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MissionGreenFuels

Guideline for Safer and Faster PtX

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List of Abbreviations

AEC	Alkaline electrolysis cell
Biofuel	Biofuel is fuels produced from biooils (see definition of biooil below)
Biogas	60% methane and 40% CO_2 based on production from biomasses via anaerobic digestion
Biooil	Biooil is oil produced from pyrolysis, liquefaction or the HVO process. Biooil also include oil from pyrolysis of plastic and tires as it is assumed that these with time will become 100 % biogenic.
BNG	Biogas upgraded to natural gas quality
CBRN	Chemical, Biological, Radiological and Nuclear defence
CC	Carbon capture
CCU	Carbon capture and utilization
CCS	Carbon capture and storage
CH_2	Compressed hydrogen
CHP	Combined heat and power plant
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
DEA	Danish Environment Agency
DEMA	Danish Emergency Management Agency
DEPA	Danish Environmental Protection Agency
DK	Denmark
DME	Dimethyl ether (C_2H_6O)
EPC	Engineering, Procurement & Construction
ENDK	Energinet Denmark
EtOH	Ethanol (C_2H_5OH)
EU	European Union
EC	Electrolysis cell
FAME	Fatty acid methyl ether (=biodiesel) (C16-C81 esters)
FCEV	Fuel cell electric vehicle
FID	Final Investment Decision
FIDIC	International Federation of Consulting Engineers
Gasoline	Light hydrocarbons (C_4-C_{12}, typically C_7-C_{11}). Same as petrol.
GHG	Greenhouse gas
H_2	Hydrogen
HAZID	Hazard Identification
HAZOP	Hazard and operability study
HFO	Heavy fuel oil (typically C_{20}-C_{50})
HIAD	Hydrogen Incident and Accident Database)
HSEQ	Health Safety, Environment and Quality
HVO	Hydrotreated vegetable oil (typically C_{15}-C_{18})

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Jet-fuel	Highly branched hydrocarbon, C_{10}-C_{13}, mostly kerosene
LCA	Life-cycle assessment analysis
LH_2	Liquefied hydrogen
LNG	Liquefied natural gas (primary CH_4)
LOHC	Liquid organic hydrogen carriers (H_2 carrier)
LOPA	Layers of Protection Analysis
LPG	Liquefied petroleum gas (primary C_3-C_4)
LULU	Locally Unwanted Land Use
M85	Methanol gasoline blend with 85 wt%
MeOH	MeOH Methanol (CH_3OH)
MGO	Marine gasoil (typically < C35)
MOU	Memorandum of Understanding
Mt	Megatonne (1.000.000.000 kg)
NG	Fossil natural gas (primarily CH4).
NH_3	Ammonia RE Renewable energy
NIMBY	Not-In-My-Backyard
SMR	Steam methane reforming
eSMR	Electric heated steam methane (reforming)
PPE	Personal Protection Equipment
PSS	Plan for Health and safety
PtX	Power to X (X = any kind of Green Fuel)
RA	Risk Assessment
RFNBO	Renewable fuels of non-biological origin
RTECS	Register of Toxic Effects of Chemical Substances
SOEC	Solid oxide electrolysis cell (high temperature with high efficiency)
WEA	Danish Environmental Protection Agency
WtE	Waste to Energy plants

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DBI, FORCE Technology, CIP (HØST PtX Esbjerg), European Energy, Siemens Gamesa, Everfuel, Rønne Havn, DFDS, Skovgaard Energy, DS (Dansk Standard), and Green Hydrogen Systems.

Executive Summary

What is PtX?

To solve global climate challenges, PtX is crucial for replacing fossil fuel consumption in industry, heavy-duty vehicles, shipping, and aviation. PtX converts green electricity into hydrogen or PtX products based on hydrogen. The PtX process begins with using green electricity (wind turbines or solar energy) to power electrolysis plants, where they split hydrogen from water. The hydrogen can then be used directly or as an element in making hydrogen-based fuels in a synthesis plant. When hydrogen is used as fuel, it produces water again without harmful emissions. In the synthesis process, hydrogen combines with nitrogen to produce ammonia. Carbon-based fuels such as methanol could also be produced in a synthesis process by combining hydrogen and captured CO_2. The amount of CO_2 emission from carbon-based fuels is the same amount of CO_2 that participates in the production. It means there is no CO_2 accumulation, and CO_2 is in the circle process of carbon-based fuels.

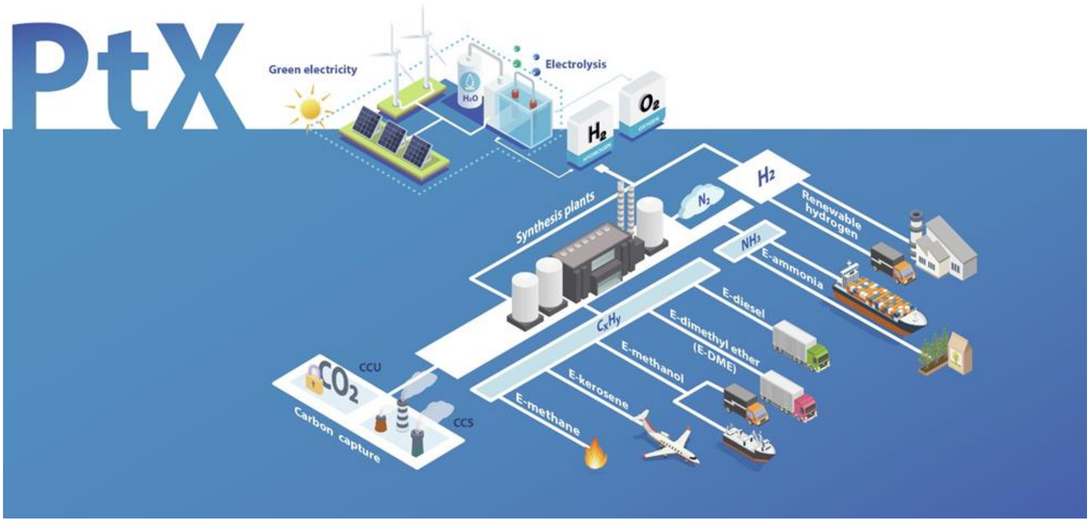

Figure 1: PtX from production to application

Considerations

This Executive Summary is an extract of the guideline and is based on data, information and reflections from interviews with stakeholders from both authorities and the industry.
Before committing to the project of establishing a PtX plant, many considerations and risks should be taken, both in relation to investment, projecting, and operation.

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Investment:
As an investor and as a part of top management, you must expect that the project will be more complex than other entrepreneur projects due to PtX being an immature industry. This can cause delays due to:

- Unknown anticipated income due to tariffs
- Delays from equipment suppliers
- Extended approval processes
- Lack of standards
- Lack of resources, knowledge and aligned approval processes among municipals
- A limited number of experts in the industry in Denmark
- Financial commitment from off-takers
- Resistance in society

Location and resources:
First and foremost, site selection plays a critical role in ensuring the safety and efficiency of the plant. Factors such as proximity to feedstock sources, transportation infrastructure, and access to utilities need to be assessed. Consideration should also be given to the potential impacts on local communities and ecosystems.
In planning the location when establishing a PtX plant in Denmark, there are issues which are crucial to relate to before the final decision, such as:

- The political environment in the municipality where the plant is planned to be established
- The public perception in the area about both NIMBY and LULU (see Chapter 5)
- Continuous and sufficient green power supply from either wind turbines or solar cells
- Continuous and sufficient clean water supply
- Deposit of wastewater and other waste products
- Opportunities for future expansion of the project (available areas around the plant)
- Access to infrastructure for distribution

Risks:
Implementing chemicals and fuels comes with well-known risks and new risks about new technologies, which is why all involved with Power to X seek solutions to issues related to all related risks in producing safer and PtX. Solutions exists but vary between the PtX industries, municipals, and societies. In the idea phase, a HAZOP should be conducted, and based on the result, risk assessments should be done at an early stage including all aspects of risks such as: (see detailed plan in Chapter 7)

- Project risks
- External Dynamics and Market Forces
- Supply Chain
- Production and equipment
- HSE (Health, Safety & Environment)
- Security

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Compliance and approvals:

PtX projects require approvals from public authorities. They are familiar but may be adapted to accommodate the growing PtX industry. Although the approvals needed are known from other industries, such as power plants and petrochemicals, several factors differentiate PtX projects.

Another important aspect is the interaction between the PtX industry and the regulators.

The most common issues mentioned by the industry and authorities are the need for harmonized standards or regulations and which normative references to comply with.

Chapter 6 in this guideline overviews the most common approval processes, including descriptions of which authorities and legislation you will meet during the process and how to handle it. Furthermore, the guideline content is a list of all the relevant legislation and standards, and in which order you can expect to be requested to deliver the applications through all the phases of the project:

- Phase 1 – From idea
- Phase 2 – Designing the concept
- Phase 3 – Engineering
- Phase 4 – Tender, Engineering, Procurement & Construction
- Phase 5 – Operation and Maintenance

This guideline gives advisories in the various authorities related to the whole process from idea to production (see Chapter 9).

Safety:

Safety measures must be implemented at every stage of plant construction and operation. Comprehensive hazard identification, risk assessments, and safety processes should be developed and complied with. Examples of emergency response plans, including fire safety systems, general HSE, and occupational health and safety, are essential for smoother processes.

This guideline aims to provide a comprehensive overview of safety issues and processes while constructing safe PtX plants. By analysing the accident database for PtX plants (HIAD), we have learned that technical reasons cause 40% of accidents and human reasons cause 60%. Therefore, we have considered all safety aspects in this guideline. It is crucial to ensure that these plants are designed, constructed, and operated with safety as a top priority while maximising production efficiency and minimising environmental impact. This is why a 360° safety evaluation has been incorporated. We have included a recommendation for implementing an effective safety management system and a sufficient HSE plan at an early stage of the project (Chapter 8 gives examples of how to do this).

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Public Perceptions:

Society and public perceptions are essential considerations in PtX projects. Public acceptance is influenced by aesthetic concerns, environmental impact, and perceived fairness in decision-making. To address public perceptions and foster acceptance, stakeholders must engage in bidirectional communication, open dialogues, and transparent information dissemination. By involving local communities early in the project's design and implementation, mutual understanding and acceptance can be achieved, reducing resistance and delays in green fuel projects. This guideline (Chapter 5) gives suggestions to “What?”, “How?” and “Why?”.

Construction:

The design and engineering phase should prioritise integrating advanced technologies to maximise the plant's efficiency and minimise waste. This includes the selection of appropriate equipment, materials, and process optimization. Due to the immatureness of the PtX industry, you may face challenges in analysing which equipment and processes are the most feasible in new integrated systems (Chapter 10 gives advice on those issues).

References: in related chapters

Challenges

- **Technological barriers:** Developing efficient and cost-effective conversion technologies to turn feedstock into green fuels is complex. Processes such as fermentation, gasification, and pyrolysis must be optimized to achieve high yields and reduce production costs.
- **Scale-up and commercialization:** Transitioning from small-scale pilot plants to large-scale commercial operations is challenging. Upscaling requires significant investment, and ensuring consistent production, quality, and cost-effectiveness becomes more difficult on a larger scale.
- **Policy and regulatory framework:** Local policies and regulations may play a critical role in supporting or hindering the growth of green fuel plants. Inconsistent or unfavourable policies, lack of incentives, and limited financial support can deter investors and slow development.
  Regulatory issues could also be, e.g., The Pressure Equipment Directive (PED) inspection intervals on Stack to be extended as full inspection probably will cause the end of Stack lifetime causing the levelized cost of hydrogen (LCOH) to increase.
  Harmonized standards still need to be related to PtX.
- **Water consumption:** Certain green fuel production processes can be water-intensive, putting additional strain on already scarce water resources in certain areas.
- **Technological diversity:** There is no one-size-fits-all solution for green fuel production. Different regions may have access to different types of feedstock and resources, requiring a diverse range of technologies to be developed and implemented.
- **Public perception and awareness:** Public acceptance and awareness of the benefits of green fuels are essential for their widespread adoption. Misconceptions or scepticism about their effectiveness and sustainability can hinder progress.

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- **Material Technology:** Known materials used are often selected as a compromise and issues like hydrogen embrittlement or corrosion can affect safety. A single company cannot support research, should be a government funded project and to be conducted by university – mission driven approach.
- **Instrumentation:** Safety critical sensors are crucial to safe plant operation and avoidance of accidents. Improving sensor technology especially in gas detection and fire detection, response time, reliability, service interval, and installation in harsh environments, could be beneficial. This could enable simplified and therefore faster design, manufacturing, and installation.

Addressing these challenges requires collaboration among governments, research institutions, investors, and industry stakeholders. Advances in technology, supportive policies, and public engagement will all play vital roles in overcoming these obstacles and realizing the potential of PtX plants in the future.

- There is no PtX-specific regulation in Denmark, which is why projects are regulated under existing regulations from other industries.
- Several approval processes are running simultaneously and rely on each other.
- The PtX is immature, which results in misunderstandings among suppliers and authorities due to doubt about which standards and regulations to comply with.
- There are deadlines for investors, which the project managers need to know if they can live up to.
- On some occasions, investments must be made without having granted approvals, and neither the plant owner nor the end user knows what the prices will be for the various green fuels.
- Project execution plans are often modified due to industry dynamics, such as new standards or regulations and rapid changes in circumstances.
- Public perception and social acceptance can be a challenge for NIMBY (Not In My Backyard) and LULU (Local Unwanted Land Use).
- There are different challenges within each industry operator for establishing PtX in ports. Interviews with partners and stakeholders show various challenges in the industry. All those identified challenges for ports are listed in **Annex D**.

Lessons Learned:

- PtX plants in Denmark are built of mostly existing technologies, which are now used for different purposes.
- PtX projects have to be adjusted to existing legislation and assumptions regarding which new regulations will be in the future.
- PtX systems can fit into existing legislation within power and environment/safety legislation. Future electricity legislation can benefit if the model for flexible consumption and own production becomes fair and adapted to actual costs.
- Planning with the municipality is often open and goes very well.

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- In some communities, the dialogue with neighbours has gone better than expected, and with firm communication, you can achieve an acceptable understanding of the project.
- The application for an environmental permit has also gone well in cooperation with the Danish Environmental Protection Agency and technology suppliers, considering that we are building the world's first ammonia plant of its kind.

Recommendations:

- Be on good time with planning.
- Understand the process – both electricity and plant regulatory.
- Designs can change, so low planning must be broad at the same time, concrete enough to get its way permission – a balancing act.
- Be in dialogue with authorities - but be ready to be able to answer detailed questions – like "What's in it for them?".
- Be clear about what the project contains in terms of technology and emissions.
- Don't reinvent the wheel – look at existing standards.
- Have landmarks and be ready for changes on the road.
- Be useful to society and lead the way - set a precedent.

References: Based on interviews

1. Scope and Introduction

Scope:

This guideline provides guidance for best practices in the management of safety in relation to establishing a Power-to-X plant. It is applicable to all industries and sectors that produce, handle or store green fuels, including but not limited to hydrogen plants, methanol producers, ammonia producers or other variations of green fuels. It provides recommendations for the safe and faster handling and storage of green fuels, and guidance for the design and safety management of green fuel systems and equipment.

Introduction:

This guideline aims to provide a safety framework for establishing safe Green Fuel plants. Green fuels include biodiesel, methanol, hydrogen, and all the other renewable sources of energy that are increasingly being used in future industries.

This guideline intends to cover the processes in relation to the establishment of a PtX plant.

The purpose is to give knowledge and guidance to all stakeholders related to the PtX industry and contribute to a safer and shorter pathway towards PtX production in Denmark.

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The guideline contains several chapters covering the challenges of the establishment of a PtX plant. These challenges include but not limited to e.g., the approval process, construction integrity, risk management, green-fuels data and characteristics, society and public perception, the role of authorities, compliance and documentation. (See overview in List of Content). It is a fact that guidelines/regulations are traditionally agreements between authorities and the industry. With this guideline, we wanted it as a tripartite document, with "general public" as the third part.

An intended way to use the guideline is by following the chapter of the overall Approval Plan and reading the more detailed information about each subject in the specific chapters. The data, illustrations, and graphics will often be in related annexes.

2. This guideline is applicable to:

The industry:
The guideline should provide more direct guidance for PtX producers (upstream), such as producers of hydrogen, methanol, ammonia and other e-fuels. On a holistic level, the guideline should be a support tool and cover both upstream, midstream and downstream such as the PtX entrepreneurs, equipment suppliers and personnel suppliers.

Furthermore, the guideline may be beneficial for authorities, branch unions, organisations, institutes, NGOs, and societies, as listed below.

The authorities:
- Danish Environmental Protection Agency *(in Danish - Miljøstyrelsen)*
- Danish Energy Agency
- Danish Work Environment Authority *(in Danish - Arbejdstilsynet)*
- Police *(in Danish - Politiet)*
- Danish Ministry of Justice *(in Danish - Justitsministeriet)*
- Danish Emergency Management Agency *(in Danish - Beredskabsstyrelsen)*
- Danish Safety and Security Agency *(in Danish - Sikkerhedsstyrelsen)*
- The Municipal Board *(in Danish - Kommunalbestyrelsen)*
- The Municipal Environmental Authority *(in Danish - Miljømyndigheden)*
- The Local Town Planning Authority *(in Danish - Planmyndigheden)*

Branch unions and associations e.g.:
- KL (Kommunernes Landsforening)
- Green Power Denmark
- Dansk Industri

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- Brintbranchen
- Alliancen vedvarende energi [https://dafre.dk/]

Institutes:
- GTS institutes
- Technological institutes
- Universities

NGOs:
- Museums
- Danish society for nature conservation
- Environment and climate related organisations

Public:
- Those living or working near PtX plants
- Schools and kindergartens near PtX plants

3. Framework

3.1. Background Material

This guideline is based on interviews with project partners from the industry, PtX operators, suppliers, and other relevant stakeholders, such as end users and societies.
Furthermore, the guideline is based on present Danish and international regulations, orders, standards, guidelines, test reports and reports relating to the PtX industry.

3.2. Method of Work

This guideline is based on interviews with a broad spectrum of relevant industry partners such as PtX operators, suppliers and other relevant stakeholders, e.g., end users and societies. These interviews have been used to map the challenges in relation to approval processes, safety issues and general perceptions in the PtX industry.

3.2.1. Fact Finding

The results from interviews with stakeholders in the PtX industry in 2022 have been collected and used as facts if the answers were similar among interviewees. Furthermore, this guideline uses previous and new research as facts.

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3.2.2. Workshops

The partners in "Safe and Faster PtX" have conducted workshops to identify industry challenges and to prioritize which topics and content should be included in this guideline.

3.2.3. Guideline Writing

The Partnership has drafted the guideline based on industry partners' input through interviews, workshops and exiting regulations. The draft guideline has then been reviewed by the industry partners and other stakeholders interested in the final guideline.

4. Authorities

The authorities will be important partners in all processes of establishing, running and maintaining a PtX plant, ensuring that Danish regulations are complied with. This chapter should provide basic knowledge of the purpose, responsibility, and mandate of each authority department/agency, in relation to PtX plants.

4.1. Risk Authorities

The Risk Authorities are:

- The Municipal Board *(in Danish - Kommunalbestyrelsen)*
- Danish Environmental Protection Agency *(in Danish - Miljøstyrelsen)*
- Danish Work Environment Authority *(in Danish - Arbejdstilsynet)*
- Police (in Danish - Politiet)
- Danish Ministry of Justice *(in Danish - Justitsministeriet)*
- Danish Emergency Management Agency *(in Danish - Beredskabsstyrelsen)*
- Danish Safety and Technology Authority *(in Danish - Sikringsstyrelsen)*
- The Municipal Environmental Authority *(in Danish - Miljømyndigheden)*
- The Local Town Planning Authority *(in Danish - Planmyndigheden)*

4.2. The Municipal Departments

The relevant municipal departments are the local authorities. The local authorities are:

- The Municipal Board *(in Danish - Kommunalbestyrelsen)*
- The Municipal Environmental Authority *(in Danish - Miljømyndigheden)*
- The Local Town Planning Authority *(in Danish - Planmyndigheden)*
- The Local Emergency Management
- The Local Plan for the Environment
- The local authority for handling of supply for electricity, heat, water, sewage, etc.

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4.3. The State Departments

The state departments are defined as the national authorities, and they are responsible for regulations and approvals. Below is a short description of the departments most related to PtX.

4.3.1. Danish Energy Agency

The Danish Energy Agency's Power-to-X secretariat is the point of contact for all inquiries concerning Power-to-X (PtX). The secretariat's task is to support the development of PtX in Denmark and assist stakeholders and authorities with guidance on permits and approval procedures related to PtX.

In 2021, the government launched a strategy for Power-to-X. The strategy is based on multiple analyses from the Danish Energy Agency and dialogue with the PtX industry.

Following a political agreement, the establishment of a PtX task force was agreed upon. The task force has two main purposes:

Contribute to the coordination between state and municipal authorities working with PtX, with a particular focus on approval and permit procedures. For this purpose, a work group for authority assistance is to be established.

Ensure continuous dialogue across the PtX sector to follow the development, as well as identifying and addressing barriers to achieving the goal of 4-6 GW electrolysis capacity by 2030. For this purpose, a PtX stakeholder forum will be established.

The PtX task force is led by a steering group within the Danish Ministry of Climate, Energy and Utilities, and it is serviced by a secretariat within the Danish Energy Agency. The task force reports back to the political parties behind the PtX agreement each year.

Workgroup for authority assistance

The workgroup for authority assistance consists of employees from public authorities involved in approvals and permits within the PtX area. The workgroup aims to promote quality and efficiency in case management and identify possible synergies or potentials for streamlining between processes. Furthermore, the workgroup acts as reference group for the Danish Energy Agency's work to guide PtX stakeholders about approval, permit procedures etc.

PtX stakeholder forum

The stakeholder forum consists of employees from several public and private stakeholders who are knowledgeable about regulatory barriers, possibilities, and new developments within PtX. The forum aims to gain a broad understanding of possible barriers to achieving the goal of 4-6 GW electrolysis capacity by 2030.

PtX Stakeholder forum consists of representatives from e.g., following organisations:

- Danish Work Environment Authorities (Arbejdstilsynet)

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- Danish Emergency Management Agency (Beredskabsstyrelsen)
- Danish Housing and Planning Authority (Bolig og Planstyrelsen)
- Energinet (Energinet)
- Danish Business Authority (Erhvervsstyrelsen)
- Danish Utility Regulator (Forsyningstilsynet)
- Local Government Denmark (Kommunernes Landsforening)
- Danish Ministry of Climate, Energy and Utilities (Klima-, Energi- og Forsyningsministeriet)
- Danish Environmental Protection Agency (Miljøstyrelsen)
- Danish Police (Rigspolitiet)
- PET (Politiets efterretningstjeneste)
- Danish Safety Technology Authority (Sikkerhedsstyrelsen)
- Danish Maritime Authority (Søfartsstyrelsen)
- Danish Civil Aviation and Railway Authority (Trafikstyrelsen)
- Ministry of Foreign Affairs of Denmark (Udenrigsministeriet)
- Ministry of Transport

[1].

4.3.2. Danish Environmental Protection Agency

The Environmental Protection Agency is organized into five centres: Centre for Rich Nature, Centre for Clean Water, Centre for Safe Chemistry, Centre for Green Production and Centre for Staff.

In relation to PtX, DEPA is the overall authority that approves all environmental issues. This is usually done in collaboration with the municipal environment departments. [2]

4.3.3. Danish Work Environment Authority

The Danish WEA somehow has a daily influence on the work of a PtX plant related to health and safety and all related regulations.

Purpose and responsibilities:

The Danish Working Environment Authority (Danish WEA) is an agency under the auspices of the Ministry of Employment. The Danish Working Environment Authority contributes to creating safe and healthy working conditions in Danish workplaces. This is done by:

- Carrying out inspections at companies
- Drawing up rules on health and safety at work
- Providing information on health and safety at work

The powers of the Danish Working Environment Authority:

The Danish Working Environment Authority has the authority to penalise enterprises that do not comply with the working environment rules. Regarding clear violations of the substantive

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rules of the Working Environment Act, the Danish Working Environment Authority has the power to issue administrative fines. In cases of extreme danger, the Danish Working Environment Authority may also order the work to be suspended.
The responsibilities of The Danish Working Environment Authority are based on the Working Environment Act and related Executive Orders.
[3]

4.3.4. Danish Safety Technology Authority

The Danish Safety Technology Authority focuses on safety technological aspects relevant to fires, accidents and explosions. Its mission is to set the standard in safety technology in Denmark, Europe, and internationally.
The organization aims to be viewed as a centre of knowledge, rather than a purely ministerial administration. That is why gathering competencies and ensuring professionalism lies at the core of its strategy. It seeks to be highly professional advisors and prioritizes dialogue and interaction with its stakeholders. Through these means, it positions itself to increase safety effectively.
As part of the Danish Ministry of Business and Growth, the Danish Safety Technology Authority was founded by merging technical tasks from several councils and agencies to ensure greater effectiveness.

Tasks of the Danish Safety Technology Authority:
The tasks of the Danish Safety Technology Authority are centred around technical safety and cover various areas, including:

- Responsibility for gas safety in all types of gas installations and plants.
- Responsibility for electrical safety, concerning production, transmission, distribution, and electricity use.
- Administration of authorisations for electricity, gas, plumbing and sewage.
- Administration of general product safety, including safety control of new products and other consumer products.
- Responsibility for safety concerning fireworks, including approval of certified pyrotechnicians.
- Conducting industrial policy and holding general authoritative responsibility for metrology and accreditation, with DANAK being the performing party based on a contract.

[4]

4.3.5. Danish Emergency Management Agency

The Danish Emergency Management Agency (DEMA) works to prepare society for and prevent crises, accidents, and disasters, primary on a national level. Though they are also involved in

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the approval processes for establishing plants for dangerous goods, but not limited to PtX plants.

About PtX plants, they may be a stakeholder in:

- **Analysis, data, and research.** Analysis, data, and research to strengthen and guide the development of, in particular, fire and rescue services.
- **Crisis communication.** Crisis communication before, during, and after major accidents and disasters and development of the institutional and technical setup for crisis communication.
- **Supervision of the municipal fire and rescue services.** Supervise and support the municipal fire and rescue services, including planning and assessing local risks.
- **Transportation of dangerous goods.** Advice and administration of the regulations on transporting dangerous goods (ADR).

DEMA assists the police, municipal fire and rescue services and other authorities in major crises, accidents, emergencies, and approval processes. Roughly 60% of DEMA's operations are in support municipal fire and rescue services, while the remaining 40% support police or other authorities.

DEMA has specialized CBRN capabilities (CBRN = Chemical, Biological, Radiological and Nuclear defence). DEMA provides expert advice and assistance to authorities in incidents involving hazardous or unknown substances. Among DEMA's tasks are:

- Sampling and chemical analyses of hazardous and unknown chemical substances.
- Consulting service in all aspects of the chemical properties of dangerous chemical substances and products, including explosives and chemical warfare agents.
- Assistance at, e.g., blast sites or crime scenes, including mobile detection systems for chemical substances.

[5]

4.3.6. PET (Politiets efterretningstjeneste)

PET advises on how to prevent terrorism, espionage, illegal influence activities and illegal procurement activities.

PET advises organizations and individuals who are particularly threatened, vulnerable or critical of Danish society.

This concerns, among other things:

- Ministries and agencies throughout the Commonwealth
- Special industries and sectors, e.g., technology and research
- Owners and operators of Denmark's critical infrastructure
- Particularly threatened individuals, e.g., politicians and members of the Royal House

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- Danish embassies, consulates etc.

When there is a concrete need, for example, concerning a threat assessment or an operation, PET directly advises the parties concerned. The counselling can be a one-off meeting or a longer course.
[6]

4.3.7. Ministry of Transport

The Ministry of Transport's main responsibility lies within the following areas: transport: roads, vehicles, railways, rapid transit systems (e.g. the Copenhagen metro), fixed links, harbours, ferry operations, aviation, airports, and postal services.

5. Society and Public Perception

5.1. Why society matters

While the development of green fuel technologies is in the spotlight, the importance of the societal questions in this matter is not the first concern regarding the green transition. It is publicly known that many wind farm projects have been put on hold due to local opposition. According to the Danish energy company Andel 14 out of 17 projects have been stopped [7], which naturally delays our renewal of the national climate goals for green transition. That is why society matters in this context and, it is crucial to tackle it. It is necessary to recognize the fundamental and complex human and social factors that form the basis of public resistance to create public acceptance. These human factors could include fears, misconception of risk, miscommunication, feelings of procedural injustice and lack of transparency.

Public perception is based on previous, existing knowledge regarding a given technology. People judge green fuel technologies based on their knowledge and feelings about familiar technologies, such as comparing e-fuels with gasoline or petrol. However, knowledge about something does not guarantee acceptance – but its absence can lead to resistance or rejection. Overall, research shows that one of the strongest determinants of low acceptance is functional or aesthetic concerns for the nearby landscape, environmental concerns for the surrounding nature, and the way that people feel they belong to the place they live – or rather, are displaced by the impact of the project. Another thing to consider is the degree of development already present in the area. Furthermore, a direct relationship exists between perceived fairness and the possibility of public participation early in the decision-making process. Indeed, perceived procedural justice, as well as perceived benefits and perceived risks are major factors for getting acceptance. Therefore, safety concerns also lead to lower acceptance levels. This means that values such as transparency, credibility, legitimacy, and trust are critical, as well as more technical or generalized information about the project.

Implementing any technological change depends on how it interacts with the structure of society. The societal structure can be divided into three perspectives:

- the national perspective (the overall popular opinion)
- the companies' perspective (the attitudes from the industry and relevant stakeholders)
- the citizens' perspective (the public perception in a local area)

All three perspectives are necessary to include, and it is essential to note that all the involved parties act based on what makes sense from their point of view.

The green fuel industry still has varying notions of safety and safety levels. Therefore, it is difficult for companies or municipalities to give clear, concise answers to the citizens who demand insight into safety precautions. Right now, the different parts of the industry are working on making common safety standards and aligning different perceptions. However, we also see that many companies are hesitant about including the citizens in that process for fear of making any communication mistakes that may backfire on their implementation process.

When it comes to the citizens' perspective, the considerable challenges to acceptance of green fuel technologies and infrastructures are posed by concerns about the safety, convenience, benefits, and negative effects as well as Not-In-My Backyard (NIMBY) attitudes. It is important to know that the NIMBY term is not the only reason for local opposition towards green fuel technologies. NIMBY is only the mere surface of the public perception. The term itself can cause misunderstood interpretations of local citizens' opinions on implementing green fuel technologies. It can indicate that the opposition is strictly on behalf of the noise nuisance and disturbance caused by wind turbines. Indeed, these factors play a role in the resistance because they interfere with the pivotal factor of belongingness as mentioned above, but there is much more to it. The NIMBY term does not provide or invite any further explanations, which is why we need to move beyond the term to acknowledge that the problems are much more complex. The misconception of NIMBY can be exemplified through the metaphorical image of a dandelion. The dandelion flower (Figure 2) is above the surface and is easy for people to see. Everyone thinks it's annoying because it takes nutrients from the flowers. Likewise, NIMBY is above the surface, and everyone considers it a problem because it fights

Figure 2: Patino, Ana. The dandelion plant- 2022, water paint. Dansk Brand og sikring Institute 2023

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the implementation of sustainable fuels. The roots of the dandelion represent the societal values that cause the opposition. It is the challenge we must take care of to address the issue. It is the part of the dandelion that people don’t see, but it’s impossible to remove the dandelion if we miss the roots. The roots consist of citizens´ perceptions of trust, fairness, justice and transparency, which we need to shed light on to remove the dandelion. The flying seeds represent what will happen if we don’t take action; then, it will spread by the wind and become an even more significant challenge. If we merely blame the local opposition for being selfish and not taking on their fair share in the green transition instead of trying to understand their position, they will only feel like they are being treated even more unfairly, which may cause the dandelion to spread.

Instead, alternative concepts such as LULU (Locally Unwanted Land Use) may offer a more fitting lens for understanding and constructively navigating community resistance. Unlike NIMBY, LULU acknowledges the validity of local perspectives and emphasizes the need for meaningful engagement and collaboration in land use decision-making processes. Usually, the LULU concept – much like several other methodologies based in the humanities and social science disciplines – entails conducting environmental and social impact assessments, transparent communication, and involvement of local stakeholders as early as possible, especially in the planning and decision-making phases. Recognizing local socio-cultural dynamics, including community identities, historical experiences, and power relations, is crucial for fostering trust, participation, and cooperation between developers, authorities, and citizens.

5.2. Reflections on how public involvement can be done

The importance of exploring public perceptions and engaging local communities in a more consent-based siting process lies in the fact that it can elucidate nuanced views of support and reasons for opposition. It also helps map key participants related to the project (local opponents, pragmatists, siting compromisers, etc.). Public involvement is a continuous effort and should be maintained throughout all phases of a PtX project. The work usually begins with and rests firmly on continuously analysing discourses and narratives qualitatively, thereby identifying local citizens´ concerns and perspective of their everyday lives regarding the project, the technology, or the matter of research.

Public perception can be addressed at any time during the ideation, implementation, or execution of a project. However, it cannot be stressed enough that it is important to start the work as early in the design, siting, planning, and construction process as possible. It requires the creation of bidirectional channels for transparent and open access to and dissemination of information and concerns to facilitate communication, enable collaboration, and foster shared understandings between relevant direct and indirect stakeholders. In research literature, public perception is linked to risk and uncertainty. It, therefore, implies responsible, clear, and timely communication with all the interested parties. Here, the role and function of local museums, schools, municipalities, and any other locally entrusted institutions become relevant and important vehicles for open interaction.

As a first step, it becomes important to map out who the direct stakeholders are and who the more indirect stakeholders are. Below, we have provided a few examples of who these different actors may be as part of a more overall framework for incorporating local communities and stakeholders regarding public perception and safety concerns in PtX projects.

5.3. Example of Public Engagement Plan

1. Identify and map all direct and indirect stakeholders in relation to the PtX facility.

a. Examples of direct stakeholders may be (but are not limited to) all immediate neighbours – citizens, businesses, institutions, churches, etc. – within a certain distance, the wildlife, the natural habitats of certain animals, communities, or tribes. If you know the place locally, you may also know of other local neighbours who do not strictly qualify as 'immediate'. However, due to their involvement in the community or for various reasons, they can be considered an immediate neighbour and thus a direct stakeholder.

b. Examples of indirect stakeholders may be (but are not limited to) the local unions, any kind of union or community (the sports club, hunters, schools, etc.) utilizing the space that will soon be turned into a PtX site, local authorities, local business that may benefit from the site's setup (e.g., hotels, restaurants, craftsmen etc.), and local religious gatherings.

2. Establish contact with direct stakeholders at the same time as you contact the authorities.

a. Invite for shared discussions on siting, layout, etc., regarding safety concerns and controversies while you also initiate talks with authorities.

b. Do what you can to respect, honour and incorporate the land and the people 'belonging' to this land as you plan the facility.

c. Be sure to invite lead engineers and plant designers to the stakeholder meetings to sustain a broad understanding of needs and concerns and to close possible gaps of understanding between experts and laypeople.

d. Visit as many direct stakeholders as possible where they reside (whether privately or in their business) to get a first-hand impression of "how the world looks from where they stand/live". Note any safety concerns or other relevant points they make.

3. Draft an "agreement" on terms for the PtX site with the direct stakeholders, similar to an MOU (Memorandum of Understanding).

a. Make it very clear to the direct stakeholders that this "MOU" is not a promise of what will be, as the authorities have not agreed with them yet. However, this "MOU" reminds the

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project owner and the design team during the design and implementation phase of what they should keep in mind. It is a "guideline" regarding safety concerns and public perceptions of the community.

4. **Be sure to continuously and consistently communicate divergence and changes from the original understanding.**
a. Remember, transparency and feelings of procedural justice are key.
b. Pay attention to the community's objections to your signed MOU. Are they objecting to any of your plans or changes? Why? Can you accommodate their concerns and frustrations in any way?

5. **Inform and invite the broader range of indirect stakeholders for input and feedback.** Once you have a final design of the facility and the main layout has been settled upon and works in overall agreement with direct stakeholders, municipalities' usual 'hearing process' may work well for this.
a. When conducting public hearings, break down the usual gym hall/classroom setup. Do small round tables and engage more directly with the participants. Make the indirect (as well as the direct) stakeholders feel that your project is a part of the community, not something that happened to the community.
   i. Discuss in the round tables what they want to see from the project. How can the project owner, the community and stakeholders all benefit from this facility?

6. **At all times during the process, keep the communication as open and transparent as possible.**
a. Be honest about potential risks and dangers and what you are doing to mitigate those possible risks.

7. **Avoid having news about your plans or facility hit the news or the media before reaching the direct and indirect stakeholders.**
a. They must be knowledgeable about it before reading about it in the news.

To sum up the above-suggested plan, the following easily accessible advice could be given on how to approach and engage citizens during PtX implementation:

Redo the public hearings/citizen meetings. Turn the meetings into a workshop, for example, or involve and invite technical experts to ensure that all questions can be answered sufficiently.

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Tell people what you know and what they need to hear. Think carefully about what's being told. Be transparent and talk to people about what they need to hear – which might not always be technical questions.

Don't tell them – ask them. Don't assume you know what people need. Ask them and take their needs and concerns seriously.

Engage the local media. Local news travels fast. Keep an eye on the local news and SoMe stories and engage in the local news landscape rather than the national press.

Don't tell them – show them. Invite the local schools to visit. Host information/visitor days or set up exhibitions or art installations. Say 'yes' to all local community and educational institution invitations.

Local relations are essential. Get local ambassadors onboard. People will rather trust a local voice talking about the coming changes, than a stranger explaining the 'alien invasion'.

Compensate the 'sacrifice'. Find out how to best compensate locally and support the local community as they 'sacrifice' a piece of land or a large area. If it's difficult due to regulations, speak openly about these challenges. Remember that the compensation doesn't have to be only economic.

Be honest. Transparency and trust are vital. But not all roads are paved yet, and all rules and regulations might not be in place. Be honest and open about these issues, and "tell it like it is". People don't like to be explained as if they are kids.

5.4. Which are the benefits if we do it?

The benefits of involving social and societal perspectives in the green fuel development are to increase the chance of acceptance and decrease the risk of resistance by promoting transparency and engagement for both directly and indirectly affected citizens and stakeholders. When citizens cannot access information or decode why things happen as they do, they start speculating and then share these stories. When citizens don't understand or know what happens, it may lead to narratives about injustice and suspected unspoken intentions from those making the final decisions.

Therefore, a mutual understanding of the different perceptions of safety, feelings of justice and open conversations about the projects create a common footing for the different parties. After all, it promotes a shared connection to the project, which is the goal. It is a matter of creating a more equal space to discuss, express and listen to people's concerns. In Science

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Communication, there is an increased focus on the role of bidirectional dialogue rather than just providing people with more information and facts. Experimentations are made to involve people earlier and with more agency to have an actual impact on decisions, also known as co-creation processes, where different types of stakeholders are put together to discuss and shape a solution together where everybody can see themselves in it. It is more time-consuming upfront but can save time, money, and local resistance later. The earlier you start involving the local community, the more connected they will feel to the project. It's about making them think the project is a part of the community, not something that happens to the community. The process itself should be involving, respectful, and transparent. That will help create a feeling of cohesion between the locals, the project, and the project owners. Ultimately, the number of stopped wind farm projects (or other green fuel projects) will significantly be reduced if societal matters are appropriately addressed. People will be more willing to accept a project they have had an influence on and been a part of from the start, rather than a project they get thrown after them when all the decisions have been made. It is not necessarily about public ownership (even though this can be the goal in some cases) but more about creating a respectful process for all parties to feel engaged and connected to the changes in their neighbourhood.

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6. Approval Plan

All Power-to-X projects involve approvals from public authorities. The approvals currently needed are not new, as no new approvals, which only apply to the Power-to-X industry, have been granted. In the future, it is likely that PtX-specific approvals may be established, or that some existing approvals will be modified to accommodate the growing PtX industry.

All approvals currently relevant to the PtX industry are thus well-known from other but comparable industries, such as the power plant industry or the petrochemical industry. However, while the approvals needed are known, there are some specific traits of the PtX industry that set the industry aside.

Firstly, the number of new projects being initiated in parallel is unprecedented, and many of the project owners are young companies with no proven track record in establishing safe industry facilities and taking projects through the public approval process.

Secondly, the industry often works with substances and processes on a larger scale than we have seen historically, adding a novelty aspect through the scale of activity.

Finally, many projects aim to meet local energy demands. They are thus located much closer to populated areas, than we typically see for power or petrochemical plants, resulting in larger safety and environmental concerns.

Due to these circumstances, it is important to establish a regulatory approval plan for the individual project progress as fast as possible towards a safe and operational facility.

This section provides an overview of the standard approval processes relevant to a PtX project. It supplements the "Step guide" issued by DEA (Energistyrelsen).

6.1. Frameworks for approvals

As part of writing this guideline, we have prepared an overview of regulatory interactions for PtX facilities.
We have used the approach of preparing the overview for the most complex PtX plant, being a column 3 facility, according to the risk handbook.
In the preparation, we have focused on the most important authority interactions, meaning the ones with general applicability.

It is important to state that all PtX projects are, in principle, quite different, and that depending on the exact nature of a PtX project, any number of additional authority interactions can be

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required. However, the presented overview of authority interactions is an attempt at writing a general framework for regulatory approvals and a standard regulatory project plan.

The authorities play many roles in regulating the PtX industry, all aiming to ensure that all HSE concerns of a PtX facility are met. The regulation translates into five distinctly different activities for a Power-to-X facility.

The roles are:

1. **Regulatory approvals:** A project owner must submit data to the authorities and cannot proceed before the authorities have granted a formal approval. Examples are:
   a. Assessment of Effect on Environment (Miljøkonsekvensvurdering (VVM))
   b. Building permit (Byggetilladelse)
2. **Technical approvals:** Certain equipment, processes or areas must be approved before use. It can be self-approval or approval by notified bodies. However, the authorities are often not directly engaged in the approval process. Examples are:
   a. CE marking (CE Mærkning)
   b. Explosion Prevention Measures (ATEX) (See Chapter 9.3)
3. **Documentation requirements:** The authorities demand certain documentation to be present at a facility, but no regulatory approval is needed for the specific documents. Examples are:
   a. Danish language user manuals (Dansksproget brugervejledning)
   b. Chemical safety documentation (Kemikalie sikkerhed)
4. **Inspection requirements:** The authorities demand that equipment and facilities be inspected regularly, though they are often not involved in the inspections themselves.
   a. Inspections of pressurised systems (Inspektion af trykbærende anlæg)
   b. Inspections of heating and cooling systems including substances used (Inspektioner og kontrol af køle- og varmeanlæg, herunder kølemidler)

The complete overview of all regulatory interactions is in Annex C.

As part of preparing this guideline, we have, through our fact-finding work, compiled a master list of the key regulatory approvals, technical approvals, document requirements and inspection requirements. The complete overview is in Annex C.

The following list from Annex C contains unique regulatory approvals relevant to a PtX project or facility. The list is in Danish, with the suggested English name in brackets.

R.1. Anmeldelse (projekt) (Announcement of project)
R.2. Ansøgning om plangrundlag (Application for area planning)
R.3. Miljøkonsekvensvurdering, §25, tidl. VVM (Assessment of Effect on Environment)
R.4. Miljøgodkendelse, overordnet, §33 (Environmental approval)
R.5. Risikovurdering ved farlige stoffer (SEVESO approval)

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R.6. Beskyttelse af kulturarv og arkæologiske interesser (Cultural heritage and archaeology approval)
R.7. Brandmyndighedsgodkendelse (Fire safety approval)
R.8. Byggetilladelse (Building permit)
R.9. Arbejdsmiljøtilladelse (Workplace safety approval)
R.10. Affaldshåndtering og -bortskaffelse (Waste disposal approval)
R.11. Sårbarhedsvurdering (Vulnerability assessment and approval)
R.12. Net-tilslutnings tilladelse (Grid connection approval)

In Annex C, you can find additional details about the approval, including the approving governmental body and the name of the permit issued.

Descriptions of approval processes are available in other chapters of this guideline and in documents from other sources. In Chapter 9.2, you will find a summary from the SEVESO directive and the Danish implementation of SEVESO in regulation order no.372 (Order regarding control of the risk of accidents related to dangerous goods).
Furthermore, a Danish handbook, Risikohåndbogen v.2, for approval processes should be consulted for details on the individual regulatory interactions.

This guideline will aim to describe the overall approval processes and list the challenges related to issues that are not described in existing descriptions. It is based on interviews with relevant stakeholders in the industry.

The list of regulatory interactions forms an important backbone for any project. Figure 3 presents the complete list of regulatory interactions with their expected start and end dates, structured by the industry project phases. This structure makes it possible to illustrate the work on individual regulatory interactions often starts very early compared to the completion date. Indeed, a frequent source of project delays is the failure to initiate work and data generation in a timely manner to receive the expected regulatory approvals.

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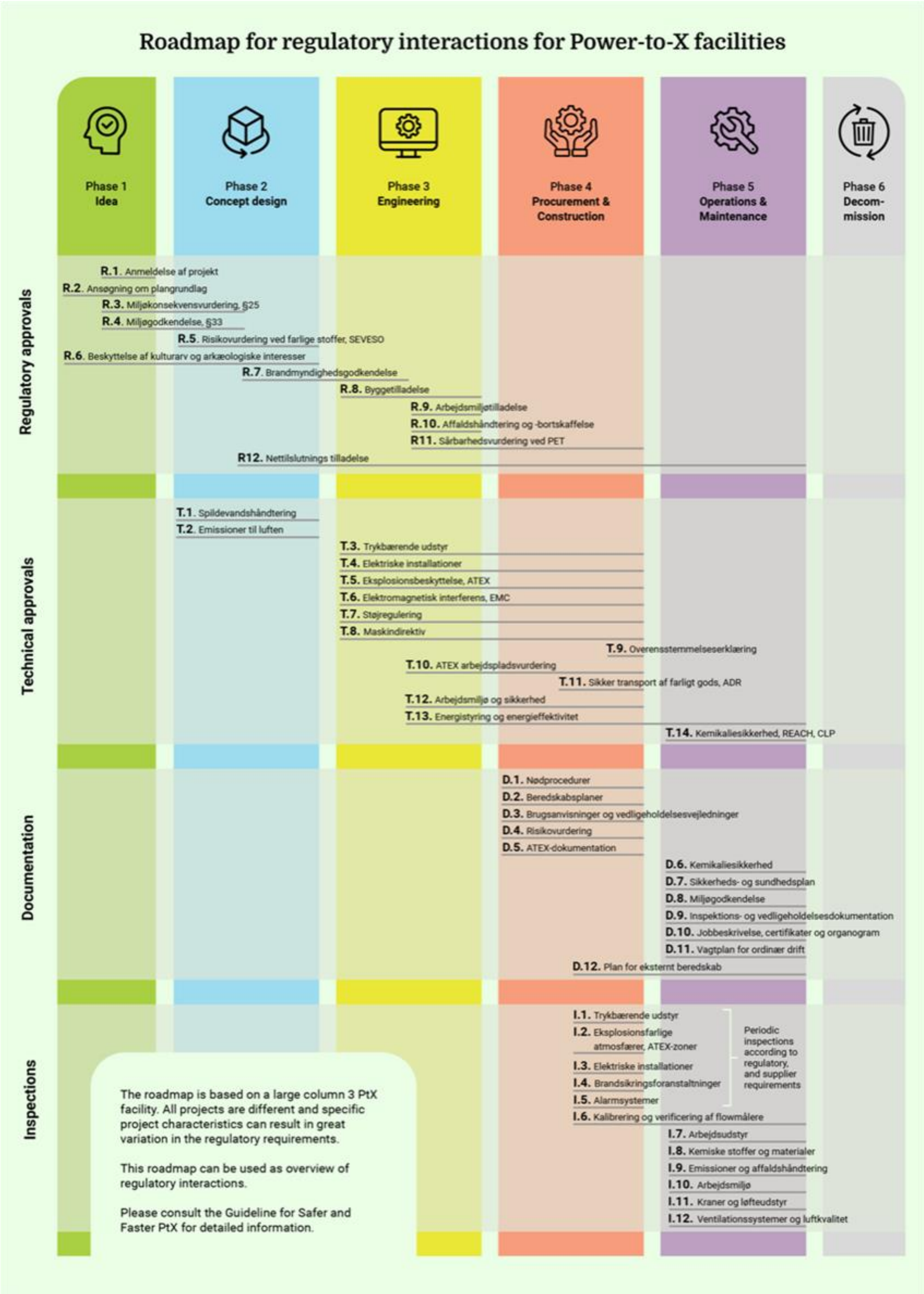

Figure 3: Overview of regulatory interactions pr phase. The bar beneath each interaction indicates the expected duration

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An important note to Figure 3 is that the overview of regulatory interactions must be adjusted based on any existing Final Investment Decision (FID). Final investment decisions are when the owner commits most of the capital to the project and are often considered a point of no return. Many project owners have requirements for what must be available before FID, which can often involve complying with regulatory requirements before it is necessary to provide the needed investment decision basis.

While Figure 3 does not provide references to the underlying legal documents, the complete list in Annex C contains the legal references.

It is recommended that a company's overview of regulatory interaction lists accountable persons for each delivery and legal reference to ensure that each requirement is anchored in one responsible person. It has been confirmed in interviews that a frequent source of delay and project modifications is failure to have clear accountability for regulatory requirements despite such requirements often being clearly stated in available documents or available through advisors.

The overview of regulatory interactions can be used for preparing sub-charts and describe related work. In Figure 4, we present the regulatory interactions in which risk management activities are a regulatory requirement. The project risk manager or chief risk officer can get an overview of all required risk management work through this overview. The risk management effort should always be coordinated and united, to ensure a safe facility, where risks are known to be actively treated throughout the project phases. The risk management effort should not be dictated by regulatory requirements. Still, it should be devised to make the facility safe, with compliance with regulatory requirements being endpoints that must also be met. The methodology for risk management and the methods to use are described in Chapter 7 and Annex B in this guideline.

Another important sub-chart is the CE-marking overview. Almost all PtX facilities will have CE-marking requirements. To achieve CE-marking all safety requirements must be complied with. This goes beyond the requirements of the machine directive (maskindirektivet) and involves compliance with all specialist safety requirements. Compliance with these directives must be considered in the engineering phase, as safety must be designed into the components. Failure to do so is often characterised by the late performance of the required risk assessments and the discovery of design-changing risks late in the process. This costly approach can significantly delay progress on the PtX facility. Therefore, a clear CE-marking strategy is important to a regulatory interaction overview or plan.

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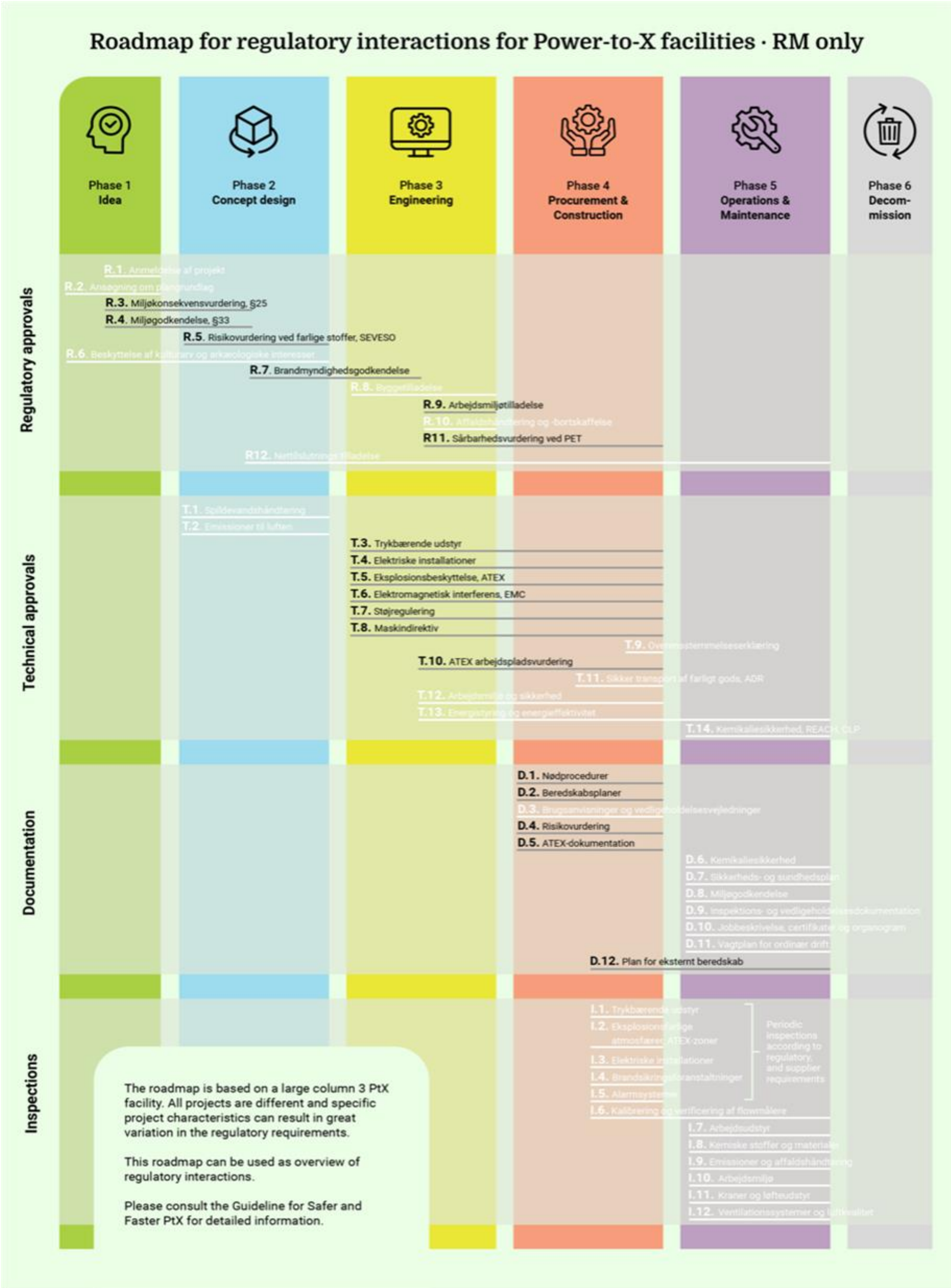

Figure 4: Overview of regulatory interactions in which risk management tasks are required

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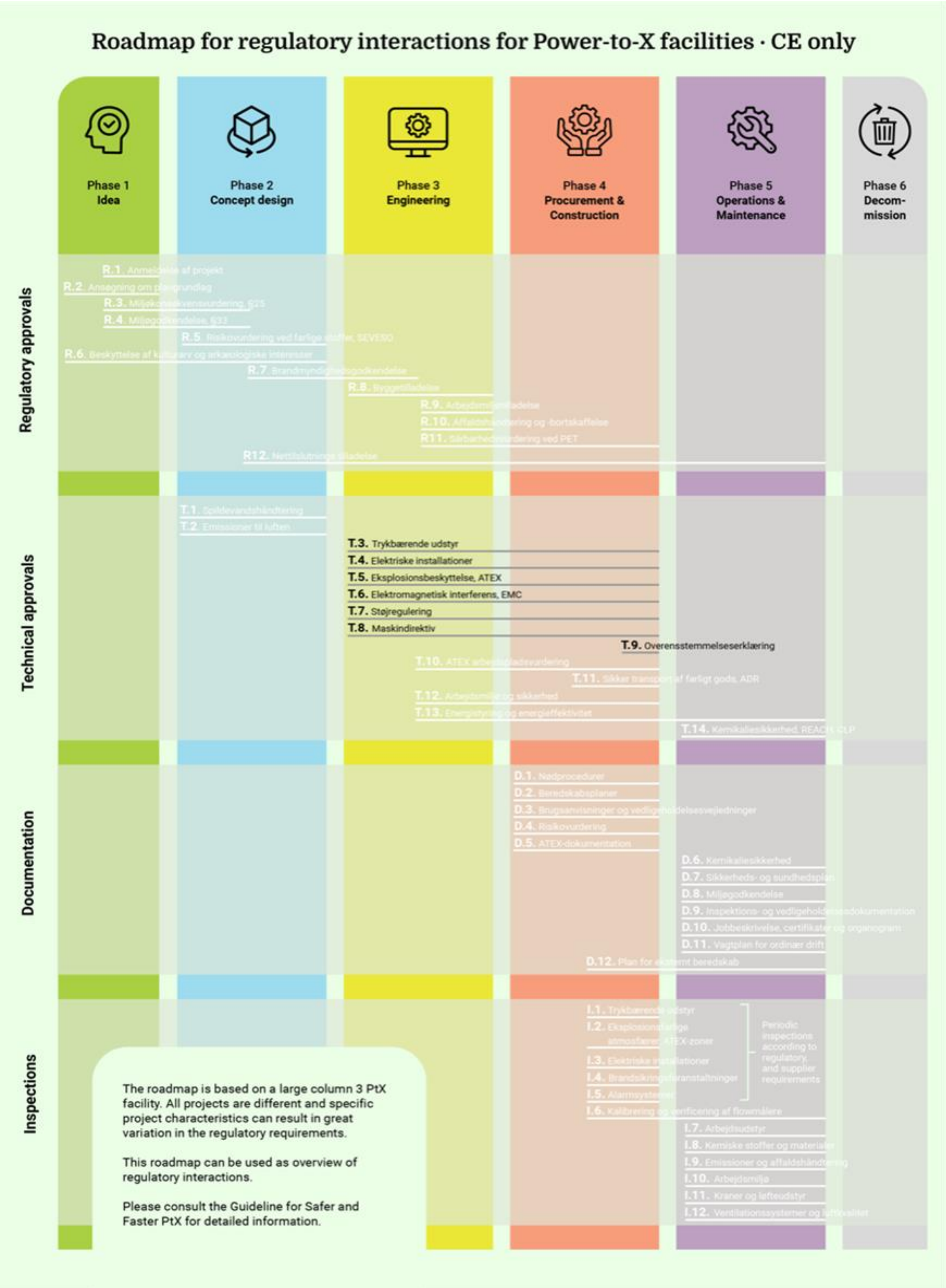

Figure 5: Overview of regulatory interactions which is part of achieving CE-marking

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It is important to use the overview of regulatory interactions as guidance only and to consult with experts, advisors, and available online sources on how the exact overview and regulatory plan should look for a specific project.

A strong and well-founded regulatory plan must be devised in the idea phase of a project and should form a basis for planning and executing a PtX project. If such plan is not available early on, the project will be exposed to delays and setbacks, as sufficient safety is not built in a timely manner. The result is re-design, rework, and ultimately, components that are unsafe, or less safe that what could easily have been achieved.

6.2. From planning to operation

One of the consequences of the PtX industry being relatively new is that the approval processes for plants to produce green fuels are not yet anchored in commonly known or proven processes. Several factors influence the process of achieving approvals, which is why our example in this guideline will be described from a more holistic view.

Some examples of factors which influence the approval process could e.g. be:
Which sort of green fuels are planned to be produced? On which scale is the production of green fuels planned to produce? How much green fuel storage is planned for the plant? Where is the plant planned to be located?

6.3. Liaise and manage stakeholders prior to planning

It is important to liaise and communicate for a PtX project that wants to proceed to the planning phase. Many external organisations will sooner or later become important stakeholders, e.g., by granting permission. By speaking with people inside these organisations (liaise), important information can be acquired early and thus used to refine the project.
Stakeholder management, which means seeking influence, is also an important tool. It can be used towards the political organisations or the public and can take the form of meetings or information, e.g., newspaper articles. This section discusses the most frequent stakeholders to liaise with and communicate as part of developing a concept.

6.3.1. Municipals

The municipalities are the primary stakeholders. There are two reasons to engage in stakeholder management work as part of a project's concept development.
The first is to find out if the intended location of the Power-to-X facility is a realistic option. To be a realistic option, the stakeholders relevant to the location must accept the facility, and, in some cases, some cases, local adaption is also required.
The second step, contingent on the success of the first, is gaining access to important information on how to prepare and conduct the dialogue with the municipality's administration.

In the municipalities, the politicians who represent the voters must be approached and presented with the project. In Denmark, the politicians do not grant permissions, but they are important as they evaluate the project's relevance according to the municipality's political intent.

The administration is another key stakeholder of the municipality. The administration is responsible for most regulatory approvals needed. Importantly, the "Application for area planning" will often involve the municipalities making changes to the intended use of a certain area or assessing the requirements for infrastructure, such as roads, wastewater, and waste management in general, which is work done by the administration.

6.3.2. Society

As land-based Power-to-X will always have neighbours, and such neighbours have a voice in the communities, it is important to communicate with the communities, e.g., by arranging information meetings and presenting information to the public.
Noise, traffic, smell, danger and hazards, pollution, waste generation, and visual aesthetics are key concerns for the communities, but other project-specific concerns may also be relevant.
A good stakeholder management strategy should take into account the project's specific details and model how the project performs on the parameters of concern to the public. Public involvement is not unusual to result in modifications to the project and improved public perception of it (See why, what, and how in Chapter 5).

6.3.3. Infrastructure

Many projects depend on an infrastructure currently not in place, whether it is CO_2 pipelines or parts of the energy grid. Infrastructure in this context refers to national infrastructure and thus does not include roads, waste, and other similar local infrastructure concerns handled by the municipalities. A communication effort in the project's concept phase can be to discuss with appropriate authorities and public supply companies if such infrastructure is possible and the timeframes for establishing such infrastructure.
To the extent that the project owner plans to establish some infrastructure, obviously, the infrastructure owners are an important interface and thus become an important stakeholder in the project. Prober, liaising with the stakeholders, then becomes an important source of information on project-specific information needed.

6.4. Processes of approvals

The process below is an example of how an approval process could be. Though we know that the process is several individual processes ongoing at the same time, we have, in our example, divided the entire process up into 6 phases as listed below:

- Phase 1. (From Idea)

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- Phase 2. (Designing the concept)
- Phase 3. (Engineering)
- Phase 4. (Documentation in Tender, Procurement & Construction phase)
- Phase 5. (Operation and Maintenance)
- Phase 6. (Decommission)

6.4.1. Phase 1. (From Idea)

Start by making a preliminary design of the station.
Considerations regarding the surrounding plots (e.g., is it an empty field, or are there a lot of surrounding buildings?). This would not be as detailed in this stage as when performing the QRA, but the general "rule of thumb" would be considered regarding distance to buildings, roads, neighbouring plots, etc. There is no regulation covering these distances when it comes to hydrogen. Still, from experience, we know some distances and existing regulations that the fire authorities would most likely use as a starting point (for example, "Bekendtgørelse" om tekniske forskrifter for gasser).

Considerations to soil conditions/pollution on site

The municipal local plan authority is already involved in this phase of the project as it can affect the possibility of placing a fuelling station on the plot, and it would normally be a lengthy process to change the zoning plan.

Final investment decision – budget/financing of the project (this could affect the project's business case).

Considerations prior to the concept design:

- Is there a sufficient business case covering all the project details?
- What are the criteria for success?
- How is the market related to the procurement of equipment?
- How is the market about off-takers?
- Do we have sufficient technology available?

6.4.1.1. Documentation in the Idea Phase (1)

- R.1. Anmeldelse af projekt
- R.2. Ansøgning om plangrundlag
- R.3. Miljøkonsekvensvurdering §25
- R.4. Miljøgodkendelse §33
- R.6. Beskyttelse af kulturarv og arkæologiske interesser

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6.4.2. Phase 2. (Designing the concept)

Preliminary talks with authorities (municipality and fire authorities). What are their expectations from the documentation, and what existing regulations will they refer to? Are there any special requirements we should consider when designing the station (especially from a safety perspective – this can be, for example, escape routes or access for the fire and rescue services to the station)? It is essential to enter a pre-dialogue with the municipality before the building application is sought. This ensures the project receives adequate priority within the municipality. Furthermore, the pre-dialog gives direction to the construction team about which documentation is relevant to obtain for the application process to succeed and to clarify potential issues before the application.

Quantitative risk assessment – could affect the placement of the station/equipment.

Site specific considerations include access to power supply, fuelling requirements etc.

Considerations of ATEX zones and how they affect surroundings (see how in Chapter 9.3).

Archaeological and WW2 underground check if necessary.

Considerations before engineering

- Which regulations, directives, and standards to comply with?
- Which equipment (size, purpose, and placement) will we need, and it is available?
- Do you have a strategy for dealing with authorities, such as local planning authorities, local fire and rescue services, local environmental authorities, safety technology authorities, etc.?
- Have you developed a report on environmental consequences?
- Have you developed a noise report?
- Have you developed a report on safety consequences?
- Do you align with the municipal local plan authority?
- Do you have documentation for budgets and financing?

6.4.2.1. Documentation in the Designing Phase (2)

- R.5. Risikovurdering af farlige stoffer, Seveso
- R.7. Brandmyndighedsgodkendelse
- R12. Nettilslutningstilladelse
- T.1. Spildevandshåndtering
- T.2. Emissioner til luften

6.4.3. Phase 3. (Engineering)

Design freeze.

The approval process would normally be initiated by the municipality, which would then contact the relevant departments/authorities (e.g., fire authorities, environmental, safety, road, etc).

Considerations before engineering:

- Do you have a finished detailed design for the project?
- Have you purchased basic equipment to get started?
- Have you initiated the approval process with authorities, such as local planning authorities, local fire and rescue service, local environmental authorities, safety technology authorities, etc.?
- Do you have all the site insurance in place?
- Have you conducted an initial HAZID (Hazard Identification)- based on the plans?
- Have you conducted an initial HAZOP (Hazard and operability study) - based on the plans?
- Have you conducted a risk assessment based on the plans?
- Have you prepared for cybersecurity? - A plant will have to interact with other systems, not within the plant firewall - Energy prices – GridService - Data to Manufacture for optimization – maintenance - Remote operation of plant - 24/7

6.4.3.1. Documentation in the Engineering Phase (3)

- R.8. Byggetilladelse
- R.9. Arbejdsmiljøtilladelse
- R.10. Affaldshåndtering og bortskaffelse
- R.11. Sårbarhedsvurdering ved PET
- T.3. Trykbærende udstyr
- T.4. Elektriske installationer
- T.5. Eksplotionsbeskyttelse, ATEX
- T.6. Elektromagnetisk interferens, EMC
- T.7. Støjregulering
- T.8. Maskindirektiv
- T.10 ATEX, arbejdspladsvurdering
- T.12. Arbejdsmiljø og sikkerhed
- T.13. Energistyring og energieffektivitet

6.4.4. Phase 4. (Tender, Engineering, Procurement & Construction)

Review the approvals from authorities, as they are conditional and require some actions after the project is finished and before the station opens.

Ensure that you have received all as-built materials and that all relevant authorities have received the required information and documentation by the end of construction and commissioning.

Considerations before operations and maintenance:

- Do you have all your contracts, e.g., FIDIC, in place?
- Have you prepared tenders for service and suppliers (sub-contractors)?
- Have your tenders and contracts finalised negotiations?

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- Have you completed your final detailed designs?
- Have you purchased all equipment and ensured CE markings (third party verifications)?
- Have you received approvals from relevant authorities? (See Chapter 4)
- Have you reviewed your HAZID (Hazard Identification)?
- Have you reviewed your HAZOP (Hazard and operability study)?
- Have you reviewed your LOPA (Layers of Protection Analysis)?
- Have you received approvals from authorities, such as local planning authorities, local fire and rescue services, local environmental authorities, safety technology authorities, etc.?

6.4.4.1. Documentation in the Tender, Procurement & Construction Phase (4)

- T.9. Overensstemmelseserklæring
- T.11. Sikker transport af farligt gods
- D.1. Nødprocedurer
- D.2. Beredskabsplaner
- D.3. Brugsanvisninger og vedligeholdsesvejledninger
- D.4. Risikovurdering
- D.5. ATEX-dokumentation
- D.12. Plan for eksternt beredskab
- I.1. Trykbærende udstyr
- I.2. Eksplotionsfarlige atmosfærer, ATEX-zoner
- I.3. Elektriske installationer
- I.4. Brandsikringsforantstaltninger
- I.5. Alarmsystemer
- I.6. Kalibrering og verificering- af flowmålere

6.4.5. Phase 5. (Operation and Maintenance)

Make sure all documentation is gathered and handed over to the operation.

Considerations to do before daily drift and maintenance:

- Have you established security controls such as gate control alarm systems?
- Do you have sufficient operation manuals in place?
- Do you have a safety management system in place? (See Chapter 8)
- Do you have your internal emergency management plan according to the Seveso Directive?
- Do you have your external crisis management plan according to the Seveso Directive (if Cullum 3)?
- Do you have your automatic fixed firefighting equipment in place? Has it been tested?
- Have your gas detectors/alarms been tested and certified?
- Is your first aid equipment on the plant sufficient and in place?

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- Do you have documentation for the competences of all people who may enter the plant?
- Have you developed a safety course for people who may work on-site at the plant?

6.4.5.1. Documentation in the Operation and Maintenance Phase (5)

- T.14. Kemikaliesikkerhed, REACH, CLP
- D.6. Kemikaliesikkerhed
- D.7. Plan for sikkerhed og sundhed
- D.8. Miljøgodkendelse
- D.9. Inspektions og vedligeholdelsesdokumentation
- D.10. Jobbeskrivelse, certifikater og organogram
- D.11. Vagtplan for ordinær drift
- I.7. Arbejdsudstyr
- I.8. Kemiske stoffer og materialer
- I.9. Emissioner og affaldshåndtering
- I.10. Arbejdsmiljø
- I.11. Kraner og løfteudstyr
- I.12. Ventilationssystemer og luftkvalitet

6.4.6. Phase 6. (Decommission)

From a sustainability perspective, the life cycle and end of life are interesting points to cover. Decommissioning a PtX plant requires careful planning and consideration to ensure it is done safely, efficiently, and environmentally responsible.
Here is a list of considerations for the decommissioning process:

- Have you conducted a thorough environmental impact assessment to understand the potential risks and impacts of decommissioning activities on the surrounding ecosystem, air quality, soil, and water?
- Have you ensured all decommissioning activities comply with relevant local and national regulations and permits?
- Have you developed a detailed safety plan that includes risk assessments, hazard identification, and measures to protect workers and the public during decommissioning?
- Have you established a comprehensive waste management plan to handle hazardous and non-hazardous waste generated during decommissioning, including recycling, treatment, or proper disposal?
- Have you created a detailed inventory of all equipment, materials, and assets to be decommissioned and assessed their potential for repurposing or resale?
- Have you explored opportunities for recovering and reusing valuable resources and materials from the decommissioned plant to minimize waste and promote circular economy principles?
- Have you developed a plan for involving the local community in the decommissioning planning process, addressing concerns, and how to keep them informed about the project's progress?
- Have you developed a workforce transition plan to support employees during decommissioning, including potential retraining, job placement, or severance packages?

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- Have you created a budget and financial plan for the decommissioning process, accounting for all costs associated with the dismantling, remediation, and site restoration?
- Have you developed a detailed plan for site remediation and restoration to return the land to its original state or to be prepared it for alternative uses?
- Have you considered opportunities to enhance biodiversity and ecological restoration in the area, such as re-establishing native vegetation or creating wildlife habitats?
- Have you developed a plan to maintain open and transparent communication with stakeholders, including investors, government agencies, suppliers, and neighbouring businesses?
- Have you implemented security measures to prevent unauthorized access to the decommissioned plant and a plan to ensure the safety of the site and surrounding areas?
- Have you prepared how to keep detailed records of all decommissioning activities and how to provide regular updates and reports to relevant authorities and stakeholders?

Each decommissioning project is unique, so this list may require tailoring based on the specific characteristics and circumstances of the green fuel plant in Denmark. Engaging with experts, environmental consultants, and relevant authorities can further ensure a smooth and responsible decommissioning process.

7. Risk Management and Assessments

This chapter's purpose is not to describe and explain the broad spectrum of risk assessment methods available but to present a reference framework that can be used consciously from the planning and development of a PtX facility and at any stage of its life span.

We will present a concrete example to illustrate the structure of thinking proposed in the framework, its interpretation, and possible approaches to designing and implementing risk assessments independently of the method chosen. In Annex B, we present the characterization of some of the most used methodologies. This characterization should be seen as a tool to internally discuss and reflect on the convenience of deciding by one or method, how to combine them depending on the needs and how to prioritize them depending on the case you want to assess. It is not intended to discard or judge their pertinence, relevance, or accuracy.

7.1. Data from previous incidents in the PtX industry

The following data is taken from the HIAD 2.0 database (Hydrogen Incidents and Accidents Database) which is produced by the International Association for Hydrogen Safety.
The HIAD 2.0 database is widely regarded as one of the most comprehensive databases on hydrogen-related accidents and incidents. It includes more than 700 accidents dating back more than 100 years. The database is created and updated by the Joint Research Centre (JRC) of the EU in the frame of the European Network of Excellence HySafe.

To ensure relevance for the Safe and Faster PtX guideline, the following data filtering has been utilized:

- Events predating 1996 are excluded.
- Events with a quality rating of less than three are excluded.
- The dataset includes only events related to the chemical industry, hydrogen production, hydrogen storage, ammonia production, and methanol [8].

After the above-stated filtering, the dataset consists of 135 events.

7.1.1. Cause of incidents

Among other aspects, the database provides information on the causes of failure in each event. Analysis of this shows that:

- 53% of the events include technical causes.
- 68% of the events include human causes.
- 5% of the events are caused by something else or have unknown causes.

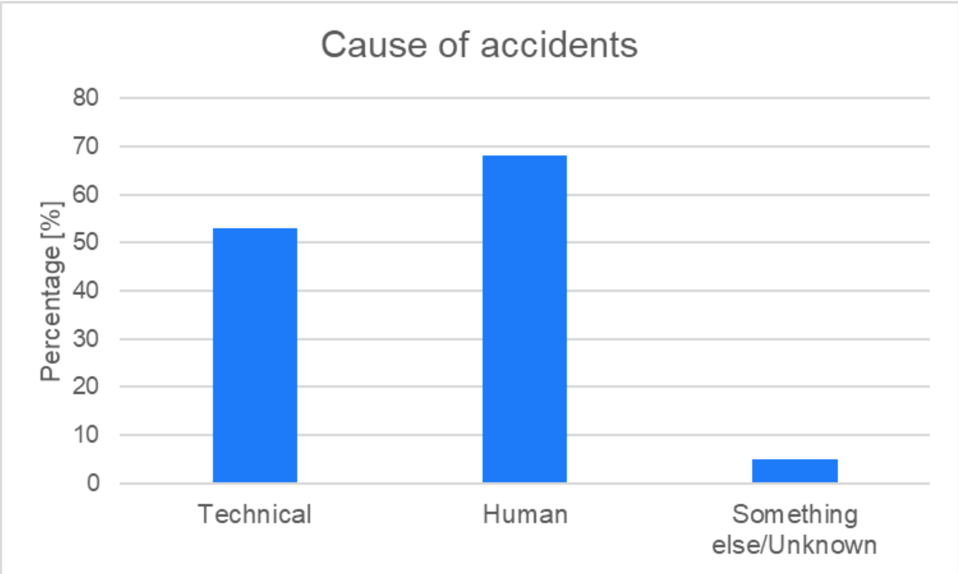

Figure 6: Cause of accidents

7.1.2. Technical cause of failures

Among the events categorized under technical causes (53% of the filtered dataset), the most common technical causes identified are:

- **Material/manufacturing error:** Occurred in 43 events, making it the most prevalent technical cause.
- **System design error:** Identified in 34 events, following as the second most common technical cause.
- **Installation error:** Found in 9 events, making it the least common of the specified technical causes.

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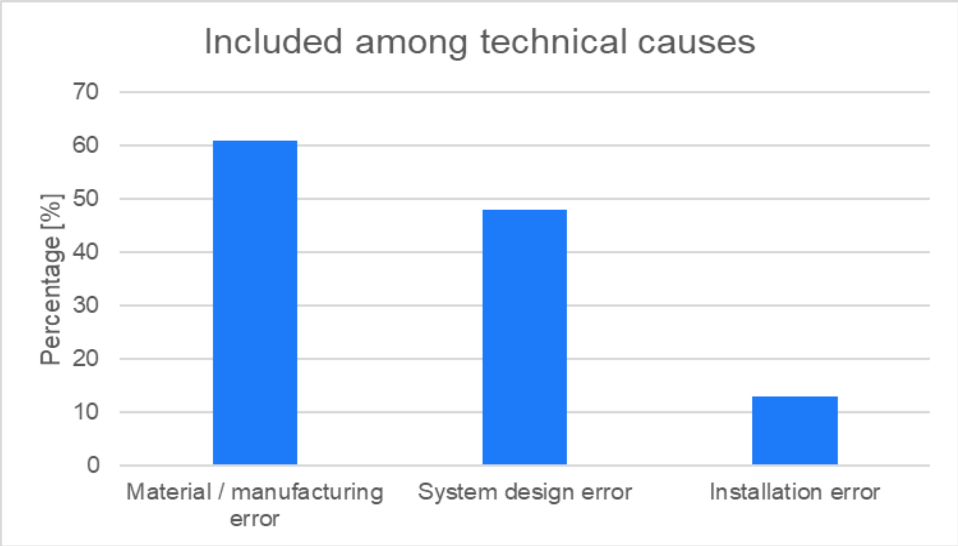

Figure 7: Included among technical causes

This indicates that issues related to materials and manufacturing are the most frequent technical contributors to the events within this dataset.

The bar chart below shows how often different keywords related to technical causes are mentioned. These keywords have been detected from all technical causes.

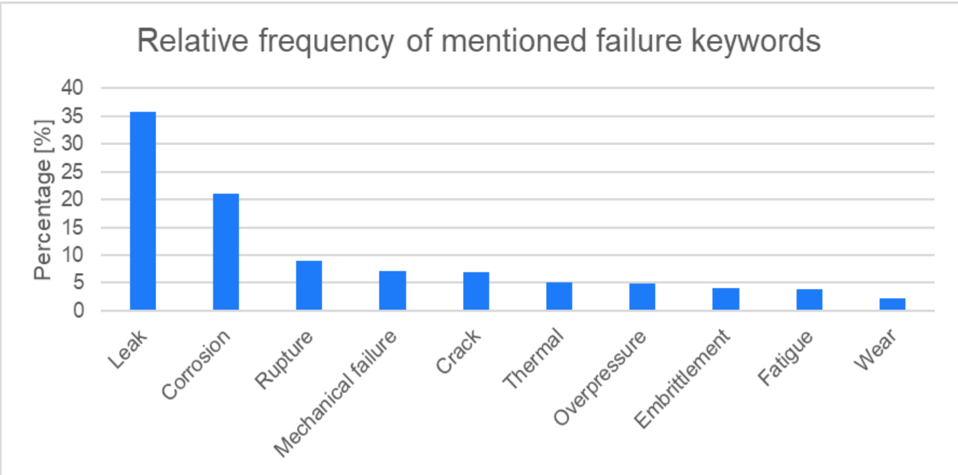

Figure 8: Relative frequency of mentioned failure keywords

These numbers show how often each term appears in the cause comments, suggesting that leaks and corrosion are the most common specific failure modes or components mentioned.

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7.1.3. Human cause of failures

Regarding human causes, the following specific distinctions of human causes have been made:

- **Management factors:** Occurred in 57% of the events, making it the most prevalent human cause.
- **Human factors:** Identified in 22% of the events, following as the second most common human cause.
- **Job factors:** Found in 11% of the events, making it the third largest contributor.

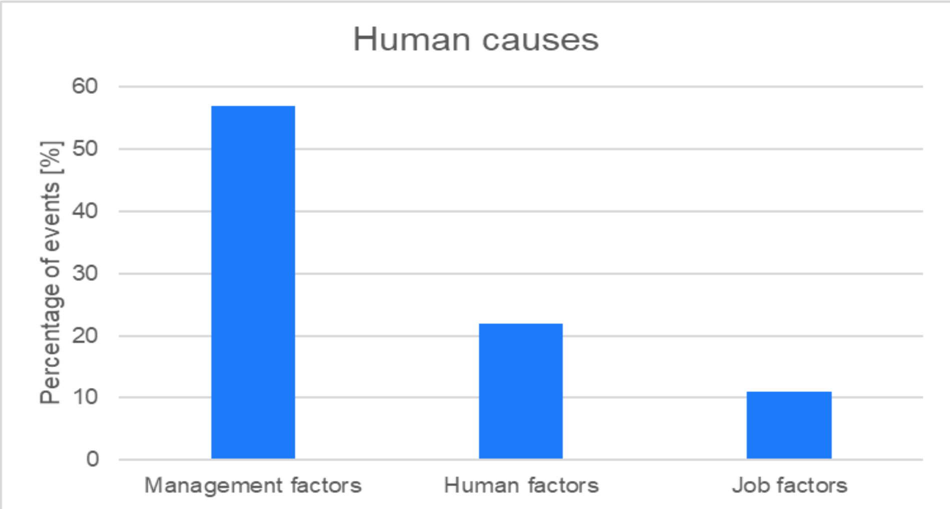

Figure 9: Human causes

7.1.4. Consequences of accidents

Any accident can have an impact in some way. The following numbers are taken from the consequences of the accidents in the dataset.

- The average number of **fatalities per event** is approximately 0.77.
- The average number of **injuries per event** is approximately 2.55.
- 85 events did not result in any fatalities or injuries.
- The average **property loss on-site** in USD is approximately 385,000 EUR.
- The average **property loss off-site** in USD is approximately 33,000 EUR.
- Consequently, the average total property loss per event, combining on-site and off-site losses, is approximately 417,000 EUR.

Of the 135 specified events, 23 have a stated official legal action.

7.2. Fundaments for Risk Assessments

In the industrial environment, it is common to find dangers, vulnerabilities, risks or threats everywhere. The interaction between platforms, infrastructures, systems, technologies, organisations, and people is diverse, unpredictable and complex. Thus, the way organisations identify, understand, structure, prioritise and prevent safety concerns to make the right decisions defines a comprehensive risk assessment. Decision makers use the outcome of a risk assessment to prioritise the organisation's efforts and resources to mitigate such risks.

7.2.1. Risk assessment motivation

Risk assessment is a process of identifying, analysing, and evaluating potential hazards and risks associated with a particular activity, process, or system. Before embarking on any risk assessment, it is important to define its motivation. When defining the motivation, you need to be aware of the company's agenda with the risk assessment or the plan for the risk assessment. For example, the motivation could be fulfilling authorities' requirements, while the plan might be to obtain the authorities' approval. Any motivation or plan you have will impact your objectivity when identifying, analysing and evaluating risks and hazards.

Furthermore, motivation provides context to the risk assessment process. It allows the risk assessors to tailor the assessment to the specific needs of the stakeholders involved. When the risk assessors are performing the assessment, they must also consider themselves stakeholders. This tailor-made process makes risk assessment complex and challenging, especially when you integrate many stakeholders into the same project that were not connected in the past, as in the case presented in the construction of a PtX facility.

Objectivity and subjectivity are two critical factors in risk assessment. Objectivity refers to using facts, data, and evidence to make informed decisions, while subjectivity refers to personal opinions, biases, beliefs and hypothetical scenarios, that can influence decision-making.

It is important to recognize that objectivity in risk assessments is not solely a matter of technical accuracy or precision. Instead, it is also shaped by social and cultural factors that influence how data is collected, analysed, and interpreted. Therefore, promoting objectivity in risk assessments requires an interdisciplinary approach, considering the complex relationship between technology and society.

One key aspect of promoting objectivity in risk assessments is increasing transparency and accountability in the process. This involves disclosing the technical details of how risk assessments are conducted and being transparent about the underlying assumptions and values that inform the assessment. By doing so, stakeholders can better understand the potential limitations and biases of the assessment and make more informed decisions based on the results.

Another important aspect of promoting objectivity in risk assessments is to engage a diverse range of stakeholders in the assessment process. This includes technical experts and non-experts, such as community members and other stakeholders who may be affected by the risks

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being assessed. By incorporating multiple perspectives and diverse forms of knowledge, risk assessments can be more inclusive and comprehensive, reducing the potential for bias and increasing the accuracy and relevance of the assessment.

Finally, objectivity should not be seen as an absolute goal but rather a continuous process of reflexivity and adaptation. Risk assessments must be constantly re-evaluated and updated as new information becomes available or as social and cultural contexts change. By remaining vigilant and responsive to changing circumstances, risk assessments can be more adaptive and better able to address the needs and concerns of all stakeholders involved.

7.2.2. The purpose of the risk assessment

Focusing the risk analysis on the wrong systems, elements or issues is more problematic than the more critical hazard identified. Defining the purpose implies that you have identified the reason why you want to practice a risk assessment; it must carry a series of considerations affected by the context where the project is embedded, the actors involved, the interactions and interdependences, tensions, uncertainties, regulations and procedures, technical considerations and how all these are direct or indirect related to the project. Understanding how variables such as time and effort, specifically corporative agreements and technical requirements, may help avoid drawbacks and delays in the subsequent stages.

Managing all these variables requires a coherent structure that can guide, regulate and control the analysis and outcomes of the risk assessments from start to end. The structure refers to the actors and the service level agreements between them, clearly defining the responsibilities and set of responsibilities, boundaries and limits for each actor´s interaction. It also implies the dissemination and communication agreements that facilitate such interaction. This is considered governance. Hopefully, this structure will be developed as a conjunction of agreements between actors, which should create the mechanisms and processes to communicate better and analyse the information collected to define decisions. The governance activities imply that a group are related to technical definitions, and a second group is characterised as organisational activities. This clear distinction between types of governance activities will facilitate the designation of responsibilities and monitoring their progression.

7.2.3. Who should be involved?

The risk assessments should be carried out by all the technical experts (project managers, engineers, technicians, and social scientists) who understand the particularities of the technologies and humans involved in the building, operation, and daily maintenance of PtX facilities. However, as mentioned in governance definition, the challenge (invitation formulated in this guideline) is to identify and include new relevant actors that can contribute from across different disciplines with additional perspectives to the analysis (assessment).

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With our experience, we identified the need for transdisciplinary teams and assessments because they yield high-quality results and create more solid and holistic assessments that are often a more accurate representation of the scenarios we attempt to assess. For instance, the inclusion of qualitative insights on, e.g., 'daily operations' in fire safety design practices incorporates vital information on daily practices, risk perceptions and safety culture among crew or technical staff which have a high impact on fire safety and overall risk assessments of given facilities [9]. Joint problem-solving across disciplines through transdisciplinary engagement is essential to tackling challenges in contemporary society – not least regarding Power-to-X facilities.

7.2.4. Identifying interfaces

Identifying systems and interfaces is critical in developing a comprehensive understanding of the potential risks that can arise from them. While some systems and interfaces may be familiar, others may be new or specific to the facility or technology being used. Overlooking these systems and interfaces can lead to potentially significant risks that may go unnoticed until too late. Therefore, it is essential to consult with experts in the field to ensure that all potential risks are identified and evaluated. By doing so, risk assessors can ensure that the facility is safe and that all potential risks are identified and mitigated. We created a separate chapter where some examples illustrate the concept of interfaces and boundaries and their relevance for risk assessments. See the part "Interfaces and boundaries of the risk assessment on different levels" (Chapter 7.5).

7.3. Risk assessment steps

Independent of the standards, approaches, and industries, risk assessment has a three step process at its core: identification, analysis and evaluation.
This guideline will pay special attention to the preliminary stages before these three steps, as well as the key elements to consider while executing the assessment.

7.3.1. Identification

How do we interpret and operationalize the concept of risk?
Defining "risk" for interdisciplinary contexts is essential, especially if people come from different cultures, industries, or technical domains. A shared understanding of the concept and a concrete agreement on it will help the multiple stakeholders commit to the purpose of the risk and where to put the attention during the assessment process. For instance, ISO 31000:2009 defines risk as "the uncertainties effect on the goals" [10], and the SFPE G.04.2006, from an engineering perspective, defines risk as "The potential for realization of unwanted adverse consequences, considering scenarios and their associated frequencies or probabilities and associated consequences." [11]. Both definitions are valid, and both provide crucial elements to consider. Nevertheless, pay attention to the fact that one focuses on uncertainty, and the second refers to probabilities, frequencies and undesirable

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consequences. An easy tool to help people understand the uncertainty and adversity of the risk is by describing a chain of events that may or may not occur. That is called a scenario, a way to operationalise the concept of risk in practice within interdisciplinary teams.

7.3.2. What is a hazard, and how can hazards be identified?

According to the engineering guide for fire risk assessment [11], a hazard is a condition or physical situation with the potential to produce harm. All risk assessment standards suggest hazard identification (HI) as a fundamental stage in a risk assessment.

Hazard identification involves identifying, predicting, and evaluating potential threats or sources of harm to people, the environment, the property, or an organisation's reputation. Hazard identification aims to proactively identify and understand the risks that could result from specific events or sequences of events so that appropriate measures can be taken to mitigate or prevent them. This process helps organisations to be prepared and ready to respond in the event of an adverse event and to reduce the likelihood and impact of potential risks.

To effectively manage risk, it is important to integrate diverse perspectives from actors throughout the organisation. This involves conducting fieldwork, gathering real data, and interacting with relevant actors to gain insights into the factors that influence human performance. As stated on the DNV website [12], "Understanding the factors influencing human performance is, therefore, a key attribute to reducing error and increasing safety", emphasising the significance of considering human factors in risk management and the importance of incorporating diverse perspectives in the process. Addressing differences in purpose, methodologies, perceptions, and agreements can help reduce risk by ensuring that all relevant perspectives are heard and considered.

A good practice is to integrate different perspectives from organisational to human factors. It implies fieldwork, real data, and interaction with workers. “Understanding the factors influencing human performance is, therefore, a key attribute to reducing error and increasing safety” [12]. Our experience shows that people have different purposes and methodologies with which to approach their work, perceptions, and agreements towards their activities. Mapping, understanding, and aligning these differences can contribute positively when reducing risk is challenging.

Organising hazards into categories is a way to make easier the identification and prioritisation of hazards, for example, some categories are:

- **Natural hazards:** These are caused by natural events such as earthquakes, hurricanes, floods, and droughts.
- **Biological hazards:** These are caused by living organisms, such as diseases and pests.

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- **Physical hazards:** These are caused by physical conditions, such as exposure to extreme temperatures, falling objects, and electrical shock.
- **Psychological hazards:** These are related to the psychological and emotional well-being of individuals, such as stress, bullying, and discrimination.
- **Socio-cultural hazards:** Socio-cultural hazards refer to hazards associated with societal and cultural factors that can affect the health and well-being of individuals and communities.
- **Chemical hazards:** These are caused by exposure to chemicals, such as toxic substances and pollutants.

This is not an exhaustive list, but understanding the different types of hazards is important for identifying and managing risks and developing strategies to minimise their impact.

7.3.3. Analysis

Risk assessment standards and type of analysis

Different frameworks and standards exist in various industries and technical domains that suggest paths, tools, and methodologies for addressing risk assessment.

For instance, any industry that works with highly hazardous chemicals usually implements a Process Safety Management (PSM) standard [13]. This standard has a key position that suggest employees perform a thorough program that includes fourteen components that will help to reduce the appearance or effects and impacts of undesired exposure, accident or any risk in general. Next, as an example, we will mention some components of the PSM.

Process Safety information (PSI) suggests the data collection, characteristics and description of chemicals, technology, and equipment. Mechanical integrity refers to establishing and implementing written procedures to maintain mechanical systems such as tanks, pipes, vent systems, etc., as well as to maintain equipment, correct deficiencies, and provide training in preventative maintenance, inspections, and testing. Another example of a component from PSM is the Process Hazards Analysis (PHA), whose main objective is to identify hazards and how to control them. To perform a PHA, there are several methodologies that, as mentioned above, selection should be clearly defined and justified by the team that performs the assessment.

The International Organization for Standardization (ISO) is another standard that is highly used by different industries. According to ISO, their standards provide a conceptual basis for risk assessments, some dedicated to specific industries or different types of risks [14]. I.e. Fire Safety Engineering – Guidance on Fire Risk Assessment (ISO 16732)– Lead Risk Manager - Risk Management (ISO 31000:2018).

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Deciding which risk assessment type of analysis is more convenient in the case of a Power to X facility will depend not only on the applicable regulatory bodies but also on the evolution and changes of the levels of perceived risk while the assessment is progressing. The level of detail also depends on the complexity of the assessed risks and the concrete decision-makers´ needs.

According to the SFPE Engineering guide [14], there are three types of analysis: qualitative, semi-quantitative and quantitative.

- Qualitative analysis refers to the evaluation of risk without explicit numerical quantification.
- A semi-quantitative analysis refers to evaluating risk with simplified quantitative elements supporting assessment.
- A quantitative analysis is a complete explicit quantification of frequencies and consequences to produce numerical risk levels.

The choice of analysis should depend on a combination of system complexity, available information, and risk assessment use cases.

Other standards, depending on industries such as Information Technologies (IT) include analytical tools like Asset-Based, Vulnerability-Based and Threat-Based, which involve special considerations for cases where the interphases, technologies and risks are connected to intangible components such as software and cloud computing commonly used in PtX facilities [16].

Each analytical approach can be more suitable depending on different scenarios, the nature of the organisation, what you need to achieve, context, organisational capacity, resources, and many other circumstances. The advantage is that all of them can be combined because they are not mutually exclusive. Again, it is advisable that the decision made is well justified and documented, which will make communication and future work easier.

7.3.4. Evaluation

Risk evaluation assesses the likelihood and consequences of identified hazards to prioritise and allocate resources for risk management. Before starting the evaluation process, the organisation must define key elements such as risk criteria, risk tolerance, and risk assessment methods in collaboration with stakeholders and consider relevant regulations. These elements provide a foundation for the risk analysis and guide the selection of appropriate methodologies. The outcome of the risk evaluation informs the subsequent steps of risk response and treatment.

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Risk criteria: Risk criteria are the standards used to assess the severity and likelihood of each hazard. These criteria can include factors such as the potential consequences of the hazard, the probability of it occurring, and the ease or difficulty of controlling or mitigating the hazard.

Risk tolerance: Organisations need to determine their risk tolerance, which is the level of risk they are willing to accept to achieve their goals. This will influence how risks are evaluated and managed.

Risk scoring (subjectivity and objectivity): Objectivity and subjectivity are essential considerations in risk scoring. Objectivity involves minimising personal biases and using verified information. Subjectivity can arise due to personal perspectives or biases. To promote objectivity, establish clear scoring criteria, use reliable, verified data, and involve multiple disciplines and perspectives. [15]

7.3.5. Methodologies for analysis

To properly choose a methodology for an assessment, it is important to consider the motivation behind the assessment. The ultimate goal of the assessment should guide the selection of the appropriate methodology. However, it is also important to recognize that not all methodologies may provide the relevant information needed for the assessment. Various methodologies are available, each with their own strengths and offering different types of analysis. The choice of method/methods should depend on several factors, such as the scope of the case, the information available, the status of the project, facility, technology, stakeholders' demand, and the results needed to meet the decision maker's needs. The assessment team should define a table that explains the reasons for choosing particular parameters consciously and thoughtfully.

It is important to note that this guideline will not provide an in-depth explanation of each method, as there are official bodies of experts that keep the methodology updated and supported. For further information, please refer to the official sources in Annex B for a comprehensive understanding of each methodology.

7.4. Identifying Interfaces for the Assessment

When conducting a risk assessment for a facility, it is essential to identify all the systems and interfaces that may be involved. These systems and interfaces can range from familiar and part of the facility's day-to-day operations to new and innovative ones that may be specific to the facility or technology being used. Identifying these systems and interfaces is important as it helps to develop a comprehensive understanding of the potential risks that can arise from them. This chapter will discuss the importance of identifying various systems and interfaces in a risk assessment and why some may be overlooked or deliberately not considered.

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Importance of Identifying Systems and Interfaces:
Identifying systems and interfaces is crucial as it helps to develop a comprehensive understanding of the potential risks that can arise from them. Some systems and interfaces may be directly involved in the facility's operations, while others may be indirectly connected. A comprehensive risk assessment must consider all the systems and interfaces that may be involved in the facility's operations to ensure that all the potential risks are identified and evaluated.

Depending on experience and profession, some systems and interfaces may be familiar, while others may be new. For example, the concept of identifying systems and interfaces may be well-known for professionals familiar with large, complex facilities. However, for PTX facilities, there are many new actors, each bringing their respective technologies, one of which might be novel. In such cases, it is important to consult with experts in the field to identify and evaluate these systems and interfaces.

Overlooking Systems and Interfaces:
Some systems and interfaces may be overlooked or deliberately not considered. This may happen for various reasons, including lack of knowledge or expertise, limited resources, or time constraints. However, overlooking these systems and interfaces can lead to potentially significant risks that may go unnoticed until too late.

For example, risks may come from outside the facility, or the area covered by the risk assessment. These risks may include natural disasters, cyber-attacks, or terrorist threats that may impact the facility's operations. Additionally, risks may be outside the risk assessor's area of responsibility. In such cases, working with other stakeholders and experts is essential to identify and evaluate all potential risks.

New Actors and Technologies:
In the case of PtX facilities, many new actors may emerge, each bringing their respective technologies, some of which might be novel. These new technologies can introduce potential risks that previous risk assessments may not have considered. Therefore, it is important to consult with experts in the field to identify and evaluate these technologies and the associated risks.

For example, in the case of a nuclear power plant, new technologies may be introduced that may impact the facility's operations or introduce new risks. These technologies may include new types of reactors or new fuel cycles. It is important to identify and evaluate these technologies to ensure they are safe and do not introduce any new risks to the facility.

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7.5. Interfaces and boundaries of the risk assessment on different levels

Identifying interfaces and boundaries is critical in carrying out risk assessments, regardless of objective and system type. This step should be carried out early to help frame the assessment, provide the necessary limitations, and focus the analysis. However, several layers or levels of interfaces and boundaries might need to be analysed. Certain aspects or layers, such as other facets, may be omitted in a risk assessment, but this should be done informally.

System's interfaces:

- The system's interface can be understood as the various technical systems working together and influencing each other.
- This interface will be familiar to engineers working with the system.
- Analysis of the system will require experts in the various systems and their interaction and interdependencies.
- The various components are not necessarily in close physical proximity to each other but can be connected via cables, pipes, etc.
- Systems can also be linked through communication or control.
- Typically, assessments will include how some systems depend on, and can influence each other and how they can be protected through isolation or other means.
- It could also include alarm systems.

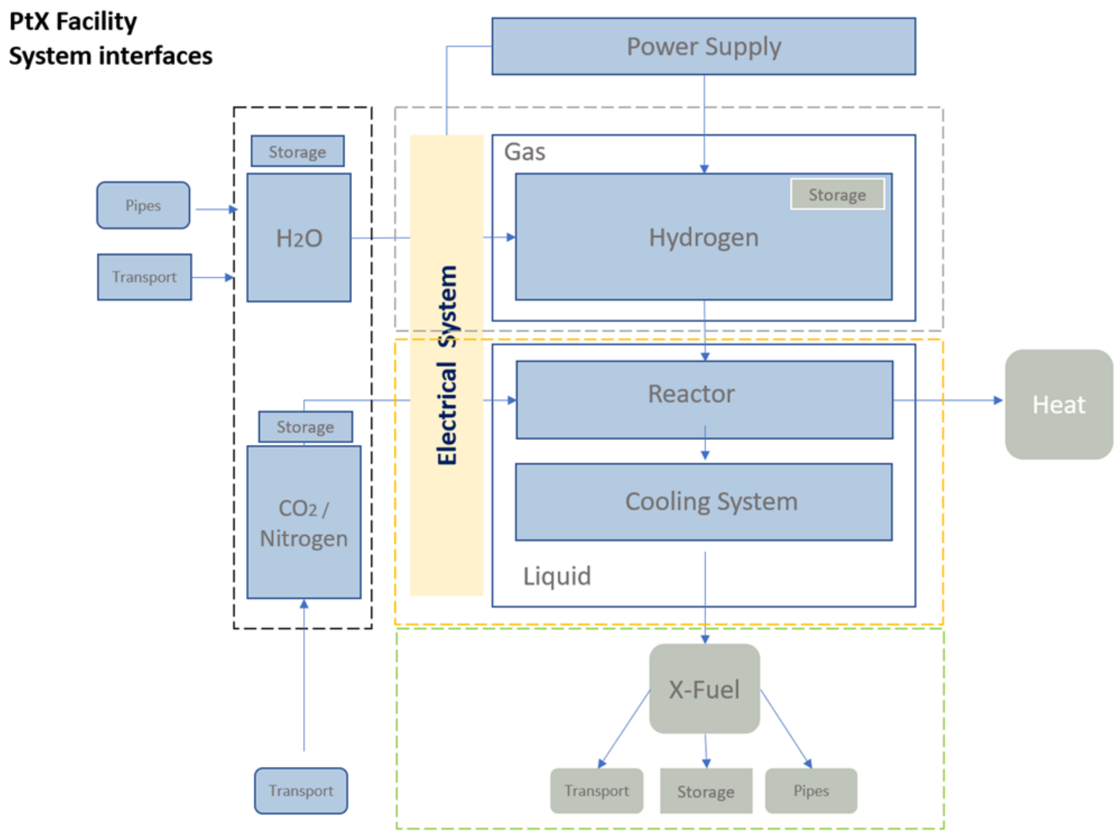

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Figure 10: Representation of system interfaces for a hypothetical PtX facility.

Physical interfaces

- Opposite the system's interfaces, the physical interfaces do require that the components be physically near each other but not necessarily interact on a systems level. Of course, they can be connected on the system's level, and in many cases, they will, but it is not a requirement.
- Often, physical interfaces are overlooked because they do not interface at the system's level.
- This negligence particularly evident with components or interactions coming from elements not considered part of the facility, such as houses, offices, utility buildings, roads, nature areas, etc., which are close to the components under scrutiny in the assessment. It is vital to remember as they are often forgotten or disregarded because they are not part of the official assessment. For fire risk assessments, offices and other houses can be important since they include many household appliances, which are not necessarily under the same degree of scrutiny and quality control as other components inside the facility.
- Similar to the machinery inside the building, the people occupying it might also be contributing to or creating risks. The people here may be in a different mindset when working in the house. They might be in a meeting, having lunch, or doing other types or work that are not traditionally considered to pose a risk.
- Particular attention should be given to buildings or elements not considered part of the 'site' and, therefore, not subject to the same safety rules. This ensures the necessary mitigation strategies are implemented and risks considered even for elements traditionally not considered in the assessment.
- Consider risks both coming to and from, i.e., both originating elsewhere and involving the main area of the assessment, and vice versa.

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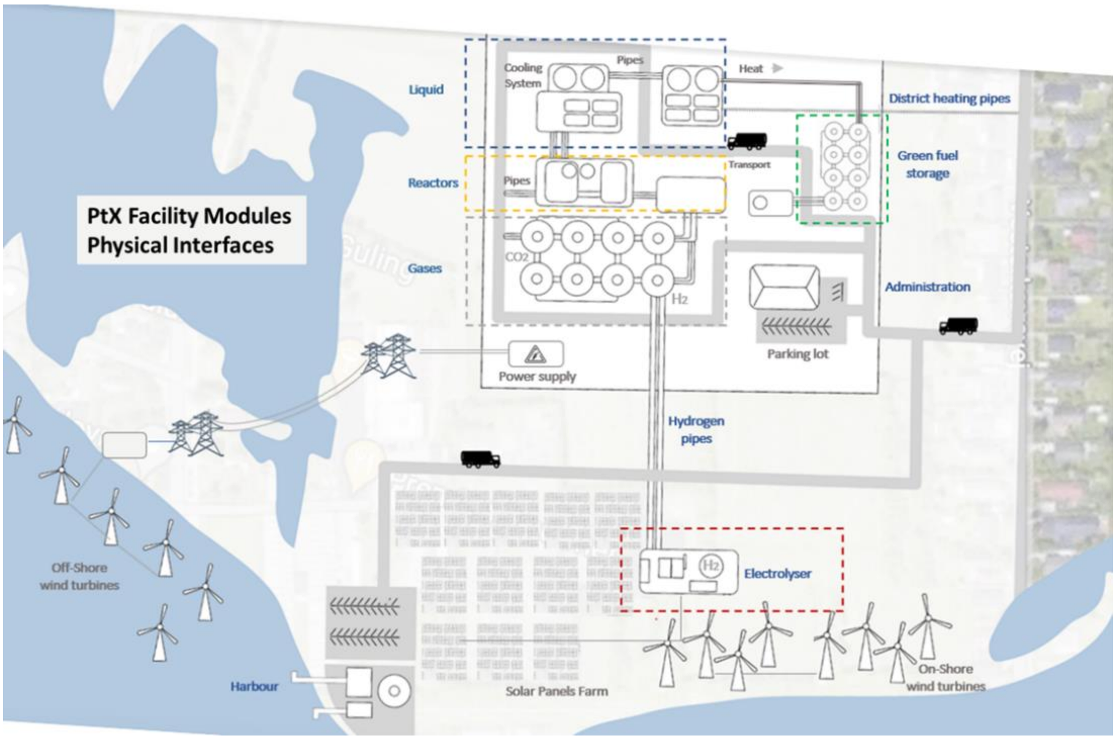

Figure 11: Representation of physical interfaces for a hypothetical PtX facility.

Organisational interfaces:

- Organisational interfaces can be difficult to comprehend from a traditional system's perspective.
- Organisational aspects are often considered 'outside the scope' and 'hypothetical'. However, they are vital as they sometimes draw invisible borders of ownership and 'care'.
- Different providers do not necessarily feel ownership or responsibility for other components. Alas, risky behaviour might not be due to a lack of care, but also knowledge.
- Various organisations and providers might be responsible for the risk assessments of their components or procedures. These are not always of the same standard as the main facility.
- Any additional sub-suppliers' risk assessments should likewise be scrutinized for quality.

Example: A f*ire originating in the parking lot, which a different company owns, spread to vital PtX components. This is a mix of a physical and organisational interface. The parking lot might, in some cases, be disregarded as part of the risk assessment since it is not owned by the parent company and is not part of the production facility.*

Example: *The janitor who services the administration facility is clearing weeds with a weed burner around the grounds. This area is outside the facility and the main owner. A fire spreads.*

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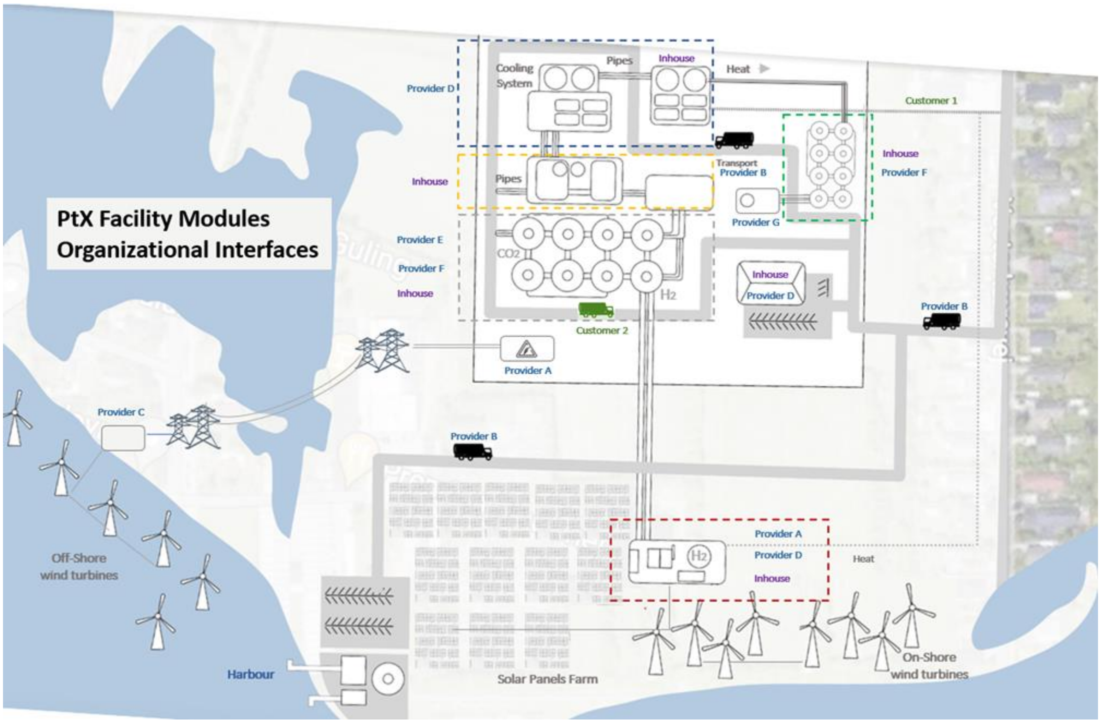

Figure 12: Representation of organizational interfaces for a hypothetical PtX facility.

7.6. Recommended list of risks to assess

The list of risks to assess may be helpful when determining which risks to assess and ensuring that all risks are considered.

The list is divided into five categories and should cover all relevant aspects of establishing a PtX plant in Denmark. The categories in our list register are listed below, and the complete list of risks to assess in Annex B.

1. External Dynamics and Market Forces

The External Dynamics and Market Forces category encompasses risks from geopolitical events, economic fluctuations, technological advancements, environmental concerns, and regulatory changes impacting the renewable energy sector. Failure to anticipate and mitigate these risks can affect project viability, profitability, and operational stability (see list in Annex B).

- Politics
- Economy
- Social and cultural influences
- Technology
- Environmental conditions
- Legal and regulatory

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2. Supply Chain

The Supply Chain category encompasses risks associated with the flow of materials, products, and information from suppliers to customers. Failure to address these risks can lead to production delays, increased costs, quality issues, and reputational damage throughout the supply chain (see list in Annex B).

- Sourcing (due diligence incl. collaboration)
- Transportation
- Regulatory and compliance

3. Production

The Production category encompasses risks associated with the selection, use, and processing of materials, and errors in manufacturing or operational processes. Failure to address these risks can result in inefficiencies, defects, or failures in the production process, leading to customer dissatisfaction, market share losses, operational disruptions, and reputational damage (see list in Annex B).

- Process errors
- Quality
- Maintenance
- Regulatory compliance

4. HSE (Health, Safety & Environment)

The HSE (Health, Safety, and Environment) category focuses on safeguarding the well-being of employees, protecting the environment, and ensuring compliance with regulatory standards. Failure to address HSE concerns can result in legal liabilities, reputational damage, and operational disruptions (see list in Annex B).

- Health
- Safety
- Environment
- Regulatory compliance

5. Security

The Security category encompasses measures to safeguard assets, data, and personnel from various threats, including theft, fraud, cyber-attacks, and physical breaches. Failure to address security risks can result in operational disruptions, financial losses, legal disputes, and reputational damage (see list in Annex B).

- Financial
- Information
- Physical
- Reputation
- Security management and human error
- Regulatory compliance

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8. General HSE (Health Safety and Environment)

During establishing and operating a PtX plant, several requirements exist for having plans/systems/procedures for managing all safety issues and precautions to avoid damage to Health, Safety and the Environment.

During the building and construction, a PSS Plan must be developed (see Chapter 8.1.).
When the plant has been built and is ready for production, an HSE Plan (Health Safety and Environment Plan) is recommended, which can be implemented in the existing management plan at companies or organisations.

A "Plan for sikkerhed og sundhed" (Plan for Safety and Health) and an "HSE Plan" (Health, Safety, and Environment Plan) are both documents aimed at ensuring safety and health in a workplace or project. While both plans share similar goals, there are differences in focus and scope. Here are some of the differences between the two types of plans:

Focus Areas for PSS:
A PSS primarily focuses on aspects related to the safety and health of workers on a specific project. It identifies hazards and risks and describes measures to address them.

Focus Areas for HSE Plan:
An HSE Plan addresses broader aspects of health, safety, and the environment. In addition to protecting workers' safety and health, it includes measures to minimise environmental impact and promote sustainability.

Scopes for PSS:
A PSS is usually specific to a single project or a particular workplace. It is developed to address the specific risks and challenges associated with the project's timeline.

Scopes for HSE Plan:
An HSE Plan can be more general, continuously covering a wide range of activities and projects within an organisation or industry. It may include policies, guidelines, and standards that apply across different projects or workplaces and work throughout the organisation's existence.

Inclusion of Environmental Aspects PSS:
A PSS primarily focuses on worker safety and health, including the identifying and managing hazards and risks to workers.

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Inclusion of Environmental Aspects HSE Plan:

A HSE Plan includes health and safety aspects for the workers as well as environmental aspects. It addresses environmental impact and includes measures to minimise pollution, reduce resource consumption, and promote sustainable practices.

Both plans are important tools to ensure compliance with applicable regulations and standards for safety, health, and environmental protection in workplaces and projects.
The choice between developing a Plan for Safety and Health or an HSE Plan depends on the context, the specific project, and the organisation's needs and requirements.

8.1. PSS (During construction and operation)

The owner is responsible for drawing up a plan for health and safety during the construction of large buildings or construction projects. The PSS (Plan for Health and Safety) must be adjusted when construction is finished, and the plant goes into operation.

The plan’s purpose is to ensure a good working environment for everyone who must work or stay on the construction site. It is a management tool for the joint work environment on the construction site. The plan must, among other things, contain an organisation plan, a construction site drawing, and a timetable, as well as -if relevant- an overview of measures for particularly dangerous work.

The PSS Plan must be drawn up during the project design and available on the construction site when construction or construction work begins. The requirement for accessibility presupposes that the plan is collected in one whole plan, which provides an easy-to-understand overview.

It is stipulated in the rules that the work on preparing the plan for safety and health is carried out in close connection with the design and planning and in such a way that the project descriptions, which is the responsibility of the designer, and the safety and health plan are adapted by all stakeholders during the design period. This applies to the time allocated to the various works or work phases, which must be carried out simultaneously or one after the other and determined based on the architectural, technical and organisational choices made during the design.

It is the owner’s responsibility that the plan is drawn up and updated so that, among other things, account is taken of the results of the preliminary investigations that have been carried out, for example, soil contamination, hazardous substances in the building/construction or the building/construction stability, as well as all other significant decisions relating to the work to be carried out, how it is to be carried out and who is to carry it out.

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The PSS Plan must consider the agreements the owner agrees upon with the individual employers/suppliers about common areas and safety measures. It must be clear from the plan who will provide, maintain and remove the planned common safety measures such as access roads, railings, construction flow, winter precautions and welfare measures on the construction site, and who will ensure order and tidiness. Agreements between contractors and their subcontractors, which imply that the subcontractors are responsible for solving tasks in the common areas, must also appear in the PSS Plan.

It is important that there is a link between the plan preparation during the design and its use during the construction period. If the coordinator for the construction process is a different person than the coordinator for the design, it is the owner’s responsibility to ensure that the plan for safety and health is adequately transferred from one coordinator to the other.

8.1.1. Example of a list of content in a PPS (Plan for Safety and Health)

1. An Organisation Plan
2. A Site Construction Plan
3. A time schedule for planned “Risky Work”
4. A plan for allowed areas of staying, working or walking
5. A plan for work areas with multiple employers and employees working simultaneously
6. A plan for the mandatory safety precautions and rules on common areas
7. A plan for restricted areas where risky work is going on
8. A procedure for ongoing inspection and control of installations, safety precautions and eventual risks
9. A schedule for who is in charge of inspections, coordinated crisis management plan, evacuation plan, and planned drills and exercises
10. Description of precautions during more hazardous work

You can find detailed guidance on what is expected of the content in your PSS in the link below:
Plan for sikkerhed og sundhed (PSS) - Arbejdstilsynet (at.dk) [17]

8.2. Health Safety and Environment Plan (During operation and maintenance)

An HSE Plan, which stands for Health, Safety and Environment Plan, is a strategic document outlining the measures and guidelines to ensure workplace health, safety, and environmental protection. The primary goal of an HSE Plan is to establish a framework that promotes a safe and healthy working environment while minimising negative impacts on the surrounding environment. The HSE Plan is typically based on daily drift and is a tool for adjusting procedures and best practices for all health safety issues.

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An HSE Plan typically includes the following components:

Policy Statement: A clear and concise statement that reflects the organisation's commitment to prioritise health, safety, and environmental protection.
Objectives: Specific goals and targets related to health, safety, and environmental performance that the organisation aims to achieve.
Risk Assessment: A systematic evaluation of potential hazards and risks in the workplace, including identification, analysis, and evaluation of possible incidents and their impacts.
Control Measures: Detailed strategies and procedures to mitigate identified risks and ensure the safety and health of workers. This may involve implementing safety protocols, providing personal protective equipment, conducting regular inspections, and establishing emergency response plans.
Training and Awareness: Programs to educate employees and stakeholders about health, safety, and environmental practices, ensuring they understand their roles and responsibilities and can actively contribute to a safe working environment.
Compliance and Legal Requirements: Ensuring adherence to relevant laws, regulations, and industry standards related to health, safety, and environmental protection.
Incident Reporting and Investigation: Procedures for reporting and investigating incidents, accidents, near misses, or environmental breaches. This helps in identifying the root causes and implementing corrective actions to prevent future occurrences.
Continuous Improvement: Mechanisms to monitor and evaluate the effectiveness of the HSE Plan, fostering a culture of continuous improvement and proactive hazard prevention.
An HSE Plan is a comprehensive document that sets the framework for integrating health, safety, and environmental considerations into the organisation's operations. It is essential for ensuring the well-being of employees, protecting the environment, and maintaining compliance with regulatory requirements.

8.2.1. Example of list of content of a HSE Plan

1. INTRODUCTION
    - Project description
    - Objective of the document
2. REFERENCES
    - References of document issued by the company
    - Codes and standards used
4. ORGANISATION CHART AND RESPONSABILITIES
5. HSE MANAGEMENT SYSTEM
    - 5.1 HSE Policy and Objectives
    - 5.2 HSE Management System Framework
    - 5.3 Compliance with local rules & COMPANY rules
        - 5.3.1 National and international laws
        - 5.3.2 Specific requirements (CONTRACTOR/COMPANY)

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8.3. PPE

In relation to PtX, the Personal Protection Equipment is very specific from site to site. It all depends on the chemicals and environment we are focused on.
In Chapter 11 (Green-Fuels Data and Characteristics), you will find PPE recommendations for each green fuel.

8.4. Environmental Considerations

8.4.1. In General

Several environmental issues should be considered when establishing a PtX production plant to ensure sustainable and responsible operations. Here are some key considerations which should be assessed during the planning and design stages of the PtX production plant to minimise environmental impacts, foster sustainability, and promote a responsible approach to renewable energy production.

8.4.2. Carbon Emissions

To minimise carbon emissions, it is important to assess the entire production process, including upstream activities like feedstock extraction or cultivation, transportation, and downstream operations. Implementing carbon capture and storage (CCS) can reduce the plant's carbon footprint by capturing and storing CO_2 emissions. Additionally, using renewable energy sources like solar or wind power for plant operations can further lower carbon emissions.

8.4.3. Resource Usage

Efficient resource usage is essential to minimise the environmental impact of a PtX production plant. Water is a significant resource, so implementing water conservation measures like recycling or reusing water in production can reduce water consumption. Advanced technologies requiring fewer raw materials or implementing closed-loop systems can optimise material usage and minimise waste generation.

8.4.4. Waste Management

A PtX production plant should have effective waste management practices. Byproducts, residues, or waste materials generated during production should be handled responsibly. Implementing recycling or reusing systems can minimise waste sent to landfills. Waste-to-energy technologies can also convert organic waste into renewable energy, reducing environmental impact.

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8.4.5. Land use and habitat protection

The choice of plant location should consider the potential impacts on land use and habitats. Conducting comprehensive environmental impact assessments can identify potential risks to ecosystems, biodiversity, or protected areas. Avoiding sensitive habitats or agricultural lands can prevent irreversible ecological damage. If land conversion is necessary, compensatory measures like habitat restoration or conservation initiatives should be implemented.

8.4.6. Air quality

PtX production plants should prioritise air quality by implementing effective emission control measures. Technologies like filters, scrubbers, or catalytic converters can reduce the release of pollutants into the atmosphere. Monitoring emissions regularly and complying with air quality regulations are crucial to minimise the impact on local air quality and public health.

8.4.7. Energy Efficiency

Enhancing energy efficiency within the production process is essential for reducing environmental impact. Utilising energy-efficient equipment and technologies, optimising process design, and implementing energy management systems can minimise energy consumption. Using energy more efficiently can reduce the plant’s overall carbon footprint and operational costs.

8.4.8. Transportation and Logistics

Consider the transportation and logistics associated with the plant's operations. Locating the plant near feedstock sources can reduce transportation distances and related carbon emissions. Utilising alternative transportation modes like rail or waterways instead of solely relying on road transport can further reduce the plant's environmental footprint. Efficient logistics planning can minimise fuel consumption and emissions during product distribution.

8.4.9. Social and Community Impacts

Alongside environmental considerations, it's important to address social and community impacts. Engage with local communities, stakeholders, and relevant authorities throughout the planning and establishment process. Conducting social impact assessments and addressing concerns related to noise, visual impact, or potential disruptions can foster social acceptance. Implementing community development programs, local employment opportunities or partnerships with local organisations can contribute positively to the community’s well-being (see Chapter 5).

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9. Compliance with PtX related regulations

9.1. Compliance

As the nation endeavours to reduce carbon emissions and embrace renewable energy sources, the establishment of these facilities holds tremendous promise for a greener future. However, alongside the aspiration to harness clean energy lies an equally significant commitment to ensuring compliance with stringent regulations, standards and guidelines.

Aspiring operators and stakeholders entering this industry must recognize the paramount importance of adhering to a framework of laws, permits, and environmental standards. Compliance serves as the foundational bedrock that supports the sustainable growth and safe operation of green fuel plants and fosters trust and confidence among communities, investors, and regulatory bodies.

From understanding the array of compliance required to addressing environmental impact assessments, safety protocols, and operational guidelines, we delve into the essential elements that constitute a compliant and environmentally responsible project. This chapter will unravel the intricate tapestry of regulatory obligations that facilitate the establishment of green fuel plants and safeguard the delicate balance between progress and well-being.

9.2. Seveso Directive

9.2.1. Background for the Seveso Directive

The Seveso accident was an industrial accident that occurred on July 10, 1976, around 12:30 at an industrial plant near the Italian city of Seveso (near Milano). During the accident, there was a spill of the toxic substance dioxin in a quantity that exposed the population around the plant to the highest measured dose ever. During the accident, 2.5 kg of dioxin was spread over a large area, because of a leak in a high-pressure boiler at ICMESA. The accident became that serious because neither the workers nor the public was informed about the substances used in the production or about the accident until eight days later when the company was closed by a court order. It was not until July 27 that the area was evacuated (17 days later). The accident was why the EU later adopted legislation to regulate the storage and handling of dangerous substances in densely populated areas, the Seveso–directive.

9.2.2. Risikohåndbogen (The Danish version of the Seveso directive)

The Danish version of the Seveso Directive is in form of a book named “Risikohåndbogen”.
This is a translation and interpretation of the Seveso Directive, which it is recommended to review before planning the development of a PtX plant.

9.2.3. The Danish implementation - Order no. 372 from 25/04/2016

In Denmark, SEVESO III was implemented in 2016 by the regulation: BEK no. 372 from 25/04/2016 - Bekendtgørelse om kontrol med risikoen for større uheld med farlige stoffer (Order regarding control of risk of accidents related to dangerous goods).

This is the Danish implementation of the EU Seveso Directive. If a company or organisation complies with this order, it will also comply with the Seveso Directive.

Order 372 from 25/04/2016 includes 14 chapters and 9 appendixes. The following sub-chapter gives a small description of both the chapters and the appendixes.

9.2.4. Chapters in Order no. 372 from 25/04/2016

Chapter 1:
Anvendelsesområde og definitioner
(To whom do the rules apply?)
Chapter 2:
Hensigtsmæssig placering af risikovirksomhed m.v. og samarbejde med planmyndighed (Town Planning)
Chapter 3:
Generelle retningslinjer om risikovirksomheder, der er omfattet af beredskabsloven (Differences between column 2 and 3 companies)
Chapter 4:
Risikovirksomheders generelle forpligtelser
(Management systems and contingency plans (internal and external). RA, Safety)
Chapter 5:
Myndighedernes opgaver og samarbejde (the holistic process through the authorities)
Chapter 6:
Dominoeffekt
(Overall assessment including the dynamic effects by the authorities)
Chapter 7:
Eksterne beredskabsplaner
(Plans covering areas outside the plant in collaboration with the police (column 3))
Chapter 8:
Information til offentligheden og andre lande
(Updating information to all stakeholders and the public in the area (at least every 5 years)
Chapter 9:
Myndighedernes opgaver ved større uheld
(The tasks for the authorities in case of major accidents (cooperation with the police))
Chapter 10:
Tilsyn

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(DEA updates the inspection plan if new data or information appears)

Chapter 11:

Administrative bestemmelser

(The Municipal Council reporting to the DWEA by reporting to the EU)

Chapter 12: Klage

(Decisions made pursuant to this executive order may be appealed in accordance with the rules of this order).

Chapter 13: Straf

(In aggravating circumstances can lead to imprisonment for up to 2 years)

Chapter 14:

Ikrafttrædelse og overgangsbestemmelser (1 May 2016)

(Date of validation)

9.2.5. Appendixes in Order no. 372 from 25/04/2016

Appendix 1.

Farlige stoffer Hazardous substances

(This part includes hazardous substances, threshold quantity and weighting factors.)

This is a very important appendix in which you can identify which column you are categorised as, which is important to identify in relation to which regulations to comply with.

Appendix 2.

Anmeldelse efter § 8

A notification (application) with the information described in the appendix.

Appendix 3.

Sikkerhedsdokument for kolonne 2-virksomheder, jf. § 8, stk. 1, nr. 2.

Documentation for safety col. 2

Appendix 4.

Sikkerhedsrapport for kolonne 3-virksomheder, jf. § 8, stk. 1, nr. 2.

Documentation for safety col. 3

Appendix 5.

Intern beredskabsplan, og ekstern beredskabsplan,

Internal and external emergency management plans

Appendix 6.

Sårbarhedsvurdering og sikringsplan, jf. § 11.

Risk assessments, training, etc.

Appendix 7.

Virksomhedens oplysninger til myndighederne efter uheld eller nærved-uheld.

Reporting of accidents and/or near misses

Appendix 8.

Oplysninger til offentligheden, jf. § 16,

With the restrictions that follow from the Public Information Act

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Appendix 9.
Tilsyn, jf. §§ 20- 22
Plan for supervision, inspections and maintenance

9.3. ATEX

9.3.1. Introduction

While shifting towards more sustainable and low-carbon economy, new technologies and processes, such as renewable energy sources, battery storage, and hydrogen production, are being increasingly used, which can create potentially explosive atmospheres. These new technologies and processes can create risks that need to be managed and controlled.

ATEX Directive (2014/34/EU) is important for the green transition for several reasons:

- It provides a framework for ensuring that equipment and protective systems used in potentially explosive atmospheres are designed and constructed to limit the risk of explosion.
- It ensures that equipment used in potentially explosive atmospheres is safe and reliable.
- It requires that equipment and protective systems are correctly installed, maintained, and inspected.
- It ensures that detailed information and documentation, including instructions for use and maintenance, are provided with equipment and protective systems.

Complying with the ATEX directive allows equipment and protective systems used in the green transition can be designed and constructed to ensure the safety of workers and the general public and to limit the risk of explosion. This is particularly important in the context of the green transition, as the increasing use of new technologies and processes can create new risks that need to be properly managed and controlled.

Additionally, renewable energy companies, hydrogen producers and other green transition sectors have a legal and social responsibility to manage and mitigate any potential risks that could arise from the use of new technologies and processes in compliance with the ATEX directive is a part of it. Adhering to the ATEX regulations can also increase the company's reliability and the reputation and could be a differentiating factor for companies in the green transition sector.

The owner of a PtX plant would need to consider several aspects of the ATEX Directive (2014/34/EU) to ensure that the facility and its equipment comply with the directive and that workers are protected from the risk of explosion.

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1. **Explosive atmospheres**
   The owner would need to conduct an ATEX risk assessment to identify any potential explosive atmospheres within the facility. The assessment should cover the design and construction of the equipment and systems, their intended use and the specific characteristics of the explosive atmosphere in which they will be used.

2. **Zoning as a result of a risk assessment**
   The owner would need to determine the areas where explosive atmospheres may occur and classify those areas according to the likelihood and duration of the explosive atmospheres. This will help ensure appropriate measures are taken to protect workers and equipment in those areas.

3. **Equipment and protective systems**
   The owner would need to ensure that all equipment and protective systems used in potentially explosive atmospheres are appropriate for the specific explosive atmosphere in which they will be used. The equipment and systems must be designed and constructed to limit the risk of explosion and to ensure that they are safe and reliable.

4. **CE and Ex-marking**
   The owner would need to ensure that all equipment and protective systems used in potentially explosive atmospheres are CE/Ex marked and that appropriate documentation and information are provided with the equipment and systems.

5. **Maintenance and inspection**
   The owner would need to ensure that all equipment and protective systems used in potentially explosive atmospheres are properly installed, maintained, and inspected. This helps ensure that the equipment and systems remain safe and reliable over time.

9.3.2. ATEX Risk Assessment

The first step in ensuring compliance with the ATEX directive (2014/34/EU) is to identify and evaluate any potential explosive atmospheres within the facility. This is typically done through a process called an ATEX risk assessment. An ATEX risk assessment systematically evaluates the potential risks associated with using equipment and protective systems in potentially explosive atmospheres. The assessment should cover the design and construction of the equipment and systems, their intended use and the specific characteristics of the explosive atmosphere in which they will be used. This assessment is usually performed as an extensive workshop with all relevant stakeholders.

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There are several steps in conducting an ATEX risk assessment; see Figure 13.

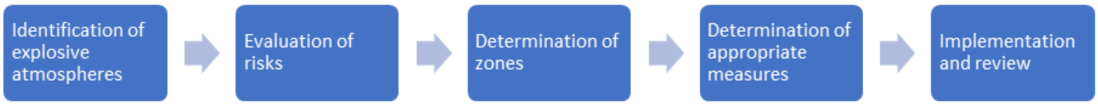

Figure 13: ATEX risk assessment process

The first step is to identify the areas within the facility where explosive atmospheres may occur. This may involve looking at factors such as the materials used in the facility, the types of processes conducted, and the likelihood and duration of explosive atmospheres. Once the areas with potential explosive atmospheres have been identified, the next step is to evaluate the risks associated with these areas. This may involve looking at factors such as the likelihood of an explosion occurring, the potential consequences of an explosion, and the possibility of workers being present in the area during an explosion.

After identifying the areas where explosive atmospheres may occur and evaluating the risks, the facility is divided into zones based on the likelihood and duration of explosive atmospheres. Zoning is a key step in the ATEX risk assessment process as it helps to identify the areas of the facility where there is the highest risk of an explosion and the areas where specific measures need to be taken to protect workers and equipment. Based on the zoning and risks identified in the evaluation, appropriate measures must be determined to manage and control the risks. These measures could include changes to the design or construction of equipment or protective systems, changes to processes, or the use of specific equipment or protective systems. The measures identified in the assessment should be implemented and review periodically to ensure they are effectively manage and control the risks.

The example above attempts to simplify and generalise the risk assessment procedure, which may differ in each case. It's important to note that ATEX risk assessment is a dynamic process and should be reviewed periodically to ensure that it reflects the current state of the facility. Any changes made to the facility, equipment, or process can affect the explosive atmosphere and the measures taken to manage the risks; thus, it's crucial to continuously monitor and review the assessment.

9.3.3. Zoning: a key step of risk assessment

Zoning must be performed as part of a P2X plant's risk assessment. The ATEX directive 1999/92/EC requires that equipment and protective systems used in potentially explosive atmospheres be appropriate for the specific explosive atmosphere in which they will be used. To determine the appropriate equipment and protective systems, the facility must first be divided into zones based on the likelihood and duration of explosive atmospheres.

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Typically, three zones are defined for presence of gases, vapours and mists, with each zone corresponding to a different level of risk. Zone 0 is where explosive atmospheres are likely to occur for long periods. Zone 1 is where explosive atmospheres are likely to occur for short periods. Zone 2 is where explosive atmospheres are not expected to occur or are only likely to occur for short periods. It's important to note that there are also similar zones for explosive dust atmospheres, denoted as Zone 20, Zone 21 and Zone 22.
The result of the ATEX risk assessment and zoning process is the identification of the areas of the facility where explosion hazards may occur and the classification of those areas according to the likelihood and duration of explosive atmospheres. This will be the basis for determining the appropriate equipment and protective systems that should be used in those areas and for providing necessary measures to protect workers and equipment.

Each zone is assigned a specific category of equipment or protective system appropriate for that zone. For example, equipment and protective systems used in Zone 0 must be in Category 1, in Zone 1 (Category 1 and 2) and in Zone 2 (Category 1, 2 and 3). This helps ensure that the risk of explosion is properly managed and controlled and that workers and equipment are properly protected.

Zoning is a key step in the ATEX risk assessment process, as it helps to identify the areas of the facility where the highest risk of an explosion and where specific measures need to be taken to protect workers and equipment.

9.3.4. Equipment and protective systems

Once the zoning process is complete and the areas within the P2X facility have been classified according to the likelihood and duration of explosive atmospheres, the next step would be to implement appropriate measures to protect workers and equipment in each zone. The measures implemented will depend on the level of risk present in each zone.

One key measure would be to ensure that all equipment and protective systems used in the facility, such as hydrogen detectors, ventilation systems, and fire suppression systems, are designed and constructed by the appropriate ATEX standards, such as IEC 60079 series or EN 60079 series and are ATEX certified. The IEC 60079 and EN 60079 series are sets of international standards for electrical equipment and systems used in potentially explosive atmospheres. These standards cover a wide range of equipment and systems, developed and maintained by the International Electrotechnical Commission (IEC) and the European Committee for Electrotechnical Standardization (CENELEC), respectively. This will ensure that the equipment and systems are safe and reliable in potentially explosive atmospheres.

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The risk assessment and the implementation of the measures should be reviewed periodically, and the equipment and protective systems should be continuously monitored to ensure that they are operating effectively and that the risks are being managed effectively.

By implementing these measures, the PtX plant owner can ensure that the facility complies with the ATEX directive and that workers and equipment are protected against explosive atmospheres. It also helps to minimise the likelihood of an explosion occurring and minimise the potential consequences of an explosion if one were to happen.

9.3.5. CE and EX marking

When marking equipment and protective systems used in a PtX plant, the plant owner must be aware of several aspects to ensure compliance with the ATEX directive. CE marking verifies that a product meets the essential requirements of the relevant EU directives. To do this, they should seek the certification of an independent organisation recognised by the EU, called a Notified Body, that can assess and certify the product for compliance with the ATEX directive.

The plant owner should ensure that all equipment and protective systems have the appropriate CE mark and the relevant technical documentation, such as testing and inspection results carried out by the Notified Body, user instructions, and maintenance instructions. The records of all equipment and protective systems that have been CE marked, including date of CE marking, model and serial numbers, and the name of the Notified Body that performed the assessment and certification, shall be kept.

The owner of a PtX plant should be aware that in addition to the CE marking, equipment used in potentially explosive atmospheres must also carry specific marking for these atmospheres. The particular marking for explosive atmospheres is the Ex-marking, also known as the ATEX marking. The Ex-marking is a symbol that indicates that the equipment has been designed, manufactured and tested by the relevant ATEX directive, and that it is suitable for use in potentially explosive atmospheres.

The Ex-marking is divided into two parts, the first part indicates the category of the equipment (i, II, or III), and the second part indicates the protection type (e, i, n, p, or m). The first part represents the level of protection the equipment provides, and the second part represents the level of protection the equipment is designed to withstand.

Additionally, it's the plant owner's responsibility to ensure that the equipment and protective systems continue to comply with the ATEX directive, even after CE marking and Ex-marking, by ensuring that no modification made to the equipment and protective systems affects its compliance with the ATEX directive and that the equipment and systems are properly maintained, inspected, and tested to ensure their ongoing compliance and safety.

9.3.6. Maintenance and inspection

Developing and implementing procedures and protocols for safely handling and storing flammable materials and using equipment and systems in potentially explosive atmospheres is necessary. Workers should be trained on these procedures and protocols to understand the risks of explosive atmospheres and how to handle and use equipment and systems in these environments properly.

The equipment and protective systems must be maintained and inspected regularly to ensure they are in proper working condition and to identify and repair any defects. The plant owner should establish a schedule for maintenance, inspection and testing of the equipment and protective systems in the facility.

Emergency procedures should be developed and implemented to minimise the risk of an explosion and the potential consequences of an explosion if one were to occur. Workers should be trained on these procedures so that they know how to respond in the event of an emergency.
[17], [18].

9.4. Power-to-X Standardisation overview

Standards are common guidelines for everything from quality and safety to product specifications and good workflows. They provide access to new markets, better competitive power, higher productivity and internationalisation to name a few examples.

Standards will play an important role in building and maintaining PtX plants, as they will create transparency about the fulfilment of safety requirements. Standards can be used as a basis for inspections made by authorities, and they can create common ground when two parties interact on the market for green fuels.

As the market for green fuels is being created, new standards for the PtX value chain must also be developed. The industry primarily writes the standards as either European or global standards, and Danish companies that wish to influence future market demands are encouraged to get involved in the ongoing development of PtX standards.

The standardisation picture of PtX is, however, complex and comprehensive. Danish Standards has therefore developed an interactive standardisation PtX-overview, that can be found here: https://www.ds.dk/da/fagomraader/energi-miljoe-og-baeredygtighed/power-to-x

[19].

How to use the overview

The guide is divided into value chain links (Figure 14).

Open the link:

https://www.ds.dk/da/fagomraader/energi-miljoe-og-baeredygtighed/power-to-x
For instance, clicking on the windmill/solar cell icon will take you to the committees currently working on standards for renewable energy.

Under each committee, you will find a description of its standardisation work area and contact information to a standardisation consultant who can inform you about relevant standards– both published standards and standards under development.

Acquiring relevant published standards and joining a committee is possible if you wish to obtain pre-knowledge about upcoming standards. Furthermore, you can become part of the working groups that write new standards and propose new standards that need to be developed.

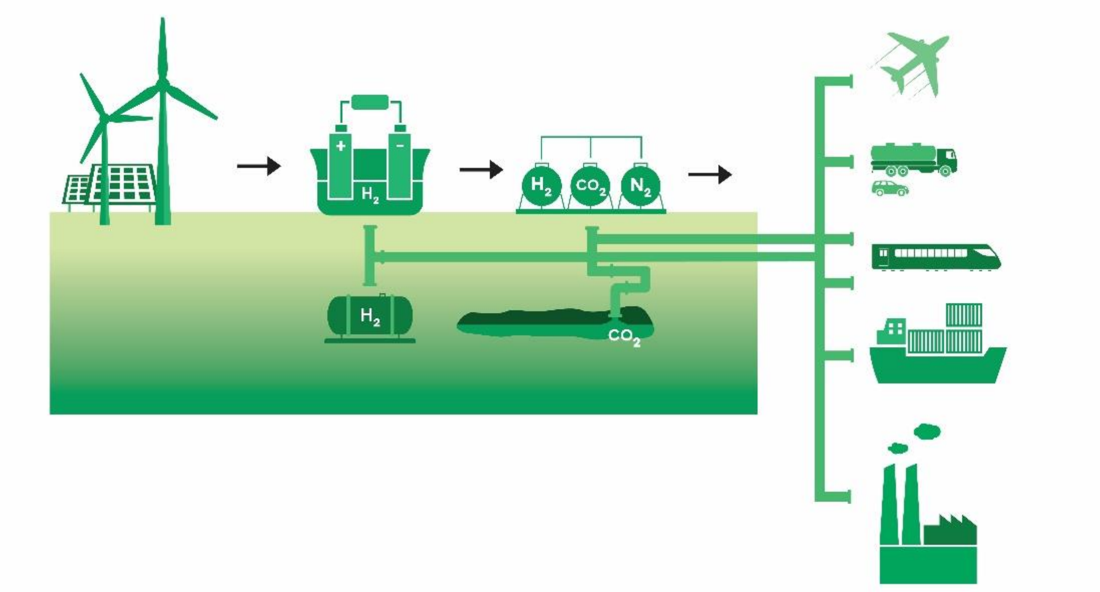

Figure 14: Overview of the existing and upcoming Standards across PtX [19]

Hydrogen standards
An overview of and access to the comprehensive international standardisation work currently being conducted within the field of hydrogen can be found in the Danish Mirror Committee S-605 *Hydrogen and Fuel Cells*. Many international safety standards have already been developed, and more are to come. Members of the Danish Mirror Committee have access to and can become members of the four international committees where international experts meet and develop hydrogen standards:

International Hydrogen Committee overview:

- IEC TC 105 Fuel Cell Technologies
- ISO TC 197 Hydrogen Technologies
- CEN CENELEC JTC 6 Hydrogen in energy
- CEN TC 268 WG 5 Specific hydrogen technologies applications

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9.5. Power-to-X related regulations

There are many regulations and standards to comply with regarding establishing a PtX plant in Denmark. It is not possible to define exactly which regulations and standards to comply with for projects in general due to very different sizes, locations, purposes, productions, etc., but in Annex A, you will find a long list of PtX-related regulations and standards, which may be helpful for an operator to review prior to planning a PtX plant.

10. Technical Safety

This chapter intends to discuss technical safety aspects of PtX and will include the background of European and Danish essential safety requirements.

10.1 Hydrogen at the core

The term "Power-to-X" seems to have originated in Germany at the beginning of the 2010s and was used to describe the conversion of electricity into molecules (Sterner and Specht, 2021). Electricity is not easy to store for later use, so the current idea behind Power-to-X is to use excess renewable electricity to make gasses and fluids, which can then be stored and transported. In Denmark, Power-to-X includes the technology that produces fuels, chemicals and materials, based on green hydrogen produced by electrolysis (Energistyrelsen). Other phrases used included green hydrogen, e-fuels and renewable fuels of non-biological origin (RFNBO).

When electrolysis is used in Power-to-X, it uses "green electricity" to split water into hydrogen and oxygen. The hydrogen can then be used to directly as an energy source, transported, and stored for later use. The use of hydrogen is not new, and hydrogen technology has been around for more than a hundred years. A new requirement is to quickly produce and use hydrogen on a much larger scale than before. Because of international trade and safety, we are also forced to create standardised definitions and requirements. The lack of these has arguable resulted in the delays we have faced for a safer and faster Power-to-X value chain.

10.2 Technical Safety and Essential Safety Requirements

Essential safety requirements are legal requirements, and they define the results to be attained, or the hazards to be dealt with, but they typically do not tell us how to achieve this. For this report, technical safety is defined as documented activities that show safe engineering practices have been followed. Technical safety will include technical risk analyses, working by recognised standards, evaluating materials and components for use in a PtX environment, and implementing measures that futureproof the technology for possible changes to its original application.

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10.3 Hydrogen Readiness

A survey of different stakeholders will likely reveal that the term "*hydrogen readiness"* will have different meanings. Hydrogen readiness, for example, could refer to the % of hydrogen blended with natural gas, specific operating pressures and temperatures, the hydrogen gas purity, the ability to measure hydrogen accurately, or the application of a label that gives the impression a product is suitable for use in hydrogen technologies. Therefore, any declaration of hydrogen readiness needs to disclose what specific application and operational conditions the readiness is intended for, and it must be supported by a technical document package to show what specific assessments have been conducted.

Besides well-known material compatibility problems, such as hydrogen embrittlement, using hydrogen in non-proven hydrogen infrastructure may impact the system due to specific properties such as gas density, net calorific value (NCV), Wobbe index and methane number. Equipment designed for use in natural gas environments will need to be re-evaluated before a hydrogen ready statement can be justified.

10.4 European Roadmap on Hydrogen Standardisation

There is political and environmental pressure for us to quickly transition from pilot PtX projects to large-scale industrial PtX projects. To make this quick transition, we will need technical and legal standardisation. To facilitate the deployment of clean hydrogen technologies by 2030, the European Commission set up the European Clean Hydrogen Alliance (ECHA). One of their first tasks was to evaluate the readiness of PtX standards. In March 2023, they published a "Roadmap on Hydrogen Standardisation", which gives an overview of the standardisation gaps, the challenges, and the forecasted needs of a developing hydrogen value chain. They reported that different hydrogen technologies have different levels of hydrogen readiness for standards, with some being at an advanced stage while others were just starting. Specific hurdles to overcome are:

- Materials and related effects
- Safety aspects of hydrogen, including explosion prevention and protection
- Interoperability within the technical system, including injection
- gas quality
- Volume about the energy content
- Gas underground storage
- Definition of hydrogen infrastructure

The Roadmap on Hydrogen Standardisation can be accessed here:
https://ec.europa.eu/docsroom/documents/53721

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10.5 Regulations and Directives for Technical Safety

A **regulation** is a statutory text imposed by a legal authority at the local, national, regional, or international level, e.g., the United Nations level. It usually states minimum safety requirements written and adopted by legislative bodies, to regulate a particular activity. Legal requirements are intended to ensure that a product, system, infrastructure, or activity will not impact human safety/health, property, or the environment.

A **directive** is binding as to the result to be achieved upon each member state to which it is addressed but gives national authorities the choice to create their own rules to achieve the results.

Establishing and operating a PtX facility will require approvals and permits from several Danish authorities and understanding the process has been challenging for many. Energistyrelsen published a generic online guide to help us find our way and at the time of writing, there are 11 steps to follow. It will be updated as more information becomes available and can be accessed here: https://veprojekter.dk/anlaeg/ptxanleag.

NOTE: Although we already have such a guide, the details of exactly how to demonstrate technical safety is still evolving. The flow of key activities to undertake are known.

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NOTE: Although we already have such a guide, the details of exactly how to demonstrate technical safety is still evolving. The flow of key activities to undertake are known.

- A risk assessment that identities risks.
- A strategy that explains how the risk will be managed
- A technical document package to show compliance with essential safety requirements

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Table 10.1 shows regulations and directives that list essential safety requirements relevant for PtX technologies.

Abbreviation	Simplified name	EU Directive	DK Regulation
PED	Pressure equipment directive	2014/68/EU	BEK nr 99
ATEX	Equipment in potentially explosive atmospheres	2024/34/EU	BEK nr 590
ATEX 153	Worker protection directive	1999/92/EC	BEK nr 478
MD	Machinery directive	2006/42/CE	BEK 428/429
EMC	Electromagnetic compatibility directive	2014/30/EU	BEK 1107
LVD	Low voltage directive	2014/35/EU	

10.6 Product Certification and Compliance

Product certification within the EU and Denmark deals with assessing whether a product meets regulatory requirements. Products are then considered certified (or compliant) when there is evidence that specific safety, health, and environmental protection requirements have been met. The usual way to do this, is by independent verification that the product has been made in accordance with harmonised technical standards.

This has been a significant hurdle because a standardised framework to authorise hydrogen products and plants has not yet been established in the EU or Denmark. For now, it is expected that existing natural gas requirements will be used as a baseline, and the responsibility will be transferred to the supplier, owner and operator to prove in some way that they comply with essential safety requirements.

Until we have established the experience and developed harmonised requirements, a detailed technical risk assessment should be considered mandatory, the aim should be to identify gaps where compliance with essential safety requirements has not been demonstrated so that additional validation and testing activities can be defined and implemented.

10.7 Compliance with Harmonised Standards

Harmonised European Standards have an “EN” in the title, meaning it is a European Norm. Working per harmonised standards during design and manufacturing proves that EU and Danish rules for technical safety have been met. This is known as a “presumption of conformity”.

Each European Directive has its list of harmonised standards, which, in most cases, also apply to Danish regulations. The “Official Journal of the European Union” (OJEU) publishes the

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harmonised standards and access to the list of standards are freely available online. There will be many standards to consider, and until we have established common PtX experience, a focussed risk analysis can be used to identify which standards need to be included in the PtX technical document package.

10.8 Compliance by Other Options

The use of harmonised standards is the easiest and most direct way to demonstrate compliance with essential safety requirements, but using harmonised standards is voluntary and, therefore, not the only method that can be used.

The European Commission's 2022 "Blue Guide" on the implementation of EU product rules tells us that the conformity of a product may also be demonstrated by other technical means, such as national standards, standards which are not harmonised, the manufacturer's specifications, other example projects or some other justifiable assessment. The manufacturer (user or purchaser in certain cases) can, therefore, apply standards and technical specifications of their own choice, but the automatic presumption of conformity is lost. Additional effort is then needed to demonstrate compliance, which makes it very relevant for PtX technologies, as other relevant technical specifications can be used, or solutions can be developed in line with general engineering and scientific knowledge. That way, compliance with essential safety requirements can then be demonstrated using alternative means.

The "Blue Guide" can be accessed here:

https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ%3AC%3A2022%3A247%3ATOC&uri=uriserv%3AOJ.C_.2022.247.01.0001.01.ENG

10.9 Technical Documentation

European and Danish legislation requires that technical documents be created to demonstrate the conformity of the product. These documents will provide information on the product's design, manufacture, operation, and traceability, where traceability also applies to the parts contained within the product. The technical documentation must support any conformity statements, whether the conformity comes from harmonised standards or any other means. Because we do not have harmonised standards for all hydrogen technologies, additional effort is recommended when compiling the technical document package, so that permitting authorities can see that the applicant understands the philosophy behind essential safety requirements. A technical document package provides information on the design, manufacture and operation of the product and will typically include the following:

- A description of the product and its intended use.
- The changes have been made when the product is re-designed or re-assessed.
- A risk analysis to identify all possible and foreseeable risks.
- The essential safety requirements for the product.

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- A list of the harmonised standards and/or other relevant technical specifications.
- Design and manufacturing drawings.
- Descriptions and explanations are necessary to understand the drawings.
- Results of design calculations, examination and testing were done.
- Test reports.
- Description and information of the quality system.

10.10 Technical Risk Analysis

The risk analysis will also be included in the technical documentation. It aims to assess all possible risks the product may pose and determine the essential requirements relevant to that hydrogen product. In other words, the risk analysis can be used as a gap analysis to determine what additional measures are needed to demonstrate compliance with essential safety requirements. It should not be limited to design and manufacture but also include the product's use, inspection, maintenance and decommissioning.

The European Hydrogen Safety Panel (EHSP) released a guide in 2021 called *"Safety Planning and Management in Hydrogen and Fuel Cell Projects"* provides information on safety planning, implementation, and reporting for hydrogen projects. It helps us to understand how compliance can be demonstrated when there are minimal harmonised standards to implement and potentially is a basis for any risk analysis that will be included in the technical document package for permitting authorities.

The document can be accessed here:

https://www.clean-hydrogen.europa.eu/media/news/webinar-safety-planning-and-management-eu-hydrogen-and-fuel-cell-projects-2022-03-30_en

10.11 The Effect of Hydrogen on Material Properties

There are two primary influences of hydrogen, namely permeation of hydrogen through the material, creating leakage, and degradation in the material's mechanical properties that is often referred to as hydrogen embrittlement or hydrogen-assisted fracture. These apply to both metals and non-metals. Both the hydrogen atom and the hydrogen molecule can damage mechanical properties. The specific way hydrogen damages mechanical properties requires several pages to explain and is therefore not included in this report. However, it can be simplified by writing that both the hydrogen molecule and the hydrogen atom can damage the material, and both interactions are considered in this report.

For the metallurgical interactions, the damage process will take time, and it will preferentially occur where there are tensile residual stresses, a chemical affinity for the hydrogen so that it can be trapped and a microstructure that will allow propagation of the hydrogen-assisted crack. The result is a failure of the material much sooner than what would normally have been expected. There is also a loss of fracture toughness and fatigue life. Another damaging

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mechanism occurs quicker and is specific for non-metallic materials when subjected to rapid decompression of hydrogen gas. During the initial high-pressure exposure, hydrogen will permeate into the non-metallic material, creating a state of equilibrium. A severe pressure gradient is created between the non-metallic material and the expanding hydrogen gas when rapid decompression occurs. The results will be extreme tensile forces acting on the non-metallic material.

10.12 Materials and Component Testing

PtX infrastructure is not new, but the large-scale industrial generation, transport and usage of hydrogen is something that we do not have widespread experience of. Standardisation of the technical (safety) rules for PtX will take a few years to complete, mainly because there are many variables to consider. Gas leakage and a weakening of the original material properties are two typical scenarios for materials and component testing.

Failures that produce gas leakage and material embrittlement can occur under different combinations of temperature, loads, fatigue cycles, gas composition and materials, and we do not have one test that can be used for every condition. The cost and schedule to test for "everything" is also not realistic, so for such an approach. As an alternative, we can do proof testing, using different worst-case conditions ... and that is what we are trying to understand ... what these worst-case conditions will be.

To help with this task, we need to identify the big risks and then test/evaluate in accordance with the risks that have been identified. In other words, a good technical risk assessment will define what materials and component testing we need to do, so that evidence of technical safety can be demonstrated.

Examples of typical test activities for PtX materials and components are:

- Visible components (fracture mechanics and fatigue) have been tested.
- Non-visible components (fracture mechanics and fatigue) have been tested.
- Corrosion and erosion testing of surfaces in contact with hydrogen gas.
- Ageing of elastomers that will be in contact with hydrogen gas.
- Testing for material stability in hydrogen gas.
- Rapid gas decompression testing.
- High-temperature testing.

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11. Green-fuels and Material Data and Characteristics

11.1. Introduction to green fuels and material characteristics

Understanding the properties of various fuels and materials is crucial in the transition to sustainable energy. This chapter explores key substances like hydrogen, ammonia, methanol, e-kerosene, e-jet fuel, carbon dioxide, oxygen, nitrogen, and potassium hydroxide, highlighting their roles in PtX technologies.

Each section discusses these substances' production methods, applications, safety considerations, and environmental impacts, providing a comprehensive overview of their potential in renewable energy solutions. Additionally, definitions related primarily to safety will be explained to ensure a clear understanding of the precautions for handling these materials. These materials are central to creating a flexible and sustainable energy system by converting surplus renewable energy into storable and transportable forms.

11.1.1. Definition

Fire Diamond: NFPA 704 identify the hazards of a material in terms of the following three principles by a numerical rating that ranges from 4 (indicating severe hazard) to 0 (indicating minimum hazard):

- Health
- Flammability
- Instability

Table 1, defines the degree of Hazards for three principles. It also defines the colloquial "Safety Square" or "Fire Diamond," as shown in Figure 15 where the red on top indicates flammability, the blue on the left indicates a health hazard, the yellow on the right indicates instability and the white contains codes for special hazards such as Oxidizer (OXY), Acid (ACID), Alkali (ALK), Corrosive (CORR), Radioactive (RA), and Use no water(W).

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Table 1: Degree of Hazards for three principles

Degree of Hazard	Health	Flammability	Instability
4	Material that, under emergency condition, can be lethal	Materials that rapidly or completely vaporize at atmospheric pressure and ambient temperature or that are readily dispersed in air and burn readily	Materials that in themselves are readily capable of detonation or explosive decomposition or explosive reaction at normal temperatures and pressures.
3	Material that, under emergency condition, can cause serious or permanent injury	Liquid and solids (including finely divided suspended solids) that can be ignited under almost all ambient temperature conditions. Materials in this degree produce hazardous atmospheres or, though unaffected by ambient temperature, are readily ignited under almost all conditions.	Materials that in themselves are capable of detonation or explosive reaction but that require a strong initiating source or must be heated under confinement before initiation
2	Material that, under emergency condition,	Materials that must be moderately heated or exposed to relatively high ambient temperature before ignition can occur. Under normal conditions, these materials would not form hazardous atmosphere with air, but under high ambient temperature or under moderate heating they could release vapor in sufficient quantities to produce hazardous atmospheres with air.	Materials that readily undergo violent chemical change at elevated temperatures and pressures
1	Material that, under emergency condition, can cause significant irritation	Materials that must be preheated before ignition can occur. Materials in this degree require considerable preheating, under all ambient temperature condition, before ignition and combustion can occur.	Materials that in themselves are normally stable but that can become unstable at elevated temperatures and pressures
0	Material that, under emergency condition, would offer no hazard beyond that of ordinary combustible materials	Materials that will not burn under typical fire conditions, including intrinsically non-combustible materials such as concrete, stone and sand.	Materials that in shelves are normally stabler, even under fire conditions

Figure 15: Fire Diamond

This shall provide a simple, readily recognized, and easily understood system of markings that provide a general idea of the hazards of a material and the severity of these hazards as they relate to emergency response.

Level of concern: A Level of Concern (LOC) is a threshold value of a hazard (such as toxicity or flammability); the LOC is usually the value above which a threat to people or property may exist.
Each toxic LOC reflects the hazard to the general public (public exposure guidelines) or adult workers (workplace exposure limits).
Public Exposure Guidelines are:

- AEGLs (Acute Exposure Guideline Levels)
- ERPGs (Emergency Response Planning Guidelines)
- PACs (Protective Action Criteria for Chemicals)

Workplace Exposure Limits for adults identified by LDLHs (Immediately Dangerous to Life and Health limits [20].

11.2. Power-to-Green Hydrogen

Hydrogen is a colourless, odourless, and tasteless gas with a chemical formula of H_2. It is the first element in the periodic table, the lightest of all gases and the most abundant element in the universe. Hydrogen forms chemical bonds with almost all other elements and is included in most of organic compounds. Together with carbon, oxygen and water, hydrogen is the most important element in living organisms.

The sun and stars consist mainly of hydrogen. The source of light in stars and sun is nuclear fusion. The fusion of four hydrogen atoms to the helium causes the stars to emit energy [21]. On earth, it is not found in free form but there is potential as an energy carrier to store and transport energy. Hydrogen is used in different industries:

- Synthetic ammonia, synthetic methanol, methane synthesis, HCl, NH_3
- In petroleum refining
- Hydrogenation of olefins, oils, fats, phenol
- In metallurgy to reduce oxides to metals
- Oxy-hydrogen blowpipe (welding) and limelight
- Autogenous welding of steel and other metals [22]
- Transport: Hydrogen can be used as fuel in combustion engines or fuel cells [23].

Hydrocarbons are the main sources to produce hydrogen on an industrial scale, however, water is an even larger source. The main methods for hydrogen production are:

- Production from coal and hydrocarbon: Most of the hydrogen for industrial uses is produced from natural gas and oil, either as a main product or as a by-product, a process involving a chemical conversion. In this method, remarkable CO_2 emits as by-product [24].
- Electrolysis: A smaller percentage is produced electrolytically or occurs as a by-product of electrochemical processes. Hydrogen can also be produced renewable through

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electrolysis, where water is split by supplying electricity and forms hydrogen and oxygen. This electricity can come from renewable energy sources such as wind turbines or solar cells.

- Thermochemical Water Cleavage
- Chemical Processes: Hydrogen from Ammonia, Methanol, and Hydrogen Sulphide catalytically or as a by-product in chemical processes.
- Biomass Processes [24].

Nowadays, energy supply and renewable energy are two remarkable topics both regarding future demands and CO_2 emission control policies. One of the challenges to providing energy from renewable resources is storage potential and mechanism. For instance, wind turbines can't produce energy when the wind is not blowing, and sometimes the wind turbines produce more energy than we can manage to consume, or solar cells can produce energy in daytime but not at night. There is no balance between energy production and energy consumption. Therefore, a substance or method is needed that can store energy to make a balance.

Moreover, we also need a fossil-free fuel that can be used in the transport sector instead of petrol and diesel; this substance could be hydrogen. Thereafter, hydrogen can be produced using surplus of electricity production and as a result the energy surplus would be stored as hydrogen gas or liquid form.

11.2.1. Hydrogen - Hazardous behaviour

The main danger of hydrogen is its very high flammability. In the literature, it is reported that high-pressure releases often ignite the release of hydrogen. The flame is very hot and nearly invisible in daylight, with low flame radiation. Delayed releases may lead to severe vapour cloud explosions. The NFPA rating for hydrogen is for health 0, flammability 4, and instability 0.

Hydrogen's small molecule size and low vapour density make it unique compared to many other fuels. It has high buoyancy and diffusivity, and as such, leaking hydrogen will rise and disperse quickly in the air. Hydrogen's ability to rise and disperse quickly can provide a safety advantage in an outside environment. However, in confined spaces, hydrogen can accumulate and reach a flammable concentration near high points. In this case, proper ventilation and the use of hydrogen detection sensors are essential to mitigate this hazard.

11.2.2. Hydrogen - Identification

Synonyms:	Protium
CAS Number:	1333-74-0
EC Number:	215-605-7
RTECS Number:	MW8900000
NFPA-704 ratings (0-4):	Health 0, Flammability 4, Instability 0

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DOT Hazard Classifications: Class 2 – Gases; Division 2.1 - Flammable gases
DOT Number: UN 1049 flammable gas; UN 1966 Flammable gas; UN 2034; UN UN2600

[25], [26]

11.2.3. Hydrogen - Important properties

Chemical formula: H_2
Molecular weight: 2.016 g/mole
Physical State: Gas
Colour: Colourless
Odour: Odourless
Taste: Tasteless
Melting Point: -259,2°C
Boiling Point: -252.8°C
Autoignition Temperature: 500°C
Explosive limits: 4% –75%
Minimum ignition Energy: 0.02mJ
Heat of combustion: 280 kJ/mol
Energy Density: 120 MJ/kg
Solubility in water: 1.62mg/L at 21°C; very low solubility in most liquids
Density of gas in STP: 0.082 kg/m3

[27], [25], [26]

11.2.4. Hydrogen - Environmental Hazards

Hydrogen has no direct environmental effects. However, several indirect effects are being discussed now, such as cooling the lower stratosphere from its oxidation product water vapour and a slight decrease of the atmospheric hydroxyl free radical concentration. Most of the hydrogen is taken up by the biosphere and degraded by biological processes.

11.2.5. Hydrogen - Human Hazards

Hydrogen is practically nontoxic. In high concentrations, this gas is a simple asphyxiant, and ultimate loss of consciousness may occur.

11.2.6. Hydrogen - Fire Hazards

Ignition: Hydrogen is a highly flammable gas that burns with an almost invisible flame and low heat radiation. Hydrogen forms explosive mixtures with air from 4 to 75% by volume.

Fire emissions: Water vapour

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Extinguishing: Jet fire is released from pressurised release by closing off the source and cooling it using water spray, dry chemicals, or carbon dioxide.

11.2.7. Hydrogen - Compatibility with other compounds

Hydrogen gives explosive mixtures with a number of substances, such as oxygen, chlorine and fluorine. It also reacts with other halogens, metal oxides, carbon and organic compounds. Reactive on metal catalysts. Hydrogen is generated by the reaction of acids with metals.

11.2.8. Hydrogen - Personal Protective Equipment/Clothing

Personnel working with liquid hydrogen who may be exposed to cryogenic vapours should wear eye and hand protection. Systems should be operated to reduce the potential for unprotected personnel contacting uninsulated piping or vessels containing cryogenic hydrogen. Any clothing splashed, sprayed, or soaked with any chemical should be removed in a safe location and replaced with a clean article. Personnel should avoid wearing nylon, silk, or wool clothing because these materials produce static electricity charges that can ignite flammable gas mixtures. Ordinary cotton, flame-retardant cotton, or Nomex clothing is preferred. Gauntlet gloves, tight clothing, or clothing that holds or traps liquid against the body should be avoided.

11.2.9. Hydrogen - First-aid measures

Eye contact: Immediately flush eyes with a large amount of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Seek medical attention if irritation occurs.

Skin contact: Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Inhalation: Move the person to fresh air and keep at rest in a position comfortable for breathing. If not breathing, breathing is irregular or respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If the person is unconscious, place them in a recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

11.2.10. Hydrogen - Storage Conditions

Hydrogen must be stored in a cool, dry, well-ventilated location. Outside or detached storage is preferred. Isolate from oxygen, halogens, and other oxidizing materials. A safe storage method for hydrogen for possible use as automotive fuel involves the use of metal hydrides

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from which the hydrogen is released at specified temperatures. Iron titanium hydride has been found to be the most satisfactory. [27]

11.2.11. Detection of hydrogen releases

Gas detection systems are essential for identifying leaks, particularly with hydrogen, to prevent explosions. These systems use sensors to trigger alarms, prompting actions such as facility shutdowns. Integration with safety systems like ventilation enhances safety, with commercial sensors forming the core of these systems.

A variety of sensors are available:

- **Catalytic Point Detection:** Utilises a catalyst (usually palladium or platinum) to trigger hydrogen combustion with oxygen, generating heat that is measured to calculate concentration.
- **Electrochemical Detection:** Gas interacts with an electrolyte through a membrane, producing a current.
- **Semiconduction Oxide:** Gas reacts with oxygen on a semiconductor surface, altering its electrical resistance.
- **Thermal Conductivity:** Measures heat transfer from a source to the environment, which depends on the gas's thermal conductivity.
- **Mass Spectrometer:** Separates gas ions by mass in an electric field to measure concentration.
- **Acoustic Detection:** Uses ultrasound to detect leaks based on noise patterns, though it cannot pinpoint location or size precisely.
- **Glow Plugs:** Ignites gas volumes for detection by other instruments.
- **Bubble Testing:** Simple but not continuous; detects leaks directly at the source with bubble solutions and it is useful when pressure/leak testing is manually building, commissioning, or repairing a system, as staff typically has to be present to observe.
  [28]

It is worth mentioning that due to their cost, some of these sensors are not practical for use in production lines.

Hydrogen detectors should be strategically placed, considering buoyancy and natural flow paths. Voting systems requiring multiple detectors to confirm a leak prevent unnecessary shutdowns due to instrument errors. Minor leaks can be very hard to detect in normal production mode, as hydrogen moves quickly upwards due to its lightweight compared to the normal atmosphere. The design normally avoids closed spaces where hydrogen accumulates, forming an explosive cloud.

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Depending on where leaks need to be detected, several types of commercial sensors should be considered, but as it is a developing market, no specific type is advised. Other important factors to consider when selecting a sensor include response time, range, accuracy, repeatability, calibration interval, calibration requirements (possible on-site), Safety Integrity Level (SIL), ATEX (Atmospheres Explosibles) certification (if required), and environmental conditions.

Because of the vital role of hydrogen sensors for risk mitigation, especially in confined spaces, fueling stations, and vehicles, several relevant standards should be noted:

- IEC 60079-29 Series: Covers performance, selection, installation, use, maintenance, and functional safety of gas detectors.
    - Part 1: Performance requirements for flammable gas detectors.
    - Part 2: Focuses on oxygen detectors and industrial/commercial installations.
    - Part 3: Guidance on functional safety for fixed gas detection systems.
    - Part 4: Performance requirements for open path detectors.
- ISO 26142:2010: Specific standard for hydrogen detectors in stationary applications. [28]

11.3. e-fuels

e-Fuels are carbon-based fuels and alternatives to fossil fuels. e-Fuels are produced with electricity from renewable energy, water, and CO_2. Hydrogen production is the key step to producing e-fuel. Hydrogen is produced by an electrolysis process by splitting water into oxygen and hydrogen, where the power of the electrolyser comes from wind power energy or solar energy. Hydrogen is combined with captured CO_2 from the air or other sources in the synthesis process to produce e-fuel such as e-gasoline, e-diesel, and e-kerosene in gas or mostly liquid state because it is easy to store and transport.

11.4. Power-to-Green Ammonia

Ammonia is a colourless and pungent-smelling gas at room temperature with a compound of nitrogen and hydrogen (NH_3). Ammonia is easily dissolved in water and is corrosive because of its alkali properties [29].

Ammonia is the second largest synthetic chemical product in the world. It is primarily used in the agriculture industry to produce fertilisers. Ammonia can also be used as a refrigerant. The other common use of ammonia is in household cleaning solutions.
Today, most ammonia is produced in the Haber-Bosch process, which uses hydrogen and nitrogen [30]. In the environment, ammonia is part of the nitrogen cycle and is produced in soil from bacterial processes. Ammonia is also produced naturally by the decomposition of organic material, including plants, animals and animal waste.

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Due to environmental concerns and attempts to reduce CO_2 emissions, ammonia has stepped up with benefits like easy storage and high energy density, making it a reasonable substitute for fossil fuel. In addition, it has three hydrogen atoms and may be used as a hydrogen carrier. However, there are some challenges associated with ammonia fuel in combustion engines regarding traditional fuels, such as:

- High ignition temperature
- Low flame velocity led to restraining temperature diffusion and causes power reduction
- Slow chemical kinetics led to ammonia emission
- NOx emissions

Many research efforts are being made to find a solution to improve combustion performance. For example, to solve the difficult ignition problem, ammonia is mixed with traditional fuels.

Considering all the challenges, when it is considered that ammonia is a carbon-free fuel and has the potential to reduce carbon emissions, it is still a worthwhile and significant alternative fuel for internal combustion engines.

11.4.1. Ammonia - Hazardous Behaviour

Ammonia is fatal to humans in large concentrations; lower levels of exposure can result in significant damage to the skin, oral cavity, and respiratory system. The main paths of ammonia exposure are through inhalation, skin and eye contact.
Ammonia has an alkaline corrosiveness and exothermic properties; when concentrated, it erodes tissue upon contact. As a gas, ammonia irritates and burns the skin, eyes, and respiratory tract. Liquified gas can cause the skin to freeze and cause permanent damage or blindness in the eyes.

Inhalation of ammonia can cause severe irritation of the nose and throat and life-threatening accumulation of fluid in the lungs (pulmonary oedema). Symptoms may include coughing, shortness of breath, difficulty breathing and tightness in the chest. Symptoms may develop hours after exposure and are made worse by physical effort.
Chronic exposure may harm the respiratory system; coincidently, long-term damage may result from severe short-term exposure.

Ammonia air mixtures are not readily ignitable, but an explosion may occur if ignited. Ammonia is considered not to sustain combustion, but flashing occurs. In the case of a fire involving ammonia, emissions of NOx and ammonia vapour with hydrogen and water must be expected. At higher temperatures, ammonia may react with carbon monoxide or methane to generate hydrogen cyanide. Ammonia is not compatible with several chemical compounds.

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11.4.2. Ammonia - Identification

Synonyms:	Anhydrous ammonia
CAS Number:	7664-41-7
EC Number:	231-635-3
RTECS Number :	BO0875000
UN number:	3318 and 1005 (Guide 125)
DOT Number:	UN 1005; UN 2073; UN guide 125
NFPA ratings (0-4):	Health 3, Flammability 1, Instability 0, CORR

[29], [31] [32], [33]

11.4.3. Ammonia - Important properties

Chemical formula:	NH_3
Molecular weight:	17.03 g/mole
Physical State:	liquid, liquid gas, gas (gas at ambient condition)
Colour:	Colourless
Odour:	Ammonia-like odour
Melting point:	-77.73°C
Boiling point:	-33.34°C
Flash point:	11°C
Autoignition temp.	651°C
Explosion limits:	15% - 28%
Minimum ignition Energy	8 mJ
Heat of combustion:	383 kJ/mol
Energy Density:	12.7 MJ/kg
Solubility in water:	444-895 g/L at 0-28°C (482 g/L at 25°C)
Gravity (at melting point):	0.817 kg/l
Vapor density:	0.59 kg/l
Vapor Pressure:	6.15-10.03 bar at 10-25°C (8.611 bar at 20°C)
IDLH:	300 ppm

ERPGs:	**ERPG-1**	**ERPG-2**	**ERPG-3**
	25 ppm	150 ppm	1500 ppm
PACs:	**PAC-1**	**PAC-2**	**PAC-3**
	30 ppm	160 ppm	1100 ppm

AEGLs:	**Exposure Period**	**AEGL-1**	**AEGL-2**	**AEGL-3**
	10 minutes	30 ppm	220 ppm	2700 ppm
	30 minutes	30 ppm	220 ppm	1600 ppm

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60 minutes	30 ppm	160 ppm	1100 ppm
4 hours	30 ppm	110 ppm	550 ppm
8 hours	30 ppm	110 ppm	390 ppm

[29], [31], [32], [33]

11.4.4. Ammonia - Environmental Hazards

Ammonia is alkaline and toxic to animals and plants, causing convulsions and interfering with carbohydrate metabolism in the latter. Potassium transport across membranes is affected in both animals and plants. Persistently high levels of discharge into the atmosphere or water bodies will adversely affect the environment, animals, and plants.

11.4.5. Ammonia - Human Hazards

The main human health hazards are concentrated solutions and vapour's extreme irritancy and corrosiveness.

Acute Health Effects:
The following acute (short-term) health effects may occur immediately or shortly after exposure to ammonia:

- Contact can severely irritate and burn the skin and eyes, with possible eye damage.
- Inhaling ammonia can irritate the nose and throat, causing coughing and wheezing.
- Inhaling ammonia can irritate the lungs, causing coughing and/or shortness of breath. Higher exposures may cause fluid build-up in the lungs, a medical emergency, and severe shortness of breath.
- Contact with liquid ammonia can cause frostbite.

Chronic Health Effects:
The following chronic (long-term) health effects can occur at some time after exposure to ammonia and can last for months or years:

- Ammonia may cause an asthma allergy. Future exposure can cause asthma attacks with shortness of breath, wheezing, coughing, and chest tightness.
- Repeated exposure may lead to permanent lung damage.
- Cancer hazards: Ammonia has not been tested for its ability to cause in animals.
- Reproductive hazard: While ammonia has been tested, it is not classified as to its potential to cause reproductive harm.

11.4.6. Ammonia - Fire Hazards

Ignition:	Hard to ignite
Fire emissions:	NOx, ammonia, hydrogen and water
Extinguishing:	Carbon dioxide; do not use water

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11.4.7. Ammonia - Combability with other compounds

Ammonia has potentially explosive or violent reactions with interhalogens, strong oxidisers, nitric acid, fluorine and nitrogen oxide. Ammonia forms sensitive explosive mixtures with air, hydrocarbons, ethanol, silver nitrate, and chlorine. Explosive products are formed by the reaction of ammonia with silver chloride, silver oxide, bromine, iodine, gold, mercury and tellurium halides.

Ammonia is incompatible or has potentially hazardous reactions with silver, acetaldehyde, acrolein, boron, halogens, perchlorate, chloric acid, chlorine monoxide, chlorites, nitrogen tetroxide, tin and sulphur.

11.4.8. Ammonia - Personal Protective Equipment/Clothing

Eye/face protection: Tightly fitting safety goggles. Face shield (8-inch minimum). Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection: Handle with ammonia-resistant gloves.

Body Protection: Complete suit protecting against chemicals. Flame retardant antistatic protective clothing. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection: Where risk assessment shows air-purifying respirators are appropriate, use a full-face respirator with multipurpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

11.4.9. Ammonia - First-aid Measures

Eye contact: Immediately flush eyes with large amounts of water for at least 30 minutes, lifting upper and lower lids. Seek medical attention immediately.

Skin contact: Immerse the affected part in warm water. Seek medical attention.

Inhalation: Move the person to fresh air. If breathing has stopped, help them by rescue breathing (using universal precautions). If heart action has stopped, help them by CPR. Monitor for respiratory distress. If coughing or breathing difficulty develops, evaluate for respiratory tract irritation, bronchitis, or pneumonitis. If trained, administer supplemental

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oxygen with assisted ventilation as required. Administer artificial respiration if the patient is not breathing.

First Aid for Ingestion: Call a physician. If conscious, give the patient milk or water to drink immediately. Do not induce vomiting.

11.4.10. Ammonia - Handling and Storage

Proper personal protective equipment must be used when working with or around ammonia. Skin protection is required for liquid, mist, and gas or vapour exposure. Neoprene or rubber gauntlet-type gloves, ammonia-resistant clothing (overalls, jacket, and boots) or vapour suit, as required.

Chemical (indirectly vented) goggles must be used when there is potential contact with liquid or mist. A full-face shield is recommended in addition to goggles for added protection. A safety shower and eyewash fountain should be provided in the ammonia handling area. Use dedicated containers - do not rinse [29].

11.4.11. Ammonia leak detection

Ammonia is easily detectable in air at a few parts per million concentrations due to its distinctive odour and alkaline reaction. Specific indicators, like Nessler's reagent (HgI in KOH), can detect ammonia at concentrations as low as 1 ppm. In industrial settings, portable and fixed ammonia detection systems are used to ensure worker safety and prevent accidents. These systems utilise a variety of sensing technologies, each operating on distinct principles:

Laser Open Path Sensors: Measure the absorption of laser light over a distance, detecting ammonia by analysing the specific absorption characteristics of NH_3 molecules.
Electrochemical Sensors: Ammonia gas interacts with an electrolyte solution in the sensor, producing a measurable electrical current proportional to the gas concentration.
Photoacoustic Infrared (IR) Sensors: Detect ammonia by measuring the absorption of infrared light at specific wavelengths, where ammonia molecules absorb IR light, causing pressure waves detectable by microphones.
Catalytic Bead Sensors: Ammonia is oxidised on a heated catalytic bead, causing a temperature change that is converted into an electrical signal proportional to the gas concentration.
Ultrasonic Sensors: Detect the ultrasonic sound produced by high-pressure gas leaks, providing an immediate indication of leaks. [29], [34]

11.5. Power-to-Green Methane

Methane is a colourless, odourless gas that occurs abundantly in nature and as a product of certain human activities. Methane is the simplest member of the paraffin series of hydrocarbons with the chemical CH_4, which is a primary component of natural gas. Methane

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is lighter than air and only slightly soluble in water. It burns readily in air, forming carbon dioxide and water vapour; the flame is pale, slightly luminous, and very hot. Methane is generally very stable, but mixtures of methane and air, with methane content between 5 and 14% by volume, are explosive.

Naturally occurring methane is found both below ground and under the seafloor and is formed by geological and biological processes. The largest methane reservoir is under the seafloor in the form of methane clathrates.

In PtX, e-methane has a main role as an energy carrier, which can be used in place of natural gas to provide long-term energy storage and meet variable loads. The natural gas infrastructure already in place can be used to transport, store, and use produced CH_4. E-methane's primary processes are electrolysis, which produces hydrogen (H_2) from water like other e-fuels, and the conversion of hydrogen and carbon dioxide (CO_2) to methane in the synthesis process.

11.5.1. Methane - Hazardous Behaviour

The main hazard is the gas's high flammability, which may lead to explosions. Liquefied methane is very cold and may cause frostbite when mishandled.

11.5.2. Methane - Identification

Synonyms:	Methane or natural gas; Methyl hydride; CH_4; Fire Damp
CAS Number:	74-82-8
EINECS:	200-812-7
RTECS Number:	PB4900000
NFPA ratings (0-4):	Health 2, Flammability 4, Instability 0
Dot no.:	UN 1971(pressurized); 1972(liquid)
DOT Hazard Classifications:	Class 2.1, Class 2.3

[35], [36]

11.5.3. Methane - Important Properties

Chemical formula:	CH_4
Molecular weight:	16.05 g/mole
Physical State:	Gas
Colour:	Colourless
Odour:	Odourless
Melting Point:	-184°C
Boiling Point:	-162°C
Flash point:	-188°C
Autoignition Temperature:	540°C

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Explosive limits (lel – uel):	5% –15%
Minimum ignition Energy:	0.33 mJ
Energy Density:	50-55.5MJ/kg
Vapor density (Relative to air):	0.55- lighter than air
Solubility in water:	3.5 mL/100mL at NTP

[35], [36], [37]

11.5.4. Methane - Environmental Hazards

Methane is recognised as a greenhouse gas.

11.5.5. Methane - Human Hazards

Methane is not toxic.

11.5.6. Methane - Fire Hazards

Ignition: Very easy to ignite at all ambient temperatures.

11.5.7. Methane - Combability with other compounds

Incompatible with strong oxidisers, e.g., chlorine and fluorine, a mixture of liquid methane and liquid oxygen is explosive.

11.5.8. Methane - Personal Protective Equipment/Clothing

Hand protection: Chemical-resistant, impervious gloves complying with an approved standard should always be worn when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check that the gloves retain their protective properties during use. It is important to note that the breakthrough time for any glove material may vary between different manufacturers. In the case of mixtures consisting of several substances, the protection time of the gloves cannot be accurately estimated.

Body protection: Personal protective equipment for the body should be selected based on the task and the risks involved and should be approved by a specialist before handling this product. When there is a risk of ignition from static electricity, wear antistatic protective clothing. For excellent protection from static discharges, clothing should include antistatic overalls, boots and gloves.

Other skin protection: Appropriate footwear and any additional skin protection measures should be selected based on the task and the risks involved and should be approved by a specialist before handling this product.

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Respiratory protection: Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use. Respirator selection must be based on known or anticipated exposure levels, the product's hazards and the safe working limits of the selected respirator.

11.5.9. Methane - First-aid Measures

Eye contact: Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.
Skin contact: Wash contaminated skin with soap and water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Inhalation: Remove the person to fresh air and keep at rest in a position comfortable for breathing. If not breathing, breathing is irregular, or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If the person is unconscious, place them in a recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

11.5.10. Methane - Handling and Storage

Protective measures: Put on appropriate personal protective equipment. Because it contains gas under pressure, avoid breathing gas. Use only with adequate ventilation. Wear an appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Do not puncture or incinerate the container. Use equipment rated for cylinder pressure. Close the valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.

Use only non-sparking tools. Avoid contact with eyes, skin and clothing. Empty containers retain product residue and can be hazardous. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment.

Conditions for safe storage, including any incompatibilities: Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool, well-ventilated area, away from incompatible materials. Eliminate all ignition sources.

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Cylinders should be stored upright, with a valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52°C. Keep the container tightly closed and sealed until ready for use.

11.6. Power-to-Green Methanol

Methanol is a colourless, water-soluble, flammable liquid with a mild alcoholic odour. It is also known as methyl alcohol or wood alcohol/spirit and has the chemical formula CH_3OH. Methanol is an important raw material for the chemical and future energy and fuel industries, such as plastics and paints [38]. Methanol can be used as fuel in internal combustion engines or as an additive to improve octane number of fuels [39].

Methanol is mostly produced by gasifying natural gas or coal. It is an important product for the PtX process as it can be produced with renewable energy. Methanol can be produced sustainably by combining hydrogen from electrolysis with captured CO2 in a catalytic process.

Methanol is promising as a future fuel as it has excellent combustion properties. Despite having an energy density of approximately half of gasoline, it has a higher octane rating than gasoline, allowing for a higher compression ratio and increased combustion efficiency [38].
Methanol can be used directly in an internal combustion engine with minor modifications or blended with gasoline to produce a high-octane and efficient fuel with lower emissions than conventional gasoline. In addition to the apparent potential of an internal combustion engine, methanol is also considered a promising marine fuel.
Due to the vast experience in handling and storing methanol, it can be integrated relatively easily into the current infrastructure for the transport sector.

11.6.1. Methanol - Hazardous Behaviour

Methanol is widely used in daily life and industrial production but is rather new to be considered as a future fuel. It is slightly toxic and a liquid at ambient conditions. It ignites readily and burns rather rapidly.

11.6.2. Methanol - Identification

Synonyms:	Methyl alcohol, wood alcohol, wood spirit
CAS Number:	67-56-1
EINECS:	2006596
RTECS Number:	PC1400000
NFPA ratings (0-4):	Health 1, Flammability 3, Instability 0
Dot no.:	UN 1230
DOT Hazard Classifications:	Class 3 - Flammable liquids; Class 6 - Toxic substances and Infectious substances, Division 6.1 - Toxic substances

[40], [41], [42]

11.6.3. Methanol - Important Properties

Chemical formula:	CH_3OH			
Molecular weight:	32.04 g/mol			
Physical State:	Clear liquid			
Colour:	Colourless			
Odour:	Alcohol-like odour- weak odour			
Melting Point:	-97.6°C			
Boiling Point:	64.6°C			
Flash point:	11°C			
Autoignition Temperature:	464°C			
Explosive limits (lel – uel):	6% –36.5%			
Minimum ignition Energy:	0.14mJ			
Heat of combustion:	726 kJ/mol			
Energy Density:	19.9 MJ/kg			
Vapor density STP:	1.1 kg/m^3			
Liquid density:	0.7915 kg/m^3			
Solubility in water:	Greater than or equal to 100 mg/mL at NTP			
Vapour Pressure:	12.3 kPa at 20°C			
IDLH:	6000 ppm			
ERPGs:		**ERPG-1**	**ERPG-2**	**ERPG-3**
		200 ppm	1000 ppm	5000 ppm
PACs:		**PAC-1**	**PAC-2**	**PAC-3**
		530 ppm	2100 ppm	5000 ppm
AEGLs:	**Exposure Period**	**AEGL-1**	**AEGL-2**	**AEGL-3**
	10 minutes	670 ppm	11000 ppm	40000 ppm
	30 minutes	670 ppm	4000 ppm	14000 ppm
	60 minutes	530 ppm	2100 ppm	7200 ppm
	4 hours	340 ppm	730 ppm	2400 ppm
	8 hours	270 ppm	520 ppm	1600 ppm

[38], [40], [40], [42]

11.6.4. Methanol - Fire Hazard

Methanol vapour/air mixtures are explosive. Violent reactions of methanol can occur with oxidising agents. Methanol is easy to ignite, burning with a blue flame or invisible.

Fire emissions: Carbon oxides and water.

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Extinguishing: For small fires, use dry chemical, carbon dioxide, water spray or alcohol-resistant foam. Water may be ineffective. For large fires, use water spray, fog, or alcohol-resistant foam. Do not use straight streams of water.

11.6.5. Methanol - Environmental Hazards

Methanol is readily degraded in the environment by photooxidation and biodegradation processes. Many genera and strains of microorganisms are capable of using methanol as a growth substrate. Methanol is readily degradable under aerobic and anaerobic conditions in a broad spectrum of environmental media, including fresh and salt water, sediments and soils, groundwater, aquifer material, and industrial wastewater. Methanol is a normal growth substrate for many soil microorganisms, which are capable of completely degrading methanol to carbon dioxide and water.

11.6.6. Methanol - Human Hazards

Methanol vapour and solutions are irritating to the skin and eyes. Prolonged or repetitive skin contact can cause dryness, cracking and dermatitis.

Methanol is well absorbed by the inhalation, oral and percutaneous routes and can cause metabolic acidosis and damage to the central nervous system, optic nerve, retina and liver.

11.6.7. Methanol - Combability with other compounds

Methanol reacts violently at room temperature with alkali metals, generating hydrogen. It gives explosive products when mixed with strong acids (e.g., nitric or perchlorate acid) or strong oxidisers.

11.6.8. Methanol - Personal Protective Equipment/Clothing

Skin: Wear appropriate protective gloves and clothing to prevent skin exposure.

Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in European Standard EN166.

Respiratory Protection: Follow the OSHA respirator regulations found in European Standard EN 149. Use European Standard EN 149-approved respirators if exposure limits are exceeded or if irritation or other symptoms are experienced.

11.6.9. Methanol - First-aid Measures

Eyes: In case of contact, immediately flush the eyes with plenty of water for at least 15 minutes.

Skin: In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes.

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Ingestion: If swallowed, there is a potential risk of aspiration. Get medical aid immediately. Do not induce vomiting unless medical personnel instruct you to. Never give anything by mouth to an unconscious person. If vomiting occurs naturally, have the person lean forward.

Inhalation: If inhaled, move the person to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen.

11.6.10. Methanol - Storage Conditions

Methanol should be stored in clean containers made from mild steel, stainless steel, high-density polyethylene or vulcanised natural rubber. Unsuitable container materials include zinc, aluminium, magnesium, magnesium alloys, lead, tin, titanium, plasticised PVC, polystyrene or polymethyl-methacrylate. Storage tanks should be constructed with an internal floating roof and an inert gas pad to minimise vapour emissions.

Methanol should be stored in well-ventilated areas away from direct sunlight and moisture. It should not be stored with oxidising materials such as perchlorates, chromium trioxide, bromine, sodium hypochlorite, chlorine or hydrogen peroxide, owing to fire and explosive dangers. Because of the flammability of methanol, storage tanks should be enclosed by a dike and protected by a foam-type (either carbon dioxide or dry chemical) fire-extinguishing system [38].

11.6.11. Methanol Leakage detection

Methanol has a faintly sweet odour that becomes noticeable only at concentrations of 2000 ppm, far above the safe exposure limit of 200 ppm. Therefore, quantitative exposure measurement is essential to protect workers' health and ensure regulatory compliance.

Methanol vapour concentration detection methods are:

Gas Detection Tubes: Colorimetric tubes provide direct readings of methanol vapour concentrations.

Portable Gas Monitors: These electronic instruments offer continuous methanol concentration readings and can trigger alarms at specified levels.

[43]

11.7. Power-to-Green Jet fuel

Jet fuel is an aviation fuel used to power aircraft with jet engines. It is a specialised form of kerosene designed to meet aviation's specific requirements, including high energy density and stability at high altitudes. There are several types of jet fuel, including Jet A, Jet A-1, Jet B, and JP-8. Jet A and Jet A-1 are the most commonly used types of jet fuel, and they have similar

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properties (Flash point temperature of both is 38°C. Jet A and Jet A-1 have a freezing point -40°C and -47°C respectively). Jet B is a less common jet fuel type with a higher flash point and lower freezing point (-60°C) than Jet A, making it suitable for cold climates. JP-8 is a military-grade jet fuel that is similar to Jet A-1 but has additional additives to enhance performance [44].

Because jet fuel consumption is very high, e-jet fuel could remarkably affect the zero CO_2 emission target. As a main jet fuel, e-kerosene can be produced in a synthesis process by combining captured CO_2 and green hydrogen. To get a specific type of e-jet fuel, e-kerosene is blended with other additives and hydrocarbons.

11.7.1. Jet Fuel - Hazardous Behaviour

Jet fuel can pose a number of hazardous behaviours if not handled and stored correctly:

- Jet fuel is highly flammable and can evaporate easily so that it can ignite and burn easily. If jet fuel is exposed to an ignition source, such as a spark or flame, it can cause a fire or explosion.
- Jet fuel contains additives, such as antistatic agents and corrosion inhibitors, which can be toxic if ingested or inhaled. Exposure to these chemicals can cause health problems, such as respiratory issues or organ damage.
- If spilled or leaked, jet fuel can negatively impact the environment. It can contaminate soil and water sources and harm wildlife and ecosystems.

11.7.2. Jet Fuel - Identification

Synonyms:	Jet A-1, Kerosene (petroleum)
CAS Number:	8008-20-6
EINECS:	Complex mixture
RTECS Number:	Complex mixture
NFPA ratings (0-4):	Health 2, Flammability 2, Instability 0
Dot no.:	UN 1863

[45], , [45]

11.7.3. Jet Fuel - Important Properties

Chemical formula:	Mixed product
Molecular weight:	Variates according to mix of product
Physical State:	Liquid
Colour:	Pale Yellow
Odour:	Petroleum/Solvent
Density:	820kg/m^3
Freezing Point:	-47°C
Boiling Point:	176-287°C

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Flash point:	60°C			
Autoignition Temperature:	246°C			
Explosive limits (lel – uel):	0.6% –4.6%			
Minimum ignition Energy:	0.22-1mJ			
Energy Density:	44-47 MJ/kg			
Solubility in water:	Negligible			
PACs:		**PAC-1**	**PAC-2**	**PAC-3**
		290 mg/m^3	1100 mg/m^3	NR
AEGLs:	**Exposure Period**	**AEGL-1**	**AEGL-2**	**AEGL-3**
	10 minutes	290 mg/m^3	1100 mg/m^3	NR
	30 minutes	290 mg/m^3	1100 mg/m^3	NR
	60 minutes	290 mg/m^3	1100 mg/m^3	NR
	4 hours	290 mg/m^3	1100 mg/m^3	NR
	8 hours	290 mg/m^3	1100 mg/m^3	NR

NR: Not Recommended due to insufficient data
[47], [46], [45]

11.7.4. Jet Fuel - Environmental Hazards

Jet fuel can have environmental hazards if it is released or spilt into the environment. Any spillage on the ground can contaminate soil and potentially groundwater, particularly if the spill is large or occurs in an area with permeable soils. Jet fuel contains various hydrocarbons, which can persist in the environment and have toxic effects on plants, animals, and microorganisms.

11.7.5. Jet Fuel - Human Hazards

Jet fuel (kerosene and additives) is toxic and irritant. Jet fuel and other hydrocarbons can affect the nervous system at high concentrations, causing headaches, dizziness, and lack of coordination. Chemicals may also cause chronic health problems, such as liver and kidney damage.

11.7.6. Jet Fuel - Fire Hazards

Vapours and air are explosive mixtures. Vapours are flammable and heavier than air. They may spread along floors, travel a considerable distance to an ignition source, and flashback to the source of ignition, potentially leading to dangerous and explosive conditions.

11.7.7. Jet Fuel - Combability with other compounds

Materials to avoid oxidising agents.

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11.7.8. Jet Fuel - Personal Protective Equipment/Clothing

Hand Protection: Any specific glove information provided is based on published literature and glove manufacturer data. Glove suitability and breakthrough time will differ depending on the specific use conditions. Contact the manufacturer for specific advice on glove selection and breakthrough times for your use conditions. Inspect and replace worn or damaged gloves. The types of gloves to be considered for this material include:
Chemical-resistant gloves are recommended. If contact with forearms is likely, wear gauntlet-style gloves.

Eye Protection: Safety glasses with side shields are recommended if contact is likely.

Skin and Body Protection: Any specific clothing information provided is based on published literature or manufacturer data. The types of clothing to be considered for this material include: Chemical/oil-resistant clothing is recommended.

Specific Hygiene Measures: Always observe good personal hygiene measures, such as washing after handling the material and before eating, drinking, and smoking. Routinely wash work clothing and protective equipment to remove contaminants. Discard contaminated clothing and footwear that cannot be cleaned. Practice good housekeeping.

11.7.9. Jet Fuel - First-aid Measures

Inhalation: Immediately remove from further exposure. Get immediate medical assistance. For those providing assistance, avoid exposure to yourself or others. Use adequate respiratory protection. Give supplemental oxygen, if available. If breathing has stopped, assist ventilation with a mechanical device.

Skin contact: Wash contact areas with soap and water. Remove contaminated clothing. Wash contaminated clothing before reuse. If a product is injected into or under the skin or into any part of the body, regardless of the appearance of the wound or its size, the individual should be evaluated immediately by a physician as a surgical emergency. Even though initial symptoms from high-pressure injection may be minimal or absent, early surgical treatment within the first few hours may significantly reduce the ultimate extent of injury.

Eye contact: Flush thoroughly with water. If irritation occurs, get medical assistance.

Ingestion: Seek immediate medical attention. Do not induce vomiting.

11.7.10. Jet Fuel - Handling and Storage

Handling: Avoid all personal contact. Do not siphon by mouth. Do not use it as a cleaning solvent or for other non-motor fuel uses. For use as a motor fuel only. It is dangerous and

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unlawful to put fuel into unapproved containers. Do not fill the container while it is in or on a vehicle. Static electricity may ignite vapours and cause fire. Place the container on the ground when filling and keep the nozzle in contact with the container. Do not use electronic devices (including but not limited to cellular phones, computers, calculators, pagers or other electronic devices, etc.) during safety-critical tasks, such as bulk fuel loading or unloading operations, or in storage areas where vapours may be present unless the devices are certified intrinsically safe by an approved national testing agency and to the safety standards required by national and/or local laws and regulations. Prevent small spills and leakage to avoid slip hazards. Material can accumulate static charges which may cause an electrical spark (ignition source). Use proper bonding and/or ground procedures. However, bonding and grounds may not eliminate the hazard from static accumulation.

Storage: The type of container used to store the material may affect static accumulation and dissipation. Keep the container closed. Handle the container with care. Open slowly to control possible pressure release. Store in a cool, well-ventilated area. Storage containers should be grounded and bonded. Fixed storage containers, transfer containers, and associated equipment should be grounded and bonded to prevent the accumulation of static charge.

11.8. Carbon Dioxide (CO_2)

Carbon dioxide is a colourless, odourless, non-flammable gas with a slightly sour taste. Its chemical formula is CO_2. CO_2 is a naturally occurring gas in the atmosphere and plays a critical role in the environment, the climate, and even the human body.

Carbon dioxide is one of the main ingredients for photosynthesis, the process by which plants produce their food from sunlight. Without carbon dioxide, plants would not be able to survive on Earth. Carbon dioxide also regulates human breathing and is a by-product of respiration. When indoor carbon dioxide levels get too high, it can be detrimental to your mental abilities and wellness.

Similarly, carbon dioxide plays a significant role in maintaining a habitable climate. Carbon dioxide traps heat in the atmosphere as a greenhouse gas, keeping our planet warm even when the sun isn't shining. However, recent outdoor carbon dioxide levels have skyrocketed due to anthropogenic CO_2 emissions.

Most carbon dioxide generated worldwide is a by-product of ammonia and hydrogen production (from natural gas). Carbon dioxide is also a component of all flue gases produced by the complete combustion of carbon-based fuels. Another source of carbon dioxide is the calcination of calcium carbonate in cement industry, carbon dioxide form fermentation, etc. [48]. CO_2 has remarkable role in global warming, and carbon capture and storage/utilisation is a proven technology suite and a vital part of reaching net-zero emissions by 2050. In PtX, CO_2 could be used as a raw material to produce carbon-based e-fuels.

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11.8.1. Carbon Dioxide - Hazardous Behaviour

CO_2 is not flammable or combustible, so many of the hazards normally associated with transporting liquified gases/gases are absent.

11.8.2. Carbon Dioxide - Identification

Synonyms:	Carbon dioxide, Carbon Anhydride
CAS Number:	124-38-9
EC No.:	204-696-9
NFPA ratings (0-4):	Health 2, Flammability 0, Instability 0, SA (simple asphyxiants)
UN/NA Number:	1013

[48], [49]

11.8.3. Carbon Dioxide - Important Properties

Chemical formula:	CO_2
Molecular weight:	44 g/mole
Physical State:	Gas
Colour:	Colourless
Odour:	Odourless
Melting Point:	-79°C
Boiling point:	-109.3°C
Triple point:	-78.51°C
Density STP:	1.98 kg/m3
Solubility in water(20°C):	1.68 g/l

[48], [49], [50], [51]

11.8.4. Carbon Dioxide - Environmental Hazards

CO_2 is a naturally occurring gas that is essential for life on Earth, but when present in high concentrations, it can also pose several environmental hazards:

1. **Climate Change:** Carbon dioxide is a potent greenhouse gas that traps heat in the Earth's atmosphere, leading to global warming and climate change. Human activities, such as burning fossil fuels for energy, deforestation, and land use changes, have significantly increased the amount of CO_2 in the atmosphere, exacerbating the impacts of climate change.
2. **Ocean Acidification:** When CO_2 dissolves in seawater, it reacts with water molecules to form carbonic acid, which lowers the pH of the ocean, making it more acidic. This process is known as ocean acidification, and it can have severe impacts on marine life, particularly on organisms with shells, such as corals and molluscs.

3. **Negative impacts on vegetation:** High levels of CO_2 can also impact vegetation, decreasing the nutritional value of crops and reducing their growth rate.
4. **Extreme weather events:** Climate change caused by CO_2 emissions can lead to extreme weather events such as droughts, heatwaves, and floods, which can have devastating effects on both human and natural systems.

Overall, while CO_2 is a natural component of the Earth's atmosphere and essential for life, human activities have significantly increased its concentrations, leading to various environmental hazards.

11.8.5. Carbon Dioxide - Human Hazards

CO_2 is commonly thought of as a threat to life through asphyxiation, which is when it displaces the oxygen in the air to dangerously low levels. For CO_2 to reduce the oxygen concentration in air down to a level that is immediately dangerous to life, the CO_2 concentration would need to be in the order of 50% v/v. Evidence shows, however, that CO_2 does create an immediate threat to life at a concentration of only 15% in air due to its toxicological impact on the body when inhaled at this concentration.

In humans, CO_2 is a standard component of blood gases at low concentrations; however, it is lethal at high exposure inhalation levels.

Table 2 presents the output of the HSE's Dangerous Toxic Load assessment for CO_2. T The table illustrates a significant danger to humans if they inhale CO_2 a at concentrations above around 7% in the air (i.e.> 70 000 ppm). It also highlights the effect of toxicity increasing rapidly for only small changes in concentration above a certain level (there is not a large difference between the SLOD and SLOT values). Differences in CO_2 concentration between different lethality levels and exposure times are relatively small; concentrations for lethality levels 1-5% and 50% for a given exposure time differ by only 33%. Although CO_2 is only mildly toxic to humans compared with hydrogen sulphide, for example, above concentrations of about 7% in air, humans are particularly sensitive to further increases [52].

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Table 2: Concentration vs time consequences for CO_2 inhalation [46]

Inhalation exposure time	SLOT*: 1-5% fatalities		SLOD**: 50% fatalities	
	CO_2 concentration in air (by vol.)		CO_2 concentration in air (by vol.)	
	%	ppm	%	ppm
60 min	6.3 %	63 000 ppm	8.4 %	84 000 ppm
30 min	6.9 %	69 000 ppm	9.2 %	92 000 ppm
20 min	7.2 %	72 000 ppm	9.6 %	96 000 ppm
10 min	7.9 %	79 000 ppm	10.5 %	105 000 ppm
5 min	8.6 %	86 000 ppm	11.5 %	115 000 ppm
1 min	10.5 %	105 000 ppm	14 %	140 000 ppm
*** Specified Level of Toxicity (SLOT) – may cause severe distress, medical attention may be required, likely to cause 1-5% fatality for highly susceptible people during a single exposure ** Significant Likelihood of Death (SLOD) – may cause 50% lethality from a single exposure**				

11.8.6. Carbon Dioxide - Fire Hazards

Not flammable.

11.8.7. Carbon Dioxide - Combability with other compounds

Incompatible Materials: Alkali metals, alkaline earth metals, metal acetylides, chromium, titanium above 550°C, uranium above 750°C, magnesium above 775°C.

11.8.8. Carbon Dioxide - Personal Protective Equipment/Clothing

Hygiene measures: Wash hands, forearms, and face thoroughly after handling chemical products, before eating, smoking, using the lavatory, and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing it. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection: Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dust. If contact is possible, the following protection should be worn unless the assessment indicates a higher degree of protection: safety glasses with side shields.

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Hand protection: Chemical-resistant, impervious gloves complying with an approved standard should always be worn when handling chemical products if a risk assessment indicates this is necessary.

Body protection: Personal protective equipment for the body should be selected based on the task and the risks involved and approved by a specialist before handling this product.

11.8.9. Carbon Dioxide - First-aid Measures

Eye contact: Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation: Remove the person to fresh air and keep them at rest in a position comfortable for breathing. If not breathing, breathing is irregular, or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If the person is unconscious, place them in a recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact: Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

11.8.10. Carbon Dioxide - Handling and Storage

In low capacity:
Protective measures: Put on appropriate personal protective equipment. Contains gas under pressure. Avoid breathing gas. Do not puncture or incinerate the container. Use equipment rated for cylinder pressure. Close the valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Avoid contact with eyes, skin and clothing. Empty containers retain product residue and can be hazardous.

Advice on general occupational hygiene: Eating, drinking, and smoking should be prohibited in areas where this material is handled, stored, and processed. Workers should wash their hands and faces before eating, drinking, and smoking. They should also remove contaminated clothing and protective equipment before entering eating areas.

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Conditions for safe storage, including any incompatibilities: Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool, and well-ventilated area, away from incompatible materials. Cylinders should be stored upright, with the valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52°C. The container must be kept tightly closed and sealed until ready for use.

11.9. Oxygen (O_2)

Oxygen is a colourless, odourless, and tasteless gas with a chemical formula of O2. It is the third most abundant element in the universe and forms approximately 21% of the Earth's atmosphere. Oxygen is essential for supporting life and involves various biochemical and physiological processes.
In nature, oxygen is primarily produced through photosynthesis by plants and algae, which convert carbon dioxide into oxygen using sunlight. Additionally, oxygen can be generated through the electrolysis of water or extracted from the atmosphere through air separation processes.

Oxygen has numerous industrial and medical applications:

Medical Use: Oxygen is used in medical settings for respiratory support, including oxygen therapy for patients with respiratory conditions or during surgeries.
Industrial Applications: Oxygen is used in various industrial processes, including metal fabrication, welding, cutting, and as an oxidiser in chemical reactions.
Environmental Remediation: Oxygen can be used in environmental remediation processes to treat contaminated soil and water, and to support aerobic bioremediation processes.

Oxygen can be produced by different methods:

Photosynthesis: In nature, oxygen is primarily produced through photosynthesis by plants and algae. During photosynthesis, plants absorb carbon dioxide and water; in the presence of sunlight, they produce oxygen and glucose. This process is essential for maintaining oxygen levels in the atmosphere and supporting life on Earth.
Water Electrolysis: Electrolysis of water is a process that involves splitting water molecules (H_2O) into oxygen (O_2) and hydrogen (H_2) gases using an electric current. This method utilises an electrolyser, which consists of electrodes submerged in water and separated by a membrane. Oxygen gas is collected at the anode, while hydrogen gas is collected at the cathode. Electrolysis can be performed using renewable energy sources such as solar or wind power, making it a sustainable method for oxygen production.
Chemical Processes: Oxygen can also be produced as a by-product of various chemical processes, including Ammonia Production, Chlorine Production, Biological Processes, etc. [53].

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11.9.1. Oxygen - Hazardous behaviour

The main hazard associated with oxygen is its ability to support combustion. Oxygen-enriched atmospheres increase the risk of fire and can accelerate the combustion of flammable materials. Oxygen can also react violently with certain substances, leading to potential explosion hazards. [54], [55]

11.9.2. Hydrogen - Identification

Synonyms:	Dioxygen
CAS Number:	7782-44-7
EC Number:	231-956-9
RTECS Number:	RS2060000
NFPA-704 ratings (0-4):	Health 3, Flammability 0, Instability 0, Special OX
DOT Hazard classification:	Class2-Gases; Division 2.2- Non-flammable gases

[55], [56]

11.9.3. Hydrogen - Important properties

Chemical formula:	O_2
Molecular weight:	32.00 g/mole
Physical State:	Gas
Colour:	Colourless
Odour:	Odourless
Taste:	Tasteless
Melting Point:	-218.79°C
Boiling Point:	-182.96°C
Density of gas (21.1°C, 1bar):	1.3088 kg/m^3

[53], [55], [54]

11.9.4. Oxygen - Environmental Hazards

Oxygen itself does not pose direct environmental hazards. However, oxygen enrichment in confined spaces can increase the risk of fire and combustion, leading to potential environmental impacts.

11.9.5. Oxygen - Human Hazards

Oxygen is not toxic at normal atmospheric concentrations. However, oxygen-enriched atmospheres can pose a fire hazard and increase the risk of combustion-related injuries. Inhalation of high oxygen concentrations can lead to respiratory irritation and toxicity.

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11.9.6. Oxygen - Fire Hazards

Oxygen supports combustion and can enhance the flammability of materials. Oxygen-enriched atmospheres increase the intensity and rate of combustion. Fire in an oxygen-enriched environment can burn more fiercely and be harder to extinguish.

11.9.7. Oxygen - Compatibility with Other Compounds

Oxygen reacts with various substances, including fuels, metals, and organic materials, to support combustion. It can react vigorously with flammable materials, leading to fire hazards and potential explosions.

11.9.8. Oxygen - Personal Protective Equipment/Clothing

Personnel working with oxygen should use appropriate personal protective equipment (PPE), including safety goggles, gloves, and protective clothing, to minimize the risk of exposure to oxygen-enriched atmospheres and potential fire hazards.

11.9.9. Oxygen - First-Aid Measures

Inhalation: In all but the most severe cases (pneumonia), recovery is rapid after reducing oxygen pressure; supportive treatment should include immediate sedation, anticonvulsive therapy if needed, and rest.
Eyes: Treat frostbite burns.
Skin: Treat frostbite, soak in lukewarm water.

11.9.10. Oxygen - Storage Conditions

Oxygen should be stored in well-ventilated areas away from flammable materials and ignition sources. Proper storage containers and handling procedures should be followed to minimize the risk of fire and combustion hazards associated with oxygen storage.

11.10. Nitrogen (N_2)

Nitrogen is a colourless, odourless, and tasteless gas with a chemical formula of N_2. It is the most abundant element in Earth’s atmosphere, constituting approximately 78% of our air. Nitrogen is crucial in various industrial, agricultural, and biological processes.
In nature, nitrogen is primarily obtained through fractional distillation of liquid air, where it is separated from oxygen and other gases. Additionally, nitrogen fixation by certain bacteria in the soil and industrial processes such as the Haber-Bosch process are significant sources of nitrogen production.

Nitrogen has numerous industrial and commercial applications:

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Industrial Use: Nitrogen is used in various industrial processes, including chemical manufacturing, food packaging, electronics manufacturing, and pharmaceutical production.
Inerting Gas: Nitrogen is utilised as an inert gas in various industrial processes to prevent the risk of combustion or explosion. For example, nitrogen is used to flush flammable gas production lines, storage tanks, and pipelines, such as those used in hydrogen production and transportation. By displacing oxygen, nitrogen creates an inert atmosphere, reducing the likelihood of fire or explosion hazards.
Food Industry: Nitrogen is commonly used in food packaging to preserve freshness and extend shelf life by displacing oxygen and moisture.
Laboratory Applications: Nitrogen is used in laboratories for inerting and blanketing and as a carrier gas in chromatography and analytical techniques.
Cryogenic Applications: Liquid nitrogen is used in cryogenic applications to cool, freeze, and preserve of biological samples, and in cryotherapy for medical treatments.
[57]

11.10.1. Nitrogen - Hazardous Behaviour

Nitrogen itself is not hazardous to human health and does not pose significant environmental risks. However, nitrogen in its liquid form (liquid nitrogen) can cause frostbite or cold burns upon contact with skin or tissue due to its extremely low temperature.

11.10.2. Nitrogen - Identification

Synonyms:	Molecular nitrogen, Dinitrogen
CAS Number:	7727-37-9
EC Number:	231-783-9
RTECS Number:	QW9700000
DOT Hazard Classifications:	Class2–Gases; Division2.2 - Non-flammable gases

[58], [59]

11.10.3. Nitrogen - Important Properties

Chemical Formula:	N_2
Molecular Weight:	28.02 g/mol
Physical State:	Gas
Colour:	Colourless
Odor:	Odourless
Taste:	Tasteless
Melting Point:	-210°C
Boiling Point:	-196°C
Solubility in Water:	poor

[57], [58], [59]

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11.10.4. Nitrogen - Environmental Hazards

Nitrogen itself does not pose direct environmental hazards. However, excessive application of nitrogen-based fertilizers in agriculture can lead to water pollution and eutrophication of water bodies, resulting in harmful algal blooms and oxygen depletion.

11.10.5. Nitrogen - Human Hazards

Nitrogen is not toxic at normal atmospheric concentrations and does not pose significant health risks to humans. However, exposure to liquid nitrogen can cause frostbite or cold burns, and appropriate safety precautions should be taken when handling or storing liquid nitrogen.

11.10.6. Nitrogen - Fire Hazards

Nitrogen is non-flammable and does not support combustion. Nitrogen-enriched atmospheres can suppress combustion and reduce the risk of fire hazards in certain applications.

11.10.7. Nitrogen - Compatibility with Other Compounds

Nitrogen is relatively inert and does not react with most substances under normal conditions. However, nitrogen can react with certain reactive metals and metal hydrides under extreme conditions, leading to potential hazards.

11.10.8. Nitrogen - Personal Protective Equipment/Clothing

When handling or working with liquid nitrogen, appropriate personal protective equipment (PPE) should be worn to protect against frostbite or cold burns. This may include insulated gloves, safety goggles, and protective clothing.

11.10.9. Nitrogen - First-Aid Measures

In the event of exposure to liquid nitrogen or cold burns, immediate first-aid measures should be taken. Affected areas should be rinsed with lukewarm water, and medical attention should be sought if symptoms persist or if the injury is severe.

11.10.10. Nitrogen - Storage Conditions

Nitrogen should be stored in well-ventilated areas away from sources of heat or ignition. Proper storage containers and handling procedures should be followed to prevent leaks and minimize the risk of exposure to liquid nitrogen.

11.11. Potassium Hydroxide (KOH)

Potassium hydroxide, commonly known as caustic potash, is an inorganic compound with the chemical formula KOH. It is a highly corrosive, white solid soluble in water, producing an alkaline solution known as potassium hydroxide or caustic potash solution.

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Potassium hydroxide is primarily produced through the electrolysis of potassium chloride (KCl) or potassium carbonate (K_2CO_3) solutions. It has numerous industrial, commercial, and laboratory applications:

Chemical Manufacturing: Potassium hydroxide is used to manufacture various chemicals, including detergents, fertilisers, pharmaceuticals, and potassium salts.

Alkaline Electrolysis: Potassium hydroxide plays a crucial role in alkaline electrolysis, a process used for the production of hydrogen gas (H_2) through the electrolysis of water. In alkaline electrolysis, a potassium hydroxide solution (30% by weight) serves as the electrolyte, facilitating the dissociation of water molecules into hydrogen and oxygen gases. The generated hydrogen gas can be collected and used as a clean and renewable energy source.

Soap and Detergent Production: It is a key ingredient in the production of liquid and solid soaps, detergents, and cleaning products due to its ability to emulsify fats and oils.

Textile Industry: Potassium hydroxide is used in textile processing to mercerise cotton fabrics and improve their strength and dye affinity.

Food Processing: It is used in food processing to produce soft drinks, cocoa, and certain food products as a pH regulator.

Biodiesel Production: Potassium hydroxide is used as a catalyst in the transesterification process for biodiesel production from vegetable oils and animal fats.

[60]

11.11.1. Potassium Hydroxide - Hazardous Behaviour

Potassium hydroxide is highly corrosive and can cause severe burns upon contact with skin, eyes, or mucous membranes. It reacts exothermically with water, releasing heat and generating an alkaline solution. Inhalation or ingestion of potassium hydroxide can cause respiratory or gastrointestinal irritation.

11.11.2. Potassium Hydroxide - Identification

Synonyms:	Caustic potash, Potash lye
CAS Number:	1310-58-3
EC Number:	215-181-3
RTECS Number:	TT2100000
NFPA-704 Ratings (0-4):	Health 3, Flammability 0, Reactivity 1
DOT Hazard Classifications:	Class 8 – Corrosive substances

[61], [62]

11.11.3. Potassium Hydroxide, Solution - Important Properties

Chemical Formula:	KOH
Molecular Weight:	56.11 g/mol
Physical State:	Solid/ Liquid (when dissolved in water)
Colour:	White/Clear or slightly yellow
Odor:	Odorless

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Melting point:	380°C/ Varies (depends on concentration)		
Boiling Point:	1320°C/ Varies (depends on concentration)		
Solubility in Water:	Soluble		
PACs:	PAC-1	PAC-2	PAC-3
	0.18 mg/m^3	2 mg/m^3	54 mg/m^3

[60], [61], [63]

11.11.4. Potassium Hydroxide - Environmental Hazards

Potassium hydroxide is highly corrosive and can cause damage to the environment if released in large quantities. It can contaminate soil, water bodies, and groundwater, leading to ecological harm and long-term environmental impacts.

11.11.5. Potassium Hydroxide - Human Hazards

Potassium hydroxide is corrosive to human tissues and can cause severe burns upon contact. Inhaling potassium hydroxide fumes or dust can irritate the respiratory tract and mucous membranes. Ingestion can cause severe gastrointestinal irritation and damage.

11.11.6. Potassium Hydroxide - Fire Hazards

Potassium hydroxide is not flammable but can react exothermically with certain metals, releasing hydrogen gas. It can react violently with acids, producing heat and potentially causing fires or explosions. Water should not be used to extinguish fires involving potassium hydroxide, as it can increase the severity of the reaction.

11.11.7. Potassium Hydroxide - Compatibility with Other Compounds

Potassium hydroxide is highly reactive and can react with various substances, including acids, metals, and organic compounds. It is incompatible with strong acids, oxidizing agents, and certain metals, such as aluminium and zinc.

11.11.8. Potassium Hydroxide - Personal Protective Equipment/Clothing

Personnel handling potassium hydroxide should wear appropriate personal protective equipment (PPE), including chemical-resistant gloves, safety goggles, and protective clothing, to minimize the risk of exposure and skin contact.

11.11.9. Potassium Hydroxide - First-Aid Measures

In the event of exposure to potassium hydroxide, immediate first-aid measures should be taken. Affected areas should be rinsed with plenty of water for at least 15 minutes, and medical attention should be sought for severe burns or injuries.

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11.11.10. Potassium Hydroxide - Storage Conditions

Potassium hydroxide should be stored in tightly sealed containers in a cool, dry, well-ventilated area away from incompatible.

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12. Bibliography

[1] "Power-to-X," Energistyrelsen. Accessed: Aug. 21, 2023. [Online]. Available: https://ens.dk/ansvarsomraader/power-x-og-groen-brint
[2] "Om Miljøstyrelsen | Miljøstyrelsen." Accessed: Aug. 21, 2023. [Online]. Available: https://mst.dk/service/om-miljoestyrelsen/
[3] "The Danish Working Environment Authority - Arbejdstilsynet." Accessed: Aug. 21, 2023. [Online]. Available: https://at.dk/en/about-us/about-the-wea/
[4] "Profile and tasks," Sikkerhedsstyrelsen. Accessed: Aug. 21, 2023. [Online]. Available: https://www.sik.dk/en/about-us/profile-and-tasks-0
[5] "Response to Accidents and Disasters," Danish Emergency Management Agency. Accessed: Aug. 21, 2023. [Online]. Available: https://www.brs.dk/en/what-we-do/response-to-accidents-and-disasters/
[6] "Få rådgivning fra PET | Rådgivning om sikkerhed | Politiets Efterretningstjeneste." Accessed: Aug. 21, 2023. [Online]. Available: https://pet.dk/raadgivning-om-sikkerhed/pets-raadgivningstilbud
[7] "Giv Plads," Andel. Accessed: Aug. 29, 2023. [Online]. Available: https://andel.dk/givplads/
[8] M. D, W. R. E, D. F, and M. P, *HIAD - Hydrogen Incident and Accident Database*. esreda, 2017. [Online]. Available: https://www.esreda.org/event/53rd-esreda-seminar/
[9] M. M. V. Karsten, A. T. Ruge, and T. Hulin, "Closing the gap: Merging engineering and anthropology in holistic fire safety assessments in the maritime and offshore industries," *Safety Science*, vol. 122, p. 104512, Feb. 2020, doi: 10.1016/j.ssci.2019.104512.
[10] "International Organization for Standardization. ISO 31000:2009." 2009.
[11] Society of Fire Protection Engineers, *Fire Risk Assessment - Engineering Guide:* 2006.
[12] "Human factors in the oil and gas industry," DNV. Accessed: Aug. 22, 2023. [Online]. Available: https://www.dnv.com/services/human-factors-1094
[13] "1910.119 - Process safety management of highly hazardous chemicals. | Occupational Safety and Health Administration." Accessed: Sep. 01, 2023. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.119
[14] "Risk Assessment Method Selection," *SFPE Guide to Fire Risk Assessment: SFPE Task Group on Fire Risk Assessment*. Springer International Publishing, Cham, pp. 27–28, 2023. [Online]. Available: https://doi.org/10.1007/978-3-031-17700-2_6
[15] "6 Types of Risk Assessment Methodologies + How to Choose." Accessed: Sep. 01, 2023. [Online]. Available: https://drata.com/blog/risk-assessment-methodologies
[16] "Plan for sikkerhed og sundhed (PSS) - Arbejdstilsynet." Accessed: Aug. 22, 2023. [Online]. Available: https://at.dk/arbejdsmiljoearbejdet/bygherrens-projekterendes-og-raadgiveres-ansvar-og-pligter/bygherrens-ansvar-og-pligter/plan-for-sikkerhed-og-sundhed-pss/
[17] "EUR-Lex - 31999L0092 - EN - EUR-Lex." Accessed: Aug. 23, 2023. [Online]. Available: https://eur-lex.europa.eu/eli/dir/1999/92/oj
[18] "EUR-Lex - 32014L0034 - EN - EUR-Lex." Accessed: Aug. 23, 2023. [Online]. Available: https://eur-lex.europa.eu/eli/dir/2014/34/oj
[19] "Standarder skaber rammen for Power-to-X." Accessed: Apr. 19, 2024. [Online]. Available: https://www.ds.dk/da/fagomraader/energi-miljoe-og-baeredygtighed/power-to-x
[20] "Levels of Concern Guide Overview." Accessed: Apr. 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/help/reference/locs_guide/overview.htm
[21] "Solar System Exploration: In Depth," Solar System Exploration: NASA Science. Accessed: Aug. 23, 2023. [Online]. Available: https://solarsystem.nasa.gov/solar-system/sun/in-depth
[22] P. Häussinger, R. Lohmüller, and A. M. Watson, "Hydrogen, 6. Uses," in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, Ed., Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2011, p. o13_o07. doi: 10.1002/14356007.o13_o07.
[23] "Alternative Fuels Data Center: Hydrogen Basics." Accessed: Aug. 23, 2023. [Online]. Available: https://afdc.energy.gov/fuels/hydrogen_basics.html

[24] P. Häussinger, R. Lohmüller, and A. M. Watson, "Hydrogen, 2. Production," in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, Ed., Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2011, p. o13_o03. doi: 10.1002/14356007.o13_o03.
[25] "HYDROGEN | CAMEO Chemicals | NOAA." Accessed: Apr. 19, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/8729
[26] "HXX.pdf." Accessed: Apr. 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chris/HXX.pdf
[27] P. Häussinger, R. Lohmüller, and A. M. Watson, "Hydrogen," in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, Ed., Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2000, p. a13_297. doi: 10.1002/14356007.a13_297.
[28] A. Kotchourko and T. Jordan, *Hydrogen Safety for Energy Applications: Engineering Design, Risk Assessment, and Codes and Standards*. San Diego: Elsevier Science & Technology, 2022.
[29] M. Appl, "Ammonia, 1. Introduction," in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, Ed., Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2011, p. a02_143.pub3. doi: 10.1002/14356007.a02_143.pub3.
[30] M. Appl, "Ammonia, 2. Production Processes," in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, Ed., Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2011, p. o02_o11. doi: 10.1002/14356007.o02_o11.
[31] "AMMONIA, ANHYDROUS | CAMEO Chemicals | NOAA." Accessed: Apr. 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/4860
[32] "AMA.pdf." Accessed: Apr. 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chris/AMA.pdf
[33] "CDC - NIOSH Pocket Guide to Chemical Hazards - Ammonia." Accessed: Apr. 18, 2024. [Online]. Available: https://www.cdc.gov/niosh/npg/npgd0028.html
[34] "Ammonia Gas Leak Detection | MSA Safety | Italy." Accessed: May 23, 2024. [Online]. Available: https://it.msasafety.com/ammonia-detection?locale=en
[35] "METHANE | CAMEO Chemicals | NOAA." Accessed: Apr. 18, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/8823
[36] "MTH.pdf." Accessed: Apr. 19, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chris/MTH.pdf
[37] Methanol Institute, "Part 1-B: Physical & Chemical Properties of Selected Fuels," Apr. 2020. [Online]. Available: https://www.methanol.org/wp-content/uploads/2020/04/Part-1-B_-Physical-Chemical-Properties-of-Selected-Fuels-.pdf
[38] J. Ott *et al.*, "Methanol," in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, Ed., Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2012, p. a16_465.pub3. doi: 10.1002/14356007.a16_465.pub3.
[39] L. Bromberg and W. K. Cheng, "Methanol as an alternative transportation fuel in the U.S.".
[40] "CDC - NIOSH Pocket Guide to Chemical Hazards - Methyl alcohol." Accessed: Apr. 18, 2024. [Online]. Available: https://www.cdc.gov/niosh/npg/npgd0397.html
[41] "MAL.pdf." Accessed: Apr. 18, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chris/MAL.pdf
[42] "METHANOL | CAMEO Chemicals | NOAA." Accessed: Apr. 18, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/3874
[43] "SafeHandlingManual-Health-Safety-Module.pdf." Accessed: May 23, 2024. [Online]. Available: https://www.methanol.org/wp-content/uploads/2017/04/SafeHandlingManual-Health-Safety-Module.pdf
[44] "Civil Aviation Fuel | Jet Fuel Specifications | Shell Global." Accessed: Aug. 23, 2023. [Online]. Available: https://www.shell.com/business-customers/aviation/aviation-fuel/civil-jet-fuel-grades.html
[45] Shell & MOH Avitation, "Avitation Fuel (JET A-1. JP-5, JP-8, AN-8) Version 1." Oct. 2021.
[46] "JPV.pdf." Accessed: Apr. 19, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chris/JPV.pdf
[47] "JET FUELS, [JP-5] | CAMEO Chemicals | NOAA." Accessed: Apr. 19, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/11699
[48] S. Topham *et al.*, "Carbon Dioxide," in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, Ed., Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2014, pp. 1–43. doi: 10.1002/14356007.a05_165.pub2.
[49] "CARBON DIOXIDE | CAMEO Chemicals | NOAA." Accessed: Apr. 18, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/330

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[50] "CDC - NIOSH Pocket Guide to Chemical Hazards - Carbon dioxide." Accessed: Apr. 18, 2024. [Online]. Available: https://www.cdc.gov/niosh/npg/npgd0103.html
[51] "CDO.pdf." Accessed: Apr. 18, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chris/CDO.pdf
[52] Dr Peter Harper, "Assessment of the major hazard potential of carbon dioxide, Health and Safety Executive," https://www.hse.gov.uk/.
[53] M. J. Kirschner *et al.*, "Oxygen," in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, Ed., Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2017, pp. 1–32. doi: 10.1002/14356007.a18_329.pub2.
[54] "OXY.pdf." Accessed: May 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chris/OXY.pdf
[55] "OXYGEN | CAMEO Chemicals | NOAA." Accessed: May 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/8967
[56] "ICSC 0138 - OXYGEN." Accessed: May 16, 2024. [Online]. Available: https://inchem.org/documents/icsc/icsc/eics0138.htm
[57] N. Böcker, M. Grahl, A. Tota, P. Häussinger, P. Leitgeb, and B. Schmücker, "Nitrogen," in *Ullmann's Encyclopedia of Industrial Chemistry*, 1st ed., Wiley-VCH, Ed., Wiley, 2013, pp. 1–27. doi: 10.1002/14356007.a17_457.pub2.
[58] "NITROGEN | CAMEO Chemicals | NOAA." Accessed: May 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/8898
[59] "ICSC 1198 - NITROGEN (COMPRESSED GAS)." Accessed: May 16, 2024. [Online]. Available: https://inchem.org/documents/icsc/icsc/eics1198.htm
[60] H. Schultz, G. Bauer, E. Schachl, F. Hagedorn, and P. Schmittinger, "Potassium Compounds," in *Ullmann's Encyclopedia of Industrial Chemistry*, 1st ed., Wiley-VCH, Ed., Wiley, 2000. doi: 10.1002/14356007.a22_039.
[61] "POTASSIUM HYDROXIDE, SOLUTION | CAMEO Chemicals | NOAA." Accessed: May 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chemical/9013
[62] "ICSC 0357 - POTASSIUM HYDROXIDE." Accessed: May 16, 2024. [Online]. Available: https://inchem.org/documents/icsc/icsc/eics0357.htm
[63] "CPS.pdf." Accessed: May 16, 2024. [Online]. Available: https://cameochemicals.noaa.gov/chris/CPS.pdf

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Annex A

PtX Related Regulations

1.1. General legislation

1. EIA Permit (approval for Environmental Impact Assessment, "Miljøvurdering" in Danish).
2. Planning Approval ("Lokalplan" in Danish).
3. Environmental Approval of Facility ("Miljøgodkendelse" in Danish).
4. Building Regulations ("Bygningsreglementet, ABR18" in Danish).
5. Aviation Regulations [HOLD].
6. Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control)
7. Directive EC 1907/2006 Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).
8. Directive 2004/35/CE on environmental liability with regard to the prevention and remedying of environmental damage.
9. Directive 2009/147/EC on the conservation of wild birds (Bird Directive).
10. Directive 89/391/EEC Introduction of measures to encourage improvements in the safety and health of workers at work (Framework Directive).
11. Directive 2006/54/EC on the implementation of the principle of equal opportunities and equal treatment of men and women in matters of employment and occupation (Equal Treatment Directive).
12. Directive 2009/104/EC concerning the minimum safety and health requirements for the use of work equipment by workers at work.
13. Directive 92/57/EEC on the implementation of minimum safety and health requirements at temporary or mobile construction sites.
14. Directive 2014/30/EC Electromagnetic Compatibility Directive.
15. Directive 2006/95 EC - Low Voltage systems.
16. The Danish Working Environment Legislation.
17. The Danish Working Environment Act.
18. The ILO convention.
19. Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work.
20. Directive 98/24/EC, on the protection of the health and safety of workers from risks related to chemical agents at work.
21. Directive 2000/54/EC, on the protection of workers from risks related to exposure to biological agents at work.
22. Directive 91/322/EEC on establishing indicative limit values.
23. Directive 1999/92/EC on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.
24. Directive 2014/34/EU - Equipment and protective systems intended for use in potentially explosive atmospheres.
25. Directive 2002/49/EC relating to the assessment and management of environmental noise.
26. Directive 2006/42/EC on machinery and amending Directive 95/16/EC (the Machinery Directive).
27. Directive 2014/33/EU on the harmonisation of the laws of the Member States relating to lifts and safety components for lifts (the Lift Directive).
28. Directive 2014/68/EU on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment (Pressure Equipment Directive).
29. Directive 2009/148/EC on the protection of workers from the risks related to exposure to asbestos at work.
30. Regulation (EU) No 517/2014 on fluorinated greenhouse gases.
31. Directive 2014/35/EU the harmonisation of the laws of member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits (Low Voltage Directive).
32. Directive 2014/30/EU on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (Electromagnetic Compatibility (EMC) Directive).
33. Directive (EU) 2019/944 on common rules for the internal market for electricity.
34. Regulation (EU) 2019/941 on risk-preparedness in the electricity sector.
35. Directive 2009/125/EC a framework for the setting of ecodesign requirements for energy-related products (Ecodesign Directive).
36. Directive 2008/98/EC on waste.
37. "Directive 2000/60/EC establishing a framework for the Community action in the field of water policy (the Water Framework Directive).
38. SEVESO Directive 2012/18/EU on control of major-accident hazards involving dangerous substances.
39. Directive 2011/92/EU; amended by 2014/52/EU on Environmental Impact Assessment.

1.2. Health safety and environmental – Executive Orders and Publications

1. Executive Order no. 866 of 11 of May 2021 on the international unit system SI
2. Executive Order No. 110 of February 5, 2013, on Duties of Project Supervisors and Consultants etc.

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3. DWEA Executive order no. 117 of February 2013 on duties of the Client.
4. Executive Order no. 2107 of 24 November 2021 on Building and Construction of the Danish Working Environment Authority as subsequently amended.
5. Executive order no. 1181 of 15 October 2010 about cooperation about health and safety with later amendments (for companies with more than 10 employees).
6. Executive order no. 1295 of 11 June 2021 on recognition of professional qualifications acquired abroad.
7. Executive order no. 372 of 25 April 2016 Bekendtgørelse om kontrol med risikoen for større uheld med farlige stoffer (Risikobekendtgørelsen).
8. Executive order no. 370 of 19 April 2016 Bekendtgørelse om kontrol med arbejdsmiljøet ved risiko for større uheld med farlige stoffer.
9. Executive order no. 253 of 4 April 2018 Bekendtgørelse om sikkerhed for gasanlæg.
10. Executive order no. 2080 of 15 November 2021 Bekendtgørelse om godkendelse af listevirksomhed (Godkendelsesbekendtgørelsen).
11. Executive order no. 1376 of 21 June 2021 Bekendtgørelse om miljøvurdering af planer og programmer og af konkrete projekter (Miljøvurderingsbekendtgørelsen).
12. Executive order no. 517 of 24 March 2021 Bekendtgørelse om vurdering af virkning på miljøet (VVM) af projekter vedrørende erhvervshavne og Københavns Havn samt om administration af internationale naturbeskyttelsesområder og beskyttelse af visse arter for så vidt angår anlæg og udvidelse af havne.
13. Executive order no. 1283 of 26 August 2020 Bekendtgørelse om sikring af havnefaciliteter.
14. Executive order no. 1282 of 26 August 2020 Bekendtgørelse om sikring af havne.
15. DWEA Builders responsibility in large construction projects AT 25.3.
16. DWEA on pressure testing of pressure vessels, pipelines and transportable pressure vessels B.4.2.
17. DWEA on artificial lighting A.1.5-1.
18. DWEA on workrooms on fixed areas A.1.11.
19. DWEA Working on gas filled pipelines BEK nr. 163.
20. DWEA Guidance on workplace layout and equipment A.1.15.
21. DWEA collaboration on working environment on temporary worksites in construction F.3.4.
22. DWEA Executive order on work planning nr. 1234.
23. DWEA Prevention of accidents from site transportation F.0.7-1.
24. DWEA on welding and metal cutting AT D.2.16.
25. DWEA working with flammable liquids C.0.6-1.
26. DWEA working with chemicals and hazardous materials AT nr. 1793.
27. DWEA machines and installations AT B.1.3.
28. DWEA Asbestos C.2.2-2.
29. DWEA executive order on manual handling nr 1164.
30. DWEA Noise D.6.1-5.
31. DWEA Fall from heights at construction sites AT 2.4.1.
32. DWEA Lifting equipment installation 2.3.0.1.
33. DWEA Usage of lifting equipment 2.02.11-1.
34. DWEA Maintenance and inspection of lifting equipment 2.3.0.2-1.
35. DWEA Proof loading lifting equipment 2.3.0.3.
36. DWEA Use of PPE nr. 1706.
37. DWEA Ionizing radiation D.7.3-1.
38. DWEA Usage of pressure carrying equipment nr. 100.
39. DWEA working in explosive atmospheres N3. 478.
40. DWEA hand-arm vibrations D.6.2-3.
41. DWEA whole body vibration D.6.7.
42. DWEA Executive order on protection from vibration when working nr. 682.

1.3. General Design, Procurement and Operation – Executive Orders and Publications

1. Executive order no. 99 of 31 January 2007 Bekendtgørelse om indretning, ombygning og reparation af trykbærende udstyr.
2. Executive order no. 190 of 19 February 2015 Bekendtgørelse om indretning m.v. af trykbærende udstyr.
3. Executive order no. 590 of 26 June 2003 Bekendtgørelse om klassifikation af eksplosionsfarlige områder.
4. Executive order no. 478 of 10 June 2003 Bekendtgørelse om arbejde i forbindelse med eksplosiv atmosfære.
5. Executive order no. 1305 of 23 November 2015 Bekendtgørelse om indretning m.v. af materiel og sikringssystemer til anvendelse i en potentielt eksplosiv atmosfære (ATEX - non-electrical equipment).
6. Executive order no. 289 of 17 March 2016 Bekendtgørelse om elektrisk materiel og elektriske sikringssystemer til anvendelse i en potentielt eksplosiv atmosfære (ATEX).
7. Executive order no. 1444 of 15 December 2010 Bekendtgørelse om tekniske forskrifter for gasser.

8. Executive order no. 1399 of 12 December 2019 Bekendtgørelse om bygningsreglement 2018 (BR18 - Bygningsreglementet).
9. Executive order no. 1082 of 12 July 2016 Bekendtgørelse om sikkerhed for udførelse og drift af elektriske installationer.
10. Executive order no. 612 of 25 June 2008 Bekendtgørelse om indretning af tekniske hjælpemidler.
11. Executive order no. 239 of 23 March 2018 Bekendtgørelse om sikkerhed for gasmateriel.
12. Executive order no. 1094 of 01 June 2021 Bekendtgørelse om indretning m.v. af maskiner (Maskindirektivet).
13. Executive order no. 1093 of 01 June 2021 Bekendtgørelse om elektrisk materiel bestemt til anvendelse inden for visse spændingsgrænser.
14. Executive order no. 100 of 31 January 2007 Bekendtgørelse om anvendelse af trykbærende udstyr.
15. Executive order no. 163 of 30 April 1980 Bekendtgørelse om arbejde på gasfyldte ledninger.
16. Executive order no. 1109 of 15 December 1992 Bekendtgørelse om anvendelse af tekniske hjælpemidler.
17. Executive order no. 1793 of 18 December 2015 Bekendtgørelse om arbejde med stoffer og materialer (kemiske agenser).
18. Executive order no. 1112 of 18 August 2016 Bekendtgørelse om sikkerhed for udførelse af ikke-elektrisk arbejde i nærheden af elektriske anlæg.
19. Executive order no. 1608 of 20 December 2017 Bekendtgørelse om sikkerhed for drift af elektriske anlæg.

1.4. Harmonised Standards

The following standards harmonised with the EU Productive Directives shall be applicable for the work.

1. EN 764-7: Pressure equipment - Part 7: Safety systems for unfired pressure equipment.
2. EN ISO 4126: Series Safety devices for protection against excessive pressure – Parts 1-5.
3. EN 13445: Series Unfired Pressure Vessels - Parts 1-8.
4. EN 13458: Series Cryogenic vessels - Static vacuum insulated vessels.
5. EN ISO 21009-2: Cryogenic vessels — Static vacuum insulated vessels — Part 2: Operational requirements.
6. EN ISO 21013-3: Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 3: Sizing and capacity determination.
7. EN ISO 21028-2: Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 2: Temperatures between -80 degrees C and -20 degrees C.
8. EN 14197: Series Cryogenic vessels - Static non-vacuum insulated vessels - Parts 1-3.
9. EN 12952-14: Water-tube boilers and auxiliary installations - Part 14: Requirements for flue gas DENOX-systems using liquified pressurized ammonia and ammonia water solution.
10. EN 13648: Series Cryogenic vessels - Safety devices for protection against excessive pressure - Parts 1-2.
11. EN ISO 12100:2010 Safety of machinery - General principles for design - Risk assessment and risk reduction (ISO 12100:2010).
12. EN ISO 13849-1: Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design (ISO 13849-1:2015).
13. EN ISO 13849-2: Safety of machinery - Safety-related parts of control systems - Part 2: Validation (ISO 13849-2).
14. EN 60204-1: Safety of machinery - Electrical equipment of machines - Part 1: General requirements.
15. EN IEC 60204-11: Safety of machinery - Electrical equipment of machines - Part 11: Requirements for equipment for voltages above 1 000 V AC or 1 500 V DC and not exceeding 36 kV.
16. EN 60204-32: Safety of machinery - Electrical equipment of machines - Part 32: Requirements for hoisting machines.
17. EN 62061: Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control systems.
18. EN ISO 20607: Safety of machinery - Instruction handbook - General drafting principles (ISO 20607).
19. EN 1127-1: Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology.
20. EN 1839: Determination of the explosion limits and the limiting oxygen concentration (LOC) for flammable gases and vapours.
21. EN 13160-1: Leak detection systems - Part 1: General principles.
22. EN 60079: Serie Explosive atmospheres.
23. EN 14522: Determination of the auto ignition temperature of gases and vapours.
24. EN 14756: Determination of the limiting oxygen concentration (LOC) for flammable gases and vapours.
25. EN 14797: Explosion venting devices.
26. EN 14994: Gas explosion venting protective systems.
27. EN 15089: Explosion isolation systems.
28. EN 15198: Methodology for the risk assessment of non-electrical equipment and components for intended use in potentially explosive atmospheres.
29. EN 15233: Methodology for functional safety assessment of protective systems for potentially explosive atmospheres.
30. EN 15794: Determination of explosion points of flammable liquids.
31. EN 15967: Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours.
32. EN ISO 80079-36: Explosive atmospheres - Part 36: Non-electrical equipment for explosive atmospheres - Basic method and requirements (ISO 80079-36:2016).
33. EN ISO 80079-37: Explosive atmospheres - Part 37: Non-electrical equipment for explosive atmospheres - Non-electrical type of protection constructional safety ''c'', control of ignition sources ''b'', liquid immersion ''k'' (ISO 80079-37:2016).

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34. EN 50104: Electrical apparatus for the detection and measurement of oxygen - Performance requirements and test methods.
35. EN 50495: Safety devices required for the safe functioning of equipment with respect to explosion risks.

1.5. Other Standards

1. EN 61508: Series Functional safety of electrical/electronic/programmable electronic safety-related systems.
2. EN 61511: Series Functional safety – safety instrumented systems for the process industry sector
3. DS/EN ISO/IEC 27001: Information technology – Security techniques – Information security management systems.
4. EN 62433: Series Security for industrial automation and control systems.
5. DNVGL-RP-G108: Cyber security in oil and gas industry based on IEC 62443.
6. ISO/TR 15916: Basic considerations for the safety of hydrogen systems.
7. ISO/WD 19884: Gaseous hydrogen — Cylinders and tubes for stationary storage (this is an ongoing activity).
8. ISO 22734:2019 Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications.
9. ISO 26142: Hydrogen detection apparatus — Stationary applications.
10. DS/HD 60364: Series Electrical installation (low voltage) - Mandatory by legislation.
11. EN 60079-14: Electrical Installations Design, Selection and Erection.
12. EN 60079-10-1: Classification of Areas - Explosive Gas Atmospheres.
13. EN 60079-20-1: Material Characteristics for Gas and Vapour Classification - Test Methods and Data.
14. EN 60079-13: Equipment Protection by Pressurized Room "P" and Artificially Ventilated Room "V".
15. TS 60079-46: Equipment assemblies (ATEX).

1.6. Mechanical Discipline - General

1. ISO 4126-1: Safety devices for protection against excessive pressure. Safety valves.
2. ISO 12100-1: Safety of machinery. Basic concepts, general principles for design. Basic terminology, methodology.
3. ISO 13849: Safety of machinery. Safety-related parts of control systems. General principles for design.
4. ISO 13857: Safety of machinery. Safety distances to prevent hazard zones being reached by upper and lower limbs.
5. ISO 13850: Safety of machinery. Emergency stop function. Principles for design.
6. ISO 22734: Hydrogen generators using water electrolysis.
7. EN 953: Safety of machinery. Guards. General requirements for the design and construction of fixed and movable guards.
8. EN 982: Safety of machinery. Safety requirements for fluid power systems and their components. Hydraulics.
9. EN 1088: Safety of machinery Interlocking devices associated with guards. Principles for design and selection.
10. EN 1090: Execution of steel structures and aluminium structures.
11. EN ISO 14122: Safety of machinery.
12. EN 14181: Stationary source emissions. Quality assurance of automated measuring systems.
13. ISO 20560: Safety information for the content of piping systems and tanks.

1.7. Welding

1. ISO 5817: Welding. Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded). Quality levels for imperfections.
2. ISO 6520-1: Welding and allied processes. Classification of geometric imperfections in metallic materials. Fusion welding.
3. ISO 9606: Qualification testing of welders. Fusion welding.
4. ISO 9712: Non-destructive testing. Qualification and certification of NDT personnel.
5. ISO 14732: Welding personnel. Qualification testing of welding operators and weld setters for mechanised and automatic welding of metallic materials.
6. ISO 15607: Specification and qualification of welding procedures for metallic materials. General rules.
7. ISO 15609: Specification and qualification of welding procedures for metallic materials. Welding procedure specification.
8. ISO 15613: Specification and qualification of welding procedures for metallic materials. Qualification based on pre-production welding test.
9. ISO 15614: Specification and qualification of welding procedures for metallic materials. Welding procedure test.
10. ISO 17635: Non-destructive testing of welds – General rules for metallic materials.
11. ISO 17636: Non-destructive testing of welds – Radiographic testing.
12. ISO 17640: Non-destructive testing of welds – Ultrasonic testing.
13. EN 1011: Welding. Recommendations for welding of metallic materials.
14. EN 1090-1: Requirements for the conformity assessment for structural components.
15. EN 1090-2: Technical requirements for the execution of steel structures.
16. EN 1090-3: Technical requirements for the execution of aluminium structures.
17. DWEA guide D.7.3-1.

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1.8. Pressure systems

1. The Pressure Equipment Directive (PED).
2. [The Pressure System Safety Regulations (PSSR)].
3. all requirements from the Danish Working Environment Authority, including but not limited to the requirements on pressure vessels.
    a. Executive order on European directives on pressure vessels nr. 564.
    b. Determination of pressure class B.4.9-2.
    c. Pressure testing B.4.2.
    d. Periodic inspection B.4.10.
4. EN 12952: Water tube boilers.
5. EN 12953: Shell boilers.
6. EN 13445: Unfired pressure vessels.
7. EN 13480: Metal Industrial piping.
8. ASME-Boiler and Pressure Vessel Code, section VIII (Pressure Vessels).
9. ASME B31.3: Process piping.

1.9. Pipework, ductwork, and accessories

1. EN 1092: Flanges and their joints – Circular flanges for pipes, valves, fittings and accessories, PN designated.
2. EN 1759: Flanges and their joints – Circular flanges for pipes, valves, fittings and accessories, Class designated.
3. EN 12954: Cathodic protection of buried or immersed metallic structures. General principles and application for pipelines.
4. EN 13480: Metal Industrial Piping.
5. ISO/TR 15608: Welding. Guidelines for metallic materials grouping system.
6. EN 15001: Gas infrastructure. Gas installation pipework with an operating pressure greater than 0.5 bar for industrial installations and greater than 5 bar for industrial and non-industrial installations.
    a. Part I: Detailed functional requirements for design, materials, construction, inspection and testing; and
    b. Part II: Detailed functional requirements for commissioning, operation and maintenance.
7. ASME Boiler and Pressure Vessel Code section V article 10 Leak testing.
8. NORSOK L-400 rev. 3 section 12 leak testing.
9. ASME B16.5 Pipe flanges and fittings.
10. ASME B16.9 Factory made wrought steel butt welding fittings.
11. ASME B16.36 Orifice flanges.
12. ASTM A153 Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.
13. ASTM A182 Standard Specification for Forged or Rolled Alloy and Stainless-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High- Temperature Service.
14. ASTM B633 Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel.
15. ASTM G48-03 Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution.
16. ASME B31.1 Power Piping.
17. ASME B31.3 Process Piping.
18. ASME B31.4 Pipeline Transportation Systems for Liquids and Slurries.
19. ISO 28522 Ships and marine technology — Hydraulic oil systems — Guidance for assembly and flushing.
20. API 614 / ISO 10438: Lubrication, Shaft Sealing and Oil Control Systems & Auxiliaries.
21. API 670: Machinery Protection Systems.
22. API 671 / ISO 10441: Special Purpose Couplings for The Petroleum, Chemical and Gas Industries Service.

1.10. Vessels and tanks

1. EN 14015: Specification for the design and manufacture of Site built, vertical, cylindrical, flat-bottomed, above ground, welded, steel tanks for the storage of liquids at ambient temperature and above.
2. EN 1992-3: Eurocode 2 – Design of Concrete Structures –. Part 3: Liquid retaining and containment structures.

1.11. Valves

1. EN 1349: Industrial process control valves.
2. EN 60534: Industrial process control valves.

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1.12. Pumps

1. EN 809: Pumps and pump units for liquids, Common safety requirements.
2. EN 12162: Liquid pumps, safety requirements, procedure for hydrostatic testing.
3. ISO 9905: Technical specifications for centrifugal pumps — Class I.
4. ISO 5199: Technical specifications for centrifugal pumps — Class II.
5. ISO 9908: Technical specifications for centrifugal pumps — Class III.
6. ISO 9906: Rotodynamic pumps Hydraulic performance acceptance tests — Grades 1, 2 and 3.
7. ANSI / HI 14.6: Rotodynamic Pumps for Hydraulic Performance Acceptance Tests.
8. API 610 / ISO 13709: Centrifugal Pumps for Petroleum Petrochemical and Natural Gas Industries.
9. API 674: Positive Displacement Pumps – Reciprocating.
10. API 675: Positive Displacement Pumps – Controlled Volume.
11. API 676: Positive Displacement Pumps – Rotary.
12. API 682 / ISO 21049: Pumps – Shaft Sealing Systems for Centrifugal and Rotary Pumps.
13. API 685: Sealless Centrifugal Pumps for Petroleum, Petrochemical and Gas Industry Process Service.

1.13. Compressors

1. EN 1012-1: Compressors and vacuum pumps. Safety requirements. Air compressors.
2. API 617: Axial and Centrifugal Compressors and Expander Compressors.
3. API 618: Reciprocating Compressors for The Petroleum, Chemical and Gas Industries Service.
4. API 619: Rotary-type Positive Displacement Compressors for Petroleum, Petrochemical and Natural Gas Industries.

1.14. Fans

1. ISO/AWI 12759-1: General Requirements.
2. ISO 12759-2: Standard Losses for Drive Components.
3. ISO 12759-3: Fans Without Drives at Maximum Speed.
4. ISO 12759-4: Driven Fans at Maximum Operating Speed.
5. ISO 12759-6: Fan Efficiency Ratio.
6. ISO 14694: Industrial fans - Specification for balance quality and vibration level[1].
7. ISO 10816-3: Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts - Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15,000 r/min when measured in situ.
8. ISO 21940-11: Mechanical vibration - Rotor balancing - Part 11: Procedures and tolerances for rotors with rigid behaviour.
9. ISO 21940-12: Mechanical vibration - Rotor balancing - Part 12: Procedures and tolerances for rotors with flexible behaviour.
10. ISO 21940-14: Mechanical vibration - Rotor balancing - Part 14: Procedures for assessing balance errors.
11. ISO 58017: Performance testing using standard airways.
12. [1] This standard is limited to fans with a power of less than 300 kW or to commercially available standard electric motor with a maximum power of 355 kW (following an R20 series). For fans of greater power than this, the applicable limits are those given in ISO 10816-3.

1.15. Heat exchangers

1. Tubular Exchanger Manufacturers Association (TEMA); or
2. Heat Exchange Institute (HEI).

1.16. Thermal and acoustic insulation systems

1. DS 452: Thermal insulation of technical service and supply systems.
2. ISO 9229: Thermal insulation – Vocabulary.

1.17. Lifting equipment

1. EN 13157: Cranes. Safety. Hand powered cranes.
2. EN 14492-2: Cranes. Power driven winches and hoists. Power driven hoists.
3. EN 13001: Crane General design.
4. EN 1677-5: Components for slings. Safety - Forged steel lifting hooks with latch. Grade 4.
5. Directive 2014/33/EU on the harmonisation of the laws of the Member States relating to lifts and safety components for lifts (the Lift Directive).

1.18. Coating systems

1. ISO 12944: Paints and Varnishes. Corrosion protection of steel structures by protective paint systems.

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2. ISO 14713: Zinc coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures.
3. ISO 20560: Safety information for the content of piping systems and tanks.
4. Danish Working Environment Authority nr. 518 appendix 8.

1.19. Steam turbine

1. ISO 20816-1: Mechanical vibration - Measurement and evaluation of machine vibration – Part 1: General guidelines.
2. ISO 10816-3: Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts - Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15,000 r/min when measured in situ.
3. ISO 7919-3: Mechanical vibration -- Evaluation of machine vibration by measurements on rotating shafts -- Part 3: Coupled industrial machines.
4. ISO 21940-11: Mechanical vibration - Rotor balancing - Part 11: Procedures and tolerances for rotors with rigid behaviour.
5. ISO 21940-12: Mechanical vibration - Rotor balancing - Part 12: Procedures and tolerances for rotors with flexible behaviour.
6. ISO 21940-14: Mechanical vibration - Rotor balancing - Part 14: Procedures for assessing balance errors.
7. ANSI/API Standard 612/ ISO 10437: Petroleum, petrochemical and natural gas industries—Steam turbines—Special purpose applications (only applies to steam turbine rotor residual imbalance limits).
8. EN/IEC 60045-1: Guide to steam turbine procurement.
9. EN 61064: Acceptance tests for steam turbine speed control systems.
10. ASME TDP-1: Prevention of Water Damage to Steam Turbines Used for Electric Power Generation: Fossil-Fuel Plants.
11. AGMA-6011: Specification for High Speed Helical Gear Units.
12. EN 61063: Acoustics. Measurement of airborne noise emitted by steam turbines and driven machinery.
13. NFPA 850: Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations.

1.20. Generator

1. EN 60470: High-voltage alternating current contactors and contactor-based motor starters.
2. EN 60865-1: Short circuit currents, Calculation of effects – Part 1: Definitions and calculation methods.
3. EN 60909: Short-circuit currents in three-phase AC systems.
4. IEC 60034: Rotating electrical machines, all parts.
5. ANSI C37 -13: Generator circuit breakers.
6. NFPA 110: Standard for Emergency and Standby Power Systems.

1.21. Water-cooled condenser

1. The following standards published by the Heat Exchanger Institute (HEI):

   a. Standards for Steam Surface Condensers;
   b. Performance Standards for Liquid Ring Vacuum Pumps and Compressors; and
   c. Standards for Steam Jet Vacuum Systems.
2. VGB-R 130-Me: VGB guideline acceptance test measurements and operation monitoring of water-cooled surface condensers.

1.22. Condensate and feedwater system

1. HEI Standards and typical specifications for tray type deaerators.

1.23. Water supply systems

1. EN 806: Specifications for installations inside buildings conveying water for human consumption.
2. EN 13076: Devices to prevent pollution by backflow of potable water. Unrestricted air gap. Family A. Type A.
3. ANSI Z-358.1: International Standard for Emergency Eyewash and Shower Equipment.
4. DS 432: Norm for water drainage.
5. DS 439: Norm for water supply installations.
6. DS/EN 806: norm for drinking water installations in buildings.

1.24. Effluent treatment

1. EN 858: Separator systems for light liquids (e.g. oil and petrol).

1.25. Demineralised water production system

1. VGB-S-010-T-00: Feed Water, Boiler Water and Steam Quality for Power Plants/ Industrial Plants.
2. IAPWS TGD3-10: Volatile treatments for the steam-water circuits of fossil and combined cycle/ HRSG power plants.

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3. IAPWS TGD4-11: Phosphate and NaOH treatments for the steam-water circuits of drum boilers of fossil and combined cycle/ HRSG power plants.

1.26. Compressed air supply

1. ISO 8573-1: Compressed air. Contaminants and purity classes.

1.27. Auxiliary fuel supply

1. EN 12285-2: Specification for workshop fabricated steel tanks. Horizontal cylindrical single skin and double skin tanks for the above ground storage of flammable and non-flammable water polluting liquids.
2. GPP2: Guidance for Pollution Prevention. Above ground oil storage tanks.

1.28. Ammonia production and storage

1. ASME Section VIII Div. 1/2 Section II, V, IX or European equivalent.
2. TEMA Class R or European equivalent.
3. ASME B31.1/3 or European equivalent.
4. API 610 or European equivalent.
5. API 617 or European equivalent.
6. API 682 or European equivalent.
7. API 614 or European equivalent.
8. API 672 or European equivalent.
9. API 670 or European equivalent.
10. API 520/521 or European equivalent.
11. API 620: Design and construction of large, welded, low-pressure storage tanks.
12. API 625: Tank systems for refrigerated liquified gas storage.
13. ACI 376: Concreate structures for the containment of refrigerated liquefied gases.
14. API 521 or European equivalent.

1.29. Electrolyser and hydrogen storage

1. ISO/TR 15916: Basic considerations for the safety of hydrogen systems (under revision).
2. ISO 14687: Hydrogen fuel quality — Product specification.
3. ISO/TR 15916: Basic considerations for the safety of hydrogen systems.
4. ISO/TS 19883: Safety of pressure swing adsorption systems for hydrogen separation and purification.
5. ISO 26142: Hydrogen detection apparatus — Stationary applications.
6. ISO 22734: Hydrogen generators using water electrolysis – Industrial, commercial and residential applications.
7. ISO 19880 Gaseous Hydrogen – Fuelling stations.
8. ISO 15649 Petroleum and natural gas industries — Piping.
9. ISO 13707 Petroleum and natural gas industries – Reciprocating compressors.
10. EN 12583: Gas Infrastructure - Compressor stations - Functional requirements.
11. EN 12732:+A1: Gas infrastructure - Welding steel pipework - Functional requirements.
12. EN 17649: Gas infrastructure - Safety Management System (SMS) and Pipeline Integrity Management System (PIMS) - Functional requirements.
13. EN 1594: Gas infrastructure - Pipelines for maximum operating pressure over 16 bar - Functional requirements.
14. ASME Section VIII Div 1 or European equivalent.
15. API 618 or European equivalent.
16. API 619 or European equivalent.
17. API 521 or European equivalent.

1.30. Nitrogen generation

1. ASME Section VIII Div 1 or European equivalent.
2. ISO 21011 or European equivalent.
3. API 610 or European equivalent.
4. API 682 or European equivalent.
5. API 614 or European equivalent.
6. API 672 or European equivalent.
7. API 521 or European equivalent.

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1.31. Electrical - General

1. EN 1838: Lighting Applications. Emergency Lighting.
2. ISO 8528: Reciprocating internal combustion engine driven alternating current generating sets.
3. EN 12464: Lighting of workplaces.
4. EN 13601: Copper and copper alloys. Copper rod, bar, and wire for general electrical use.
5. EN 50160: Voltage characteristics of electricity supplied by public electricity networks.
6. EN 50172: Emergency escape lighting systems.
7. EN 60079: Explosive atmospheres.
8. EN 60445: Basic and safety principles for man-machine interface, marking and identification. Identification of equipment, terminals, conductor terminations and conductors.
9. EN 60529: Degrees of protection provided by enclosures (IP Code).
10. EN 60909: Short-circuit currents in three-phase AC systems.
11. EN 61000: Electromagnetic compatibility (EMC).
12. EN 61082: Preparation of documents used in electrotechnology.
13. EN 61660: Short circuit currents in DC auxiliary systems in power plants and substations.
14. EN 61936: Power installations exceeding 1 kV AC. Common rules.
15. EN 62337: Commissioning of electrical, instrumentation and control systems in the process industry. Specific phases and milestones.
16. IEC 60071: Insulation coordination.
17. IEC 60038: IEC standard voltages.
18. IEC 60204: Safety of Machinery. Electrical equipment of machines.
19. IEC 60617: Graphical symbols for diagrams.
20. IEC 61111: Electrical insulating matting.
21. The Energinet Demand Connection Code (DCC) - Grid Code.
22. The Danish Heavy Current Regulation part 2 (Stærkstrømbkendtgørelsen afsnit 2).
23. "BEK nr 1114 af 18.08.2016 - "Bekendtgørelse om Sikkerhed for udførelse af Elektriske anlæg".

1.32. Earthing, lightning protection and equipotential boding

1. EN 50310: Application of equipotential bonding and earthing in buildings with information technology equipment.
2. EN 50522: Earthing of power installations exceeding 1 kV AC.
3. EN 62305-1, 2, 3 & 4: Protection against lightning.
4. IEC 60050-195: International Electro-Technical Vocabulary: Earthing and protection against electric shock.
5. IEC 62561: Lightning protection components.
6. IEC 61000-5-2: Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines. Section 2: earthing and cabling.
7. IEC/TS 60479: Guide to effects of current on human beings and livestock.
8. IEC/TS 61201: Use of conventional touch voltage limits - Application guide.
9. ENA Technical Specification 41/24 - Guidelines for The Design, Installation, Testing and Maintenance of Main Earthing Systems in Substations.
10. Engineering Recommendation S34 - A Guide for Assessing the Rise of Earth Potential at Substation Sites.
11. Engineering Recommendation S36 – Identification and recording of 'hot' sites – joint procedure for Electricity Industry and Communications Network Providers.
12. IEEE 80: Safety in AC Substation Grounding.
13. IEEE 81: Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System.
14. IEEE 81.2: Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems.
15. IEC 60364: Electrical Installations in Buildings.
    1. EN 13601: Copper and copper alloys — Copper rod, bar and wire for general electrical purposes.
    2. EN 10025: Hot rolled products of structural steels.
    3. EN 60228: Conductors of Insulated Cables.
    4. EN 50363: Insulating, sheathing, and covering materials for low-voltage energy cables.
    5. IEC 60502: Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um=1.2 kV) up to 30 kV (Um=36 kV).
    6. EN 13636: Cathodic protection of buried metallic tanks and related piping.
    7. IEC 60364-5-54: Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors.
    8. IEC 61936-1: Power installations exceeding 1 kV AC and 1.5 kV DC - Part 1: AC.
    9. IEEE 575: Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV.
    10. CIGRE 283: Special bonding of high voltage power cables.

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1.33. Cables and wiring

1. EN 50525: Electric cables. Low voltage energy cables of rated voltages up to and including 450/750 V (U0/U) - General requirements.
2. EN 50085: Cable trunking systems and cable ducting systems for electrical installations.
3. EN 50288-7: Multi-element metallic cables used in analogue and digital communication and control. Sectional specification for instrumentation and control cables.
4. EN 61537: Cable management. Cable tray systems and cable ladder systems.
5. PAS 5308: Control and instrumentation cables. Specification for polyethylene insulated cables.
6. IEC 50377 Connector sets and interconnect components to be used in optical fibre communication systems.
7. IEC 50378: Passive components to be used in optical fibre communication systems.
8. IEC 60060: High Voltage Test Techniques - Part I: General Definitions and Test Requirements.
9. IEC 60183: Guide to the selection of high-voltage cables.
10. IEC 60189: Low-frequency cables and wires with PVC insulation and PVC sheath.
11. IEC 60228: Conductors of insulated cables.
12. IEC 60229: Test on extruded over-sheath with a special protective function.
13. IEC 60230: Impulse Tests on Cables and their Accessories.
14. IEC 60287: Electric cables – Calculation of the current rating.
15. IEC 60331: Tests for electric cables under fire conditions.
16. IEC 60332: Tests on electric and optical fibre cables under fire conditions.
17. IEC 60332-3: Tests on electric and optical fibre cables under fire conditions.
18. IEC 60364: Low Voltage Electrical Installations.
19. IEC 60502: Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1.2 kV) up to 30 kV (Um = 36 kV).
20. IEC 60754-1: Test on gases evolved during combustion of materials from cables. IEC 60793-1 Optical fibres - Part 1-1: Measurement methods and test procedures - General and guidance.
21. IEC 60794: Optical fibre cables.
22. IEC 60794-2: Optical Fibre colour coding.
23. IEC 60811: Electric and optical fibre cables - Test methods for non-metallic materials.
24. IEC 60885: Electrical test methods for electric cables.
25. IEC 60949: Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects.
26. IEC 60986: Short-circuit temperature limits of electric cables with rated voltages from 6 kV (Um = 7.2 kV) up to 30 kV (Um = 36 kV).
27. IEC 61034: Measurement of smoke density of cables burning under defined conditions.
28. IEC 61442: Electric Cables - Test Methods for accessories for Power Cable with rated voltages from 6 kV (Um= 7.2 kV) up to 30 kV (Um= 36 kV).
29. IEC 61914: Cable cleats for electrical installations.
30. IEC 62444: Cable glands for electrical installations.
31. IEC TR 62691: Guidelines to the installation of optical fibre cables.
32. IEEE Std 575: Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV.
33. BEAMA: Best Practice Guide to Cable Ladder and Cable Tray Systems Channel Support Systems and other Associated Supports.
34. ITU-T Optical Fibre Recommendations and testing - G650 and G652. VOIP Recommendations – G711 and G729.

1.34. Variable speed drives

1. EN 50178: Electronic equipment for use in power installations.
2. EN 55011: Limits and Methods of measurement of radio disturbance characteristics of industrial, scientific, and medical (ISM) radio-frequency equipment (EMC).
3. EN 60051-1: Direct acting indicating analogue electrical measuring instruments and their accessories. Definitions and general requirements common to all parts.
4. IEC 60068-2: Environmental testing of electronic equipment.
5. EN 60146-1-1: Semiconductor converters. General requirements and line commutated converters. Specification of basic requirements.
6. EN 60269-1:+A2: Low-voltage fuses. General requirements.
7. EN 60801-2, IEC 60801-2: Electromagnetic compatibility for industrial-process measurement and control equipment. Electrostatic discharge requirements.
8. EN 60947-1:+A2: Low-voltage switchgear and control gear. General rules.
9. EN 61000-6-2: Electromagnetic compatibility (EMC). Generic standards - Immunity standard for industrial environments.
10. EN 61000-4-4: Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrical fast transient/burst immunity test.
11. EN 61000-6-4+A1: Electromagnetic compatibility (EMC). Generic standards. Emission standard for industrial environments.
12. EN 61439-2: Low-voltage switchgear and control gear assemblies. Power switchgear and control gear assemblies.

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13. EN 61800-3: Adjustable speed electrical power Drive systems. EMC requirements and specific test methods.
14. EN 61800-5-1: Adjustable speed electrical power drive systems. Safety requirements. Electrical, thermal and energy.

1.35. Motors

1. EN 60034-1 to 9 & 12: Rotating electrical machines.
2. EN 60085: Electrical insulation – thermal evaluation and designation.
3. IEC 60072: Dimensions and output ratings for rotating electrical machines.

1.36. Power metering

1. EN 61869 (all parts): Instrument transformers.
2. EN 62053: Electricity metering equipment (AC) requirements.

1.37. Switchgear

All switchgear shall comply with the following specifically applicable standards:

1. EN 60255: Measuring relays and protection equipment.
2. EN 62053: Electricity metering equipment (AC). Requirements.
3. IEC 61850: Communication networks and systems in substations.

All HV switchgear shall comply with the following specifically applicable standards:

4. EN 60137: Insulated bushings for alternating voltages above 1 kV.
5. EN 60282-1: High-voltage fuses. Current limiting fuses.
6. EN 60644: Specifications for high voltage fuse links for motor circuit application.
7. EN 61936: Power installations exceeding 1 kV AC - Common rules.
8. EN 62271 – All parts: High voltage switchgear and controlgear.
9. IEC 60060: High-voltage test techniques.
10. IEC 60270: High-voltage test techniques – Partial discharge measurements
11. IEC 60273: Characteristic of indoor and outdoor post insulators for systems with nominal voltages greater than 1000 V.
12. EN 60865-1: Short-circuit currents - Calculation of effects - Part 1: Definitions and calculation methods.
13. EN 60529: Degrees of protection provided by enclosures (IP Code).
14. EN 61000: Electromagnetic compatibility (EMC).

All LV switchgear shall comply with the following specifically applicable standards:

15. EN 60664: Insulation coordination for equipment within low voltage systems.
16. EN 60947: Low-voltage switchgear and controlgear.
17. EN 61439: Low-voltage switchgear and controlgear assemblies.
18. IEC/TR 61641: Enclosed low-voltage switchgear and controlgear assemblies. Guide for testing under conditions of arcing due to internal fault.
19. IEC 60376: Specification of technical grade sulphur hexafluoride (SF6) and complementary gases to be used in its mixtures for use in electrical equipment
20. IEC 60099-4: Metal-Oxide surge arresters without gaps for a. c. system.
21. IEC 60099-5: Surge Arresters: Selection and application recommendations.
22. IEC 60358: Coupling capacitors and capacitor dividers.
23. IEC 60269: Low voltage fuses.
24. IEC 60059: IEC standard current rating.
25. IEC 61869: Instrument Transformers.
26. IEC 60898: Air-break circuit breakers for a.c. circuits.
27. IEC 61008: Residual Current Circuit Breaker.
28. IEC 61439: Low-voltage switchgear and control gear assemblies.

1.38. Instrument Transformers

All Instrument Transformers shall comply with the following specifically applicable standards:

1. EN 61869-1-5: Instrument Transformers.

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1.39. Transformers/reactors

1. EN 50180: Bushings above 1 kV up to 52 kV and from 250 A to 3,15 kA for liquid filled transformers.
2. EN 50216: Power transformers and reactor fittings.
3. EN 60214-1: Tap Changers. Part 1. Performance requirements and test methods.
4. EN 61558: Isolating transformers and safety isolating transformers.
5. EN 61869 (all parts): Instrument transformers.
6. EN 60076: Power transformers- All parts.
7. IEC 60137: Bushings for alternating voltages above 1,000 V.
8. IEC 60270: High-voltage test techniques – Partial discharge measurements.
9. IEC 60296: Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear.
10. IEC 60422: Mineral insulating oil in electrical equipment – Supervision and maintenance guide.
11. IEC 60567: Oil-filled electrical equipment – Sampling of gases and analysis of free and dissolved gases – Guidance.
12. IEC 60599: Mineral oil-impregnated electrical equipment in service – Guide to the interpretation of dissolved and free gases analysis.
13. IEC/TR 60616: Terminal and tapping markings for power transformers.
14. IEC/TS 60815-3: Selection and dimensioning of high-voltage insulators intended for use in polluted conditions.
15. IEC 61869: Instrument transformers- All parts.
16. ENATS 41-36: Distribution switchgear for service up to 38 kV (cable and overhead conductor connected).
17. DS-EN 50110-1: Operation of electrical installations – Part 1: General requirements including the Danish Executive order no. 1113 Operation of plant.
18. DS-EN 61936-1: Power installations exceeding 1 kV a.c. – Part 1: Common rules including the Danish Executive order no. 1114 Construction of plant.
19. European Union directive 2013/35/EU: Electromagnetic fields including the Danish Executive order no. 472 Bekendtgørelse om eksponering for elektromagnetiske felter i forbindelse med arbejdet.
20. European Union Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection.
21. IEC 62262: Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code).
22. IEC 60502-1,2,4: Power cables with extruded insulation and their accessories.
23. IEC 60616: Terminal and tapping markings for power transformers.
24. IEC 60475: Method of sampling insulating liquids.
25. IEC 61181: Mineral oil-filled electrical equipment.
26. IEC 60071- all parts: Insulation co-ordination.
27. IEC 60529: Degrees of protection provided by enclosures.

1.40. Emergency generator

1. ISO 3046: Reciprocating internal combustion engines.
2. PPG2: Pollution Prevention Guideline above ground oil storage tanks.
3. IEC 60034: series Rotating electrical machines.
4. ISO 9000: Series of standards.

1.41. Uninterruptible power supply

1. EN 60146: Semiconductor converters - General requirements and line commutated converters.
2. EN 60622: Secondary cells and batteries containing alkaline or other non-acid electrolytes - Sealed nickel-cadmium prismatic rechargeable single cells.
3. EN 60623: Secondary cells and batteries containing alkaline or other non-acid electrolytes. Vented nickel-cadmium prismatic rechargeable single cells.
4. EN 60896: Stationary lead-acid batteries.
5. EN 62040: Uninterruptible power systems (UPS).
6. EN 62259: Secondary cells and batteries containing alkaline or other non-acid electrolytes – Nickel-cadmium prismatic secondary single cells with partial gas recombination.
7. EN 62485: Safety requirements for secondary batteries and battery installations.
8. IEEE Std. 485: Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.
9. IEEE Std. 1115: Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications.
10. IEC 60622: Secondary cells and batteries containing alkaline or other non-acid electrolytes - Sealed nickel-cadmium prismatic rechargeable single cells.
11. IEC 60359: Electrical and electronic measurement equipment. Expression of performance.
12. IEC 60146-1-1: Semiconductor converters — General requirements and line commutated Converters.
13. IEC 50272: Safety requirements for secondary batteries and battery installations.

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14. IEC 60529: Degrees of protection provided by enclosures (IP code).
15. IEC 60255: Measuring relays and protection equipment.
16. IEC 50272: Safety requirements for secondary batteries and battery installations.
17. NFPA 110: Standard for Emergency and Standby Power Systems.

1.42. 400 kV and 150 kV GIS Switchgear

1. IEC 62271-1: Common specifications for alternating current switchgear and control gear.
2. IEC 62271-100: High-voltage switchgear and control gear -Alternating-current circuit-breakers.
3. IEC 62271-102: Alternating current disconnectors and earthing switches.
4. IEC 62271-104: Alternating current switches for rated voltages higher than 52 kV.
5. IEC 62271-110: High-voltage switchgear and control gear– Inductive Load Switching.
6. IEC 62271-203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV.
7. IEC 62271-207: High-voltage switchgear and control gear - Part 207: Seismic qualification for gas-insulated switchgear assemblies for rated voltages above 52 kV.
8. IEC 62271-209: Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV - Fluid-filled and extruded insulation cables - Fluid-filled and dry-type cable-terminations.
9. IEC62271-211: Direct Connection Between Power Transformer and Gas enclosed Metal enclosed switchgear for rated voltage above 52 kV
10. IEC 62271-302: Alternating current circuit-breakers with intentionally non-simultaneous pole operation.
11. IEC62271-303: High Voltage Switchgear and Control gear use and handling of SF6 in High voltage Switchgear and Control gear.
12. IEC60618: Inductive voltage dividers.
13. IEC 60137: Insulated bushings for alternating voltages above 1000 V.
14. IEC 62155: Hollow pressurized and unpressurized ceramic and glass insulators for use in electrical equipment rated voltages more than 1000 V.
15. IEC 60099-4: Metal - Oxide surge arresters without gaps for a.c. systems.
16. IEC 60099-5: Surge arresters - Part 5: Selection and application recommendations.
17. IEC 60059: IEC Standard Current Rating.
18. IEC 61869-1: Instrument transformers – Part 1: General requirements.
19. IEC 61869-2: Instrument transformers - Part 2: Additional requirements for current transformers.
20. IEC 61869-3: Instrument transformers - Part 3: Additional requirements for inductive voltage transformers.
21. IEC 60376: Specification of technical grade Sulphur hexafluoride (SF6) and complementary gases to be used in its mixtures for use in electrical equipment.
22. IEC 60480: Specifications for the re-use of Sulphur hexafluoride (SF6) and its mixtures in electrical equipment.
23. IEC 60270: High-voltage test techniques - Partial discharge measurements.
24. IEC 60060: High-voltage test techniques - ALL PARTS.

1.43. HV and EHV transformers

1. IEC 60076 Parts 1 to 5,8: Power Transformers.
2. IEC 60076-7: Loading guide for oil immersed power transformers.
3. IEC 60076-10: Determination of transformer and reactor sound levels.
4. IEC 60076-18: Measurement of Frequency Response.
5. IEC 60076-19: Rules for the determination of uncertainties in the measurement of the losses on power transformers and reactors.
6. IEC 60076-20: Energy efficiency.
7. IEC 60076-21: Standard requirements, terminology, and test code for step-voltage regulators.
8. IEC 60076-22: Power transformer and reactor fittings - Protective devices.
9. IEC 61936-1: Power installations exceeding 1 kV AC and 1,5 kV DC - Part 1: AC.
10. IEC 60616: Terminal and tapping markings for power transformers.
11. IEC 60214-1: Tap-changers - Part 2: Application guidelines.
12. IEC 60214-2: Tap-changers - Part 1: Performance requirements and test methods.
13. IEC 60137: Insulated bushings for alternating voltages above 1000 V.
14. IEC 60296: Fluids for electrotechnical applications – Mineral insulating oils for electrical equipment.
15. IEC 60422: Mineral insulating oils in electrical equipment - Supervision and maintenance guidance.
16. IEC 60567: Oil filled electrical equipment- Sampling of gases and analysis of free and dissolved gases- Guidance.
17. IEC 60475: Method of sampling electrical liquids.
18. IEC 60599: Mineral oil-filled electrical equipment in service - Guidance on the interpretation of dissolved and free gases analysis.
19. IEC 61181: Mineral oil filled electrical equipment – Application of dissolved gas analysis to factory tests on electrical equipment.
20. IEC 62535: Insulating liquids - Test method for detection of potentially corrosive sulphur in used and unused insulating oil.

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21. IEC 60071: Insulation co-ordination.
22. IEC 60529: Degrees of protection provided by enclosures (IP Code).

1.44. HV reactors

1. IEC 60076: Parts 1 to 5,8 Power Transformers.
2. IEC 60076-6: Power transformers - Part 6: Reactors.
3. IEC 60076-10: Determination of transformer and reactor sound levels.
4. IEC 60076-18: Measurement of Frequency Response.
5. IEC 60076-19: Rules for the determination of uncertainties in the measurement of the losses on power transformers and reactors.
6. IEC 60076-20: Energy efficiency.
7. IEC 60076-21: Standard requirements, terminology, and test code for step-voltage regulators.
8. IEC 60076-22: Power transformer and reactor fittings - Protective devices.
9. IEC 61936-1: Power installations exceeding 1 kV AC and 1,5 kV DC - Part 1: AC.
10. IEC 60616: Terminal and tapping markings for power transformers.
11. IEC 60137: Insulated bushings for alternating voltages above 1000 V.
12. IEC 60296: Fluids for electrotechnical applications – Mineral insulating oils for electrical equipment.
13. IEC 60422: Mineral insulating oils in electrical equipment - Supervision and maintenance guidance.
14. IEC 60567: Oil filled electrical equipment- Sampling of gases and analysis of free and dissolved gases- Guidance.
15. IEC 60475: Method of sampling electrical liquids.
16. IEC 60599: Mineral oil-filled electrical equipment in service - Guidance on the interpretation of dissolved and free gases analysis.
17. IEC 61181: Mineral oil filled electrical equipment – Application of dissolved gas analysis to factory tests on electrical equipment.
18. IEC 62535: Insulating liquids - Test method for detection of potentially corrosive sulphur in used and unused insulating oil.
19. IEC 60071: Insulation co-ordination.
20. IEC 60529: Degrees of protection provided by enclosures (IP Code).

1.45. Protection System

1. IEC 61850: Communication Networks and Systems in Substations.
2. IEC 61869-1: Instrument Transformers - General requirements.
3. IEC 61869-2: Current Transformers.
4. IEC 61869-3: Inductive Voltage transformers.
5. IEC 60282: High-Voltage Fuses.
6. IEC 60269: Low-Voltage Fuses.
7. IEC 60529: Degrees of Protection Provided by Enclosures.
8. IEC 60255: Measuring Relays and Protection Equipment.
9. IEC 60270: Partial Discharge Measurements.
10. IEC 62271-1: High-voltage switchgear and control gear.
11. IEC 62243: Artificial Intelligence Exchange and Service Tie to All Test Environments (AI-ESTATE).
12. IEC 62271-3: High-voltage switchgear and control gear - Part 3: Digital interfaces based on IEC 61850.
13. IEC 61000-4-1: Electromagnetic compatibility (EMC) - Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test.
14. IEC 61000-6-4: Electromagnetic compatibility (EMC). Generic standards. Emission standard for industrial environments.
15. IEC 61000-6-2: Electromagnetic compatibility (EMC). Generic standards. Immunity for industrial environments.
16. IEC 60068: Environmental Testing.
17. IEC 55022: Information technology equipment. Radio disturbance characteristics. Limits and methods of measurement.
18. IEC 61010-1: Safety requirements for electrical equipment for measurement, control, and laboratory use. General requirements.
19. EC 60664-1: Insulation coordination for equipment within low-voltage systems. Principles, requirements and tests.

1.46. STATCOM System

1. IEC 60417: Graphical symbols for use on equipment.
2. IEC 60050: International Electrotechnical Vocabulary.
3. IEC 60056: High Voltage Breakers.
4. IEC 60060: series High voltage test techniques.
5. IEC 60060-2: High Voltage Test Techniques – Part 2: Measuring Systems.
6. IEC 60068-2-33: Guidance on change of temperature tests.
7. IEC 60071: Insulation Coordination.
8. IEC 60071: Insulation Coordination All parts.
9. IEC 60099: Surge Arresters.

10. IEC 60129: Disconnectors and Earthing Switches.
11. IEC 60137: Bushings.
12. IEC 60146: Semiconductor converters.
13. IEC 60160: Standard atmospheric conditions for test purposes.
14. IEC 60073: Colours of indicating lights, push buttons, Annunciators and Digital readouts.
15. IEC 61000: EMC compliance, Electrical stress, Ripple in dc auxiliary voltages, Vibration and shock, Electrical disturbance.
16. IEC 60255: Electrical Protection Relays.
17. IEC 60265-1: High Voltage Switches above 1 kV and below 52 kV.
18. IEC 60269 (Parts 1-4): Low voltage fuses.
19. IEC 60273: Characteristics of indoor and outdoor post insulators for systems with nominal voltages greater than 1000 V.
20. IEC 60282 (Parts 1-3): High voltage fuses.
21. IEC 60076: Reactors.
22. IEC 60296: Insulating Oil for Transformers and Switchgear.
23. IEC 60298: Specification for AC metal-enclosed switchgear and control gear for rated voltages above 1 kV and up to 52 kV.
24. IEC 60358: Coupling capacitors and capacitor dividers equipment.
25. IEC 60376: Specification and acceptance of new SF6.
26. IEC 60383-1&2: Tests on insulators of ceramic material or glass for overhead lines with a nominal voltage greater than 1000 V.
27. IEC 60437: Radio interference test on high voltage insulators.
28. IEC 60439: Low-voltage switchgear and control gear assemblies.
29. IEC 60502: Power cables with extruded insulation and their accessories for rated voltages 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV).
30. IEC 60518: Dimensional standardisation of terminals for high voltage switchgear and control gear.
31. IEC 60521: Electricity Meters.
32. IEC 60529: Degrees of protection provided by enclosures.
33. IEC 60549: Enclosures for electrical Apparatus.
34. IEC 60551: HV Fuses for the Prot. Of Shunt Power Capacitors.
35. IEC 60623: Audible sound.
36. IEC 60654: Secondary cells and batteries containing alkaline or other non-acid electrolytes - Vented nickel-cadmium prismatic rechargeable single cells.
37. IEC 60688: Operating conditions for industrial – process measurement and control equipment
38. IEC 60694: Electrical measuring transducers for converting arc. electrical quantities to analogue or digital signals.
39. IEC 60700: Common Specifications for High-Voltage Switchgear and Control Gear Standards.
40. IEC 60721: VSC Valves for High Voltage Direct Current (HVDC) Power Transmission – Part 1: Electrical Testing.
41. IEC 60747-1: Classification of environmental conditions.
42. IEC 60747-6: Semiconductor Devices – Discrete Devices – Part 1: General.
43. IEC 60747-9: Semiconductor devices, discrete devices and integrated circuits; VSCs.
44. IEC 60794-1,2: Semiconductor Devices – Discrete Devices – Part 6: IGBT.
45. IEC 60801: Optical Fibre cables.
46. IEC 60815: Fast transient & Electrical discharge.
47. IEC 60870-5-101: Guide for the selection of insulators in respect of polluted conditions.
48. IEC 60870-5-104: Telecontrol equipment and systems – Transmission Protocols.
49. IEC 60871: Shunt capacitors for AC power systems having a rated voltage above 1 kV.
50. IEC 61000: Electromagnetic compatibility (EMC).
51. IEC 61000-4-2,3,4,5: Control Systems EMC (immunity).
52. IEC 61071-1: Power electronic capacitors: General.
53. IEC 61071-2: Power electronic capacitors: Requirements for disconnecting tests on fuses, destruction test, self-healing test and endurance test.
54. IEC 61233: HV AC Circuit Breakers – Inductive Load Switching.
55. IEC 61786: Measurement of Low-Frequency Magnetic and Electric Fields with regard to exposure of human beings – Special Requirements for Instruments and Guidance for Measurements.
56. IEC 61850: Standard for the design of electrical substation automation.
57. IEC 61869 – 1: General Requirements for Instrument Transformers.
58. IEC 61870: Telecontrol equipment and systems.
59. IEC 61954: Power electronics for electrical transmission and distribution systems -testing of VSC valves for static VAr compensators.
60. IEC 61968: Application integration at electric utilities - System interfaces distribution management.
61. IEC 61970: Energy management system application program interface (EMS-API).
62. IEC 62927: Voltage sourced converter valves for static synchronous compensator -Electrical Testing.
63. CIGRE 391: Guide for measurement of radio frequency interference from HV and MV substations.

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64. CISPR Publication 18-2: Radio Interference Characteristics of Overhead Power Lines and HV Equipment Part 2: Methods of Measurement and Procedures for determining Limits.
65. IRPA Guideline for EM Field Strength Limits.
66. NEMA Pub. 107: Methods of Measurement of Radio Influence Voltage of High-Voltage Apparatus.
67. NEMA Pub. No. Cp1 Shunt Capacitors.
68. IEEE 1052: IEEE Guide for Specification of Transmission Static Synchronous Compensator (STATCOM) Systems.

1.47. HV cables

1. IEC 60060: High-voltage test techniques.
2. IEC 60183: Guidance for the selection of high-voltage A.C. cable system.
3. IEC 60228: Conductors of insulated cables.
4. IEC 60229: Electric cables – Test on extruded oversheaths with a special protective function.
5. IEC 60230: Impulse tests on cables and their accessories.
6. IEC 60270: High-voltage test techniques – Partial discharge measurement.
7. IEC 60287: Electric cables – Calculation of the current rating.
8. IEC 60331: Test for electric cables under fire conditions.
9. IEC 60332: Test on electric and optical fiber cables under fire conditions.
10. IEC 60754: Test on gases evolved during combustion of materials from cables.
11. IEC 60811: Electric and optical fiber cables – Test methods for non-metallic materials.
12. IEC 60853: Calculation of the cyclic and emergency current rating of cables.
13. IEC 60885: Electric test method for electric cables.
14. IEC 60949: Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects.
15. IEC 62271-209: Cable connections for GIS for rated voltage above 52 kV.

1.48. Metering

1. IEC Standard 62052: Electricity metering equipment (AC) - General requirements, tests and test conditions.
2. IEC Standard 62053-22: Electricity metering equipment (a.c.) - Particular Requirements - Part 22: Static meters for active energy (classes 0,2 S and 0,5 S).
3. IEC Standard 62053-24: Electricity metering equipment (a.c.) - Particular requirements Part 24: Static meters for reactive energy at fundamental frequency (classes 0,5 S, 1S and 1).
4. IEC Standard 61869-1: Instrument transformers - Part 1: General requirements.
5. IEC Standard 61869-2: Instrument transformers - Part 2: Additional requirements for current transformers.
6. IEC Standard 61869-3: Instrument transformers - Part 3: Additional requirements for inductive voltage transformers.
7. IEC Standard 62056: Electricity metering data exchange - The DLMS/COSEM suite.
8. IEC 61850: Communication networks and systems for power utility automation.

1.49. Electrical Rooms

1. EN 62271-202: High-voltage switchgear and control gear. High-voltage/ low-voltage prefabricated substations.

1.50. Instrumentation and control - General

1. EN 746-2: Industrial thermoprocessing equipment. Safety requirements for combustion and fuel handling systems.
2. EN 50156: Electrical equipment for furnaces and ancillary equipment.
3. EN 60073: Basic and safety principles for man-machine interface, marking and identification. Coding principles for indicators and actuators.
4. EN 62708: Document kinds for Electrical and Instrumentation Projects in the Process Industry.
5. IEC 61987 Industrial-process measurement and control.

1.51. Hardware requirements

1. EN 60204: Safety of machinery - Electrical equipment of machines.
2. EN 61000: Electromagnetic compatibility.
3. EN 61131: Programmable controllers.

WEEE Directive 2012/19/EU on Waste Electrical and Electronic Equipment

1.52. Software requirements

1. EN 60445: Basic and safety principles for man-machine interface, marking and identification - Identification of equipment, terminals, conductor, terminations and conductors.
2. EN 60073: Basic and safety principles for man-machine interface, marking and identification. Coding principles for indicators and actuators.
3. EN 61131: Programmable Controllers.
4. EN 62682: Management of alarm systems for the process industries.
5. EEMUA 191: Alarm systems. A guide to design, management and procurement.
6. EEMUA 201: Process plant control desks utilising Human-Computer Interfaces.

1.53. Safety instrumented systems

1. EN 61508: Functional safety of electrical/electronic/programmable electronic safety-related systems.
2. EN 61511: Functional safety - Safety instrumented systems for the process industry sector.
3. EN 62061: Safety of machinery. Functional safety of safety-related electrical, electronic and programmable electronic control systems.

1.54. ATEX equipment

1. Directive 1999/92/EC on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.
2. Directive 2014/34/EU: Equipment and protective systems intended for use in potentially explosive atmospheres.
3. EN 60079: Explosive atmospheres (all parts).
4. EN 13463: Non-electrical equipment for use in potentially explosive atmospheres.
5. EN 15198: Methodology for the risk assessment of non-electrical equipment and components for intended use in potentially explosive atmospheres.

1.55. Network and cyber security

1. IEC 62443: Security for Industrial Automation and Control Systems.
2. NIST SP 800-82: Guide to Industrial Control Systems (ICS) Security.
3. EU NIS Directive.
4. ISO/IEC 27001.
5. IEC 61850-90-4: Redundancy and High availability networks.
6. IEC 61850-90-4: Network Engineering Guidelines (IEC61850-90-4 section 5, Network Design Checklist).
7. IEC 61850: Communication standard for electrical substation automation systems.

1.56. Instrumentation

1. ISO 5167 parts 1 & 2: Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full.
2. EN 60584: Thermocouples.
3. EN 60751: Industrial platinum resistance thermometers and platinum temperatures sensors.
4. IEC 62828: Reference conditions and procedures for testing industrial and process measurement transmitters.

1.57. Cabling

1. EN 50173: Information technology. Generic cabling systems.
2. EN 50174: Information technology. Cabling installation.
3. EN 50288: Multi-element metallic cables used in analogue and digital communication and control.
4. PAS 5308: Control and instrumentation cables.
5. ITU-T Optical Fibre Recommendations and testing - G650 and G652
6. IEC 60794-2: Optical Fibre colour coding

1.58. Commissioning and testing

1. EN 61508: Functional safety of electrical/ electronic/ programmable electronic safety-related systems. Software requirements.
2. EN 61511: Functional safety - Safety instrumented systems for the process industry sector.
3. EN 62337: Commissioning of electrical, instrumentation and control systems in the process industry. Specific phases and milestones.
4. EN 62381: Automation systems in the process industry — Factory acceptance test (FAT), Site acceptance test (SAT) and Site integration test (SIT).

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1.59. Plant control system workstations

1. ISO 11064: Ergonomic design of control centres.

1.60. Civil - General

1. General work specifications - link: en.Vejregler.dk - The Danish Road Directorate
2. Molio basisbeskrivelser - link: Molio Beskrivelsesværktøj

1.61. Loadings and design

1. DS EN 1990: Basis of structural design.
2. DS EN 1991: Eurocode 1. Actions on structures.
3. DS/EN 1997: Eurocode 7.
4. All national annexes for Eurocodes 1-9.
5. DS/INF 1990.
6. DS EN 1993: Eurocodes 3. Incl. crane constructions.
7. Instructions of the Danish Building Research Institute 271, Documentation of load-bearing structures.
8. DS/EN 1990: Basis for planning of load-bearing structures, Annex B4.

1.62. Earthworks and foundations

1. ISO 20816: Mechanical vibration – Measurement and evaluation of machine vibration.
2. DS EN 1991: Actions on structures.
3. DS EN 1992: Eurocode 2. Design of concrete structures.
4. DS EN 1997: Eurocode 7. Geotechnical design.
5. DS/EN 1997-2.
6. All national annexes for Eurocodes 1-9.
7. DIN 4024: Machine foundations; flexible structures that support machines with rotating elements.
8. CP 2012: Code of practice for foundations for machinery or other such internationally recognised standards for dynamic analysis.
9. DS 475: Code of Practice for trenching for underground pipes and cables.
10. General Work Specification (GWS); Concrete Bridge - Foundation – GWS

1.63. Drainage and underground services

1. Design of all drainage and underground services shall be carried out in accordance with the appropriate parts of the General Work Specification of The Danish Road Directorate.
2. DS 430: Dansk Ingeniørforening's code of Practice of laying underground flexible pipelines.
3. DS 437: Dansk Ingeniørforening's code of Practice of laying underground rigid pipelines.
4. DS 455: Dansk Ingeniørforening's code of Practice for impenetrability of underground sewer systems.
5. DS 475: Code of Practice for trenching for underground pipes and cables.
6. DS/EN 858 parts 1 and 2: Separator systems for light liquids.
7. DS/EN 1295: Structural design of buried pipelines under various conditions of loadings.
8. DS/EN 1610: Construction and testing of drains and sewers.
9. DS/EN 12056: Gravity drainage systems inside buildings.
10. municipality's overall wastewaterplan and the Danish Wastewater Committees recommendations.
11. DS432:2020: Norm for afløbsinstallationer Code of Practice for Sanitary Drainage – Wastewater Installations.
12. BEK nr 473 af 07/10/1983.
13. Danva/DTVK: The photo manual - CCTV survey of drainage pipes.

1.64. Concrete Works

1. EN 206-1: Concrete. Specification, performance, production and conformity.
2. EN 1991: Eurocode 1. Actions on structures.
3. EN 1992: Eurocode 2. Design of concrete structures.
4. All national annexes for Eurocodes 1-9.
5. Current national annex for DS/EN 206.
6. EN 13670: Execution of concrete structures.
7. DS 2427: Concrete execution – Rules for application of EN 13670 in Denmark.
8. Municipality's overall wastewaterplan and the Danish Wastewater Committees recommendations.
9. DS 432:2020 Norm for afløbsinstallationer Code of Practice for Sanitary Drainage – Wastewater Installations.
10. BEK nr 473 af 07/10/1983.

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11. Danva/DTVK: The photo manual - CCTV survey of drainage pipes.

1.65. Roads, footpaths and hardstanding areas

1. Design of all roads and hardstanding areas shall be carried out in accordance with the appropriate parts of the General Work Specification of The Danish Road Directorate.
2. Related specification: DS/EN 13285 Unbound fixtures – specification.
3. Håndbog. Grundlag for udformning af trafikarealer. Maj 2021. Anlæg og Planlægning. Vejdirektoratet.
4. Håndbog. Projektering af vejbefæstelser. September 2018. Anlæg og Planlægning. Vejdirektoratet.

1.66. Structural steelwork

1. DS EN 1993: Eurocode 3. Design of steel structures.
2. All national annexes for Eurocodes 1-9.
3. ISO 14122: Safety of machinery - Permanent means of access to machinery.
4. ISO 1461: Hot dip galvanized coatings on fabricated iron and steel articles.
5. ISO 12944: Paints and varnishes - corrosion protection of steel structures by protective paint systems.
6. ISO 14713: Zinc coatings — guidelines and recommendations for the protection of iron and steel in structures.
7. EN 1090: Execution of steel structures and aluminium structures.
8. EN 10025: Hot rolled products of structural steels.
9. EN 10210: Hot finished structural hollow sections of non-alloy and fine grain steels.
10. Regulation (EU) No 305/2011 laying down harmonised conditions for the marketing of construction products.

1.67. G Masonry Works

1. EN 1996 – Design of masonry structures.
2. All national annexes for Eurocodes 1-9.

1.68. Lifts

1. DS/EN 81-20: Safety rules for the construction and installation of lifts.
2. Announcement of installation and DS/HD 60364 series.
3. DS/EN 60204.
4. DS/EN ISO 25745.
5. 5. AT (arbejdstilsynet) requirements.

1.69. Fire protection

1. Requirements/ guidance from the certified fire engineer.
2. Requirements/ guidance from the Insurer.
3. DS/EN 61936-1: the design and the erection of electrical power installations in systems with nominal voltages exceeding 1 kV AC.
4. EN 671: Fixed firefighting systems. Hose systems.
5. EN 1028: Fire-fighting pumps. Fire-fighting centrifugal pumps with primer.
6. EN 12101-2: Smoke and heat control systems. Natural smoke and heat exhaust ventilators.
7. EN 12259: Fixed firefighting systems.
8. Components for sprinkler and water spray systems.
9. EN 12845: Fixed Firefighting systems. Automatic sprinkler systems. Design, installation and maintenance.
10. EN 13565: Fixed firefighting systems. Foam systems.
11. EN 14384: Pillar fire hydrants (if applicable).
12. EN 14710: Fire-fighting pumps. Fire-fighting centrifugal pumps without primer.
13. EN 14972: Fixed firefighting systems. Water mist systems.
14. EN 15004: Fixed firefighting systems. Gas extinguishing systems.
15. NFPA 1: Fire Code.
16. NFPA 2: Hydrogen Technologies Code.
17. NFPA 30: Flammable and Combustible Liquids Code.
18. NFPA 55: Compressed Gases and Cryogenic Fluids Code.
19. NFPA 56: Standard for Fire and Explosion Prevention During Cleaning and Purging of Flammable Gas Piping Systems.
20. NFPA 67: Guide on Explosion Protection for Gaseous Mixtures in Pipe Systems.
21. NFPA 68: Standard on Explosion Protection by Deflagration Venting.
22. NFPA 69: Standard on Explosion Prevention Systems.
23. NFPA 72: National Fire Alarm and Signalling Code.

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24. NFPA 80A: Recommended Practice for Protection of Buildings from Exterior Fire Exposures.
25. NFPA 214: Standard on Water Cooling Towers.
26. NFPA 329: Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases.
27. NFPA 400: Hazardous Materials Code.
28. NFPA 497: Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas.
29. NFPA 850: Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations.
30. Following FM Global Property Loss Prevention Data Sheets:

    a. FMDS 06-14: Heat Recovery Boilers;
    b. FMDS 07-13: Mechanical Refrigeration;
    c. FMDS 07-14: Fire Protection for Chemical Plants;
    d. FMDS 07-17: Explosion Protection Systems;
    e. FMDS 07-23: Data on General Class of Chemical Processing;
    f. FMDS 07-35: Air Separation: Oxygen and Nitrogen;
    g. FMDS 07-42: Vapor Cloud Explosions;
    h. FMDS 07-43:Process Safety;
    i. FMDS 07-49: Emergency Venting of Vessels;
    j. FMDS 07-59: Inerting and Purging Vessels and Equipment;
    k. FMDS 07-83: Drainage and Containment Systems for Ignitable Liquids.
    l. FMDS 07-88: Outdoor Ignitable Liquid Storage Tanks;
    m. FMDS 07-91: Hydrogen;
    n. FMDS 07-95: Compressors;
    o. FMDS 07-101: Fire protection for Steam Turbines and Electric Generators;
    p. FMDS 07-111: Chemical Process Industries;
    q. FMDS 07-111g: Ammonia and Ammonia Derivatives;
    r. FMDS 12-2: Vessels and Piping;
    s. FMDS 12-43: Pressure Relief Devices; and
    t. FMDS 13-3: Steam Turbines.

1.70. Heating, ventilation and air conditioning (HVAC) Systems

1. BR18 with associated norms and guides including, but not limited to:
2. DS 418:2011 + Till. 1:2020 Calculation of heat loss from buildings.
3. DS 428:2019 + Till. 1 +Till. 2.:2021 Fire protection of ventilation system.
4. DS/447:2021 Ventilation in buildings - Mechanical, natural and hybrid ventilation systems.
5. DS 469:2013 Heating and cooling systems in building.
6. DS EN 16798; including the national annex.
7. EN 13030: Ventilation for buildings. Terminals. Performance testing of louvres subjected to simulated rain.
8. EN 15650: Ventilation for buildings.
9. EN 13779: Ventilation for non-residential buildings.

1.71. Lighting and small power

1. BR18 with associated norms and guides.
2. EN 12464: Light and lighting. Lighting of workplaces.
3. EN 12464-1: Light and lighting- Lighting of workplaces. Part 1: Indoor workplaces.
4. EN 12464-2: Light and lighting- Lighting of workplaces. Part 1: Outdoor workplaces.
5. EN 60255-1: Measuring relays and protection equipment. Common requirements.
6. EN 60669: Switches for household and similar fixed-electrical installations.
7. EN 1838: Lighting applications. Emergency lighting.
8. IEC 60598: Luminaries.
9. IEC 60364: Electrical Installations in Buildings. IET Wiring Regulations, can be applied where they do not contradict SEWA Rules and Regulations of Electrical Connection.
10. IEC 62717: LED modules for general lighting.
11. IEC 62612: Self-ballasted LED lamps for general lighting services with supply voltages 50 V.
12. IEC 62722: Luminaire performance.
13. ISO 7010: Graphical symbols. Safety colours and safety signs. Registered safety signs.
14. Danish announcement of power (Stærkstrømsbekendtgørelsen).

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1.72. Electric vehicle charging infrastructure

1. EN 61851: Electric vehicle conductive charging system.
2. ISO 15118: Road vehicles -- Vehicle to grid communication interface.

1.73. Security systems

1. EN 60839-11: Alarm and electronic security system. Electronic access control systems.
2. EN 62676: Video surveillance systems for use in security applications.

1.74. Building management system (BMS)

1. ISO 14001: Environmental management systems.

1.75. Telecommunications and Site IT system - General

1. EN 50174: Information technology. Cabling installation.
2. ISO 14763-2: Information technology — Implementation and operation of customer premises cabling.
3. ISO 30129: Information technology — Telecommunications bonding networks for buildings and other structures.

1.76. Operations and maintenance - General

1. EN 13306: Maintenance terminology.
2. EN 61078: Analysis techniques for dependability – reliability block diagram method.

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Annex B

Risk Assessments Methodologies

Methodology	Main Characteristic	How it is used (mainly)
FMEA	Failure Modes and Effects Analysis (FMEA) is commonly used in various stages of product design, development, and production to identify potential failures and minimise risk. Some relevant characteristics are: • Proactive: FMEA is performed before the product or process is put into use, allowing potential problems to be identified and addressed before they occur. • Systematic: FMEA follows a structured and documented process to ensure that all potential failures are considered and evaluated consistently. • Comprehensive: FMEA considers all possible failure modes, including those that may be rare or unlikely. • Quantitative: FMEA uses numerical scores and ranking systems to prioritise and compare different failure modes. • Iterative: FMEA is a continuous process that can be updated and revised as the product or process evolves or as new information becomes available. • Team-based: FMEA involves multiple stakeholders, including design engineers, manufacturing engineers, and quality specialists, to ensure that all perspectives are considered. • Risk-focused: The goal of FMEA is to identify and prioritise potential risks and to develop strategies for mitigating or eliminating these risks.	FMEA is commonly used in industries such as aerospace, automotive, defence, medical devices, and electronics, where product or process failures can have serious consequences, such as safety risks, financial losses, or damage to reputation. • New product development: FMEA can be used during the design phase of a new product to identify potential failures and refine the design to minimise risk. • Process improvement: FMEA can be used to identify potential problems in an existing process and suggest improvements to minimise risk. • Quality control: FMEA can be used to assess the quality of a product or process and identify opportunities for improvement. • Reliability analysis: FMEA can be used to evaluate the reliability of a product or process and identify areas where improvements can be made. • Maintenance planning: FMEA can be used to identify potential problems that may occur during the maintenance of a product or process and to plan for preventive maintenance activities.
ALARP	• As Low As Reasonably Practicable. A principle used in risk assessment to determine the acceptability of risks. • Some of his more representative characteristics are: • Hierarchical approach: The ALARP principle follows a hierarchical approach where risk reduction efforts are prioritised based on the level of risk. • Cost-benefit analysis: The ALARP methodology involves a cost-benefit analysis to determine the most reasonable and practical way of reducing risks. • Proportional and Justified: The level of risk reduction must be proportional and justified in relation to the level of risk and the cost of risk reduction measures.	ALARP methodology is used in situations where the level of risk and the cost of risk reduction measures must be balanced to determine the most reasonable and practical way of reducing risks. • This methodology is commonly used when decisions on risk reduction measures must be based on sound scientific and economic principles. Some of the common applications of the ALARP methodology include:

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	• Acceptable risk threshold: An acceptable risk threshold is established, beyond which further risk reduction measures are not economically or technically feasible. • Re-evaluation: The ALARP methodology involves regular re-evaluation of the risk and risk reduction measures to ensure that they remain justified and effective.	• Health and safety: The ALARP principle is widely used in the health and safety sector to determine the acceptability of risks and to prioritise risk reduction measures. • Nuclear power: The ALARP methodology is used in the nuclear power industry to ensure that radiation exposure to workers, the public, and the environment is as low as reasonably practicable. • Chemical and pharmaceutical industries: The ALARP principle is used in the chemical and pharmaceutical industries to evaluate the risks associated with the manufacture, use, and disposal of chemicals and pharmaceuticals. • Complex systems and processes: The ALARP methodology is also used in the assessment of the safety of complex systems and processes, such as oil and gas production, where the consequences of failure can be significant. • Environmental protection: The ALARP principle is used in the assessment of the impact of human activities on the environment, such as the construction of new buildings, roads, and other infrastructure projects.
LOPA	Layer of Protection Analysis is a methodology used for the qualitative risk assessment of complex safety-critical systems. Some of the main characteristics of the LOPA methodology include: • Simplicity: LOPA is a simple and straightforward methodology that can be easily applied to complex systems and processes. • Sufficient level of detail: LOPA provides a sufficient level of detail to evaluate the risk of potential incidents, while at the same time avoiding the complexity of a full-fledged quantitative risk analysis. • Risk mitigation layers: LOPA evaluates the effectiveness of multiple layers of protection, such as design features, operational procedures, and emergency response systems, to determine the overall level of risk associated with a system or process.	The LOPA methodology is used in industries such as petrochemical, chemical, pharmaceutical, and nuclear power, where the safety of complex systems and processes must be ensured, and decisions on risk reduction measures must be based on sound scientific and economic principles.

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	• Screening criteria: LOPA uses screening criteria, such as frequency and consequence, to determine the need for further risk assessment and to prioritise risk reduction measures. • Integration with other methodologies: LOPA can be integrated with other risk assessment methodologies, such as fault tree analysis, event tree analysis, and quantitative risk analysis, to provide a more comprehensive assessment of risk. • Clear decision-making criteria: LOPA provides clear decision-making criteria to determine the acceptability of risk and to guide the selection of risk reduction measures.	
FSA	• Fault Tree Analysis is a graphical and systematic method for modelling complex system failures and their causes. Some characteristics of FSA are: • Graphical representation: Fault tree diagrams are used to visually represent the cause-and-effect relationships between different components and events within a system. • Bottom-up approach: FTA starts with the failure mode of interest and works backwards to identify the events and conditions that contributed to the failure. • Event-oriented: FTA focuses on specific events, such as component failures or human errors, rather than on the system. • Logical approach: FTA uses logical symbols and operators, such as AND, OR, NOT, etc., to model the relationships between events and to evaluate the probability of failure. • Quantitative evaluation: FSA can be combined with statistical data and mathematical models to estimate the probability of failure and its consequences. • Risk reduction analysis: FTA can be used to evaluate the effectiveness of different risk reduction strategies and to determine the most cost-effective way to reduce the risk of system failure.	It is typically applied to complex systems or processes where it is important to understand the cause-and-effect relationships between various events and the likelihood of failure. Some common applications of FTA include: • Aerospace and defence systems • Nuclear power plants • Chemical and petrochemical plants • Medical devices • Automotive systems • Electronic systems FTA can be used at any stage of the product life cycle, from product design to operation and maintenance, and can be particularly useful for identifying potential failure modes and for evaluating risk mitigation strategies.
BOWTIE	The main characteristics of the BOWTIE study methodology are: • Provides a visual representation of the risk and hazard scenarios through a diagram that shows the causes and effects of an event. • Involves a structured approach to identify and assess the top events that could lead to a serious accident. • BOWTIE focuses on the identification and analysis of the "barriers" or the measures in place to prevent the top events from happening or mitigate their effects. • It allows for a clear distinction between the different types of events and the role of various safety measures and their level of protection.	This methodology is particularly suitable for analysing high-consequence, low-probability events and is often used to support decision-making processes related to safety, security, and environmental management. BOWTIE is particularly implemented in the oil and gas, chemical, and process industries, mining and aviation.

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	BOWTIE methodology is commonly used for major hazard assessment, incident investigation, and emergency preparedness planning.	
HAZOP	The main characteristics of HAZOP include: • Team-based approach: A HAZOP study is usually conducted by a team of experts from various disciplines such as process engineering, safety, and operations. • Guided-what-if analysis: The HAZOP methodology uses a "what if" approach to identify and analyse potential deviations or failures in a process or system. • Node-by-node analysis: A HAZOP study is usually conducted node-by-node, where each node represents a specific stage in the process or system. • Use of standard deviation keywords: A standard set of deviation keywords is used to identify potential hazards during a HAZOP study. • Identification of safety measures: The HAZOP study methodology not only identifies potential hazards but also recommends appropriate safety measures to mitigate or eliminate these hazards. Documentation and follow-up: A HAZOP study typically results in a detailed report that documents the findings, recommendations, and follow-up actions.	Hazard and Operability Study is a systematic and structured risk assessment methodology that is commonly used in the process industries (such as chemical, petrochemical, oil and gas, and power generation) to identify potential operational problems and hazards associated with a process or system.

List of recommended risks to consider

a. Table 1 - Project risks

1. Project risks	This category encompasses uncertainties in the planning and execution of green energy projects, including construction challenges, financial uncertainties, supply chain complexities, technical hurdles, environmental considerations, stakeholder management issues, operational resilience factors, and impacts from market and regulatory changes.		
	1.1 Permits and regulations	1.1.1	Challenges or delays in acquiring permits and licenses from authorities may increase costs and introduce financial uncertainties
		1.1.2	Challenges or delays in obtaining necessary approvals from citizens, leading to project delays
		1.1.3	Unforeseen changes in environmental regulations, may lead to compliance challenges and increased costs
	1.2 Planning	1.2.1	Project tasks expanding beyond the original scope, leading to increased complexity and potential delays
		1.2.2	Failure to evaluate and anticipate potential risks, leading to unforeseen challenges and disruptions during project execution
		1.2.3	Project timelines extending beyond initial estimates, causing delays and increased costs
		1.2.4	Insufficient control over project stakeholders with significant influence, capable of halting or delaying the project

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	1.3 Financial, budget and funding	1.3.1	Inaccurate initial cost estimates, may result in budget overruns and financial uncertainties
		1.3.2	Unexpected costs, may strain finances and pose challenges to project viability
		1.3.3	Difficulty in securing adequate financing for the project, resulting in delays
		1.3.4	Economic downturns, affecting project financing and viability
		1.3.5	Complexity of large-scale projects, may lead to coordination challenges, delays, and increased costs
	1.4 Workforce	1.4.1	Difficulty in sourcing skilled labour, may lead to project delays
		1.4.2	Labour strikes, impacting project progress
		1.4.3	Theft or mishandling of construction materials, affecting timelines
		1.4.4	Unrealistic project timelines may strain the workforce, causing errors
		1.4.5	Challenges in adhering to regulatory guidelines, affecting workforce efficiency
		1.4.6	Difficulty in sourcing skilled labour, leading to workforce shortages
		1.4.7	Accidents or safety breaches during construction, causing delays and legal repercussions
	1.5 Construction	1.5.1	Unexpected soil or geological conditions, causing delays in construction
		1.5.2	Adverse weather conditions, impacting construction progress
		1.5.3	Interruptions or delays in the supply chain for construction materials, can lead to project setbacks or increased costs
		1.5.4	Transportation issues, may result in delays, component damage, and increased logistics costs
		1.5.5	Failures in critical equipment, can lead to operational disruptions, potentially causing delays
		1.5.6	Uncovering historical artifact during construction, leading to project delays
	1.6 Supply chain	1.6.1	Insufficient availability of critical construction materials, can lead to project delays, impacting timelines and delivery schedules
		1.6.2	Financial instability or bankruptcy of key suppliers, may result in increased costs
		1.6.3	Defective components or materials from suppliers, may compromise the quality of construction
		1.6.4	Issues in transportation and logistics of construction materials, can cause disruptions in supply chains
		1.6.5	Disagreements or disputes with suppliers or contractors, may lead to legal implications or project stoppages
		1.7.1	Challenges integrating technologies, may cause delays and operational inefficiencies

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	1.7 Technical and engineering issues	1.7.2	Errors in technical specifications, may result in suboptimal performance and increased maintenance
		1.7.3	Undetected design flaws may disrupt implementation, causing delays and budget overruns
	1.8 Decommissioning	1.8.1	Unexpected costs and challenges in decommissioning, impacting project finances
		1.8.2	Safety and environmental risks in the disposal of decommissioned materials, posing risks to health and the environment
		1.8.3	Inadequate community communication during decommissioning, risking opposition
		1.8.4	Delays in obtaining decommissioning permits, affecting project timelines

b. Table 1 – continued - External Dynamics and Market Forces

1. External Dynamics and Market Forces	The External Dynamics and Market Forces category encompasses risks stemming from geopolitical events, economic fluctuations, technological advancements, environmental concerns, and regulatory changes that impact the renewable energy sector. Failure to anticipate and mitigate these risks can affect project viability, profitability, and operational stability.		
	1.1 Politics	1.1.1	Geopolitical events, trade policies, or diplomatic tensions, impacting cross-border operations and trade
		1.1.2	Political instability or conflicts, affecting the stability of regions where international projects are located
		1.1.3	Fluctuations in the supply and demand for renewable energy, affecting project viability and profitability
	1.2 Economy	1.2.1	Economic downturns, impacting project financing, investor confidence, and project viability
		1.2.2	Fluctuations in currency exchange rates, affecting financial stability
		1.2.3	Changes in interest rates, impacting the cost of financing
		1.2.4	Price volatility in the energy market, impacting revenue
		1.2.5	Increased competition in the renewable energy sector, affecting market share
	1.3 Social and cultural influences	1.3.1	Negative public perception, impacting operations
		1.3.2	Changes in cultural preferences, affecting the demand for specific types of renewable energy
	1.4 Technology	1.4.1	Advancements in renewable technologies, making current business model obsolete
		1.4.2	Technologies becoming outdated, affecting the efficiency and competitiveness
		1.4.3	Difficulties in integrating new technologies with existing infrastructure, leading to increased time and budget expenditures
	1.5 Environmental conditions	1.5.1	Increasing awareness and concerns about climate change, affecting public and regulatory attitudes
		1.5.2	Extreme weather (e.g. heavy rain, hurricanes, snowstorm), affecting operations
		1.5.4	Natural disasters (e.g. earthquakes, tsunami, volcano eruption), affecting operations
		1.5.5	Changes in weather patterns, affecting supply of raw materials

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	1.6 Legal and regulatory	1.6.1	Changes in environmental regulations, potentially leading to compliance challenges and increased costs
		1.6.2	Changes in government policies or regulations, impacting the renewable energy sector
		1.6.3	Challenges in maintaining necessary permits and licenses, halting operations
		1.6.4	Changes in import and export regulations affecting the movement of equipment, materials, and products
		1.6.5	Failure to comply with legal and regulatory requirements affecting ability to operate

c. Table 2 - Supply Chain

2. Supply Chain	The Supply Chain category encompasses risks associated with the flow of materials, products, and information from suppliers to customers. Failure to address these risks can lead to production delays, increased costs, quality issues, and reputational damage throughout the supply chain.		
	2.1 Sourcing (due diligence incl. collaboration)	2.1.1	Insufficient raw materials can lead to production delays, increased costs, and market share loss
		2.1.2	Lack of supplier and partner due diligence, introduces risks to supply chain security, intellectual property and company reputation
		2.1.3	Lack of solid contractual agreements with suppliers and partners, can cause collaboration conflicts, legal challenges, and supply chain disruption
		2.1.4	Dependency on few suppliers can cause supply chain disruption e.g. delays, inconsistency in deliveries and increased costs
		2.1.5	Dependency on suppliers from remote or unstable regions cause supply chain disruption e.g. delays, inconsistency in deliveries and increased costs
	2.2 Transportation	2.2.1	Delays or issues in transportation may disrupt the supply chain, causing late deliveries and increased costs
		2.2.2	Physical damage during transit may result in quality issues, increased costs, and customer dissatisfaction
		2.2.3	Restrictions on transportation routes create complexity, potential delays, and impact customer satisfaction
	2.3 Regulatory and compliance	2.3.1	Alterations in regulations affecting the movement of materials and products
		2.3.2	Failure to comply to (or ensure compliance with) local/national regulations throughout the supply chain, can affect the ability to operate
		2.3.3	Failure to ensure compliance with international standards, directives etc., can cause financial penalties and reputation risk
		2.3.4	Failure to adhere to ethical standards in sourcing and manufacturing, can cause reputation risk

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d. Table 3 - Production

3. Production	The Production category encompasses risks associated with the selection, use, and processing of materials, as well as errors in manufacturing or operational processes. Failure to address these risks can result in inefficiencies, defects, or failures in the production process, leading to customer dissatisfaction, market share losses, operational disruptions, and reputational damage.		
	3.1 Process errors	3.1.1	Excessive complexity in the production processes, can delay operations and increase the risk of errors
		3.1.2	Insufficient backup systems or redundancy in critical processes, can delay or stop production
		3.1.3	Dependence on outdated or obsolete technologies, can delay or stop production due to lack of e.g. ability to repair or source spare parts
		3.1.4	Lack of robust monitoring systems for critical production processes, can delay or stop production
	3.2 Quality	3.2.1	Failure to ensure quality control of produced energy or related products, can lead to customer dissatisfaction and market share losses
		3.2.2	Failure to quality control manufacturing processes, can lead to undiscovered errors and defects as well as fluctuations in production output
		3.2.3	Lack of rigorous quality control system and processes, can lead to inefficient and flawed quality control
	3.3 Maintenance	3.3.1	Lack of an updated control and maintenance plan or failure to adopt predictive maintenance strategies, can lead to maintenance oversight
		3.3.2	Neglecting routine maintenance, may lead to equipment failures and manufacturing defects
		3.3.3	Mistakes or oversights during repair or maintenance procedures, can cause machine/technology/equipment failure
		3.3.4	Insufficient inventory and management of critical spare parts, can delay repair or maintenance of operation critical machine/technology/equipment
		3.3.5	Machine/technology/equipment breakdown, can lead to unexpected disruptions in operations
	3.4 Regulatory compliance	3.4.1	Non-compliance with regulatory standards in production, may result in fines, legal actions, or operational disruptions
		3.4.2	Lack of transparency in reporting and ensuring regulatory compliance, can cause reputational risk

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e. Table 4 - HSE (Health, Safety & Environment)

4. HSE (Health, Safety & Environment)	The HSE (Health, Safety, and Environment) category focuses on safeguarding the well-being of employees, protecting the environment, and ensuring compliance with regulatory standards. Failure to address HSE concerns can result in legal liabilities, reputational damage, and operational disruptions.		
	4.1 Health	4.1.1	Lack of management focus on physical, mental and emotional well-being in the workplace, may lead to company failure in legal and ethical obligations
		4.1.2	Lack of adequate employee health programs, activities and benefits, can lead to the company being perceived as a less attractive place to work
		4.1.3	Physical, mental and emotional challenges in the workplace, can lead to increased employee lack of motivation, job-dissatisfaction and absenteeism
		4.1.4	Lack of health focused preventive measures e.g. ergonomics, can lead to e.g. physical damage due to wrong or no variation of working postures
	4.2 Safety	4.2.1	Accidents or incidents related to operational safety, can lead to health hazards
		4.2.2	Lack of management focus on safety standards and regulations, may lead to company failure, to protect employees from workplace hazards
		4.2.3	Failure to meet safety standards and regulations, can lead to workplace accidents, safety breaches, injuries, and illnesses.
		4.2.4	Lack of clear safety protocols and guidelines, can lead to improper handling or use of equipment and an unsafe work environment e.g. collisions
		4.2.5	Lack of observing a clear and clean work environment can expose employees to e.g. falls, slips, trips
		4.2.6	Lack of following safety protocols and guidelines, can lead to accidents e.g. falling objects
		4.2.7	Employee fatigue and lack of alertness, may contribute to accidents involving bodily injury and decreased productivity
		4.2.8	Employee exposure to hazardous compounds, may lead to contamination with health consequences
		4.2.9	Human errors in daily operations, can develop into safety hazards that may compromise overall production efficiency
		4.2.10	Lack of adequate employee training on safety procedures, can increase the risk of human error
		4.2.11	Lack of establishing a strong safety culture may lead to safety protocol and procedure breaches
		4.2.12	Ineffective communication leading to misunderstandings can result in errors with potential safety implications
		4.2.13	Lack of (planned) maintenance of safety equipment, may cause it to malfunction or fail
		4.2.14	Malfunction or failure of safety equipment, can cause or increase harm to employees during an incident or emergency
		4.2.15	Lack of or inadequate emergency preparedness planning, limits the company's ability to handle HSE incidents as well as other emergencies
		4.2.16	Inadequate (pre-) coordination with external emergency responders, may cause delayed response times e.g. in case of a fire
		4.2.17	Inadequate and unclear internal communication about emergency preparedness plans, can increase harm, disruption, and damage during HSE incidents

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		4.2.18	Lack of regular and realistic emergency response and management training as well as drills, may hindering efficiency and effectiveness in sharp situations
		4.2.19	Disrupted or ineffective communication channels during emergencies, may affect timely and coordinated responses
	4.3 Environment	4.3.1	Control failure in industrial processes, causing emissions of pollutants (air, water and land)
		4.3.2	Improper handling, storage, or disposal of waste generated during production processes, can cause employee exposure or environmental pollution
		4.3.3	Excessive light, noise and vibration during operations, may impact the local environment, wildlife, and community
		4.3.4	Facility construction or operational activities may cause soil erosion
		4.3.5	Inadequate measures for preventing and managing facility fires, may affecting surrounding areas
		4.3.6	Lack of effective monitoring systems for environmental parameters, may permit changes to go undetected
	4.4 Regulatory compliance	4.4.1	Non-compliance with HSE regulations, may result in fines, legal actions, operational disruptions and reputational damage
		4.4.2	Evolving HSE regulation impacting the company and facility operations, may require costly adaptations to procedures and operating practices
		4.4.3	Lack of transparency in reporting and ensuring regulatory compliance, can cause reputational risk

f. Table 5 - Security

5. Security	The Security category encompasses measures aimed at safeguarding assets, data, and personnel from various threats, including theft, fraud, cyber-attacks, and physical breaches. Failure to address security risks can result in operational disruptions, financial losses, legal disputes, and reputational damage.		
	5.1 Financial	5.1.1	Theft of financial assets, may lead to operational disruptions, reputational risk and financial losses
		5.1.2	Fraudulent financial activities e.g. internal theft, misuse and unauthorised transfer, may lead to financial losses, legal dispute and reputational risk
		5.1.3	Poor financial management practices leading to financial inefficiencies or loss of assets and resources
		5.1.4	Insider trading exploiting confidential information for personal gain, may result in financial losses as well as, legal and reputational damage
		5.1.5	Bribery incident, may result in legal and reputational damage
	5.2 Information	5.2.1	Theft of data or intellectual property, may lead to operational disruptions, reputational risk and financial losses
		5.2.2	Cyber-attack e.g. by political hackers or extremist groups, breaching IT-security systems, leading to loss or disruption of digital data
		5.2.3	Unauthorised digital access leading to the theft of sensitive digital or physical data
		5.2.4	Unauthorised physical access leading to the theft of sensitive digital or physical data

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		5.2.5	Malicious software encrypting critical systems for ransom (ransomware), leading to operational disruption and financial losses
		5.2.6	Deceptive tactics and social engineering targeting employees, to gain unauthorised access to information (phishing)
		5.2.7	Overloading systems with requests, to disrupt operation (DDOS)
		5.2.8	Weaknesses in network infrastructure leading to vulnerabilities and infiltration
		5.2.9	Industrial espionage using/exploiting any of the methods above or recruiting intentional insider informants to access digital or physical data
	5.3 Physical	5.3.1	Theft of equipment or raw materials, may lead to operational disruptions, reputational risk and financial losses
		5.3.2	Intruders gaining unauthorised access to secure areas, may lead to material and immaterial asset loss, theft, sabotage and violent injury
		5.3.3	Breaches into facility premises e.g. kid play and vandalism, may result in safety incidents and material damage
		5.3.4	Unauthorised use of vehicles near or on facility premises, may increase safety and security risks
		5.3.5	Physical damage and sabotage on e.g. utility lines, such as power cables or pipelines, can impact the energy supply and disrupt production
		5.3.6	Theft, sabotage or violent attacks by aggrieved former or current employees (revenge), may cause injury to material, immaterial and human assets
		5.3.7	Sabotage, violent, CBRNE attacks by terrorists/violent extremists, causing injury to material, immaterial and human assets
		5.3.8	Simultaneous attacks on multiple points of the energy supply chain (sabotage), can cause operational disruption
		5.3.9	Employee kidnap or hostage incidents, may lead to injury, loss of life, legal disputes, financial loss and reputation risk
	5.4 Reputation	5.4.1	Protests or actions by environmental activists, may disrupt operations and cause reputational damage
		5.4.2	Local community opposition leading to security challenges
		5.4.3	Negative public sentiment resulting in security concerns or customer loss
		5.4.4	Negative media coverage of e.g. owners, company or production facility, may increase security risks
	5.5 Security management and human error	5.5.1	Human errors in daily operations, can lead to unintentional loss of sensitive digital or physical data
		5.5.2	Human errors in daily operations, can lead to unintentional physical security breaches
		5.5.3	Lack of management focus on security standards and regulations, may lead to company failure, to protect company assets and ensure employee safety
		5.5.4	Failure to meet security standards and regulations, can lead to material and immaterial asset loss, theft, sabotage and violent injury
		5.5.5	Lack of security policy, strategy, plans, procedures etc. can lead to lack of or failed prevention of security incidents
		5.5.6	Lack of adequate employee training on security procedures, can increase the risk of human error and intentional procedural breaches
		5.5.7	Lack of security training and drills can lead to inefficiency and ineffectiveness in sharp situations
		5.5.8	Lack of establishing a strong security culture may lead to security protocol and procedure breaches

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		5.5.9	Lack of or inadequate background screening of employees/ service providers/ partners, may result in data breaches and physical security incidents
	5.6 Regulatory compliance	5.6.1	Non-compliance with security regulations, may result in fines, legal actions, operational disruptions and reputational damage
		5.6.2	Evolving security regulation impacting the company and facility operations, may require costly adaptations to procedures and operating practices
		5.6.3	Lack of transparency in reporting and ensuring regulatory compliance, can cause reputational risk

References for the Annex B:

1. De Ruijter, A. and Guldenmund, F. (2016) 'The bowtie method: A review', Safety Science, 88, pp. 211–218. Available at: https://doi.org/10.1016/j.ssci.2016.03.001.
2. Human factors in the oil and gas industry (no date) DNV. Available at: https://www.dnv.com/services/human-factors-1094 (Accessed: 24 August 2023).
3. International Organization for Standardization (2005) Fire Safety Engineering – Fire Risk Assessment. ISO/TS 16732:2005. Geneva, Switzerland. Available at: https://www.iso.org/standard/37654.html (Accessed: 24 August 2023).
4. International Organization for Standardization (2018) Risk Management – Guidelines. ISO 31000:2018. Geneva, Switzerland. Available at: https://www.iso.org/obp/ui/en/#iso:std:iso:31000:ed-2:v1:en (Accessed: 24 August 2023).
5. Karsten, M.M.V., Ruge, A.T. and Hulin, T. (2020) 'Closing the gap: Merging engineering and anthropology in holistic fire safety assessments in the maritime and offshore industries', Safety Science, 122, p. 104512. Available at: https://doi.org/10.1016/j.ssci.2019.104512.
6. Occupational Safety and Health Administration (no date) 'Process Safety Management of Highly Hazardous Chemicals'. Available at: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.119 (Accessed: 24 August 2023).
7. Rick Stevenson (2022) 6 Types of Risk Assessment Methodologies + How to Choose. Available at: https://drata.com/blog/risk-assessment-methodologies (Accessed: 24 August 2023).
8. Siemens PLM Software: White pape: (2016) 'How to conduct a failure modes and effects analysis (FMEA)'. https://polarion.plm.automation.siemens.com/.
9. Society of Fire Protection Engineers (2006) Guidelines for Substantiating a Fire Model for a Given Application. SFPE G-04.2006. Bethesda, MD: Society of Fire Protection Engineers (SFPE).
10. Society of Fire Protection Engineers (2022) Guidelines for Peer Review in the Fire Protection Design Process. SFPE G-11.2022. Bethesda, MD: Society of Fire Protection Engineers (SFPE).
11. Steve Lewis and Kris Smith (2010) 'Lessons Learned from Real World Application of the Bow-tie Method', in. Prepared for Presentation at American Institute of Chemical Engineers 2010 Spring Meeting 6th Global Congress on Process Safety San Antonio, Texas: SPE, p. SPE-154549-MS. Available at: https://doi.org/10.2118/154549-MS.
12. Tehler, H. and Hassel, H. (no date) 'A GENERAL FRAMEWORK FOR RISK ASSESSMENT USING SCENARIOS', Knowledge FOr Resilient soCiEty K-FORCE, Lund University- European Union.

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Annex C

1. Authority regulatory framework for PtX Plants

A lot of the information in this annex is written in Danish, as all Danish regulations are originally written in Danish. However, we have included brief translations of the essential text (in parentheses).

There are no specific regulations for Power-to-X systems, which is why all requirements for that type of system are expected to be identical to e.g. the requirements for petrochemical plants.

Below is a list of requirements for industrial facilities. The list is made for:
- Myndighedsgodkendelser (Authorities approvals)
- Tekniske godkendelser (Technical approvals)
- Dokumentationskrav (dokumenter der skal findes på site) (Site documentation)
- Inspektions krav (Inspection requirements)

1.1. Regulatoriske godkendelser (regulatory approvals)

R.1. Anmeldelse af project (Announcement of project review)
Bekendtgørelse om kontrol med risikoen for større uheld med farlige stoffer (risikobekendtgørelsen)
BEK 372 af 25/4/2016
Godkendende myndighed: Miljøstyrelsen
Tilladelse: Projekttilladelse

R.2. Ansøgning om plangrundlag (Application for planning basis in relation to protection of nature)
Planloven (LBK nr. 1557 af 01/07/2020)
Bekendtgørelse af lov om naturbeskyttelse, Naturbeskyttelsesloven (LBK 3192 af 04/10/2022)
Varianter: Kommuneplanramme, lokalplan, landzonetilladelse, erstatningsnatur
Godkendende myndighed: Den kommunale bygge- og planlægningsmyndighed
Tilladelse: Landzonetilladelse eller lokalplan

R.3. Miljøkonsekvensvurdering, §25, tidl. VVM (Environmental impact assessment)
Bekendtgørelse af lov om miljøvurdering af planer og programmer og af konkrete projekter (VVM) (Miljøvurderings-loven) (LBK nr. 04 af 03/01/2023)
Varianter: VVM Screening og VVM Redegørelse
Godkendende myndighed: Miljøstyrelsen eller den relevante kommunale myndighed
Tilladelse: Miljøgodkendelse
Relevant viden: Risikohåndbogen; VVM Screenings template

R.4. Miljøgodkendelse, §33 (Environmental approval)

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Bekendtgørelse af lov om miljøbeskyttelse, Miljøbeskyttelsesloven (LBK nr. 5 af 03/01/2023)
Bekendtgørelse om godkendelse af listevirksomhed (BEK nr. 2080 af 15/11/2021)
Bekendtgørelse nr. 994 af 9/09-2014 af lov om erstatning for miljøskader. (Miljøskadeerstatningsloven)
Bekendtgørelse nr. 2362 af 26/11/2021 om kvalitetskrav til miljømålinger.
(Analysekvalitetsbekendtgørelsen) Myndighedsgodkendelser

Godkendende myndighed: Miljøstyrelsen eller den relevante kommunale myndighed
Tilladelse: Miljøtilladelse

R.5. Risikovurdering ved farlige stoffer, SEVESO (Risk assessment for dangerous substances)
Bekendtgørelse om kontrol med risikoen for større uheld med farlige stoffer, Beredskabsloven (LBK nr. 372 af 01/05/2016)
Bekendtgørelse nr. 370 af 19/04/2016. Bekendtgørelse om kontrol med arbejdsmiljøet ved risiko for større uheld med farlige stoffer (Arbejdstilsynets risikobekendtgørelse)
Godkendende myndighed: Den kommunale beredskabsmyndighed
Tilladelse: Seveso-tilladelse
Relevant viden: Risikohåndbogen

R.6. Beskyttelse af kulturarv og arkæologiske interesser (Protection of cultural, archaeological interests)
Bekendtgørelse af Museumsloven, Museumsloven (LBK nr. 358 af 08/04/2020)
Godkendende myndighed: Lokale museum eller Slots- og Kulturstyrelsen eller den relevante kommunale myndig-hed
Tilladelse: En anbefalet udtalelse forud for byggeri

R.7. Brandmyndighedsgodkendelse (Fire authority approval)
Bekendtgørelse om brandsyn, Brandsynsbekendtgørelsen (BEK nr. 2341 af 09/12/2021)
Bekendtgørelse nr. 1444 af 15/12/2010 om tekniske forskrifter for gasser
Bekendtgørelse nr. 1639 af 06/12/2016 om brandfarlige og brandbare væsker.
Meddelelse nr. 23 om elektrolyseanlæg med brintfremstilling (beredskabsstyrelsen)

Godkendende myndighed: Beredskabsstyrelsen
Tilladelse: Godkendt brandsyn forud for ibrugtagning
Relevant viden: Risikohåndbogen

R.8. Byggetilladelse (Building permit)
Bekendtgørelse om bygningsreglement 2018 (BR18) BEK nr. 1399 af 12/12/2019
Varianter: Kræver oftest certificeret brandrådgiver vurdering. Det er praksis at adskille sin konstruktionsansøgning fra øvrige ansøgninger, herunder arkitekt- og afløbsansøgningerne.
Godkendende myndighed: Den kommunale bygge- og planlægningsmyndighed
Tilladelse: Byggetilladelse og Ibrugtagningstilladelse

R.9. Arbejdsmiljøtilladelse (Working environment permit)
Bekendtgørelse af lov om arbejdsmiljø, Arbejdsmiljøloven (LBK nr. 2062 af 16/11/2021)
Varianter: Forskellige krav afhængigt af virksomhed og aktiviteter
Godkendende myndighed: Arbejdstilsynet (www.at.dk)
Tilladelse: Arbejdsmiljøgodkendelse

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R.10. Affaldshåndtering og -bortskaffelse (Waste management and disposal')
Bekendtgørelse om affald, Affaldsbekendtgørelsen, Miljøbeskyttelsesloven (BEK nr. 2512 af 10/12/2021)
Varianter: Separate regler for byggeaffald, transport af farligt affald og elektronisk affald
Godkendende myndighed: Miljøstyrelsen eller den relevante kommunale myndighed
Tilladelse: Affaldstilladelse

R.11. Sårbarhedsvurdering ved PET (Vulnerability assessment by PET)
Risikobekendtgørelsen §11 appendiks 6 part 1
Godkendende myndighed: Politiets efterretningstjeneste
Tilladelse: Godkendelse af sårbarhedsvurdering

R.12. Nettilslutnings tilladelse (Infrastructure connection permission)
EON – Energisation Operational Notification (Spændingssætningstilladelse).
ION – Interim Operational Notification (Midlertidig Driftstilladelse)
FON – Final Operational Notification (Endelig Driftstilladelse)
Godkendende myndighed: Energinet (Energinet er en uafhængig offentlig virksomhed, der ejes af den danske stat under Klima-, Energi- og Forsyningsministeriet.)

Tilladelse: Aftag eller tilkobling af el, gas eller andre forsyninger

1.2. Tekniske godkendelser (Technical approvals)

NOTE:
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T.1. Spildevandshåndtering (Waste water management)
Bekendtgørelse om spildevandstilladelser m.v. efter miljøbeskyttelseslovens kapitel 3 og 4 (BEK nr. 1393 af 21/06/2021)
Godkendende eller certificerende part: Den kommunale myndighed

T.2. Emissioner til luften (Emissions to the air)
F.eks. NOx og SOx, partikler.
LBK: Bekendtgørelse om begrænsning af visse luftforureninger fra større fyringsanlæg (BEK nr. 670 af 22/06/2020)
LBK: Bekendtgørelse om miljøkrav fra mellemstore fyringsanlæg (BEK nr. 1535 af 09/12/2019)
Godkendende eller certificerende part: Miljøstyrelsen og den kommunale myndighed

T.3. Trykbærende udstyr (Pressurized equipment)
F.eks. trykbeholdere og dampkedler.
Bekendtgørelse om indretning m.v. af trykbærende udstyr, Lov om indretning m.v. af visse produkter (BEK nr. 190 af 19/02/2015)
Godkendende eller certificerende part: Af Arbejdstilsynet udpeget bemyndigede organer

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T.4. Elektriske installationer (Electric installations)
Bekendtgørelse om sikkerhed for udførelse og drift af elektriske installationer, El-sikkerhedsloven (BEK nr. 1082 af 12/07/2016)
Bekendtgørelse om sikkerhed for elektrisk materiel, Lov om produkter og markedsovervågning (BEK 2516 af 14/12/2021) (Elmaterielbekendtgørelsen)
Godkendende eller certificerende part: Autoriserede elinstallatørvirksomheder og/eller el-tilsynsmyndigheder

T.5. Eksplosionsbeskyttelse, ATEX (Explosion protection, ATEX)
Bekendtgørelse om produkter til anvendelse i en potentielt eksplosiv atmosfære, Lov om produkter og markeds-overvågning (BEK nr. 811 af 03/06/2022)
Godkendende eller certificerende part: Notified Bodies (anmeldte organer) udpeget af EU

T.6. Elektromagnetisk interferens, EMC (Electromagnetic interference)
Bekendtgørelse af lov om radioudstyr og elektromagnetiske forhold (LBK 958 af 22/06/2022)
CE Mærkning af elektromagnetiske komponenter
Godkendende eller certificerende part: Selvcertificering

T.7. Støjregulering (Noise regulation)
Bekendtgørelse om kortlægning af ekstern støj og udarbejdelse af støjhandlingsplaner, (Støjkortlægningsbekendt-gørelsen), Miljøbeskyttelsesloven. (BEK nr. 2092 af 18/11/2021)
Godkendende eller certificerende part: Den kommunale myndighed og akustikrådgivere

T.8. Maskindirektiv (Machinery Directive)
Bekendtgørelse om maskiner, Lov om produkter og markedsovervågning (BEK nr. 1094 af 01/06/2021)
Godkendende eller certificerende part: Fabrikant eller Bemyndiget organ udpeget af Sikkerhedsstyrelsen

T.9 Overensstemmelseserklæring (Declaration of Conformity)
EU Declaration of Conformity
Sammenfatning af mange tekniske godkendelser (CE-mærkning af EMC, ATEX mm)
Godkendende eller certificerende part: Sikkerhedsstyrelsen

T.10 ATEX arbejdspladsvurdering (ATEX workplace assessment)
Bekendtgørelse om arbejde i forbindelse med eksplosiv atmosfære (BEK 478 af 10/06/2003)
Arbejdsmiljøloven
Godkendende eller certificerende part: Selvcertificering

T.11. Sikker transport af farligt gods, ADR (Safe transport of dangerous goods, ADR)
LBK: Bekendtgørelse om vejtransport af farligt gods (BEK nr. 596 af 26/05/2023)
Godkendende eller certificerende part: Trafik-, Bygge- og Boligstyrelsen og certificerede rådgivere

T.12. Arbejdsmiljø og sikkerhed (Working environment and safety)
Bekendtgørelse af lov om arbejdsmiljø, Arbejdsmiljøloven (LBK nr. 2062 af 16/11/2021)
Godkendende eller certificerende part: Arbejdstilsynet

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T.13. Energistyring og energieffektivitet (Energy management and energy efficiency)
LBK: Bekendtgørelse om obligatorisk energisyn i store virksomheder (BEK nr. 1064 af 27/05/2021)
Omfattet af ISO 5001 certificering
Godkendende eller certificerende part: Energistyrelsen og certificerede energikonsulenter

T.14. Kemikaliesikkerhed, REACH, CLP (Chemical safety, REACH, CLP)
Bekendtgørelse af lov om kemikalier (BEK nr. 6 af 04/01/2023) (Kemikalieloven) Kap 4. om klassificering, mærkning, emballering og annoncering af kemiske stoffer og produkter
Godkendende eller certificerende part: Miljøstyrelsen og European Chemicals Agency (ECHA)

1.3. Dokumentationskrav (Documentation requirements)

NOTE:
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Liste over dokumentationskrav, dvs. dokumenter som skal findes på PtX anlægget.
(list of documentation requirements which must be present on site).

D.1. Nødprocedurer (Emergency procedures)
Anlægget skal have klare og letforståelige nødprocedurer på dansk, der angiver, hvad medarbejderne skal gøre i tilfælde af en nødsituation. Dette kan omfatte brand, eksplosion, kemiske udslip og andre nødsituationer, der kan opstå på anlægget.
Bekendtgørelse om kontrol med risikoen for større uheld med farlige stoffer (BEK 372 af 25/04/2016) (risikobekendtgørelsen)

D.2. Beredskabsplaner (Emergency management plans)
Opdaterede beredskabsplaner skal være tilgængelige på anlægget.
Bekendtgørelse om kontrol med risikoen for større uheld med farlige stoffer (BEK 372 af 25/04/2016) (risikobekendtgørelsen)

D.3. Brugsanvisninger og vedligeholdelsesvejledninger (Instruction and maintenance plans)
Disse dokumenter skal være på dansk og indeholde instruktioner om, hvordan man betjener og vedligeholder anlægget sikkert og effektivt. De skal også omfatte oplysninger om potentielle risici og nødvendige sikkerhedsforanstaltninger.
Bekendtgørelse om arbejdets udførelse (BEK nr. 1234 29/10/2018)

D.4. Risikovurdering (Risk assessment)
Anlægget skal have en risikovurdering, der identificerer og evaluerer potentielle farer og risici forbundet med anlægget og dets drift. Denne dokumentation skal også omfatte de nødvendige kontrolforanstaltninger for at minimere risiciene.
Bekendtgørelse nr. 370 af 19/04/2016. Bekendtgørelse om kontrol med arbejdsmiljøet ved risiko for større uheld med farlige stoffer (Arbejdstilsynets risikobekendtgørelse)

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D.5. ATEX-dokumentation (ATEX documentation)
Hvis anlægget indeholder zoner med eksplosionsfarlige atmosfærer, skal der udarbejdes ATEX-dokumentation, der beskriver de nødvendige sikkerhedsforanstaltninger og den korrekte brug af udstyr i disse zoner.
Bekendtgørelse om arbejde i forbindelse med eksplosiv atmosfære (BEK 478 af 10/06/2003)
Arbejdsmiljøloven

D.6. Kemikaliesikkerhed (Chemical safety)
Anlægget skal have dokumentation for sikker håndtering og opbevaring af kemikalier, herunder materiale-sikkerhedsdatablade (MSDS) for de kemikalier, der anvendes på anlægget.
Bekendtgørelse af lov om kemikalier (BEK nr. 6 af 04/01/2023) (Kemikalieloven) Kap 4. om klassificering, mærkning, emballering og annoncering af kemiske stoffer og produkter.

D.7. Plan for sikkerhed og sundhed (Plan for Safety and Health)
Anlægget skal have en sikkerheds- og sundhedsplan, der beskriver, hvordan man opretholder et sikkert arbejdsmiljø og beskytter medarbejdernes sundhed og sikkerhed under drift. APV skal være tilgængelig på pladsen.
Bekendtgørelse af lov om arbejdsmiljø, Arbejdsmiljøloven (LBK nr. 2062 af 16/11/2021)

D.8. Miljøgodkendelse (Environmental approval)
Dokumentation for miljøgodkendelsen, der beskriver de miljømæssige krav og betingelser, der skal overholdes under drift af anlægget.
Lovgrundlag: Bekendtgørelse af lov om miljøbeskyttelse, Miljøbeskyttelsesloven (LBK nr. 5 af 03/01/2023)

D.9. Inspektions- og vedligeholdelsesdokumentation (Inspection and maintenance documentation)
Anlægget skal have regelmæssige inspektions- og vedligeholdelsesrapporter, der dokumenterer udførte inspektioner, vedligeholdelsesarbejde og eventuelle nødvendige opgraderinger eller reparationer.
Lovgrundlag: Kravene til inspektions- og vedligeholdelsesrapporter kan variere afhængigt af de specifikke komponenter og udstyr, der er involveret, samt relevante myndigheds- og tekniske godkendelser, der gælder for anlægget.

D.10. Jobbeskrivelse, certifikater og organogram (Job description, certificates and organizational chart)
Dokumentation der beskriver roller og ansvar, samt dokumentation for krævet uddannelse. Optræder der hvor der er et lovkrav om en organisering, som f.eks. Arbejdsmiljøloven som foreskriver krav om en arbejdsmiljøorganisation
Lovgrundlag: Arbejdsmiljøloven

D.11. Vagtplan for ordinær drift (Watch schedule for ordinary operation)
Krav til driftsplanlægningen, kompetencer, roller og ansvar
Lovgrundlag: Bekendtgørelse om kontrol med arbejdsmiljøet ved risiko for større uheld med farlige stoffer (BEK nr. 370 af 19. apr. 2016)

D.12. Plan for eksternt beredskab (External contingency plan)
Plan for adgangsveje for interessenter i det eksterne beredskab (udarbejdes af ekstern part)
Lovgrundlag: Bekendtgørelse om kontrol med risikoen for større uheld med farlige stoffer (BEK nr 372 af 25 apr. 2016)

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1.4. Inspektioner (Inspections)

A lot of the information in this annex is written in Danish, as all Danish regulations are originally written in Danish. However, we have included brief translations of the essential text (in parentheses).

Inspektioner som skal udføres af et PtX anlæg i drift.
(Inspections to be conducted on a PtX plant in operation)

I.1. Trykbærende udstyr (Pressurised equipment)
F.eks. herunder beholdere, rørledninger og kedler:
Grundlag: Bekendtgørelse nr. 190 af 19/02/2015 om indretning, drift og kontrol af trykbærende udstyr (Trykbekendt-gørelsen)
Arbejdstilsynets BEK om anvendelse af trykbærende udstyr (BEK 1977 af 27/10/2021)
Arbejdstilsynets BEK om indretning ombygning og reparation af trykbærende udstyr (99 af 31. januar 2007)
Opstillingskontrol og periodiske inspektioner?
Inspektionsansvarlig: Akkrediterede inspektionsorganer

I.2. Eksplosionsfarlige atmosfærer, ATEX-zoner (Explosive atmospheres, ATEX zones)
Grundlag: Bekendtgørelse om arbejde i forbindelse med eksplosiv atmosfære (BEK 478 af 10/06/2003)
Arbejdsmiljøloven
Bekendtgørelse om brandsyn, Brandsynsbekendtgørelsen (BEK nr. 2341 af 09/12/2021)
Inspektionsansvarlig: Arbejdstilsynet eller akkrediterede inspektionsorganer

I.3. Elektriske installationer (Electric installations)
Grundlag: Bekendtgørelse nr. 1256 af 23. oktober 2020 om sikkerhed for elektriske lavspændingsinstallationer (Lavspændingsbekendtgørelsen)
Inspektionsansvarlig: Akkrediterede inspektionsorganer

I.4. Brandsikringsforanstaltninger (Fire protection measures)
Grundlag: LBK nr. 761 af 24. juni 2021 om brandsikring af byggeri (Brandsikringsloven)
Inspektionsansvarlig: Kommunale brandmyndigheder

I.5. Alarmsystemer (ABA Automatisk Brand Alarm) (Automatic fire alarms)
F.eks. ABA (automatisk brandalarm), gasdetekteringssystemer, alarmsystemer mm.
Lovgrundlag: Bekendtgørelse nr. 116 af 23. januar 2017 om beskyttelse mod eksplosionsfare (ATEX-bekendtgørelsen)
Inspektionsansvarlig: Arbejdstilsynet eller akkrediterede inspektionsorganer

I.6. Kalibrering og verificering af flowmålere (Calibration and verification of flow meters)
I forbindelse med Salg og Fakturering, Sikkerhedskritiske Anvendelser, miljøovervågning samt ved Kvalitetskontrol kan der være krav om kalibrering af flowmålere
Lovgrundlag: Måleinstrumentdirektivet også kaldet MID
Inspektionsansvarlig: akkrediterede inspektionsorganer

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I.7. Arbejdsudstyr (Work equipment)
Grundlag: Arbejdstilsynets bekendtgørelse nr. 1109 af 15. september 2020 om brug af arbejdsudstyr (Arbejdsudstyrsbekendtgørelsen)
Inspektionsansvarlig: Arbejdstilsynet eller akkrediterede inspektionsorganer

I.8. Kemiske stoffer og materialer (Chemical substances and materials)
Grundlag: Bekendtgørelse nr. 220 af 26. februar 2019 om arbejde med kemiske stoffer og materialer (Kemikaliebekendtgørelsen)
Inspektionsansvarlig: Arbejdstilsynet

I.9. Emissioner og affaldshåndtering (Emissions and waste management)
Grundlag: LBK nr. 1968 af 09. december 2021 om miljøbeskyttelse (Miljøbeskyttelsesloven)
Inspektionsansvarlig: Miljøstyrelsen eller kommunale miljømyndigheder

I.10. Arbejdsmiljø (Work environment)
Grundlag: Bekendtgørelse nr. 896 af 25. juni 2021 om anvendelse af personlige værnemidler
Inspektionsansvarlig: Arbejdstilsynet

I.11. Kraner og løfteudstyr (Cranes and lifting equipment)
Grundlag: Arbejdstilsynets bekendtgørelse nr. 1109 af 15. september 2020 om brug af arbejdsudstyr (Arbejdsudstyrsbekendtgørelsen)
Inspektionsansvarlig: Arbejdstilsynet eller akkrediterede inspektionsorganer

I.12. Ventilationssystemer og luftkvalitet (Ventilation systems and air quality)
Lovgrundlag: Bekendtgørelse nr. 87 af 31. januar 2019 om arbejdsmiljø (Arbejdsmiljøbekendtgørelsen)
Inspektionsansvarlig: Arbejdstilsynet

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Annex D

1. Experience from the industry

1.1. Challenges from a port's perspective

1.1.1. Regulatory Environment

Port authorities and shipping companies must follow complex regulatory frameworks and ensure compliance with local and national authorities. Energistyrelsen has published a step-by-step guideline for establishing PtX facilities on land and an overview of the rules for establishing PtX facilities. Both documents apply to ports if hydrogen, methanol, ammonia, and other fuels are stored on location.

Port of Rønne has run investigations along with Rambøll in relation to Bornholm Bunker Hub, which evaluated several scenarios covering hydrogen, methanol and ammonia. The main takeaways are:

- Storage in Port of Rønne most likely would be classed as a Kolonne 2 business (Table 2) and, therefore, will be a site that has to live up to the so-called Seveso directive of the EU, requiring the company to make extensive preparations to apply for all the required permits to all pertinent authorities.

- The study identified manageable volumes with the potential to get approval from the authorities. It also maps the risk contours in each scenario, following the guidelines by national legislation in Denmark (Risikohåndbogen), which specific individual risk is considered acceptable. For example:
  - The company with the risk source has full control of the area inside the risk contour for individual risk of 1·10-5 per year (10-5 iso-risk curve)
  - No sensitive-use-areas (residential areas, hotels, office areas or a corresponding area where many persons are expected to be present) exist or are planned inside the risk contour of 1·10-6 per year (10-6 iso-risk curve)
  - No emergency services facilities (e.g. hospitals, fire- or police stations) exist or are planned inside the risk contour of 1·10-9 per year (10-9 iso-risk curve).

Most scenarios are expected to be feasible at the Port of Rønne, but the local authorities seem to interpret the risk contour of 1·10-6 differently, which might increase safety areas for bunkering and potentially hinder the final approval for storage and bunkering.

Table 1. Examples of notice types and threshold quantities stated in tonnes

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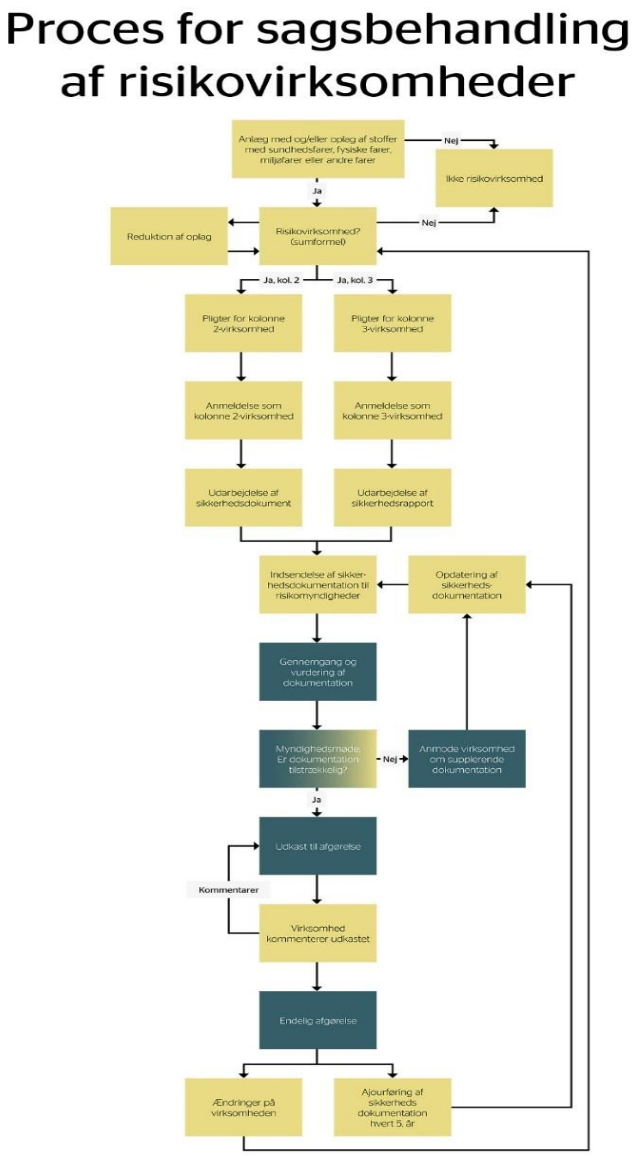
Stoffer	Kolonne 2	Kolonne 3
Hydrogen	5	50
Oxygen	200	2.000
Metanol	500	5.000
Andre brændstoffer (fx jetbrændstof)	2.500	25.000
Vandfri ammoniak	50(5)*	200

*For anlæg, der ligger nærmere end 200 meter til boligområder, er tærskelmængden nedsat til 5 tons.

Figure 1. Decision-making process for a risk company[ii]



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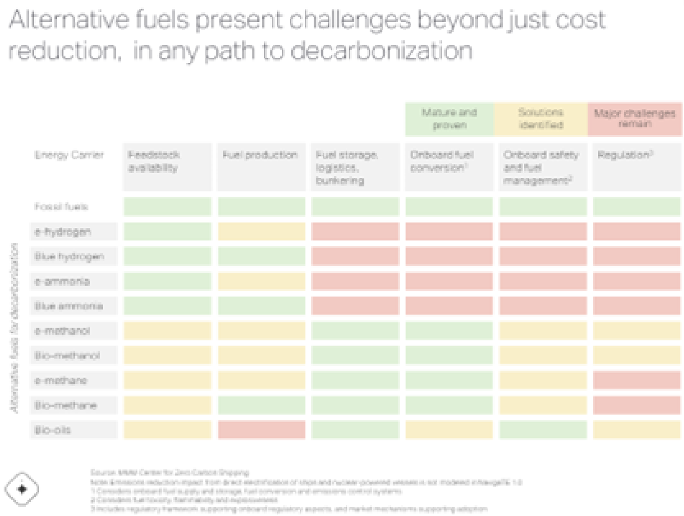
If the storage is instead onboard a tank ship moored alongside a quay, the regulatory framework changes as Danish Maritime Authorities become the authority on the storage. In principle, if the ship is approved according to international standards, it can be located at a spot where it would not be possible to get permission for an equivalent-sized land-based storage.

1.1.2. Infrastructure

Table 2. Challenges faced in the implementation of alternative fuels (Source: MMM Center for Zero Carbon Shipping)



One of the primary challenges is the lack of infrastructure for green fuels. Ports need to invest in new infrastructure for storing, handling, and distributing green fuels such as hydrogen, biofuels, and electricity. Retrofitting existing infrastructure or building new facilities can be costly and time-consuming. Table 1 summarizes the main challenges by fuel typeiii.

1.1.3. New risks and learning curve

Methanol and ammonia pose two significantly different risk factors. Where methanol is highly flammable and potentially explosive, the biggest risks from ammonia are related to toxicity to humans and the water environment. Ammonia could also pose a risk of explosion if stored as pressurised ammonia. Therefore, the industry should consider only storing and using ammonia that is fully refrigerated, where the risks in relation to leaks are significantly reduced compared to pressurised.

Other new safety concerns exist compared to traditional fossil fuels. For example, hydrogen is highly flammable and explosive in many air/hydrogen mixtures and requires special handling procedures to ensure safe storage and usage. Port authorities must update training programs and internal safety measures to mitigate the new risks associated with green fuels.

1.1.4. Transport and Storage

Port of Rønne also led a feasibility study for a PtX plant in Bornholm, in which the transport and storage of products were evaluated. The following takeaways are extracted directly from the WP5 Report - REACTRF-22-0054 Feasibility study for Power-to-X production on Bornholm, in reference to the scenarios involving the port directly.

Transport:

Plant placed on land and storage placed at an existing port:

- By truck: This is not a sustainable solution if the product is in large amounts.
- Underground pipes: Does not require municipal planning, but includes risk assessment, environmental permits and multiple legal cadastral agreements.
- On-ground/piped: Requires municipal planning and is only possible in areas with low population density.

Plant and storage placed on land, transport of product:

- By truck: This is not a sustainable solution if the product is in large amounts.
- Underground pipes: Does not require planning, but includes risk assessments, environmental permits and multiple legal cadastral agreements.
- On-ground/piped: Requires municipal planning and is only possible in areas with low population density.

Storage

There are no planning restrictions for storing e-fuels at Port of Rønne, as fuel storage is included in the existing municipal planning. Still, strict environmental screening is required by several government agencies, including the Danish Environment Agency and Bornholms Regionskommune (See 1. Regulatory Environment). The safety zone will be defined based on the entire project: the situation plan, the structure of the tank, safety procedures, etc.

1.1.5. Public Perception

Overall, the public supports decarbonisation initiatives. However, there could be resistance to change and a reluctance to accept new fuels that might be considered more dangerous than traditional fossil fuels. Early public participation and initiatives to improve the understanding of new fuels will be beneficial during the planning process, including applications for permits.

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