Chapter 8

Feasibility Study of Large-scale Development of Hydrogen Energy Industry in China from the Perspective of Safety Laws and Regulations

Wang Jianfu

Hydrogen demand in China has risen quickly in recent years; more than 20 million tonnes in 2020, it has reached number one in the world. Under the goal of 'Carbon Neutral' and 'Carbon Peak', the annual demand for hydrogen in China is expected to jump from 37.15 million tonnes in 2030 to 130 million tonnes in 2060. Hydrogen energy will assume more prominence as a zero-carbon energy and industrial raw material. Therefore, it requires that the laws, regulations, and standards need to match safety requirements, while not curbing its large-scale application. There are many regulations in the hydrogen energy industry chain of 'production, storage, transportation, and use' in China. Some of the requirements are more stringent, such as the restriction on land property in the process of producing hydrogen. Some regulations need to be improved, such as the lack of requirements for long-distance hydrogen pipelines. The international experience can be used for reference in the following directions: the process and manufacturing requirements of hydrogen pipelines in the United States, hydrogen energy safety management in the European Union, safety checks in Japan, and hydrogen laws in the Republic of Korea. Priority has been given to the development of the examination and approval system of hydrogen energy testing and hydrogen energy filling stations in many provinces of China. The above experience shows that China should improve the top-level design as soon as possible and speed up the technical basic research to support the continuous improvement of safety standards. Finally, a sound regulatory system is needed to promote hydrogen energy to play a more important role in the process of decarbonising economy in China.

Keywords: hydrogen energy, safety, regulation, large-scale application.

The large-scale development of the hydrogen energy industry is based on safety guarantees; hence, it should be guided and restrained by laws and regulations, and constantly adjusted and improved to promote its healthy and sustainable development. Only by ensuring the safe use of hydrogen (especially green hydrogen) can it play an important role in energy conservation and carbon reduction in transportation, industry and other fields, so as to replace fossil energy, reduce carbon emissions, and achieve China's goals of 'carbon peak' and 'carbon neutrality'. This chapter analyses the current situation and obstacles of laws, regulations, and standard systems related to hydrogen safety in China; summarises the experience and related practices at home and abroad; and makes suggestions on promoting the development of hydrogen energy industry from the perspective of safety.

1. Current Situation and Obstacles of Laws and Regulations System

The current laws and regulations in China include *Law on Work Safety*, *Law on Special Equipment Safety*, *Regulations on Safety Supervision for Special Equipment*, *Administrative Regulations on Road Transportation of Hazardous Goods*, *Rules for Transport of Hazardous Goods by Waterway*, *Regulations on the Safety Protection of Railway Transport,* and *Law on Safety of Hazardous Chemicals (Exposure Draft)*, which are different in effectiveness and scope of application, but can restrict the safety of hydrogen energy to varying degrees. In addition, although in Article 115 of the Energy Law (Exposure Draft) enacted in April 2020, hydrogen energy has been stripped from the category of hazardous chemicals and attributed to energy, the current application of hydrogen energy in China falls within the category of hazardous chemicals.

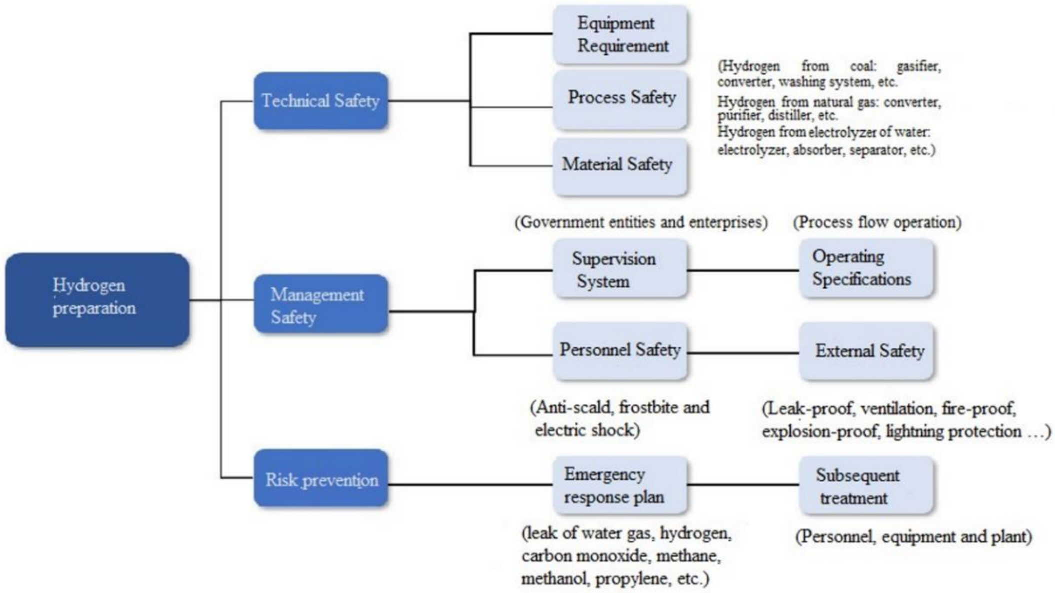
China's standards related to hydrogen energy, such as the *Essential Requirements for the Safety of Hydrogen Systems* and the *Code for Design of Hydrogen Stations*, put forward requirements for safe application of hydrogen energy vis-à-vis preparation, storage, transportation, and filling. However, compared with the rapid development of the industry, these standards are slightly backwards and most of them have been laid down for 10+ years and cannot better support the development of the industry. In the future, China should put forward high requirements and new legislation for technical safety, management safety, and risk prevention to match the large-scale development of the hydrogen energy industry.

1.1. There are laws to follow in the safety of hydrogen energy preparation and land properties and safe distance restrict the industrial development.

1.1.1. Requirements of safety laws, regulations, and standard systems in hydrogen energy preparation

The *Bluepaper on the Development of China's Hydrogen Energy Industry* (2018) demonstrated that 62% of China's hydrogen sources are coal and industrial by-product, 19% are natural gas, and a small part are water electrolysis. With the accelerated application of hydrogen energy in the field of transportation, hydrogen can be generated in hydrogen filling stations in the future.**Error! Reference source not found.** According to the characteristics of hydrogen energy preparation, the safety requirements of several main hydrogen production modes in China are analysed from perspectives of technology, management, and risk prevention in Figure 8.1. In Technical Safety: fire and explosion protection of production equipment (gasifier, reformer, electrolyser, etc.); the preparation process and flow are safe and reliable; in Management Safety: safety control of flammable and toxic gases generated in the production process, safe distance between facilities, establishment of safety supervision authorities, etc.; in Risk Prevention: disposal methods for flammable and explosive gas leakage, and treatment methods for any accident in personnel and equipment or plant.**Error! Reference source not found.**

Figure 8.1: Requirements of Safety Laws, Regulations, and Standard Systems in Hydrogen Energy Preparation



Source: Author.

1.1.2. Current safety laws, regulations, and standard systems for hydrogen production

a) There are many categories of laws and regulations, which can play a guidance role.

At present, there are many safety laws and regulations in China for hydrogen energy preparation. The main content and characteristics are shown below:

Table 8.1: Main Content of China's Laws, Regulations, and Standards System for Hydrogen Production

Safety system	Specific requirement	Relevant laws and regulations	Properties	Main Content of Laws, Regulations and Standards
Technical safety	Equipment Requirement	Law on work safety (China law, 2014)	Legislation	Technology and material safety protection Supporting requirements for safety facilities
		Basic safety requirements for hydrogen systems (SAC, 2014)	National standards	Equipped with relief device, flame arrester, safety control system, etc.
	Process Safety	Law on work safety Fire protection law Code for design of hydrogen stations (SAC, 2014)	Legislation National standards	Process safety protection Fire Protection Design and Construction Requirements of Building Works The pressure difference between hydrogen and oxygen is less than 0.5kPa.
	Material safety	Supervision Regulation on Safety Technology for Stationary Pressure Vessel (GQSIQ, 2013)	Legislation	Requirements for fireproof materials, physical and chemical properties such as resistance to hydrogen embrittlement, resistance to hydrogen corrosion and compatibility with medium
		Basic safety requirements for hydrogen systems Evaluation method of resistance to hydrogen-induced cracking of pipeline steel and pressure vessel steel (SAC, 2015) Test method for hydrogen embrittlement of copper (SAC, 2013)	National standards	Compatibility, Failure Mode, Machinability, Toughness, Plasticity, Manufacturability, Resistance to Hydrogen Penetration, Low Susceptibility to Hydrogen Embrittlement Test Method for Material Strength, Stiffness and Other Characteristics of Hydrogen Containers
		Hydrogen embrittlement test of plating process (SAC, 2013) Low hydrogen embrittlement forged cadmium (titanium quality inspection) of high-strength steel part (CN-HB, 1986) Low hydrogen embrittlement forged cadmium (titanium process) of high-strength steel part(CN-HB, 1986) Specification for stress relief before plating and dehydrogenation after plating	Industry standard	Safety Test of Plating Process Material

		(CN-HB, 1998)		
Management Safety	Supervision System	Law on work safety Fire protection law Regulations on Safety Management of Hazardous Chemicals (SAC, 2013)	Legislation	Establish Safety Responsibility System, Government Supervision and Administration Regulations on License of Work Safety
		Basic safety requirements for hydrogen systems	National standards	Land for hydrogen production and chemical industry and fire resistance rating
	Operating Specifications	Law on work safety Fire protection law Basic safety requirements for hydrogen systems	Legislation National standards	Fire Safety Practice Certified Safety Engineer
	Personnel Safety			Training and Evaluation of Safety Operators
	External Safety			Fire Safety System
				Fire break outside the station ≥12m, inside the station ≥8m The clear distance between hydrogen compressors is ≥1.5m and the distance between hydrogen purifiers is ≥1m.
Risk prevention	Emergency response plan	Fire Protection Law	Legislation	Firefighting and emergency evacuation plan
		Basic safety requirements for hydrogen systems	National standards	Install an alarm device for detecting leakage and over-pressure in the hydrogen production process. Eliminate the leaked hydrogen in time after accident.
	Subsequent processing	Law on work safety	Legislation	Emergency Rescue, Investigation and Treatment of Work Safety Accident
		Basic safety requirements for hydrogen systems Code for design of electrical installation for atmosphere of fire and explosion (SAC, 2014)	National standards	The leaked hydrogen shall be eliminated in time after an accident has occurred. The selection of accident exhaust fan shall conform to the *Code for Design of Electrical Installation for Atmosphere of Fire and Explosion* (GB50058).

Source: Author.

From the perspective of technical safety, the *Work Safety Law* (revised in 2014) required producers and operators to adopt new processes, new technologies, new materials, or new equipment, and to understand and master their safety technical characteristics and take effective safeguard measures. Safety facilities must also be constructed and put into service at the same time during the reconstruction and expansion of enterprises.

The *Fire Protection Law* (revised in 2019) clearly stipulated that the design and construction of building works completed by hydrogen energy production enterprises must conform to the national technical standards for fire protection. The *Supervision Regulation on Safety Technology for Stationary Pressure Vessel* stipulated that the mechanical properties, physical properties, and compatibility with media of materials should be considered for pressure vessels meant to be used for hydrogen energy preparation. Specific safety requirements are proposed for the chemical composition and mechanical properties of reactor materials (metal and nonmetal). The law on work safety is used to guide fire protection design in hydrogen production construction projects.

From the perspective of management safety, the *Law on Work Safety* has provisions regarding employee rights and obligations in work safety, supervision, and management of work safety: for example, establishing an accountability system for safe production, carrying out training and evaluation, and clarifying the governmental responsibilities of supervision and administration. For enterprises with more than 100 employees, the *Law on Work Safety* stipulates work safety management institutions or full-time work safety management personnel, and requires them to have certified safety engineers. The *Fire Protection Law* (revised in 2019) clearly stipulates that fire control management and supervision enterprises, for example, should implement the responsibility system for fire safety and formulate their own systems and safety procedures. The *Regulations on Safety Management of Hazardous Chemicals* clearly regulate the full operation process of production, storage, and use of hazardous chemicals; for example, before production of hazardous chemicals, production enterprises should follow the provisions of *Regulations on License of Work Safety*; in addition, it stipulated that production enterprises must be on chemical land or their premises shall be located in an chemical industry park. In fire protection law, government management, safe production responsibility, and other management systems required for production and operation are clearly formulated.

From the perspective of risk prevention, the *Law on Work Safety* stipulates the emergency rescue, investigation, and handling of accidents; formulates emergency rescue plans; and organises regular drills. After any accident, the relevant personnel shall immediately report to the head of their unit; take effective measures quickly; organise rescue; prevent accidents from expanding; and reduce casualties and property losses. The *Fire Protection Law* (revised in 2019) stipulates that hydrogen energy production enterprises shall make relevant fire-fighting and emergency evacuation plans, and a series of laws and regulations related to fire fighting and rescue have been laid down under the Law. *The Regulations on Emergency Response to Production Safety Accidents* have provided terms of emergency preparedness and rescue regarding rescue teams, drills, and command enforcement.

b) The Standards have identified risk factors and puts forward clear indicators.

Relevant standards for hydrogen production include the *Essential Requirements for the Safety of Hydrogen Systems* (GB/T29729-2013), *Safety Requirements for Hydrogen Production System by Pressure Water Electrolysis*, *Code for Fire Protection Design of Buildings*, and cover the following key points to ensure the safety of hydrogen production:

In terms of technical safety, the Standards have specified hydrogen risk factors and stipulated that hydrogen energy preparation enterprises shall set up relief devices, flame arresters, safety control systems, etc. Further, the Standards require reasonable selection of equipment material, including compatibility, failure mode, machinability, etc.; at the same time, materials should have good toughness, plasticity, manufacturability, hydrogen permeation resistance, and low hydrogen embrittlement sensitivity. Through the requirement on performance of hydrogen equipment material, explosion and leakage can be avoided. Through hydrogen embrittlement plating tests, low-hydrogen-embrittlement forged cadmium (titanium quality inspection) of high-strength steel parts, and specification for stress relief before plating and dehydrogenation after plating, the surface mechanical properties of materials in hydrogen production systems are strictly geared to avoid hydrogen embrittlement.

In terms of management safety, the Standards mainly limit the nature, qualification and building layout of production enterprises. According to the management requirement on safe production of hazardous chemicals, hydrogen production must be situated on land available for the chemical industry or located in a chemical park. In addition, the fire resistance rating of hydrogen production stations must not be lower than Level II, and plants must be in a single-storey building, with the highest part having vent holes. Pressure relief facilities must be set up in any plant with explosion hazards; the hydrogen compression plant shall be a semi-open building structure; there shall be no fewer than 2 emergency exits; and the fire break outside the hydrogen production station shall be ≥12m and the fire break inside the station shall be ≥8m. The Standards also require arranging hydrogen production equipment as follows: equipment for hydrogen and oxygen preparation cannot exist in the same plant; the distance between hydrogen production compressors must be ≥1.5m; the distance between hydrogen purifiers must be ≥1m; the distance between bottles for hydrogen production must be larger than the net width of the channel; and belt drive and electrical equipment for hydrogen production shall be grounded for fire prevention and removal of static electricity.

In terms of safety protection, the Standards require hydrogen leak detection capability: combustible gas detection and alarm devices shall be set up in areas with fire and explosion hazards in the hydrogen production system, while air concentration detection and alarm devices shall be set up at the highest place or where hydrogen is most likely to accumulate in the water electrolysis hydrogen production house, and leakage detectors shall be set up at the air inlet and outlet. The Standards further require installing an alarm device for detecting leakage and over-pressure in the hydrogen production process. The leaked hydrogen shall be eliminated in time after an accident has occurred. The selection of accident exhaust fans shall conform to the *Code for Design of Electrical Installation for*

Atmosphere of Fire and Explosion (GB50058). Finally, the Standards also require operators to wear electrostatic protective clothing, and that operators shall be regularly trained and evaluated.

Table 8.2: Safety Requirement for Hydrogen Production Station

Safe fire break of hydrogen production station			
Inside/outside			**Safe distance (m)**
Buildings (Outside the station)	Fire-resistant rating	Level 1 and Level 2	12
		Level 3	14
		Level 4	16
	Civil buildings		25
	Important public buildings		50
Hydrogen production room (Inside the station)	Primary station		15
	Secondary station		10
	Tertiary station		8

Source: Author.

1.1.3. Main obstacles to safety laws, regulations, and standards systems for hydrogen production

Through research on application of the aforementioned laws, regulations, and standard systems in the field of hydrogen production, the following obstacles are common with the hydrogen production process:

1) **Lack of focus on the safety of preparation process.** The prevailing Chinese laws, regulations, and standard systems attach importance to standardising the physical and chemical properties of materials in terms of technical safety to avoid leakage and fire; however, there is a lack of focus on the safety technical indicators of the hydrogen energy preparation process and the hazards response plan in management. It is only mentioned in the *Law on Work Safety* that the new process needs supporting safety equipment. For example, hydrogen production from natural gas requires the reformer to prevent leakage, and meet the temperature and pressure requirements of safe reaction and collection during hydrogen production from coal. However, the relevant standards focus on hydrogen embrittlement or hydrogen corrosion more on the back end of the production line, i.e. the material requirements in the storage stage, and lack guidance on the safety risks of the production process itself.
2) **Lack of specialised laws and regulations on hydrogen energy production supervision.** For the present, professional categories of certified safety engineers exclude control of hydrogen energy, which has been deleted from the scope of hazardous chemicals. China's relevant laws on safety evaluation, safety review, safe

construction, safe acceptance, rescue, punishment and safety certificates fail to cover the hydrogen energy industry chain, and the supervision and enforcement of hydrogen energy are still absent at this stage.

3) **Restriction on number of safety controllers is easing.** According to Chinese law, any enterprise with 100+ employees shall have full-time safety controllers. Given the future trend of hydrogen production, restriction to 100 employees may be too loose to regulate the development of the industry.

4) **Requirement for land properties is too strict.** For the present, hydrogen production (including green hydrogen produced with renewable energy) in chemical industry parks as required by China's *Regulations on Safety Management of Hazardous Chemicals* has become the foundation and orientation of the hydrogen energy industry's development. It is determined according to the distribution characteristics of renewable energy resources in China that hydrogen energy in the future will mainly come from large-scale production in renewable energy bases, while the land properties have limited the development of this model.

5) **The safe fire break is too long**. For the present, in the *Essential Requirements for the Safety of Hydrogen Systems*, the minimum safe fire break outside the station is 12 metres. Due to the limitation of distance, it is difficult to miniaturise the 'integrated station' in China and thus it is difficult to popularise and apply it on a large scale in cities and other regions with scarce land resources.

1.2. The hydrogen energy storage and transportation are under increased supervision and strict audit, and their material and technical safety standards available still have shortcomings.

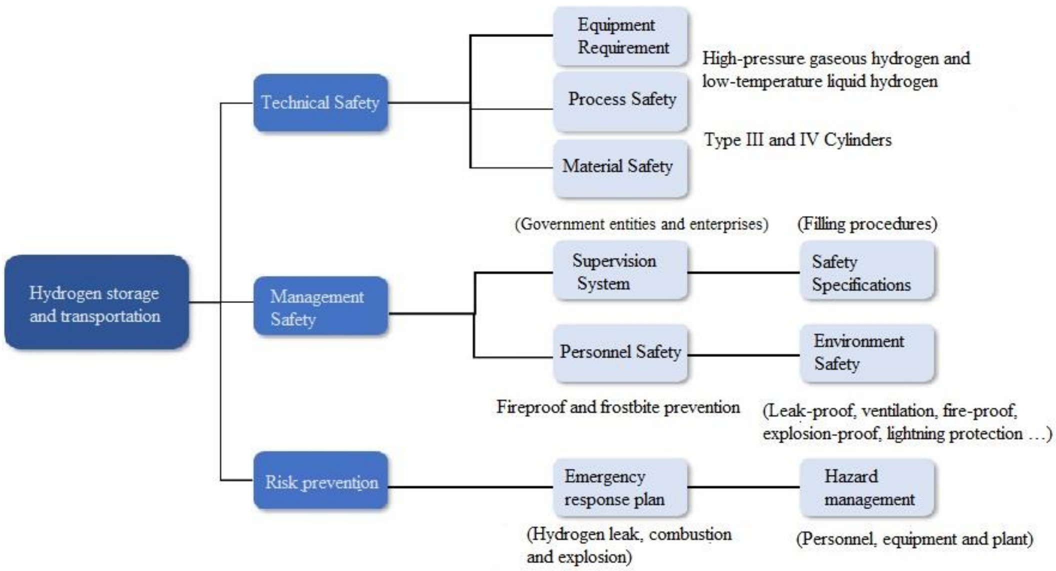
1.2.1. Requirements of safety laws, regulations and standard systems in hydrogen energy storage and transportation

As an intermediate process in preparation and use, the storage and transportation of hydrogen energy is of great importance. Safe storage and transportation are closely related to the large-scale, wide-range and mobile use of hydrogen energy in China. For the present, there are no series of standards for high-pressure (35MPa or above) gaseous hydrogen transportation, liquid hydrogen transportation, piping hydrogen transportation, etc. in China, so it is required to refer to relevant regulations on transportation of inflammable and explosive hazards.

Hydrogen storage is based on technical safety. At present, China's hydrogen storage mode is mainly employing high-pressure technology, which is relatively mature; the pressure is generally less than 70MPa, the compression energy consumption is high, and the potential safety hazards are mainly reflected in the reliability risk and leakage danger of material available for hydrogen storage. In addition, the supplementary means of liquid hydrogen storage requires higher equipment and material conditions. At present, most hydrogen storage cylinders in China are Type III (metal liner), compared with Type IV. Type III cylinders with metal liners will heat up faster in the process of filling, and, due to high material density, the hydrogen storage capacity of Type III is lower than that of Type IV. Globally, Type IV (polymer liner) has represented the trend. Therefore, China's safety demand for hydrogen energy storage is mainly based on new materials, technologies, and the promotion of safe storage technology. Hydrogen energy is mainly transported through long tube trailers in China at present, and piping transport is still at the demonstration stage. The safety requirement for long tube trailers is kept consistent with hydrogen storage. There may be great potential space for pipeline hydrogen transportation in the future. Pipeline hydrogen transmission can be divided into pure hydrogen pipelines and natural gas hydrogen-mixed pipelines. Safety regulations mainly focus on reliable material, leakage detection systems, and standardised management system.

Standards for hydrogen pipelines mentioned in China include GB50177 *Code for Design of Hydrogen Stations* and GB4962 *Technical Regulations for Safety of Hydrogen Use*. GB50177 is applicable to the design of hydrogen piping in newly built, rebuilt, and expanded hydrogen stations, hydrogen supply stations, plant areas, and workshops, which has been described in detail in 9.1.1.2. GB4962 has specified the safety technical requirements of gaseous hydrogen in the process of use, replacement, storage, compression and filling, discharge, firefighting, emergency management, and safety protection. It is suitable for all workplaces on the ground after gaseous hydrogen production, but not for liquid hydrogen, gaseous hydrogen on water, aviation hydrogen use and on-board hydrogen supply systems, and for which the corresponding process in hydrogen production can be taken for reference. The above standards are not applicable to buried long-distance hydrogen pipelines. At present, there is no standard system applicable for long-distance hydrogen pipelines in China.

Figure 8.2: Requirements of Safety Laws, Regulations and Standard Systems in Hydrogen Energy Storage and Transportation



Source: Author.

1.2.2. Current situation of safety laws, regulations and standard system for storage and transportation

a) Common safety laws and regulations are mainly applied for storage and transportation, which are under increased supervision and strict audit

Table 8.3: Main Content of China's Laws, Regulations and Standards System for Hydrogen Energy Storage and Transportation

Safety system	Specific requirement	Relevant laws and regulations	Properties	Main Content of Laws, Regulations and Standards
Technical safety	Equipment Requirement	Special Equipment Safety Law Regulations on Road Transportation of Hazardous Cargo -	Legislation	Comply with safety technical specifications. Equipped with special containers such as tank- type and van-type vehicles or pressure vessels and safety protection, environmental protection and firefighting facilities and equipment; there are no equipment safety regulations for long-distance piping of hydrogen for the present.
		Basic safety requirements for hydrogen systems Requirement for storage and transportation of liquid hydrogen (SAC, 2021)	National standards	Stationary gaseous hydrogen storage tanks shall be provided with safety accessories such as pressure gauge, safety release device, hydrogen leak alarm, purge replacement interfaces, etc. There shall be a hydrogen escape pipe at the top and a discharge outlet at the bottom. The liquid hydrogen tanker and tank container must be equipped with an electrostatic grounding device. The liquid hydrogen receiver port of the tanker shall be equipped with a 10 micron filter.
	Process safety	Non-available for the present	Non-available for the present	Type III Cylinder, Type IV Cylinder, etc.
	Material safety	Supervision Regulation on Safety Technology for Stationary Pressure Vessel Pressure Vessel Painting and Transport Packaging	Legislation	Rust removal, anti-corrosion, protective film, etc. Tensile strength, impact absorbed energy, elongation after breaking, etc. There is no requirement on material for long- distance piping of hydrogen

				for the present.
		Essential Requirements for the Safety of Hydrogen Systems	National standards	The liquid hydrogen tank is well insulated.
Management Safety	Supervision System	Law on work safety Regulations on Road Transportation of Hazardous Cargo Fire Protection Law Regulations on Safety Management of Hazardous Chemicals	Laws and Regulations	Establish a special safety management system Assign full-time safety management personnel during transportation The Transportation Administration is responsible for transportation license and safety administration (hazardous chemicals).
	Operation Safety	Special Equipment Safety Law Liquid Hydrogen Storage and Transportation Requirement Regulations on Safety Management of Hazardous Chemicals Code for Design of Electrical Installation for Atmosphere of Fire and explosion(SAC,2014)	Laws and Regulations	Safety evaluation and safety review shall be carried out for storage and handling. Corresponding safety measures shall be taken in the filling process of tankers and tank containers, and devices against tensile pull shall be provided.
	Personnel Safety			Personnel shall be educated and trained in safety and should not take up their jobs without certification; and shall be conducted static electricity away and wear work clothes, etc. before operation.
	Environment Safety			
		Basic safety requirements for hydrogen systems	National standards	The place for liquid hydrogen storage tanks should be kept a corresponding safe distance from residential buildings, public roads, and warehouses.
Risk prevention	Emergency response plan	Fire Protection Law	Legislation	Cut off transmission of electricity, combustible gas, and combustible liquid.
		Basic Safety Requirements for Hydrogen Systems Requirement for Storage and Transportation of Liquid Hydrogen	National standards	When an accident occurs in the transit of tankers or tank containers, it shall be reported to competent local authorities for handling in time and emergency response measures shall be taken in addition.
		Regulations on Safety Supervision for Special	Legislation	In case of explosion or leak of pressure vessels and pressure pipes, characteristics of media shall be

	Risk Management	Equipment		distinguished during emergency rescue, and such explosion or leak shall be handled in strict accordance with the procedures specified in the relevant plans to avoid secondary explosion.
		Basic Safety Requirements for Hydrogen Systems	National standards	Leak in the piping system of tankers and tank containers, if any, shall be timely repaired and treated.
		Code for Design of Electrical Installation for Atmosphere of Fire and Explosion		

Source: Author.

Technical safety is mainly governed by general regulations. Since hydrogen energy is mainly stored and transported through long tube trailers in China, laws and regulations mostly focus on this means of transport. For the present, long piping transportation of hydrogen energy is still at the demonstration stage, and there is no specialised law related to it. In addition, the *Special Equipment Safety Law* has stipulated that the performance indicators of hydrogen storage and transportation pressure vessels shall conform to the safety technical specifications; the safety technical supervision regulations for stationary pressure vessels require that the material of storage and transportation equipment should have anti-rust, anti-corrosion and the like characteristics, as well as high tensile strength and impact resistance to absorb energy. For the present, there is no clear legal regulation on process material for hydrogen cylinders.

Management safety is mainly under increased supervision and strict audit. China's laws clearly define the regulatory responsibilities for hydrogen energy storage and transportation, and the Transportation Administration shall be responsible for transportation licenses and safety administration (hazardous chemicals). It is also required that the personnel responsible for the supervision and management of special equipment should be familiar with relevant laws and regulations and have corresponding expertise and work experience. It has also specified the way to set qualifications and regular inspections so as to improve the timeliness of equipment operation: the Special Equipment Safety Law stipulates that special equipment users shall, in accordance with technical safety technical specifications, request special equipment inspection agencies to perform regular inspection one month prior to the expiration of the validity period of inspection, and perform a safety evaluation and safety review in the full process of hydrogen energy storage and handling. For specific safety operation procedures, the requirement for storage and transportation of liquid hydrogen has mentioned that corresponding safety measures shall be taken in the filling process of tankers and tank containers, and devices against tensile pull shall be provided. The protection of personnel safety by laws and regulations is mainly reflected in operation procedures: personnel shall be educated and trained in safety and should not take up their jobs without certification, and shall conduct static electricity away and wear work clothes, etc. before operation. The safety protection environment is reflected in that the place for liquid hydrogen storage tanks should be kept a corresponding safe distance from residential buildings, public roads, and warehouses.

In addition, the code of conduct for operational safety includes: no transport in bad weather, prohibition of over-pressure, grounding of equipment before loading and unloading, capacity limitation, prohibition of overload, isolation of storage area from employees accommodation area, no passenger vehicles available for hydrogen transportation, keeping surroundings of hydrogen system clean, taking measures such as controlling the hydrogen filling rate and pre-cooling, preventing the wall temperature of hydrogen cylinders from exceeding the predetermined value, eliminating ignition sources in the storage and operation areas, and using road barriers and warning signs to control the storage and operation areas, transporting hydrogen in compliance with laws and regulations on transportation of hazardous (flammable) cargo. No long-distance transportation appropriate for liquid hydrogen and hydrogen slurry, and explosion-proofing is required for all the above-mentioned.

For risk prevention, the *Specification for Special Equipment* is available for reference. The use of special equipment should have the prescribed safe distance and safety protection measures. Buildings and ancillary facilities related to the safety of special equipment shall comply with the provisions of relevant laws and administrative regulations. This can provide legal protection for safe construction of hydrogen production stations and hydrogen filling stations. The Fire Protection Law has stipulated that when an accident occurs in the transit of tankers or tank containers, it shall be reported to competent local authorities for handling in time and emergency response measures shall be taken at the same time. The risk prevention for leaks is mainly based on detection: leak detectors shall be installed at the air inlet and the air outlet, selection of accident exhaust fans shall conform to the *Code for Design of Electrical Installation for Atmosphere of Fire and Explosion* (GB50058), an alarm device shall be installed for detecting leakage and over-pressure in the hydrogen production process and at least one of audible and visual alarms should be given, and operators shall wear electrostatic protective clothing in the process of operation and shall be regularly trained and evaluated. Transmission of electricity, combustible gas, and combustible liquid shall be cut off in case of danger. Leaks in the piping system of tankers and tank containers, if any, shall be timely repaired and treated after the danger.

1.2.3. Main obstacles to safety laws and regulations of storage and transportation

The development of hydrogen energy storage and transportation technology is subject to safety supervision. Although great progress has been made in technologies such as pressurised compression hydrogen storage, liquefied hydrogen storage, compound hydrogen storage, and alloy hydrogen storage, the balance among hydrogen storage density, safety, and costs has not yet been addressed and is not enough to support the large-scale commercial development of the industry. It is necessary to continuously improve the technical level and reliability in order to keep promoting the large-scale development of the hydrogen energy industry.

1) **Absence of standard systems for long-distance hydrogen pipelines.** At present, the domestic natural gas piping network has not yet launched a pilot demonstration of hydrogen mixing. Due to the particularity of hydrogen media, the problems it faces are very prominent. It is necessary to strengthen the compatibility between pipe material and hydrogen-compressed natural gas; fully consider factors such as accelerated leakage rate, enlarged combustible range, and accelerated combustion rate caused by hydrogen mixing; and comprehensively analyse the leak and combustion explosion of hydrogen-compressed natural gas. The steel of China's West-East Natural Gas Piping is Grade X70 or X80. Under high pressure (approx. 4~12MPa) for transmission, the area shrinkage rate can be reduced to 30%~60%; with 1% hydrogen mixed, greater impacts such as hydrogen embrittlement will easily occur, thus leading to pipe rupture, leak, and explosion, or similar potential safety hazards. Therefore, it is not feasible to mix hydrogen into most natural gas pipes in China, and the future development prospect remains unclear.
2) **Hydrogen storage and transportation standards are largely inadequate.** For the present, China only has promulgated safety standards and demonstrations for ordinary Type III steel cylinders, and has not yet formed safety laws and regulations or national standards and specifications for vehicle-mounted, lightweight, high-pressure hydrogen storage containers, liquid hydrogen tanks, and solid-state hydrogen storage facilities. In addition, it is not clear whether 35MPa or 70MPa is applicable for high-pressure gaseous hydrogen transportation. China's prevailing standard system restricts Type III cylinders, while the standard systems applicable for Type IV cylinders is still blank, which has certain obstacles to the future development of the industry.

1.3. Safety regulations such as supervision, fire prevention, business license and land use in hydrogen energy filling are absent

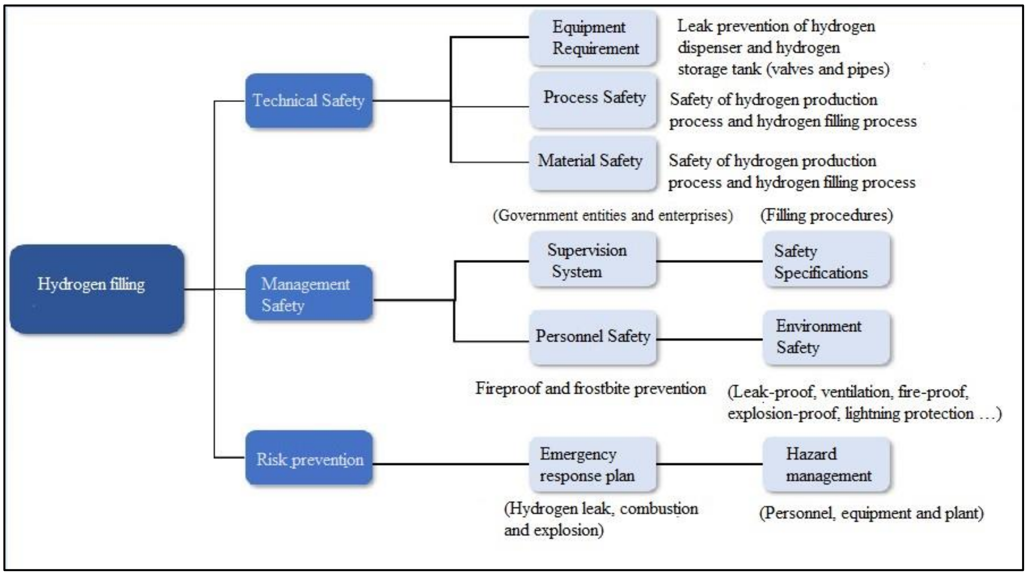
1.3.1. Requirements of safety laws, regulations, and standard systems in hydrogen energy filling

China's hydrogen filling stations have not yet been applied on a large scale. Those in operation are all at their demonstration stage. Relevant laws and regulations on investment, construction, and operation of general building projects that should be observed by hydrogen filling station projects are still blank; however, there are more national standards regulating construction of hydrogen filling stations. The safety requirements of hydrogen filling stations are mainly reflected in safety and fire prevention, leakage prevention, protection of personnel and protection of surrounding environment. The following apply to hydrogen leak prevention:

- hydrogen filling stations are required to have much safer storage equipment and processes;

- hydrogen filling stations should have the capability of monitoring leaks so as to acquire such specific information as their location in a timely fashion and speed and avoid any greater potential safety hazard;
- the construction layout of a hydrogen filling stations should ensure that leaked hydrogen not remain but instead dissipate to avoid burning or explosion accidents caused by an open flame; and
- hydrogen filling stations should have a high level of firefighting and the ability to extinguish fire in time.

Figure 8.3: Requirements of Safety Laws, Regulations and Standard Systems in Hydrogen Energy Filling



Source: Author.

1.3.2. Current situation of safety laws, regulations, and standard system for hydrogen filling stations

At present, China has no specialised laws and regulations applicable for hydrogen filling stations and the analysis in this chapter is mainly based on national standards.

Table 8.4: Main Content of China's Laws, Regulations and Standards System for Hydrogen Energy Filling

Safety system	Specific requirement	Relevant laws and regulations	Properties	Main Content of Laws, Regulations and Standards
	Equipment Requirement	Code for design of hydrogen stations	National standards	Safety relief device, hydrogen escape pipes at the top of equipment, pressure measuring instrument, nitrogen purging/replacement interface, hydrogen leak detection/alarm device, etc.

Technical safety	Process Safety	Code for design of hydrogen station Safety technical code for hydrogen filling station	National standards	Hydrogen compression process requirement (long tube trailers and hydrogen pipeline) Requirement for hydrogen production process within the station (water electrolysis, reforming, etc.)
	Material safety	Basic safety requirements for hydrogen systems	National standards	Mechanical properties of metallic material (solution treatment and heat treatment)
Managemen t Safety	Supervision System	/	/	There are only local specialized hydrogen energy supervision regulations.
	Operation Safety	Technical specification for hydrogen filling station(SAC,2021) Safety technical specification for hydrogen filling station(SAC,2021) Fire Protection Law	Legislation National standards	Rated work pressure of 35MPa or 70MPa The filling flow rate is no more than 5kg/min. The design pressure is 110% of the maximum working pressure, etc.
	Personnel Safety			Refer to the Fire Protection Law
	Environment Safety			
		Basic safety requirements for hydrogen systems	National standards	Spacing between devices of hydrogen stations and width of fire lanes of hydrogen stations. Protection of civil buildings
Risk prevention	Emergency response plan	Technical specification for hydrogen filling station	National standards	Over-pressure or low-pressure alarm, flame alarm detection, roof hydrogen detection, alarm when the hydrogen has reached 0.4%, and automatically turning on the exhaust fan when the hydrogen has reached 1%.
	Subsequent processing	Fire Protection Law	Legislation	Refer to the Fire Protection Law

Source: Author.

There are only local specialised regulations in supervision systems for hydrogen filling stations. For specific operation matters, the *Technical Specification of Hydrogenation Station* has clearly specified the rated pressure and gas flow rate of hydrogen-filling operation environments. The external environment is mainly protected by setting a safe distance, including spacing between devices of hydrogen stations and width of fire lanes of hydrogen stations and protection of civil buildings. See Table 8.5 below for details.

For risk prevention in hydrogen filling stations, the main monitoring of leaks requires an auto alarm system to be turned on when the hydrogen concentration has reached 0.4%, and the exhaust fan to be turned on automatically when it has reached 1%. Due to lack of relevant standards for hazard management, only relevant content of the Fire Protection Law is available for reference.

Table 8.5: Relevant Requirement for Hydrogen Filling Station

Buildings		Hydrogen Filling Station	Total volume of hydrogen filling station (m^3)			
			≤1,000	1,001~10,000	10,001~50,000	>50,000
Fire-resistant rating	Level 1 and Level 2	12	12	15	20	25
	Level 3	14	15	20	25	30
	Level 4	16	20	25	30	35
Civil buildings		25	25	30	35	40
Important public buildings		50	50			

Source: The author.

1.3.3. Main obstacles to safety laws and regulations of hydrogen filling stations

The following main obstacles are found in relevant laws, regulations, departmental rules, and standard systems:

1) **Strict requirements on fire breaks hinder the construction of hydrogen filling stations in mature urban centers.** The standards of hydrogenation stations on fire break and construction equipment spacing are not uniform, thus hindering the large-scale construction of hydrogen filling stations, especially in urban centers.
2) **No explicit authorities are assigned for administration or the process of examination and approval will be impeded.** Hydrogen filling stations lack similar gas service licenses issued by urban gas administrations and there is no competent equivalent authority, resulting in a limited approval process.
3) **Restrictions on land properties hinder the construction of hydrogen filling stations.** At present, land available for hydrogen filling must be either industrial or chemical land. Except for some industrial parks, hydrogenation stations should mostly be built at gas stations in cities or expressways for filling of fuel cell electric vehicles (FCEVs); restrictions on land properties hinders construction of hydrogen filling stations.

4) **The emergency response plan is incomplete and lacking a targeted guidance.** Due to the absence of specialised laws and regulations for accidental leaks, fires, explosions, and any other accidents in hydrogen filling stations, the Fire Protection Law can play a guiding role for the present, but the lack of a characteristic guiding scheme for hydrogen energy accidents also limits the development of the industry.

1.4. Hydrogen energy is mainly applied in the fields of transportation and industry, and the application experience and regulations are in the initial stage.

At present, hydrogen energy is mainly applied in the fields of transportation and industry, and there is no condition for wide-range household application. The transportation field is dominated by safe FCEV application, while the industrial field is dominated by metallurgy, chemicals, and oil refining. This chapter focuses on the safety problems with the above applications and the current situation of national laws, regulations, and standard systems.

1.4.1. Attention should be focused on FCEV hydrogen filling temperature rises and collision hazards in the transportation field.

FCEVs are still in an emerging field with rapid technological iterations. The process of forming safety regulations and standard systems should be a process of continuous deepening of technology research and development. According to their structure, the safety needs of FCEVs are divided into that of fuel cell systems and that of the whole structure, of which the safety needs of fuel cell systems cover filling of hydrogen, supply in fuel cells, and operation of the system.

China has a large number of standards applicable for fuel cells, most of which are related to safety; Table 8.6 lists the contents.

Table 8.6: Main Content of China's Laws, Regulations and Standards System for FCEVs

Safety system	Specific requirement	Relevant laws and regulations	Properties	Main Content of Laws, Regulations and Standards
Technical safety	Equipment Requirement	Fuel cell electric vehicle (FCEV) - Safety Requirement (SAC, 2009)	National standards	Safe Relief Device Hydrogen leak detection sensor Thermal insulation protection
	Process Safety	Safety Guide for FCEVs(CAIA, 2019)	Technical Instructions	The proton exchange membrane should have good thermal stability, chemical stability, and good mechanical stability. The gas diffusion layer needs to avoid long burrs in manufacturing and the proton exchange membrane needs to avoid puncture in thermo-compression resulting in gas leak and

				danger. In the preparation process of membrane electrode, proton exchange membrane may be pierced due to excessive compression of carbon paper, thus causing gas blow-by on both sides of the cathode and anode to result in danger. Therefore, thermocompression of carbon paper should be controlled to an appropriate extent according to the thickness of proton exchange membrane. Thermocompression of carbon paper should be controlled to an appropriate extent according to the thickness of proton exchange membrane. The electrode plate requires high conductivity, high thermal conductivity, and high strength to ensure the safety of fuel cells during the full life cycle.
				The end plate of fuel cell needs certain strength and good insulation.
	Material safety	Proton exchange membrane fuel cell (SAC, 2017)	National standards	Safety technical requirements such as proton conductivity and tensile rate
Management Safety	Regulatory Architecture		National ministries and commissions	Ministry of Communications
	Operation Safety	FCEV Safety Requirements Fuel cell electric vehicles - refueling receptacle On-board hydrogen system of FCEV - Technical requirements - Safety requirements of FCEVs	National standards	Reminder of low residual amount of hydrogen The receptacle shall be dust-proof and pollution-proof. The operating pressure of grounded receptacle does not exceed 35MPa and the operating environment temperature ranges from -40℃ to 60℃.
	Personnel Safety			Hydrogen leak alarm device (2% concentration, audible and visual alarm)
	Environment Safety			Leaked gas should not be discharged to passenger cabin, luggage cabin and cargo- hold. Hydrogen leak test in confined space
Risk prevention	Emergency response plan	FCEV Safety Requirement		Cut off power, close solenoid valve and eliminate open flame in case of hydrogen leak.
	Risk Management	FCEV Safety Requirement	National standards	Reasonable ventilation and accelerated diffusion.

Source: Author.

The above FCEV safety standard systems have covered the full process from equipment and material and process safety to filling parameters and use safety, but lacked any specialised rules. Compared with laws and regulations, standards are weaker in implementation and their applicability should be improved gradually with the progress of technology. Therefore, there is a need for safety regulations and standards for FCEVs in the transportation field to keep pace with the times, mainly due to the following:

Mismatching between the hydrogen filling pressure and the actual demand. China's current standard GB/T 26779-2011 *Fuel Cell Electric Vehicles - Refueling Receptacle* gives the safety indicators of hydrogen filling for fuel cells with pressure of 35MPa or below, while there are hydrogen filling systems under each pressure gradient of 11MPa~70MPa in the world. China's standards cannot match the future technical demand and there is room for revision.

The temperature rise control strategy of hydrogen filling should be improved. Hydrogen temperatures are extremely susceptible to rising during filling; when the filling speed is too fast, temperature rise is accelerated and the natural cooling speed is slow. In relevant standards, the filling temperature range is required to be -40℃~60℃, but there is no specific guidance applicable. The temperature rise can be significantly reduced by pre-cooling when filling hydrogen, but the temperature rise will remain under high flow rate. Therefore, it is necessary to adopt pressure limits, flow limits, or other safety guidelines to avoid excessive temperature rise.

Regulators lack attention to collision safety. As safety tests on hydrogen storage tanks is of particular importance in the event of a FCEV collision, any such traffic accident caused by this may lead to greater safety problems, and it is worthwhile for regulators to adopt stronger regulatory schemes to ensure the safe operation of FCEVs.

1.4.2. Hydrogen energy substitution in the industrial field involves technological innovation, and supporting standards and specifications have failed to catch up.

The chemical properties of hydrogen are mostly employed in industry, i.e. as a reducing agent. Although the energy performance of hydrogen has been initially confirmed, supporting regulatory policies and mechanisms have not yet been adjusted. Industry accounts for 70% of China's carbon emissions, with the chemical sector accounting for the largest share, according to data from the Energy Conservation and Environmental Protection Institute of CCID Research Institute. This is mainly due to carbon and carbon-containing molecules having acted as irreplaceable reducing agents in chemical processes. Therefore, the chemical industry is one of the more difficult areas to reduce emissions. Under the background of 'carbon peak' and 'carbon neutral', higher requirements have been put forward for the transformation of the chemical industry. The chemical industry is both the largest source of hydrogen production and an important user. Promoting blue hydrogen and green hydrogen to replace carbon in the chemical industry (such as exploring the development of hydrogen metallurgy) is an important path to achieve the goal of 'carbon peak' and 'carbon neutral' in China.

a) **The hydrogen metallurgy industry is still in its infancy, and safety regulations should be gradually explored.**

The present research on global hydrogen metallurgy projects is divided into three steps: the first is to establish a pilot plant for a feasibility study of large-scale application of hydrogen energy for industrial smelting before 2025; the second is to use hydrogen generated from coke oven gas, chemicals, and other by-products for industrial production by 2030; the third is to realise industrialised production of green and economic hydrogen by 2050, and launch high-purity steel hydrogen smelting with hydrogen energy, which is mainly generated from electrolysed water that used hydropower, wind power, and nuclear power. The hydrogen smelting technology of China is still in the initial stage of research and development. Most enterprises are still in the stage of project planning. Only a few have set the goal of producing hydrogen from clean energy for the purpose of smelting and most still use coke oven gas and chemical by-products as a hydrogen source. For the present, China lacks top-level design in terms of specialised planning, policy systems, standard systems, and safety specifications supporting hydrogen metallurgy. The main obstacles are detailed as follows:

Lack of examination and approval regulations to guide construction. Taking ferrous metal smelting as an example, the widely used blast furnace iron-making mode is mainly mixed smelting of solid coke and crude ore. This mode cannot match the operating condition of hydrogen metallurgy, and it is necessary to reshape smelting modes, plant construction, and safeguards. Therefore, many steel mills will be transformed or rebuilt, and their safety regulations should be redesigned. In this process, technical experts shall be assigned to make continuous study and demonstration, and national guiding standards or stricter laws and regulations shall be launched to give full play to the strictness of the examination and approval process to ensure the safety of the hydrogen metallurgy process.

Inexperience in establishment of regulatory system and mode. With the gradual development of hydrogen metallurgy in China in the future, enterprises will face safety problems in the process of operation. It is necessary for regulatory authorities to adopt the regulatory modes, ideas, and principles that keep pace with the times to further standardise the safe operation of hydrogen metallurgy enterprises. Hydrogen metallurgy is still in its infancy in China, and there is no practical historical experience for reference at the regulatory level.

Lack of personnel safety training. Study of any other energy source such as oil and natural gas shows that regular operator training and evaluation are an important part of safety work. Many accidents come from improper operation, carelessness, etc. Though safety training on hydrogen metallurgy operators is essential, it is all but absent in China.

Lack of risk prevention mechanism. It is difficult to formulate hazard prevention regulations accommodating every safety risk in the hydrogen metallurgy process due to a lack of actual operation data and experience.

b) Work safety laws and regulations of synthetic ammonia have limited specification for hydrogen energy.

The prevailing laws and standards on safe production of synthetic ammonia include the *Access Conditions for Synthetic Ammonia Industry* issued by the Ministry of Industry and Information Technology in 2012; local laws and regulations include the *Guidelines for Safety Standardization for Synthetic Ammonia Production Enterprises* (AQ T3017-2008) issued by Shanxi province in 2008. Both are designed to regulate access to synthetic ammonia and standardise operations, but the relevant expressions concerning hydrogen energy are insufficient. The regulatory system requirements for the large-scale application of hydrogen energy in the field of synthetic ammonia are mainly reflected in the following fields:

Safety of synthetic ammonia equipment: control of synthetic tower material and inlet and outlet temperature. The synthesis tower is subjected to high temperature and high pressure, and hydrogen is flammable and explosive. The temperature and tightness of the inlet and outlet should be well controlled to avoid explosion. The synthetic tower is mostly made of steel. Under a high-temperature environment, the synthetic tower is vulnerable to corrosion and hydrogen embrittlement due to the influence of hydrogen and ammonia. Therefore, the synthetic tower material should be strictly regulated and reference can be made to laws and regulations on hydrogen energy transportation.

Safe production of synthetic ammonia: fire, explosion, and virus prevention. It is necessary to keep improving the awareness of personnel on safety precautions, formulate and follow strict operating procedures, rules, and regulations, and strengthen management on hydrogen. For example, adopting mature, reliable, and safe technology can fundamentally improve production; properly controlling the temperature and pressure of containers and preventing open fire sources from approaching any combustible material can prevent accidents; monitor all variables in the production process, set combustible gas alarm, H_2 and H_2S detection alarm, and automatic alarm for leakage. The formulation of safety regulations for synthetic ammonia can refer to the relevant contents of *Code for Electrical Design of Explosion and Fire Hazardous Environmental Installations*.

c) Absence of specification on hydrogen energy in laws, regulations, and standards on safe production of methanol

At present, methanol is mainly synthesised by hydrogenation after coal gasification in China. In the process of producing methanol from coal, the ignition points of raw coal, hydrogen, and any intermediate product are very low, and explosions will occur in lengthy circumstances of high temperature and high pressure. This should be regulated. China's prevailing laws and standards mainly focus on regulating transportation and the use of methanol, and there are few regulations on the key part related to hydrogen in methanol production. In GB18218-2000 *Identification of Major Hazard Installations for Hazardous Chemicals*, major concerns are identified for hazardous substances during methanol production and storage. The requirements for a safety regulatory system for the large-scale application of hydrogen energy in the field of methanol production are mainly reflected in the following fields:

Effective allocation of production equipment. In the process of methanol production, fire risk is classified as Category A; in order to reduce the incidence of potential safety hazards, it is necessary to optimise the allocation of production equipment. For example, production equipment is arranged in the open air, compressed plants are designed as Level-I fire-resistant buildings, the roofing is made of lightweight material, and the pressure relief area is strictly tested to ensure compliance with the specific explosion-proof regulation of plant building. In addition, the flooring is designed with material generating no spark and an accident ventilation system is installed indoors. Natural ventilation holes are designed on the roof. Once carbon monoxide concentration within the plant has risen to $20mg/m^3$ or H2 concentration has risen to 4%, the indoor accident ventilation system should be opened automatically. Mechanical exhaust systems and combustible gas alarms shall be installed in rectification pump houses and refrigeration stations. In case of a safety accident, an alarm shall be given immediately.

Strict precautions against leakage of converter. The main materials at the converter inlet are steam and crude gas, while gases at the converter outlet are carbon dioxide, carbon monoxide, hydrogen, and methane, and the temperature of outlet gas is 450℃~590℃. If the converter leaked in the production process, then gas would leak to cause an accident such as a fire and poisoning. Therefore, in order to ensure the normal operation of a converter and avoid leakage, relevant personnel must control the water-to-steam ratio within the range of 0.5~2.0; the content of hydrogen sulfide in the crude gas entering the furnace shall be controlled to ensure that the content of hydrogen sulfide is higher than 300ppm so as to avoid affecting the activity of conversion catalyst and causing reverse sulfidation.

d) Laws and regulations on hydrogen refining should be improved in hydrogen storage, reactor, and fire prevention.

A safe transition is required between hazardous chemical management regulation and energy legislation. Hydrogen is used as chemical material to hydrocrack and reform heavy oil under high pressure; this is the main application of hydrogen refining. Article 24 of *Regulations on Safety Management of Hazardous Chemicals* states that hazardous chemicals (including hydrogen for industrial use) shall be stored in dedicated warehouses, specialised places, or specialised storage (hereinafter referred to as specialised warehouses), and shall be managed by full-time personnel. This legislation has strict binding significance in the hydrogen chemical industry. With hydrogen energy included in governance of energy law, whether the hydrogen energy storage management mode of chemical enterprises will be adjusted remains unclear. The legislation on hydrogen energy, if it cannot achieve a good transition, will have an impact on the safe production of hydrogen in chemical enterprises.

Lack of special safety laws, regulations, and standards for hydrogen refining. The existing hydrocracking system is a process in which hydrogen can cause heavy oil to undergo hydrogenation, cracking, and isomerisation under the action of a catalyst under higher pressure and high temperature (100~150 atmospheric pressure, approximately 400℃) for converting to light oil (gasoline, kerosene, diesel oil or material for catalytic cracking to produce olefins). The difference between hydrocracking and catalytic cracking is that the reaction of catalytic cracking is accompanied by hydrocarbon hydrogenation. The yield of liquid product from hydrocracking is over 98% and the quality of hydrocracking is far higher than that of catalytic cracking. Hydrocracking, though having a large number of benefits, is not as widely used as catalytic cracking, since it has to be operated under high pressure, requires more alloy steel, consumes more hydrogen, and needs more investment. Safeguards are reflected in relevant laws and regulations against leakage and explosions during the high temperature and high-pressure reaction, and mainly in the following legal requirements:

a) Requirements on stiffness and strength of reactor material and characteristics of alloy steel;
b) Requirements on air tightness of high-pressure system and emergency management for leakage;
c) Technical specification for safe start and stop of catalytic reactor:
d) Emergency plan for emergency shutdown of reactor (circulating hydrogen);
e) Safety regulations for fire prevention and emergency treatment;
f) Precautions against spontaneous combustion and emergency treatment for catalyst and reactant (FeS, H_2S, etc.); and
g) Poisoning prevention and emergency treatment of catalyst and reactant ($Ni(CO)_4$, H_2S, etc.).

In addition to laws and regulations, there are many standards in China for regulating safe operation of chemical enterprises; however, the content on hydrogen safety is obviously insufficient. For example, it is required in Section 4.1.10: Fire Break in the *Code for Fire Protection Design of Petrochemical Enterprises* (GB50160-2018) that the fire break for combustible liquid be 50~90m and that, for process facilities, it be 10~90m. This section has no regulation on the safety of high-pressure gaseous hydrogen used by some chemical enterprises; the requirement for combustible emission gases in Section 4.2.2 is mainly reflected in the specifications for alkane, since liquefied petroleum gas and the like have higher density than air and are easy to deposit on the surface.

By contrast, hydrogen has extremely low density and is a potential safety hazard when remaining in any dead corner of the roof during diffusion. There is no reference to the arrangement of exhaust equipment on the top of buildings in Section 4.2.2; Section 4.3: Access Road imposes the corresponding requirement according to the transportation capacity of hazardous chemicals. The regulatory requirement mentioned in the Standard under the storage capacity of 50,000m^3 and 120,000m^3 are more applicable for oil and gas storage and transportation, and cannot fully adapt to the transportation characteristics of high-pressure gas hydrogen and liquid hydrogen industries, and correspondingly cannot match the road safety specifications during hydrogen transportation. The fire break of buildings arranged is given in Section 4.3, in which combustible gas, liquefied hydrocarbon, and combustible liquid fall into separate categories, and, due to significant difference between the physical and chemical characteristics of hydrogen and alkane, hydrogen is more necessary to be classified as a single category under the background that liquefied hydrocarbon is classified into a separate category.

At present, the requirement on the arrangement of safe distance for hydrogenation stations and hydrogen production equipment is common in transportation fields, but the specification for safe distance of hydrogen-using equipment in the chemical industry is absent, making it necessary to study this.

2. Reference from foreign experience

With the wide application of hydrogen energy, countries and international organisations have done a lot of work on its safe development: for example, ISO/TC197 Hydrogen Energy Technical Committee, established in 1990 with 22 participating members and 13 observing members, which is mainly responsible for formulation and revision of international standards in hydrogen production, hydrogen storage and transportation, hydrogen-related tests, and hydrogen energy utilisation. IA-Hysafe organises the International Conference for Hydrogen Safety biennially to provide an open platform for display and discussion of latest research. Laboratories and associations organised by each country have also contributed to the technology and standard of hydrogen safety, including Japanese HySUT, Japanese HyTReC, Sandia National Laboratories of the US, the European Union's FCH2JU, Northern Ireland's HySAFER, Canada's PowerTech, etc.

2.1. The US has established the concept of hydrogen safety and the standard for piping and tank availability for our reference.

The main goal of the US development of hydrogen energy is reserve of strategic technology in the medium and long term and realisation of energy diversity and flexibility. The annual output of hydrogen in the US exceeds 10 million tonnes, representing about 15% of global supply; there are about 2,500 kilometres of hydrogen pipelines and 46 hydrogenation stations. The US Department of Energy in the *Hydrogen Program Plan 2020* that it is committed to technological research and development of the full industrial chain of hydrogen energy, and will intensify demonstration and deployment in order to realise scale.**Error! Reference source not found.** According to the US National Laboratory, the demand for hydrogen energy in the US will increase to 41 million tonnes per year by 2050, representing 14% of the total energy consumption in the future.

Hydrogen safety accidents still occur in the US. In April 2020, an explosion occurred in a hydrogen fuel plant in Longview, North Carolina, causing damage to 60 houses nearby. Based on the strong demand for hydrogen safety, a series of laws, regulations, and standard systems have been deployed in the US, including the *National Hydrogen Energy Road-map* issued by the Department of Energy in 2002, the Energy Policy Act enacted in July 2005, and the *Hydrogen and Fuel Cell Program* issued by the Obama administration in September 2011, all of which outline the national hydrogen safety concept, which is to **confirm which hazardous sources of hydrogen can be used**.**Error! Reference source not found.** The Department of Energy has proposed a broad concept of hydrogen safety, that is, not only concerning hydrogen, but also handling its relationship with ignition sources (sparks and heat) and oxidants (oxygen, etc.), thus expanding on China's safety precaution ideas.

Ventilation has been fully considered in construction of US hydrogen filling stations and natural ventilation holes have been arranged on the top of buildings.

In addition to safety concepts, the US has formulated a series of safety laws and regulations, mainly including material management and traffic control. Management of material for hydrogen energy in the US is similar to that of hazardous chemicals for hydrogen energy in China; in order to avoid any accident in the full industrial chain such as production, transportation, loading, unloading, and storage of hydrogen (and other hazardous chemicals), the US has formulated the *Hazardous Materials Code*, which has clearly stipulated safe operation, response plans, training, and supervision regarding hazardous chemicals in all processes.

In the field of transportation, the US has established the National Fire Administration (USFA) for fire research, precautions against hazard, publicity, and education, etc. In order to ensure the safe application of hydrogen energy, USFA has promulgated laws, regulations, and standard systems such as Hydrogen Technical Regulations (NFPA2), and the Use and Technical Standards of Compressed Gas in Portable and Fixed Containers (NAPF55).**Error! Reference source not found.** For example, the type of hydrogen filling station is limited to a stationary one, thus avoiding the risk of a leak caused by movement of equipment; hydrogen in stations is supplied from a designated source outside so as to reduce the potential safety hazard; and the strategic choice of hydrogen transportation is mainly long tube trailers, while a small part is transported with liquid hydrogen tankers. In order to avoid accidents in the hydrogen filling process, laws and regulations require shutting down the engine, no smoking, no use of any mobile phone, and no open flame during hydrogenation. In order to avoid any large-scale lethal effect of emergencies, the US has performed tests on hydrogen systems, fuel tank leaks, simulations of garage leakages, and on tank drops.

It can be seen through study on hydrogen safety regulations that the US holds a more cautious attitude towards the development of hydrogen energy and has more restrictions on safety. Some safety measures, such as emphasis on explosion and leak prevention, are worthwhile to learn from.

Table 8.7: US Hydrogen Safety Standard Systems (Excerpts of Key Points)

Standard No.	English Name/Chinese Name	Main content
ANSI/AIIA G- 095-2004	Guide for safety of hydrogen systems(US-ANSI, 2017)	Close to *the Essential Requirements for the Safety of Hydrogen Systems* of China.
ANSI/ASME B31.12-2019	Hydrogen piping and pipelines(ANSI/ASME B31.12-2019)	Requirement for process materials: pipe heat treatment and thermoforming inspection and test. Safety requirements for pipes manufacturing and assembling (bolts and seals). Detection and prevention of gas leakage. Allowable stress and quality factors of metal pipes.
CSA B51-14(R2019)	Boiler and pressure vessel (CSA, 2019)	Close to China's *Supervision Regulation on Safety Technology for Stationary Pressure Vessel*.
ANSI/CSA HGV 2-2014(R2019)	Standard hydrogen vehicle fuel containers(CSA, 2019)	Application conditions: Requirements for mass production, material, design, manufacture, marking and test of compressed hydrogen storage tanks for fuel cell road vehicles. Permanently attached to the vehicle. The operating temperature ranges from -40℃ to 85℃, the capacity is less than 1,000 liters and the operating pressure does not exceed 70MPa. Mainly specified the testing requirements that materials need to meet: Deformation of material within different pressure and tension ranges, stress ratio under different wall thickness conditions and product test.
ANSI/CSA HGV 4.1-2020	Hydrogen dispensing systems.(ANSI, 2020)	Applicable to standards for safe operation, substantial and durable construction, and performance test of mechanical and electrical characteristics of vehicle hydrogen distribution system. Applicable conditions: operating pressures of 25MPa, 35MPa, 50MPa and 70MPa.
		Scope of management: standardize the metering, registration, control, and management of hydrogen fuel cell vehicle filling, and put forward preventive measures against vehicle hydrogen over- filling and vehicle hydrogen storage tank over-pressure.

CSA ANSI/CSA HGV 4.5-2013(R2018)	Prioritization device for filling of hydrogen-powered automobile (CSA, 2018)	The operating temperature of filling equipment is -40℃~60℃, and use of screws, nuts and bolts shall comply with relevant standards; The use of equipment must be inspected per ASTM Standards or can be proved to meet the conditions; All movable parts shall be replaceable at any time and can be easily replaced; manual/automatic valves shall comply with the CSA requirements; The operators who install the filling equipment should be certified by automobile manufacturers and have been qualified accordingly (it has not made explicit that which qualification is required), and China has a similar situation, so it is necessary to specify the safety qualification (license) required for hydrogen operation worldwide. The temperature in the hydrogen filling room is limited to 25℃~30℃.
CSA HPIT 1-2015	Compressed Hydrogen Powered Industrial (CSA, 2015)	Minimum requirement for material, design, manufacture, and test of newly produced compressed hydrogen fuel system component has been specified. These containers are only used to store compressed hydrogen installed in hydrogen powered industrial truck applications or other heavy industrial applications.
	Gaseous Hydrogen Powered Industrial Truck/Heavy-duty Vehicle/Light-duty Surface Vessel Filling Agreement (CSA, 2015)	Filling operation procedures, filling time limit, cut-off time, emergency stop, fuel surplus monitoring; The inner diameter range of hydrogen piping is determined according to the velocity, pressure, and enthalpy of hydrogen at the outlet;

SAE/USCAR-5- 5: 2019-02-27	Avoidance of Hydrogen Embrittlement of Steel (SAE, 2019)	Hydrogen embrittlement of steel, i.e. brittle fracture that may be caused under pressure, is the result of hydrogen absorption in the process of cleaning, phosphate coating and electroplating; The susceptibility to hydrogen brittleness can increase with the stress (applied internally or externally) and material strength. The condition for increasing the risk of hydrogen embrittlement of steel has defined the decompression procedure needed to minimize the risk of hydrogen embrittlement.

Source: Processed by author from Mao, Z.Q. (2020).

This chapter excerpts some key content from numerous standards for reference. The above standards have specifications on equipment, material properties, operation procedures, etc., especially with regard to ANSI/ASME B31.12-2014 on hydrogen piping and pipelines, and ANSI/CSA HGV 2-2014 (R2019) on FCEV hydrogen storage tanks. China has no safety standard applicable in these two fields. According to the summary of construction and operation experience of the existing 2,500 km hydrogen pipeline, the US has formulated the *Standard of Hydrogen Piping and Pipelines*; as the temperature changes in different seasons, the safety of the pipe material is analysed and the safe temperature range is formulated in accordance with the existing material level, which is worth incorporating into China's equivalents. The storage and transportation of hydrogen energy represents almost 30% of the cost of the full industrial chain, and the high-pressure range is conducive to promoting the economy of hydrogen energy. In view of this, the US has formulated the *Standard Hydrogen Energy Storage Tank*, setting the operating pressure to be 70MPa, which is higher than the 20MPa limit defined by the prevailing standard in China. Of course, raising the operating pressure also requires the technical support of hydrogen storage equipment and material. Through the close cooperation between enterprises and the government, the technology and standards in the US have been upgraded simultaneously and created preconditions for large-scale application. Through research and analysis, it can be seen that the American fuel cell industry adopts a standard-first approach, which is consistent with the research of many scholars on the durability of fuel cells. For example, Nilesh Ade and other scholars have studied the durability of proton exchange membrane fuel cells (PEMFC) and analysed the safety hazards of explosions. After that, some scholars analysed the technical methods of how to improve the economics of hydrogen refueling stations within a safe range, which provided a reference for the large-scale development of hydrogen energy by the US Department of Energy.

2.2. The EU hydrogen energy regulations have every detail in place, focusing on safety management and hazard detection.

The development of EU hydrogen energy is mainly to replace fossil fuels, reduce carbon emissions, and make a greater effort to develop new energy sources. In the *European Hydrogen Energy Strategy* released in July 2020, safe application of hydrogen energy was mentioned nine times, demonstrating that the EU attached greater importance to safety. The main characteristics of safety legislation are sound legal systems, detailed content, and few cross-references, while the legal system related to hydrogen energy development is mainly mandatory. In addition, for codes in the same field, there will be many details required in EU Regulations, and words like 'see relevant standards for specific provisions' rarely appear.

Mandatory environmental impact assessment. The main laws and regulations related to production and use of hydrogen energy include 85/337/EEC *Environmental Impact Assessment Act for Public and Private Projects*, 2008/1/EC *Concerning Integrated Pollution Prevention and Control*, 2004/35/EC *Environmental Liability with Regard to Prevention and Remedying of Environmental Damage*, and European Hydrogen Energy Strategy (2020), of which 85/337/EEC clearly pointed out that, before a new project is approved, an environmental impact assessment of any major project must be performed; further, hydrogen filling stations are mandated to perform environmental impact assessments. **Error! Reference source not found.**

Attach greater importance to the safety management of practitioners. EU legislation attached greater importance to production safety, and there are regulations applicable to each production section in particular. In Germany, a safety controller shall be assigned if a factory has employed 20 people; in the EU, it is required to make an emergency response plan and designate a staff member to be in charge of accident prevention. In contrast, China has no safety regulations specifically for employees in the hydrogen field and the current personnel safety regulations have been promulgated and implemented as part of relevant legislation.

Attach importance to inspection and test of hydrogen transportation. The laws and regulations of the European Union, Germany, and China on hydrogen transportation are similar, and most of them focus on road transportation safety, which is also in line with the actual situation of the European Union. Directives 94/55/EC and 96/35/EC are special regulations for the technical indicators of hazardous goods transportation and the safeguard of operators. It is required in 96/96/EC that regular inspection and test are mandatory for all motor vehicles and drivers for cargo transport. In pipeline transportation, laws of EU and Germany require strict environmental impact assessment on related building projects. In addition, they must comply with prevailing national engineering and safety laws and regulations.**Error! Reference source not found.**

Table 8.8: Main Content of EU Hydrogen Safety Laws and Regulations

Standard No.	English Name/Chinese Name	Main content
BS EN 10229: 1998	Evaluation of resistance of steel products to hydrogen induced cracking (HIC) (EU, 1998)	Steel, hydrogen, visual inspection (test), cracking, corrosion test, sample preparation, accelerated corrosion test, test equipment, split test, mathematical calculation, and test sample
CEN 1251:2019	Cryogenic vessels- transportable vacuum insulated vessels of not more than 1000 litres volume - Part 1: Basic Requirements; Part 2: Design, fabrication, inspection, and test (EU, 2019)	Requirements for mechanical loading, chemical effects, thermal conditions, material properties, design, fabrication, inspection, and final acceptance test
CEN 13648	Cryogenic Vessels - Safety devices for protection against excessive pressure: Part 1: Safety valves for cryogenic equipment; Part 2: Safety devices for bursting disc of cryogenic equipment ((EU, 2000))	Focus on safety test of equipment
CEN 13530 UNE-EN 13458-2/AC-2007	Cryogenic Vessels - Large Transportable(EU, 2000) Vacuum Insulated Vessels Part 1: Basic Requirements; Part 2: Design, fabrication, and test(EU, 2004)	
CEN14197	Cryogenic Vessels - Static non-vacuum insulated vessels: Part 1: Basic Requirements; Part 2: Design, fabrication, inspection, and test; Part 3: Operational requirements. (EU, 2007)	Requirements for construction, marking and test of static non- vacuum insulated vessels, portable/stationary fuel cell systems.
EN62282-5-1- 2007	Portable fuel cell appliances-Safety (EU, 2007)	
EN62282-3-1- 2007	Stationary fuel cell appliances-Safety (EU, 2010)	

Source: Processed by author from Mao, Z.Q. (2020).

2.3. Strong enforcement of safety regulations and support guarantee with advanced detection technologies in Japan

Since Japan has high population density and small land space, it is difficult to avoid densely populated areas for the construction of hydrogen energy industry. Therefore, the implementation of the safety policies, laws, and regulations is very urgent. In Japan, the main intentions for safe application of hydrogen energy lie in the following aspects: (a) alleviating the energy crisis and reducing dependence on oil and natural gas; (b) improving the energy supply side structure and increasing the diversity of the energy structure; (c) promoting fuel cell vehicles; and (d) exporting hydrogen energy safety technologies to the world and becoming the technological leader of the industry.

Table 8.9. Laws, Regulations, and Standards Related to Hydrogen Safety in Japan

Category		Name	Main Contents
Regulations		Hydrogen fuel cell safety regulations Vessel safety regulations (Japan, 1994)	The basic technical requirements for hydrogen system safety, electrical system safety, drive system and fuel system safety have been formulated. In 2014, Japan extended the safety upper limit for the one-time charging pressure of the on-board hydrogen storage tanks of fuel cell vehicles, increasing from 70 MPa to 87.5 MPa.
Laws		High pressure gas security law (Japan, 1994)	The technical specifications, periodic inspections, and seismic design of general high-pressure gas equipment are applicable to high-pressure hydrogen. The high-pressure hydrogen safety requirements for hydrogen fuel cell vehicles, as well as safety management on the marks and scrappage are added in the latest version in 2017.
Standards	JIS C8822-2008	General safety specifications for small polymer electrolyte fuel cell systems (Japan, 2008)	
	JIS K0512-1995	Hydrogen (Japan, 1995)	Analysis of the basic characteristics of hydrogen used in industry and transportation, determination of oxygen content, storage precautions, etc. (When storage according to the storage method, attentions should be paid to the following: (1) Vessels must be chained to prevent it from tipping over; (2) The vessels should be placed in a well-ventilated and fire-free place, and stored at a temperature below 40°C.

			10. Treatment method. Hydrogen has a wide explosion range of 4.1% to 74.2% in the air, it is highly flammable, easy to leak, and has a low ignition temperature and difficult to see flames, etc. When collecting and testing samples, with consider these nature; in terms of safety, attentions should be paid to the following: (1) The vessel must be chained to prevent it from tipping over. (2) Use the prescribed tools to open and close the valves of vessels quietly. If it sprays out suddenly, there is a risk of fire. (3) When handling hydrogen, a warning of no combustion should be displayed. (4) Be careful not to leak hydrogen from the gas flow paths such as sample introduction pipes, measuring instrument, etc. The connection parts must be checked of leak with soapy water. (5) When performing the operations of 6.5.1 and 6.6.1, use a tipper fixed on the ground. In addition, when performing the operation of 6.6.2, perform the gas replacement completely, pay attention to backfire. (6) Fully ventilate to prevent the exhaust gas from the analyzer staying in the room. In addition, the exhaust is carried out under safe conditions without flames, mechanical sparks, high temperature objects, electric sparks, and static electricity.
	JISC 8822:2008	Safety standards for small solid polymer fuel cell systems (Japan, 2008)	Scope of application: The standard covers the overall safety criteria of the system, performance maintenance and management, etc. of the fixed and portable small solid polymer fuel cell systems (hereinafter referred to as fuel cell systems), their structures, materials, functions, setting standards, displays, markings, instructions for use, etc. Material requirements: Corrosion-resistant materials or coatings; when the outer contour materials such as synthetic resin are placed in the air of 80C±3C for 1 hour and then naturally cooled, there should be no cracks, rupture or other abnormalities. The materials of equipment parts must not contain PCB, asbestos or asbestos material; in terms of mechanical requirements, all parts should have

			a safe structure, which can resist distortion, strain and other damages; Control over temperature change: The temperature at the touch area is below 70C. Requirement for fuel cell stacks: a) Have a structure that can sufficiently withstand the stresses caused by assumed pressure, vibration, heat, etc. b) Have corrosion resistance in the intended use environment. c) Have electrical safety in the intended use environment. The heat preservation materials and thermal insulation materials adjacent to the gas passage, burning parts and electrical components shall be tested according to 5. in the Table 17 of HSS 2093. They shall not burn and must extinguish the fire within 10 seconds. When testing the insulation strength of the fuel cell stacks under the conditions 1) or 2) specified below, we must do the following: 1) charge the DC voltage or 1 time the AC voltage (500 V when it is lower than 500 V) to 1.5 times the maximum working voltage, continuously for 10 minutes between earth. 2) When the rated voltage is 150 V or less, the voltage is 1,000 V to the ground, and when the rated voltage is greater than 150 V, apply a 1,500 V AC voltage to the ground continuously for one minute. In the power generation unit, set up an automatic stop device under the conditions listed in the following: a) when fuel pressure or temperature in the fuel system and the heavy system has increased significantly; b) When the flame of the resetter burner goes out; c) When a gas leak is detected; d) When the control device is abnormal; e) When the control power supply voltage drops significantly; f) When the fuel cell stack has overcurrent; g) When the voltage generated by the fuel cell stack is abnormal; h) When the temperature of the fuel cell stack has increased significantly.

Processed by author from Mao, Z.Q. (2020).

At present, regulations related to hydrogen energy safety include high-pressure gas security laws (rules for security of general high-pressure gas, security of vessels, specific equipment inspection, and security of joint enterprises), fire protection laws, construction standard laws, labour safety and health laws, etc. The main standards include Japanese Industrial Standards (JIS), International Standard ISO/TC197, High Pressure Gas Security Association, Japan Petroleum Energy Technology Center, and the Japan Industrial and Medical Gas Association.

Strict regulations and strong enforcement. An important feature of Japan's legislation is strong operability, which is mainly reflected by the clear and specific legal provisions, and the timely promulgation of supporting regulations. After enacting a new energy law, the Japanese government will promptly formulate related supporting regulations in the form of 'implementation orders', 'implementation rules', etc., in order to regulate related issues in a more specific and detailed manner. For example, Japan enacted the *Law on Special Measures to Promote the Utilization of New Energy* in April 1997. To ensure its implementation, in June of the same year, the government enacted the *Enforcement Order of Law on Special Measures to Promote the Utilization of New Energy*. Although the above-mentioned laws are not closely related to hydrogen energy safety, they have certain reference significance for the formulation and implementation of hydrogen energy safety regulations in China.

Strict standards and thoughtful consideration. As regards standards and specifications, Japan has regulated the safety technology of hydrogen refueling stations. A hydrogen refueling station has a combination of large-capacity and high-pressure hydrogen storage cylinders, high-pressure compressors, and hydrogen unloading facilities. Construction of hydrogen refueling stations in gas stations is allowed in Japan; in other words, oil and hydrogen mixing stations are allowed. Further, containerised natural gas or hydrogen production devices using propane as raw material in hydrogen refueling stations, or those used in online hydrogen production, are allowed. The safe distance between hydrogen refueling stations and surrounding buildings is only required to be in accordance with provisions of the *Safety Law on High Pressure Gas*, and the distance from residential houses and various public facilities should be no less than 8 metres. Hydrogen refueling stations, residential houses, and public facilities are installed with 10 cm-thick separation walls.

Table 8.10: Comparison of Major Safety Distances

Comparison of major safety distances planned by various countries (unit: m)							
Categories	Requirements on control		China	US	Germany	Japan	UK
In-station distance	Constraint distance	Open fire in the station	12~14*	12	1~5	8	5
	Layout distance	Distance between hydrogen equipment	3~15	/**	0.5~1	/	/
		Distance between hydrogen and non-hydrogen equipment	4~8	/	2	/	/
	Protective distance	Equipment and road	2~5	3	/	3	8
		Plant/ warehouse	5~15	0 (2h***)	5	/	/
Outer-station distance	Out-station distance	Buildings outside the station	12~50	2 (2H)	/	/	/
		Open fire outside the station	20~40	3~4.6	/	/	8
Note:* Open flame is valued according to gas (oil) water heater/gas kitchen in the station: ** Due to introduction of risk assessment from abroad, some values are not mandatory and are determined based on the assessment result: ***Fire resistance time duration subject to American standards is not less than 2h.							

Source: Author.

Advanced safety detection technology. Japan's FCEVs apply 70MPa high-pressure hydrogen. The maximum outlet pressure of a refueling station hydrogen compressor and a storage bottle are up to 90MPa. Reliability and safety performance testing of hydrogen storage bottle manufacturing is very important. 70MPa and 90MPa hydrogen storage bottles usually adopt a three-layer structure: the surface layer applies glass fibre composite material, the middle layer is made of carbon fibre composite material, the inner layer of type III bottles is made of aluminium alloy liner, and the inner layer of type IV bottles is made of plastic liner. Hydrogen storage bottle design and manufacturing technology should be tested by hydraulic blasting, gunshot, fire, etc.; bottles should be given an automobile crash test.

For hydrogen refueling stations, the main safety technical measures include installation of high-sensitivity leak detectors in strategic locations, timely alerts when the volume concentration is higher than 1, and multiple flame detectors with alarms. Buildings such as high-pressure hydrogen storage rooms and compressor rooms should consider factors for dispersing hydrogen after leakages, and adopting a roof design that is both rainproof and prone to vent air. The roof design of outdoor hydrogenation units should be conducive to diffusion of hydrogen to high altitudes.

First, as the highest requirement for hydrogen-usage safety, Japan's laws and regulations are demanding; second, as guidelines for practice, Japan's standards are comprehensive, elaborate and strong in execution; and last, as the main means to ensure safety, the development of technologies and detection means interworking to ensure continuous improve and to make sure that safety parameters of the entire process of hydrogen energy use are distinctive.

2.4. Republic of Korea formulates full-process regulations to provide rules and guidance for industrial development

On 4 February 2020, the Republic of Korea (henceforth, Korea) government officially launched the world's first hydrogen law, the *Safety Management Law on Promotion of Hydrogen Economy and Hydrogen Safety* (hereinafter referred to as the Hydrogen Law), which provides strong support for safety management of hydrogen energy supply and facilities. The Hydrogen Law formulated the entire process of regulations and systems, established a hydrogen safety agency, stipulated strict access and business change conditions, and clearly required establishment of a safety administrator.**Error! Reference source not found.**

Whole-process laws and regulations. Korea's Hydrogen Law enforces strict laws and regulations throughout the entire process of operating a hydrogen energy business, ranging from operating permits to project declarations to completion inspections.

Establishment of a hydrogen safety agency. To regulate management boundaries and responsible parties for hydrogen safety, Korea has established a specialised agency responsible for hydrogen safety. The Minister of Industry, Commerce, Industry and Energy designated organisations, teams, or legal persons related to hydrogen project safety as specialised hydrogen safety organisations. The hydrogen safety organisation's work focuses on research and development of hydrogen safety technology, including through international cooperation; education and training on hydrogen safety; and boosting the importance of hydrogen safety.

Strict access and business change conditions. Articles 36 to 40 of Korea's Hydrogen Law stipulate that a report should be submitted to the mayor regarding access permits and changes to business permits. Commencement, suspension, and resumption of projects also need to be declared with causes being explained. High-level administrative approval strictly regulates access and operating timeliness of hydrogen energy. At the same time, it stipulates that specific requirements should be declared when major events such as ownership inheritance and bankruptcy auctions occur that would affect business activities.

Strict safety guarantee on filling of hydrogen. The hydrogen filling process has a high potential safety hazard. Korea's Hydrogen Law has clarified the scope and process of this work. Article 49 mentions that a mobile pressure vessel and gas cylinder filling unit shall meet the following conditions and obtain permission of the department responsible for safety supervision and management of special equipment before it can engage in filling activities. The filling unit shall establish an inspection and recording system before and after filling, and it is forbidden to fill mobile pressure vessels and gas cylinders that do not meet requirements of safety technical specifications. The gas cylinder filling unit shall provide users with cylinders that conform to the safety technical specifications, guide them on their safe use, register them, and apply for regular declarations in a timely manner.

Assign a security administrator. Korea's Hydrogen Law clearly stipulates that a safety administrator must be assigned to operate a hydrogen business. As the principal party, the security administrator is mainly responsible for fulfilling responsibilities and ensuring safety, and guarding against danger of hydrogen supplies. The appointment of corporate security officers must be reported to the mayor, county guard, or district director. At the same time, when safety officers are unable to perform their duties due to other matters including retirement, travel or illness, they need to submit declarations 30 days in advance to ensure the smooth transition of safety protection work.

Study of Korea's Hydrogen Law reveals that its work on hydrogen energy security is mainly to establish strict administrative approval procedures, strict business scope definitions, prudent business changes, and continuous improvement of safety concepts. The above management experience is worth learning.

3. Related domestic practices

Safety is one of the main constraints to the development of the hydrogen energy industry, and it is also a topic receiving relatively high public concern. At present, China is deficient in laws and regulations on the safety of the entire hydrogen energy industry chain and shows unclear regulatory authorities. Some cities regard hydrogen as a hazardous chemical and are supervised by the city management department. With rapid development of the domestic hydrogen energy industry, various places have continuously attempted to promulgate regulations on the safe operation and supervision of hydrogen energy. As the most important part of the hydrogen energy application field, FCEV safety particularly stands out.

3.1. All relevant agencies are actively carrying out research on hydrogen energy development strategies in a bid to provide directions for industrial safety

The hydrogen energy industry has just started in China, but national strategic plans have not yet been issued. At present, the strategic level studies that have been carried out include those on infrastructure and fuel cell development; further, more than 20 provinces, cities, and regions across the country have carried out hydrogen energy industry development research. Studies of various kinds have clarified the goal of industrial development, presented strategy paths, and come up with development suggestions.

It is worth mentioning that the major strategic project of the Chinese Academy of Engineering, i.e. 'China's strategic study on hydrogen energy and fuel cell development', carries out special research on five fronts, namely the role of hydrogen energy and fuel cells in advancing energy revolution, hydrogen production and supply industry development strategy research, fuel cell industry development strategy, strategic research on development of hydrogen use industry and China's hydrogen energy and fuel cell development policy recommendations. This research covers development of the entire hydrogen energy industry chain and provides orientations for promotion of scientific development of China's hydrogen energy and fuel cell industry.**Error! Reference source not found.**

3.2. Implementation of several hydrogen energy testing centers indicates a major step forward for industrial development

At present, construction of the hydrogen energy testing center is gradually implemented, which mainly includes the National Hydrogen Energy Center, the National Hydrogen Vehicle Research and Testing Public Service Platform, the Great Wall Hydrogen Energy Testing Technology Center, the Future Science City Hydrogen Energy Technology Collaborative Innovation Platform, the Kunshan Innovation Research of Nanjing University Institute of Testing and Inspection Center, and Shanghai Shenli Technology Co., Ltd. Testing Center. The main body of investment coverage from research institutes to automobile manufacturers and from research and development to applications also reflects urgent needs of industrial development. Although most of the hydrogen energy testing centers at this stage are dedicated to testing of fuel cell vehicles including fuel cell testing, hydrogen storage safety testing, new energy vehicle testing and so on, the completion of major testing centers will vigorously promote formation of a more comprehensive hydrogen energy detection test method and a complete evaluation system in China, and will propel development of the domestic hydrogen energy industry.

3.2.1. Establishment of the National Hydrogen Power Quality Supervision and Inspection Center has achieved a breakthrough from scratch

The National Hydrogen Power Quality Supervision and Inspection Center is the first national hydrogen energy testing organisation in China. The center was built by China General Technology Group and China Automotive Engineering Research Institute Co., Ltd. with an investment of CNYU500 million and is in Yufu Industrial Development Zone, Liangjiang New District, Chongqing.

Main inspection content: it focuses on inspection and testing, prioritises testing content of fuel cell stacks, fuel cell systems and key components, hydrogen storage systems, hydrogen energy power systems, fuel cell vehicles and other fields, and centers on hydrogen energy applications. Based on three main technical lines of safety, greenness and experience, it attempts to create a comprehensive service platform for hydrogen energy power testing and evaluation that integrates testing and certification, standard systems, evaluation research, application promotion, and industrial incubation.

After the project is completed, it will serve hydrogen energy industry clusters in Southwest China, the overall country, and the world, and will become a fair and authoritative third-party technical testing service. It will have a profound impact on promotion of the development of hydrogen energy power industry.

3.2.2. As a domestic automobile manufacturer and supplier, Great Wall Motor's Hydrogen Energy Testing Center leads development of the industry

The Great Wall Hydrogen Energy Testing Technology Center was established by Great Wall Motor Co., Ltd. It is the world's largest battery testing device application company. With potent hardware strength and influence, it will become an important base for fuel cell enterprise testing. The center was brought online in Baoding in 2018 with a total input of US$570 million. It is committed to hydrogen storage safety testing, fuel cell testing, system performance testing, vehicle performance testing, and life cycle testing.

It is worth mentioning that the Great Wall Hydrogen Energy Testing Center has a 105 MW power hydrogen core ring test used to verify the safety of the entire vehicle, including the impact of liquid, gas, and eventually hydrogen, as well as a dropping and shooting test. Safety can be ensured through the entire inspection system. This is also a first in China. The establishment of the center will provide better support for development of China's fuel cell vehicle industry.

3.2.3. The future science city hydrogen energy technology collaborative innovation platform to promote coordinated development of technology and industry in the hydrogen energy field

In 2019, the Beijing Future Science City Hydrogen Energy Technology Collaborative Innovation Platform began giving full play to its advantages of major scientific research institutes in the field of hydrogen energy; further, it cooperated with Beijing Aerospace Experimental Technology Institute (Aerospace 101), Beijing Science and Technology Cooperation Center, and China Special Equipment Testing and Research Institute and the Zhongguancun Huadian Energy and Power Industry Alliance to announce the opening of Beijing's hydrogen energy equipment test and detection capabilities and to promote the coordinated development of technology and industrial entities in the hydrogen energy field. This also marks an important step taken towards the promotion and safe application of hydrogen energy equipment.

The platform focuses on the hydrogen energy equipment test and detection base of the Aerospace 101 Institute, supports the construction of hydrogen energy equipment test and detection capabilities, and has built the first 95 megapascal (MPa) level high-pressure hydrogen energy equipment test and test platform in China. It is equipped with fire, fatigue, leakage and reliability performance assessment test and type test capabilities of various hydrogen storage vessels, valves and other components under the hydrogen media and is the first domestic rapid charging and discharging test system for hydrogen storage tanks above 70MPa.

3.2.4. State Power Investment Corporation builds a hydrogen energy technology company to roundly promote research and development and testing of hydrogen energy applications

State Power Investment Corporation Hydrogen Energy Technology Development Co., Ltd. was established in 2019. Its main business scope includes research, development and production of core hydrogen fuel cell technologies, research and development of key technologies and materials for hydrogen energy production and storage, research, development and production of hydrogen energy power systems, research and development and services of hydrogen fuel cell testing and inspection technology and hydrogen safety technology research, etc.

After less than 2 years of development, the company has attained remarkable achievements in research and development of hydrogen fuel cells. The 100-kilowatt power metal bipolar plate hydrogen fuel cell stack launched by the company has realised fuel localisation of key raw materials and core components of batteries. As regards hydrogen energy demonstration projects, a transportation demonstration project is being carried out. At the same time, it is also working with Zhejiang University to carry out research on natural gas pipeline hydrogenation material verification, which will provide support for the model project of natural gas hydrogenation.

Moreover, other testing centres such as the Testing and Inspecting Center of Kunshan Innovation Research Institute of Nanjing University, the Testing Center of Shanghai Shenli Technology Co., Ltd., and the New Energy Vehicle Testing Center of China Automobile Center all focus on testing of fuel cells and new energy vehicles.

Table 8.11: Status on Establishment of Hydrogen-Energy-Related Testing Centers

Item	Test content	Investment subject	Location	Start Time	Land Occupation	Total Investment
Kunshan Innovation Research of Nanjing University Institute of Testing and Inspection Center	Fuel cell testing, new solar cell testing, biomass fuel testing, lighting electrical product testing, environmental testing	Nanjing University, Kunshan	Kunshan	2016	3 mu	Unknown
Future Science City Hydrogen Energy Technology Collaborative Innovation Platform	Fire, fatigue, leakage and reliability performance assessment tests of various hydrogen storage vessels, valves and other components under hydrogen media	The 101st Research Institute of China Aerospace Science and Technology Corporation, China Special Inspection Institute, Institute of Physics and Chemistry, Chinese Academy of Sciences	Beijing	2017	Unknown	(Military enterprise)
Great Wall Hydrogen Energy Testing Technology Center	Hydrogen storage safety testing, performance testing of fuel battery, system performance testing, vehicle performance testing	Great Wall Motor	Baoding	Completed in June 2018	50 mu	570 million yuan
Shanghai Shenli Technology Co., Ltd. Testing Center	Fuel cell stacks and modules, fuel cell system testing	Shenli Technology	Shanghai	Obtained CNAS certification on 14 August 2018	Unknown	Unknown
China Automotive Center New Energy Vehicle Inspection Center	More than 20 comprehensive test buildings including fuel cells, power batteries, electric drive assemblies, electromagnetic compatibility, new energy vehicles, etc.	China Automotive Center	Tianjin	25 May 2020	308 mu	1.99 billion yuan

National Hydrogen Vehicle Research and Testing Public Service Platform	A total of ten laboratories of parts, systems, and vehicles	Rugao Economic and Technological Development Zone and Shanghai Motor Vehicle Testing and Certification Technology Research Center Co., Ltd.	Rugao	15 September 2020	44 mu	260 million yuan
National Hydrogen Energy Center	Technical consulting services of fuel cell stack, fuel cell system and key components, hydrogen storage system, hydrogen power system, fuel cell vehicles	China General Technology Group, China Automotive Engineering Research Institute Co., Ltd.	Chongqing	16 September 2020	190 mu	500 million yuan

Source: Author.

3.3. National standards related to hydrogen energy safety are being formulated and modified at a faster rate, hoping that standardisation will guarantee the development of the industry.

Standardisation is very crucial to the development of the industry. China's current hydrogen energy technology standard system consists of eight standard sub-systems, one of which is the hydrogen safety standard. Through years of hard work, more than 100 national standards for hydrogen energy have been issued, with 30 standards concerning safety. The first national standard for hydrogen energy is GB/T 29729-2013 *Basic Requirements for Hydrogen System Safety*. As the first systematic national standard for hydrogen system safety, it plays an active role in promoting the development of hydrogen energy technology and enhancing its recognition in the market and society. In addition to national standards, industry standards, regional standards, and community standards have also been gradually established and improved. At present, a series of national standards are being revised. They are mainly standards related to hydrogen fuel cells and hydrogen vehicle, such as terminology for proton exchange fuel cells, standard system for proton exchange membrane fuel cells, proton exchange membrane fuel cell stacks, portable proton exchange membrane fuel cells, stationary proton exchange membrane fuel cell power generation systems, technical and testing specifications for motors and their controllers in electric vehicles, technical requirements for hydrogen production by hydrogen energy-water electrolysis, and technical specification of hydrogen purification systems on pressure swing adsorption, etc.

Although there are not so many special standards for hydrogen energy safety as other standards, and they are mainly concentrated on the relevant standards of the fuel cell vehicle application, given the particularity of hydrogen, great importance is attached to standardisation in the industrial development process. With the rapid development of the industry, relevant safety standards will be formulated and revised constantly.

3.4. Pioneering explorations in the safety approval of hydrogen refueling stations have been carried out with remarkable achievements in many cities.

In addition to the existing relevant national standards and regulations, currently, more than 10 cities in China have issued regulatory documents concerning the construction of hydrogen refueling stations, and the infrastructure of hydrogen fuel cell vehicles, including Foshan, Zhangjiakou, Wuhan, Weifang, and Wuhai, Fuzhou, Yueyang, Laohekou, Changchun, and Baoding City. Some of them are concerned with hydrogen energy safety. Although they may be similar or different in some ways, and they may not be perfect, they still provide a groundbreaking reference for the construction of hydrogen refueling stations in China, particularly in terms of their safe operation, management, and supervision.

Table 8.12. Documents on the Management of Hydrogen Refueling Stations in China and the Key Points Concerning Safety

Time of release	Name of document	Key points concerning safety
March 2018	Interim Measures for the Approval and Management of Hydrogen Refueling Stations in Wuhan Economic and Technological Development Zone (Hann an District) (Wu Jingkai [2018] No. 24) (Wuhan, 2018)	4 . Report for project construction. (5) Review of safety conditions and design of safety facilities: hydrogen refueling station projects shall refer to urban g as projects. The project construction units shall entrust a qualified safety evaluation agency to carry out safety pre-evaluation in accordance with the 'Three Simultaneousness' Supervision and Management Measures for Construction Project Safety Facilities, and safety pre- evaluation reports should be prepared.
August 2018	Interim Measures for the Administration of Hydrogen Refueling Stations in Foshan City (Draft for Comments) (Foshan, 2018)	Chapter III Operation and Safety Management: Provisions concerning safety ranging from system to operation are mentioned in 13 items through Article 9 to Article 21.
May 2019	Opinions from Weifang Municipal People's Government Office on Doing a Good Job in the Planning, Construction, Operation and Management of Hydrogen Refueling Stations in the City (Weifang government office [2019] No. 61) (Weifang, 2019)	5 . Effectively strengthen the safety management of hydrogen refueling stations, referring to improving the safety system, increasing staff, standardizing operation records, and imp roving emergency response capabilities.
July 2019	Interim Administrative Approach for Temporary business license of Automobile Hydrogen Refueling Stations (Draft for Comments) (Shanghai, 2019)	Details are mentioned regarding the application, acceptance, review, approval, certificate issuance, and relevant supervision and management of business license for auto mobile hydrogen refueling stations in Shanghai city.
August 2019	The People's Government of Laohekou City in Hubei issued the Administrative Measures for Hydrogen Refueling Stations in Laohekou City (for Trial Implementation) (Laohekou, 2019)	Chapter VI Operation and Safety Management: Provisions concerning Safety management system, safety distance, safety warning, safety assessment are mentioned in 18 items through Article 24 to Article 41.
January 2020	Administrative Procedures for Hydrogen Refueling Stations in Wuhai City (Trial) (2019 - 2022) (Wuhai, 2019)	Chapter IV Operation and Safety Management: Provisions concerning Safety are mentioned in 4 items through Article 14 to Article 17 , referring to carrying out safety inspections on hydrogen systems, fire and safety facilities, electrical facilities, and ventilation devices, according to Technical Specifications for Hydrogen Refueling Stations .
May 2020	Program for Hydrogen Energy Industry Safety Supervision and Management in Zhangjiakou City (Zhangjiakou, 2020)	There are 9 chapters and 90 articles in the program, covering the safety management of the entire industry chain, referring to the company's own safety management, key points of safe operation, and the management responsibilities of various regulatory agencies.
October 2020	Notice of the People' s Government of Changchun City on Issuing the Interim Measures for the Administration of Automobile	In Article 12, Article 13, and Article 15, it is made clear that details such as the Security Officer at all levels, the safety management system of auto mobile hydrogen refueling stations, and the hydrogen hazard risk notification board

	Hydrogen Refueling Stations in Changchun City (Changchun Municipal Regulation [2020] No. 1) (Changchun, 2020)	should be unveiled to the public, and the safety operation specifications should be posted in an eye-catching place, etc.
October 2020	Opinions of the Baoding Municipal People's Government Office on Doing a Good Job in the Approval and Management of Hydrogen Refueling Station Projects (Baoding, 2020)	2 . Review of project planning and design program and plan of land use (6) Design for safety conditions and safety facilities. The hydrogen refueling station project shall be carried out in accordance with the 'Three Simultaneous' Supervision and Management Measures for Construction Project Safety Facilities with reference to urban gas projects, and the safety pre-evaluation of its construction projects will be conducted. Also safety pre-evaluation reports and safety facility design documents will be prepared.
November 2020	Interim Measures for the Construction, Operation and Management of Hydrogen Refueling Stations in Fuzhou City (Fuzhou Municipal government Office [2020] No. 109) (Fuzhou, 2020)	The measures have repeatedly mentioned safe production, training, and operation, and proposed the establishment and improvement of relevant safety management systems for hydrogen refueling stations.
December 2020	Interim Measures for the Construction and Management of Hydrogen Refueling Stations in Yueyang City (Yueyang, 2020)	In Article 7 and 12 , security review work of hydrogen refueling station construction project is mentioned, Namely, the operation and management of hydrogen refueling stations shall comply with the Safety Technical Requirements for Hydrogen Storage Devices for Hydrogen Refueling Station s(GB/ T 3 4583 — 2017) , Hydrogen Station Safety Technical Specification s(GB/ T 34584 - 2017) and relevant national standard s .

Source: Authors.

3.4.1. The first local management document for hydrogen refueling stations was issued in Wuhan, and its safety approval and supervision system is worth promoting.

Wuhan has taken the lead in the development of hydrogen energy in China. It not only abounds with industrial by-product hydrogen, but also gains some advantage in key core technologies such as membrane electrodes, storage and transportation, efficient production, and FCEV power systems. In addition, it also has a strong foundation in technology and industrialisation.

Refueling stations are the key infrastructure for the development of the hydrogen vehicle industry. Regarding site selection, construction approval, and other procedures, there are no normative or guiding documents issued by local governments at all levels. To promote the development of the hydrogen energy industry and speed up the construction of supporting infrastructure, Wuhan Economic and Technological Development Zone (Hannan District) made a good try in approving and supervising hydrogen refueling stations in 2018. It issued the Interim Provisions for the Approval and Management of Hydrogen Refueling Stations in Wuhan Economic and Technological Development Zone (Hannan District). This document clarifies the approval and management procedures and regulatory department concerning site selection, reporting, construction, and operation of hydrogen refueling station projects.

Regarding hydrogen energy safety, the document proposes that hydrogen refueling station projects shall refer to urban gas projects. The project construction units shall entrust a qualified safety evaluation agency to carry out safety pre-evaluation in accordance with the 'Three Simultaneousness' Supervision and Management Measures for Construction Project Safety Facilities, and safety pre-evaluation reports should be prepared. Meanwhile, design concerning the safety facilities of the construction project should be carried out by entrusting a qualified design unit, and safety facility design documents should be compiled. Safety pre-evaluation reports and facility design documents should be submitted to the district safety supervision bureau for the record. Although the measure only sets forth brief provisions on the safety of hydrogen refueling stations, and it does not cover the entire industry chain and related management systems, it has been developed from scratch, and it means a big step forward for standardising infrastructure construction in the hydrogen energy field. It can provide valuable reference for other cities.

3.4.2. Foshan City has made a pioneering exploration on the safety of hydrogen refueling stations and issued the first Interim Measures for the Administration of Hydrogen Refueling Stations in China

Foshan's hydrogen energy industry began in 2014. After 6 years of development, it has taken the lead in China in introducing the Canadian Ballard production line for commercial vehicles; introducing and implementing support and preferential policies; putting 16 hydrogen refueling stations into service; and establishing a standard innovation base for the hydrogen energy industry. However, various problems emerged in the development process of Foshan's hydrogen energy industry, such as the production, preparation, and refilling of hydrogen. Fortunately, progress has been made in identifying and solving problems. It is worth mentioning that Foshan has made pioneering explorations in hydrogen energy safety management. China's first 'Interim Measures for the Administration of Hydrogen Refueling Stations' was issued in Foshan in August 2018. It made clear regulations on administrative approval, safety system construction, and safety management.

In terms of administrative examination and approval and competent authorities, Foshan City has borrowed from the natural gas administrative examination and approval model and established a model of housing construction taking the lead in administrative examination and approval. It filled the gap in the approval process of hydrogen refueling stations. It maintained that the Housing and Urban-Rural Construction Administration should be responsible for the city's industry management of hydrogen refueling stations and also the guidance and supervision of the construction approval, business license and safety supervision of hydrogen refueling stations in various districts. The housing and construction department at the people's government district level specifically implements the approval of the construction of hydrogen refueling stations, the issuance of business licences, operation supervision and safety management.

In terms of the construction of safety system, it not only proposed that someone should be responsible for the safe operation of hydrogen refueling stations, but it also clearly stated that the operating entity must establish a sound safety management system, safety production responsibility system, risk management system, and emergency response plans. Emergency drills should be carried out, with special drills at least once a quarter, comprehensive emergency drills at least once a year. The safety management system of the hydrogen refueling station shall include, but is not limited to, operation site safety management, fire safety management, equipment safety management, staff safety management, safety inspection management, the accident reporting and handling process, the regular inspection system, and security work management. A series of regulations above provide both guidelines and guarantees for the safe operation of hydrogen refueling stations.

3.4.3. Zhangjiakou City has issued China's first approach for the safe supervision and management of hydrogen energy, setting a good example.

As a national demonstration zone with renewable energy and the host city of the 2022 Winter Olympics, Zhangjiakou City has seen rapid development and taken the lead in the hydrogen energy industry in recent years. Targeting green, low-carbon, and sustainable development, Zhangjiakou City provide transportation services for the Winter Olympics with hydrogen fuel cell vehicles. According to Zhangjiakou's hydrogen energy industry plan, by 2022, hydrogen fuel cell vehicles will have been put into demonstration operation in batches in the Zhangjiakou competition area and the main urban area in order to meet the transportation needs of the Winter Olympics. It is planned to promote more than 2,000 vehicles with hydrogen fuel cell for city buses and passenger and logistics services.

Safety issues occurred inevitably along with the rapid development of the hydrogen energy industry and they cannot be ignored. In order to prevent and defuse major risks and ensure the safe and stable development of the hydrogen energy industry, Zhangjiakou City issued the first *Safety Supervision and Management Approach for the Hydrogen Energy Industry* in May 2020. There are nine chapters and 90 articles in this approach. The biggest highlight is that it is concerned with the safety management of the entire industry chain, including the company's own safety management, the key points of safety operation, and the management responsibilities of various regulatory departments.

In terms of safety management of hydrogen-related enterprises, the *Safety Supervision and Management Approach* covers the key points of safety management of the entire industrial chain from the production, storage, transportation, refueling, to the use of hydrogen energy. In reference to the *Law of the People's Republic of China on Safety Production*, it put forward requirements for the safety management of hydrogen energy companies in the entire production and operation process ranging from hydrogen energy industry planning, license application, staffing, personnel qualifications, three systems, emergency plans and drills, personnel training, and equipment maintenance, etc. For example, it made clear statements about the safety distance between the hydrogen production enterprise and the facilities outside the plant, as well as the architectural characteristics and fire resistance limits of the buildings.

For hydrogen energy storage, hydrogen gas tanks and vessels are the equipment mainly used. Hydrogen gas tanks should be limited in their height and water seal level to prevent hydrogen from escaping. Hydrogen vessels should be put under proper pressure with safety devices installed to prevent overpressure explosions.

Safety requirements are also put forward for the transportation of hydrogen. Corresponding qualifications are demanded in the design and manufacture of hydrogen energy vehicles. The users should register and regularly inspect the vehicles in accordance with the regulations. Qualified safety management personnel, drivers, escorts, and operators should be equipped correspondingly. Also, some necessary safety protection equipment is needed for daily operation.

Regarding the safe operation and control of the hydrogen refueling system, it is required that the site selection of hydrogen refueling stations should meet the requirements of planning and safety. The hydrogen refueling stations should take measures to prevent hydrogen leakage, avoid static sparks and open flames, and ensure that all electrical instruments should be explosion-proof.

In terms of the safety requirements for the use of hydrogen energy, it is proposed that electric vehicles fueled by gaseous hydrogen cells should comply with the relevant national mandatory standards for motor vehicles and the safety requirements for electric vehicles. They should work hard to avoid over-temperature and over-pressure of hydrogen storage tanks, hydrogen leakage. Hydrogen leak detectors should be installed and make measures to prevent static electricity.

In terms of the supervision and management of hydrogen energy, clear divisions about their respective management functions in the hydrogen energy industry chain are made among 13 relevant supervision and management departments, namely the department of administrative approval, market supervision, ecological environment, transportation, housing construction, urban management, and emergency management and so on. All departments are required to strengthen the supervision of hydrogen energy according to their responsibility division to ensure the safe, stable, and efficient operation of the hydrogen energy industry.

4. Propositions on policy

Due to the particularity of hydrogen, the safe development of the hydrogen energy industry is particularly important. The safe utilisation of hydrogen energy runs through all links of the entire industrial chain, from preparation, storage, transportation, refueling, to the application of hydrogen, and it is a prerequisite and necessary condition for the healthy development of the hydrogen energy industry. International and domestic application practices have proved that as long as hydrogen energy is used in production and storage in accordance with laws, regulations and standards, the safety of hydrogen energy can be guaranteed. This chapter makes propositions on how to improve the legal system, technical standards, and specifications; accelerate the production, learning, research, and application; and improve safety testing capabilities, etc.

4.1. To speed up top-level design and establish safety laws and regulations for the entire hydrogen energy industry chain

At present, it is not yet clear what role hydrogen energy plays, and this will restrict it from playing its due role in the energy revolution. Besides, there is no systematic development goal and implementation path for the hydrogen energy and fuel cell industry, which is not conducive to maximising the utility of existing industrial factors and building a policy guarantee system for industrial development. Thus, it is proposed to speed up the top-level design, formulate a national development blueprint for hydrogen energy industry, and clarify the role of hydrogen energy in industrial development.

Meanwhile, the development of the hydrogen energy industry can only refer to the safety regulations of gas-related hazardous chemicals in the current legislative system. However, those regulations cannot play a specific role in the safe development of hydrogen energy, not to mention meeting the needs of hydrogen energy development. Thus, it is proposed to learn from the advanced experience of Japan, Korea, and other countries. That is to say, efforts should be made to speed up the top-level design, and accelerate the formulation of mandatory laws and regulations for the safe development of the hydrogen energy industry so that it can cover all links of the hydrogen energy industry chain, from the safety regulations of hydrogen production devices and equipment, the safety performance testing for devices of hydrogen storage and transportation, and all links involving safety in hydrogen energy applications. In addition, much attention should be paid to the safety of hydrogen production and its working personnel. It is proposed to set up institutions for the research, development, guidance, and supervision of hydrogen energy with specific provisions about their functions and powers as well as their operating procedures, and add provisions to guarantee the safety of the employees and their working environment in hydrogen energy industry by developing relevant supporting systems.

4.2. To accelerate the formulation and revision of the hydrogen energy safety standard system to provide support for industrial development

By comparing with the relevant EU regulations, it was found that the latter provide clear detailed requirements for the specifications in the same field. By contrast, in China's standard specifications, there are rarely such detailed requirements for technical indicators in the production process. As a result, they cannot standardise industry development. This also explains why, in China, industry standards used to account for the main proportion of hydrogen production standards in the past. Taking FCEVs as an example, Japan has established an advanced and complete standards system in the field of hydrogen energy for vehicles. In China, there is as much enthusiasm for the development of FCEV as in Japan, but there is no such completeness in the national mandatory standards related to FCEV safety, with some standards also lacking advancement.

It is proposed to continuously modify and improve the relevant safety standard system in China's hydrogen energy industry on the basis of systematic research in safety technology and learning from foreign advanced standards, so as to provide support for industrial development. Relevant businesses and enterprises should be encouraged to

participate in the formulation and revision of norms and standards for hydrogen energy. Systems should be established to monitor the industry, and safety inspection institutions should be established. In addition, it is necessary to explore an innovation-driven legal and regulatory standard system applicable to the development of new technologies and crafts, and the development of new business forms and models.

4.3. To strengthen basic research in hydrogen safety technology to provide intellectual support for industrial development

The research of hydrogen energy safety technology mainly focuses on the basic areas of fuel cell safety, hydrogen behavior, and material compatibility of hydrogen-related equipment. China should broaden the depth and breadth of research on the safety technology of the whole industry chain, with a focus on safety and reliability testing methods and certification of related equipment, materials, and components. At the same time, simulated analysis should be made about all accident scenarios in fuel cell safety, vehicle safety, and hydrogen storage tank safety application processes. It is proposed to give full play to the initiatives of local governments and enterprises, encourage qualified regions and enterprises to build hydrogen energy testing and research institutions, and gradually form a research system with the State Key Laboratory of Hydrogen Safety as the main body and the active participation of social science and technology forces.

In addition, it is proposed to strengthen technological research and development and cooperation among departments, promote the deep integration and penetration between all links of the industry chain, link up key 'materials-core components-integrated control-terminal applications', lower industry barriers, and strengthen the coordinated development of the entire industry chain.

4.4. To further clarify the safety supervision mechanism and promote the rapid development of the industry

It is proposed to clarify the competent authority of the hydrogen energy industry, establish a complete procedure of hydrogen energy infrastructure approval, construction, and acceptance; strengthen the main agents' safety risk awareness and safety supervision in the production, storage and transportation, refueling, and utilisation of hydrogen; and formulate feasible safety risk prevention and control measures, safety accident prevention mechanisms, and safety emergency response mechanisms. We should build a hydrogen energy operation monitoring system to implement real-time monitoring, analysis and early warning of hydrogen storage and transportation facilities and hydrogen refueling stations. The guiding policies and supporting laws and regulations should be issued at a faster rate to ensure that they play restraining and standardising roles.

References

Ade, N. et al. (2020), 'An Integrated approach for safer and economical design of hydrogen refueling stations', *International Journal of Hydrogen Energy*. https://doi.org/10.1016/j.ijhydene.2020.08.232.

Cao, H.X. and Z.Q. Wei (2020), *Technologies for the Safe Use of Hydrogen and Construction of the Safety Standards System. Strategic Study of Chinese Academy of Engineering*, 22(5), pp.144–51. https://doi.org/10.15302/J-SSCAE-2020.05.018

Compressed Hydrogen Powered Industrial Truck On-Board Fuel Storage and Handling Components. https://xueshu.baidu.com/usercenter/paper/show?paperid=d3fa0e3b3d1d074a08e19a99220de5e8&site=xueshu_se

Chemicals Code for Design of Electrical Installation for Atmosphere of Fire and explosion. https://wenku.baidu.com/view/6c197bbbcad376eeaeaad1f34693daef5ef71323.html

China law 2014, *Law on work safety*, SCCC. http://www.npc.gov.cn/wxzl/gongbao/2014-11/13/content_1892156.htm

China legislation (2013), *Fire protection law Regulations on Safety Management of Hazardous Chemicals*, State Council of the PRC. http://www.gov.cn/flfg/2011-03/11/content_1822902.htm

China Code for design of hydrogen stations. Rules China (2016), *Supervision Regulation on Safety Technology for Stationary Pressure Vessel*, GAQSIQ, Beijing. http://www.jstzsb.com/zbcms/dbfile.svl?n=/u/cms/www/201812/252050126pjq.pdf

FAO, FAOLEX. Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment.

IPPC. Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control.

Japan legislation, *Hydrogen fuel cell safety regulations*, HYSUT 2014.

Japan legislation, *Vessel safety regulations*, HYSUT 2011.

Japan legislation, *High pressure gas security law*, HYSUT 1994. http://www.cnki.com.cn/Article/CJFDTotal-YLRQ198503019.htm

LaFleur, A.C., A.B. Muna, and K.M. Groth (2017), 'Application of quantitative risk assessment for performance-based permitting of hydrogen fueling stations', *International Journal of Hydrogen Energy*, 42(11), p.7529e35.

Local legislation in China (2018), *Interim Measures for the Approval and Management of Hydrogen Refueling Stations in Wuhan Economic and Technological Development Zone (Hannan District)*, Wu Jingkai [2018] No. 24, Wuhan Economic and Technological Development Zone 2018. http://cnsubsites.chinadaily.com.cn/hannancn/2018/04/25/c_56048.htm

Local legislation in China (2018), *Interim Measures for the Administration of Hydrogen Refueling Stations in Foshan City (Draft for Comments)*, Foshan housing and Urban Rural Development Bureau 2018. https://max.book118.com/html/2019/0907/6112204220002102.shtm

Local legislation in China (2019), *Opinions from Weifang Municipal People's Government Office on Doing a Good Job in the Planning, Construction, Operation and Management of Hydrogen Refueling Stations in the City*, Weifang government office [2019] No. 61, Weifang government office 2019. http://csglj.weifang.gov.cn/XXGK/ZCFG/201905/t20190524_5367217.htm

Local legislation in China (2019), *Interim Administrative Approach for Temporary business license of Automobile Hydrogen Refueling Stations (Draft for Comments)*, Shanghai Municipal Commission of housing and urban rural development 2019. http://auto.people.com.cn/n1/2019/0729/c1005-31260697.html

Law on work safety Fire protection law Code for design of hydrogen stations Standards China 2014, *Basic safety requirements for hydrogen systems,* GB/T 29729—2013, SAC, Beijing. https://www.cnis.ac.cn/bydt/bzyjzq/gbyjzq/202102/P020210205592600744537.pdf

Local legislation in China (2019), *the Administrative Measures for Hydrogen Refueling Stations in Laohekou City (for Trial Implementation),* The People's Government of Laohekou City 2019. https://chuneng.bjx.com.cn/news/20190812/999262.shtml

Local legislation in China (2020), *Administrative Procedures for Hydrogen Refueling Stations in Wuhai City (Trial) (2019–2022)*, Wuhai development and Reform Commission 2020. http://fgw.wuhai.gov.cn/fgw/507668/507671/790672/index.html

Local legislation in China (2020), *Program for Hydrogen Energy Industry Safety Supervision and Management in Zhangjiakou City*, Zhangjiakou Emergency Management Bureau 2020. http://www.zjk.gov.cn/content/2020/21043.html

Local legislation in China (2020), *Notice of the People' s Government of Changchun City on Issuing the Interim Measures for the Administration of Automobile Hydrogen Refueling Stations in Changchun City,* Changchun Municipal Regulation [2020] No. 1, Changchun Municipal People's Government 2020. http://www.changchun.gov.cn/zw_33994/zfwj/szfwj_108293/202011/t20201109_2531294.html

Local legislation in China (2020), *Opinions of the Baoding Municipal People's Government Office on Doing a Good Job in the Approval and Management of Hydrogen Refueling Station Projects,* Baoding Municipal People's Government 2020. http://www.gev.org.cn/news/4336.html

Local legislation in China (2020), *Interim Measures for the Construction, Operation and Management of Hydrogen Refueling Stations in Fuzhou City*, Fuzhou Municipal government Office [2020] No. 109, Fuzhou Municipal People's

Government 2020.
http://www.fuzhou.gov.cn/zgfzzt/sajj/fzaj/zwgk_35707/zcfg/202011/t20201120_3653776.htm

Local legislation in China (2020) , *Interim Measures for the Construction and Management of Hydrogen Refueling Stations in Yueyang City*, Yueyang Municipal People's Government 2020.
http://www.yueyang.gov.cn/web/2570/2586/2971/2972/content_1781671.html

Mao, Z.Q. (2020), Hydrogen Safety. Chemical Industry Press (10).

Mayer, T., M. Semmel, M.A. Guerrero Morales, K.M. Schmidt, A. Bauer, and J. Wind (2019), 'Techno-economic evaluation of hydrogen refueling stations with liquid or gaseous stored hydrogen', *International Journal of Hydrogen Energy*, 44(47), p.25809e33, https://doi.org/10.1016/j.ijhydene.2019.08.051.

Melani, L., I. Sochet, X. Rocourt, and S. Jallais (n.d.), Review of methods for estimating the overpressure and impulse resulting from a hydrogen explosion in a confined/obstructed volume. International conference on hydrogen safety.

Mayer, T,, M. Semmel, M.A. Guerrero Morales, K.M. Schmidt, A. Bauer, and J. Wind (2019), 'Techno-economic evaluation of hydrogen refueling stations with liquid or gaseous stored hydrogen', *International Journal of Hydrogen Energy*, 44(47), p.25809e33.

Nakayama, J, J. Sakamoto, N. Kasai, T. Shibutani, and A. Miyake (2016), 'Preliminary hazard identification for qualitative risk assessment on a hybrid gasoline-hydrogen fueling station with an on-site hydrogen production system using organic chemical hydride', *International Journal of Hydrogen Energy*, 41(18), p.7518e25.

Pasman, H.J. and W.J. Rogers (2012), 'Risk assessment by means of Bayesian networks: A comparative study of compressed and liquefied H2 transportation and tank station risks', *International Journal of Hydrogen Energy*, 37(22), p.17415e25, https://doi.org/10.1016/j.ijhydene.2012.04.051.

South Korea's parliament. Hydrogen Economy and Hydrogen Safety Management Act.

Sun, K., X. Pan, Z. Li, and J. Ma (2014), 'Risk analysis on mobile hydrogen refueling stations in Shanghai', *International Journal of Hydrogen Energy*, 39(35), p.2041

Standards China (2015), *Evaluation method of resistance to hydrogen-induced cracking of pipeline steel and pressure vessel steel,* GB/T 8650—2015, SAC, Beijing.

Standards China (1986), *Low hydrogen embrittlement forged cadmium (titanium quality inspection) of high-strength steel part,* HB/T 5360—86, CN-HB, Beijing.
https://www.docin.com/p-1294281787.html

Standards China (1998), *Specification for stress relief before plating and dehydrogenation after plating,* HB/Z 318—1998, CN-HB, Beijing.
https://www.docin.com/p-1294281787.html

Standards China (2021), *storage and transportation of liquid hydrogen*, GB/T 40060—2021, SAC, Beijing.
https://wenku.baidu.com/view/114aece5a4c30c22590102020740be1e640ecc6a.

html
Standards China (2009), *Fuel cell electric vehicle (FCEV) - Safety Requirement*, GB/T 24548—2009, SAC, Beijing.
http://www.china-nengyuan.com/tech/73702.html
Standards China (1992), *Code for design of electrical installation for atmosphere of fire and explosion*, GB50058-1992, SAC, Beijing. https://www.doc88.com/p-0488323922840.html
Safety technical specification for hydrogen filling station. https://gf.1190119.com/list-1254.htm
Standards China (2017), *Proton exchange membrane fuel cell*, GB∕T 20042.1-2017, SAC, Beijing. https://www.doc88.com/p-3187852322272.html?r=1.
Standards China (2021), *Technical specification for hydrogen filling station*, GB50516-2010, SAC, Beijing. https://gf.1190119.com/list-1254.htm
Standards U.S.A, (2017), *Hydrogen Technologies Code: NFPA2*, United States Fire Administration, Washington DC. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=2
Standards U.S.A. (2017), *Hydrogen Technologies* , NAPF55,United States Fire Administration, Washington DC. https://catalog.nfpa.org/NFPA-55-Compressed-Gases-and-Cryogenic-Fluids-Code-P1185.aspx
Standards U.S.A. (2004), *Guide for safety of hydrogen systems*, ANIS/AIIA G-095-2004, Washington, DC: NASA. https://ntrs.nasa.gov/api/citations/20070018005/downloads/20070018005.pdf.
Standards U.S.A. (2017), *Boiler and pressure vessel*, ASME, Washington DC. https://max.book118.com/html/2017/0811/127159563.shtm.
Standards U.S.A. (2017), *Prioritization device for filling of hydrogen-powered automobile*, ASME, Washington DC.
Standards U.S.A. (2017), *Compressed Hydrogen Powered Industrial*, ASME, Washington DC. http://www.simop.com.cn/detail-95-e6e1a536fd36d050.html
Standards U.S.A. (2017), *Avoidance of Hydrogen Embrittlement of Steel*, SAE UCAE5-4 SAE, Washington, DC. https://www.doc88.com/p-3837424986711.html?r=1
Standards U.S.A. (2020), *Hydrogen dispensing systems*, CSA/ANSI/CSA/AM HGV 4.1:20-2020, Washington, DC. https://xueshu.baidu.com/usercenter/paper/show?paperid=126t0xp0nm7k0mw0gn5t0ch058173975&site=xueshu_se
Standards U.S.A. (2017), *Avoidance of Hydrogen Embrittlement of Steel*, SAE UCAE5-4 SAE, Washington DC. https://www.doc88.com/p-3837424986711.html?r=1
Standard Europe (1998), *Evaluation of resistance of steel products to hydrogen induced cracking*, BS EN 10229, European Committee for Standardization. https://xueshu.baidu.com/usercenter/paper/show?paperid=1s3d0mk0n53806a0wk0d0px0ss763495&site=xueshu_se
Standard Europe (2000), *Cryogenic vessels- transportable vacuum insulated vessels of not more than 1000 litres volume*, CEN 1251, European Committee for Standardization.

https://xueshu.baidu.com/usercenter/paper/show?paperid=1m0j06b08k6x08w0xy1k0ap0t0219257&site=xueshu_se

Standard Europe (2003), *Cryogenic Vessels - Safety devices for protection against excessive pressure*, DIN EN 13648-3 (2003-01), European Committee for Standardization. http://www.simop.com.cn/detail-95-dd98d15c06a3fa72.html

Standard Europe (2002), *Cryogenic Vessels - Large Transportable,* BS EN 13530-1 2002, European Committee for Standardization. http://www.cngspw.com/Doc/WebNote/201103/Y2011M03D30H12m23s17/bs20en2014398-1-200320u4F4Eu6E29u5BB9u5668.pdf

Standard Europe (2007), *Vacuum Insulated Vessels,* UNE-EN 13458-2/AC-2007, European Committee for Standardization. https://xueshu.baidu.com/usercenter/paper/show?paperid=1c0x08d09m060rt07k6g0p303u766027&site=xueshu_se

Standard Europe, *Cryogenic Vessels - Static non-vacuum insulated vessels,* CEN14197, European Committee for Standardization. https://xueshu.baidu.com/usercenter/paper/show?paperid=1b6e06u0yq7u0gu0pe3t0cm06e295549&site=xueshu_se

Standard Europe (2007), *Portable fuel cell appliances-Safety,* EN62282-5-1- 2007, European Committee for Standardization. http://www.stdtick.com/standard/58DC4EBA07

Standard Europe (2007), *Stationary fuel cell appliances-Safety,* EN62282-3-1- 2007, European Committee for Standardization. https://xueshu.baidu.com/usercenter/paper/show?paperid=1j0y06f0k43d0js07u1r06k0rd412586&site=xueshu_se

Standard Japan (2008), *General safety specifications for small polymer electrolyte fuel cell systems,* JIS C8822- 2008, JIS 2008. https://www.antpedia.com/standard/5693134.html

Standard Japan (1995), *hydrogen,* JIS K0512- 1995. JIS 1995. https://www.antpedia.com/standard/265765.html

Standard Japan (2008), *Safety standards for small solid polymer fuel cell systems*, JISC 8822:2008. JIS 2008. http://www.doc88.com/p-013657898479.html

U.S. Department of Energy (2020), Hydrogen Program Plan 2020. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf.

U.S. Department of Energy (2002), Proceedings of the National Hydrogen Energy Roadmap Workshop 2002. https://www.energy.gov/sites/default/files/2014/03/f12/workshop_proceedings.pdf

U.S. Department of Energy (2005), Energy Policy Act Of 2005. https://www.energy.gov/sites/prod/files/2020/07/f76/EPACT%202005%20%28PL%20109-58%29_1.pdf

U.S. Department of Energy (2011), The Department of Energy Hydrogen and Fuel Cells Program Plan. https://www.docin.com/p-1217103137.html

Wang, G., J.Y. Zheng, L.I. Jiang, J., Chen, W.L. Han, and L.X. Chen (2017), *Considerations on the Development of Hydrogen Energy in China*, 35(22), pp.105–10.

Yan Xu, H. et al. (2019), Safety Guide for FCEVs. CAICA. http://www.china-nengyuan.com/news/147431.html

Zou, Q, Y. Tian, and F. Han (2019), 'Prediction of state property during hydrogen leaks from high- pressure hydrogen storage systems', International Journal of Hydrogen Energy, 44(39), p.22394e404.

Nomenclature	
ANSI	American National Standards Institute
ASME	The American Society of Mechanical Engineers
CHEI	China's Hydrogen Energy Industry
CSA	Canadian Standards Association
CN-HB	Industrial standards of the people's Republic of China
FCV	Fuel cell vehicles
FCH2JU	Fuel Cells and Hydrogen 2 Joint Undertaking
GAQSIQ	General Administration of Quality Supervision, Inspection and Quarantine of the people's Republic of China
HETC	Hydrogen Energy Technical Committee
HySUT	Hydrogen Supply and Applied Technology Research Association
HyTReC	Hydrogen Energy Test and Research Center
HySAFER	International Association for Hydrogen Safety
HFCP	Hydrogen and Fuel Cell Program
IA-Hysafe	International Association for Hydrogen Safety
ISO	International Organization for Standardization
JIS	Japanese Industrial Standards
JISC	Japanese Industrial Standards Committee
NFPA2	Technical specification for hydrogen energy
PEMFC	Proton Exchange Membrane Fuel Cell
SAE	Society of Automotive Engineers
SAC	Standardization Administration of China
SCCC	Standing Committee of the Chinese people's Congress
USFA	United States Fire Administration
USCAR	The United States Council for Automotive Research