

Frequently Asked Questions

About

Commercial Hydrogen Vehicle Refueling



General Questions

1. Why is the U.S. continuing to develop hydrogen fuel cell vehicle technology?

U.S. industries and government are at the forefront of research and development of hydrogen and fuel cell technology to power vehicles, homes, businesses, and remote equipment such as cell phone towers. The goals of this effort were to lessen U.S. dependence on foreign oil and advance an environmentally clean, safe, and reliable energy agenda. Hydrogen is one of many alternative fuels being explored. When hydrogen is used to power a hydrogen fuel cell electric vehicle (HFCEV), it offers one possible solution to meeting some of the growing demand in the U.S.A. for a reliable supply of clean and sustainable energy.

Hydrogen is considered the ultimate clean vehicle fuel. The only emissions from a HFCEV are heat and clean water, which makes hydrogen a fuel that can help to protect the environment and keep our air cleaner. Hydrogen gas is 14.4 times lighter than air and dissipates rapidly and harmlessly if released into the air.

Hydrogen has higher energy content by weight than other fuels, but lower energy content by volume. This means that sufficient quantities of hydrogen stored in liquid or compressed gaseous form onboard a HFCEV can provide a comparable driving range to conventional gasoline-powered vehicles. Fuel cells are lighter in weight than batteries used in plug-in electric vehicles, also making hydrogen fuel cell vehicles lighter and more suited to long-range applications than battery electric vehicles. In addition, FCEVs can be fully refueled in under 5 minutes at a hydrogen fueling station, compared to the 3 hours to more than 20 hours it takes to recharge battery electric vehicles. Charge time is dependent on the type of battery electric vehicle and the type of electric vehicle service equipment.

Hydrogen can be produced using renewable energy sources such as the wind or sun. Renewable energy technology is an attractive investment because the return on investment is enduring and is unbounded by a finite pool of natural resources that must first be located, then extracted and refined, and eventually depleted.

The most common methods used to produce hydrogen today rely on resources that are readily available in the United States; for example, electrolysis of water and steam reformation of natural gas. As such, hydrogen can be produced regionally in ways that meet the economic and social goals of each region. Factors to consider include the available feedstocks or energy resources used to produce the supply of hydrogen, the energy efficiency of those methods used to produce the hydrogen; the infrastructure in place to transport, distribute, deliver, and store the hydrogen; and the efficiency of the energy conversion devices in converting the hydrogen into work, such as propelling a vehicle. Every advance in technology that reduces the cost or

improves the efficiency of these components is a permanent cost-savings improvement. The advances within the hydrogen and fuel cell industry today are part of a major effort to make hydrogen a viable step towards American independence from foreign energy imports.

2. **What is different about driving a fuel cell electric vehicle (FCEV)?**

Hydrogen fuel cell vehicles (HFCV) are designed to replicate the experience of operating a gasoline powered vehicle. FCEVs are designed to have similar response times, speed, and acceleration as vehicles with gasoline powered engines, and are smoother and quieter than vehicles using internal combustion engines. However, the exhaust and refueling connection differ from a gasoline powered vehicle. The exhaust from a HFCV is clean water and heat rather than air pollutants and greenhouse gases. Because the hydrogen fuel cell powers an electric drive motor to power the vehicle drive train, a HFCV is much quieter than a vehicle with an internal combustion engine. HFCVs have a driving range of approximately 480 kilometers (km) (300 miles) using a single tank of hydrogen fuel. Some HFCVs have achieved an impressive 800 km (500 mile) driving range, significantly more than the average battery electric vehicle.

3. **How is hydrogen fuel made available today?**

The predominant storage method for hydrogen fuel cell electric vehicles (HFCEVs) is gaseous hydrogen storage. However, there are auto and dispenser manufacturers that have designed equipment for liquid hydrogen fueling applications; although it is most likely that liquid hydrogen storage may be used at a fueling station for delivering compressed gaseous hydrogen to a vehicle. A compressed gas fueled HFCEV uses hydrogen that is stored onboard the vehicle in a pressurized cylindrical tank. Due to low volumetric energy density noted above, hydrogen gas must be compressed to high pressure to store enough fuel to achieve a 480 kilometer (300 mile) or more driving range.

4. **How can I purchase hydrogen for a fuel cell vehicle?**

Dispensers for a hydrogen fueling station are very similar in appearance to gasoline dispensers. You may even find hydrogen fuel dispensers in the same filling station with gasoline dispensers. Hydrogen fuel dispensers sit on an island where vehicles can pull in and gain access to a hose that connects to the vehicle to deliver the fuel. Hydrogen dispensers will have a customer interface with a display and keypad controls that a driver can use to start and stop the delivery.

The process for fueling a fuel cell electric vehicle is quite similar to a gas pump and takes approximately the same amount of time – roughly three to five minutes. The driver pulls into the station and stops next to an available dispenser. The transaction is initiated by following instructions on the dispenser's display screen. The driver takes the hose and attaches it to the vehicle fueling connection and secures the connection by rotating a lever on the nozzle. The driver activates a control to tell the dispenser to start the fueling process, and the dispenser does the rest. A typical passenger vehicle will accept between 1 kilogram to 6 kilograms (2.205 pounds to 13.23 pounds) of hydrogen fuel, to achieve a fill up depends on how much hydrogen is in the fuel tank at the beginning of the fueling process and the tank size. When the fill is complete, the dispenser automatically stops the delivery and signals the driver to disconnect and return the hose.

As this fact sheet is being published, work is underway in the U.S. hydrogen and weights and measures communities to make certain the necessary components in the hydrogen infrastructure are in place for the start of national commercial sales of hydrogen vehicle fuel. The compliance process for public gasoline fueling stations has been in place for over 100 years.

Hydrogen fuel will be available for sale through refueling dispensers based on a recognized unit of measurement. This is already taking place in California. This allows consumers to make value

comparisons when purchasing a hydrogen fuel cell vehicle and hydrogen fuel for their vehicle. As of July 2010, hydrogen vehicle fuel is to be sold by mass units of the kilogram (kg).

5. **Where does hydrogen fuel come from?**

The most commonly used methods for hydrogen production include:

- *Natural Gas Reformation.* The majority of hydrogen produced today is for industrial purposes and is made by reforming natural gas. This same process is used to produce hydrogen for vehicle fuel.
- *Electrolysis* is another process whereby electricity is used to split water molecules (which can be supplied from a municipal water supply system) into oxygen and hydrogen fuel. The electrolyzer used to split the water may be located onsite at the fueling station and powered by some other source of energy. The electricity for powering the electrolyzer may be generated by a renewable energy technology using wind, solar, geothermal, or hydroelectric power, thus, providing further reductions in greenhouse gas emissions.
- Hydrogen can also be produced from the gasification of coal or biomass (sustainable/renewable plant and animal materials), photo-biological production (algae), or reforming certain liquid fuels.
- Nuclear power has the potential to produce hydrogen from high temperature electrolysis.

These are many of the known methods currently in use and under development to produce hydrogen. The list of alternative methods for hydrogen production continues to grow as researchers make new discoveries.

6. **How much hydrogen do I need in order to travel as far as I can on a gallon of gas?**

Since July 2010, gaseous hydrogen vehicle fuel is sold by mass units of the kilogram (kg). Coincidentally, the energy content of 1 kg (2.205 pounds [lb]) of hydrogen is slightly higher than the energy content in 3.785 liters (1 gallon) of gasoline (which has a mass of approximately 2.732 kg [6.025 lb]). To compare a fuel cell vehicle and a gasoline internal combustion engine vehicle in terms of distance travelled for a certain amount of fuel, it is important to consider that a fuel cell electric vehicle converts fuel energy into locomotive work two to three times more efficiently than a gasoline powered vehicle. Fuel cell electric vehicles achieve 40 % to 60 % energy efficiency, compared to gasoline powered vehicles that typically operate at 20 % efficiency. The quantity of compressed gaseous hydrogen fuel required to travel the same distance as a gallon of gasoline would weigh less but would occupy more space than the gasoline.

Comparing solely by mass, 1 kg of hydrogen contains roughly three times more energy than 1 kg of gasoline. In contrast, when the energy content of equal volumes of hydrogen gas (at 70 megapascals [10 000 psi]) and gasoline are compared, hydrogen has four times less energy.

7. **Is hydrogen safe as a vehicle fuel?**

Equipment in use at hydrogen refueling stations is designed, constructed, and installed in accordance with safety codes and standards, and fuel cell electric vehicles (FCEVs) must meet the National Highway and Transportation Safety Administration's highest safety standards.

Extensive research has been conducted by government, industry, and academia to assess hydrogen's properties and behavior as they relate to the safe storage, transportation, and delivery of hydrogen fuel. Therefore, the likelihood of a safety incident occurring while refueling a FCEV is not any greater than other refueling operations. Stations will be posted with safety information (such as no ignition sources) and attendants trained to respond to hazardous situations.

Hydrogen is non-toxic. A hydrogen system designed to appropriate codes and standards can provide a comparable (or even higher) level of safety than gasoline systems. If hydrogen is released into the atmosphere, it does not pollute the air or ground water. Because hydrogen is 14 times lighter than air, it very quickly dissipates and will not remain in high concentrations if released. A hydrogen system such as in a FCEV may, in fact, be designed to release hydrogen in a controlled manner, facilitating venting or even flaring of the hydrogen as the situation warrants.

Hydrogen is colorless and odorless. Additive odorants (like the sulfur-containing butyl mercaptan used to facilitate the detection of natural gas) are not compatible with fuel cell technology. Instead, detection equipment is in use in fueling stations and is also available for use in operations where a hydrogen release might be entrapped in an enclosed space.

Hydrogen is stored in liquid or gaseous form, and delivered during fueling as a gas at high pressure. The high pressure is necessary to compress the hydrogen enough to enable sufficient amounts of hydrogen for suitable driving distances. You will see dispenser service pressure expressed in metric units of megapascal (MPa). Hydrogen fuel cell electric vehicles have storage pressures up to 70 MPa (10 000 psig). High strength carbon fiber reinforced tanks are designed and manufactured to contain these pressures safely. Earlier designs of fuel storage cylinders have been used successfully in compressed natural gas (CNG) vehicles for onboard storage of high pressure gaseous fuel for many years.

8. What other uses are there for hydrogen fuel cells?

Hydrogen fuel cells, along with powering passenger and fleet vehicles, can also be found in stationary and portable power generation applications. Hydrogen fuel cells are used in stationary applications as backup power generation systems to provide a reliable uninterrupted energy source for hospitals and data centers. Hydrogen fuel cells have also seen recent success in warehouse and distribution center operations where they are used to power forklifts operated in enclosed spaces where engine exhaust emissions are undesirable, and where fleet management favors fewer vehicles with less down time. Hydrogen fuel cells, which have a higher energy density and lighter weight than batteries, are also being marketed in portable applications to power personal electronic devices such as cell phones, chargers, and laptops.

9. Where can I learn more about what is happening with hydrogen as a vehicle fuel?

The NIST Office of Weights and Measures maintains a hydrogen information website available at: <https://www.nist.gov/pml/weights-and-measures/legal-metrology-devices/hydrogen-us-national-work-group>. This resource is dedicated to providing information on the latest efforts to develop uniform, fair, and appropriate legal metrology requirements for commercial hydrogen measurement. The web page has links to other websites that provide additional information on

the development of related hydrogen topics such as basic safety, fueling station locations, fact sheets, and more. Other websites for more information are available at:

<https://www.energy.gov/eere/fuelcells/fuel-cell-technologies-office>
<http://energy.gov/eere/fuelcells/hydrogen-storage>;
<http://energy.gov/eere/fuelcells/hydrogen-delivery>;
<http://www.fchea.org/factsheets/>;
<http://www.h2usa.org/faq>; and
<http://cafcp.org/faqs>

Questions Related to Legal Metrology

1. What legal metrology standards exist for hydrogen fueling applications?

The National Institute of Standards and Technology (NIST) Handbook 44, “Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices,” Section 1.10 General Code and Section 3.39 Hydrogen Gas-Measuring Devices - Tentative Code provide specifications, tolerances, and other technical requirements for hydrogen measuring devices. NIST Handbook 44 requirements form the basis for type evaluation under the National Type Evaluation Program and for routine inspection and test procedures for commercial measuring equipment. NIST Office of Weights and Measures (OWM), through a Department of Energy (DOE)/NIST sponsored U.S. National Work Group, has developed a draft Examination Procedure Outline (EPO), which is a detailed step-by-step inspection and test procedure (using a gravimetric method) for a hydrogen dispenser, based on NIST Handbook 44 device code requirements. Test procedures for other alternative test methods are under consideration.

NIST Handbook 130, “Uniform Laws and Regulations in the Areas of Legal Metrology and Fuel Quality,” provides the Method of Sale Regulation 2.32 “Retail Sales of Hydrogen Fuel” that specifies the kilogram (kg) as the unit of measurement for sales of gaseous hydrogen vehicle fuel and for related labeling and advertising requirements. More information on these codes and regulations are available on the NIST OWM website at: <http://www.nist.gov/pml/wmd/>. Handbook 130 includes fuel quality standards and references to test methods.

2. Where did the legal metrology standards for hydrogen come from?

The legal metrology requirements in the National Institute of Standards and Technology (NIST) Handbook 44 and Handbook 130 were developed by the U.S. National Work Group (USNWG) for the Development of Commercial Hydrogen Measurement Standards. Startup of the USNWG was sponsored by the U.S. Department of Energy (DOE) and the U.S. Department of Commerce’s (DOC) National Institute of Standards and Technology (NIST). This group is comprised of stakeholders from private industries, standards organizations, and state and federal government. Broad participation was sought so as to include hydrogen dispenser and component manufacturers, fuel suppliers, standards developers, and weights and measures device type evaluation laboratories and regulators in developing its recommendations. The USNWG adhered to the weights and measures standards development process that has been in place since 1905.

The draft standards created by the USNWG were adopted by the National Conference on Weights and Measures (NCWM) in 2010 and first published by NIST in the 2011 editions of Handbook 44 and Handbook 130. Handbook requirements are adopted by the states, in part or entirety, as law and/or regulation. More information on work efforts by the USNWG is available

on the NIST Office of Weights and Measures (OWM) website available at:
<http://www.nist.gov/pml/wmd/lmdg/usnwg.cfm>.

3. What types of hydrogen fueling systems are in use in the U.S.A.?

Both stationary and portable hydrogen refueling systems are in use. Dispensers are permanently installed in service stations capable of generating hydrogen through natural gas reformation, an electrolyzer powered by electricity supplied by the grid, or renewable sources such as solar or wind power. Stationary installations may also be supplied with hydrogen through deliveries from tanker or tube trailer trucks. There are platform and vehicle-mounted refueling systems also in use to refuel road tours and to temporarily fuel fleet operations based in a certain geographic location.

4. Why is the recognized method of sale for hydrogen vehicle fuel on the basis of price per kilogram (\$/kg)?

Industry pre-market practice has been to dispense hydrogen in mass units of measurement. Because the hydrogen is delivered in a compressed gaseous form, volume measurement would not be suitable due to the dependency on pressure and temperature of the gas. To ensure accuracy in the amount of hydrogen fuel delivered, mass units have been the preferred method of delivery in the weights and measures and hydrogen communities. The corresponding international standard developed by the International Organization of Legal Metrology (OIML) in Recommendation (R) 139 "Compressed gaseous fuel measuring systems for vehicles" also recognizes mass as the basis for dispensing compressed gases. The latest version of OIML R 139, is available at: <http://www.oiml.org/en>.

The "Gasoline Gallon Equivalent" (GGE) was considered as a specialized mass unit for dispensing hydrogen, but not supported. With a standardized unit of measurement (the kilogram) used for advertisement, dispenser labeling, and hydrogen gas deliveries through retail dispensers, consumers can make value comparisons between competing retailers, and the unit is traceable. The U.S. has a national policy to establish the SI (International System of Units, commonly known as the metric system) as the preferred system of weights and measures for U.S. trade and commerce. Most commercial gaseous hydrogen metering systems measure in mass, an equitable, efficient means of measurement that is based on a traceable unit of measure. Coincidentally, a kilogram of hydrogen has virtually the same energy content as one gallon of gasoline. Consequently, the kilogram was adopted as the quantity unit for commercial sales of hydrogen vehicle fuel.

5. What criteria are used to obtain U.S. type evaluation approval of a hydrogen vehicle fuel dispenser?

A set of general evaluation criteria (checklist) based on General Code and device specific design requirements in Section 3.39. of the NIST Handbook 44 was developed for inclusion in National Conference on Weights and Measures (NCWM) Publication (Pub) 14, "Measuring Devices Technical Policy, Checklists, and Test Procedures." Checklists are typically developed by the NCWM National Type Evaluation Technical Committee (NTETC) Measuring Sector Subgroup.

The Department of Energy/NIST U.S. National Work Group for the Development of Commercial Hydrogen Measurement Standards as well as the NTETC all provided input to fully develop the performance test procedures for the NCWM Pub 14, Field Evaluation and Permanence Tests Section specific to hydrogen dispensers.

The final draft of the general checklist was forwarded to the National Type Evaluation Program

(NTEP) Committee for inclusion in NCWM Pub 14 in late 2011 resulting in their approval of the checklist in late 2012.

U.S. type evaluations are carried out by NCWM NTEP, whose laboratories use NCWM Pub 14.

6. **What is the accepted tolerance for the performance of a hydrogen dispenser?**

The NIST Handbook 44, Section 3.39. Hydrogen Gas-Measuring Devices - Tentative Code, paragraph T.2. Tolerances specifies that hydrogen dispensers fall within the Accuracy Class 7.0. These devices are required to meet a performance of $\pm 5.0\%$ for acceptance tolerance and $\pm 7.0\%$ for maintenance tolerance.

7. **What test methods are recognized for verifying the performance of a hydrogen dispenser?**

The NIST Handbook 44, Section 3.39. Hydrogen Gas-Measuring Devices - Tentative Code, paragraph N.4. Tests recognizes three official methods for testing the measurement performance of a hydrogen dispenser: the gravimetric test, master meter transfer standard test, and PVT (pressure volume temperature) test. More detailed procedures are available in the NIST Examination Procedures Outline 29 for Hydrogen Gas Retail Vehicle Fuel Dispensers (Draft 5) that address the gravimetric test method.

8. **How many test drafts are required in a test of a hydrogen vehicle refueling dispenser?**

The type and number of test drafts required during the performance test of a hydrogen vehicle fuel dispenser are prescribed in the Notes section of the NIST Handbook 44, Section 3.39. Hydrogen Gas-Measuring Devices - Tentative Code. The Code forms the basis for both type evaluation test criteria and for testing and inspection of devices while in commercial operation.

For hydrogen dispensers in commercial use, the test will consist of a minimum of two test drafts. One test draft shall consist of a draft size that represents the smallest quantity the device is designed to accurately deliver (which might be the amount of fuel necessary to top-off a nearly full vehicle tank), but is usually defined as the manufacturer's marked Minimum Measured Quantity (MMQ). The other draft shall consist of a draft size of either ten times the MMQ or 1 kilogram, whichever is greater. The flow rates selected for the test are to reflect normal delivery conditions. More tests may be performed if conditions warrant further testing. It is worth noting that dispensers must also meet other industry performance standards as well as legal metrology requirements.

9. **What is type evaluation and what does the process involve?**

A device undergoing type evaluation is intended to represent a particular design that will be mass produced for commercial use. Therefore, type evaluation tests are structured to provide sufficient data to demonstrate a device's performance over a lifetime of use and are more extensive than the periodic field performance testing that is used to determine a device's performance compliance and proper maintenance while in commercial service. Type evaluation enables testing of a same "type" or pattern to provide confidence to weights and measures jurisdictions, facilitates acceptance, assists the manufacturer in identifying any problems or deficiencies and correcting them before making equipment more widely available.

10. **Can a type of hydrogen dispenser be issued a National Conference on Weights and Measures (NCWM) National Type Evaluation Program (NTEP) Certificate of Conformance (CC)?**

Because the NIST Handbook 44, Hydrogen Gas-Measuring Devices Code currently has tentative status, it is only possible to obtain a provisional NTEP CC at this time. When the status of the

code is changed from tentative to permanent, a device covered by a provisional Certificate of Conformance may need to undergo additional evaluation to demonstrate compliance with any additional requirements added to the code. If no additional requirements are added, then any existing provisional certificates would automatically be upgraded to full certificates. More information on NTEP is available on the NCWM website at: <http://ncwm.net/content/ntep>. Additionally, it should be noted that the state/local weights and measures authority having jurisdiction over commercial dispensers may also have provisions in place for performing type evaluations.

11. What is the smallest permissible quantity unit value that can be displayed for a delivery on a hydrogen dispenser or recorded on a hydrogen fuel sales receipt?

The NIST Handbook 44, Section 3.39. Hydrogen Gas-Measuring Devices - Tentative Code, paragraph S.1.4. Value of Smallest Unit specifies 0.001 kg as the value of the smallest unit permitted and not to be exceeded for devices with a maximum flow rate of 30 kilograms/minute (kg/min) or less; 0.01 kg is the value of the smallest unit permitted and not to be exceeded on devices with flow rates greater than 30 kg/min.

12. What is unique about hydrogen vehicle fuel when compared to compressed natural gas (CNG)?

The weights and measures and hydrogen communities were able to develop many hydrogen standards by building on what they have learned from similar compressed gas applications such as compressed natural gas (CNG). However, hydrogen has several unique properties that must be considered when addressing safety, storage, and commercialization of the technology. Hydrogen has 6 to 8 times lower density than CNG, even at higher service pressures. The pressures at which hydrogen is dispensed and stored can be more than 2.5 times higher than those for CNG. Hydrogen dispensers are equipped with safety features to regulate the fill cycle in order to prevent the heating that occurs during the fueling process from raising the receiving tank's temperature above the typical maximum allowable temperature of 85 °C (185 °F).

13. Are there any requirements for hydrogen vehicle fuel quality? Multiple organizations in the fuel standards community worked to fully develop a hydrogen fuel quality standard. There has been a concerted effort to harmonize these standards among the different organizations. The vehicle fuel quality standard recognized and required by many weights and measures jurisdictions and other enforcement agencies is included in the NIST Handbook 130, "Uniform Laws and Regulations in the Areas of Legal Metrology and Fuel Quality." This standard specifies that hydrogen fuel meet the requirements of the most current version of Society of Automotive Engineers (SAE) Standard J2719, "Hydrogen Fuel Quality for Fuel Cell Vehicles." The SAE J2719 Standard is aligned with the corresponding International Organization for Standardization (ISO) standard for hydrogen fuel quality (ISO/DIS 14687-2 Hydrogen fuel - Product specification - Part 2 Proton exchange membrane fuel cell applications for road vehicles). SAE J2719 references the specific ASTM sampling and testing methods that are necessary to ensure that hydrogen fuel meets the designated 99.97 % purity standard and that all remaining constituents are within allowable limits. The citation for this reference standard is in the NIST Handbook 130, Section IV., G. Uniform Fuels and Automotive Lubricants Regulation, Section 2. Standard Fuel Specifications, paragraph 2.17. Hydrogen Fuel.

Pressure Conversions

These conversions are based on National Institute of Standards and Technology (NIST) Special Publications (SP) 330 “The International System of Units (SI)” and SP 811 “Guide for the Use of the International System of Units (SI)” that provide guidelines on the use of the International System of Units (SI), the metric system. These publications are available on the NIST Office of Weights and Measures web site at: <https://www.nist.gov/pml/weights-and-measures/publications/metric-publications>. This information was prepared to provide a ready reference for commercial measurement systems designed to dispense hydrogen vehicle fuel at various service pressure ratings. This information is limited to units of measurement that might typically be used to declare service pressure on dispensers, street signs, and advertisements. The U.S. weights and measures and hydrogen communities agreed to standardize industry practices and to present information in a consistent manner by recognizing the “pascal” as the unit of measurement for expressing hydrogen dispenser service pressure.

- To convert pressure values in measurement units of pounds-force per square inch (psi) to megapascal (MPa)
Multiply by 0.006 894 757
 - e.g., $10\,000\text{ psi} \times 0.006\,894\,757 = 68.947\,57\text{ MPa}$
(This number rounded to the nearest ten is 70 MPa)

- To convert pressure values in measurement units of bar to megapascal
Multiply by 0.1
 - e.g., $700\text{ bar} \times 0.1 = 70\text{ MPa}$

- To convert pressure values in measurement units of “bar” to “psi:”
Multiply by 14.503 774
 - e.g., $700\text{ bar} \times 14.503\,774 = 10\,152.641\text{ psi}$
(This number rounded to the nearest thousand psi is 10 000 psi)

The General Table for conversion of units of pressure shown below was excerpted from NIST Handbook 44 “Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices,” Appendix C and provided to assist in working with and reporting in pressure units of measurement. NIST Handbook 44 is available on the NIST OWM web site at: <https://www.nist.gov/pml/weights-and-measures/publications>.

Units of Pressure
(all underlined figures are exact)

Starting Unit ↓	Multiply by the Conversion Factor Below the Ending Unit:						
	Ending Unit →	Pascal (Pa)	kilopascal (kPa)	megapascal (MPa)	pound-force per square inch (psi) (lbf/in ²)	millimeter of mercury (mm Hg (0 °C))	Inch of water (in H ₂ O (4 °C))
1 Pa =		<u>1</u>	<u>0.001</u>	<u>0.000 001</u>	0.000 145 037 74	0.007 5006 15	0.004 014 742 13
1 kPa =		<u>1000.0</u>	<u>1</u>	<u>0.001</u>	0.145 037 744	7.500 615 05	4.014 742 133
1 MPa =		<u>1 000 000</u>	<u>1 000</u>	<u>1</u>	145.037 744	7 500.615 05	4 014.742 13
1 psi (lbf/in ²) =		6 894.757	6.894 757	0.006 894 757	<u>1</u>	51.714 918 1	27.680 671 4
1 mm Hg (0 °C) =		133.322 4	0.133 322 4	0.000 133 322 4	0.019 336 78	<u>1</u>	0.535 255 057
1 in H ₂ O (4 °C) =		249.082	0.249 082	0.000 249 082	0.036 126 291	1.868 268 198	<u>1</u>

Hydrogen and Other Vehicle Fuels Comparison Table					
Retail Vehicle Fuel	Method of Sale	Energy Content ¹ (compared to 3.785 liters (L) (1 gallon (gal) of gasoline)	Approximate Specific Gravity ²		State of Fuel
	Unit of Measurement		(Air = 1.0)	(Water = 1.0)	
Compressed Hydrogen Gas	Mass	1.0 kg (2.205 pound [lb]) has slightly more than 100 % of the energy	0.0696		Compressed gas at 35 MPa ³ to 70 MPa ³ (5000 psi to 10 000 psi)
	Kilogram (kg)				
Liquefied Petroleum Gas (LPG) or Commercial Propane	Volume or Mass	3.785 L (1 gal) has 73 % of the energy		0.500 to 0.580	Pressurized liquid at 1.6 MPa (250 psi)
	Gallon ⁴ or Pound				
Liquefied Natural Gas (LNG)	Volume Equivalent Units or Mass	3.785 L (1 gal) has 64 % of the energy		0.41 to 0.50	Liquid (− 162 °C @ 101.325 kPa [− 260 °F @ 1 atm ⁶])
	Diesel Gallon Equivalent ⁵ (DGE _{LNG}) or Pound or kg				
Diesel Fuel No. 2	Volume	3.785 L (1 gal) has 113 % of the energy		0.85 (15 °C @ 101.325 kPa [60 °F @ 1 atm ⁶])	Liquid
	Gallon or Liter				
Gasoline	Volume	100 % of the energy		0.72 to 0.78 (15 °C @ 101.325 kPa	Liquid
	Gallon or Liter				

Hydrogen and Other Vehicle Fuels Comparison Table

Retail Vehicle Fuel	Method of Sale	Energy Content ¹ (compared to 3.785 liters (L) (1 gallon gal) of gasoline)	Approximate Specific Gravity ²		State of Fuel
	Unit of Measurement		(Air = 1.0)	(Water = 1.0)	
				[60 °F @ 1 atm ⁶]	
Compressed Natural Gas (CNG)	Volume Equivalent Units or Mass	2.567 kg (5.660 lb) has 100% of the energy	0.6 to 0.8		Compressed gas at 20 MPa to 35 MPa (3000 psi to 5000 psi)
	Gasoline Gallon Equivalent ⁷ (GGE _{CNG}), Diesel Gallon Equivalent ⁷ (DGE _{CNG}), Pound or kg				

¹The energy content values are not exact and are for information purposes since there are multiple variables that affect the energy content of a fuel supply.

²Specific Gravity – The ratio of the density (mass per unit volume) of a liquid to the density of water or the ratio of the density of a gas to the density of air at standard conditions.

³NOTE: Liquid storage is at a pressure of 1 MPa (150 psi).

⁴Retail motor-fuel application

At this time the weights and measures community has only addressed retail sales of gaseous (rather than liquid) hydrogen for vehicle refueling applications.

⁵Diesel Gallon Equivalent (DGE) means 6.059 lb of liquefied natural gas.

⁶atm – atmosphere

⁷Gasoline Gallon Equivalent (GGE) means 5.660 lb of compressed natural gas; Diesel Gallon Equivalent (DGE) means 6.384 lb of compressed natural gas.