



AEROSPACE INFORMATION REPORT

AIR8466™

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Hydrogen Fueling Stations for Airports, in Both Gaseous and Liquid Form

RATIONALE

Hydrogen, produced from low-carbon sources, is one of the most promising decarbonization technologies for aviation. Adoption of hydrogen is supported by the International Civil Aviation Organization (A41-WP/514 EX/246), the International Air Transport Association (IATA Factsheet 7, August 2019), and numerous aerospace manufacturers. Hydrogen is considered to be an important technological pathway to achieve low-carbon commercial aircraft. Today, aviation accounts for around 2.5% of global CO₂ emissions. Although aviation represents a relatively small percentage of global emissions today, that could rise to 22% by 2050¹ as more people fly and other sectors decarbonize quicker. This SAE Aerospace Information Report (AIR) provides guidance for development of fueling stations in preparation for hydrogen becoming a standard fuel type.

Presently, there are established codes and standards for ground vehicles at SAE, ISO, NFPA, etc., that could also be applicable to some applications for hydrogen at the airport. While there are some existing fuel cell and hydrogen standards for aerospace (such as SAE/EUROCAE information reports), there is a need to create new fueling station standardization efforts, which are outlined herein. For one, the ambient conditions are significantly different related to expected temperatures on the airfield apron and tanks that could be exposed to direct sunlight. Large aircraft such as a regional, narrow body, or a wide-body require up to 100x to 1000x more hydrogen storage (e.g., 1000 to over 10000 kg) than light to heavy-duty ground vehicle fueling (5 to over 120 kg). With this larger amount for aircraft fueling, there will be an exponentially larger need for hydrogen supply and fueling on site.

Gaseous hydrogen fueling and liquid hydrogen fueling at cryogenic temperatures are two different types of fuel stored in different types of vessels with safety mitigations. Similar to CNG and LNG at the same location, the objective of AIR8466 is to start with an overarching AIR for both gaseous and liquid hydrogen fueling stations and, after publishing, establish a family of documents covering these categories of hydrogen as a fuel as determined by the SAE AE-5CH team. AIR8466 is to provide hydrogen fueling station guidelines and process for both gaseous and liquid hydrogen fueling (eCTOL, eRotor, eVTOL, LTA, etc.) at the airport from small aircraft to wide-body.

The hydrogen fueling process described herein (including fuel temperature, the maximum flow rate, time required, etc.) are affected by factors such as ambient temperature, fuel delivery temperature, and initial pressure in the hydrogen storage system. At the airport, similar to conventional hydrocarbon fuels, there will be both mobile fueling trailers and stationary hydrogen fueling stations that are planned to be within the scope of AIR8466 and EUROCAE DP007. A further goal is to harmonize and establish common aircraft fueling safety definitions wherever possible with other SAE and EUROCAE standards and NFPA codes alike. Gaseous hydrogen fueling and liquid hydrogen fueling at cryogenic temperatures are two very different types of fuel stored in different types of vessels with safety mitigations. The goal is to start with an all-encompassing AIR for hydrogen fueling and, after publishing, establish a family of documents covering categories of fueling as determined by the SAE AE-5CH task group.

¹ <https://www.weforum.org/agenda/2021/09/aviation-flight-path-to-net-zero-future/>

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TABLE OF CONTENTS

1.	SCOPE.....	5
2.	REFERENCES.....	6
2.1	Applicable Documents	6
2.1.1	SAE Publications.....	6
2.1.2	ANSI Accredited Publications	6
2.1.3	API Publications	7
2.1.4	Code of Federal Regulations (CFR) Publications.....	7
2.1.5	FAA Publications.....	7
2.1.6	IATA Publications.....	7
2.1.7	ICAO Publications.....	7
2.1.8	IEC Publications.....	7
2.1.9	ISO Publications.....	7
2.1.10	NFPA Publications	8
2.1.11	U.S. Government Publications.....	8
2.1.12	Vertical Flight Society Publications.....	8
2.1.13	Aerospace Technology Institute Publications	8
2.2	Related Publications	8
2.2.1	SAE Publications.....	8
2.2.2	CSA Publications	9
2.2.3	FAA Publications.....	9
2.2.4	ISO Publications.....	9
2.2.5	NFPA Publications	9
2.3	Abbreviations and Symbols	9
2.3.1	Abbreviations	9
2.3.2	Symbols	11
2.4	Definitions	12
3.	HYDROGEN AIRPORT: GASEOUS AND LIQUID FUELING TARGET TABLE.....	12
3.1	AIR8466 Fueling Categories.....	13
4.	GASEOUS HYDROGEN FUELING DEFINITIONS.....	14
5.	GASEOUS GENERAL FUELING PROTOCOL DESCRIPTION	20
5.1	Performance Goals	21
5.2	Gaseous Fueling Normal Operating Boundaries	22
6.	GENERAL PROCESS REQUIREMENTS FOR GASEOUS HYDROGEN FUELING.....	22
6.1	Hazard Analysis and Avoidable Flammable Concentration Limits	22
6.2	Grounding	23
6.3	CHSS Storage Limits	23
6.3.1	Fuel Delivery Temperature Sensor Specification	23
6.3.2	Ambient Temperature	23
6.3.3	Fuel Delivery Temperature	24
6.3.4	Aircraft CHSS Gas Temperature	24
6.4	Pressure Process Requirements	24
6.4.1	Initial Pressure	24
6.4.2	Nozzle Pressure.....	24
6.4.3	Operating Pressure.....	24
6.5	Other Process Requirements.....	24
6.5.1	State of Charge (SOC).....	24
6.5.2	Hydrogen Quality	24
6.5.3	Gaseous Hydrogen Flow Rate.....	24
6.5.4	Maximum Hydrogen Mass During Start-Up.....	24
6.5.5	Tolerances	25
6.5.6	System Purging.....	25



6.5.7	Pressure Relief.....	25
6.5.8	Icing Considerations for Quick Disconnect	25
7.	KEY GASEOUS HYDROGEN MODELING ASSUMPTIONS.....	25
7.1	Reference Conditions.....	25
7.2	Station Dispenser Assumptions	25
7.3	Aircraft Vessel Soak State - Initial CHSS Temperatures	25
7.4	Gaseous Hydrogen Coupler H35.....	26
7.5	Small Aircraft (100 kg) at 35 MPa Nominal Working Pressure (NWP).....	26
7.6	Active Gaseous Fueling Methodologies and Differences with Ground Vehicle Fueling.....	26
7.7	Pressure Vessel and Container Terminology	26
8.	LIQUID HYDROGEN FUELING.....	27
8.1	Liquid Hydrogen Fuel General Definitions	27
8.1.1	Liquid Hydrogen Density and Characteristics	28
8.1.2	Liquid Hydrogen (LH2) Refueling.....	28
8.1.3	LH2 Return.....	28
8.1.4	Subcooled Liquid Hydrogen (sLH2) Refueling.....	28
8.1.5	Cryo-Compressed Hydrogen (CcH2) Refueling	28
8.1.6	Densified Hydrogen Refueling	28
8.2	Liquid Hydrogen Fueling Overview	29
8.2.1	Hazard Analysis and Avoidable Flammable Concentration Limits	29
8.2.2	Liquid Hydrogen Fueling Connectors.....	30
8.2.3	Aircraft LH2 Fueling Coupling Target Requirements	30
8.2.4	Harmonization of Fueling Standards.....	30
8.3	High-Level Guideline Description of Liquid Hydrogen Fueling Protocols	31
8.3.1	Protocol A and B-sLH2.....	31
8.3.2	Protocol C, D, and E-LH2.....	31
8.3.3	Fueling Set Point PRV	31
8.3.4	LH2 Fueling Options, Process, and Requirements.....	32
8.3.5	High Level, LH2 Refueling Process	33
9.	MOBILE and STATIONARY FUELING.....	36
9.1	Mobile Fueling (Trailer)	37
9.1.1	Description of Mobile Hydrogen Fueling	37
9.2	Stationary Refueling.....	38
9.2.1	Stationary (Hydrant/Dispenser).....	38
10.	NOTES	39
10.1	Revision Indicator.....	39
APPENDIX A	HYDROGEN FUELING SAFETY.....	40
APPENDIX B	PRELIMINARY LH2 FUELING NOZZLE SPECIFICATION (TYPE C).....	50
APPENDIX C	AIRPORT HYDROGEN FUELING CATEGORIES (AHFC).....	52
Figure 1	Gravimetric density in various storages (a); Hydrogen density versus pressure and temperature, CGH ₂ / LH ₂ /CcH ₂ (b)	5
Figure 2	Graphically depicted hydrogen fueling categories per aircraft type/fuel capacity	14
Figure 3	Example of a fixed-orifice hydrogen fueling system	16
Figure 4	Representative hydrogen fueling time diagram	17
Figure 5	Representative aircraft CHSS temperature and pressure profile during a fueling	21
Figure 6	Normal H35 gaseous temperature, pressure boundary conditions	22
Figure 7	Hypothetical liquefied aircraft hydrogen fuel system (gas return and signals may not be required by all aircraft)	29
Figure 8	Liquid hydrogen delivered to airport storage tanks.....	36
Figure 9	Gaseous hydrogen pipeline supply to the airport with on-site liquefaction.....	37
Figure 10	Mobile small aircraft fueling with single liquid hydrogen fueling trailer	37
Figure 11	Mobile aircraft fueling with multiple liquid hydrogen fueling trailers.....	37
Figure 12	Stationary aircraft fueling with multiple liquid hydrogen fueling hoses/arms	39

Table 1 Aircraft range, hydrogen storage, and turnaround time per aircraft type (reference)..... 13

Table 2 Pressure vessel versus container technology terminology (refer to SAE J2579)..... 27

Table 3 LH2 fueling connector type with LH2 flow rates/aircraft storage 30

1. SCOPE

The purpose of this AIR is to establish a baseline for hydrogen fueling protocol and process limits for both gaseous and liquid hydrogen fueling of aircraft (eCTOL, eRotor, eVTOL, LTA) at the airport from small aircraft to wide-body. A further goal is to harmonize and establish common aircraft fueling safety definitions wherever possible with other SAE and EUROCAE standards and NFPA codes alike.

Hydrogen fueling process limits (including the fuel temperature, the maximum flow rate, time required, etc.) are affected by factors such as ambient temperature, fuel delivery temperature, and initial pressure in the hydrogen storage system. The further goal is to establish basic fueling protocols within these limits as a starting point while evaluating minimum criteria, including evaluation of fueling with or without communications. AIR8466 establishes the protocol and process limits for hydrogen fueling of aircraft and plans to establish fueling protocols starting with small aircraft. Optionally, communications may be used, and a general description will be included.

Gaseous hydrogen fueling and liquid hydrogen fueling at cryogenic temperatures are two very different types of fuel stored in different types of vessels with safety mitigations. The goal is to start with an all-encompassing AIR for hydrogen fueling, both gaseous and liquid, and, after publishing, establish a family of documents covering categories of fueling as determined by the SAE AE-5CH team.

To minimize storage volumes, compressed hydrogen gas stored under pressure up to 700 bar (70 MPa) achieves 39.5 kg per m³, or as a cryogenic liquid 20 K achieves 71 kg per m³. Other methodologies of liquified hydrogen, such as subcooled liquid or cryo-compressed, offer the potential for higher storage densities (the latter is not covered in this document).

Figure 1 compares the volumetric and gravimetric densities of hydrocarbon fuels as well as the most common hydrogen storage methods in liquid and gaseous hydrogen and three types of hydrogen storage with different hydrogen density versus phases, pressure, and temperature (gaseous hydrogen, liquid hydrogen, and cryo-compressed).

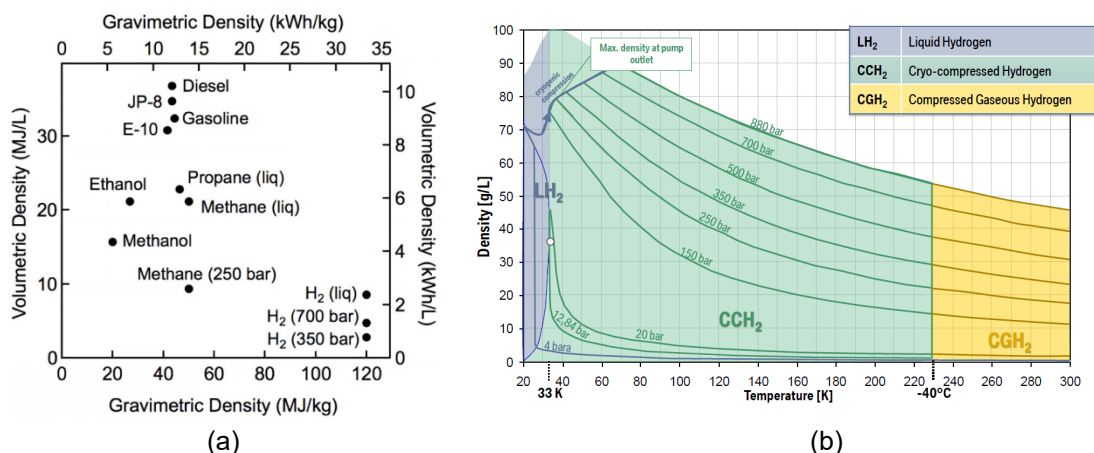


**Figure 1² - Gravimetric density in various storages (a)³;
Hydrogen density versus pressure and temperature, CGH₂/ LH₂/CCH₂ (b)⁴**

² A Review on the Cost Analysis of Hydrogen Gas Storage Tanks for Fuel Cell Vehicles <https://www.mdpi.com/1996-1073/16/13/5233>.

³ Reprinted from <https://www.energy.gov/eere/fuelcells/hydrogen-storage>.

⁴ Courtesy of BMW AG

Presently, there are established codes and standards for ground vehicles at SAE, ISO, NFPA, etc., that could also be applicable to some applications for hydrogen at the airport. While there are some existing fuel cell and hydrogen standards for aerospace (such as SAE/EUROCAE information reports), there is a need to create new fueling station standardization efforts, which are outlined herein. The volume of hydrogen required will depend on the pressure and phase (ambient gaseous or cryogenic liquid) and the size of aircraft. Therefore, a series of ground standards will be required to cover the phase, thermal, and pressure variables.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines for Conducting the Safety Assessment Process on Civil Aircraft, Systems, and Equipment
SAE J2579	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles
SAE J2600	Compressed Hydrogen Surface Vehicle Fueling Connection Devices
SAE J2601	Fueling Protocols For Light Duty Gaseous Hydrogen Surface Vehicles
SAE J2601-2	Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles
SAE J2601-4	Ambient Temperature Variable and Fixed-Orifice Fueling Protocols for Light-Duty Gaseous Hydrogen Surface Vehicles
SAE J2601-5	High-Flow Prescriptive Fueling Protocols for Gaseous Hydrogen Powered Medium and Heavy-Duty Vehicles
SAE J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles
SAE J2799	Hydrogen Surface Vehicle to Station Communications Hardware and Software

2.1.2 ANSI Accredited Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ANSI/AIAA G-095A-2017	Guide to Safety of Hydrogen and Hydrogen Systems
ANSI/AIAA S-080	Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components

2.1.3 API Publications

Available from API, 1220 L Street, NW, Washington, DC 20005-4070, Tel: 202-682-8000, www.api.org.

API RP 2003 Protection against Ignitions Arising Out of Static, Lightning, and Stray Currents

2.1.4 Code of Federal Regulations (CFR) Publications

Available from United States Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

29 CFR § 1910.119 Process Safety Management of Highly Hazardous Chemicals

2.1.5 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 25.981-1D Fuel Tank Ignition Source Prevention Guidelines

2.1.6 IATA Publications

Available from International Air Transport Association, Publications Assistant, 800 Place Victoria, P.O. Box 113, Montreal, Quebec H4Z 1M1, Canada, Tel: 1-514-874-0202, www.iata.org.

Factsheet 7 Liquid hydrogen as a potential low-carbon fuel for aviation

2.1.7 ICAO Publications

Available from International Civil Aviation Organization, 999 University Street, Montreal, Quebec H3C 5H7, Canada, Tel: +1 514-954-8219, <http://www.icao.int/>

A41-WP/514 EX/246 Hydrogen, A Key Solution to Decarbonize Aviation

2.1.8 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 61508 Application of Safety Instrumented Systems for the Process Industries

IEC 61511 Functional safety - Safety instrumented systems for the process industry sector

IEC 61882 Hazard and Operability Studies (HAZOP Studies) - Application Guide

IEC 62061 Safety of machinery - Functional safety of safety related electrical, electronic and programmable electronic control systems

2.1.9 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 13984 Liquid hydrogen - Land vehicle fueling system interface

ISO 13985 Liquid hydrogen - Land vehicle fuel tanks

- ISO 14687 Hydrogen fuel quality - Product specification
- ISO 17268 Gaseous hydrogen land vehicle refueling connection devices
- ISO 19880-1 Gaseous hydrogen - Fueling stations - Part 1: General requirements

2.1.10 NFPA Publications

Available from National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

- NFPA 2 Hydrogen Technologies Code
- NFPA 704 Standard System for the Identification of the Hazards of Materials for Emergency Response

2.1.11 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

- MIL-STD-1472F Human Engineering

2.1.12 Vertical Flight Society Publications

Available from the Vertical Flight Society, 2700 Prosperity Avenue, Suite 275, Fairfax, VA 22031, Tel: 703-684-6777, www.vtol.org.

Schneider, J, et. al. (2023). *Multimodal Hydrogen Airport Hub* [White paper]. Vertical Flight Society. https://vtol.org/files/dmfile/h2-aero-whitepaper--multimodal-h2-airport-hub-2022_public-final.pdf.

2.1.13 Aerospace Technology Institute Publications

Available from the Aerospace Technology Institute, 10 Midford Place, 4th Floor, London, W1T 5BJ, www.ati.org.uk.

FlyZero Report

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

- AIR6464 EUROCAE/SAE WG80/AE-7AFC Hydrogen Fuel Cells, Aircraft Fuel Cell Safety Guidelines
- AIR7765 Considerations for Hydrogen Fuel Cells in Airborne Applications
- AS6858 Installation of Fuel Cell Systems in Large Civil Aircraft
- AS7141 Hydrogen Fuel Cells for Propulsion
- AS7373 Gaseous Hydrogen Storage for General Aviation

Monde, M. and Kosaka, M., "Understanding of Thermal Characteristics of Fueling Hydrogen High Pressure Tanks and Governing Parameters," *SAE Int. J. Alt. Power.* 2(1):61-67, 2013, <https://doi.org/10.4271/2013-01-0474>.

Schneider, J., Mathison, S., Ward, J., Taha, E. et al., "Gaseous Hydrogen Station Test Apparatus: Verification of Hydrogen Dispenser Performance Utilizing Vehicle Representative Test Cylinders," SAE Technical Paper 2005-01-0002, 2005, <https://doi.org/10.4271/2005-01-0002>.

Schneider, J., Meadows, G., Mathison, S., Veenstra, M. et al., "Validation and Sensitivity Studies for SAE J2601, the Light Duty Vehicle Hydrogen Fueling Standard," *SAE Int. J. Alt. Power.* 3(2):257-309, 2014, <https://doi.org/10.4271/2014-01-1990>.

2.2.2 CSA Publications

Available from CSA International, 178 Rexdale Boulevard, Toronto, Ontario, Canada M9W 1R3, Tel: 416-747-4000, www.csagroup.org.

ANSI/CSA HPRD 1 Thermally activated pressure relief devices for compressed hydrogen aircraft fuel containers

2.2.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

FAA 150/5230-4C Aircraft Fuel Storage, Handling, and Dispensing on Airports

2.2.4 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 23273 Fuel cell road vehicles - Safety specifications - Protection against hydrogen hazards for vehicles fueled with compressed hydrogen

ISO 26262 Road Vehicles - Functional safety

2.2.5 NFPA Publications

Available from National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

NFPA 55 Compressed Gases and Cryogenic Fluids Code

NFPA 70 National Electric Code (NEC)

NFPA 407 Standard for Aircraft Fuel Servicing

NFPA 415 Standard on Airport Terminal Buildings, Fueling Ramp Drainage, and Loading Walkways

2.3 Abbreviations and Symbols

2.3.1 Abbreviations

AAM Advanced Air Mobility

AHFC Airport Hydrogen Fueling Category (see Appendix C)

AIR Aerospace Information Report

APRR Average Pressure Ramp Rate (MPa/min)

CcH2 Cryo-Compressed Hydrogen

CD	Cold Dispenser
CHSS	Compressed Hydrogen Storage System
CNG	Compressed Natural Gas
dT	Differential Temperature
FC	Fueling Command
FCA	Fuel Cell Electric Aircraft
FCEV	Fuel Cell Electric Vehicle
GH2	Gaseous Hydrogen
H ₂	Hydrogen
H35	350-bar (35-MPa) nominal service pressure
H70	700-bar (70-MPa) nominal service pressure
HA	Hydrogen Aircraft
HDTA	Hydrogen Dispenser Test Apparatus
ID	Protocol Identifier
IrDA	Infrared Data Association
LH2	Liquid Hydrogen
LHFI	Liquid Hydrogen Fueling Interface
LNG	Liquefied Natural Gas
LTA	Lighter than Air
MAWP	Maximum Allowable Working Pressure
MPa	Megapascal
MOP	Maximum Operating Pressure
MP	Measured Pressure
MT	CHSS Measured Temperature
NIST	National Institute of Standards and Technology
NWP	Nominal Working Pressure
OD	Optional Data
OEM	Original Equipment Manufacturer
PRV	Pressure Relief Valve

PSH	Pressure Switch High
RT	Receptacle Type
SAE	Society of Automotive Engineers
sLH2	Subcooled Liquid Hydrogen
SOC	State of Charge
SW	Software Version
TSH	Temperature Switch High
TSL	Temperature Switch Low
TV	Tank Volume
VN	Version Number
UAM	Urban Air Mobility

2.3.2 Symbols

Table-Based Protocol Symbols:

APRR _{target}	Target Average Pressure Ramp Rate
APRR _{final}	APRR from fallback look-up table (based on ambient temperature and P ₀)
g/sec	Grams per second, also indicated as g/s
kg	kilogram
$\rho(P,T)$	Gas density - a function of pressure, P, and temperature, T
P ₀	Initial CHSS pressure level prior to fueling
P _{target}	Target Fueling Pressure
P _{station}	Fueling pressure as measured by station
P _{aircraft}	CHSS Pressure
t _{fueling}	Overall Fueling Time
t _{end}	Shutdown Time
T _{aircraft}	CHSS temperature data received by station from aircraft during communications fueling
T _{fuel}	Fuel Delivery Temperature
T _{fuel-ave}	Mass average of the fuel delivery temperature after the first 30 seconds of the main fueling time
T _{fuel-ave-roll}	A 30-second rolling mass average of fuel delivery temperature after 30 seconds of main fueling time
T _{fuel-ave-tot}	Total mass average fuel delivery temperature after the first 30 seconds of the main fueling time

T _{fuel_inst}	Instantaneous Fuel Delivery Temperature
T _{amb}	Ambient temperature as measured by fueling station, not in direct sunlight
SOC _{station}	SOC calculated by using P _{station} and MT
SOC _{aircraft}	SOC calculated by using P _{aircraft} and MT
V _{CHSS}	Volume of the CHSS measured or otherwise determined by the station

2.4 Definitions

2.4.1 COMPRESSED HYDROGEN

Hydrogen at ambient temperature pressurized to 350 bar (35 MPa) or 700 bar (70 MPa).

2.4.2 CRYO-COMPRESSED

Pressure: 15 to 700 bar (1.5 to 70 MPa); temperature: 20 to 233 K; supercritical state.

2.4.3 LIQUID HYDROGEN

Hydrogen below its boiling point of -253 °C (20 K) at ambient pressure of 1 bar (both gas and liquid in storage container).

2.4.4 SUPERCRITICAL

Temperature and pressure above the critical point, where distinct liquid and gas phases do not exist, but below the pressure required to compress it into a solid.

3. HYDROGEN AIRPORT: GASEOUS AND LIQUID FUELING TARGET TABLE

Table 3 describes the AIR8466 hydrogen use case per aircraft type, or fueling target table for both gaseous and liquid hydrogen. Each type of aircraft has an approximate range shown (without reserve). The table shows the hydrogen storage amounts for each of these aircraft types, which is necessary to be able to calculate hydrogen fueling as well as understanding the scaling toward the airport hub. The table was developed from the VFS H2-Aero "Multimodal H2-Airport Hub" white paper developed consensus upon the acceptable aircraft fueling time, which is based on conventional vehicle limits. Note that the larger jet-fueled aircraft (regional, narrow body, and wide-body) are harmonized on the Aerospace Technology Institute's FlyZero Report. There are also multiple use cases representing the location where the hydrogen fueling would occur, such as the airport tarmac, rooftop, airfield, etc. See Table 3 for LH2 coupling and storage guidance.

Table 1 - Aircraft range, hydrogen storage, and turnaround time per aircraft type (reference)

Use Case vs. H2 Aircraft Type	Typical vs. Maximum Range (no reserve) nm	Typical Onboard H2 (kg) GH2/LH2	Customer Fueling Time (average)	Use Case Location	Fuel Use Case Location
Small Aircraft: H2-eCTOL/eSTOL	250-500 nm	GH2 - 100kg	30 minutes	Airport	Airport tarmac
UAM/AAM (short range)	57 nm (UAM)	GH2 <100 kg	10 minutes	Rooftop/ Vertiport/ Airport, etc.	Heliport/Vertiport ⁽¹⁾ Airport/Autonomous refueling
H2-eVTOL - AAM (long range)	~150 nm (AAM)	LH2 >100 kg	10 minutes		
H2-eRotor (5pa/7000 pounds)	350 nm	LH2 100kg	10 minutes	Rooftop/H-Pad, etc.	Heliport/Vertiport/ Airport/Autonomous refueling
H2-eRotor (13pa/9000 pounds)	512 nm	LH2 210-360kg	30 minutes		
Large Aircraft eCTOL				Airport	Airport tarmac ATI Two Scenarios Small-Medium LH2 Fueling Trucks Airport tarmac large: (2040) LH2 Hydrant Pipeline
Regional	800 nm	LH2 1300 kg	20 minutes		
	2400 nm	LH2 6000 kg	20 minutes		
Narrow body	3200 nm	LH2 6000 kg	30 minutes-1 hour		
	5000 nm	LH2 10000 kg	30 minutes-1 hour		
Wide-body	5000 nm	LH2 20000 kg+	1 hour		
H2-Airships	540 nm 5000 nm	LH2 5000-10000 kg	30 minutes-1 hour	Airfields	Airfield, Hangar

⁽¹⁾ Helipad encompasses heliport - ground and rooftop (vertiport), helideck - all maritime applications including oil rig and ship, and all austere take-off and landing conditions.

3.1 AIR8466 Fueling Categories

Figure 2 graphically depicts the AIR8466 hydrogen fueling categories between different types of aircraft (and fuel capacity) from small UAM to regional to narrow body and wide-body as well as lighter than air (LTA). This figure is meant to summarize Table 1. The AIR8466 guideline establishes gaseous and liquid fueling connector types based on flow rates and aircraft storage categories. This is also exemplified in Table 3, which shows liquid hydrogen coupling categories.

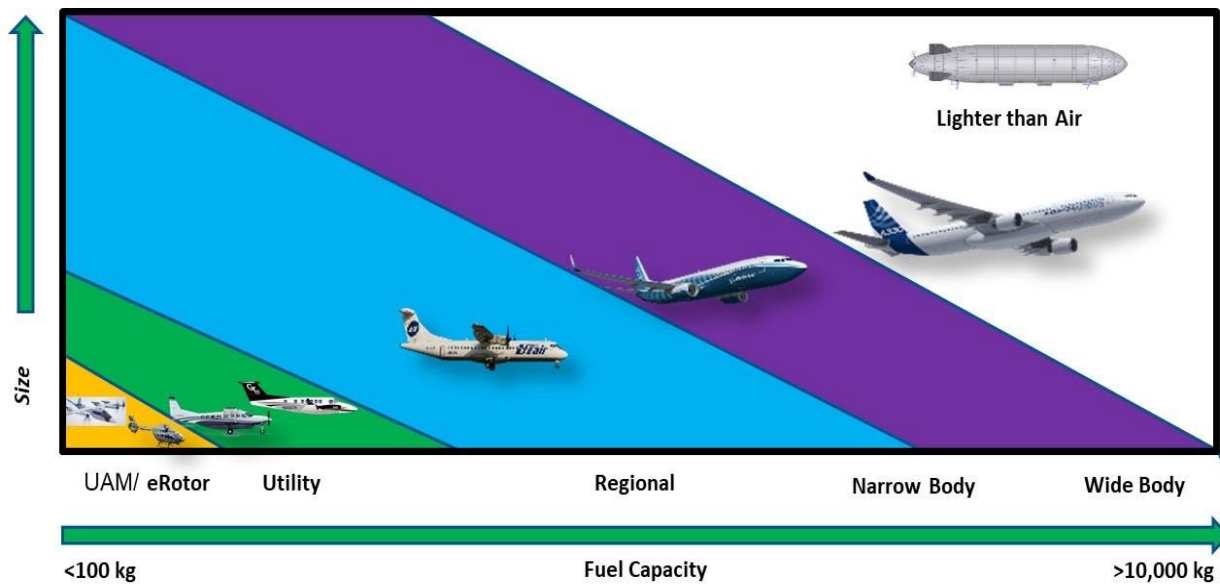


Figure 2 - Graphically depicted hydrogen fueling categories per aircraft type/fuel capacity⁵

4. GASEOUS HYDROGEN FUELING DEFINITIONS

Gaseous hydrogen fueling refers to pressure refueling of pressure vessels with supercritical hydrogen such that the storage temperature of hydrogen in the storage vessel could be greater than 233.15 K. This is distinct from cryo-compressed refueling, where the storage vessel may be operated in temperatures in the range of 33.18 to 233.15 K.

4.1 AVERAGE PRESSURE RAMP RATE (APRR)

The average increase in pressure (MPa/minute) from the start of fueling to the end of fueling.

4.2 COMPRESSED HYDROGEN STORAGE SYSTEM (CHSS)

The CHSS (refer to SAE J2579) consists of the pressurized containment vessel(s), pressure relief devices (PRDs), shutoff device(s), and all components, fittings, and fuel lines between the containment vessel(s) and these shutoff device(s) that isolate the stored hydrogen from the remainder of the fuel system and the environment.

4.3 CHSS CAPACITY

The total mass of hydrogen stored in the CHSS at the nominal working pressure (at 15 °C), which is equivalent to the CHSS 100% state of charge.

4.4 CHSS CAPACITY CATEGORIES

The CHSS capacity category is a range of CHSS capacities that may fuel in a similar manner by a fueling protocol.

4.5 DISPENSER COMPONENTS

4.5.1 Hydrogen Dispensing Equipment

The equipment required to condition and transfer fuel from the station to aircraft CHSS for the purpose of fueling the aircraft.

⁵ Courtesy of ZEV Station, Novadev Inc.

4.5.2 Connector or Coupling

A joined assembly of a nozzle and receptacle that permits rapid coupling (or connecting) and decoupling (or disconnecting) of the fuel supply nozzle to the aircraft fueling receptacle, as per SAE J2600.

4.5.3 Fixed-Orifice Fueling

A simplified, conservative fueling protocol based on a fixed flow restriction in the hydrogen to allow for fueling without compressors or control.

4.5.4 Nozzle

Device connected to a fuel dispensing system that engages the hydrogen aircraft (HA) receptacle and permits transfer of fuel (see 4.5.2).

4.5.5 Receptacle

Device connected to an aircraft or storage system that receives the dispenser nozzle and permits transfer of fuel. This may also be referred to as a fueling inlet (see 4.5.2).

4.5.6 Dispenser Hose

The flexible hose assembly that transfers hydrogen between the dispenser and nozzle.

4.5.7 Hose Breakaway

A device that allows the hose to separate from the dispenser if exposed to a sufficient mechanical stress. Typically, the hose is the only component between the nozzle and hose breakaway. The frangible part of the breakaway is fitted downstream of an isolation valve.

4.6 FUELING WITH COMMUNICATIONS AND NON-COMMUNICATIONS

4.6.1 Communications

Communications fueling means that a valid data connection has been established from the aircraft to a fueling station dispenser. Appropriate communication standards will be defined in future SAE standards for aircraft bidirectional communication.

4.6.1.1 Non-Safety Integrity Level (SIL) Rated Communications Assumptions

SIL (refer to IEC 61508 and IEC 61511) may be used to qualify refuel station components and systems for the station to secure SIL certification. Aircraft manufacturers may have ground station communication integrity requirements. In the absence of aircraft manufacturer requirements and SIL certification, the signals are not guaranteed to be accurate and the station is responsible to ensure that process requirements are followed if it uses the communications signals.

4.6.2 Non-Communications

Non-communications means that no valid data connection from the aircraft to a fueling station dispenser exists or that the received data has not been recognized as valid (or wished to be used) by the dispenser.

4.7 FUELING PROTOCOL CATEGORIES

Station fueling protocol will be defined by the aircraft's nominal working pressure (NWP) and the station's fuel delivery temperature category. The category is denoted by the letter "H" followed by the nominal working pressure in MPa, a hyphen, and the letter "T" followed by the absolute value of the fuel delivery temperature category in °C. For example, H70-T40 is the station category for a hydrogen fueling protocol with an NWP of 70 MPa and a fuel delivery temperature category of -40 °C.

4.8 GASEOUS FUELING PROTOCOL TYPES

4.8.1 Orifice

A device or fixed geometry in a fluid system used to control or measure a flow rate. It can be as simple as a hole through a plate or as complicated as the tortuous flow path through a valve or device.

4.8.2 Fixed-Orifice Fueling Protocol

A fixed-orifice fueling protocol is a simple vessel-to-vessel gas transfer in which the flow rate is governed by a flow orifice of fixed size and geometry. A protocol may be defined by the orifice size and configuration, the upstream pressure and volume, various upper and lower temperature and pressure limits, and the downstream CHSS volume and target pressure. These conditions may be applied by a simple control system with appropriate temperature and pressure inputs and on-off valve outputs, which are configured to ensure that a specifically defined set of pressure and temperature boundaries are maintained, ensuring a safe fueling event that complies with the CHSS safe process limits. A conceptual schematic of a fixed-orifice hydrogen fueling system is shown in Figure 3. Safety elements and control elements are not depicted in the drawing.

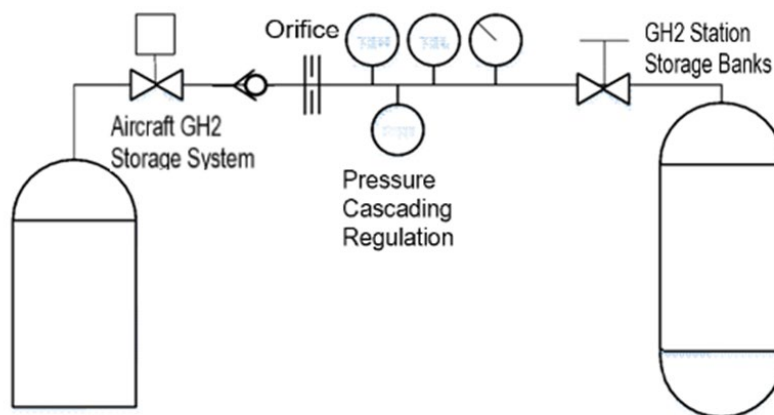


Figure 3 - Example of a fixed-orifice hydrogen fueling system

4.8.3 Table-Based, Precooled Fueling

A fueling event that follows the guidance of the lookup tables in SAE J2601 documents for ground vehicle fueling. There will be an Aerospace GH2 Fueling Standard in future revisions.

4.8.4 MC Method

The MC Method is an analytical method that allows a hydrogen station to calculate the end-of-fill gas temperature in a hydrogen CHSS and thereby determine the appropriate fueling speed and ending pressure.

4.8.5 Standard Fueling Protocol

A fueling protocol that has been validated by the SAE Hydrogen Airport Taskgroup, SAE AE-5CH, will be defined in future hydrogen aerospace standards herein. Ground vehicle fueling references are done in the SAE J2601 family of documents. For instance, heavy-duty fueling is covered in SAE J2601-2 and SAE J2601-5.

4.8.6 Non-Standard, Development Fueling

A fueling protocol that has not yet been validated by SAE AE-5CH and thus is not defined in the main body of its standards.

4.9 FUELING TIME AND FUELING EVENTS

Figure 4 illustrates the fueling time definitions for the main and overall fueling time (refer to SAE J2601).

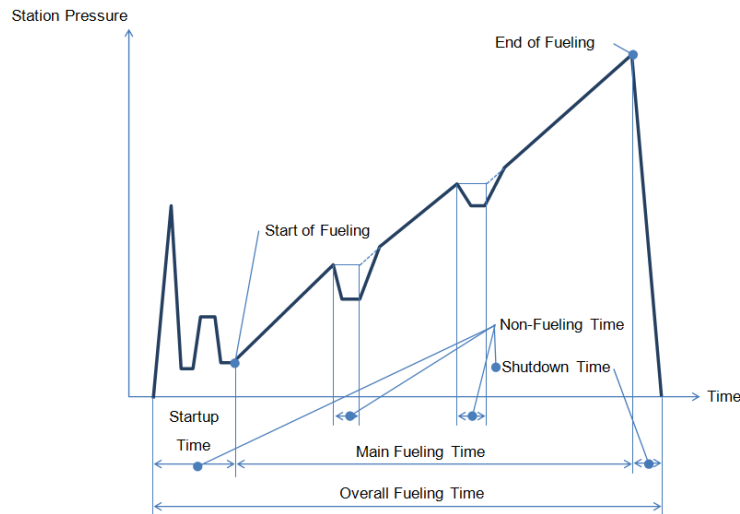


Figure 4 - Representative hydrogen fueling time diagram

4.9.1 Overall Fueling Time

The total amount of time between when the user initiates the fueling at the dispenser until the nozzle can be removed from the aircraft and returned to the dispenser. It includes the start-up time, main fueling time, and shutdown time.

4.9.2 Non-Fueling Time

The amount of time during the overall fueling time when fueling pressure ramp rate is not applied. The non-fueling time includes the start-up and shutdown time, plus any planned interruptions during the main fueling time. However, non-fueling events do not include stopping or pausing fuel flow due to safety issues, lack of performance, etc.

4.9.3 Intended Non-Fueling Events

A planned event when gas does not flow during the overall fueling time in order to test the integrity of the system or to change the source of fuel. Intended non-fueling events do not include stopping or pausing fuel flow due to safety issues or lack of performance.

4.9.4 Connection Pulse

The pulse of gas when a pressurized, SAE J2600 Type A nozzle is first connected to the receptacle.

4.9.5 Initial Leak Check

The initial leak check may be implemented after the nozzle is connected and prior to the start of main fueling time. This can be accomplished by pressurizing the fueling path and measuring any decrease in pressure.

4.9.6 Fueling Leak Check

A fueling leak check may be implemented during fueling to determine if there are any leaks in the system. This can be accomplished by pausing the fueling and measuring any decrease in pressure.

4.9.7 Bank Switching

Bank switching occurs when the station changes the flow source from one storage bank to another. There may be a flow rate variation or short-term pause in fueling during bank switching.