Development of standards for liquid hydrogen in China

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Abstract. Liquid hydrogen is important to long distance hydrogen transportation and development of heavy-duty vehicles, etc. China starts to deploy liquid hydrogen since 2020. To support the development of liquid hydrogen, three national standards for liquid hydrogen have been published. In this paper, national standards for liquid hydrogen specification, production, storage and transportation, and hydrogen fueling station are reviewed. Compared to USA, standards for liquid hydrogen in China are insufficient. It is important to establish a complete standard system for liquid hydrogen to better support the commercial, safe use of liquid hydrogen.

1. Introduction
China is willing to contribute more to the fight against climate change, as it aims to bring carbon emissions to a peak by 2030, and achieve carbon neutrality by 2060 with more forceful policies and measures. Hydrogen, a clean and carbon-free energy, is expected to play an important role in carbon neutrality based on renewable energy sources[1,2]. For commercial use of hydrogen technology, it is important to develop cost-effective and safe technologies for storage and transportation of hydrogen. H₂ exists in different phases, including gaseous, liquid and solid. Under atmospheric conditions, Energy density of liquid H₂ is about three times that of compressed H₂ at 35 MPa[3,4]. High energy consumption in liquefaction process is one of the main barriers to liquid hydrogen. However, it shows advantage in long distance hydrogen transportation.

2. Deployment of liquid hydrogen
Since 2017, hydrogen industry is booming in China as the development and demonstration of hydrogen fuel cell vehicles. Till the end of 2020, cumulative sales number of fuel cell vehicles is more than 7000 and about 128 hydrogen fueling stations have been built. However, there is no liquid hydrogen fueling station in China. In most cases, hydrogen is delivered by tube trailers, which is not cost-effective for long distance.

For a long time, liquid hydrogen has been used as a fuel in space technology, semiconductor industry, and petrochemical industry. It can also be used for fuel cell vehicles, fuel cell stationary applications, internal combustion engines, etc. Now, the world installed hydrogen liquefaction capacity is more than 500 t/d. About 85% of the hydrogen production is in North America. The installed hydrogen liquefaction capacity in China is only about 5 t/d [5,6].

2.1. Technical research
Since 2020, Ministry of Science and Technology of P.R.C. has launched two liquid hydrogen projects in National Key R&D Program. One is Research on Key Equipment and Safety for Liquid Hydrogen
Production, Storage and Transportation, and Fueling, which is started in 2020. The other is Research on Hydrogen Expander for Hydrogen Liquefaction, which will start in the end of 2021.

2.2. Demonstration and application
Heavy-duty truck fueled by liquid hydrogen was released in 2020. Fire test of land vehicle fuel tanks for liquid hydrogen succeeded in 2021. As the development and deployment of hydrogen industry, ten-thousands ton liquefaction capacity per year is now in planning or under construction. Four liquid hydrogen fueling stations are in planning.

3. Liquid hydrogen standards
Standards are foundation for the deployment and development of liquid hydrogen. Table 1 shows the national standards for liquid hydrogen. GB/T 30179-2014 is identical with ISO 13984: 1999 Liquid hydrogen - Land vehicle fueling system interface. In 2018, Standardization Administration of P.R.C. launched three national standard projects for liquid hydrogen. The three standards - GB/T 40045-2021, GB/T 40060-2021, GB/T 40061-2021 are published in April, 2021. Requirements of liquid hydrogen fueling station are specified in GB 50516 and GB 50156, which are revised and republished in 2021.

| No. | Standard Number | Standard Name | Published Time |
|-----|----------------|---------------|----------------|
| 1   | GB/T 30179-2014| Liquid hydrogen land vehicle fueling system interface | 2014.6 |
| 2   | GB/T 40045-2021| Fuel specification for hydrogen powered vehicles - Liquid hydrogen (LH₂) | 2021.4 |
| 3   | GB/T 40060-2021| Technical requirements for storage and transportation of liquid hydrogen | 2021.4 |
| 4   | GB/T 40061-2021| Technical specification for liquid hydrogen production system | 2021.4 |
| 5   | GB 50516      | Technical code for hydrogen fueling station | 2021.5 |
| 6   | GB 50156      | Technical standard for fueling station | 2021.6 |

3.1. National standards for liquid hydrogen

3.1.1. Liquid hydrogen specification. GB/T 40045-2021 specifies specifications of liquid hydrogen fuel for PEM fuel cell road vehicles, analytical methods, parking and marking requirements. Table 2 illustrates comparison of quality characteristics of hydrogen fuel for PEM fuel cell vehicles. Specifications of individual non-hydrogen gas are consistent in GB/T 40045-2021 and GB/T 37244-2018. GB/T 37244-2018 specifies the requirement of gaseous hydrogen for PEM fuel cell vehicles, which is in accordance with ISO 14687-2: 2012. In GB/T 40045-2021, content of para-hydrogen is specially specified not less than 95%. ISO 14687-2: 2012 is revised to ISO 14687: 2019, in which specifications of hydrocarbons, N₂, Ar, CO, HCHO and HCOOH are updated according to the developments of fuel cell technologies and updates of testing data. SAC/TC 309 (National Standardization Technical Committee of Hydrogen Energy) is planning to update GB/T 40045-2021 and GB/T 37244-2018 to keep in consistent with ISO 14687: 2019.

| Components | GB/T 40045-2021 | GB/T 37244-2018 | ISO 14687:2019 |
|------------|-----------------|-----------------|----------------|
| hydrogen content | ≥ 99.97% | 99.97% | 99.97% |
| para-hydrogen content | ≥ 95% | | |
| total non-hydrogen gases | ≤ 300 μmol/mol | 300 μmol/mol | 300 μmol/mol |

| Maximum of individual non-hydrogen gas |
|--------------------------------------|
| Water(H₂O) | ≤ 5 μmol/mol | 5 μmol/mol | 5 μmol/mol |
| Total hydrocarbons except | ≤ 2 μmol/mol | 2 μmol/mol | 2 μmol/mol |
### Components

| Components                     | GB/T 40045-2021 | GB/T 37244-2018 | ISO 14687:2019 |
|-------------------------------|-----------------|-----------------|----------------|
| Methane(CH₄)                  | ≤ 100 μmol/mol   | ≤ 5 μmol/mol    |                |
| Oxygen(O₂)                    | ≤ 5 μmol/mol     | ≤ 5 μmol/mol    |                |
| Helium(He)                    | ≤ 300 μmol/mol   | ≤ 300 μmol/mol  |                |
| Nitrogen(N₂)                  | ≤ 100 μmol/mol   | ≤ 100 μmol/mol  |                |
| Argon(Ar)                     | ≤ 300 μmol/mol   | ≤ 300 μmol/mol  |                |
| Carbon dioxide(CO₂)           | ≤ 2 μmol/mol     | ≤ 2 μmol/mol    |                |
| Monoxide(CO)                  | ≤ 0.2 μmol/mol   | ≤ 0.2 μmol/mol  |                |
| Total sulfur compoundsb       | ≤ 0.004 μmol/mol | ≤ 0.004 μmol/mol|                |
| Formaldehyde(HCHO)            | ≤ 0.01 μmol/mol  | ≤ 0.01 μmol/mol |                |
| Formic acid(HCOOH)            | ≤ 0.2 μmol/mol   | ≤ 0.2 μmol/mol  |                |
| Ammonia(NH₃)                  | ≤ 0.1 μmol/mol   | ≤ 0.1 μmol/mol  |                |
| Total halogenated compoundsc  | ≤ 0.05 μmol/mol  | ≤ 0.05 μmol/mol |                |
| particulate concentrations    | ≤ 1 mg/kg        | 1 mg/kg         | 1 mg/kg        |

* a Total hydrocarbons may exceed 2 μmol/mol due to methane, in which case sum of CH₄, N₂ and Ar shall not exceed 100 μmol/mol.

b Total sulfur compounds shall be measured on H₂S equivalent, include H₂S, COS, CS₂, mercaptans, etc.

c Total halogenated compounds shall be measured on a halogen ion equivalent, include hydrogen chloride(HCl), organic chlorides(R-Cl), etc.

d Sum of measured CO, HCHO and HCOOH shall not exceed 0.2 μmol/mol.

### Production of liquid hydrogen

GB/T 40061-2021 specifies basic requirements for liquid hydrogen production system, including liquefaction device, storage vessel, venting system, control and analytical system, electrical device, lightning and electrostatic protection, auxiliary facilities, etc. Layout of liquid hydrogen production system shall meet mandatory national standards GB 50177 (Design code for hydrogen station), GB 50516 (Technical code for hydrogen fueling station) and GB 50156 (Technical standard for fueling station). Pipe and pipelines shall be protected with thermal insulated measures. Low temperature values shall meet with GB/T 24925 (Low temperature valve—Technical specifications). Liquefaction device shall be selected according to technical process requirements, capacity, and fuel characteristics. Liquid hydrogen storage shall consider the evaporation and transfer loss. Safety distance between liquid hydrogen vessels and buildings shall meet with GB 50177. Venting velocity shall not exceed 100 m/s. Control system and instruments in explosion hazardous areas shall comply GB 50058 (Code for design of electrical installations in explosive atmospheres). Fuel quality should be monitored at inlet and outlet of liquefaction device, outlet of low temperature adsorber and storage vessel. Electrical device, lightning and electrostatic protection shall meet the requirements of GB 50177, GB 50508, GB 3836.4 (Explosive atmospheres - Part 4: Equipment protection by intrinsic safety “i”) and GB 3836.14 (Explosive atmospheres—Part 14: Classification of areas—Explosive gas atmosphere). Auxiliary facilities specify the requirements of gas for instruments, nitrogen and helium supplement and cooling water.

### Storage and transportation for liquid hydrogen

GB/T 40060-2021 specifies requirements for liquid hydrogen storage, transportation, purging and replacement, and protections. Setting of liquid hydrogen storage vessels shall meet mandatory national standards GB 50177, GB 50516 and GB 50156. Transportation of liquid hydrogen tank vehicle and liquid hydrogen tank container shall meet the requirements of GB 21668 (Provisions of vehicle for the carriage of dangerous goods with regard to their specific constructional features) and JT/T 617 (Regulations concerning road transportation of dangerous goods). Liquid hydrogen vessels shall be purged with N₂ and replaced with high purity N₂ and H₂. Requirements of clothing, anti-static and anti-freezing injury of operators are defined.
3.1.4. Liquid hydrogen fueling station. GB/T 50516 and GB 50156 specify the requirements for independent hydrogen fueling stations and combined hydrogen fueling stations separately. GB 50516 and GB 50156 gives technical and safety protection requirements of liquid hydrogen booster pump and liquid hydrogen storage vessels. Besides, requirements of pipe and pipelines are determined in GB 50156.

3.2. International standards for liquid hydrogen

Table 3 shows international standards for liquid hydrogen. Since 1999, ISO/TC 197 has published two ISO standards for liquid hydrogen. ISO 13984:1999 specifies the characteristics of liquid hydrogen fueling and dispensing systems on land vehicles of all types in order to reduce the risk of fire and explosion during the fueling procedure and thus to provide a reasonable level of protection from loss of life and property. ISO 13985:2006 specifies the construction requirements for refillable fuel tanks for liquid hydrogen used in land vehicles as well as the testing methods required to ensure that a reasonable level of protection from loss of life and property resulting from fire and explosion is provided. Theses two standards were reviews and confirmed by ISO in 2021.

Table 3. International standards for liquid hydrogen.

| No. | Standard Number       | Standard Name                                                      |
|-----|-----------------------|-------------------------------------------------------------------|
| 1   | ISO 13984:1999        | Liquid hydrogen - Land vehicle fueling system interface           |
| 2   | ISO 13985:2006        | Liquid hydrogen - Land vehicle fuel tanks                          |

3.3. Standards for liquid hydrogen in other countries

Table 4 shows liquid hydrogen standards in UK, Russia, South Korea and USA. UK, Russia and South Korea have identically adopted ISO 13984 and ISO 13985. USA has published about 13 standards for liquid hydrogen by NFPA, ASME, and CGA, etc. Compared to ISO and other countries, USA has basically established a liquid hydrogen standard system, including safety, storage, venting, and other aspects [7].

Table 4. Standards for liquid hydrogen in other countries.

| No. | Standard Number       | Standard Name                                                      |
|-----|-----------------------|-------------------------------------------------------------------|
| 1   | BS ISO 13985-2007     | Liquid hydrogen - Land vehicle fuel tanks                          |
| 2   | DS/ISO 13984-2005     | Liquid hydrogen - Land vehicle fueling system interface           |
| 3   | DS/ISO 13985-2012     | Liquid hydrogen - Land vehicle fuel tanks                          |
| 4   | GOST ISO 13984-2016   | Liquid hydrogen - Land vehicle fueling system interface           |
| 5   | GOST R ISO 13985-2013 | Liquid hydrogen - Land vehicle fuel tanks                          |
| 6   | GOST R 56248-2014     | Liquid hydrogen. Specifications                                   |
| 7   | KS B ISO 13984-2004   | Liquid hydrogen - Land vehicle fueling system interface           |
| 8   | KS B ISO 13985-2009   | Liquid hydrogen - Land vehicle fuel tanks                          |
| 9   | NFPA 2-2020           | Hydrogen Technologies Code                                        |
| 10  | NFPA 55-2020          | Compressed Gases and Cryogenic Fluids Code                        |
| 11  | ASME B31.12-2019      | Hydrogen Piping and Pipelines                                     |
| 12  | CGA G-5.3-2017        | Commodity Specification for Hydrogen                              |
| 13  | CGA G-5.5-2014        | Hydrogen vent systems                                             |
| 14  | CGA H-3-2019          | Cryogenic hydrogen storage                                        |
| 15  | CGA H-5-2014          | Standard for bulk hydrogen supply systems                         |
| 16  | CGA P-8.8-2017        | Safe design and operation of cryogenic enclosures                 |
| 17  | CGA P-28-2014         | OSHA process safety management and EPA risk management plan guidance document for bulk liquid hydrogen supply systems |
| 18  | CGA P-41-2018         | Locating Bulk Liquid Storage Systems In Courts                    |
| 19  | CGA PS-17-2004 CGA    | Position Statement On Underground Installation Of Liquid Hydrogen Storage Tanks |
| 20  | CGA PS-48-2016        | Clarification of existing hydrogen setback distances and development of new hydrogen setback distances in NFPA 55 |
| 21  | MIL-PRF-27201         | Propellant Hydrogen                                               |
4. Conclusions
National standards for liquid hydrogen are published in 2021, which provides basic requirements and principles for liquid hydrogen characteristics, production, storage and transportation, and hydrogen fueling stations. Compared to USA, standards for liquid hydrogen in China is insufficient. To support commercial and safe use of liquid hydrogen, standardization suggestions are given as follows:

- Policies and regulations are important for production, storage and transportation, fueling and application of liquid hydrogen.
- It is essential to establish a standardization system for liquid hydrogen to depict the overall plan for liquid hydrogen standards.
- Standards for liquid hydrogen vessels and tanks, pump, materials, pipe and pipelines, fueling protocols, liquefaction systems and other devices should be drafted as the development of liquid hydrogen technologies and industry.
- National standards for liquid hydrogen should keep in accordance with ISO and IEC standards.

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