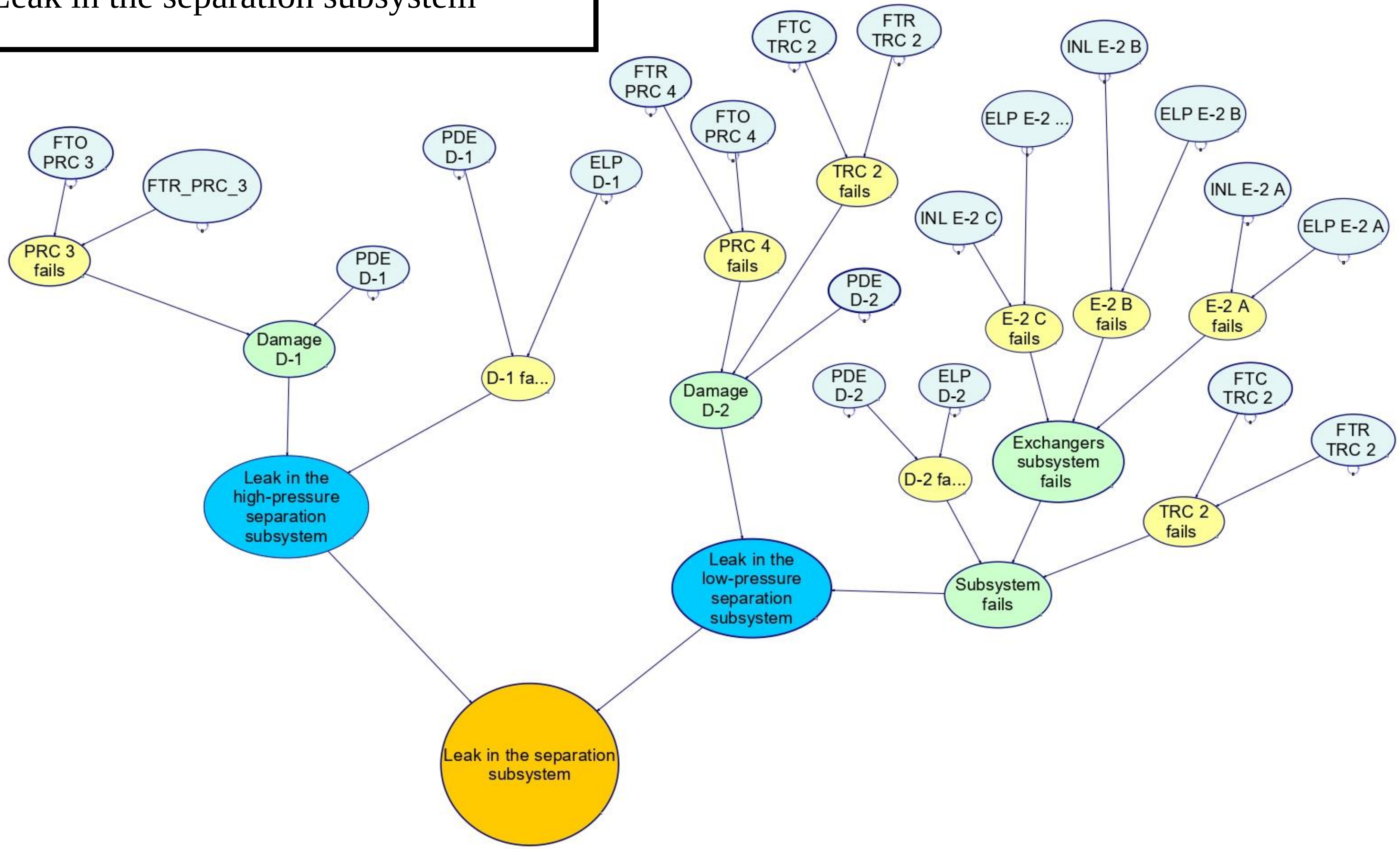
In order to carry out the dynamic Bayesian, it is essential to follow the table that is presented below:

Table 12 : *Dynamic Bayesian*

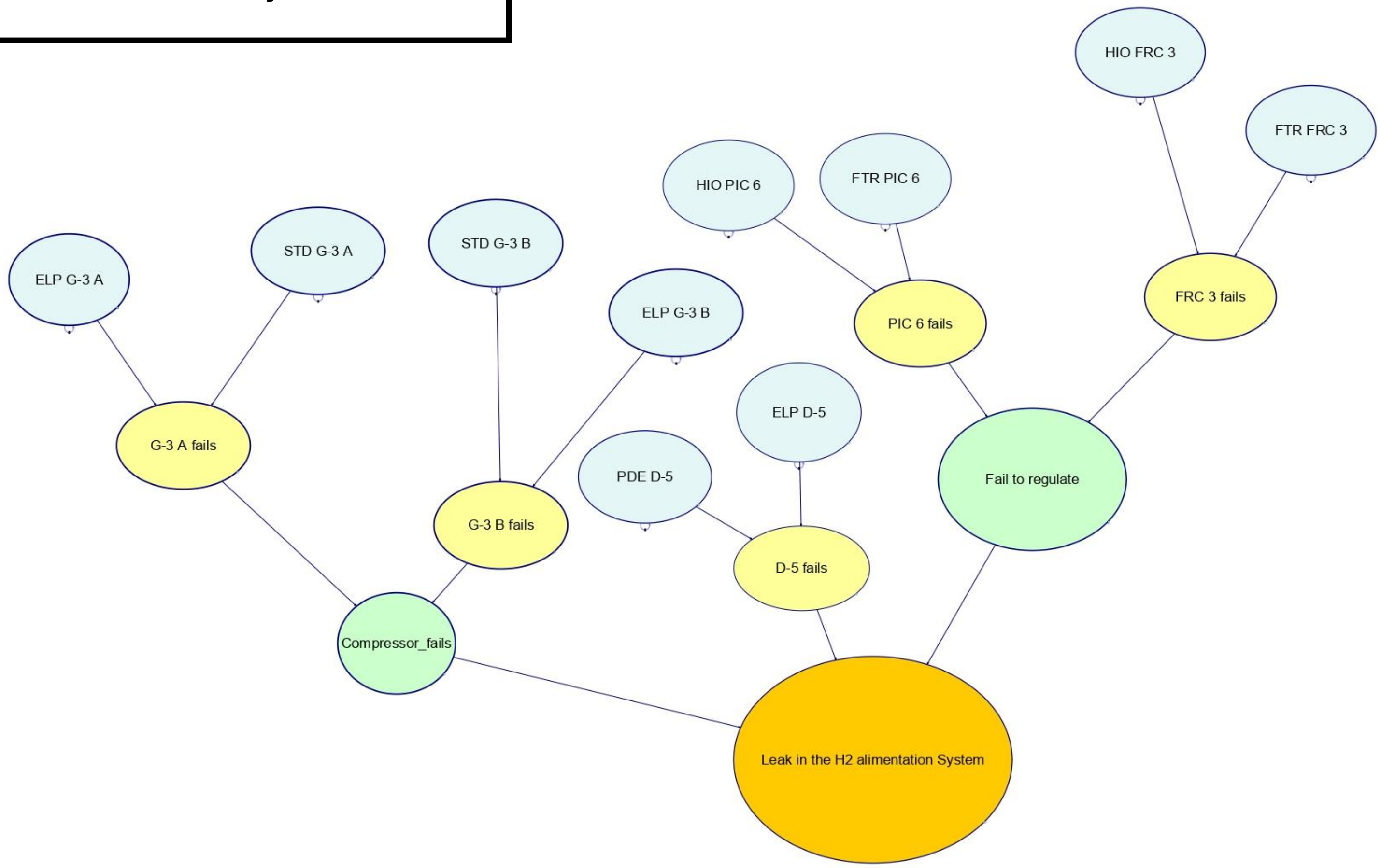
Not occur	$e^{-(\lambda.t)}$	0
Occur	$1-e^{-(\lambda.t)}$	1

Now, in accordance with the procedures described before, let's build the entire Bayesian network for the Unit 25.

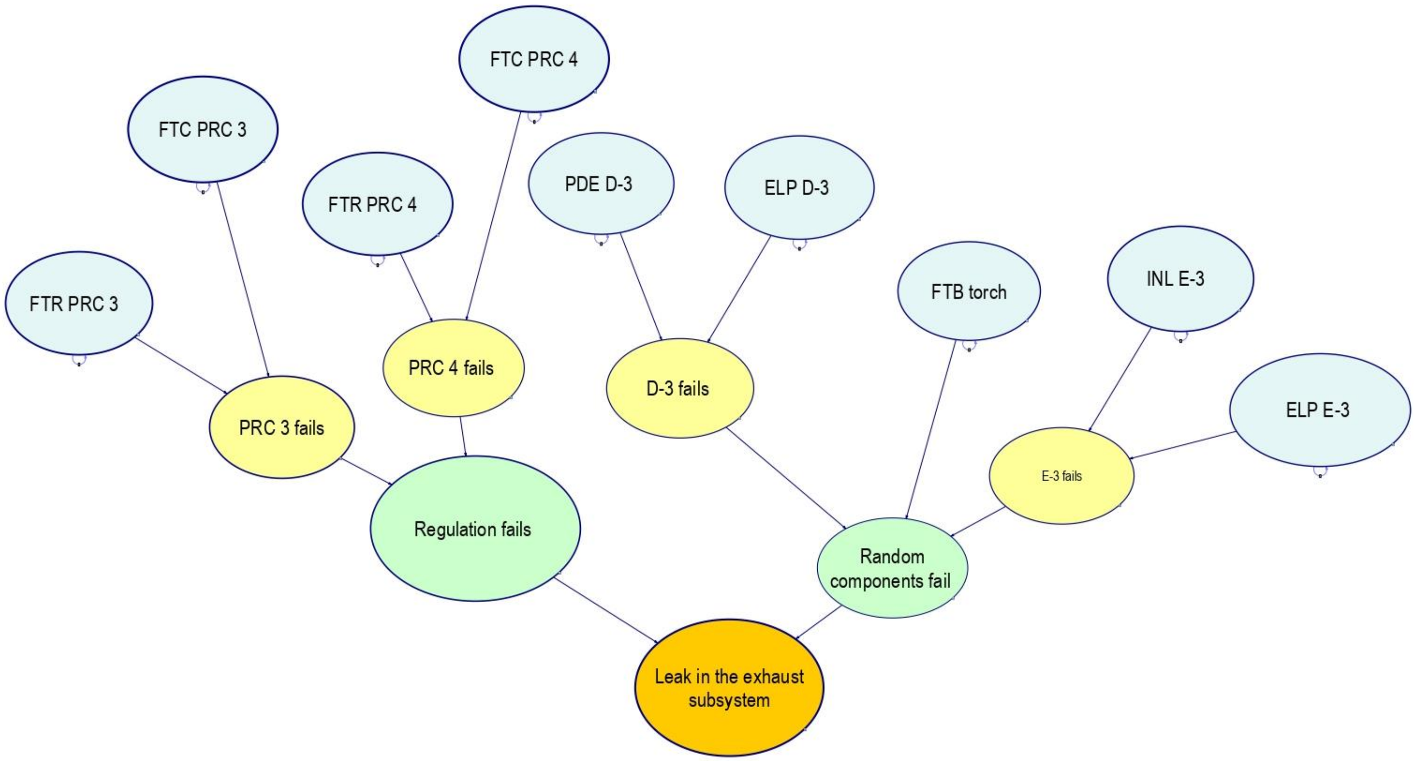
Leak in the separation subsystem



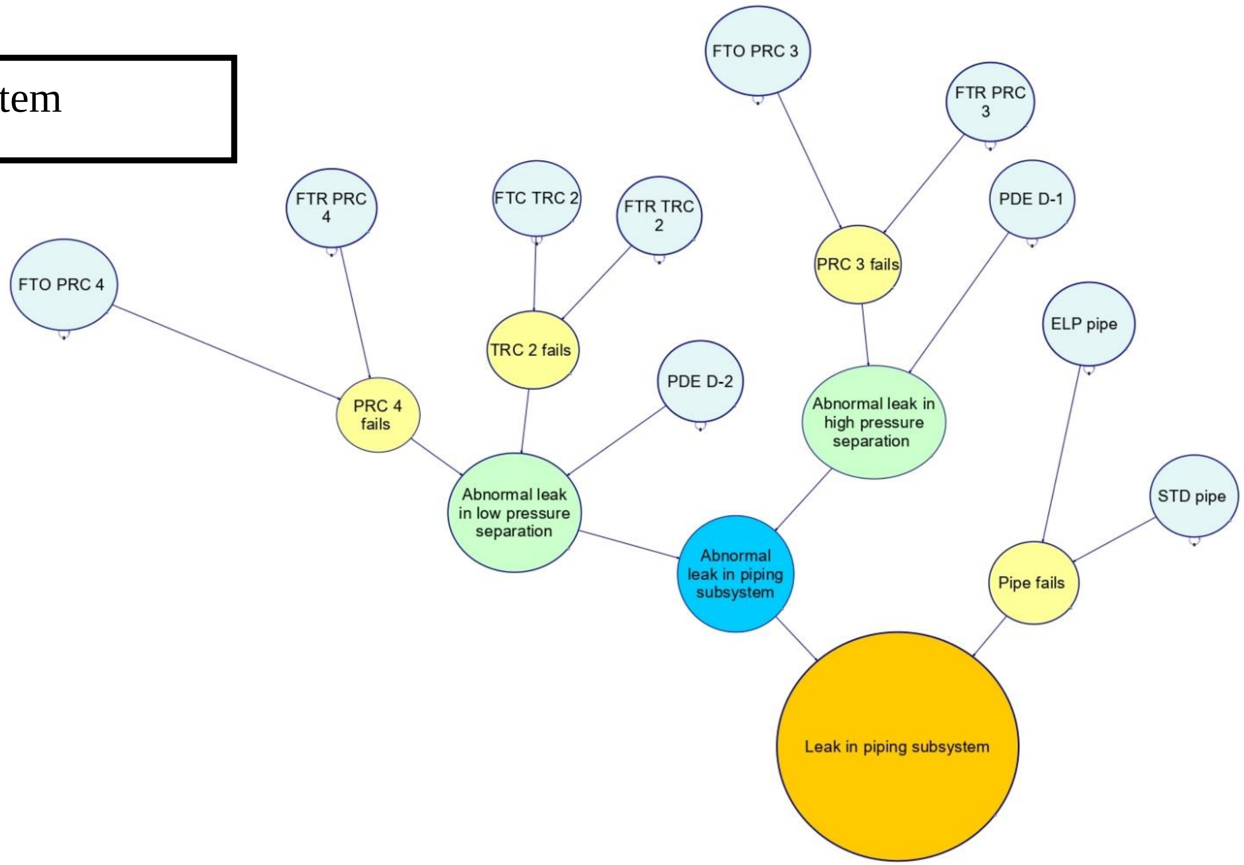
Leak in H2 alimentation system



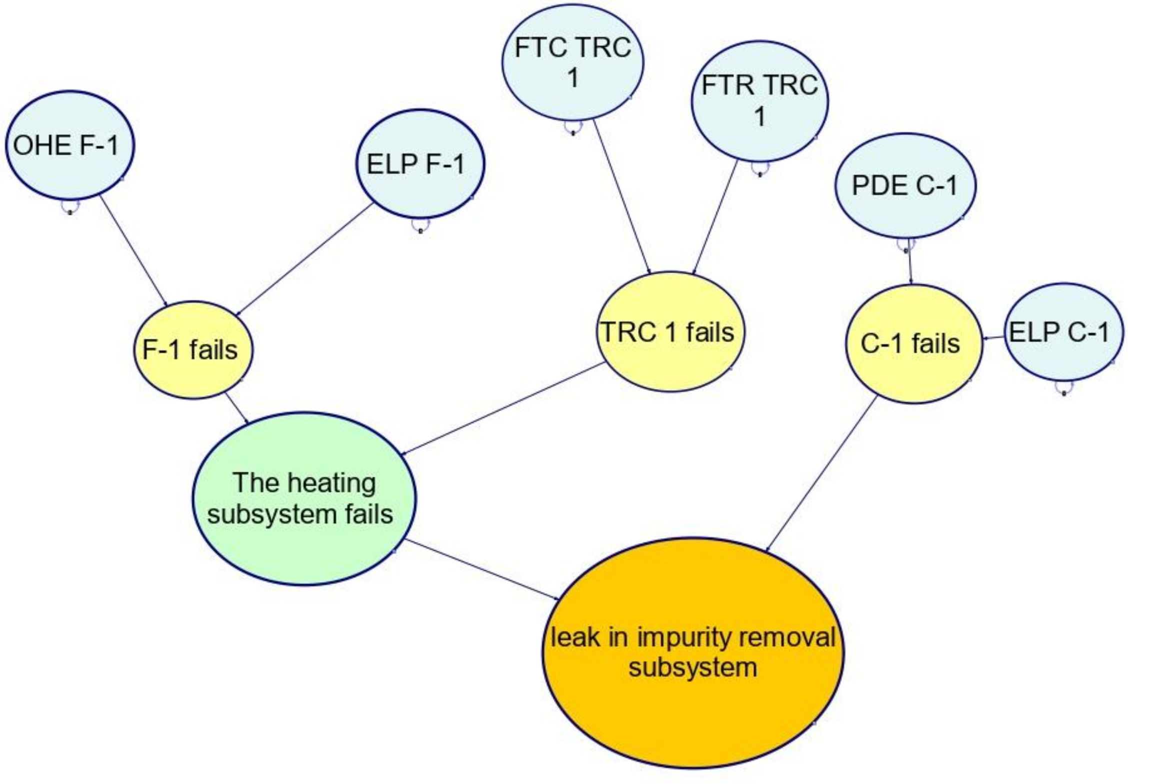
Leak in the exhaust subsystem



Leak in the piping subsystem



Leak in impurity removal subsystem



2.6 Sensitivity Analysis:

Following this equation will enable us to identify the most crucial component, allowing us to focus on it and develop precise risk-reduction strategies, such as purchasing a replacement or scheduling annual maintenance, as determined by the experts. Given the failure of the regulatory system, the posterior probability for each node Xi is:

- Posteriors (BN): probability of the component after the H2 leakage happen.
- Posteriors (BN): probability of the component before the H2 leakage happen.

Table 13 *The posterior and prior of each component.*

The component	Posteriors (BN)	Prior (BN)
ELP D-2	0.067075276	0.025
PDE D-2	0.011786775	0.012
FTR TRC 2	0.0048879689	0.0048
FTC TRC 2	0.020369578	0.02
INL E-2 C	0.023565996	0.0087
ELP E-2 C	0.099861679	0.037
ELP E-2 A	0.099861679	0.037
INL E-2 A	0.023565996	0.0087
INL E-2 B	0.023565996	0.0087
ELP E-2 B	0.099861679	0.037
FTO PRC 4	0.024721601	0.024
FTR PRC 4	0.0048877811	0.0048
PDE D-1	0.012341366	0.012
ELP D-1	0.067075276	0.025
FTO PRC 3	0.025178215	0.024
FTR PRC 3	0.0049778301	0.0048
STD pipe	0.13740152	0.051
ELP pipe	0.01039961	0.0038
FTB torch	0.0042079815	0.0038
PDE D-3	0.012663603	0.012
ELP D-3	0.027140588	0.025
ELP E-3	0.040406911	0.037

INL E-3	0.0095354804	0.0087
FTC PRC 3	0.023087523	0.02
FTC PRC 4	0.023087523	0.02
ELP D-5	0.067075276	0.025
PDE D-5	0.012663603	0.012
HIO PIC 6	2.671297e-05	3e-8
FTR PIC 6	0.0049778301	0.0048
ELP G-3 A	0.087306391	0.086
STD G-3 A	2.0389952e-05	2.0389952e-05
STD G-3 B	2.0389952e-05	2.0389952e-05
ELP G-3 B	0.087306391	0.086
PDE C-1	0.012663603	0.012
ELP C-1	0.067075276	0.025
OHE F-1	0.091647036	0.034
ELP F-1	0.18013468	0.067
FTR TRC 1	0.0049778301	0.0048
FTC TRC 1	0.023087523	0.02

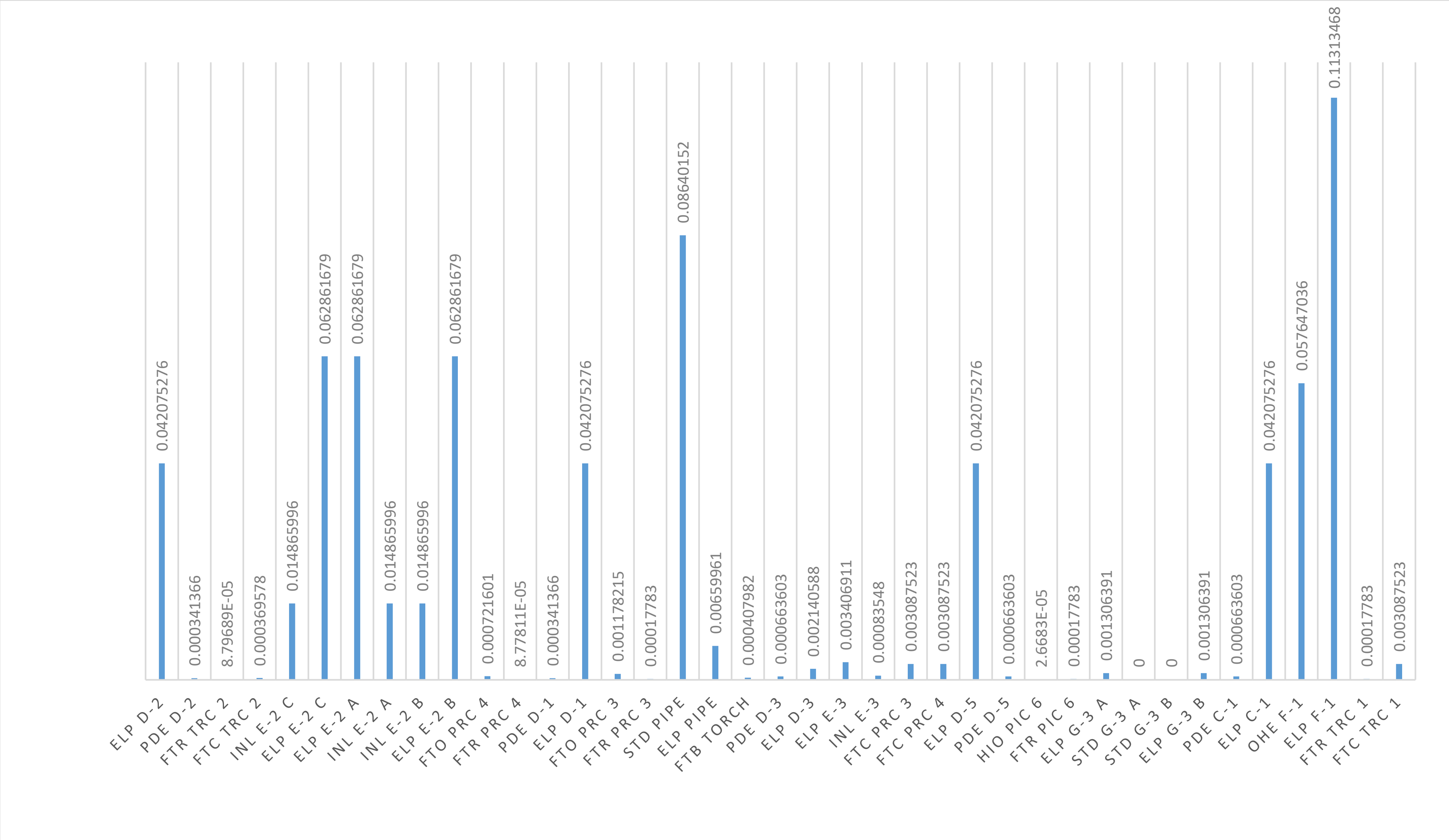


Figure 5 : *Sensitivity Analysis chart*

A chart is frequently used to display the outcome of a computation so that it is easier to understand. ELP F-1 is the largest, at nearly 0.12, followed by STD PIPE at nearly 0.9, and in third place are ELP E-2A, ELP E-2B, and ELP E-2C. Graphs and charts are a fantastic method to graphically display data and make it easier to grasp. And then there was OHE F-A followed by ELP D-2.

If we attempt to influence the probability of this component by reducing their probabilities and integrating them into our unit to determine how this affects the probability of H2 leakage in the unit, we would do the following:

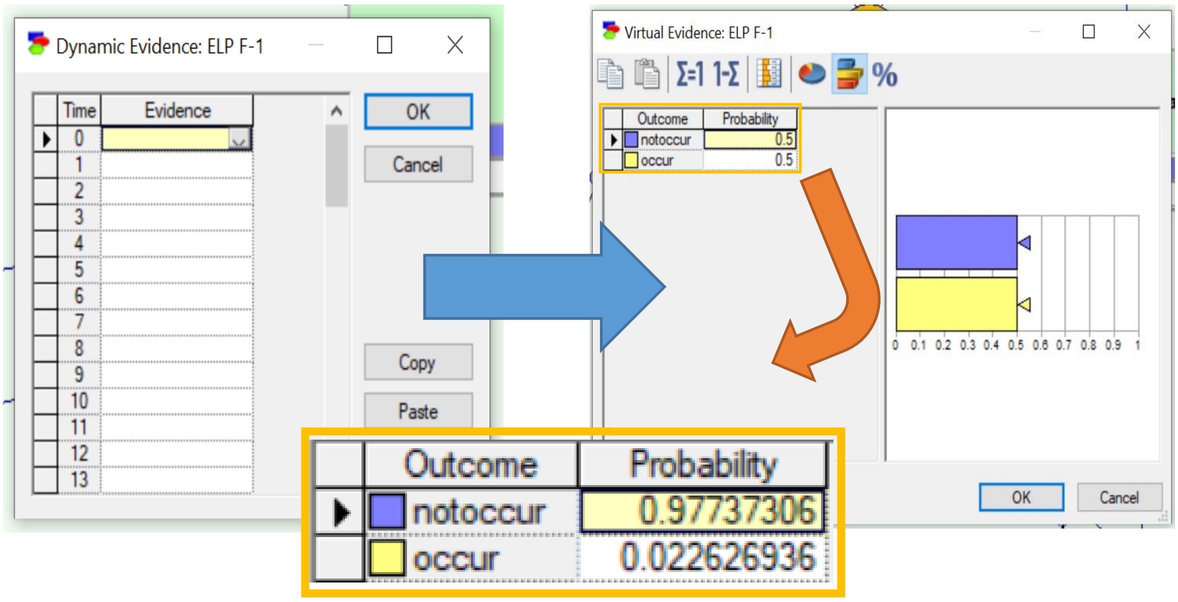
- Regular maintenance: Regular maintenance of the furnace, pipes, and heat exchangers can aid in detecting and preventing leakage. This may involve cleansing, inspecting, and replacing any damaged components.
- Leak detection instruments, such as gas detectors, can be used to detect any breaches in the furnace, pipe, and exchangers. These instruments can detect even the tiniest leaks, which may not be visible to the unaided eye.
- Repair or replace damaged components: As soon as feasible, all damaged components of the furnace, pipe, and exchangers should be repaired or replaced to prevent further leakage.
- Sealants can be utilized to seal any breaches in the furnace, pipe, and heat exchangers. This can help prevent further leakage and increase the system's efficiency.
- Use of pressure testing: Pressure testing can be used to test the furnace, conduit, and exchangers for structural integrity. This can aid in detecting breaches and preventing their worsening.
- Application of corrosion inhibitors: Corrosion inhibitors can be utilized to prevent corrosion in the furnace, conduit, and exchangers. Corrosion can deteriorate the system and cause leakage.
- Use of high-quality materials: To prevent corrosion and other forms of damage that can contribute to leaks, high-quality materials should be used in the construction of the furnace, pipe, and exchangers.
- Proper installation: Proper installation of the furnace, pipe, and heat exchangers is crucial for preventing leakage. This may involve ensuring that all connections are secure and the system is adequately sealed.

Assuming that we've adhered to the aforementioned imperatives, we're going to presume that the following values will be assigned to this vital component:

- ELP F-1: 20% occur, 80% not occur
- STD PIPE : 15% occur, 75% not occur
- OHE F-A: 15% occur, 75% not occur
- ELP D-2 : 15% occur, 75% not occur
- ELP E-2A, ELP E-2B, and ELP E-C: 10% occurrence, 90% absence

Now that we have these values, we can incorporate them into our Bayesian model and calculate the probability of H2 leakage in the unit.

The to achieve that is by adding evidence in Genie software



Now, if we run the results, we will discover that the probability of H2 leakage in the unit decreases from 0.38 to 0.16:

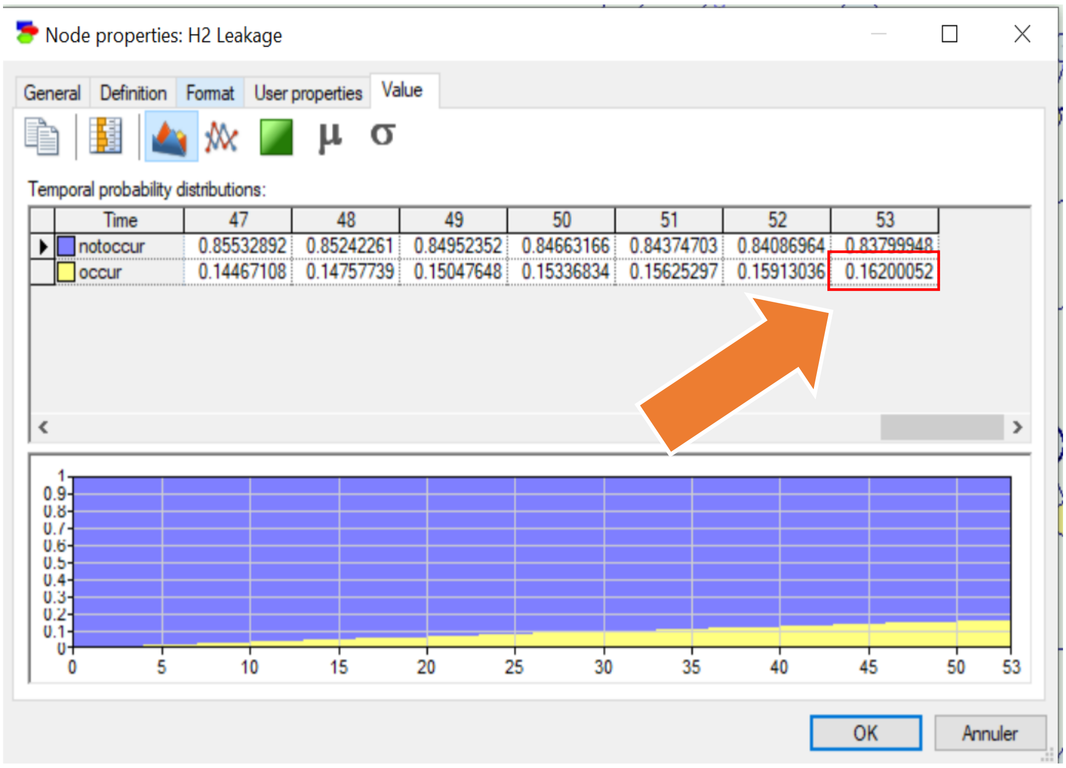


Figure 6 : *H2 leakage Probability*

In addition, if we attempted to anticipate the human factor as barrier safety, whether for good or bad influence, for detection, the large H2 leakage would produce an anomalous sound:

We provide human element: 40% detect, 60% not detect. We assume that the human factor is not affected by time, so it does not belong to the dynamic model, but must be added to the system using AND gate logic.

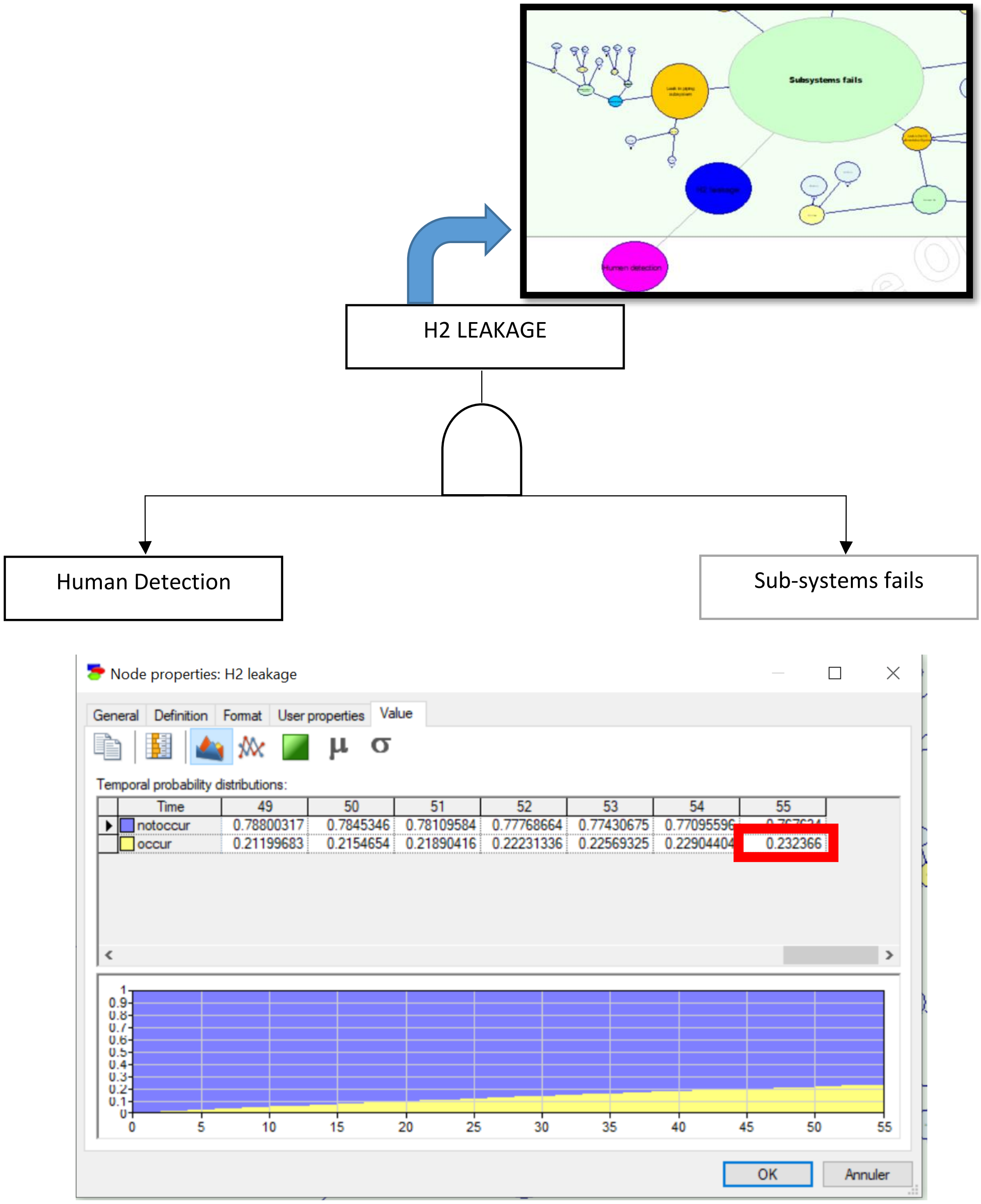


Figure 7 : *H2 leakage Probability after adding human factor*

3 Recommendations:

The essential recommendations to reduce the likelihood of hydrogen leaking in unit U25.

- Annual review of the installations.
- Adding redundancy to the valves such that, in the event of a blocked valve, the other valve opens.
- Use materials with low carbon percentage.
- Control the exposure of metals to hydrogen by minimizing the hydrogen pressure in pipes or applications
- Select materials that are less susceptible to hydrogen embrittlement, such as stable austenitic stainless steels, alloys composed of nickel, and alloys founded on copper.
- Workers need to be educated on the dangers of hydrogen and taught in what to do in the case of a leak.
- Apply protective coatings to metal surfaces exposed to hydrogen.
- Apply heat treatment to reduce the residual stress in the material (the higher the stress in a lattice, the stronger the weakening effect caused by the hydrogen atoms).

The essential recommendations to reduce the likelihood of fire/explosion in unit U25.

- Provide more fire extinguishers in the unit
- Ignition sources must be eliminated or safely isolated.
- The hydrogen is tasteless, colorless, and odorless. Its presence cannot be detected by humans, use safety sensors to indicate a potentially hazardous situation. The flammable range is 4–75 vol% hydrogen in air. Accordingly, sensors are used to detect the presence of hydrogen and prevent the formation of a flammable concentration
- Electrical circuit designs should consider types of electrical insulation used and bonding techniques to prevent arcing.
- Use flame detectors that can detect hydrogen flames, which are nearly invisible, to prevent ignition.
- Provide an adequate ventilation system to quickly remove any accumulated hydrogen.
- Implement proper grounding and bonding procedures to reduce the risk of static sparking.

4 Conclusion

Bayesian network analysis is a sophisticated method that can be utilized to model complicated systems as well as the correlations that exist between variables. When applied to the process of hydro treatment, Bayesian network analysis can be utilized to predict the components that lead to H2 leakage and estimate the probability that a leak will occur. Bayesian network analysis has been shown to be useful in risk assessment in a variety of contexts, including marine applications and signaling networks.

It has been demonstrated that Bayesian networks are better to other methods such as fault tree analysis and event tree analysis due to the fact that Bayesian networks permit the incorporation of qualitative in addition to quantitative data. The use of Bayesian networks in risk assessment can be helpful in identifying the probable sources of H2 leakage, estimating the likelihood of a leak occurring and the implications of such a leak, and developing measures to either prevent or minimize the risk.

The significance of Bayesian networks as a robust tool in risk assessment has been established in a case study of the ARZEW refinery. In this study, the tool was utilized to investigate the causal links between risk factors and adverse events. This study demonstrates that Bayesian networks have a significant impact on risk assessment. The use of Bayesian networks in risk assessment can be helpful in identifying the probable sources of H2 leakage, estimating the likelihood of a leak occurring and the implications of such a leak, and developing measures to either prevent or minimize the risk.

In conclusion, the use of Bayesian network analysis in risk assessment can assist in the identification of the probable sources of H2 leakage in the hydro treatment process, the estimation of the likelihood of a leak occurring and the implications of such a leak, and the development of measures to minimize or mitigate the risk. Bayesian networks are a strong tool that can be used to model complicated systems and the interactions between variables. Their application in risk assessment has been proved in a variety of domains, and they can be used to model complex systems and the relationships between variables. The use of Bayesian networks in risk assessment can help to assure the safety and efficiency of the hydro treatment process, in addition to providing high-quality fuel products and conforming to environmental standards. Bayesian networks can be used to accomplish all of these goals.

General Conclusion

General conclusion

Renewable energy has emerged as a promising way to meet Algeria's expanding energy needs and reduce greenhouse gas emissions. Algeria, which is endowed with bountiful renewable resources such as solar, wind, and biomass, has made substantial progress in developing its renewable energy industry. Algeria has demonstrated a strong commitment to renewable energy initiatives, recognizing the significance of diversifying its energy mix and reducing reliance on fossil fuels.

Algeria's adoption of renewable energy technologies has been influenced by several factors, including government support, favorable policy frameworks, and international cooperation. The construction of large-scale solar power plants and wind farms has not only increased the nation's energy capacity, but it has also generated jobs and stimulated economic growth.

In recent years, Algeria's emphasis on hydrogen technologies has acquired momentum. As a versatile and pure energy carrier, hydrogen has enormous potential for decarbonizing a variety of sectors, including transportation, industry, and electricity generation. Given Algeria's substantial natural gas reserves, the country is ideally adapted for hydrogen production by means of processes such as steam methane reforming.

Safety is an essential component of hydrogen technologies, necessitating cautious consideration and adherence to stringent protocols during production, storage, and transport. Quantitative Risk Assessment (QRA) techniques, specifically Bayesian networks, have proved useful in evaluating and managing the safety risks associated with hydrogen infrastructure.

QRA, a probabilistic technique, permits the evaluation of multiple scenarios and their possible outcomes. Specifically, Bayesian networks provide a graphical representation of variable relationships, quantifying system-wide uncertainties and dependencies. The safety of hydrogen processes can be effectively analyzed using Bayesian networks, allowing for the identification of potential dangers and the implementation of preventative measures.

Quantitative Risk Assessment (QRA) and the Bayesian approach play crucial roles in the risk management and mitigation processes of a variety of industries. They provide valuable insights and decision-making tools to assure the safety and well-being of people, the environment, and property.

QRA is a comprehensive and systematic technique for evaluating and quantifying risks associated with particular activities or systems. It entails identifying risks, analyzing their potential repercussions, and estimating the likelihood of those repercussions occurring. QRA generates meaningful risk assessments by integrating scientific data, statistical analysis, and engineering expertise.

One of the most significant benefits of QRA is its capacity to provide quantitative risk measurements, enabling organizations to effectively prioritize and allocate resources. The assignment of numeric values to risks enables decision-makers to objectively compare various threats and make well-informed decisions regarding risk mitigation strategies. QRA also aids in establishing safety objectives and risk acceptability criteria, allowing organizations to define safety goals and track their progress over time.

The Bayesian approach, on the other hand, provides a probabilistic framework for revising beliefs and making decisions based on available evidence. It combines prior knowledge or beliefs with new data to generate posterior probabilities, or updated probabilities. This iterative process of updating probabilities permits a more nuanced and accurate comprehension of risks.

The Bayesian method is especially useful when dealing with uncertain or complex systems or limited data points. It allows decision-makers to incorporate subjective opinions and expert judgment while maintaining an empirical evidence base. By continuously updating probabilities with new information, organizations are able to modify their risk management strategies in real-time, thereby enhancing safety measures and decreasing uncertainty.

Moreover, both QRA and the Bayesian approach facilitate the identification of important risk factors and vulnerabilities. They aid in identifying potential scenarios and their associated probabilities, allowing organizations to develop targeted risk management strategies. These techniques also contribute to resource optimization by identifying cost-effective risk mitigation measures and prioritizing safety investment expenditures.

Nonetheless, it is essential to recognize that both QRA and the Bayesian approach have limitations. QRA is dependent on the availability and quality of data, and inaccurate data inputs can impact the precision of the results. Similarly, the Bayesian approach relies heavily on the selection of prior probabilities and the interpretation of new evidence, which can introduce subjectivity and bias if not carefully considered.

The use of Bayesian networks in safety-related areas, such as the detection and management of hydrogen leakage in a hydro-treating unit, has demonstrated significant benefits. In the case of ARZEW in Algeria, Bayesian networks provide a reliable and effective method for assessing the risk of hydrogen leakage, as well as crucial insights for decision-making.

By incorporating Bayesian networks, the safety management team at ARZEW is able to model and analyze the complex relationships between factors such as equipment conditions, process parameters, and environmental conditions that impact the occurrence and severity of hydrogen leakage incidents. Using historical data, expert knowledge, and probabilistic reasoning, the network can be trained to account for the system's dependencies and uncertainties.

The Bayesian network allows for the identification of significant variables and possible causal relationships that contribute to hydrogen leakage incidents. By continuously updating the network with real-time data, the system enhances its precision and provides timely alerts or recommendations to prevent or mitigate leakage risks. This proactive approach substantially improves the hydro treating unit's safety performance and decreases the likelihood of accidents, environmental damage, and human injuries.

Several steps can be taken to promote the use of Bayesian networks in safety applications. Organizations should invest in research and development to improve Bayesian networks' modeling capabilities and computational efficacy. Considering the inherent uncertainties and interdependencies of safety-critical systems, this requires the development of advanced algorithms and software tools capable of administering larger and more complex networks.

Hydrogen and technologies founded on hydrogen have enormous potential for shaping a sustainable future. As a versatile and pure energy carrier, hydrogen has garnered significant attention as a crucial solution for decarbonizing a variety of sectors, including transportation, industry, and power generation. Its unique properties, including a high energy density and the ability to produce electricity through fuel cells, position it as a potential fossil fuel substitute.

Hydrogen can be derived from numerous sources, including fossil fuels with carbon capture and storage (CCS), electrolysis of renewable energy, and biomass gasification. To assure widespread adoption, it is essential to develop cost-effective, efficient, and scalable methods for hydrogen production. In addition, technological advancements in hydrogen storage and transportation are required for the development of a robust hydrogen infrastructure.

Hydrogen also facilitates the incorporation of intermittent renewable energy sources such as solar and wind into the power grid. Energy can be retained and utilized during periods of low renewable generation by utilizing excess renewable energy for hydrogen production through electrolysis. This process, known as power-to-gas, is an effective method for energy storage and grid balancing.

However, implementing hydrogen technologies presents obstacles that must be overcome. It is crucial to ensure the safe management and storage of hydrogen. Hydrogen is an eco-friendly fuel, but it is extremely flammable and forms explosive mixtures with air. To mitigate the risks associated with hydrogen storage, transport, and utilization, stringent safety measures and protocols must be implemented.

In the hydrocarbon industry, hydrogen is widely used in hydro treating units to refine petroleum products. Hydro treating is essential for removing impurities from crude oil or intermediate products, such as gasoline or diesel, through high-temperature and-pressure hydrogen reactions. Hydrogen leakage can however occur in these units, posing serious environmental and safety risks.

The detection and mitigation of hydrogen leakage in hydro treatment units can be enhanced by integrating Bayesian networks. Bayesian networks are probabilistic models that can represent ambiguous information and provide valuable insights into complex systems. By incorporating real-time sensor data, historical data, and expert knowledge, a Bayesian network can accurately assess the likelihood of a hydrogen escape and provide operators with timely alerts.

In addition, the incorporation of Bayesian networks enables predictive maintenance strategies, allowing operators to address potential problems proactively before they escalate.

This strategy improves operational efficiency, decreases idleness, and reduces the likelihood of accidents.

It is essential to develop and implement stringent regulations and standards to ensure the safe implementation of hydrogen technologies and prevent hydrogen leaks. These regulations should cover all aspects of hydrogen handling, storage, and utilization, taking into consideration industry best practices and lessons learned.

In addition, comprehensive training and certification programs for educating professionals in the safe management and operation of hydrogen-based systems should be established. These programs should address topics like risk assessment, safety protocols, emergency response, and maintenance procedures unique to hydrogen technologies. Organizations can ensure the safe implementation and operation of hydrogen systems by providing individuals with the required knowledge and abilities.

In addition, continued research and development efforts are required for the advancement of breach detection technologies, hydrogen storage materials, and safety systems. By investing in cutting-edge technologies, businesses can mitigate risks further and improve the overall safety performance of hydrogen-based systems.

A comprehensive strategy is required for the transition to a sustainable energy economy that incorporates hydrogen technologies. Innovations in technology, such as the incorporation of Bayesian networks, provide valuable instruments for risk management and safety improvement. Important role played by regulatory frameworks in establishing safety standards and assuring compliance. Education and training programs equip professionals with the knowledge required to securely handle hydrogen. All of these factors contribute to the widespread adoption of hydrogen technologies, while ensuring safety and mitigating environmental impact.

In conclusion, the incorporation of Bayesian networks in safety applications, particularly for hydrogen leakage detection in hydro treating units, offers substantial advantages in terms of risk assessment, decision-making, and safety enhancement. Hydrogen technologies have enormous potential for a sustainable and carbon-free future, but their secure implementation is of the utmost importance. By combining technological advances, robust regulatory frameworks, and extensive educational initiatives, organizations can ensure the safe and efficient use of hydrogen while advancing towards a cleaner and more sustainable energy landscape.

Bibliographic references

Bibliographic references

[1] Coyle, E. D., & Simmons, R. A. (2014). Understanding the Global Energy Crisis. Purdue University Press, page 16.

[2] Zuttel, A., Borgschulte, A., & Schlapbach, L. (2008). Hydrogen as a Future Energy Carrier. Wiley-VCH Verlag GmbH & Co. KGaA. Page 14.

[3] Martin-Amouroux, J.-M. (2003) IEPE, Grenoble, France, personal communication; BP Statistical Review of World Energy (2004) United Kingdom.

[4] 3 International Energy Agency (IEA, AIE) (2002) Key World Energy Statistics, 2002 edn

[5] The subject of oil depletion has always been discussed very controversially. Colin J. Campbell forecasted the peak in conventional oil production to occur around 2010. Campbell, C.J. (1997) The Coming oil Crisis, Multi-Science Publishing Co. Ltd., Brentwood. See also Hall, C., et al. (2003) Hydrocarbons and the evolution of human culture. Nature, 426, 318–22; http://www.lifeaftertheoilcrash.net/; and Ref. 3. A contrary opinion is given in Chapter 4.4.

[6] Nelson, Vaughn C. Introduction to Renewable Energy. Boca Raton: CRC Press, 2011, page 27, 28 ,30. https://doi.org/10.1201/9781439891209.

[7] « Fundamental Forces ». Consulté le 14 mai 2023. http://hyperphysics.phy-astr.gsu.edu/hbase/Forces/funfor.html.

[8] Project, The Chisholm Legacy. « Net Zero, Gross Zero, Negative Zero. Simply Put, Which One Is Better? » The Chisholm Legacy Project, 30 novembre 2021. Consulté le 15 mai 2023. https://thechisholmlegacyproject.org/net-zero-gross-zero-negative-zero-simply-put-which-one-is-better/.

[9] Annalisa Savaresi. “The Paris agreement: a new beginning?” In: Journal of Energy

& Natural Resources Law 34.1 (2016), pp. 16–26. doi: 10.1080/02646811.2016.1133983.

[10] Statistical review of world energy 2021. Accessed on 10-08-2021. url:

bp.com/content/dam/bp/businesssites/en/global/corporate/pdfs/energyeconomics/statistical-review/bp-stats-review-2021-full-report.pdf

[11] Timmons, D., Harris, J. M., & Roach, B. (2017). The economics of renewable energy. Edward Elgar Publishing Page 18

[12] Maczulak, Anne Elizabeth. Renewable Energy: Sources and Methods. Infobase Publishing, 2010.

[13] Bernhard Brand and Jonas Zingerle the renewable energy targets of the Maghreb countries: Impact on electricity supply and conventional power markets, Institute of Energy Economics at the University of Cologne, may (2010).

[14] Zaid, Mourad, Salah Khouildat, et Ahmed Ramzi Siagh. « Strategy of the Renewable Energy in Algeria, as an Inevitable Drift to Diversification of the Economy ». مجلة أداء المؤسسات الجزائرية 6, no 2 (31 décembre 2017): 61 68.

[15] Nina, Howell. « Types of Renewable Energy Sources and Consumption Statistics », 30 juillet 2021. https://earthandhuman.org/renewable-energy-sources-and-consumption/.

[16] I. A. Zino, "Renewable Energies in Algeria", Arab Climate Resilience initiative: Climate Change Impacts in the Arab Region "Towards Sustainable Energy: Resources, Challenges and Opportunities", Manama, Bahrain, 06-07 October, 2010.

[17] Kacem Gairaa and Yahia Bakelli, "Solar Energy Potential Assessment in the Algerian South Area: Case of Ghardaïa Region," Journal of Renewable Energy, vol. 2013, Article ID 496348, 11 pages, 2013. https://doi.org/10.1155/2013/496348.

[18] Salman, Zafar. « Renewable Energy in Algeria | EcoMENA ». Consulté le 18 mai 2023. https://www.ecomena.org/renewables-algeria/.

[19] Lassouane, Fatiha, Sabah Menia, et Abdallah Khellaf. « An overview of the hybrid sulfur cycle process for solar hydrogen production ». 3rd International Symposium on Environment Friendly Energies and Applications, EFEA 2014,12 mars 2015. https://doi.org/10.1109/EFEA.2014.7059999.

[20] Himri Y. Optimisation de certains paramètres d'un Aérogénérateur situe dans le Sud Ouest de l'Algérie. Mémoire de magister, Université de Béchar Algérie; Mai 2005.

[21] Himri, Youcef, Arif Malik, A. Stambouli, S. Himri, et Draoui Belkacem. « Review and use of the Algerian renewable energy for sustainable development ». Renewable and Sustainable Energy Reviews 13 (18 février 2013): 1584 91. https://doi.org/10.1016/j.rser.2008.09.007.

[22] IEA. « The Future of Hydrogen – Analysis ». Consulté le 22 mai 2023. https://www.iea.org/reports/the-future-of-hydrogen.

[23] IEA. « Hydrogen - Fuels & Technologies ». Consulté le 22 mai 2023. https://www.iea.org/fuels-and-technologies/hydrogen.

[24] « What is Green Hydrogen and its importance - Iberdrola ». Consulté le 22 mai 2023. https://www.iberdrola.com/sustainability/green-hydrogen.

[25] Energy.gov. « Hydrogen: A Clean, Flexible Energy Carrier ». Consulté le 22 mai 2023. https://www.energy.gov/eere/articles/hydrogen-clean-flexible-energy-carrier.

[26] « Hydrogen | Properties, Uses, & Facts | Britannica », 3 mai 2023. https://www.britannica.com/science/hydrogen.

[27] BYJUS. « Hydrogen (H) - Element Information, Preparation, Physical and Chemical Properties & Uses with FAQs », 14 septembre 2020. https://byjus.com/chemistry/hydrogen/.

[28] Energy.gov. « Hydrogen: A Clean, Flexible Energy Carrier ». Consulté le 23 mai 2023. https://www.energy.gov/eere/articles/hydrogen-clean-flexible-energy-carrier.

[29] « Hydrogen - Element information, properties and uses | Periodic Table ». Consulté le 22 mai 2023. https://www.rsc.org/periodic-table/element/1/hydrogen.

[30] Hydrogen Newsletter. « Progress and Problems in Hydrogen Storage Methods », 23 février 2023. https://www.hydrogennewsletter.com/a-review-about-progress-and-problems-in-hydrogen-storage-methods/.

[31] Hydrogen news and intelligence | Hydrogen Insight. « Algeria Aims to Supply Europe with 10% of Its Clean Hydrogen Needs by 2040 in New National H2 Roadmap », 27 mars 2023. https://www.hydrogeninsight.com/policy/algeria-aims-to-supply-europe-with-10-of-its-clean-hydrogen-needs-by-2040-in-new-national-h2-roadmap/2-1-1426265.

[32] « PtX : Green Hydrogen ». Consulté le 22 mai 2023. https://www.energypartnership-algeria.org/home/ptx-green-hydrogen/.

[33] FuelCellsWorks. « Algeria Planning To Compete With Morocco On Production Of Green Hydrogen ». Consulté le 22 mai 2023. https://fuelcellsworks.com/news/algeria-planning-to-compete-with-morocco-on-production-of-green-hydrogen/.

[34] IRIS. « Les enjeux stratégiques de l’hydrogène dans la transition énergétique ». Consulté le 23 mai 2023. https://www.iris-france.org/165548-les-enjeux-strategiques-de-lhydrogene-dans-la-transition-energetique/.

[35] P. MALBRUNOT – Mémento de l'hydrogène : fiche 2.1 – octobre 2003 - Association Française de l’Hydrogène : http://www.afh2.org/

[36] Team, Y. C. C. « The Difference between Gray, Blue, and Green Hydrogen » Yale Climate Connections ». Yale Climate Connections, 15 février 2022. http://yaleclimateconnections.org/2022/02/the-difference-between-gray-blue-and-green-hydrogen/.

[37] TÜV SÜD. « Sécurité et efficacité dans vos projets de production d’hydrogène ». Consulté le 22 mai 2023. https://www.tuvsud.com/fr-fr/themes/hydrogene/explorez-la-chaine-de-valeur-de-l-hydrogene-/production-d-hydrogene.

[38] Bressan L., Collodi G. and Ruggeri F., 2009, Hydrogen generation for modern refineries, Hydrocarbon Engineering, November 2009.

[39] Scribd. « Hydrogen Production and Storage | PDF | International Energy Agency | Gasification ». Consulté le 20 mai 2023. https://www.scribd.com/document/50728173/Hydrogen-Production-and-Storage.

[40] Dolci, F. (2018). Green hydrogen opportunities in selected industrial processes. JRC Technical Reports

[41] « Steam Reforming Hydrogen ». Consulté le 22 mai 2023. http://www.making-hydrogen.com/steam-reforming-hydrogen.html.

[42] « Partial-Oxidation Methane Stock Vector. Illustration of Metallic - 83365039 ». Consulté le 22 mai 2023. https://www.dreamstime.com/stock-illustration-partial-oxidation-methane-anaerobic-aom-microbial-process-occurring-anoxic-marine-freshwater-sediments-aom-image83365039.

[43] ResearchGate. « Figure 2. Section 1: Auto-Thermal Gas Reforming. » Consulté le 22 mai 2023. https://www.researchgate.net/figure/Section-1-Auto-thermal-gas-reforming_fig2_277347039.

[44] ResearchGate. « Figure 2: Hydrogen Production by Gasification of Coal [53-58]. » Consulté le 22 mai 2023. https://www.researchgate.net/figure/Hydrogen-production-by-gasification-of-coal-53-58_fig4_282746267.

[45] H. Audus, Olav Kaarstad and Mark Kowal, Decarbonisation of Fossil Fuels: Hydrogen as an Energy Carrier, CO2 Conference, Boston/Cambridge 1997, published in Energy Conversion Management, Vol. 38, Suppl., pp. 431-436.
Bossel, Ulf, et Baldur Eliasson. « Energy and the Hydrogen Economy », s. d.
[46] Limited, Alamy. « Electrolysis Cell of Water to Produce Hydrogen and Oxygen Stock Photo - Alamy ». Consulté le 22 mai 2023. https://www.alamy.com/stock-photo-electrolysis-cell-of-water-to-produce-hydrogen-and-oxygen-116479805.html.

[47] Simbolotti, Giorgio. « Hydrogen Production and Storage », janvier 2006, 38.HYDROGEN PRODUCTION AND - R&D Priorities and Gaps (readkong.com)

[48] A. Chambers, C. Park, R.T.K. Baker, N.M. Rodriguez: J. Physical Chemistry B, 102 (1998) p. 4253- 4256.
[49] ResearchGate. « Figure 3. Principle of Operation of Proton Exchange Membrane (PEM)... » Consulté le 22 mai 2023. https://www.researchgate.net/figure/Principle-of-operation-of-proton-exchange-membrane-PEM-electrolyzers_fig3_341810839.

[50] ResearchGate. « Fig. 6. High-Temperature Electrolysis. » Consulté le 22 mai 2023. https://www.researchgate.net/figure/High-temperature-electrolysis_fig6_254591751.

[51] VISEUR, Mathieu. « Etude de faisabilité de l'utilisation de l'hydrogène comme vecteur alternatif d'énergie ». Projet fin d'études, Université Libre de Bruxelles Institut de Gestion de l'Environnement et de l'Aménagement du Territoire Faculté des Sciences, 2007. https://www.academia.edu/40475881/Etude_de_faisabilit%C3%A9_de_l_utilisation_de_lhydrog%C3%A8ne_comme_vecteur_alternatif_d_%C3%A9nergie.

[52] Prince RC, Kheshgi HS. The photobiological production of hydrogen: potential efficiency and effectiveness as a renewable fuel. Crit Rev Microbiol. 2005;31:19–31.

[53] Energy.gov. « Hydrogen Production: Biomass Gasification ». Consulté le 17 mai 2023. https://www.energy.gov/eere/fuelcells/hydrogen-production-biomass-gasification.

[54] « Connaissance des énergies : infos pétrole,énergie renouvelable,photovoltaïque ». Consulté le 17 mai 2023. https://www.connaissancedesenergies.org/.

[55] Hanssen, Jan Erik. *Prospects for hydrogen from biomass,* 2006.

[56] Dresselhaus, M, G. Crabtree, M. Buchanan, T. Mallouk, Laurens Mets, K. Taylor, P. Jena, et al. « Basic Research Needs for the Hydrogen Economy. Report of the Basic Energy Sciences Workshop on Hydrogen Production, Storage and Use, May 13-15, 2003 », 1 janvier 2004. https://doi.org/10.2172/899224.

[57] VISEUR, Mathieu. « Etude de faisabilité de l'utilisation de l'hydrogène comme vecteur alternatif d'énergie ». Projet fin d'études, Université Libre de Bruxelles Institut de Gestion de l'Environnement et de l'Aménagement du Territoire Faculté des Sciences, 2007. https://www.academia.edu/40475881/Etude_de_faisabilit%C3%A9_de_l_utilisation_de_lhydrog%C3%A8ne_comme_vecteur_alternatif_d_%C3%A9nergie.

[58] « Use of hydrogen - U.S. Energy Information Administration (EIA) ». Consulté le 18 mai 2023. https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php.

[59] iStock. « Studio Photo of a Hydrogen Fuel Cell Vehicle. This Unit Converts... », 10 mars 2015. https://www.istockphoto.com/photo/hydrogen-fuel-cell-for-alternative-fuel-vehicles-gm466051186-60223402.

[60] S. Verhelst, P. Maesschalck, N. Rombaut, and R. Sierens, BIncreasing the power output of hydrogen internal combustion engines by means of supercharging and exhaust gas recirculation, [Int. J. Hydrogen Energy, vol. 3

[61] O. M. Bockris and T. N. Vezirog˘lu, BA solar-hydrogen economy for USA,[Int. J. Hydrogen Energy, vol. 8, no. 5, pp. 323————————————340, 1983.

[62] H. Nojoumi, I. Dincer, and G. F. Naterer, BGreenhouse gas emissions assessment of hydrogen and kerosene-fueled aircraft propulsion, [Int. J. Hydrogen Ene

[63] Derek Abbott, Fellow IEEE; PAPER Keeping the Energy Debate Clean: How Do We Supply the World's Energy Needs?

[64] « Comment fonctionne un moteur à hydrogène ? » Consulté le 23 mai 2023. https://www.lhyfe-heroes.com/about-hydrogen/how-does-a-hydrogen-engine-work.

[65] Corneil, H.G. et F.J. Heinzelmann, 1980. L'hydrogène pour le raffinage futur. Hydro. Proc., pages : 85-90.

[66] Ratan, S. et P. Wentink, 2001. Hydrogène rentable à partir des gaz de dégagement de raffinerie. Pétrochimie et traitement du gaz, été, pp : 131-137.

[67] Reid, Dennis. « Council Post: Hydrogen In Oil Refineries: Understanding The Importance Of Hydrogen Monitoring And Best Practices ». Forbes. Consulté le 23 mai 2023. https://www.forbes.com/sites/forbesbusinesscouncil/2022/09/08/hydrogen-in-oil-refineries-understanding-the-importance-of-hydrogen-monitoring-and-best-practices/.

[68] Rukini, Asywendi, M Akbar Rhamdhani, Geoffrey Brooks, et A. Bulck. « Metals Production and Metal Oxides Reduction Using Hydrogen: A Review ». *Journal of Sustainable Metallurgy* 8 (12 janvier 2022). https://doi.org/10.1007/s40831-021-00486-5.

[69] https://www.facebook.com/siliconcanals. « Stockholm's H2 Green Steel Closes Series B Round at €260M; to Build Large Scale Green Steel Plant | Silicon Canals », 19 octobre 2022. https://siliconcanals.com/news/startups/h2-green-steel-closes-260m/.

[70] « Everything You Need to Know About Hydrogen Energy Storage | EnergyLink », 25 janvier 2022. https://goenergylink.com/blog/hydrogen-energy-storage/.

[71] « The Many Dangers of Hydrogen | Martek Marine ». Consulté le 20 mai 2023. https://www.martek-marine.com/blog/the-many-dangers-of-hydrogen/.

[72] « Green Job Hazards - Hydrogen Fuel Cells: Fire and Explosion | Occupational Safety and Health Administration ». Consulté le 21 mai 2023. https://www.osha.gov/green-jobs/hydrogen/fire-explosion.

[73] Crowcon Detection Instruments Ltd. « Les dangers de l'hydrogène ». Consulté le 21 mai 2023. https://www.crowcon.com/fr/blog/the-dangers-of-hydrogen/.

[74] « Hydrogen Properties & Leak Detection Considerations | Hydrogen Tools ». Consulté le 21 mai 2023. https://h2tools.org/bestpractices/hydrogen-properties-leak-detection-considerations.

[75] « What is Hydrogen Embrittlement? - Causes, Effects and Prevention - TWI ». Consulté le 21 mai 2023. https://www.twi-global.com/technical-knowledge/faqs/what-is-hydrogen-embrittlement.

[76] « Hydrogen Leaks | Hydrogen Tools ». Consulté le 23 mai 2023. https://h2tools.org/bestpractices/hydrogen-leaks.

[77] « Hydrogen Safety for Energy Applications - 1st Edition ». Consulté le 23 mai 2023. https://www.elsevier.com/books/hydrogen-safety-for-energy-applications/kotchourko/978-0-12-820492-4.

[78] Ustolin, Federico, Ernesto Salzano, Gabriele Landucci, et Nicola Paltrinieri. « Modelling Liquid Hydrogen BLEVEs: A Comparative Assessment with Hydrocarbon Fuels ». In *Proceedings of the 30th European Safety and Reliability Conference and 15th Probabilistic Safety Assessment and Management Conference*, 1876-83. Research Publishing Services, 2020. https://doi.org/10.3850/978-981-14-8593-0_3982-cd.

[79] Ecofin, Agence. « L'Algérie envisage d'investir 20 à 25 milliards USD dans l'hydrogène vert ». Agence Ecofin. Consulté le 21 mai 2023. https://www.agenceecofin.com/actualites/0403-106130-l-algerie-envisage-d-investir-20-a-25-milliards-usd-dans-l-hydrogene-vert.

[80] euronews. « Les grandes ambitions de l'Algérie dans les énergies renouvelables », 3 octobre 2022. https://fr.euronews.com/2022/10/03/energies-renouvelables-les-grandes-ambitions-de-algerie-solaire-et-hydrogene-vert. Consulté le 21/05/2023.

[81] « Hydrogène vert : l'Algérie à la conquête de l'Europe ». Consulté le 21 mai 2023. https://www.h2-mobile.fr/actus/hydrogene-vert-algerie-conquete-europe/.

[82] El watan. « Développement de l'hydrogène : L'Algérie Affiche Ses Ambitions ». Consulté le 21 mai 2023. https://elwatan-dz.com/developpement-de-lhydrogene-lalgerie-affiche-ses-ambitions.

[83] « PtX : Green Hydrogen ». Consulté le 21 mai 2023. https://www.energypartnership-algeria.org/home/ptx-green-hydrogen/.

[84] FuelCellsWorks. « Algeria Planning To Compete With Morocco On Production Of Green Hydrogen ». Consulté le 23 mai 2023. https://fuelcellsworks.com/news/algeria-planning-to-compete-with-morocco-on-production-of-green-hydrogen/.

[85] Government of Canada, Canadian Centre for Occupational Health and Safety. « CCOHS: Hazard and Risk - Risk Assessment », 5 Avril 2023. https://www.ccohs.ca/oshanswers/hsprograms/hazard/risk_assessment.html.

[86] Chapman, C. B., Ward, S., & Chapman, C. (2003). Project risk management: processes, techniques and insights (2nd ed.). Wiley.

[87] Young, C. E. (2010). Essentials of project and systems engineering management (3rd ed.). Wiley.

[88] Aven, T. (2010). Risk assessment and risk management: review of recent advances on their foundation. European Journal of Operational Research.

[89] Trainer, Practical Risk. « ISO31000 Risk Management Process ». Practical Risk Training, 5 juin 2021. https://practicalrisktraining.com/iso-31000-risk-process.

[90] ISO 17776:2000, Petroleum and natural gas industries – Offshore production installations – Guidelines on tools and techniques for hazard identification and risk assessment (ISO).

[91] AS/NZS 4360:2004: Joint Standards Australia/Standards New Zealand Committee OB-007. AS/NZS ISO 31000:2009 Risk management - Principles and guidelines. Accessed June 8, 2023. https://project.lsst.org/riskmanagement/31000-2009.pdf

[92] « Risk-Management-Stakeholders ». Consulté le 8 juin 2023. https://www.diligent.com/insights/grc/risk-management-stakeholders/.

[93] Esra, Tepeli. « Why Stakeholder Involvement Is Important for Risk Management? », 19 janvier 2023. https://www.projectmanagement.com/blog/blogPostingView.cfm?blogPostingID=73832&t

hisPageURL=/blog-post/73832/why-stakeholder-involvement-is-important-for-risk-management-#_=_.

[94] SafetyCulture. « Risk Assessment: Process, Examples, & Tools ». Consulté le 8 juin 2023. https://safetyculture.com/topics/risk-assessment/.

[95] SafetyCulture. « Qualitative & Quantitative Risk Analysis ». Consulté le 8 juin 2023. https://safetyculture.com/topics/qualitative-and-quantitative-risk-analysis/.

[96] Team, Risk Management. « Qualitative & Quantitative Risk Assessment Process ». ComplianceBridge, 20 mai 2019. https://compliancebridge.com/quantitative-risk-assessment/.

[97] « What Is Predictive Analytics? - 3 Things You Need to Know ». Consulté le 8 juin 2023. https://www.mathworks.com/discovery/predictive-analytics.html.

[98] CIO. « What Is Predictive Analytics? Transforming Data into Future Insights ». Consulté le 8 juin 2023. https://www.cio.com/article/228901/what-is-predictive-analytics-transforming-data-into-future-insights.html.

[99] « The Risk Assessment Matrix: What Is It and Why Is It Important? », 8 juin 2023. https://www.auditboard.com/blog/what-is-a-risk-assessment-matrix/.

[100] « ALARP Principle ». Consulté le 8 juin 2023. https://www.primatech.com/technical/alarp-principle.

[101] « Risk management: Expert guidance - ALARP at a glance ». Consulté le 8 juin 2023. https://www.hse.gov.uk/enforce/expert/alarpglance.htm.

[102] GreyCampus. « Risk Identification Tools and Techniques | CAPM — OpenCampus », 28 février 2023. https://www.greycampus.com/opencampus/certified-associate-in-project-management/risk-identification-tools-and-techniques-in-capm/.

[103] www.duodesign.co.uk. « Fault Tree Analysis Explained ». Wilde Risk. Consulté le 10 juin 2023. https://www.wilderisk.co.uk/about/blog/fault-tree-analysis-explained/.

[104] « Hazard and Operability Study (HAZOP): Definition and Tips | Indeed.Com ». Consulté le 10 juin 2023. https://www.indeed.com/career-advice/career-development/hazop.

[105] Crawley, Frank, Malcolm Preston, et Brian Tyler. HAZOP: Guide to Best Practice : Guidelines to Best Practice for the Process and Chemical Industries. IChemE, 2000. Page 22

[106] IEC, (2008): Risk Management, Risk Assessment Techniques. 1st edition. International Electro technical Commission

[107] Aissani, Nassima, Islam Hadj Mohamed Guetarni, et Zoubida Lounis. *Decision process for safety based on Bayesian approach*, 2018. https://doi.org/10.1109/PAIS.2018.8598533.

[108] Unnikrishnan, G. Oil and Gas Processing Equipment: Risk Assessment with Bayesian Networks. CRC Press, 2020. Page 17, 18

[109] « Summary of Probability Theory ». In *Structural Reliability Analysis and Prediction*, 371-402. John Wiley & Sons, Ltd, 2017. https://doi.org/10.1002/9781119266105.app1.

[110] M. Rausand, "Risk Assessment: Theory, Methods, and Applications," John Wiley & Sons, 2013.

[111] Bougofa, Mohammed, Abderraouf Bouafia, et Ahmed Bellaouar. « An Integrated Quantitative Bayesian Network in Risk Management for Complex Systems ». *International Journal of Performability Engineering* 16, nº 3 (2020): 354. https://doi.org/10.23940/ijpe.20.03.p4.354366.

[112] R. Sterritt, A. H. Marshal, C. M. Shapcott, S. I. McClean, "Exploring Dynamic Bayesian Belief Networks for Intelligent Fault Management System," IEEE International Conference on Systems, Man and Cybernetics V, Nashville, Tennessee, USA, pp. 3646-3652, 2000.

[113] coursRdP-seance1.pdf https://www.i3s.unice.fr/~comet/SUPPORTS/Nice-EPU-GB4-TechSim/coursRdP-seance1.pdf pages :08

[114] Techno-Science.net. « Réseau de Petri - Définition et Explications ». Techno-Science.net. Consulté le 10 juin 2023. https://www.techno-science.net/glossaire-definition/Reseau-de-Petri.html.

[115] Labadi, Karim. « Contribution à la modélisation et à l'évaluation de performances des systèmes logistiques à l'aide d'un nouveau modèle de réseaux de Petri stochastiques », s. d. https://theses.hal.science/tel-00389432/document.

[116] Etienne, Renault. Les automates synchronisés ne sont pas suffisants. », avril 2015. https://www.lrde.epita.fr/~renault/teaching/imc/2-petri.pdf

[117] « Markov Chains | Brilliant Math & Science Wiki ». Consulté le 9 juin 2023. https://brilliant.org/wiki/markov-chains/.

[118] « Markov Chain Explained | Built In ». Consulté le 9 juin 2023. https://builtin.com/machine-learning/markov-chain.

[119] Columbia University Mailman School of Public Health. « Markov Chain Monte Carlo », 5 août 2016. https://www.publichealth.columbia.edu/research/population-health-methods/markov-chain-monte-carlo.

[120] Chaines de Markov chapitre 2 26 pages https://www.imo.universite-paris-saclay.fr/~pierre-loic.meliot/agreg/markov.pdf

[121] « Chaîne de Markov ». In *Wikipédia*, 3 octobre 2022. https://fr.wikipedia.org/w/index.php?title=Cha%C3%AEne_de_Markov&oldid=197447123.

[122] L'Ecuyer, Pierre. « Chaînes de Markov en temps discret », s. d., 107. https://www.iro.umontreal.ca/~lecuyer/ift3655/chaines-Markov.pdf

[123] « chaîne de Markov - Définir les termes commerciaux », 17 novembre 2022. https://www.definebusinessterms.com/fr/chaine-de-markov/.

[124] Oregon Occupational Safety and Health Administration. (2007). Section 4, Chapter 2. Occupational health and safety regulations technical manual. https://osha.oregon.gov/OSHARules/technical-manual/Section4-Chapter2.pdf

[125] Gohar, Gamal Abdel-Nasser, et Mohamed Sherif El-Gayar. « Upgrading of Light Dewaxed Oil through Hydro finishing and Additives Blending for Producing Automatic Transmission Fluid ». *American Journal of Applied Sciences* 3, n° 12 (1 décembre 2006): 2136-46. https://doi.org/10.3844/ajassp.2006.2136.2146.

[126] LEWANDOWSKI M., SARBAK Z., FAʙit G., Elimination of organic nitrogen and sulphur compounds from crude petroleum oils, Chemistry and Ecological Engineering, 2001, No. 4, 371-389.

[127] « Hydrofining - an overview | ScienceDirect Topics ». Consulté le 6 juin 2023. https://www.sciencedirect.com/topics/engineering/hydrofining.

[128] « ALCÈNES ou OLÉFINES - Encyclopædia Universalis ». Consulté le 6 juin 2023. https://www.universalis.fr/encyclopedie/alcenes-olefines/.

[129] « Fundamentals of Hydrotreating Part 1 ». Consulté le 6 juin 2023. https://what-when-how.com/petroleum-refining/fundamentals-of-hydrotreating-part-1/.

[130] Prentice, Krista Marie, Gary Paul Schleicher, Lei Zhang, Timothy Lee Hilbert, Michel A Daage, Sylvain Hantzer, Wenyih F Lai, et al. « (54) SOUR SERVICE HYDROPROCESSING FOR LUBRICANT BASE OL PRODUCTION », s. d.

[131] Prado, Glaucia H. C., Yuan Rao, et Arno De Klerk. « Nitrogen Removal from Oil: A Review ». *Energy & Fuels* 31, n° 1 (19 janvier 2017): 14-36. https://doi.org/10.1021/acs.energyfuels.6b02779.

[132] Magiera, Janusz, et Aw Markiewicz. « Environment Protection Engineering », 2003. https://dbc.wroc.pl/Content/43710/epe_29_2003_3_4_08.pdf

[133] « Hydrofining - an overview | ScienceDirect Topics ». Consulté le 7 juin 2023. https://www.sciencedirect.com/topics/engineering/hydrofining.

[134] Anindyta, Afra, Ir Eko Julianto, et Agung Nugroho. « Analisis Risiko Kebocoran Gas pada Sistem Perpipaan Recycle Gas Hydrofinishing Plant dengan Menggunakan Metode Quantitative Risk Analysis (QRA) (Studi Kasus : Perusahaan Produksi Pelumas) », nº 2581 (s. d.). https://core.ac.uk/download/pdf/236670389.pdf

[135] ENVIRONMENTAL, HEALTH, AND SAFETY GUIDELINES PETROLEUM REFINING November 17, 2016 /35 pages

https://www.ifc.org/wps/wcm/connect/bde2da1d-3a09-400b-be24-3f6a60353ddc/2016-EHS+Guidelines+for+Petroleum+Refining+FINAL.pdf?CVID=lxPS7Bu&MOD=AJPERES

[136] Etude de dangers de la raffinerie d'Arzew Chapitre B8-P1: Hydrofinishing Bertin Technologies www.bertin.fr 35 page

[137] KAMEL Mohammed et BEN ABDALLAH Aziz. « OVERVIEW OF SAFETY IN HYDROGEN PRODUCTIOON ». University Oran 2 Mohamed Ben Ahmed Institut de Maintenance et de Sécurité Industrielle, 2021.

[138] « Arbre Analyst - Logiciel d'arbres de défaillances pour l'analyse de performances de Sûreté de fonctionnement gratuit et libre d'utilisation. » Consulté le 20 juin 2023. https://www.arbre-analyste.fr/.

[139] Malika, Medkour. « Transformation of Fault Tree into Bayesian Network Methodology for Fault Diagnosis ». *Mechanics* 23, nº 6 (8 janvier 2018) : 891-99. https://doi.org/10.5755/j01.mech.23.6.17281.