ARENHA

ADVANCED MATERIALS AND **R**EACTORS FOR **EN**ERGY STORAGE T**H**ROUGH **A**MMONIA

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Content

1. Executive summary

1.1. Description of the deliverable content and purpose

This deliverable aims to give an insight about the regulatory framework and the non-legal limitations of the use of ammonia as an energy carrier. This study includes the definition of the relevant legislation, regulations and standards with respect to bottlenecks concerning ammonia as an energy carrier. Moreover, a study of the technical and regulatory requirements and a comparison to existing approaches and policies was carried out. Finally, a guidance for the further development of appropriate legislation and regulation was also carried out.

1.2. Briefly description of the state of the art and the innovation brought

Although there are currently existing studies regarding hydrogen as an energy carrier, there is not much development on the needed frameworks for the use of ammonia as an energy carrier. This deliverable aims to framework all the relevant existing legislation, also of the technical limitations that might affect and drive the development of new regulatory frameworks and also provide the crucial points that need to be assess in the upcoming future to normalize the use of ammonia as an energy carrier.

1.3. Deviation from objectives

N/A

2. Definition of technological limitations

Ammonia has traditionally been used for fertilizer production through the Haber Bosch process since 1909 and to the day, is one the main commodities produced worldwide. However, in the last years ammonia has gained momentum as an energy carrier, and as technology is overall making a substantial shift towards more sustainable process, less intensive in energy and less material-demanding processes that ensure that ammonia is produce at large scale minimizing the overall impact of its industrial production and usage. Moreover, three different steps can be identified in the ammonia as an energy carrier value chain: synthesis, storage and final use. Thus, a study of each of these technical limitations will be assess independently.

2.1. Technological limitations of ammonia synthesis

The production of ammonia at a large scale is, by far, made through the Haber-Bosch process. This process however has a high requirement of energy, with operation temperatures around 350-500ºC and operation pressures of around 150-300 bar, which greatly increase not only the OPEX but also the CAPEX associated as the materials should withstand those operating conditions. Moreover, high CO_2 emissions associated to the production of ammonia greatly limits the application of the conventional Haber-Bosch method on the current global context [1].

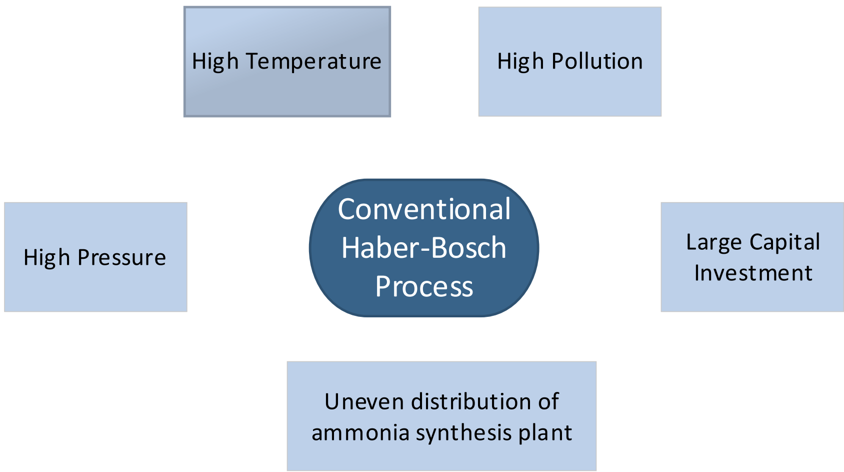

Figure 1. Main limitations of the Haber-Bosch conventional Process.

Not only this, but the overall flexibility of this system is very limited: starting a conventional large-scale ammonia production plant and to operate it at a full capacity needs, roughly, more than 12 hours of start-up procedure. If using non-reduced catalyst, this time could be as high as 3 days. Moreover, a shutdown to keep the system at a hot stand-by state takes approximately 6 hours, and in the case of total shut down and cooling to ambient conditions, the procedure could take up to 6-24 hours. Also, the catalyst used in the Haber-Bosch reactor and the feed composition led to limitations in the flexibility of the steady-state operation of the system, and steady-state is mainly the design approach modern plants are designed for. Not only this, but the rest of the BoP (Balance of Plant) components can generate more constraints that narrow even more the load range between 55-115%. If those limits are surpassed, surge can occur on the lower limit whilst choke on the higher margins. For instance, minimum load rate to prevent is set at around 50% of the nominal load, below that limit the reactor could not operate and would lead to a non-safe operation of the plant. Another example is the rapid increase on the catalyst´s bed temperature dangerously if abrupt ramp-down of the gases fed to the system. To avoid this excessive heating of the reactor, pressure can be reduced to slow down the reaction, but this will inevitably lead to mechanical fatigue of the components which have a negative effect on the safe reliability of the plant. Summarizing, varying the pressure would allow some flexibility but jeopardizing the mechanical integrity of the system, thus, pressure on its own is not enough to provide a flexible yet safe ammonia synthesis production system.

Aiming to achieve better efficiencies and cost-effective processes, extensive research regarding the development of new catalyst for the Haber-Bosch process has been made in the last years. For example, a wüstite Fe-based catalyst that replaced magnetite Fe-catalyst greatly reduced the operating pressure of the process down to 100 bar. Later on, the discovery of Ru-based catalyst for ammonia synthesis at lower pressures resulted in even better activities to the iron-based catalyst, though condensation is not possible at those low pressures due to the low ammonia partial pressure yield. [2]

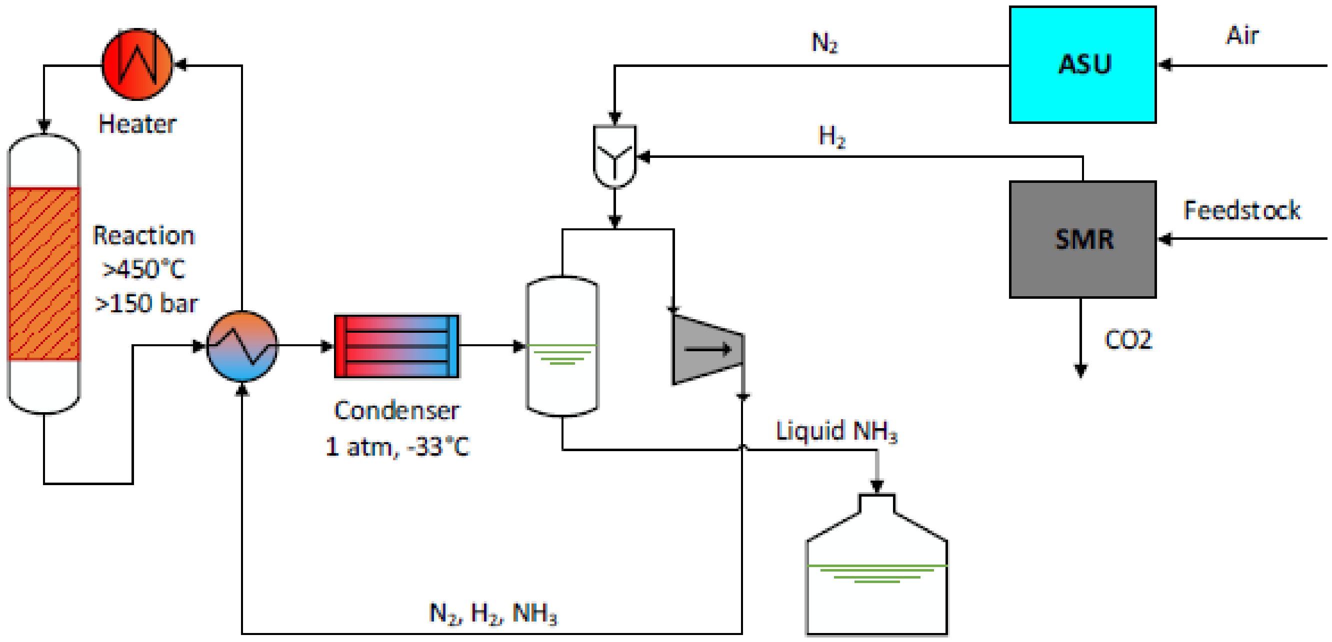

Figure 2. Conventional Haber Bosch Process.

Other technologies for direct ammonia production include thermocatalytic, electrocatalytic and photocatalytic ammonia production under mild conditions and the derived chemical looping and plasma ammonia production methods These technologies have been widely studied in the last years. Electrocatalytic and photocatalytic methods, which use low fossil fuels, are naturally being considered as future directions for the development of ammonia production. Although their catalytic efficiency of ammonia generation is not yet sufficient to satisfy the actual demands, considerable progress has been made in terms of regulating structure and morphology of catalyst and improving preparation efficiency. The chemical looping approach of ammonia production differs from the thermocatalytic, electrocatalytic, and photocatalytic methods, and is the method of reusing raw materials. The plasma treatment approach alters the overall ammonia production approach and builds up a new avenue of development in combination with thermal, photocatalytic, and electrocatalytic methods as well.

Table 1. Comparison between direct NH_3 production pathways. [3]

Technology	Pros.	Cons.	Comments
Electrochemical High-temperature NH_3 production (Solid state)	1- Possibility for direct ammonia production from water and nitrogen. 2- The design of the cell is easy. 3- Low pressure required. 4- Zero carbon emissions and reactants can be generated on the same cell.	1- Low durability for the electrodes owing to high temperature. 2- Low formation rate and faradic efficiency. 3- High temperature require high power consumption. 4- Challenges related to the nitrogen triple bond dissociation on the surface catalyst.	This system reveals a potential for direct ammonia synthesis; however, many considerations with the cell and catalyst are still required.
Electrochemical Medium-temperature NH_3 Production (Molten state)	1- Possibility for direct ammonia production from water and nitrogen. 2- Lower operation temperatures. 3- Zero carbon emissions and reactants can be generated on the same cell.	1- Limited faradic efficiency and ammonia production rate. 2- The electrolyte is corrosive for the electrodes. 3- Environmental issues due to the corrosive electrolytes. 4- Challenges related to the nitrogen triple bond dissociation on the surface catalyst.	It is considered a clean energy direct ammonia synthesis; however, consideration should be taken with the electrolytes.
Electrochemical Low-temperature ammonia synthesis	1- Direct ammonia production at very low temperatures < 100 ◦C. 2- Variant of electrolytes can be used. 3- Zero carbon emissions and reactants can be generated on the same cell.	1- Higher voltage is needed to overcome the overpotential. 2- low NH_3 production rate and limited FE. 3- High capital cost of the technology. 4-Challenges related to the nitrogen triple bond dissociation on the surface catalyst.	Still not viable for industrial applications.
Photochemical NH_3 Production	1- Possibility for direct ammonia production from water and nitrogen. 2- The reactor design is already an existing technology. 3- Low temperature synthesis. 4- Zero-carbon emission.	1- The main issue for this is the competing toward hydrogen evolution reaction; 2- Ammonia production rate is very low. 3- Challenges related to supply electrons through light.	It reveals the potential of using solar energy to transform water and nitrogen into O_2 and NH_3; however, considerable attention should be taken for developing photocatalyst that can reduce the band gap with a high active site and capable to inhibit HER. Furthermore, new reactor system design should be taken on consideration.
Plasmatic NH_3 Synthesis	1- The mean electron energies of non-thermal plasma, which is around 20 eV, make it ideal for room temperature synthesis. 2- Clean and carbon free production. 3- Small scale production at the site on interest.	1- The efficiency and conversion are very low. 2- Many challenges would face large scale production.	Still this method requires more investigation to be viable for large scale production.

2.2. Technological limitations of ammonia storage

Ammonia is commonly storage in both liquid or gaseous form, each of these requiring its own specific consideration for safe handling and storage. As shown in the graph below, ammonia is in liquid phase when applying -33ºC at ambient pressure or 8 bar at ambient temperature, but every possible combination of P and T according to the graph below would make the liquefaction process possible.

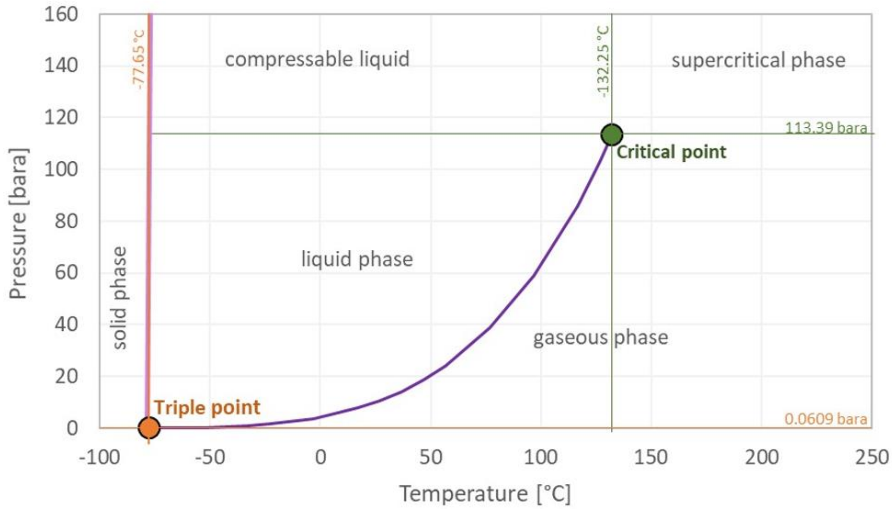

Figure 3. Ammonia phase diagram.

Overall, there are three methods for storing ammonia:

1- Storing ammonia under high pressure (15–18 bars) at room temperature using spherical or cylindrical vessels with a capacity up to 2000 tons.
2- Storage of ammonia at low temperatures (– 33 ◦C) and a pressure around (1.1 to 1.2 bar) using insulated vertical cylindrical tanks with a capacity up to 50,000 tons.
3- Intermediate pressure storage at 0 ◦C using insulated reduced-pressure spherical vessels with a capacity up to 2500 tons. [3]

Compressed gas at atmospheric temperature and refrigerated at atmospheric pressure are the most common ways used to store ammonia. However, low-pressure storage was later preferable to high-pressure for two main reasons: capital costs are lower per capacity volume and it is a safer storing way when compared to spherical ammonia storage under high pressure. Currently, the large industrial scale has shown a great interest in refrigerated ammonia storage at ambient pressure owing to the high-capacity storage.

For pressure storage, cylindrical tanks can withstand up to 25 bar pressure and spherical tanks, maximum design pressure is normally set at 16 bar to prevent a wall thickness above 30 mm.
Currently, refrigerated ammonia storage is preferred owing to its lower capital cost per unit volume compared to other methods and the higher volume capacity.

The main limitations regarding the storage of ammonia in a liquid phase are listed as below:

- Corrosion of materials: being ammonia a corrosive substance to metals, especially in water is present in the solution, deterioration of the storage tank and equipment is common and can potentially lead to leaks or structural failures.
- Need of specialized equipment and facilities: because of the high pressure/low temperature needed for maintaining ammonia on a liquid phase, specialized equipment (compressors, heat exchangers, chilling units…) are needed and can result in a high cost both for the CAPEX and also

the OPEX costs of the system. Not also the cost is relevant, but also an appropriate monitoring and maintenance plan is needed to preserve the good functioning of the system.

- Possibilities of leakages and spilling: as a leak of ammonia due to malfunctioning of the system can result in the formation of an ammonia cloud, the containment and mitigation of the leaks is a real challenge also because of the high volatile properties of ammonia.

The main limitations for storage ammonia on a gas phase include, apart from the above issues, the requirement of larger tanks due to the lower density compared to same amount of ammonia storage in a liquid phase.

The development of storage systems in solid state for ammonia has been identifies as a promising method to simply the plant layout and thus, reducing the investment needed. Not only the associated costs to the system could be reduced, but also the solid state could reduce the risks associated to liquid or gaseous phase storage, as there is likely less probability of formation of clouds in case of malfunctioning of the system. Moreover, the capacity of storage can be enhanced. For instance, a capacity of 100g of $MgCl_2$ can storage up to 135 l of NH_3. For the ARENHA project, the targeted capacity is beyond 450 g NH_3/L and the desorption temperature below 150ºC, with an output pressure of 10 bar NH_3. Taking for instance the density value of ammonia at -33ºC and 1 atm of 0,6818 kg/m^3 and the density at 15ºC and 7,18 atm of 0,6175 kg/m^3, solid state ammonia is indeed a very promising storing option in terms of space requirements.

2.3. Technological limitations of ammonia final use

Apart from the extremely extended use of ammonia in the fertilizer industry, ammonia has a great potential in several energy sectors. This technology includes the combustion of ammonia on ICE (internal combustion engines), catalytic decomposition of the ammonia, highlighting the use of membrane reactor, the electrochemical decomposition of ammonia, including phenomena such as EPOC (electrochemical promotion of catalysis) and also the direct use of ammonia on high temperature solid oxide fuel cells.

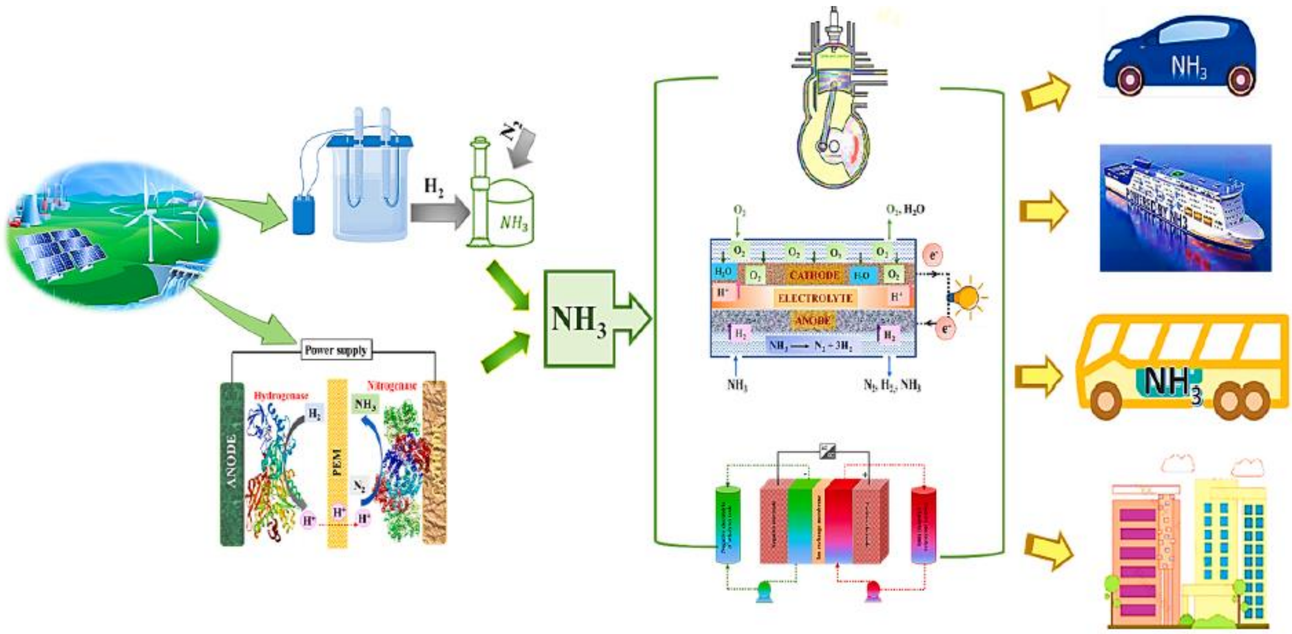

Figure 4. Schematic diagram describing the most promising application of ammonia (fertilizing applications not included).

A comparison between the main technologies regarding the final use of ammonia is shown below.

Table 2. Main technologies of ammonia final use.

Technology	Pros.	Cons.	Comments
Combustion	1. Combustion is an extensive researched topic. 2. Ammonia combustion could be beneficiated through improvements on combustion. 3. Less prone to accidental ignition due to the higher auto-ignition temperature of ammonia. 4. Lower propensity for knocking due to its lower flame speed and different combustion characteristics.	1. Formation of NO_x. 2. Low radiation intensity. 3. Low flammability. 4. Lower heating value compared to hydrocarbons. 5. Lower laminar burning velocities. 6. Higher auto-ignition temperature. 7. Minimum ignition energies than other fuels. [4] 8. Few studies about the use of pure ammonia as fuel. 8. Low amounts of H_2 needed for promoting the engine performance.	Further research on the dynamics and chemistry of ammonia is necessary. Major mitigation of NO_X formation is a crucial issue for the further implementation of this technology.
Catalytic Membrane Reactor (Decomposition)	1. Operate at more flexible conditions. 2. Reduces waste generation. 3. Energy usage is minimized. 4.Enhances process´s conversion and selectivity. 5.Potential to accomplish conversion rates higher than thermodynamic equilibrium conversion. [5] 6. Scientific understanding of the ammonia decomposition over standard catalyst is well understood. 7. Ultrapure hydrogen can be obtained in a single stage.	1. Need for high cost and scarce catalyst in many cases. 2. Technology significantly less advanced than the ammonia synthesis reaction. 3. Catalyst sintering could occur at high temperatures. 4. Limitation on the maximum pressure across the membrane can withstand is strict. 5. Delamination of the membrane can occur.	Nature of the membrane is an ongoing topic of research. Membrane can serve as a distributor, contractor and extractor.
Electrochemical Decomposition	1. High purity hydrogen can be produced at near-ambient temperatures. 2. High conversion rates. 3.Avoids formation of contaminants compared to the high-thermal decomposition processes. 4. Enhances the catalytic reaction rates compared to heterogeneous catalyst. [6]	1. Few studies about the topic. 2. Need of scarce elements, such as Ru. 3. Catalytic activity severely affected by various factors, such as size of the metal particles.	Various actives phases (Ni, Co, Rh, Pd, Pt, etc) and various supports (Al_2O_3, SiC, ZrO_2, CeO_2, La_2O3, MgO and carbonaceous materials) are being investigated.
Ammonia based fuel cells	1. Cost relatively low as there is no need of a cracking unit. 2. No need of precious catalyst. High T enhances the electrolyte´s ionic conductivity.	1. Challenges in material selection. 2. System reliability must be studied. 3. Longer start-ups times compared to low temperature FC. 4. High manufacturing costs.	This category includes ASOFC-O (ammonia-fed oxygen anion conducting electrolyte-based SOFC), ASOFC-H (ammonia-fed proton conducting electrolyte-based oxide fuel cells), AAMFC (ammonia alkaline molten fuel cell), AMFC (ammonia-based microbial fuel cell).

Also, it is important to remark that when the final usage of ammonia is decomposition and thus, hydrogen can be later on used, a very interesting use is through hydrogen fuel cells. The limits in terms of ammonia impurity that the FC can withstand must also be considered, meaning that the decomposition stage has to be able to achieve those restrictions. Otherwise, a further NH_3 removing stage should be added to guarantee the compliance of the limitations below shown.

Table 3. Summary of main features of fuel cell technologies. [7]

FC type	AFC	SOFC	PEMFC	PAFC	MCFC
Anode reaction	$H_2+2OH^- \rightarrow 2H_2O+2e^-$	$H_2+O_2^- \rightarrow H_2O+2e^-$ $H_2 \rightarrow 2H^++2e^-$	$H_2 \rightarrow 2H^++2e^-$	$H_2 \rightarrow 2H^++2e^-$	$H_2+CO_3^{2-} \rightarrow H_2O+CO_2+2e^-$
Ion	OH^-	O^{2-}, H^+	H^+	H^+	CO_3^{2-}
Cathode reaction	$1/2O_2+H_2O+2e^- \rightarrow 2OH^-$	$1/2O_2+2e^- \rightarrow O_2^-$ $1/2O_2+2H^++2e^- \rightarrow H_2O$	$1/2O_2+2H^++2e^- \rightarrow H_2O$	$1/2O_2+2H^++2e^- \rightarrow H_2O$	$1/2O_2+CO_2+2e^- \rightarrow CO_3^{2-}$
Temperature (°C)	60–220	600-1000 (O^{2-}) 400-800 (H^+)	60-85 (LT) 130-220 (HT)	160–220	600–700
Pressure (MPa)	0.5	0.3	1–2	0.1	0.2
Electrolyte	35 wt%-85 wt% KOH	Ceramics, e.g., YSZ	Polymer membrane	Phosphoric acid	Carbonates, e.g., Na_2CO_3, Li_2CO_3
Anode catalyst	Ni, Pt/C	Ni, Zr	Pt/C	Pt/C	Ni (Cr, Al)
Cathode catalyst	Ag, Pt/C	$LaMnO_4$	Pt/C	Pt/C	NiO
Electrical efficiency	45–60%	50–60%	40–60%	40–45%	45–55%
CHP efficiency	68–76%	79–87%	60–80%	85–90%	85%
Available fuel	Pure hydrogen	Natural gas, Hydrogen, CO, HC	Hydrogen	Natural gas, Hydrogen, LPG	Nature gas, Hydrogen, LPG
Oxidant	O_2	Air	Air	Air	Air
Sensitive impurity	S, CO_2	S	S, CO, NH_3	S	S
Electrolyte storage matrix	Asbestos	–	–	SiC	$LiAlO_2$
Lifetime (h)	8k	80k	80k	60k	20k
Stack output power (kW)	1–100	5–3000	1–100	150–400	300–1000
Start time	1–10min	>30min	1–5s	1–10min	>30min
CO tolerance	<10 ppm	<10%	<10 ppm (LT) <1% (HT)	<1%	<10%
CO_2 tolerance	<100 ppm	<10% (O^{2-}) <5% (H^+)	<15%	<15%	<15%
NH_3 tolerance	–	<0.5%	<0.1 ppm	<4%	

3. Definition of Environmental and Safety Constraints

3.1. CO_2 Emission from Ammonia Production

Ammonia is considered the low-carbon energy and expected to use in several industries, such as shipping, transport, and steel manufacturing. However, its production is heavily dependent on fossil fuels at moment. Today, global ammonia production accounting for around 2% (8.6EJ) of final energy consumption. Total direct emissions from ammonia production are currently 450 Mt CO_2, a footprint equivalent to South Africa's total energy system emissions [1]. In the Haber-Bosch steam methane reforming process, CO_2 is emitted in the process of decomposing feedstock hydrocarbons to produce H_2. fossil-based ammonia production causes global emissions of 0.5 Gt of CO_2 annually, or around 1% of total greenhouse emissions [2]. Moreover, indirect CO_2 emissions from ammonia production come from two main sources.

The first is from electricity generation, which occurs during the production of electricity used for ammonia production. Today, electricity generation still emits 436.1gCO_2/kWh on average worldwide [3]. However, since indirect CO_2 emissions from power generation depend on the technologies and fuels used in the power sector, CO_2 emissions will decrease as fossil fuels used for power generation are reduced towards net zero.

The second is the chemical reaction that takes place when urea-based fertilisers are applied to land. When ammonia reacts with carbon dioxide, it forms urea. Urea is the most widely used source of nitrogen fertilizer in the world. However, adding urea to soils during fertilization can lead to a release of carbon dioxide that was fixed during the industrial production process [4].

Ammonia is very promising in terms of climate impact, as the introduction of ammonia fuels would mitigate the CO_2 impact. However, studies quantifying the total societal cost of emissions, including air quality and climate impacts, indicate that the combined societal cost of combustion by-products is many times greater than the CO_2 impact [5]. Therefore, technologies using ammonia must be carefully designed to minimise these by-products, resulting only in the production of water and nitrogen, while capturing or consuming the residual nitrogen oxides, unburned ammonia and other harmful species in the process

3.2. NO_x Emission from Ammonia Use

Ammonia plays a critical role in the formation of PM2.5, a particle with a mass median aerodynamic diameter of less than 2.5 micrometres. Not only ammonia itself but also nitrogen oxides (NO_x) produced by oxidation reactions during the combustion of ammonia is important precursors of PM 2.5 formation in the atmosphere. PM2.5 penetrates through the lungs and further enter the body through the blood stream, affecting all major organs. Exposure to PM 2.5 can cause diseases both to our cardiovascular and respiratory system, provoking stroke, lung cancer and chronic obstructive pulmonary disease. Indeed, PM 2.5 is one of the leading environmental risk factors for premature deaths worldwide, including in Europe [6].

Besides air quality impacts, NO_x also results in soil and water pollution. Emitted NO_x is carried by the atmosphere and brought to the surface as acid rain. This can cause harm to terrestrial vegetation and adds to the reactive nitrogen load to water bodies. Excess nitrogen in water leads to rapid growth of algae beyond the capacity of the ecosystem to process it. Large increases in algal blooms have a negative impact on water quality, food resources and habitat, and reduce the oxygen needed for fish and other aquatic organisms to survive [7]. When NO_x and ammonia fall on natural land surfaces, for example from acid rain, they increase soil nutrient levels and contribute to acidification. This results in a nutrient imbalance with deficiencies of calcium, potassium and magnesium and an excess of nitrogen. Then plant diversity is reduced, with consequences for birds and other wildlife.

In some conditions, NO_x grounded on the surfaces is also emitted back into the atmosphere as dinitrogen monoxide (N_2O), which, like NOx, reinforces the greenhouse effect and contributes to climate change. A new study published in the journal Nature suggests that N_2O is counted as one of the significant GHG contributors and its effect to global warming is 300 times higher than CO_2 [8].

Therefore, the potential for residual or increased NO_x emissions as well as increased ammonia emissions has negative impact on air quality, land, water, and human health while the use of ammonia produced by carbon free hydrogen as fuel eliminates carbon-based emission by-products. Using ammonia as energy resource or fuel must consider the issue.

Finally, estimates of CO_2 and NO_x emissions from the ammonia production process and from ammonia combustion depend on the test set-up and conditions, the combustor temperature and the amount of hydrogen supplied, and in practical applications are largely dependent on engine power and combustion efficiency. For ammonia-fuelled engines, further research is needed to unify these estimates for different engine setups. Overall, NO_x emissions, which are higher at higher temperatures, need to be balanced with unburned ammonia emissions, which are higher at lower temperatures and richer mixtures. What balance is appropriate is related to the environmental non-linearity between NO_x and ammonia emissions mentioned above and requires further investigation.

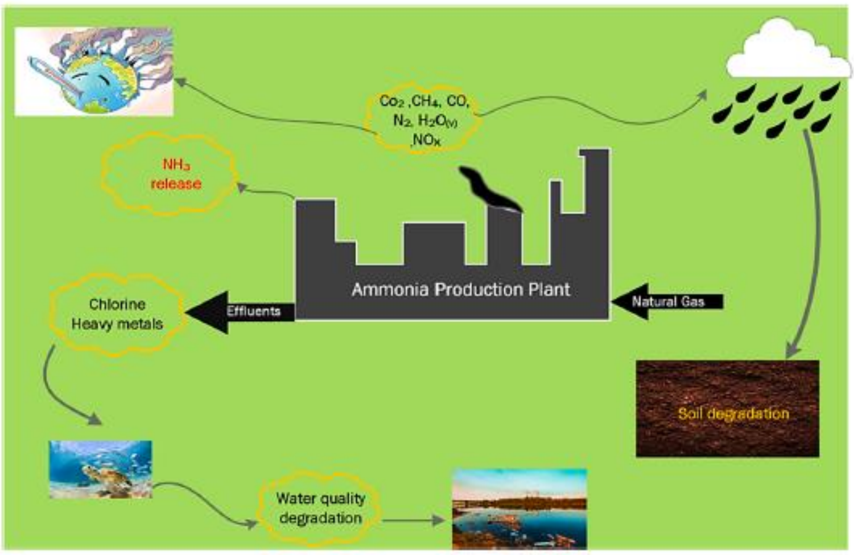

Figure 5. A schematic diagram for the impact of ammonia on surface water and marine life. [3]

4. Definition of Social Constraints

4.1. The Health Effect of Ammonia

Ammonia is extremely soluble in water, sucking water out of anything it encounters. It is also exothermic, so contact of ammonia with the eyes, skin, or mucous membranes of the oral cavity or respiratory tract can cause immediate and severe irritation symptoms and burns. Inhalation of high concentrations of ammonia gas causes pulmonary oedema and cessation of breathing.

According to US. National Institute for Occupational Safety and Health (NIOSH), the permissible exposure limit for ammonia is 50 ppm for 8 hours, and 300 to 500 ppm for 0.5 to 1 hour. A change in respiration rate and moderate to severe irritation has been reported when exposed to 500 ppm for 30 minutes [9].

To protect workers from high levels of ammonia exposure, the European committee regulates the occupational exposure limits at the risk of being exposed to ammonia by Directive 2000/39/EC. In the directive, the values for reference period of eight-hour time weighted average is limited to 20 ppm and for a short-term period of 15 minutes is 50 ppm.

4.2. Ammonia and Society

The industry has worked with ammonia for more than 150 years. Ammonia is used for fertilizer, for explosives, plastics, synthetic fibres and resins, refrigerants, and chemicals like nitric acid. Over time, our society has developed ways to use ammonia in safe conditions. However, ammonia accidents still occur today due to accident, negligence and mistakes.

Ammonia is flammable chemical but it only catches fire in the air at concentration between 16% and 25%, according to EPA [10]. In fact, severe explosion accidents involving ammonia is mainly due to hydrogen when producing ammonia, or ammonium nitrate fertilizer. The ammonia incidents considered are therefore all related to releases of ammonia and its toxic and corrosive effects.

One of the worst industrial accidents involving ammonia occurred in Dakar, Senegal, in 1992. It was occurred at a peanuts oil processing plant. Anhydrous ammonia was stored on the site in the portable tank that had been repaired in a previous year. However, the inappropriate repair led cracks on the tank surface and made overpressure inside the tank, resulting releasing 22mt of pressurized ammonia into the air. More than 110 deaths and 1150 injured were declared and most of those victims developed fatal pulmonary oedema in the days following the accident, due to inhaling ammonia near the site [11].

Europe produced 17 million tonnes of ammonia at 32 plants in 2020. Germany produces the most ammonia, followed by the Netherlands and Poland [12]. Most of the large production sites in these countries haven't had any ammonia incidents, yet several has been detected in other EU countries in the last 5 years. In 2022, the leakage of ammonia occurred at Yara's fertilizer plants in France. Ammonia cloud formed while filling a truck with liquid ammonia in the plant, injuring 14 workers [13]. The southeaster Serbian city of Pirot, declares emergency after cargo train carrying ammonia derailed and a fog and strong ammonia smell were reported [14].

Since 1985, over 85 ammonia incidents happened in the US. One of the significant incidents releasing ammonia was happened in Nebraska, US. In 1986, A train carrying several tank cars of anhydrous ammonia derailed at Crete, resulting in a collision between cars on the train, which split one of the three ammonia tank cars. It released 29,200 gallons of ammonia almost instantly. The incident has taken three Crete residents during the accident, another three died later in the hospital [15]. Another example of incidents was happened in Kentucky, US. A leak of anhydrous ammonia at the plant killed two workers. The leakage was discovered by one of the employees that described the vapers in the plant as too thick to see through [16]. In 2022, one person died after ammonia leakage from the food process plant in Massachusetts [17].

Due to the concern of its toxicity, backing up by those incidents, ammonia is often under criticize. The debate became heated about the cocoa factory Olam in the Netherlands with local media reporting in 2022 that the company has been using large quantities of ammonia for years, adding it to ground cocoa beans to give the powder its typical black colour. That cocoa powder is then bought by biscuit manufacturer Mondelez to make Oreo cookies. In the food industries, ammonia has been often used as the catalysis of alkalization. It is widely known and not illegal. However, the toxicity of ammonia and the fear of ammonia emissions from the factory confused the community and sparked much debate as the news spread. In the end, the accusation mainly aimed to that the factory had not disclose the information promptly to local resident and that the governments knew the emission [18].

Public activism against ammonia is growing too due to concerns about both soil and air pollution. Philip Lymbery, CEO of Compassion in World Farming, called ammonia as “a huge public health and environmental issue that needs to be tackled urgently” in a 2019 interview with the Guardian newspaper [19].
Governments in European states are also working to mitigate the pollution by nitrogen, mainly targeting agricultural sector. Caroline Lucas, the UK’s only Green Party MP, mentioned about her concerns about the pollution of the rural areas due to ammonia emission from livestock’s and fertilizers, and claimed to monitor beef and dairy farms. In Northern Ireland, ammonia emission by agricultural activities has significant negative impact to its soil and air, damaging sensitive species and affecting to its biodiversity. To tackle the problem, the government launched ammonia reduction target plan in 2023. It aims to reduce total agricultural ammonia emissions in Northern Ireland by at least 30% from 2020 levels by 2030 [20].

Reducing emissions of nitrogenous chemicals such as ammonia, on the other hand, is also resisted. When the Netherlands implemented the new government's target of a 50% reduction in domestic nitrogen emissions by 2030, there was a backlash from large farmers [21]. The Netherlands has a number of Natura 2000 areas, where certain species of animal and their natural habitats are protected in order to preserve the biodiversity. It’s obliged by the EU directive to limit the emissions of nitrogen in those area to an acceptable level but most of the area in the Netherlands exceed the limit and the source is mainly from agricultural sector. The target required the farmers to make significant changes to their farming practices. Farmers were, therefore, concerned that their business would suffer.

5. Technical and Regulatory Requirements of Ammonia Process and the Application of Products to Different Industries.

5.1. European Framework

Because of its toxicity and flammability, ammonia as product must be handled by established safety protocol. In Europe, ammonia producers, off-takers, and users must follow the regulations, directives, decision, and recommendations legislated by European Union. The aims set out in the EU treaties are achieved by several types of legal act. Some are binding, others are not. A "regulation" is a binding legislative act. It must be applied in its entirety across the EU. A "directive" is a legislative act that sets out a goal that all EU countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals. A "decision" is binding on those to whom it is addressed (e.g. an EU country or an individual company) and is directly applicable. Finally, A "recommendation" and An "opinion" are not building but are instrumental that would not have any legal consequence [22]. European Union has established several acts for handling dangerous goods, including Ammonia. Some of those laws are specific to ammonia, while others regulate it in groupings with other toxic and flammable liquids. These laws include general standards for ammonia storage containers, safety measurements in ammonia production facilities, and electrical equipment used in facilities.

For instance, directive 2014/34/EU describes the minimum safety requirements for workplaces and equipment used in explosive atmospheres as part of ATEX regulation. The directive applies to all equipment intended for use in explosive atmospheres, whether electrical or mechanical, including protective systems.

The transportation of dangerous goods in in-land Europe has been governed by ADR (the agreement concerning the international carriage of dangerous goods by road), by RID (the agreement concerning the international carriage of dangerous goods by rail) and ADN (European agreement concerning the international carriage of dangerous goods by inland waterway) for a half of century. These regulations was taken over by directive 2008/68/EC. This directive applies the international rules to transport of dangerous goods also at the national level. Both hydrogen and ammonia are classified to dangerous goods in ADR, RID, and ADN but those in the fuel tank are not.

Directive 2010/35/EU, EU transportable pressure equipment directive (TPED), establishes the rules, the safety requirements, and the conformity assessment procedure for transportable pressure equipment used exclusively for the transport of dangerous goods (Class 2) within EU, in accordance with directive 2008/68/EC. This directive is also applicable to hydrogen and ammonia as they are classified as a flammable gas under Class 2, which also includes Acetylene, Methane, and LPG.

Another Directive, 2014/68/EU, aims to ensure that pressure equipment is not dangerous to the safety or health of people or animals while installed, used and maintained.

Overall, those directives and regulations in EU are intended to only minimize risks associated with the use of ammonia and to control risk from explosion and fires in the working environments. But the nitrogen oxide (NO_x) emission due to combustion of ammonia also need to be considered as EU has set the standard of air quality for the protection of health, cooperating with WHO, and to achieve zero air pollution as part of the green deal by 2050. Directive 2008/50/EC sets threshold concentrations of pollutants that must not be exceeded within a certain period. The authorities must develop and implement air quality management plans to bring the concentration of air pollutants to a level below the limit or target.

Although those are not binding, the European committee of the international organization set the standards of the use of ammonia as EN standards. The purpose of EN standards is to harmonise technical rules and laws within the European market. In principle, The International Organization (ISO) and International Electrotechnical Commission (IEC) set international voluntary standards covering almost all aspects of technology and manufacturing. ISO standards must generally be adopted as EN standards in unaltered form. However, if an IEC standard is adopted as a European standard, its technical part has minor modifications as per EN requirements.

One of the examples is ISO 5771 that specifies the minimum requirements for rubber hoses used for transferring ammonia, in liquid or in gaseous form. This ISO standard has been adopted to European level and approved as EN ISO 5771.

Table 4 European Standard Ecosystem

	Mechanics	Electrical/Electrical Engineering
International Standard	International Organization for Standardization (ISO)	International Electrotechnical Commission (IEC)
European Standard (EN)	European Committee for Standardization (CEN)	European Committee for Electrotechnical Standardization (CENELEC)
National Standard (Spain)	Spanish Association for Standardization (UNE)	

Private international institutions also set the standards. ASTM international, which was founded in the US as American Society for Testing and Materials and then was developed as international organization beyond the US, issued Standard Practice for Ammonia Colorimetric Leak Testing as ASTM E1066M-19. This standard is useful for locating and measuring the size of gas leaks either as a quality-control test or as a field-inspection procedure. It can be used to test critical parts or containers that will hold toxic or explosive gases or liquids or as a quick test for other containers. Compressed Gas Association (CGA) is another example of private institutions that has developed safety standards and technical specifications for association members in gas-related industries. Through the guideline of CGA-G2.2, Guideline Method for Determining Minimum of 0.2% Water in Anhydrous Ammonia, CGA provides shippers and carriers with a guideline method of analysis to determine the presence of the minimum 0.2% by weight water content in anhydrous ammonia as required by the US Department of Transportation (DOT).

In the US, Occupational Safety and Health Administration (OSHA), a part of the United States Department of Labor, was established in 1970 to issue safety requirements that rule over different industries both in private and public sectors to protect their workers in hazard. OSHA published OSHA – 29 CFR 1910.111 - Storage and handling of anhydrous ammonia. This rule has been mainly for ammonia usage in refrigeration, but it covers from equipment and machinery including hose, tanks, and even motor vehicle used for the transportation of ammonia to operations in manufacturing and loading/unloading of ammonia. Safety management and emergency protocol in the workplaces to prevent or minimize the consequences of catastrophic releases of explosive chemicals are regulated by another OSHA guideline, OSHA – 29 CFR 1910.119.

The use of hydrogen and fuel quality of hydrogen are widely covered by several directives and standards. ISO 14687 states hydrogen quality requirements for PEM fuel cell road vehicle application. Hydrogen fuels are classified into various grades based on their intended end use and type of form. Gaseous hydrogen for power generation and heat generation is classified to Type 1/B, while gaseous hydrogen for PEM fuel cells for road vehicles is classified to type 1/D, which specified the maximum concentration of individual chemical contaminant to maintain fuel quality. According to this standard, ammonia shall not exceed 0.1ppm. Yet these regulations and standards does not mention the use of ammonia as a fuel for automobiles, railroads, and power generation.

To accelerate commercial use of ammonia beyond traditional industries, legislation, and standards for the use of ammonia as a fuel is under development.

Since 2020, the European Clean Hydrogen Alliance (ECH2A) has supported the development of a European framework and standards for hydrogen and hydrogen derivatives, including ammonia, to facilitate large-scale clean hydrogen business in the region. ECH2A published a report [23] in October 2021 that identified the lack of standards for hydrogen as a key barrier to the deployment of hydrogen technologies and applications. As a result, a dedicated working group on hydrogen standardization was established. Under this WG, there are several subgroups that are engaged in detailed discussions. However, most of the work tasks in ECH2A remain within the scope of gaseous or liquid hydrogen utilization and does not focus on Ammonia.

Governmental legislation to regulate ammonia fuels may finally be moving forward, albeit behind private institutions. Commissioner for Transport, Adina Vălean stated in the European Green Deal press release, 14 July 2021 that EU would help the transportation sector transition to a future-ready system with its three transport-specific initiatives – ReFuel Aviation, FuelEU Maritime and the Alternative Fuels Infrastructure Regulation [24].

After European Council adopted five laws in 2023 as part of the 'Fit for 55' package that would enable the EU to cut greenhouse gas emissions within the main sectors of the economy, revision of the Directive 2014/94/EU on alternative fuels infrastructure was introduced [25]. The revised directive proposed binding targets for electric vehicle charging points and hydrogen refuelling points, electric charging for stationary aircraft at airports and on-shore power supply for ships at ports. Remarkably, it defines ammonia as alternative fuel, as well as electricity and hydrogen. The directive orders the member states to draft national policy framework for the development of the market of alternative fuels in the transport sector and the deployment of the relevant infrastructure.

Technical standards of ammonia as fuel are also needed to be developed in depth. Ammonia Energy Association (AEA) has established the committee for setting out the standard of quality and the use of ammonia as fuel in vehicle. AEA completed the draft of ammonia fuel standard and presented in Ammonia Energy Conference in 2020 [26]. According to AEA, the grade of ammonia as fuel needs a new set of standards that should have high purity of ammonia, such as the quality of refrigeration (R-grade) ammonia at 99.995% purity and Commercial or Agricultural (C-grade) ammonia at 99.5% purity. MAN Energy Solution's preliminary marine fuel standard for ammonia is based on C-grade. MAN surmises the small amount of water content in ammonia (0.5% and above) would significantly improves the safety of storing the product due to reduction in corrosion stress cracking. Indeed, C-grade ammonia accounts for large share in the existing ammonia market. However, when ammonia is used for power generation, the appropriate purity may vary. Unification of ammonia storage methods, i.e., refrigerated or pressurized tanks, and whether it is stored and used in liquid or gaseous form, is also essential for the scandalization of ammonia fuel.

SAE international, an international organization developing technical standards for engineering, has published several technical papers regarding ammonia as fuel for gas turbine, diesel engine, and spark-ignition engine. In one of the reports, the organization points out major unsettled issues of using ammonia as an automotive fuel, including the lack of regulations and standards for automotive applications, technology readiness, safety perception, and presently limited supply [27].

While ammonia combustion engine is still under development, ammonia-based fuel cell has been carried out already. In January 2023, Amogy, a U.S. clean energy start-up, succeeded to test-drive of a semitruck running on its ammonia-based fuel cell platform [28]. The semitruck, having 900 kWh of total stored net electric energy, was tested for several hours after fuelling ammonia in 8 minutes. Amogy has been developing unique powerpack in which catalyst cracks ammonia into hydrogen and for direct integration into a fuel cell.

5.2. Spanish Framework

Spanish government has legislated several doctrines for ammonia. Because EU legislation applies in Spain with preference over domestic law as in other EU member state, the Royal Decree (RD), a legal rule in Spain, must conform to the EU rule. Many EU directives related to ammonia have been cascaded to the RD, so that producers and users of ammonia in Spain must comply with RD on ammonia that are nearly identical to EU directives. As mentioned, EU regulates the environment of ammonia production and storage facilities and equipment used in the facilities by stipulating the ATEX Directive in 2014, the minimum safety requirement for explosive atmosphere for the storage of ammonia. To comply with this, Spanish government established RD 144/2016 in 2016, a mandatory health and safety requirements for equipment and protection systems intended for use in potentially explosive atmospheres.

One of the remarkable regulations in Spain regarding the use of ammonia is RD 656/2017. RD 656/2017 regulates the storage of chemical products to cover several EU directives and standards for hazardous, flammable, toxic chemical products, with Supplementary Technical Instructions MIE APQ 0 to APQ 10. Of these, MIE APQ 4,5,6,7 must be considered for ARENHA project, particularly MIE APQ 4. MIE APQ 4 is the safety requirement and standard for storage of anhydrous ammonia and it specifies wider range of fields including location, distance from other facilities, and capacity of the storage (filling decree) for both refrigerated storage and non-refrigerated storage with pressure, security, maintenance, personal protection, and effluent treatment. The supplemental instruction applies to the storage of anhydrous ammonia in fixed containers, except for storage stations integrated within the process unit (Considered storage stations integrated within the process unit are containers with a capacity of less than 3,000 litters, directly connected to the process by piping, and fed to the process by suction pump or gravity). In this case, the capacity of the container must be limited to the amount required for a 48-hour process supply, considering the continuous process at maximum capacity. In addition to that, storage station integrated within the process units is defined as those in which the capacity of the vessels is less than 3,000 l and are connected directly to the process by piping, with the process being fed by the use of suction pumps or by gravity. Under MIE APQ 4, ammonia purity is specified as 99.5% or higher, complying to regulation EC No1272/2008. Storage shall be located outdoors and prohibited to be inside buildings. Also, mobile safety services shall be able to access storage from two opposite points, preferably according to the direction of prevailing winds. Minimum distance from ammonia storage facilities to both industrial and non-industrial environments must be considered. For instance, ammonia storages in fixed tanks need to be located at least 500m away from public facilities, and 200m away from residential area.

If hydrogen or ammonia is stored in mobile pressure vessel, MIE APQ 5 shall be applied. MIE APQ 5 is technical requirements for the storage and use of mobile pressure vessels containing compressed, liquefied, and dissolved gases under pressure and mixtures. This royal order specifies requirements for both open and closed warehouses where ammonia in mobile pressure vessels is stored, including location, ventilation, electrical installation, and example layout of mobile pressure vessel storage method.

Other supplementary instructions, MIE APQ 6 and 7, regulate storage of corrosive or toxic liquid in fixed vessel. Because ammonia is classified as both corrosive and toxic in EU regulation (CLP regulation), these laws also applied to ammonia storage. MIE APQ 6 states material and design of equipment used for storage, transportation, and manufacturing of ammonia as well as protection systems against environmental corrosion.

MIE APQ 7 is the instruction for storage of toxic liquid in fixed containers. Similar to APQ 6, this instruction defines the design and equipment used in the environment to prevent hazardous situations, with additional requirements such as the installation of a permanent identification plate with the manufacturer's name, year of construction, design density of the container, etc.

Regarding the use of ammonia as fuel for vehicles, neither the Spanish government nor the EU has directives to instruct the standard, except for the maritime industry. RD 61/2006 provides for the composition and the use of diesel, LPG, and biofuels for the transport sector in Spain, as well as for hazardous substances during combustion. However, it does not refer to ammonia fuel. To give the clear guideline of the use of hydrogen and ammonia as fuel, the directive should be revised or similar directive to RD61/2006 should be established.

RD 639/2016 established the minimum requirements for the creation of an infrastructure for alternative fuels, including recharging points for electric vehicles and refuelling points for natural gas and hydrogen. In the directive, “alternative fuel” includes electricity, hydrogen, CNG, LPG, LNG and biofuels, but again, it does not cover ammonia. Another RD, RD 919/2006 specifies the technical guideline of gaseous fuel receiving/suppling facilities. The RD is mainly for LPG usage and does not intend to use for hydrogen.

Greenhouse gas emission from the use of ammonia must also be considered. In 2013, Spain enacted the legislation to regulate industrial emissions and develop the prevention and integrated control of the pollution. This regulation, RD 815/2013, limits emissions of certain pollutants into the atmosphere from plants, including electric power generation facilities. Under the regulation, the maximum emission of NOx into the atmosphere is specified by a limit value(mg/Nm3), depending on the industrial activity and the size of the facilities, and the operators of facilities must comply with the limit value and submit an environmental impact assessment to the authority and must carry out an environmental impact inspection. The regulation also lists categories of activities and facilities that must comply with the royal decree to prevent pollution and control the emission. However, the generation of electricity from ammonia, such as an ammonia-fuelled SOFC system, is not regulated. This only applies where fossil fuel, waste or biomass combustion is used.

Like other European countries, Spain has its national standard for various sectors and technologies. In Spain, this is the UNE standard. UNE stands for “Spanish Association for Standardization”, which defines the criteria for each standard. Proven experts in their respective fields develop rules based on the latest technology and from an economic point of view, which are then ideally applied to all products and solutions. Today, the general aim is to harmonize national standards. Standards that are adopted at European level are marked with the EN standards, and vice versa. For instance, UNE 14620, which has been standardized since 2008, is the Spanish adaptation of the EN 14620 standard. This standard applies to the design and manufacture of cylindrical, vertical, and flat-bottomed steel tanks built on the site for the storage of refrigerated liquefied gases, including ammonia, with working temperatures between 0º and -165ºC.

6. Comparison to Existing Approaches and Policies

6.1. EU Policy for Ammonia as Energy Resource

Today, almost all hydrogen produced is used as a feedstock in the chemical and refining industries. Over 80% of hydrogen in Europe is used for refining, ammonia and methanol production [7]. However, the environmental and political situation in Europe suggests that hydrogen, together with ammonia, will become one of the key levers for decarbonisation in all major energy-consuming segments of the economy (power system, industry, transport and buildings).

In 2021, the EU Commission proposed the “Fit for 55 in 2030 package” [35]. This is the EU’s plan to reduce GHG emissions by at least 55% by 2030 compared to 1990 levels in line with the European Climate Law. The European climate law make these targets binding on the EU and its member states.

One of the main pillars of the Fit for 55 is the revision of the EU-ETS for phase 4(2021-2030). The EU-ETS has covered emissions of CO2, nitrous oxide(N2O), and perfluorocarbons (PFCs) from large energy-consuming industrial sectors, including electric power generation and steel manufacturing. The revised EU-ETS extends its policy to the maritime shipping, road transportation, and building sectors while reducing the number of emission allowances (EUAs) to increase the pace of emissions reductions from 2024.

To prevent carbon leakage, a situation in which companies in the EU move their production facilities or import products outside the EU to avoid EU-ETS taxation, the EU will implement Carbon Border Adjustment Mechanism (CBAM) scheme from 2023. CBAM will cover imports of hydrogen and ammonia as well as organic chemicals, plastics, and steel into the EU. Under the CBAM, companies importing these goods will need to obtain a permit from a CBAM authority and purchase a CBAM certificate to offset the difference between the carbon price paid in the country of production and the price of carbon allowances in the EU-ETS. During the transition period from 2023 to 2026, CBAM will only apply to direct emissions (Scope 1) resulting from the production of the goods. At the end of the transitional period, the Commission will re-evaluate whether to extend the scope of the CBAM should be extended to indirect emissions (Scope 2, 3) and to more products in the supply chain [30].

As part of the Fit for 55 packages, the EU also launched two initiatives- FuelEU maritime [31] and ReFuelEU aviation [32] initiatives – and the Social Climate Fund to support these policies. The main objective of these two initiatives is to encourage the transition to low-carbon fuels in these sectors by, for example, introducing GHG reduction targets, amending provisions on zero-emission technologies, and establishing rules on fines. Both the FuelEU Maritime and ReFuelEU Aviation initiatives clearly identify green hydrogen as a key low-carbon fuel, while the former also mentions e-methanol and green ammonia. The Social Climate Fund [33] promotes investments in energy efficiency and transformation to accelerate decarbonization in the road transport and buildings sectors, and will finance temporary direct income support for vulnerable households.

In 2022, the European Parliament reached a provisional agreement on the REPowerEU proposal which aims to diversify the EU’s energy supply and to produce more clean energy [34]. While the EU ETS stems from the 1997 Kyoto Protocol, the first international treaty that set targets for countries to reduce greenhouse gas emissions and established the carbon market to combat climate change, REPowerEU focuses on reducing its dependence on Russian fossil fuels through its 300 billion EUR fund. The plan includes a hydrogen strategy that scales up demand and supply even faster and higher than in the 2020 hydrogen strategy. The REPowerEU aims to produce 10 million tonnes of clean hydrogen in the EU and import 10 million tonnes of renewable hydrogen, including 4 million tonnes of "hydrogen as ammonia", from third countries by 2030.

Given the need to accelerate the EU's clean energy transition, the European Parliament revised the Renewable Energy Directive (2009/28/EC) in March, 2023 [35]. It increased the European renewable energy target to minimum of 42.5%, but aiming for 45% by 2030.

Currently, using ammonia for energy purpose is not discussed in detail in these European policies compared to hydrogen. The EU hydrogen strategy adopted in 2020 aims to implement 20 actions, including facilitating the use of hydrogen and its derivatives in the transport sector in the region [36]. However, ammonia is only mentioned as one of the hydrogen carriers or ends uses of hydrogen. One of the objectives of the RePowerEU plan is to use the existing natural gas infrastructure for hydrogen. But there is no mention of using it for green ammonia.

The International Maritime Organization (IMO) has been working to develop safety guidelines for the use of ammonia as fuel [37]. However, there are several challenges that the industry must overcome. As mentioned in the previous chapter, the technical standard for ammonia as a fuel is still under discussion. The risk of spillage needs to be considered, but is not currently covered by MARPOL Annex I or II. The main concern is that the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code) does not cover ammonia as a fuel. If the ship carries ammonia and uses it as fuel, it must comply with the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) but it identifies ammonia as a toxic product and prohibits the use of toxic cargo as a fuel. Draft interim guidelines for the safety of ships using ammonia as fuel are currently being developed.

On the other hand, investment in green ammonia projects continues, mainly for use as raw materials for fertilizer and to supply the maritime shipping industry as a fuel. According to IEA, 14 green ammonia projects with over 2,000GW are underway worldwide [7]. 5 of these projects have already completed feasibility studies.

6.2. Spanish Policy for Ammonia as Energy Resource

Over the past few years, Spain has adopted several renewable energy policies and laws to promote the development of renewable energy in the country.

In 2021, the Spanish government proposed the Integrated National Energy and Climate Plan 2021-2030 to meet the Paris Agreement and the European Green Deal. The main objectives of the plan are to reduce GHG emissions by 23% compared to 1990 levels, to cover 42% of energy consumption with renewable energy sources, to generate 74% of the national electricity supply from renewable energy sources, and to improve energy efficiency by 39.5% by 2030 [38]. The long-term goal of the plan is to make Spain carbon neutral by 2050. The plan was then incorporate into Spanish law and published with additional regulations. For example, it requires municipalities with a population of 50,000 or more to adopt a sustainable urban mobility plan by 2030 that includes measures to reduce emissions from mobility by promoting the use of alternative fuels, including green hydrogen and ammonia [39]. The government estimates that over 100GW of renewable energy capacity will be needed to meet the target, almost double the 2020 levels.

At same time, the government released 'National Hydrogen Roadmap: A Commitment to Renewable Hydrogen'. It is intended to not only meet the objectives set out in the Integrated National Energy and Climate Plan but also gain economic recovery from the coronavirus pandemic by building a greener and digitalized economy. The roadmap targets to install, by 2030, 4GW capacity of electrolysers, to gain the share of green hydrogen at least 25% in total hydrogen consumption, to deploy hydrogen-powered fleet of 150-200 buses; around 5 to 7,000 light and heavy freight vehicles; 2 commercial train lines; and the installation of at least 100-150 hydrogen refuelling stations of public access [40].

It is estimated that around 8.9 billion EUR will be required between 2020 and 2030 to achieve the target. The prime minister already announced in November 2020 that Spain would spend 1.5 billion EUR over the next 3 three years to develop green hydrogen production [41]. The budget will be funded mainly by European Recovery and Resilience Facility from the Coronavirus Pandemic ('Next Generation EU').

Stimulated by these policies, both industries and governments set off investing in green hydrogen and ammonia. Iberdrola, a large Spanish electricity company, plans to launch 175 projects ranging from green hydrogen to smart power grids with the support of the Next Generation EU program and the European Investment Bank Fund (EIB fund). The total investment required for the projects exceeds 30 billion euro, of which more than 2.5 billion EUR would be allocated to the green hydrogen business, including the production of 60,000 tonnes of green hydrogen per year, equivalent to 25 % of the national target (4 GW installed by 2030), and the adaptation of green hydrogen as fuel for heavy urban transport, logistics, and ports. The company has already carried out the development of 830MW of green hydrogen plants in Puertollano and Palos de la Frontera with Fertiberia to produce green ammonia for fertilizers.

In Aragon, Fertiberia, Enagás, Naturgy, Copenhagen Infrastructure Partner, and Vestas are developing large-scale green hydrogen production plant. The project, called the Catalina Project, will have 1.7GW of renewable energy and 500MW electrolysers that will produce 40,000 tonnes of green hydrogen per year. The hydrogen will be transported through a pipeline to Fertiberia's newly built ammonia plant in Valencia, which will produce 200,000 tonnes of green ammonia per year [42].

Fertiberia has also joined in the HyDeal Espana project, a first implementation of the HyDeal ambition platform, which covers the entire green hydrogen value chain from upstream to downstream and brings together 30 companies. Through this project, Fertiberia, together with ArcelorMittal, will acquire 6.6 million tonnes of renewable hydrogen over the next 20 years [43].

Spain and the Netherlands are actively working to establish renewable hydrogen corridor. In February 2023, Cepsa, a Spanish oil and gas company, signed a contract with to supply green ammonia to the terminal in the port of Rotterdam [44]. Cepsa is currently developing new green hydrogen plants with a total capacity of 2GW of electrolysers in Andalusia, southern Spain, and will export the hydrogen as ammonia. The ammonia would be converted back into hydrogen for industry or used directly as a fuel for shipping in north-western Europe. Cepsa has also agreed a strategic partnership with Yara to establish the first green hydrogen maritime corridor between the ports of Algeciras and Rotterdam in June 2023 [45].

The port of Bilbao and Amsterdam signed a memorandum of understanding, together with the Energy Agency of the Basque Government (EVE), Petronor, SkyNRG, Evos Amsterdam and Zenith Energy Terminals, to create a renewable hydrogen supply chain between the ports. In Bilbao, Repsol, a Spanish energy and petrochemical company, has produced renewable hydrogen using biomethane as a feedstock [46]. Repsol is planning to invest a total of 2.5 billion EUR to install 1.9 GW of renewable hydrogen by 2030, and to develop an e-fuel plant with Saudi Aramco in Bilbao [47].

6.3. Subsidies and Fund Instrument

In Europe, several funds, both private and public, have been set up to promote a shift away from fossil fuels in the energy and transport sectors, with the aim of achieving carbon neutrality by 2050.

With a budget of 95.5 billion EUR, Horizon Europe Fund will support research and innovation over 7 years to tackle climate change, help achieve the UN's Sustainable Development Goals, and boost EU's competitiveness and growth. The fund has 3 pillars, with pillar II covering 6 clusters. Among those 6 clusters, cluster 5 'Climate, Energy & Mobility' funds projects that contribute to research and innovative solutions for greener society, including renewable energy systems, energy storage, carbon capture, and zero-emissions mobility. It has a budget of 15 billion EUR (including 1.35 billion EUR from NextGenerationEU). Funding opportunities are provided through joint program partnerships such as the

Clean Hydrogen Partnership or Clean Hydrogen Joint Undertaking (CHJU), Zero Emission Waterborne Transport Partnership (ZEWT), Process for Planet Partnership (P4P) [48].

The CHJU aims to scale up the development and deployment of the European value chain for safe and sustainable clean hydrogen technologies and to strengthen its competitiveness in order to support business, especially SMEs. There are currently 9 ammonia-related projects awarded by CHJU [49]. The TOWERPOWR project aims to demonstrate fuel cell-based integrated generator systems to power off-grid mobile phone towers, using ammonia fuel. The AMON project will develop an innovative system to convert ammonia into electricity using a solid oxide fuel cell. The main focus of the project is the design of the critical components, such as the fuel cell, ammonia cracker, ammonia burner, and anode gas recirculation.

The ZEWT is a public-private partnership between the EU Commission and the Waterborne Technology Platform (WTP) 36, which has members from both the maritime and inland waterway sectors. The partnership focuses, for example, on enabling the safe and efficient on-board storage and integration of large quantities of ammonia and hydrogen fuel in ships, and demonstrating the feasibility of a large clean ammonia marine engine [50].

Established between A. SPIRE and the EU Commission, the P4P partnership aims to transform EU's process industries to achieve circularity and climate neutrality by 2050 with a total budget of 2.6 billion EUR (among which 1.3 billion EUR in grants from Horizon Europe). The P4P will support emerging technologies and the scaling up of higher TRL solutions to deliver expected CO_2 emission reductions by 2030. One of the projects, HyinHeat, aims to integrate hydrogen as a fuel for high-temperature heating processes in energy-intensive industries, particularly in the aluminium and steel sectors [51].

Pillar III addresses innovation performance, innovation transfer and innovation scale-up in Europe. It has 3 initiatives: European Innovation Council (EIC), European Innovation Ecosystems (EIE), and European Institute of Innovation and Technology (EIT).

The EIC has a budget of 10.1 billion EUR for the period 2021-2027, and runs 3 programs: EIC Pathfinder to support breakthrough technologies and game changing innovations, EIC Transition to validate technologies and develop business plans for specific applications, EIC Accelerator to support small and mid-sized enterprises to bring their innovations to market and scale up [52]. The development of ammonia as a fuel is one of the objectives of the EIC pathfinder Challenge: Carbon dioxide and nitrogen management and valorisation, which focuses on converting CO_2 and nitrogen into valuable products.
While the EIC is intended to support all stages of innovation from research and development, the EIE is to stimulate ecosystems conducive to technological innovation by setting up joint programs among innovation ecosystems actors, fostering and retaining deep-tech talent, and providing specialist advisory services to build capacities on innovation procurement [53].

The EIT is an independent body of the EU to stimulate knowledge and innovation communities. Although the EIT is not part of the specific programs in Horizon Europe, it contributes to the achievement of some key strategic orientations of the Horizon Europe Strategic Plan such as fostering the development of entrepreneurial and innovation skills and supporting the entrepreneurial transformation of EU universities.

The EU Innovation Fund (IF) is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies. The IF will provide around 10 billion euro of support over the period of 2020-2030 for both small- and large-scale projects in Europe, with the aim of bringing industrial solution to the market to decarbonise the region and support its transition to climate neutrality [54]. However, as the IF is funded by the monetisation of 530 million ETS allowances in addition to the unspent funds from the NER300 program, the predecessor of the IF, the total funding of the IF depends on the carbon price and could amount to over 40 billion EUR between 2020 and 2030, calculated by using a carbon price of €75/tCO2 [55]. Up to now, already 2 green-ammonia projects and many hydrogen projects have been selected by the IF.

The EIB has invested over 1.6 billion EUR in 19 green hydrogen projects, including Iberdrola green hydrogen project, through EIB fund over the last 5 years. The EIB is one of the world's largest green-finance institutions. It was also the first EIB in the world to issue green bonds in 2017. The Bank has also provided advisory support to projects.

Since 2021, the EIB group has organized the InvestEU program. It builds on the success of the European Fund for Strategic Investments (EFSI) and contributes to the climate and environmental goals of the EU through the InvestEU fund. InvestEU is expected to mobilise at least 372 billion EUR in additional investment between 2021-27. At least 30% of the investment will support the objectives of the European Green Deal, while creating and supporting jobs across the EU.

While the EIB fund mainly focuses on large-scale projects, the InvestEU fund provides financing to small and medium-sized enterprises. It has already approved 5 green hydrogen projects.

The Connecting Europe Facility (CEF) is a key EU funding instrument for growth, jobs and competitiveness through targeted investments in European infrastructure. The CEF has a total budget of 33.71 billion EUR from 2021 to 2027 for its three main action areas: transport, energy and digital [56].

CEF-Transport aims to support investments of 25 billion EUR in the construction of new transport infrastructure in Europe or the rehabilitation and upgrading of existing infrastructure, as well as innovation in the transport system, in order to improve the use of infrastructure, reduce the environmental impact of transport, enhance energy efficiency and improve safety. Moreover, with a total budget of 1.5 billion EUR, CEF-T also establishes the Alternative Fuels Infrastructure Facility (AFIF) to support the deployment of alternative fuel supply infrastructure, including green hydrogen and ammonia hubs, and contribute to the decarbonization of the transport sector [57].

Since its launch in 2014, CEF-Energy has supported more than 90 projects in the electricity, gas, smart-grid, and CO_2 network sectors. It continues to support infrastructure development in Europe with a budget of 5 billion EUR between 2021 and 2027 [58].
Both CEF-Transport and CEF-Energy have selected more than 150 green hydrogen projects in total, from production to use as a fuel.

Through the Green Climate Fund (GCF), the United Nations is helping developing countries meet the goals of the Paris Agreement. Established by the United Nations Framework Convention on Climate Change (UNFCCC), the GCF helps developing countries transform their economies and societies in response to climate change. The fund contributes to low-emission or climate-resilient projects, including the deployment of hydrogen fuel in Latin America and the Caribbean. By the end of 2021, the GCF portfolio will have 10 billion USD in GCF resources with 190 projects in 127 countries [59].

The Global Environment Facility (GEF) is a multilateral environmental fund that provides grants and blended finance for projects related to biodiversity, climate change, international waters, land degradation, and persistent organic pollutants [60]. The GEF is based on a partnership with 18 implementing organizations, including the World Bank, United Nations Development Program (UNDP) and United Nations Environment Program (UNEP). The GEF has already committed to total of 44 million USD to 5 green hydrogen projects around the world. One of the projects aims to demonstrate hydrogen fuel cell buses in Brazil, India, China, Egypt and Mexico [61].

Most of these fundings have been implemented in the last 5 years following the adoption of the Paris Agreement. Due to the devastating extreme weather events caused by climate change, the EU and international organisations are being urged to provide funding to mitigate and adapt to its effects. Hydrogen projects have been widely applied for and approved by these funds. However, funding for green ammonia energy is lower than for hydrogen projects, partly because ammonia fuel projects are less developed than hydrogen projects.

7. Conclusion - Guidance to new policies to be implemented.

As mentioned above, the use of ammonia as a fuel is a potential solution to achieve carbon neutrality, but there are several barriers. CO_2 emissions from ammonia production can be solved by replacing fossil fuels with green hydrogen. However, NO_x emissions as a result of ammonia combustion will be considered due to the environmental pollutions concerns, and therefore, technical regulations to limit excessive NOx emissions during the combustion must be provided.

The establishment of quality standards for ammonia fuels will play an important role in promoting the widespread use of ammonia fuels. International organisations should work closely with the ammonia fuel industry to legislate laws and/or standards as soon as possible. At the same time, government agencies should also work with organizations and the industry to develop regulatory requirements for ammonia fuel, in particular design and safety measures for equipment, engines and electrical systems to protect stakeholders from its toxicity. It is essential for the government, the organization, and the industry to corporate with each other in order to promote ammonia fuel in the society.

The most important policy is closing significant costs gaps between brown and green ammonia production. There are also many technical barriers affecting the infrastructure of green ammonia. One important barrier is the need of hydrogen for ammonia production, thus, developing direct synthesis ways could be a significant step towards minimizing the costs of the synthesis process. Supporting green ammonia production in countries with plenty of renewable energy sources is also a policy that should be boost to achieve the zero emission goals framework.

Finally, governments must have a communication strategy to positively influence public perception of ammonia and to develop a society that accepts ammonia fuel for its net-zero goal. Disseminating accurate information about the potential of green ammonia as a sustainable energy resource, together with its toxicity and environmental impact, will foster a deeper understanding of ammonia and increase the interest in the use of ammonia as fuel, which in turn will encourage investment and development in ammonia fuel.

8. References

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9. APPENDIX I: List of Global and European Hydrogen/Ammonia Regulations and Guidelines Associated with the ARENHA Project.

Institutions	Region	Normative	Enactment	Category	Title	Description
The European Law	EU	1999/92/EC	1999	D	Risks from explosive atmospheres	This Directive lays down minimum requirements for improving the safety and health of workers potentially at risk from explosive atmospheres.
The European Law	EU	2006/42/CE	2006	D	Machinery Directive	This Directive aims at the free market circulation on machinery and at the protection of workers and consumers using such machinery. It defines essential health and safety requirements of general application, supplemented by a number of more specific requirements for certain categories of machinery.
The European Law	EU	2008/50/EC	2008	D	The Ambient Air Quality Directives	This directive limits sulphur dioxide, NO_2 and other oxides of nitrogen, particulate matter (PM10, PM2,5), lead, benzene and carbon monoxide emissions from 2010. Hourly average emissions of NO2 are limited 200 µg/m^3 which may not be exceeded more than 18 times per year, and yearly to 40 µg/m^3 [1] As of 2018 several EU member states are being sued for violating the limits.
The European Law	EU	2008/68/EC	2008	R	Inland transport of dangerous goods	This Directive establishes a common regime for all aspects of the inland transport of dangerous goods, by road (ADR), rail (RID), and inland waterway (AND)
The European Law	EU	2010/35/EU	2010	R	Transportable pressure equipment	This Directive applies to: (a) new transportable pressure equipment as defined in Article 2(1), which does not bear the conformity markings provided for in Directives 84/525/EEC, 84/526/EEC, 84/527/EEC or 1999/36/EC, for the purpose of making it available on the market. (b) transportable pressure equipment as defined in Article 2(1), bearing the conformity markings provided for in this Directive or in Directives 84/525/EEC, 84/526/EEC, 84/527/EEC or 1999/36/EC, for the purposes of its periodic inspections, intermediate inspections, exceptional checks and use. (c) transportable pressure equipment as defined in Article 2(1), which does not bear the conformity markings provided for in Directive 1999/36/EC, for the purposes of reassessment of conformity. This Directive does not apply to transportable pressure equipment which was placed on the market before the date of implementation of Directive 1999/36/EC and which has not been subject to a reassessment of conformity. This Directive does not apply to transportable pressure equipment used exclusively for the transport of dangerous goods between Member States and third countries, carried out in accordance with Article 4 of Directive 2008/68/EC.
The European Law	EU	2012/18/EU	2012	D	Control of the risks inherent to major	This Directive establishes rules for the prevention of serious accidents involving dangerous substances, as well as for the limitation of their consequences on human

Category: R(Regulations),D(Directive),S(Standards), N(Recommendation)
"Regulation" is a binding legislative act. "Directive" is a legislative act that sets out a goal that all members must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals.

Institutions	Region	Normative	Enactment	Category	Title	Description
					accidents hazard involving dangerous substances	health and the environment, with a view to consistently and effectively ensuring a high level of protection throughout the Union. The Directive aims to prevent such accidents and minimize their risks. All EU countries are obliged to introduce measures at national and company level to prevent serious accidents and to ensure adequate preparedness and response should an accident occur. Under this Directive, establishments where industrial processes involving hazardous substances are carried out are subject to reporting requirements to the relevant Member State national authorities. For example, each company must meet safety and environmental requirements, produce safety report, draw up major accident prevention policy, and inform the inventory of dangerous goods to the authorities
The European Law	EU	2014/30/EU	2014	D	Harmonisation of the laws of the Member States relating to electromagnetic compatibility	The EMC Directive (2014/30/EU) aims to ensure that any electrical and electronic equipment minimizes the emission of electromagnetic interference that may influence other equipment. The directive also requires equipment to be able to resist the disturbance of other equipment.
The European Law	EU	2014/34/EU	2014	D	Harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres, replacing with ATEX 94/9/EC	The guidelines clarify certain matters and procedures regarding the relevant equipment and protective systems which are used in potentially explosive atmospheres. The guide's objective is to help find a common understanding of the Directive and its provisions among government representatives, stakeholders and interested parties such as manufacturers, trade associations and bodies in charge of establishing standards.
The European Law	EU	2014/35/EU	2014	D	Harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment	The low voltage directive (LVD) (2014/35/EU) ensures that electrical equipment within certain voltage limits provides a high level of protection for European citizens, and benefits fully from the single market. It has been applicable since 20 April 2016. The low voltage directive covers health and safety risks on electrical equipment operating with an input or output voltage of between: - 50 and 1000 V for alternating current - 75 and 1500 V for direct current

Category: R(Regulations),D(Directive),S(Standards), N(Recommendation)
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Institutions	Region	Normative	Enactment	Category	Title	Description
					designed for use within certain voltage limits	
The European Law	EU	2014/68/EU	2014	D	Harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment	The Directive concerns manufacturers of items such as vessels pressurised storage containers, heat exchangers, steam generators, boilers, industrial piping, safety devices and pressure. The manufacturer must ensure that his products are assessed with regard to conformity to the provisions of the Directive before they are being placed at the market. Manufacturers, importers and distributors are responsible for the compliance of their products with this law. Manufacturer information must be provided with the product. Applies to pressure equipment (vessels, piping, safety devices, accessories) with a maximum allowable pressure PS exceeding 0.5 bar (0.05 MPa). The categorization of the equipment will depend on the type of process fluid, the pressure and the volume of the equipment, defined in annex II of the regulation. It contains the bases to obtain the CE certificate of conformity.
American National Standards Institute	USA	API RP 941	2016	N	Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants	This recommended practice (RP) summarizes the results of experimental tests and actual data acquired from operating plants to establish practical operating limits for carbon and low alloy steels in hydrogen service at elevated temperatures and pressures. The effects on the resistance of steels to hydrogen at elevated temperature and pressure that result from high stress, heat treatment, chemical composition, and cladding are discussed.
American National Standards Institute	International	ASME B31.12	2019	S	Hydrogen Piping and Pipeline Code Design Rules and Their Interaction With Pipeline Materials Concerns, Issues and Research	This standard on Hydrogen Piping and Pipelines contains requirements for piping in gaseous and liquid hydrogen service and pipelines in gaseous hydrogen service. The general requirements section covers materials, brazing, welding, heat treating, forming, testing, inspection, examination, operating, and maintenance. The industrial piping section covers requirements for components, design, fabrication, assembly, erection, inspection, examination, and testing of piping.
American National Standards Institute	International	ASME B31.3	2018	S	Process Piping	It contains requirements for piping typically found in petroleum refineries; chemical, pharmaceutical, hydrogen, textile, paper and pulp, power generation, semiconductor, and cryogenic plants; and related processing plants and terminals. It covers materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping.

Category: R(Regulations),D(Directive),S(Standards), N(Recommendation)
"Regulation" is a binding legislative act. "Directive" is a legislative act that sets out a goal that all members must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals.

Institutions	Region	Normative	Enactment	Category	Title	Description
						This Code applies to piping for all fluids including: - raw, intermediate, and finished chemicals. - petroleum products. - gas, steam, air and water. - fluidized solids. - refrigerants. - cryogenic fluids.
American Society of Mechanical Engineers	International	ASME BPVC.VIII.1	2023	N	Construction of Pressure Vessels to meet ASME's Boiler and Pressure Vessel Code (BPVC)	The requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures exceeding 15 psig. Such pressure vessels may be fired or unfired. Specific requirements apply to several classes of material used in pressure vessel construction, and also to fabrication methods such as welding, forging and brazing. It contains mandatory and nonmandatory appendices detailing supplementary design criteria, non-destructive examination and inspection acceptance standards. Rules pertaining to the use of the U, UM and UV ASME Product Certification Marks are also included.
American Society for Testing and Materials	International	ASTM A213	2021	S	Tubing Standard Specification	ASTM A213 covers seamless ferritic and austenitic steel boiler, superheater, and heat-exchanger tubes, designated Grades T5, TP304, etc. Grades containing the letter, H, in their designation, have requirements different from those of similar grades not containing the letter H. These different requirements provide higher creep-rupture strength than normally achievable in similar grades without these different requirements. The tubing sizes and thicknesses usually furnished to this specification are 1⁄8 in. [3.2 mm] in inside diameter to 5 in. [127 mm] in outside diameter and 0.015 to 0.500 in. [0.4 to 12.7 mm], inclusive, in minimum wall thickness or, if specified in the order, average wall thickness. Tubing having other diameters may be furnished, provided such tubes comply with all other requirements of this specification General use A213/SA213 alloy tubing grades are T5, T9, T11, T12, T22, T91, stainless tubing is TP304/304L, TP316/316L.
American Society for Testing and Materials	International	ASTM A269	2013	S	Standard Specification for Seamless and Welded Austenitic Stainless-Steel Tubing for General Service	This specification covers nominal-wall-thickness, seamless and welded austenitic steel tubing for general corrosion-resisting and low- or high-temperature service. All material shall be furnished in the heat-treated condition. The steel shall conform to the chemical composition requirements. Different mechanical test requirements that includes, flaring test, flange test, hardness test, and reverse flattening test are presented. Also, each tube shall be subjected to the non-destructive electric test or the hydrostatic test. Finally, the hardness requirements for different grades of tubes are highlighted.

Category: R(Regulations),D(Directive),S(Standards), N(Recommendation)
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American Society for Testing and Materials	International	ASTM E1066M-19	2019	S	Standard Practice for Ammonia Colorimetric Leak Testing	This method is useful for locating and measuring the size of gas leaks either as a quality-control test or as a field-inspection procedure. It can be used to test critical parts or containers that will hold toxic or explosive gases or liquids or as a quick test for other containers. The practice covers the testing of large single- and double-walled tanks, pressure and vacuum vessels, laminated, lined- or double-walled parts, complex piping systems, flexible containers (such as aircraft fuel tanks), glass-to-metal seals in hybrid packages, and systems that inherently contain or will contain ammonia (such as large tonnage refrigeration systems and fertilizer storage systems).
Compressed Gas Association	International	CGA-G2.2	2016	N	Guideline Method for Determining Minimum of 0.2% Water in Anhydrous Ammonia	This publication is intended to provide shippers and carriers with a guideline method of analysis to determine the presence in anhydrous ammonia of the prescribed minimum water content of 0.2% by weight as required by DOT regulations. Lack of the appropriate percentage of water in single loads of ammonia has been found by experience to result in extensive stress corrosion damage to the QT cargo tanks. This method is intended for field use and thus the equipment and procedure selected may vary slightly from that used under laboratory conditions.
Compressed Gas Association	International	CGA-G5 Hydrogen		S	Standards for hydrogen pipeline/venting system	This publication covers the design, fabrication, installation, and operation of vent system. The design of vent systems includes: - Hydrogen properties and how they impact vent stack design and operation - Sizing methodology, including how to determine reaction forces from vent discharges - Special requirements for designing vent stacks for cryogenic storage tanks - How to design vent stacks to maintain mechanical integrity in a hydrogen deflagration or detonation The fabrication and installation of vent systems includes: - Methods to drain water from stacks and avoid creating an ice blockage - Examples of preferred methods of connecting vent lines to stacks as well as configurations to avoid - Examples of preferred and non-preferred vent stack rain covers - How to ground a hydrogen vent stack and piping connected to the stack to avoid problems from lightning and static electricity The operation of hydrogen vent systems includes: - How to deal with thermal radiation from vent stack ignitions - Where to locate vent stacks in terms of equipment and personnel - Best practices for operating, maintaining, and repairing a hydrogen vent stack, including the safe use of isolation valves on vent lines

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European Industrial Gas Association	International	EIGA P15/21	2021	N	Gaseous Hydrogen Installations	Private members' association
European Committee for Standardization	EU	EN 1012-3	2013	S	Compressors and vacuum pumps - Safety requirements - Part 3: Process compressors	It is applicable to process gas compressors and process gas compressor units having an operating pressure greater than 0,5 bar (gauge), an input shaft power greater than 0,5 kW and designed to compress all gases other than air, nitrogen or inert gases which are covered in Part 1. This document deals with all significant hazards, hazardous situations and events relevant to the design, installation, operation, maintenance, dismantling and disposal of process gas compressors and process gas compressor units, when they are used as intended and under conditions of misuse which are reasonably foreseeable by the manufacturer
European Committee for Standardization	EU	EN 1127-1	2019	S	Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology	It specifies methods for the identification and assessment of hazardous situations leading to explosion and the design and construction measures appropriate for the required safety. This is achieved by: - risk assessment; - risk reduction. The safety of equipment, protective systems and components can be achieved by eliminating hazards and/or limiting the risk,
European Committee for Standardization	EU	EN 13480-3	2017	S	Metallic industrial piping - Part 3: Design and calculation (includes Amendment A1:2021)	Specifying the design and calculation of industrial metallic piping systems. -This publication is applied when hydrogen/ammonia pass through by metal pipe
European Committee for Standardization	EU	EN 13807	2017	S	Transportable gas cylinders - Battery vehicles and multiple-element gas containers (MEGCs) - Design, manufacture, identification and testing	It is applicable to battery vehicles containing compressed gas, liquefied gas and mixtures thereof. It is also applicable to battery vehicles for dissolved acetylene. This European Standard is not applicable to toxic gases with an LC50 value less than or equal to 200 ml/m3.

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European Committee for Standardization	EU	EN 13849-1	2016	S	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design	Where a hazard referred to in Annex I of the Directive is covered in whole or in part more specifically in machines by another Community Directive, this Directive shall cease to apply or cease to apply to such machines in respect of that hazard from the date of implementation of the other Directive.
European Committee for Standardization	EU	EN 14620	2008	S	Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C -	This document is a specification for vertical, cylindrical tank systems, built on site, above ground and of which either the primary liquid container or the liquid tight barrier is made of steel. The secondary liquid container, if applicable, can be of steel or of concrete or a combination of both. A primary liquid container made of pre-stressed concrete is excluded from the scope of this document. Typical products stored in the tank systems are: methane, ethane, propane, butane, ethylene, propylene, butadiene (this range includes the Liquefied Natural Gas (LNG's) and Liquefied Petroleum Gas (LPG's)), ammonia, nitrogen, oxygen and argon.
European Committee for Standardization	EU	EN 15653	2009	S	Metallic materials - Method of test for the determination of quasistatic fracture toughness of welds	This regulation specifies methods for determining fracture toughness in terms of stress intensity factor (K), crack tip opening displacement or CTOD (δ) and experimental equivalent of the J-integral for welds in metallic materials (J). This document complements ISO 12135, which covers all aspects of fracture toughness testing of parent metal and which needs to be used in conjunction with this document
European Committee for Standardization	EU	EN 17127	2020	S	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols	This document defines the minimum requirements to ensure the interoperability of hydrogen refuelling points, including refuelling protocols that dispense gaseous hydrogen to road vehicles (e.g. Fuel Cell Electric Vehicles) that comply with legislation applicable to such vehicles. The safety and performance requirements for the entire hydrogen fuelling station, addressed in accordance with existing relevant European and national legislation, are not included in this document.
European Committee for Standardization	EU	EN 60079-0	2021	S	Electrical apparatus for explosive	Electrical apparatus for explosive atmospheres. General requirements EN-IEC 60079-0 specifies the general requirements for construction, testing and marking of Ex Equipment and Ex Components intended for use in explosive

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					atmospheres. General requirements	atmospheres. The standard atmospheric conditions (relating to the explosion characteristics of the atmosphere) under which it may be assumed that Ex Equipment can be operated are: - temperature -20 °C to +60 °C; - pressure 80 kPa (0,8 bar) to 110 kPa (1,1 bar); and - air with normal oxygen content, typically 21 % v/v. This part of IEC 60079 and other standards supplementing this standard specify additional test requirements for Ex Equipment operating outside the standard temperature range, but further additional consideration and additional testing may be required for Ex Equipment operating outside the standard atmospheric pressure range and standard oxygen content. Such additional testing may be particularly relevant with respect to Types of Protection that depend on quenching of a flame such as 'flameproof enclosures "d"' (IEC 60079-1) or limitation of energy, 'intrinsic safety "i"' (IEC 60079-11)
European Committee for Standardization	EU	EN 60079-1	2015	S	Explosive atmospheres - Part 1: Equipment protection by flameproof enclosures "d"	Explosive atmospheres - Part 1: Equipment protection by flameproof enclosures "d" The Flameproof ATEX protection concept is providing a strong and closely fitting enclosure to protect its contents. The enclosure must be capable of containing an potential explosion. Any electronic sparking equipment may be placed in a flameproof enclosure, however there are some restrictions for fluids and batteries and minimum requirements for internal free space. Flameproof protection lends itself to utilising off-the-shelf parts for the contents, for example electronic control boards or pcb's. The enclosures can either be custom designed or standard. Using a standard certified Flameproof enclosure removes any uncertainty about its integrity. For operator control, certified components such as pushbuttons can be fitted to an enclosure. Generally flameproof enclosures are made of cast iron or die cast aluminium, making them quite heavy. They are generally small to medium size because the casting process is more expensive as the size increases and the subsequent weight makes installation difficult. Plastic enclosures can be designed to meet ATEX flameproof construction and strength requirements. Usually plastic enclosures are quite small because they have to have thicker wall sections, compared to a metal counterpart, to withstand the explosion pressure. A metal enclosure is usually cheaper to manufacture.
European Committee for Standardization	EU	EN 60079-10	2016	S	Explosive atmospheres - Part 10-1: Classification of	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres. The ATEX standard EN 60079-10-1 is concerned with the classification of areas where flammable gas or vapour hazards may arise and may then be used as a basis to support the proper selection and installation of equipment for use in hazardous areas.

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					areas - Explosive gas atmospheres	
European Committee for Standardization	EU	EN 60079-11	2013	S	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i"	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i" EN 60079-11 Intrinsic Safety relies upon the equipment supplies being of low voltage and power and is suited to electronic devices. The operating current of the circuitry should be low enough to not be affected by series resistance, which may be required to limit energy
European Committee for Standardization	EU	EN 60079-14	2016	S	Explosive atmospheres - Part 14: Electrical installations design, selection and erection	Explosive atmospheres - Part 14: Specific requirements for the design, selection, erection and initial inspection of electrical installations in, or associated with, explosive atmospheres.
European Committee for Standardization	EU	EN 60079-17	2014	S	Explosive atmospheres - Part 17: Electrical installations inspection and maintenance	Explosive atmospheres - Part 17: Electrical installations inspection and maintenance. EN-IEC 60079-17 applies to users and covers factors directly related to the inspection and maintenance of electrical installations within hazardous areas only, where the hazard may be caused by flammable gases, vapours, mists, dusts or fibres.
European Committee for Standardization	EU	EN 60079-25	2017	S	Explosive atmospheres - Intrinsically safe electrical systems	EN-IEC 60079-25 contains the specific requirements for design, construction and assessment of intrinsically safe systems, Type of Protection "i", intended for use, as a whole or in part, in locations in which the use of Group I, II or III Ex Equipment is required. This document supplements and modifies the general requirements of IEC 60079-0 and the intrinsic safety standard IEC 60079-11. Where a requirement of this standard conflicts with requirements of IEC 60079-0 or IEC 60079-11, the requirement of this standard takes precedence. The installation requirements of Group II or Group III systems designed in accordance with this standard are specified in IEC 60079-14.
European Committee for Standardization	EU	EN 60079-29	2016	S	Explosive atmospheres -- Part 29-4: Gas detectors - Performance requirements of open path detectors for flammable gases	This part of IEC 60079-29 specifies general requirements for construction, testing and performance, and describes the test methods that apply to portable, transportable and fixed equipment for the detection and measurement of flammable gas or vapour concentrations with air. The equipment, or parts thereof, is intended for use in explosive atmospheres and in mines susceptible to firedamp. This part of IEC 60079-29 is applicable to flammable gas detection equipment with a measuring range up to any volume fraction as declared by the manufacturer, and which is intended to provide an indication, alarm or other output function; the purpose of which

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						is to indicate a potential explosion hazard and, in some cases, to initiate automatic or manual protective action(s). For the purposes of this part of IEC 60079-29, the term "indicating up to a volume fraction of X % or X %LFL" includes equipment with an upper limit of the measuring range equal to or less than X % or X %LFL. This part of IEC 60079-29 is applicable to equipment, including the integral sampling systems of aspirated equipment, intended to be used for commercial, industrial and non-residential safety applications. This part of IEC 60079-29 does not apply to external sampling systems, or to equipment of laboratory or scientific type, or to equipment used only for process monitoring and/or control purposes. It also does not apply to open path (line of sight) detectors which are within the scope of IEC 60079-29-4. Only equipment with very short optical paths intended for use where the concentration is uniform over the optical path are within the scope of this standard. For equipment used for sensing the presence of multiple gases, this part of IEC 60079-29 applies only to the detection of flammable gas or vapour. This part of IEC 60079-29 supplements and modifies the general requirements of IEC 60079-0. Where a requirement of this standard conflicts with a requirement of IEC 60079-0, the requirement of IEC 60079-29-1 takes precedence.
European Committee for Standardization	EU	EN 60079-32	2018	S	Explosive atmospheres - Part 32-1. Electrostatics hazards.	This gives guidance about the equipment, product and process properties necessary to avoid ignition and electrostatic shock hazards arising from static electricity as well as the operational requirements needed to ensure safe use of the equipment, product or process. It can be used in a risk assessment of electrostatic hazards or for the preparation of product family or dedicated product standards for electrical or non-electrical machines or equipment
European Committee for Standardization	EU	EN 60079-7	2016	S	Explosive atmospheres - Part 7: Equipment protection by increased safety "e"	This specifies the requirements for the design, construction, testing and marking of electrical equipment and Ex Components with type of protection increased safety “e” intended for use in explosive gas atmospheres. Electrical equipment and Ex Components of type of protection increased safety “e” are either: a) Level of Protection “eb” (EPL “Mb” or “Gb”); or b) Level of Protection “etc” (EPL “Gc”) Level of Protection “eb” applies to equipment or Ex Components, including their connections, conductors, windings, lamps, and batteries; but not including semiconductors or electrolytic

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						capacitors. The requirements of this standard apply to both Levels of Protection unless otherwise stated. For Level of Protection “eb”, this standard applies to electrical equipment where the rated voltage does not exceed 11 kV r.m.s. and 15 kV for level of protection “ec”.
European Committee for Standardization	EU	EN 60204-1	2007	S	Safety of machinery - Electrical equipment of machines - Part 1: General requirements	The IEC 60204-1 is intended to be used in the following range of application: -Within electric, electronic and programmable equipment and systems for machines. -Equipment starting at the point of connection of the supply to the electrical equipment of the machine. -Control cabinets with rated voltages up to 1000 V for alternating current (AC) and up to 1500 V for direct current (DC) and for nominal frequencies not exceeding 200 Hz-Electrical equipment or parts of the electrical equipment that operate with higher nominal supply voltages can be found in IEC 60204-11.
European Committee for Electrotechnical Standardization	EU	EN 80079-36	2017	S	Part 36: Non-electrical equipment for explosive atmospheres - Basic method and requirements	Part 36: Non-electrical equipment for explosive atmospheres - Basic method and requirements ISO 80079-36:2016 specifies the basic method and requirements for design, construction, testing and marking of non-electrical Ex equipment, Ex Components, protective systems, devices and assemblies of these products that have their own potential ignition sources and are intended for use in explosive atmospheres. Hand tools and manually operated equipment without energy storage are excluded from the scope of this standard. This standard does not address the safety of static autonomous process equipment when it is not part of equipment referred to in this standard. This standard does not specify requirements for safety, other than those directly related to the risk of ignition which may then lead to an explosion. The standard atmospheric conditions (relating to the explosion characteristics of the atmosphere) under which it may be assumed that equipment can be operated are: - temperature -20 °C to 60 °C; - pressure 80 kPa (0,8 bar) to 110 kPa (1,1 bar); and - air with normal oxygen content, typically 21 % v/v. Such atmospheres can also exist inside the equipment. In addition, the external atmosphere can be drawn inside the equipment by natural breathing produced as a result of fluctuations in the equipment's internal operating pressure, and/or temperature. This part of ISO/IEC 80079 specifies the requirements for the design and construction of equipment, intended for explosive atmospheres in conformity with all Equipment Protection Levels (EPLs) of Group I, II and III. These standard supplements and modifies the general requirements of IEC 60079-0, as shown in Table 1 in the Scope of the document. Keywords: mechanical explosion protected equipment

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European Committee for Standardization	EU	EN 80079-37	2018	S	Explosive atmospheres - Part 37: Non-electrical equipment for explosive atmosphere - Non-electrical type of protection constructional safety "c", control of ignition sources "b", liquid immersion "k"	It specifies the requirements for the design and construction of nonelectrical equipment, intended for use in explosive atmospheres, protected by the types of protection constructional safety “c”, control of ignition source “b” and liquid immersion “k”
European Committee for Electrotechnical Standardization	EU	IEC 61439-1	2012	S	Low-voltage switchgear and control gear assemblies - Part 1: General rules	This part of IEC 61439 lays down the general definitions and service conditions, construction requirements, technical characteristics and verification requirements for low-voltage switchgear and control gear assemblies. NOTE Throughout this document, the term assembly(s) (see 3.1.1) is used for a low-voltage switchgear and control gear assembly(s). For the purpose of determining assembly conformity, the requirements of the relevant part of the IEC 61439 series, Part 2 onwards, apply together with the cited requirements of this document. For assemblies not covered by Part 3 onward, Part 2 applies. This document applies to assemblies only when required by the relevant assembly standard as follows: - assemblies for which the rated voltage does not exceed 1 000 V AC or 1 500 V DC; - assemblies designed for a nominal frequency of the incoming supply or supplies not exceeding 1 000 Hz; - assemblies intended for indoor and outdoor applications; - stationary or movable assemblies with or without an enclosure; - assemblies intended for use in connection with the generation, transmission, distribution and conversion of electric energy, and for the control of electrical energy consuming equipment. This document does not apply to individual devices and self-contained components such as motor starters, fuse switches, power electronic converter systems and equipment (PECS), switch mode power supplies (SMPS), uninterruptable power supplies (UPS), basic drive modules (BDM), complete drive modules (CDM),

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						adjustable speed power drives systems (PDS), and other electronic equipment which comply with their relevant product standards. This document describes the integration of devices and self-contained components into an assembly or into an empty enclosure forming an assembly. For some applications involving, for example, explosive atmospheres, functional safety, there can be a need to comply with the requirements of other standards or legislation in addition to those specified in the IEC 61439 series.
IEC	International	IEC 62282-3-200	2015	S	Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test method	IEC 62282 covers operational and environmental aspects of the stationary fuel cell power systems performance. The test methods apply as follows: - power output under specified operating and transient conditions; - electrical and heat recovery efficiency under specified operating conditions; - environmental characteristics; for example, exhaust gas emissions, noise, etc. under specified operating and transient conditions. This standard does not apply to small stationary fuel cell power systems with electric power output of less than 10 kW which are dealt with IEC 62282-3-201.
ISO	International	ISO 11114-1	2020	S	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials	This document provides requirements for the selection of safe combinations of metallic cylinder and valve materials and cylinder gas content. The compatibility data given is related to single gases and to gas mixtures. Seamless metallic, welded metallic and composite gas cylinders and their valves, used to contain compressed, liquefied and dissolved gases are considered.
ISO	International	ISO 11114-2	2022	S	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 2: Non-metallic materials	This document provides requirements for the selection of safe combinations of metallic cylinder and valve materials and cylinder gas content. The compatibility data given is related to single gases and to gas mixtures. Seamless metallic, welded metallic and composite gas cylinders and their valves, used to contain compressed, liquefied and dissolved gases are considered.
ISO	International	ISO 11114-3	2011	S	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 3: Autogenous	This part of ISO 11114 specifies a test method to determine the autogenous ignition temperature of non-metallic materials in pressurized gaseous oxygen. The autogenous ignition temperature is one criterion for ranking materials, and can be used to assist with the choice of materials used in the presence of gaseous oxygen.

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					ignition test for non-metallic materials in oxygen atmosphere	A comprehensive bibliography of the published material on which this part of ISO 11114 is based is included.
ISO	International	ISO 11114-4	2017	S	Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting steels resistant to hydrogen embrittlement	This document specifies test methods and evaluation of test results for quality the appropriate steels to manufacture gas cylinders (up to 3000L) for hydrogen and other embrittlement hydrogenated gases. The requirements are not applicable if at least one of the following conditions for the intended gas service is fulfilled; - the working pressure of the filled embrittling gas is less than 20 % of the test pressure of the cylinder; - the partial pressure of the filled embrittling gas of a gas mixture is less than 5 MPa (50 bar) in the case of hydrogen and other embrittling gases, with the exception of hydrogen sulphide and methyl mercaptan; in such cases, the partial pressure shall not exceed 0,25 MPa (2,5 bar).
ISO	International	ISO 11114-5	2022	S	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 5: Test methods for evaluating plastic liners	Specifying several gas compatibility test methods to evaluate plastic materials suitable for use in the manufacture of composite liners for type 5 gas cylinders.
ISO	International	ISO 12100	2012	S	Safety of machinery - General principles for design - Risk assessment and risk reduction	This International Standard specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. It specifies principles of risk assessment and risk reduction to help designers in achieving this objective. These principles are based on knowledge and experience of the design, use, incidents, accidents and risks associated with machinery. Procedures are described for identifying hazards and estimating and evaluating risks during relevant phases of the machine life cycle, and for the elimination of hazards or the provision of sufficient risk reduction. Guidance is given on the documentation and verification of the risk assessment and risk reduction process. This international standard is also intended to be used as a basis for the preparation of type B safety standards or type C.

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ISO	International	ISO 13341	2015	S	Gas cylinders — Fitting of valves to gas cylinders — Amendment 1	This standard is classified in these ICS categories: 23.020.35 Gas cylinders 23.060.40 Pressure regulators This International Standard specifies the procedures to be followed when connecting cylinder valves to gas cylinders. It specifically applies to all valve and cylinder combinations connected with ISO screw threads as specified in ISO 10920 and ISO 11363-1 . It defines routines for inspection and preparation prior to valving for both taper and parallel screw threads. Torque values are given in Annex A for steel and aluminium gas cylinders including composite cylinders with steel or aluminium boss.
ISO	International	ISO 14687	2019	S	Hydrogen fuel quality — Product specification	It specifies the minimum quality characteristics of hydrogen fuel as distributed for utilization in vehicular and stationary applications. It is applicable to hydrogen fuelling applications, which are listed in Table 1 of this international standard specifies.
ISO	International	ISO 17179	2016	S	Stationary source emissions — Determination of the mass concentration of ammonia in flue gas — Performance characteristics of automated measuring systems	This International Standard specifies the fundamental structure and the most important performance characteristics of automated measuring systems for ammonia (NH3) to be used on stationary source emissions, for example, combustion plants where SNCR/SCR NOx control systems (deNOx systems) are applied. The procedures to determine the performance characteristics are also specified. Furthermore, it describes methods and equipment to determine NH3 in flue gases including the sampling system and sample gas conditioning system. This International Standard describes extractive systems, based on direct and indirect measurement methods, and in situ systems, based on direct measurement methods, in connection with a range of analysers that operate using, for example, the following principles: — ammonia conversion to, or reaction with NO, followed by chemiluminescence (CL) NOx difference measurement for ammonia (differential NOx); — ammonia conversion to, or reaction with NO, followed by non-dispersive ultraviolet (NDUV) spectroscopy NOx difference measurement for ammonia (differential NOx); — Fourier transform infrared (FTIR) spectroscopy; — non-dispersive infrared (NDIR) spectroscopy with gas filter correlation (GFC); — tuneable laser spectroscopy (TLS).
ISO	International	ISO 17268	2022	S	Gaseous hydrogen land vehicle refuelling connection devices	This document defines the design, safety and operation characteristics of gaseous hydrogen land vehicle (GHLV) refuelling connectors. GHLV refuelling connectors consist of the following components, as applicable: - receptacle and protective cap (mounted on vehicle)

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						- nozzle; - communication hardware. This document is applicable to refuelling connectors which have nominal working pressures or hydrogen service levels up to 70 MPa
ISO	International	ISO 19880-1	2020	S	Gaseous hydrogen — Fuelling stations — Part 1: General requirements	ISO 19880-1 defines the minimum design, installation, commissioning, operation, inspection and maintenance requirements, for the safety, and, where appropriate, for the performance of public and non-public fuelling stations that dispense gaseous hydrogen to light duty road vehicles (e.g. fuel cell electric vehicles). This document is not applicable to the dispensing of cryogenic hydrogen, or hydrogen to metal hydride applications. Since this document is intended to provide minimum requirements for fuelling stations, manufacturers can take additional safety precautions as determined by a risk management methodology to address potential safety risks of specific designs and applications
ISO	International	ISO 19880-2	2022 (Draft 2024)	S	Gaseous hydrogen — Fuelling stations — Part 2: Dispensers	It describes the safety requirements and test methods for the components and systems that enable the transfer of compressed hydrogen to a hydrogen vehicle as addressed in ISO 19880-1 by a hydrogen dispenser with dispensing pressures up to the H70 pressure class designation. This document is intended to cover a hydrogen dispensing system, referred to as a “dispenser”, the configuration of which can range from i) a dispenser cabinet, located in the fuelling area, that can perform all of the functionality needed to deliver hydrogen to a vehicle, to ii) a minimum set of components mounted in or on (as applicable) a dispenser cabinet, or other supporting structure as appropriate, with the remaining functionality provided elsewhere in the hydrogen fuelling station. A dispensing system includes the user and vehicle interface and may include components starting from the hydrogen supply, such as a connection to the banking system, a cooling unit, a dispenser control system, a flow meter, fuel temperature sensor, user interface and a fuelling hose assembly. Not all dispensing system equipment has to be physically housed within the enclosure at the dispensing area as long as the specification of component design or type and location are adequate to ensure that the overall process meets requirements in this document.
ISO	International	ISO 19880-3	2018	S	Gaseous hydrogen — Fuelling stations — Part 3: Valves	The requirements and test methods for the safety performance of high-pressure gas valves that are used in gaseous hydrogen stations of up to the H70 designation. This document covers the following gas valves: check valve; excess flow valve; flow control valve; hose breakaway device; manual valve; pressure safety valve; shut-off valve.

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ISO	International	ISO 19880-5	2019	S	Gaseous hydrogen — Fuelling stations — Part 5: Dispenser hoses and hose assemblies	It specifies the requirements for wire or textile reinforced hoses and hose assemblies suitable for dispensing hydrogen up to 70 MPa nominal working pressure, in the operating temperature range of −40 °C to 65 °C. This document contains safety requirements for material, design, manufacture and testing of gaseous hydrogen hose and hose assemblies for hydrogen fuelling stations. Hoses and hose assemblies excluded from the scope of this document are the following: 1) those used as part of a vehicle high pressure on-board fuel storage system, 2) those used as part of a vehicle low pressure fuel delivery system, and 3) flexible metal hoses.
ISO	International	ISO 19880-8	2019	S	Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control	This International Standard specifies the protocol for ensuring the quality of the gaseous hydrogen quality at hydrogen distribution bases and hydrogen fuelling stations for proton exchange membrane (PEM) furl cells for road vehicles.
ISO	International	ISO 19882	2018	S	Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	This document establishes minimum requirements for pressure relief devices intended for use on hydrogen fuelled vehicle fuel containers that comply with ISO 19881, IEC 62282-4-101, ANSI HGV 2, CSA B51 Part 2, EC79/EU406, SAE J2579, or the UN GTR No. 13. The scope of this document is limited to thermally activated pressure relief devices installed on fuel containers used with fuel cell grade hydrogen according to SAE J2719 or ISO 14687 for fuel cell land vehicles, and Grade A or better hydrogen according to ISO 14687 for internal combustion engine land vehicles. This document also contains requirements for thermally activated pressure relief devices acceptable for use on-board light duty vehicles, heavy duty vehicles and industrial powered trucks such as forklifts and other material handling vehicles
ISO	International	ISO 22734	2019	S	Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications	ISO 22734 defines the construction, safety, and performance requirements of modular or factory-matched hydrogen gas generation appliances, herein referred to as hydrogen generators, using electrochemical reactions to electrolyse water to produce hydrogen. This document is applicable to hydrogen generators that use the following types of ion transport medium: - group of aqueous bases; - group of aqueous acids; - solid polymeric materials with acidic function group additions, such as acid proton exchange membrane (PEM); - solid polymeric materials with basic function group additions, such as anion exchange membrane (AEM)
ISO	International	ISO 26142	2010	S	Hydrogen detection apparatus — Stationary applications	This defines the performance requirements and test methods of stationary hydrogen detection apparatus that is designed to measure and monitor hydrogen concentrations. The provisions in this standard cover the hydrogen detection apparatus used to achieve the single and/or multilevel safety operations such as nitrogen purging or ventilation and/or system shutoff corresponding to the hydrogen concentration. The requirements applicable to the control system as well as the installation requirements of such

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						apparatus are excluded. This standard sets out only the requirements applicable to a product standard of hydrogen detection apparatus, such as precision, response time, stability, measuring range, selectivity and poisoning. This standard is intended to be used for certification purposes.
ISO	International	ISO 4126-7	2016	S	Safety devices for protection against excessive pressure — Part 7: Common data	This part of ISO 4126 specifies requirements for safety valves. It contains information which is common to ISO 4126-1 to ISO 4126-6 to avoid unnecessary repetition. For flashing liquids or two-phase mixtures, see ISO 4126-10. The user is cautioned that it is not recommended to use the ideal gas formula presented in 6.3 when the relieving temperature is greater than 90 % of the thermodynamic critical temperature and the relieving pressure is greater than 50 % of the thermodynamic critical pressure. Additionally, condensation is not considered. If condensation occurs, the method presented in 6.3 should not be used.
ISO	International	ISO 5771	2024	S	Rubber hoses and hose assemblies for transferring anhydrous ammonia — Specification	It specifies the minimum requirements for rubber hoses used for transferring ammonia, in liquid or in gaseous form, at ambient temperatures from 40 °C up to and including +55 °C at working pressure of 2,5MPa (25 bar). It does not include specifications for end fittings and is limited to the performance of the hoses and hose assemblies.
ISO	International	ISO 9455-9	2020	S	Soft soldering fluxes — Test methods — Part 9: Determination of ammonia content	It specifies a distillation method for the determination of the ammonia content of solid, paste or liquid fluxes. The method is applicable to fluxes of class 311 and 321 only, as defined in ISO 9454-1.
ISO	International	ISO/TR 11364	2019	S	Gas cylinders — Compilation of national and international valve stem/gas cylinder neck threads and their identification and marking system	It lists the different valve stem to gas cylinder connection threads currently and historically existing worldwide and provides official coded designations for them. These coded designations will then be available for identification and marking purposes. It also gives guidance concerning which threads are dimensionally identical and which are interchangeable. Furthermore, this document provides guidance for valving procedures when fitting valves to gas cylinders.
ISO	International	ISO/TR 15916	2015	S	Basic considerations for the safety of hydrogen systems	It provides guidelines for the use of hydrogen in its gaseous and liquid forms as well as its storage in either of these or other forms (hydrides). It identifies the basic safety concerns, hazards and risks, and describes the properties of hydrogen that are relevant to safety. Detailed safety requirements associated with specific hydrogen applications

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						are treated in separate International Standards. “Hydrogen” in this paper means normal hydrogen (1H2), not deuterium (2H2) or tritium (3H2).
Joint Research Center, EU commission’s service	EU	JRC122565	2021	N	EU harmonized protocols for testing of low temperature water electrolyzes	This report is the outcome of a combined effort of experts active in water electrolysis related projects coordinated by FCH2JU. It considers all three technologies of low temperature water electrolysis: proton (PEMWE), anion exchange membrane (AEMWE) and alkaline water electrolysers (AWE). It consists of a set of harmonised operating conditions, testing protocols and procedures for assessing both performance and durability of low temperature water electrolysis devices at every level of aggregation, from materials to stacks, up to grid-coupled systems. For the operating conditions, a number of agreed reference settings are presented, covering a.o. temperature, pressure, gas flow rate and gas composition. System boundaries are defined for these conditions, within which the electrolyser cell or stack is expected to operate. The report also presents an approach for assessing the effect on electrolyser performance and degradation of the exposure to more challenging conditions, known as “stressor conditions”.
Joint Research Center, EU commission’s service	EU	JRC129387	2023	N	EU harmonized testing protocols for high temperature steam electrolyzes – Performance and durability of stacks and systems	The objective of this document is to present testing protocols for establishing the performance and durability of high-temperature electrolyser (HTE) stacks and high-temperature steam electrolysis (HTSEL) systems for the generation of bulk amounts of hydrogen by the electrolysis of steam (water vapour) using electricity mostly from variable renewable energy sources (RESs). In addition, stacks and systems may utilise heat from energy conversion, natural resources (geothermal and solar) and industrial processes. By applying these testing protocols, it will be generally possible to characterise and evaluate the performance and durability of different stacks and systems aiming at an adequate comparison of two HTSEL technologies namely solid oxide steam electrolysis (SOEL) and proton-conducting ceramic steam electrolysis (PCCEL)
National Fire Protection Association	International	NFPA-2	2023	N	Hydrogen Technologies Code	The purpose of this code shall be to provide fundamental safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas (GH2) form or cryogenic liquid (LH2) form
National Fire Protection Association	International	NPFA-400	2022 (Draft 2025)	N	Fundamental safeguards for the storage, use, and handling of hazardous materials in all occupancies and facilities	NFPA 400, Hazardous Materials Code helps protect workers, communities, and emergency response. It provides the newest safety information for any facility or occupancy that stores, handles, or uses one or more of the covered classes of hazardous materials. NFPA 400 consolidates requirements on oxidizers, organic peroxides, pesticides, and ammonium nitrate based on requirements from previous stand-alone documents: NFPA 430, NFPA 432, NFPA 434, and NFPA 490, respectively. It also includes requirements for materials that are classified as unstable

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						/ reactive, water reactive, corrosives, pyrophoric, toxic and highly toxic, and flammable solids.
International Organization of Legal Methodology	Internatio nal	OIML R 139-1	2021	N	International Recommendation for Compressed gaseous fuel measuring systems for vehicles. Part 1: Metrological and technical requirements	OIML R139-1 recommends measuring systems that are intended for the refuelling of motor vehicles, small boats, and aircraft with compressed natural gas, hydrogen, biogas, gas blends or other compressed gaseous fuels. They may also be applicable to other vehicles, for instance trains. Measuring systems for liquid petroleum gas are not included in the scope of this Recommendation. These are within the scope of OIML R 117, which covers fluids in a liquid state. In principle, this Recommendation applies to all measuring systems fitted with a meter as defined in 3.2.2(continuous measurement), whatever the measuring principle may be of the meters or their application. This Recommendation is not intended to prevent the development of new technologies. According to the state of the art, this Recommendation is intended for measuring systems providing mass indications.
Occupational Safety and Health Administration	USA	OSHA – 29 CFR 1910.111	2007	D	Storage and handling of anhydrous ammonia.	This regulation is intended to apply to the design, construction, location, installation, and operation of anhydrous ammonia systems including refrigerated ammonia storage systems. The systems cover container appurtenances, piping, tubes, valves, hoses, safety devices, loading/unloading cars, and electrical equipment. This standard does not apply to: (a) Ammonia manufacturing plants. (b) Refrigeration plants where ammonia is used solely as a refrigerant.
Occupational Safety and Health Administration	USA	OSHA – 29 CFR 1910.119	2023	D	Process safety management of highly hazardous chemicals	This section contains requirements for preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals. These releases may result in toxic, fire or explosion hazards This section applies to the following: - A process which involves a chemical at or above the specified threshold quantities listed in appendix A to this section. - A process which involves a Category 1 flammable gas (as defined in 1910.1200(c)) or a flammable liquid with a flashpoint below 100 °F (37.8 °C) on site in one location, in a quantity of 10,000 pounds (4535.9 kg) or more except for: - Hydrocarbon fuels used solely for workplace consumption as a fuel (e.g., propane used for comfort heating, gasoline for vehicle refuelling), if such fuels are not a part of a process containing another highly hazardous chemical covered by this standard; - Flammable liquids with a flashpoint below 100 °F (37.8 °C) stored in atmospheric tanks or transferred which are kept below their normal boiling point without benefit of chilling or refrigeration.

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SAE International	International	SAE J2601-1	2020	S	Fuelling Protocol for Light Duty Gaseous Hydrogen Surface Vehicles	This standard is based on a look-up table approach with performance targets. It covers standard for fuel temperature, the maximum fuel flow rate, and rate of pressure increase and end pressure affected by factors such as ambient temperature, fuel delivery temperature and initial pressure in the vehicle's compressed hydrogen storage system
SAE International	International	SAE J2572	2014 (Stabilized 2024)	N	Recommended Practice for Measuring Fuel Consumption and Range of Fuel Cell and Hybrid Fuel Cell Vehicles Fuelled by Compressed Gaseous Hydrogen	This practice provides standard tests that will allow for determination of fuel consumption and range based on the US Federal Emission Test Procedures, using the Urban Dynamometer Driving Schedule (UDDS) and the Highway Fuel Economy Driving Schedule (HFEDS).
SAE International	International	SAE J2578	2023	N	Recommended Practice for General Fuel Cell Vehicle Safety	This SAE Recommended Practice identifies and defines requirements relating to the safe integration of the fuel cell system, the hydrogen fuel storage and handling systems (as defined and specified in SAE J2579) and high voltage electrical systems into the overall Fuel Cell Vehicle. The document may also be applied to hydrogen vehicles with internal combustion engines. This document relates to the overall design, construction, operation and maintenance of fuel cell vehicles.
SAE International	International	SAE J2579	2023	S	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	This standard is to define design, construction, operational, and maintenance requirements for hydrogen fuel storage and handling systems in on-road vehicles. Performance-based requirements for verification of design prototype and production hydrogen storage and handling systems are also defined in this document. Complementary test protocols (for use in type approval or self-certification) to qualify designs (and/or production) as meeting the specified performance requirements are described.
SAE International	International	SAE J2600	2015	S	Compressed Hydrogen Surface Vehicle Fuelling Connection Devices	SAE J2600 applies to the design and testing of Compressed Hydrogen Surface Vehicle (CHSV) fuelling connectors, nozzles, and receptacles. Connectors, nozzles, and receptacles must meet all SAE J2600 requirements and pass all SAE J2600 testing to be considered as SAE J2600 compliant
SAE International	International	SAE J2601-2	2023	S	Fuelling Protocol for Gaseous	The purpose of this document is to provide performance requirements for hydrogen dispensing systems used for fuelling 35 MPa heavy duty hydrogen transit buses and

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					Hydrogen Powered Heavy Duty Vehicles	vehicles (other pressures are optional). This document establishes the boundary conditions for safe heavy-duty hydrogen surface vehicle fuelling, such as safety limits and performance requirements for gaseous hydrogen fuel dispensers used to fuel hydrogen transit buses. For fuelling light-duty vehicles SAE J2601 should be used. SAE J2601-2 is a performance-based protocol document that also provides guidance to fuelling system builders, manufacturers of gaseous hydrogen powered heavy duty transit buses, and operators of the hydrogen powered vehicle fleet(s).
SAE International	International	SAE J2601-3	2022	S	Fuelling protocol for Gaseous Hydrogen Powered Industrial Trucks	This document establishes safety limits and performance requirements for gaseous hydrogen fuel dispensers used to fuel Hydrogen Powered Industrial Trucks (HPITs). It also describes several example fuelling methods for gaseous hydrogen dispensers serving HPIT vehicles. SAE J2601-3 offers performance-based fuelling methods and provides guidance to fuelling system builders as well as suppliers of hydrogen powered industrial trucks and operators of the hydrogen powered vehicle fleet(s). This fuelling protocol for HPITs can support a wide range of hydrogen fuel cell hybrid electric vehicles including fork lifts, tractors, pallet jacks, on and off-road utility, and specialty vehicles of all ty. Multiple fuelling methods are described in this document and include: 1.1 Fill to service pressure with fixed area flow-limiting device 2.2 Fill to target pressure with fixed area flow-limiting device 3.3 Fill to pressure with variable area flow-limiting device.
SAE International	International	SAE J2615	2011	S	Testing Performance of Fuel Cell Systems for Automotive Applications	his recommended practice is intended to provide a framework for performance testing of fuel cell systems (FCS's) designed for automotive applications with direct current (DC) output. The procedures described allow for measurement of performance relative to claims by manufacturers of such systems with regard to the following performance criteria. -Power -Efficiency -Transient Response -Start and Stop Performance -Physical Description -Environmental Limits -Operational Requirements -Integration

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SAE International	International	SAE J2719	2020	S	Hydrogen Fuel Quality for Fuel Cell Vehicles	This standard provides background information and a hydrogen fuel quality standard for commercial proton exchange membrane (PEM) fuel cell vehicles. This report also provides background information on how this standard was developed by the Hydrogen Quality Task Force (HQTF) of the Interface Working Group (IWG) of the SAE Fuel Cell Standards Committee.
SAE International	International	SAE J2799	2024	S	Hydrogen Surface Vehicle to Station Communications Hardware and Software	This standard specifies the communications hardware and software requirements for fuelling hydrogen surface vehicles (HSV), such as fuel cell vehicles, but may also be used where appropriate, with heavy-duty vehicles (e.g., busses) and industrial trucks (e.g., forklifts) with compressed hydrogen storage. It contains a description of the communications hardware and communications protocol that may be used to refuel the HSV. The intent of this standard is to enable harmonized development and implementation of the hydrogen fuelling interfaces. This standard is intended to be used in conjunction with the hydrogen fuelling protocols in SAE J2601 and nozzles and receptacles conforming with SAE J2600.
SAE International	International	SAE J2908	2023	S	Vehicle Power Test for Electrified Powertrains	This SAE Information Report provides test methods and determination options for evaluating the maximum wheel power and rated system power of vehicles with electrified vehicle powertrains. The scope of this document encompasses passenger car and light- and medium-duty (GVW <10000 pounds) hybrid-electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel-cell electric vehicles (FCEVs). These testing methods can also be applied to conventional ICE vehicles, especially when measuring and comparing wheel power among a range of vehicle types.
SAE International	International	SAE J2990/1	2016	N	Gaseous Hydrogen and Fuel Cell Vehicle First and Second Responder Recommended Practice	The electrical hazards associated with the high voltage systems of hybrid-electric vehicles and FCVs are already addressed in the parent document, SAE J2990. This Recommended Practice therefore addresses electric issues by reference to SAE J2990 and supplements SAE J2990 to address the potential consequences associated with hydrogen vehicle incidents and suggest common procedures to help protect emergency responders, tow and/or recovery, storage, repair, and salvage personnel after an incident has occurred. Industry design standards and tools were studied and where appropriate, suggested for responsible organizations to implement.
SAE International	International	SAE J3089	2018	S	Characterization of On-Board Vehicular Hydrogen Sensors	This SAE Technical Information Report (TIR) provides test methods for evaluating hydrogen sensors when the hydrogen system integrator and/or vehicle manufacturer elect to use such devices on board their hydrogen vehicles, including hydrogen fuel cell electric vehicles (FCEV).

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Bequinor	Internatio nal	Seguridad H2-Bequinor 2023	2023	N	BEQUINOR Hydrogen Safety Guide	The report includes technical information about storage, security, and safety of hydrogen facilities and present the challenge that must be considered.

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10. APPENDIX II: List of Spanish Hydrogen/Ammonia Regulations and Guidelines Associated with the ARENHA Project

Institutions	Region	Normative	Enactment	Category	Title	Description
Royal Decree-Law	Spain	RD 144/2016	2016	R	The essential health and safety requirements for equipment and protective systems intended for use in potentially explosive atmospheres, complying with 2014/34/EU	This Royal Decree shall apply to the following apparatus, systems, devices and components (all referred to generically as 'products' in this standard): (a) Equipment and protective systems intended for use in potentially explosive atmospheres. (b) safety, control and adjustment devices intended for use outside potentially explosive atmospheres but which are necessary or contribute to the safe operation of equipment and protective systems in relation to explosion hazards. (c) components intended to be incorporated into the equipment and protective systems referred to in point (a).
Royal Decree-Law	Spain	RD 145/1989	1989	R	The National Regulation of Admission, Manipulation and Storage of Dangerous Goods in the Ports.	The regulation is only applied to when the DG cargos are stored in the ports.

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Royal Decree-Law	Spain	RD 222/2001	2001	R	Periodic inspections of transportable pressure vessels	This Royal Decree is to strengthen the safety of transportable pressure equipment accepted for the inland transport of dangerous goods by road and rail and to ensure the free movement of such equipment within the EU. The RD shall apply: (a) as regards placing on the market, new transportable pressure equipment as defined in Article 2. (b) as regards the reassessment of conformity of existing transportable pressure equipment, as defined in Article 2, which meets the technical requirements of: -RD 2115/1998, on the transport of dangerous goods by road, which declares the application of the European Agreement on the International Carriage of Dangerous Goods by Road and its annexes, hereinafter ADR, and -RD 2225/1998, on the transport of dangerous goods by rail, which declares the application of the Regulation on the international transport by rail of dangerous goods, hereinafter RID. (c) With regard to use and periodic checks: -The transportable pressure equipment referred to in paragraphs a) and b). -Gas cylinders currently in use bearing the mark of conformity provided for in Directives 84/525/EEC, 84/526/EEC and 84/527/EEC, on: Seamless steel gas cylinders; gas cylinders of non-alloy aluminium and seamless alloyed aluminium, and welded gas cylinders of non-alloy steel respectively, transposed into Spanish regulations by the Order of the Ministry of Industry and Energy of 3 July 1987, amending the complementary technical instruction MIE-AP7 of the Regulation of pressure equipment, Referring to bottles and bottles for compressed, liquefied and dissolved gases under pressure -Transportable pressure equipment placed on the market before 1 July 2001 or, in the case of the first transitional provision, within two years of that date, which has not been reassessed to meet the requirements of the ADR and RID, shall be excluded from the scope of this Royal Decree. -Transportable pressure equipment used exclusively for the transport of dangerous goods between the territory of the European Union and that of third countries, carried out under the following conditions, shall be excluded from the scope of this Royal Decree.

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Royal Decree-Law	Spain	RD 2267/204	2004	R	Fire safety regulations for industrial establishments, complying with ISO 17268	1. The scope of this Regulation is industrial establishments. The following shall be understood as such: (a) Industries, as defined in article 3.1 of Law 21/1992, of July 16, on Industry. (b) Industrial storage. (c) Repair shops and parking of vehicles intended for the transport of persons and transport of goods. (d) Services auxiliary to or complementary to the activities referred to in the preceding paragraphs. 2. It shall also apply to all storage facilities in any type of establishment where their total fire load, calculated in accordance with Annex I, is equal to or greater than three million Megajoules (MJ).
Royal Decree-Law	Spain	RD 337/2014	2014	R	Regulation on technical conditions and safety guarantees in high voltage electrical installations and its Complementary Technical Instructions ITC-RAT 01 to 23.	The provisions of this Regulation shall apply to high-voltage electrical installations, understood as three-phase alternating current installations; (a)Installations with a nominal voltage equal to or greater than 220 kV and those with a lower voltage that are part of the Transmission Network in accordance with the provisions of Law 24/2013, of December 26, on the Electricity Sector (b)Those with a nominal voltage of less than 220 kV and more than 66 kV. (c)Second category: Those with a nominal voltage equal to or less than 66 kV and greater than 30 kV. (d)Those with a nominal voltage equal to or less than 30 kV and greater than 1 kV. Those installations in which it is planned to use direct current, polyphase alternating current or single-phase, must be the subject of a special justification by the designer, who must adapt the basic requirements and principles of this regulation to the peculiarities of the proposed system

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Royal Decree-Law	Spain	RD 513/2017	2017	R	Regulation on fire protection installations. complying with Directive 98/34/EC as amended by Directive 98/48/EC.	The purpose of this Regulation is to determine the conditions and requirements for the design, installation/application, maintenance and inspection of equipment, systems and components that make up active fire protection installations
Royal Decree-Law	Spain	RD 639/2016	2016	R	A framework of measures for the implantation of an infrastructure for the alternative fuel, complying with 2014/94/EU	The purpose of this Royal Decree is the establishment of the framework of measures for the implementation of an infrastructure for alternative fuels, in order to minimize the dependence of transport on oil and mitigate the environmental impact of transport. This royal decree establishes the minimum requirements for the creation of an infrastructure for alternative fuels, including recharging points for electric vehicles and refuelling points for natural gas and hydrogen.
Royal Decree-Law	Spain	RD 656/2017 ITC MIE APQ-1	2017	R	Storage of flammable and combustible liquids in fixed containers	The regulation is to establish the technical requirements for the storage, loading, unloading and transfer of flammable and combustible liquids, with the following exception: 1. Storage with a capacity of less than 250 l of class C. 2. The integrated storages within the process units, which are those in which the capacity of the vessels will be limited to the amount necessary to feed the process during a period of 48 hours, considering the continuous process at maximum capacity. Integrated storage within the process units is also considered to be those in which the capacity of the vessels is less than 3,000 l and are connected directly to the process by piping, with the process being fed by the use of suction pumps or by gravity. However, this ITC shall also apply to loading and unloading stations of containers, vehicles or tank wagons of flammable and combustible liquids and flammable liquefied gases, even if the loading or unloading is to or from process facilities. 3. Storage of cryogenic gases (refrigerated liquefied gases). 4. Carbon sulphide storage. However, the Regulation shall apply. 5. Storage of products with a flash point above 100 °C, provided that they are not stored above their flash point.

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Institutions	Region	Normative	Enactment	Category	Title	Description
Royal Decree-Law	Spain	RD 656/2017 ITC MIE APQ-10	2017	R	Storage in mobile containers	This regulation shall apply to storage facilities for chemical, including flammable liquids/gases, provided that the quantity limits are equal to or exceeded. Also included in the scope of this Instruction are services, or the part thereof relating to storage (for example: accesses, drainage of the storage area, the corresponding fire protection system and treatment plants for contaminated water). The following containers or storage are excluded from the scope of this JTI: a) Storage of mobile vessels included in other specific JTIs (MIE APQ-3, MIE APQ-5, MIE APQ-8 and MIE APQ-9). (b) Chemicals to be used in construction, repair, maintenance or maintenance provided that the following three conditions are met: i. which are used in isolated cases (maximum once a year) and ii. used and stored on site, and iii. that the necessary quantity foreseen for 10 days and a storage period of 30 days is not exceeded. c) Mobile vessels whatever their capacity, which are connected directly to the process by piping, being fed to the process by using suction pumps or by gravity.

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Royal Decree-Law	Spain	RD 656/2017 ITC MIE APQ-4	2017	R	Storage of anhydrous ammonia	This regulation applies to the storage of anhydrous ammonia in fixed containers, with the exception of storage integrated within the process units, which are those in which the capacity of the containers will be limited to the amount necessary to feed the process during a period of 48 hours, considering the continuous process at maximum capacity. Integrated storage within the process units is also considered to be those in which the capacity of the vessels is less than 3,000 l and are connected directly to the process by piping, with the process being fed by the use of suction pumps or by gravity. However, facilities where anhydrous ammonia tank containers, tank vehicles or tank cars are loaded/unloaded must comply with this ITC even if the loading/unloading is to/from process facilities. Also included in the scope of this instruction are services, or part thereof, relating to the storage of liquids in fixed containers (e.g. accesses, drainage of the storage area, the corresponding fire protection system and treatment plants for contaminated water). The definitions of Anhydrous ammonia is liquefied gas with an ammonia content exceeding 99,5 % by mass. The rest of the definitions are included in the ITC MIE APQ-0.
Royal Decree-Law	Spain	RD 656/2017 ITC MIE APQ-5	2017	R	Storage of Gases in Mobile Pressure Vessels	This regulation is to lay down the technical requirements for the storage and use of mobile pressure vessels containing compressed, liquefied and dissolved gases under pressure and mixtures thereof. The following facilities are not considered within the scope of this ITC: (a) Storage of gases in pressure vessels included in the ITC MIE APQ-3 'Storage of chlorine'; (b) Warehouses located in gas recharge plants intended to carry out activities of classification, packaging, inspection, quality control, prepared loads and preparation of loads. However, it will apply to the finished product storage area, including warehouse storing compressed gas and ammonia. (c) The storage of open cryogenic containers, fire extinguishers, as well as equipment, machinery and objects containing gases. (d) Aerosols, which will be governed by the ITC MIE APQ-10.

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Royal Decree-Law	Spain	RD 656/2017 ITC MIE APQ-6	2017	R	Storage of corrosive liquids in fixed vessels	This instruction (ITC) shall apply to facilities for the storage, handling, loading and unloading of corrosive liquids whose hazard statement classified in "Chemical Storage Regulation" in APQ-0 is H290/314 except: a) Storage not exceeding the total stored quantity of 200 l of class 1A, 400 l of class 1B and 1000 l of class 1C, according to the classification indicated in Article 3. b) The integrated storages within the process units, which are those in which the capacity of the containers will be limited to the amount necessary to feed the process during a period of 48 hours, considering the continuous process at maximum capacity. Integrated storage within the process units is also considered to be those in which the capacity of the vessels is less than 3,000 l and are connected directly to the process by piping, with the process being fed by the use of suction pumps or by gravity. 2. However, this JTI shall also apply to loading and unloading stations of containers, vehicles or tank wagons of corrosive liquids, even if the loading or unloading is to or from process facilities.

Category: R(Regulations),D(Directive),S(Standards), N(Recommendation)
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Institutions	Region	Normative	Enactment	Category	Title	Description
Royal Decree-Law	Spain	RD 656/2017 ITC MIE APQ-7	2017	R	Storage of toxic liquids in fixed containers	This instruction (ITC) shall apply to facilities for the storage, handling, loading and unloading of toxic liquids whose hazard statement classified in "Chemical Storage Regulation" in APQ-0 is H300/301/302/310/311/312/330/331/332/370 except: a) Storage of liquefied toxic gases. However, the Regulation shall apply. b) The storage of products that, being toxic, are also explosive or radioactive or organic peroxides. c) The integrated storages within the process units, which are those in which the capacity of the containers will be limited to the amount necessary to feed the process during a period of 48 hours, considering the continuous process at maximum capacity. Integrated storage within the process units is also considered to be those in which the capacity of the vessels is less than 3,000 l and are connected directly to the process by piping, with the process being fed by the use of suction pumps or by gravity. 2. However, this JTI shall also apply to loading and unloading stations of toxic liquid containers, vehicles or tank wagons, even if the loading or unloading is to or from process facilities.
Royal Decree-Law	Spain	RD 709/2015	2014	R	Essential requirements of security for the commercialization of the equipment to pressure complying with 2014/68/EU	The purpose of RD 709/2015 is to lay down the essential safety requirements for pressure equipment and assemblies which maybe newly placed on the European Union market. When placing pressure equipment or assemblies on the market or using for their own purposes, manufacturers shall ensure that it has been designed and manufactured in accordance with the essential safety requirements set out in Annex I. When placing on the market or using for their own purposes the pressure equipment or assemblies referred to in Article 4.3, manufacturers shall ensure that it has been designed and manufactured in accordance with good technical practice in use in a Member State of the European Union.
Royal Decree-Law	Spain	RD 809/2021	2021	R	Regulation of pressure equipment and its Complementary Technical Instructions	The purpose of this Regulation is to establish safety standards and criteria for the proper use of pressure equipment in relation to the fields defined in the scope of this Regulation. It applies to the installation, periodic inspections, repair and modification of pressure equipment subject to a maximum permissible pressure exceeding 0,5 bar, and in particular to the equipment regulated in RD709/2015, 108/2016, 1388/2011.

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Institutions	Region	Normative	Enactment	Category	Title	Description
Royal Decree-Law	Spain	RD 815/2013	2013	R	Regulation of industrial emissions and of development of the Law 16/2002, of 1 July, of prevention and integrated control of the pollution	This regulation limit establishes the limitation of emissions into the atmosphere of certain pollutants from plants, including large combustion plants, and sets certain conditions for the control of emissions into the atmosphere. This Regulation shall apply to installations owned by the public or private sector in which any of the industrial activities falling within the categories listed in Annex 1 are carried out. The operator of facility should submit environmental impact assessment to the authority and need to carry out environmental impact inspection, mainly at the installation.
Royal Decree-Law	Spain	RD 840/2015	2015	R	Control of the risks inherent to major accidents involving hazardous substances, complying 2012/18/EU	The regulation includes major incident prevention policy, developing emergency plan and purpose of security report to be drawn up. The regulation shall not apply to; (c) The transport of dangerous goods by road, rail, inland waterway, sea or air and intermediate temporary storage directly related thereto; as well as loading and unloading activities and the transfer to and from other types of transport to docks, jetties or railway logistics facilities or railway terminals outside the establishments referred to in this Royal Decree; d) The transport of dangerous substances by pipelines, including pumping stations, which are outside the establishments referred to in this Royal Decree;
Royal Decree-Law	Spain	RD 842/2002	2002	R	Low voltage electrotechnical regulations	This Regulation shall apply to installations distributing electricity, to electricity generators for own consumption and to receiving power within the following nominal voltage limits: a) Alternating current: equal to or less than 1,000 volts. b) Direct current: equal to or less than 1,500 volts
Royal Decree-Law	Spain	RD 919/2006	2006	R	Technical regulation for the distribution and use of gaseous fuels and its complementary technical instructions ICG 01 to 11, substituting with ISO 19880-1	The regulation applied to Installations for the distribution of gaseous fuels by pipeline, and vessel/containers for LPG/LNG. In the regulation, the definition of gaseous fuel is those related in the three gaseous familiar with UNE 60002 standards, which is replaced by EN 437:2003+A1:2009.

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