Welcome to the U.S. Department of Energy's

Introduction to Hydrogen for Code Officials

U.S. Department of Energy
Hydrogen Program
www.hydrogen.energy.gov

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Introduction to Hydrogen for Code Officials

The information presented here is intended to help code officials understand the basics about hydrogen and fuel cell technologies, how these technologies are applied, and their applicable codes and standards.

Welcome to the U.S. Department of Energy's

Introduction to Hydrogen for Code Officials

This course was developed to help code officials—

- Understand the basic properties of hydrogen and fuel cell technologies
- Be familiar with fuel cell applications
- Know where to find codes and standards applicable to hydrogen technologies

A short quiz is offered at the end of each module and a printable certificate of completion is offered at the end of the course.

Roll over each numbered circle to learn more about how to navigate through this course.

1. Navigation bar indicates where you are in the course.
2. Sub-navigation bar indicates which module you are in.
3. Supplementary content, including links to external Web sites, is offered in the small box.
4. Definitions for glossary terms are provided via pop-up windows.
5. Additional information is offered via the blue clickable buttons.
6. Next and Back buttons allow you to navigate sequentially from page to page. Between them is the location indicator, which shows what slide you are on in relation to the total number of slides in the section.
7. Audio button allows you to turn the course audio on and off.
8. Play-pause button allows you to resume or pause the course audio.

Slide 1 of 2

To navigate through the course, use the navigation tabs at the top of the screen.

Use the "course materials" tab to view the course content, which consists of four modules. You can view the modules in order or select an individual module from the sub-navigation buttons across the top of the screen.

Use the "library" tab to find additional resources including a glossary, supplemental documents, information about codes and standards organizations, and related links.

Use the "exit" tab to exit the course.

Supplementary Content

Composite graphic of the cover of the 2006 International Fire Code handbook, Gas Transmission and Distribution Piping Systems, and NFPA 55 Standards.

> **Caption**: Examples of codes and standards handbooks from the International Code Council, the American Society of Mechanical Engineers, and the National Fire Protection Association.

Slide 2 of 2

Hydrogen Basics

Although we never see it, hydrogen is everywhere in the world around us. It's the simplest element on Earth and the most abundant element in the universe.

A hydrogen atom consists of one proton and one electron. A hydrogen molecule consists of two hydrogen atoms, so hydrogen is often abbreviated as H_2. Hydrogen combines easily with other elements. On Earth, it's rarely found in pure form. Instead, it is found in combinations such as water, methane, and biomass.

Supplementary Content

Animation of a proton with an electron circling it. A second proton appears along with another circling electron. These two items merge and form a single water droplet.

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Hydrogen as an Energy Carrier

Hydrogen isn't a primary energy source. Instead, it's an energy carrier (like electricity), meaning that it can store and deliver energy in an easily usable form.

Hydrogen's volumetric energy content is relatively low. Compared to natural gas, hydrogen—when burned—releases only one-third the energy per cubic foot of gas. Because of its low molecular weight, however, hydrogen has the highest energy content per pound of any fuel.

Image

Photo of a pond with ripples extending outward from the center of the water. At the top of the photo is a reflection of green trees.

> **Caption**: Hydrogen is found in combination with other elements; for example, it is found with oxygen in water.
> *Stock photo*

Supplementary Content

To learn more, visit the What is Hydrogen section of the Alternative Fuels & Advanced Vehicles Data Center (AFDC).

Slide 2 of 30

Hydrogen Characteristics

At standard temperature and pressure, hydrogen is a gas that human senses can't detect.
Hydrogen gas is:

- Odorless
- Tasteless
- Nontoxic
- Colorless
- Stable
- Noncorrosive

Hydrogen is also the lightest gas. Because it's 14 times lighter than air, it rises and disperses rapidly—at speeds of almost 20 meters per second (44 miles per hour)—a property known as buoyancy.

Image

Photo of two researchers in the early part of the 20th century experimenting with a weather balloon. One researcher is measuring the height of the suspended hydrogen balloon, and the other is recording the results on a clipboard.

Caption: Early weather balloons took advantage of the buoyancy of hydrogen gas to gather radiosonde measurements.

Photo courtesy of the National Oceanic and Atmospheric Administration

Supplementary Content

Graphic of Increase Your H2 IQ.

Caption: To learn more, visit the Increase Your H_2IQ section of the Fuel Cell Technologies (FCT) Program Web site.

Slide 3 of 30

General Hydrogen Properties

Hydrogen is a flammable gas, so it must be stored properly away from heat, flames, and sparks.

When hydrogen burns in air, it doesn't produce smoke. Its pale blue flame is difficult to see; in fact, in daylight, the human eye can barely detect it. And although a hydrogen flame burns just as hot as those of other common fuels, it radiates less heat and is less likely to start secondary fires.

Image

Photo of a 100% hydrogen diffusion flame. The flame is dark blue at the base and extends upward while transitioning from a light purple to a dark purple.

Caption: A 100% hydrogen flame

Photo courtesy of Sandia National Laboratories

Supplementary Content

To learn more, visit the Hydrogen Properties section of the Hydrogen Data Book.

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Specific Hydrogen Properties

Learn more about hydrogen's specific properties.

- **Molecular Weight**: The molecular weight of hydrogen is 2.02 g/mol.
- **Boiling Point**: The boiling point of hydrogen is –423°F (–252.9°C).
- **Melting Point**: The melting point of hydrogen is –435°F (–259.2°C).
- **Density**: The density of hydrogen gas is 0.0052 lb/ft3 (0.08375 kg/m^3) at 70°F and 0.083 lb/ft^3 (1.33 kg/m^3) at its boiling point. The density of liquid hydrogen is 4.42 lb/ft^3 (70.80 kg/m^3) at its boiling point.
- **Flammability Range**: The flammability range of hydrogen is 4%–75%.
- **Ignition Energy**: The ignition energy of hydrogen is 1.9E-8 Btu (0.02 mj).
- **Heat Value**: The heat value of hydrogen is 51,500 Btu/lb (120 kJ/g).

Supplementary Content

To learn more, visit the Basic Hydrogen Properties section of the Hydrogen Data Book.

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Fuel Comparison

In general, hydrogen is neither more nor less hazardous than common fuels like natural gas, propane, and gasoline. It is, though, less familiar to most people. The text below compares hydrogen to other fuels we use today.

Hydrogen has no odorant added, is non-toxic, has a vapor density (% relative to air) of 0.07, has an autoignition temperature of 1,085°F (585°C), has an ignition energy (mJ) of 0.02, and has a flammability range (% in gas-to-air volume ratio) of 4 to 75.

Natural gas has odorant added if compressed but not if liquefied, is non-toxic, has a vapor density of 0.55, has an autoignition temperature of 1,003° (540°C), has an ignition energy of 0.29, and has a flammability range of 5 to 15.

Propane has odorant added, is non-toxic, has a vapor density of 1.52, has an autoignition temperature of 914°F (490°C), has an ignition energy of 0.26, and has a flammability range of 2.1 to 10.1.

Gasoline has no odorant added, is toxic, has a vapor density of 4.00, has an autoignition temperature of 450°F (232°C), has an ignition energy of 0.24, and has a flammability range of 1.4 to 7.6.

Supplementary Content

To learn more, visit the Comparative Properties of Hydrogen and Fuels section of the Hydrogen Data Book.

Slide 6 of 30

Hydrogen Production

Hydrogen has long been produced and used in manufacturing industries in the United States. Its potential as a fuel, however, has only recently been explored.

Image

Photo of an engineer wearing a hardhat in a manufacturing plant while he examines the machinery and records data.

> **Caption**: Today, hydrogen is used in manufacturing and for producing electricity.
> *Stock photo*

Supplementary Content

To learn more, visit the Hydrogen Production Basics page on the FCT Web site.

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More than 9 million tons of hydrogen are produced and used in the United States each year. Hydrogen is used in petroleum refining, aerospace applications, pharmaceuticals, petrochemical manufacturing, and the food and semiconductor industries. It's also used in fertilizer production, for glass purification, in welding, and in power generators.

Currently, we use only a small percentage of the hydrogen we produce as a fuel. As hydrogen applications become more common, though, demand for hydrogen will rise. Researchers around the country are exploring numerous ways to supply our future hydrogen needs.

Image

Photo of a worker welding with sparks flying in many directions.

> **Caption**: Hydrogen is commonly used in manufacturing and industrial applications, including welding.
> *Stock photo*

Supplementary Content

To learn more, visit the following links:

- Hydrogen Production fact sheet (PDF 331 KB)
- Hydrogen Production Current Technology page on the FCT Web site

Some of the documents in this course are available as Adobe Acrobat PDFs. Download Adobe Reader.

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Thermochemical Hydrogen Production

Hydrogen is most often produced through thermochemical processes, which use heat to separate hydrogen from its source.

Natural Gas Reforming

About 95% of the hydrogen produced in the United States today is created through steam methane reforming. In this process, high-temperature steam and heat are used to separate hydrogen from a methane source, usually natural gas. An alternative method, called partial oxidation, reacts methane and other hydrocarbons found in natural gas with oxygen to produce synthesis gas, from which hydrogen can be separated.

Gasification

Gasification involves applying heat, pressure, and steam to convert coal or biomass into a gaseous mixture of hydrogen, carbon monoxide, carbon dioxide, and other compounds. Adsorbers then separate the hydrogen from the gas mix.

Renewable Liquid Fuel Reforming

Like natural gas reforming, renewable liquid fuel reforming uses high-temperature steam to create a gaseous mixture of hydrogen and carbon monoxide. In this case, however, the source is a renewable fuel such as bio-oil or ethanol.

Supplementary Content

To learn more, visit the Thermal Processes page on the FCT Web site.

Electrolytic Hydrogen Production

Electrolytic hydrogen production methods use electricity to split water (H_2O) into hydrogen (H_2) and oxygen (O). When the process is reversed, hydrogen and oxygen are combined to produce electricity and water.

Image

Photo of a photovoltaic system at about a 45-degree angle on the left and a white electrolysis unit on the right that is made up of three metal cubes built together with doors on each side.

Caption: This photovoltaic system in Thousand Palms, California, provides electricity for the electrolysis unit on the right.

Photo courtesy of SunLine Transit Agency

Supplementary Content

Animation of a water molecule that is split into hydrogen and oxygen by an electric current. In a fuel cell, this process is reversed; the hydrogen and oxygen combine to produce electricity and water.

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Although electrolyzers require electricity to split water, the electricity can be produced from a range of energy sources. For example, renewable electrolysis uses electricity from renewable energy sources such as wind and sunlight to power the process.

Image

Photo of a researcher standing in front of an electrolyzer, a machine as tall as the researcher that consists of many metal tubes and gauges.

Caption: This electrolyzer at the Department of Energy's National Renewable Energy Laboratory separates hydrogen from water using wind power.

Photo courtesy of the National Renewable Energy Laboratory

Supplementary Content

To learn more, visit the Electrolytic Processes page on the FCT Web site.

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Hydrogen Delivery

Today, almost all hydrogen is produced on the site where it is to be used in a practice called captive use. This is particularly common at industrial sites where hydrogen is used in manufacturing processes.

For some applications, though, hydrogen is delivered from off site. The delivery method depends on the distance to be traveled.

Pipeline

Although pipelines are efficient for delivering hydrogen in large quantities, they're also the least common. Hydrogen pipelines are expensive to construct, and few regions currently have the hydrogen demand to justify their expense. In the United States today, approximately 700 miles of hydrogen pipelines are centered in a few high-use regions near large petroleum refineries and chemical plants.

> **Image**
> Photo of piping showing where the hydrogen feed comes up from the floor to the station at a compressed hydrogen storage facility.
> *Photo courtesy of NextEnergy Center*

High-Pressure Tube Trailer

High-pressure tube trailers are used to transport compressed hydrogen gas at pressures up to 3,000 psi (200 bar), with payloads ranging in size from 25,104 to 75,311 standard cubic feet. Because of the limited amount of hydrogen that can be transported at this pressure, though, the use of tube trailers is economically constricted to about a 200-mile radius from the point of production. Compressed hydrogen gas can also be delivered by rail, ship, or barge.

> **Image**
> Photo of a parked high-pressure tube trailer loaded with red tubes. The trailer is parked in an area enclosed by a chain-link fence.
> *Photo courtesy of Linde LLC*

Liquefied Hydrogen Tanker

Because liquefied hydrogen is denser and has a higher energy content than compressed hydrogen gas, it can be transported more economically over long distances. Liquefied hydrogen—known as cryogenic liquid hydrogen or LH_2—is commonly transported in superinsulated cryogenic tanker trucks. It can also be delivered by rail, ship, or barge.

Image

Photo of a liquid cargo tanker truck with two men dressed in blue standing at the back of the vehicle and a space-shuttle launching site in the background.

Photo courtesy of Air Products

Mobile Refueler

Mobile refuelers are transportable, trailer-mounted units typically used to deliver hydrogen to remote areas or those with lower demand. Mobile refuelers store and sometimes even produce their own hydrogen for distribution at the point of use. But because of the small amount of hydrogen they hold, mobile refuelers are generally the most expensive hydrogen delivery option.

Image

Photo of mobile refueler carrying hydrogen with three hydrogen storage tanks in the background.

Photo courtesy of Linde LLC

Supplementary Content

To learn more, visit the following links:

- Hydrogen Distribution and Delivery Infrastructure fact sheet (PDF 331 KB)
- Hydrogen Delivery Basics page on the FCT Web site

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Hydrogen Storage

Hydrogen has a very high energy content by weight (about three times more than gasoline), but a very low energy content by volume (about four times less than gasoline). As a result, storing hydrogen—particularly within the size and weight constraints of a vehicle—is challenging. All systems for storing and handling hydrogen are designed with safety in mind.

Today, hydrogen is commonly stored and transported in two ways. The two most common forms of hydrogen fuel are compressed hydrogen gas and cryogenic liquid hydrogen.

Image

Photo of a hydrogen fueling station with a zero emissions bus and a sport utility vehicle parked in front of the pumps.

> **Caption**: AC Transit maintains this hydrogen fueling facility in Oakland, California, to power fuel cell buses.
> *Photo courtesy of Filmsight Productions*

Supplementary Content

To learn more, visit the following links:

- Hydrogen Storage fact sheet (PDF 426 KB)
- Hydrogen Storage Basics page on the FCT Web site

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Compressed Hydrogen Gas Storage

Industry commonly compresses and stores hydrogen gas at pressures of about 2,000 psi (140 bar). Hydrogen used to fuel vehicles is typically compressed, stored, and dispensed at pressures of 5,000 psi (350 bar) or 10,000 psi (700 bar). At fueling stations, gaseous hydrogen is compressed in stages, and the pressurized hydrogen is stored in banks of containers that allow the hydrogen to be cascaded in increments of pressurization.

Image

Photo of three white compressed hydrogen storage tanks stacked in a metal holder against a brick wall. A blue sign to the right of the tanks reads, "Solar Panel 1."

Caption: Compressed hydrogen storage tanks at a hydrogen fueling station.

Photo courtesy of Sacramento Municipal Utility District

Supplementary Content

Animation of gaseous hydrogen that is compressed at 2,000 psi, then 5,000 psi, and finally 10,000 psi. With each compression increase, the space housing the hydrogen decreases and the hydrogen becomes denser.

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Onboard Compressed Hydrogen Gas Storage

Vehicles that feature high-pressure onboard storage are equipped with tanks reinforced with carbon fibers. These tanks are composed of several layers. The innermost layer is either aluminum or a polymer with a high molecular weight. The next layer is a carbon-fiber/epoxy-resin shell, which bears the pressure load. Finally, an outer shell protects against impacts and damage. Tanks are equipped with a thermally activated pressure regulator.

Image

Image of a Quantum pressurized hydrogen storage tank composed of two cylinders connected by multicolored wires.

> **Caption**: Illustration of a compressed hydrogen storage tank from Quantum Technologies.
> *Photo courtesy of Quantum Technologies*

Supplementary Content

To learn more, visit the Gaseous and Liquid Hydrogen Storage page on the FCT Web site.

Compressed Hydrogen Gas System Safety

The text below describes the unique characteristics of compressed hydrogen gas, the potential hazards associated with it, and the safety measures designed into compressed hydrogen gas systems.

Hydrogen is colorless, odorless, and tasteless, so it is potentially hazardous because it is undetectable to human senses. Detection sensors can be used as a safety measure.

Hydrogen has a low viscosity and small atoms that can be absorbed into materials, so leaks and embrittlement of certain materials are possible, which can result in structural failure. Leak-detection systems, ventilation, and material selection can be used as safety measures.

Hydrogen also has low volumetric energy density, so it is potentially hazardous when stored at high pressures. Storage container design and pressure-relief devices can be used as safety measures.

Hydrogen is not breathable, so it can accumulate in confined spaces and act as an asphyxiant like any other gas that displaces oxygen. Ventilation and leak-detection systems can be used as safety measures.

Hydrogen has a wide flammability range of 4 percent to 75 percent, so leaks of all sizes are a concern. Ventilation and leak-detection systems can be used as safety measures.

According to hydrogen's properties, the energy required to ignite hydrogen is very low compared to other fuels, so ignition by a small spark is possible under some conditions. Ventilation, grounding, and removal of possible ignition sources can be used as safety measures.

Hydrogen burns with a pale blue flame that is nearly invisible in daylight, produces no smoke, and emits little heat, so there is potential for undetected flames. Flame detectors and leak-detection systems can be used as safety measures.

Supplementary Content

To learn more, refer to the Hydrogen Safety fact sheet (PDF 385 KB).

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Cryogenic Liquid Hydrogen

Hydrogen can also be stored as liquid fuel. In this case, hydrogen gas is cooled until it reaches –423°F (–252.9°C) and turns to liquid (a process called liquefaction). Because liquid hydrogen is denser than hydrogen gas, it contains more energy per unit of volume. In fact, the volume ratio of liquid hydrogen to hydrogen gas is 1:848.

But the energy required to liquefy hydrogen constrains its use. The necessary energy is equal to about 30% of the energy content in the liquid hydrogen fuel. This method, therefore, is normally used only to transport large amounts of hydrogen. Researchers are working on improved liquefaction methods that will bring liquid hydrogen fuel into more widespread use.

Image

Photo of a liquid cargo tanker truck with two men dressed in blue standing at the back of the vehicle and a space-shuttle launching site in the background.

Caption: Liquid cargo tanker truck.

Photo courtesy of Air Products and Chemicals, Inc.

Supplementary Content

Animation of gaseous hydrogen that is cooled to -423°F, at which point it turns into liquid. As the temperature decreases, the space housing the hydrogen decreases and the hydrogen becomes denser.

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Cryogenic Liquid Hydrogen Storage

Liquid hydrogen is stored in special insulated pressure vessels for safety and to minimize evaporation and boiloff. The hydrogen vapor lost from boiloff is vented from the storage containers and released into the atmosphere.

Image

Photo of a white hydrogen storage tank with the name and logo of Air Products on the side in green.

Caption: The Santa Clara Valley Transportation Authority in San Jose, California, stores liquid hydrogen on site to fuel its fleet of hydrogen-powered buses.

Photo courtesy of Santa Clara Valley Transportation Authority

Supplementary Content

To learn more, visit the Gaseous and Liquid Hydrogen Storage page on the FCT Web site.

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Cryogenic Liquid Hydrogen System Safety

This text outlines the unique characteristics of cryogenic liquid hydrogen, the potential hazards associated with it, and the safety measures that are designed into storage and handling systems.

Hydrogen has a low liquefying temperature (-423°F, -252.9°C), so cryogenic burns and lung damage are possible. System design, leak-detection systems, and personal protective equipment can be used as safety measures.

Hydrogen undergoes rapid phase change from liquid to gas, so pressure explosions are possible. System design, pressure-relief devices, and ventilation can be used as safety measures.

Supplementary Content

To learn more, refer to the Hydrogen Safety fact sheet (PDF 385 KB).

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Fuel Cell Basics

Access the fuel cell animation text version to see a fuel cell in action and learn more about how it operates.

Supplementary Content

Fuel cells use hydrogen (or hydrogen-rich fuel) and oxygen to create electricity through an electrochemical process. A single fuel cell consists of an electrolyte and two catalyst-coated electrodes (a porous anode and a cathode).

To learn more, refer to the Hydrogen Fuel Cells fact sheet (PDF 453 KB).

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Fuel Cell Benefits

Fuel cells have a number of advantages over traditional technologies:

- Reductions in electric grid losses and easing of distribution system bottlenecks, leading to enhanced reliability and quality of electricity
- Less fuel consumption per mile than vehicles with internal combustion engines
- Longer run times than battery systems
- Cogeneration of energy and heat in combined heat and power applications for buildings
- Zero to near-zero levels of harmful emissions from vehicles and power plants
- High energy density and long-lasting power in a compact package for portable power applications
- No recharging time
- Quiet operation

Image

Photo of a small fuel cell stack, which consists of thin metals plates sandwiched between two thick metal plates held together by nuts and bolts.

Caption: A small fuel cell stack.

Photo courtesy of the National Renewable Energy Laboratory

Supplementary Content

To learn more, visit the Hydrogen Benefits page in the Alternative Fuels & Advanced Vehicles Data Center.

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These benefits allow fuel cells to be used in place of conventional battery and generator systems.

Images

Image 1: Photo of a gas turbine generator that consists of a brown cylinder with a metal duct at the top and copper tubing entering and exiting the generator in many areas.

Caption: Compared with generators, fuel cells are easier to maintain because they have fewer moving parts and can be monitored remotely. They're also quiet and produce fewer emissions.

Photo courtesy of the National Renewable Energy Laboratory

Image 1: Photo of a collection of batteries similar to car batteries stacked on storage shelves.

Caption: Compared with battery systems, fuel cells offer longer continuous run times. They also don't need to be recharged, and they're more durable in harsh environments.

Photo courtesy of the National Renewable Energy Laboratory

Supplementary Content

To learn more, refer to the Early Markets: Fuel Cells for Backup Power fact sheet (PDF 521 KB).

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Summary

Congratulations! You've completed the Hydrogen and Fuel Cell Basics section of this course. In this section, you learned about hydrogen properties, production, delivery, storage, and fuel cells.

Although using hydrogen as a consumer fuel is a relatively new concept, the United States produces millions of tons of hydrogen each year and has been using it safely in a wide variety of industrial applications for decades. Hydrogen has become part of our nation's long-term energy strategy, not only because it can be used as a transportation fuel, but also because it can power fuel cells that generate electricity and heat in stationary and portable applications of varying sizes.

Now, take the quiz.

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Note: Slides 24 through 30 contain electronic quiz questions that are only available in the Flash version of the course. To have someone contact you so you can answer the quiz questions verbally and receive a certificate of completion, send an e-mail to Hydrogen Education at hydroedu@nrel.gov with "Verbal Quiz Request" in the subject line.

Hydrogen Internal Combustion Engines

With only modest design modifications, an internal combustion engine (ICE) can run on hydrogen. And because hydrogen contains no carbon, these engines don't emit carbon dioxide or other carbon compounds that contribute to climate change. In fact, the emissions from hydrogen-powered internal combustion engines are near zero.

Hydrogen-powered internal combustion engines offer several advantages:

- They perform well under all weather conditions
- They start easily in cold weather, even at subzero temperatures
- They don't need to be warmed up
- They use fuel efficiently

Image

Photo of a Ford 12-passenger shuttle bus with the slogan "Leading the Way in Hydrogen" painted in blue on the side.

> **Caption**: The Ford H2ICE E-450 is a 12-passenger shuttle bus powered by a hydrogen internal combustion engine.
> *Photo courtesy of Ford*

Supplementary Content

To learn more, visit the Migrating to Alternative Fuels: Hydrogen Internal Combustion Engines page on the Ford Web site.

Slide 1 of 16

Hydrogen Fuel Cells

The fuel cell—an energy conversion device that can capture and use hydrogen efficiently—will be an essential element of our energy future.

Hydrogen-powered fuel cells ("hydrogen fuel cells") have enormous potential, not only to replace the internal combustion engine in vehicles, but also to generate electrical power in both stationary and portable applications. And because hydrogen is such a versatile energy carrier, we can actually revolutionize the way we energize our nation by harnessing hydrogen power on a large scale.

Image

Photo of the Verizon Telecommunications Center with six large white facilities powered by fuel cells and a parking lot in the background.

> **Caption**: The Verizon Telecommunications Center in Garden City, New York, is powered by fuel cells in parallel with the electric power grid.
> *Photo courtesy of UTC Power*

Supplementary Content

To learn more, visit the Fuel Cell Current Technology page on the Fuel Cell Technologies (FCT) Program Web site.

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Like batteries, hydrogen fuel cells convert chemical energy into electrical energy and heat. But, unlike batteries, fuel cells don't need recharging; instead, they use hydrogen to produce continuous power.

They're also relatively modular, quiet during operation, and energy efficient (with two to three times the efficiency of traditional combustion technologies). Finally, hydrogen fuel cells are pollution-free, generating electricity with only water and potentially usable heat as by-products.

Image

Photo of three fuel cells: 5000-W, 30-W, and 25-W. Each fuel cell consists of a stack of metal fuel cells sandwiched between two thicker metal ends that are held together by nuts and bolts or large rods.

> **Caption**: Fuel cells are produced in a variety of sizes for different applications. Shown here are 5000-W, 30-W, and 25-W fuel cells.
> *Photo courtesy of the National Renewable Energy Laboratory*

Supplementary Content

To learn more, refer to the Hydrogen Fuel Cells fact sheet (PDF 403 KB).

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Types of Fuel Cells

As the technology has evolved, researchers have developed different fuel cell designs to meet different needs. Fuel cells are classified primarily by the type of electrolyte they use. This determines, for example, the kind of chemical reactions that take place within the cell, the type of catalysts required, and the temperature range in which the cell operates. These design and operating characteristics, in turn, determine which type of fuel cell is best for which application.

The five most common types of hydrogen fuel cells are:

- Polymer electrolyte membrane (PEM)
- Phosphoric acid (PAFC)
- Solid oxide (SOFC)
- Molten carbonate (MCFC)
- Alkaline (AFC)

Image

Photo of a worker assembling a polymer electrolyte membrane fuel cell stack. The individual fuel cells are held together by a temporary wooden frame until the entire fuel cell is complete.

Caption: A worker assembles a polymer electrolyte membrane fuel cell stack.

Photo courtesy of UTC Power

Supplementary Content

To learn more, visit the Types of Fuel Cells page on the FCT Web site.

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The following compares the five types of fuel cells.

Polymer electrolyte membrane fuel cells have an operating temperature between 50°C and 100°C (122°F and 212°F). System output is between <1 kW and 250 kW. Applications include backup power, portable power, small distributed generation, transportation, and specialty vehicles. Advantages include the fact that having a solid electrolyte reduces corrosion and electrolyte management problems, low temperature, and quick start-up.

Alkaline fuel cells have an operating temperature between 90°C and 100°C (194°F and 212°F). System output is between 10 kW and 100 kW. Applications include military and space uses. Advantages include the fact that cathode reaction is faster with an alkaline electrolyte—which leads to higher performance—and the fact that they can use a variety of catalysts.

Phosphoric acid fuel cells have an operating temperature between 150°C and 200°C (or 302°F and 392°F). System output is between 50 kWs and 1 MW (or 250 kWs for a typical fuel cell module). Applications include distributed generation. Advantages include higher overall efficiency with combined heat and power (or CHP), and increased tolerance to impurities (non-hydrogen constituents) in the hydrogen fuel.

Molten carbonate fuel cells have an operating temperature between 600°C and 700°C (or 1112°F and 1292°F). System output is between less than 1 kW and 1 MW (or 250 kW for a typical fuel cell module). Applications include electric utility and large distributed generation. Advantages include high efficiency, fuel flexibility, the fact that they can use a variety of catalysts, and the fact that they are suitable for combined heat and power.

Solid oxide fuel cells have an operating temperature between 600°C and 1000°C (or 1202°F and 1832°F). System output is between less than 1 kW and 3 MW. Applications include auxiliary power, electric utility, and large distributed generation. Advantages include high efficiency, fuel flexibility, the fact that they can use a variety of catalysts, the fact that having a solid electrolyte reduces electrolyte management problems, the fact that they are suitable for combined heat and power, and hybrid or gas turbine cycle.

Supplementary Content

To learn more, visit the Types of Fuel Cells page on the FCT Web site.

Fuel Cell Applications

Hydrogen fuel cells can be scaled for use in a variety of applications—large and small, stationary and portable:

- Small, portable fuel cells (20–100 W) can power cell phones, laptops, MP3 players, and other electronic devices
- Medium-sized portable fuel cells (8–125 kW) can propel cars, trucks, buses, and specialty vehicles like forklifts
- Small stationary fuel cells (1–5 kW) can power homes and supply backup power for telecommunications and emergency response radio towers
- Large stationary fuel cells (200 kW–10 MW or more) can generate base-load electricity and heat.
- Very large stationary fuel cells (1–200 MW or more) can distribute electricity across the existing grid

Image

Photo of five fuel cells at a snow-covered mail processing center. The background is filled with more fuel cells and a mountain landscape on the horizon.

Caption: At the U.S. Postal Service mail-processing facility in Anchorage, Alaska, five 200-kW fuel cells generate all on-site electricity and meet most of the facility's heating needs as well.
Photo courtesy of U.S. Postal Service

Supplementary Content

To learn more, visit the Fuel Cell Current Technology page on the FCT Web site.

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Portable Applications

Portable fuel cells can power almost any mobile application that typically uses batteries. Small ("micro") fuel cells for portable power are among the first applications available to the public. In demonstrations, micro fuel cells have powered cell phones up to 30 days and laptops up to 20 hours without recharging, using a single fuel cartridge.

And larger fuel cells (15–100 W) can be incorporated into portable generators, supplying power for, as an example, mobile military operations.

Images

Image 1: Photo of a micro fuel cell held by a person's hand with a cell phone in the other hand. The micro fuel cell is about one-fifth of the surface-area size of the cell phone and just a fraction of the width.

Image 2: Photo of a laptop powered by a micro fuel cell.

Caption: Micro fuel cells provide power for this cell phone and laptop.

Photos courtesy of MTI (cell phone) and Toshiba (laptop)

Supplementary Content

To learn more, refer to the Hydrogen Fuel Cells fact sheet (PDF 453 KB).

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Stationary Applications

Stationary fuel cell systems are already generating power for industrial and commercial applications around the globe. They're used, for example, to supply base-load electric power, backup power, and power for remote or off-the-grid locations, as well as in combined heat and power systems.

Base-Load Electric Power

Fuel cells can supply high-quality base-load electricity to homes as well as industrial and commercial facilities. To date, approximately 600 systems of 10 kW or more have been built and operated around the globe, and thousands of smaller systems have been installed and demonstrated as well. These systems operate silently and can run independently of or in parallel with the power grid. Today's systems typically run on natural gas, but the long-term goal is to use hydrogen directly, avoiding the use of natural gas or liquefied petroleum gas entirely.

In the United States, fuel cells are also used to generate base-load power at landfills and wastewater treatment plants, where they have proved to be a valid technology for reducing emissions and producing power from waste methane gas.

Backup Power

When the electric power grid fails, fuel cells can step in, supplying backup power that keeps critical systems running. For example, emergency preparedness and response operations depend on the reliability and quality of first responders' energy supplies. If the primary grid power goes down, so can 911 and emergency communication centers, first responder stations, hospitals, control centers, and traffic signals, along with vital infrastructure components like water pumping and filtration systems. Fuel cells stand ready to furnish backup power for all of these.

The telecommunications industry also uses fuel cells for backup power. These fuel cells generate direct current (DC) power—without noise or emissions—for switch nodes, cell phone towers, and other electronic systems. They're also durable and function well at sites that are hard to access, subject to bad weather, or both.

Remote or Off-Grid Power

Because they're durable and require little maintenance, fuel cells are ideal for producing power in remote locations. Today, fuel cells are being demonstrated in applications like railroad crossing lights and fire-watch towers. In the future, they may be used to power remote homes and cabins.

Combined Heat and Power

Fuel cells can generate power not only to meet base loads, but also to run combined heat and power systems. These systems take advantage of the waste heat produced by the fuel cells to heat water and warm living or working spaces.

Supplementary Content

To learn more, visit the following links:

- Early Markets: Fuel Cells for Backup Power fact sheet (PDF 521 KB)
- Stationary Fuel Cell Systems page on the FCT Web site

Transportation Applications

As we move further into the 21st century, fuel cells will find perhaps their most important use in transportation. Fuel cells can be used to power a variety of vehicles, from the family car, long-haul truck, and transit bus to trains, planes, and boats.

More than 50 fuel cell buses have already hit the road in demonstration projects around the world. Fuel cells are efficient, so even if the hydrogen they run on is produced from fossil fuels, fuel cell buses can reduce carbon dioxide emissions.

Modern heavy-duty trucks are equipped with many electrical appliances, including computers, televisions, stereos, refrigerators, microwaves, heaters, and air conditioners. To power these devices when trucks are parked, drivers often idle their engines—a practice that's unnecessary when using onboard fuel cells as auxiliary power units.

Images

Image 1: Photo of a white sport utility vehicle parked in front of six wind turbines in the near background and a mountain scene in the distance.
Image 2: Photo of a semi truck parked in a garage without cargo.
Image 3: Photo of a commercial airplane in flight with a clear blue sky and the sun in the background.
Image 4: Photo of a red train traveling on a railroad track.
Image 5: Photo of a zero emission hydrogen fuel cell bus.

Photos courtesy of Chevrolet (SUV), stock photo (airplane), Department of Transportation (train), National Renewable Energy Laboratory (truck), and AC Transit (bus)

Supplementary Content

To learn more, visit the following links:

- "What is a Fuel Cell Vehicle?" page in the Alternative Fuels & Advanced Vehicles Data Center (AFDC)
- Fuel Cells for Transportation page on the FCT Web site
- Fuel Cell Vehicle Availability page in the AFDC
- Hydrogen Fuel Cell Bus Evaluation page on the FCT Web site
- National Hydrogen Learning Demonstration page on the FCT Web site
- Hydrogen Technology Validation fact sheet (PDF 444 KB)

Slide 9 of 16

Specialized equipment and vehicles like forklifts and industrial movers can operate on fuel cells, transporting people and goods in indoor and outdoor environments. Fuel cells in these applications are less than 100 kW and can be expected to operate 2,000 to 5,000 hours per year with zero or low emissions.

And personal transport vehicles like scooters, wheelchairs, motorcycles, and bicycles can also run on fuel cells. Manufacturers are interested in fuel cells for this type of equipment because they offer low emissions and high reliability.

Images

Image 1: Photo of a four-wheel, mechanical scooter.

Image 2: Photo of a fuel cell-powered golf cart on a golf course.

Image 3: Photo of a green bicycle.

Image 4: Photo of a hydrogen fuel cell forklift in airport service with a commercial airplane in the background.

Photos courtesy of Chromogenics (golf cart), Shanghai Pearl Hydrogen Power Source Technology Company (bicycle), Suzuki (scooter), and Hydrogenics (forklift)

Supplementary Content

To learn more, refer to the Early Markets: Fuel Cells for Material Handling Equipment fact sheet (PDF 691 KB).

Slide 10 of 16

Summary

Congratulations! You've completed the Hydrogen and Fuel Cell Applications section of this course. In this section, you learned about the characteristics and advantages of the different types of fuel cells. You also began to discover the many ways hydrogen fuel cells can contribute to a reliable and secure energy future, in applications large and small, modes portable and stationary, and usages that run the gamut from power plants to bicycles.

Now, take the quiz.

Slide 11 of 16

Note: Slides 12 through 16 contain electronic quiz questions that are only available in the Flash version of the course. To have someone contact you so you can answer the quiz questions verbally and receive a certificate of completion, send an e-mail to Hydrogen Education at hydroedu@nrel.gov with "Verbal Quiz Request" in the subject line.

Hydrogen Fueling Stations

Construction and operation approvals typically require permits from several different agencies responsible for implementing codes and standards for fire safety, general building safety, waste water discharge, air quality, public health, and other areas. These permitting processes involve a number of steps that are generally included in the graphic below.

Image

Graphic showing three general steps in the order of the permitting process: project considerations, construction approval, and operation approval.

In this section, we will focus on the construction and operation approvals.

Supplementary Content

To learn more, visit the following links:

- Hydrogen Fueling Stations page on the Permitting Hydrogen Facilities Web site
- Hydrogen Fueling Station Case Studies page on the Permitting Hydrogen Facilities Web site

Slide 1 of 27

While a hydrogen fueling station is still on the drawing board, developers conduct a safety analysis to analyze, quantify, and mitigate potential risks.

Safety planning tools include:

- Failure modes and effects analysis (FMEA)
- What-if analysis
- Hazard and operability analysis (HAZOP)
- Checklist analysis
- Fault tree analysis
- Event tree analysis
- Probabilistic risk assessment (PRA)

Images

Image 1: Photo of a hydrogen fueling station with two pumps. A hydrogen zero emission bus is fueling at the pump on the left.

Caption: A hydrogen fueling station in Oakland, California.

Graphic courtesy of California Fuel Cell Partnership

Image 2: Graphic showing three general steps in the order of the permitting process: project considerations, construction approval, and operation approval. Construction approval is accentuated with a red square around it.

Supplementary Content

To view references for related hydrogen codes and standards and learn more about hydrogen safety, visit the links below:

- Operation approvals for fire safety and emergency planning (see page 1 of appendix for references)
- Safety planning guidance for hydrogen projects (PDF 157 KB)

Slide 2 of 27

Construction Approval

A number of national codes and standards govern requirements for the general design and layout of hydrogen fueling facilities.

For example, model code provisions cover:

- Fueling station design
- Equipment design (including listing and labeling)
- Barrier wall design, orientation, and construction
- Weather protection

Image

Graphic of three hydrogen fueling stations. The first includes a car wash and two fuel dispenser islands with canopies. The second includes a food market and a fuel dispenser island with a canopy. The third includes car wash, a fuel dispenser island with a canopy, and a food market.

Caption: Designs for three hydrogen fueling station layouts.

Supplementary Content

To view references for related hydrogen codes and standards, visit the following links:

- Fueling station design (see page 2 of appendix for references)
- Equipment design (see page 2 of appendix for references)
- Barrier wall design (see page 2 of appendix for references)
- Weather protection (see page 2 of appendix for references)

Slide 3 of 27

Setbacks and Footprints

Just like any station that dispenses transportation fuel, hydrogen fueling stations have setback and footprint requirements that influence station layout and design. These provisions differ for hydrogen gas and liquid hydrogen systems.

Image

Composite graphic of the cover of the 2006 International Fire Code handbook and the National Fire Protection Association.

Caption: Examples of codes and standards handbooks from the International Code Council and the National Fire Protection Association.

Supplementary Content

To view references for related codes and standards, visit the following links:

- Setbacks and footprints for outdoor gaseous hydrogen systems (see page 3 of appendix for references)
- Setbacks and footprints for liquid hydrogen systems (see page 3 of appendix for references)

Slide 4 of 27

Equipment and Specifications

National codes and standards specify requirements for equipment and installation at hydrogen fueling stations to ensure that hydrogen is produced, stored, and dispensed safely.

Equipment used with liquid and gaseous hydrogen fuels must be selected and installed according to these requirements. The station must protect people from injury by putting measures in place that detect hydrogen leaks early and rapidly detect and suppress hydrogen fires.

Image

Photo of a Shell gas station that dispenses hydrogen fuel at one pump.

Caption: This fueling station in Washington, DC, offers hydrogen fuel in addition to gasoline.
Photo courtesy of National Renewable Energy Laboratory

Supplementary Content

To view references for related hydrogen codes and standards and learn more about hydrogen safety, visit the following links:

- Operation approval for fire safety and emergency planning (see page 4 of appendix for references)
- Safety planning guidance for hydrogen projects (PDF 157 KB)

Like other fuels, hydrogen has specific properties that determine the appropriate equipment and specs for its use. Hydrogen fueling stations are equipped with pressure relief devices including rupture disks, pressure relief valves, and safety vents. Vent stacks are standard for liquid hydrogen storage systems; excess gaseous hydrogen (created from boiloff of liquid to gas) is routinely vented, a practice commonly known as "burping."

Monitoring, controlled access, and emergency stops and shutoffs can also add a level of safety. Keep in mind, too, that using incompatible materials or installing equipment improperly can lead to fuel contamination, which can degrade the performance of the fuel cells that power hydrogen-fueled vehicles. Incompatible materials can also cause blistering or embrittlement, which can result in leaks.

Images

Image 1: Photo of twelve red tanks filled with compressed hydrogen and bundled in a vertical position. To the left of the tanks is a tall metal tube that makes up the vent stack.

Image 2: Photo of a metal pressure-regulator panel.

Caption: Vent stack, compressed hydrogen tanks, and pressure-regulator panel at the NextEnergy Center in Detroit, Michigan.

Photos courtesy of NextEnergy

Supplementary Content

To view references for related codes and standards, visit the following links:

- Fueling station design (see page 5 of appendix for references)
- Equipment design (see page 5 of appendix for references)
- Barrier wall design (see page 5 of appendix for references)
- Weather protection (see page 5 of appendix for references)
- Compression systems and equipment (see page 5 of appendix for references)
- Vaporizers (see page 6 of appendix for references)
- Canopy tops (see page 6 of appendix for references)
- Fire safety for construction (see page 6 of appendix for references)
- Fire safety for equipment (see page 6 of appendix for references)
- Fire safety signage (see page 7 of appendix for references)
- Gaseous hydrogen safety (see page 7 of appendix for references)
- Liquid hydrogen safety (see page 7 of appendix for references)

Hydrogen Delivery and Storage

Like gas stations, hydrogen fueling stations can have their hydrogen delivered. Typically, trucks deliver the fuel as a compressed gas or a liquid.

At the station, hydrogen gas is stored in banks of aboveground containers that must meet strict functional and operational requirements. Liquid hydrogen is stored in special double-walled, vacuum-insulated storage vessels that can be sited above or below the ground.

Hydrogen stations typically combine bulk storage and dispensing. They may provide gaseous hydrogen, liquid hydrogen, or both to cars, buses, or other types of vehicles.

Images

Image 1: Photo of three white compressed hydrogen storage tanks stacked in a metal holder against a brick wall. A blue sign to the right of the tanks reads, "Solar Panel 1."

Caption: Compressed hydrogen storage tanks at a solar-powered hydrogen fueling station.

Photo courtesy of Sacramento Municipal Utility District

Image 2: Photo of a bundle of white storage tanks on the back of a flatbed semitruck.

Caption: Compressed hydrogen fuel tanks can be delivered by truck.

Photo courtesy of National Renewable Energy Laboratory

Supplementary Content

To view references for related hydrogen codes and standards, visit the following links:

Liquid Hydrogen Storage

- Equipment location (see page 9 of appendix for references)
- Containers (see page 9 of appendix for references)
- General safety requirements (see page 9 of appendix for references)

Compressed Hydrogen Gas Storage

- Equipment location (see page 10 of appendix for references)
- Containers (see page 10 of appendix for references)
- General safety requirements (see page 10 of appendix for references)

Slide 7 of 27

On-Site Production

Today, hydrogen fueling stations can produce hydrogen on site through either natural gas reforming or water electrolysis. On-site production eliminates the need for transporting the fuel to the station.

Because of the unique properties of hydrogen, special safety considerations are necessary. Several possible codes and standards can come into play for on-site hydrogen production.

Image

Photo of a hydrogen fueling station with two pumps.

Caption: This hydrogen fueling station in Oakland, California, dispenses gaseous hydrogen generated by steam methane reforming.

Photo courtesy of AC Transit

Supplementary Content

To learn more, visit the following link:

- Hydrogen Production Basics page on the Fuel Cell Technologies (FCT) Program Web site
- On-Site Hydrogen Production Equipment and Specifications (see page 11 of appendix for references)

Slide 8 of 27

Dispensing Hydrogen Fuel

Fueling a hydrogen vehicle is similar to filling up a compressed natural gas vehicle, which many drivers now do every day all around the country. Like compressed natural gas fueling systems, hydrogen vehicles are fueled in a closed-loop system. The dispensing nozzle "locks on" to the vehicle receptacle before any hydrogen will flow.

Hydrogen dispensing nozzles are unique to particular operating pressures, so nozzles specific to one pressure can't physically connect to vehicles with onboard storage at a different pressure.

And like natural gas systems, hydrogen dispensers are equipped with safety devices including breakaway hoses, leak detectors, and electrical grounding mechanisms. These types of controls help when people make mistakes, like trying to drive away while the nozzle is still connected to the vehicle.

Images

Image 1: Photo of a hydrogen pump at a compressed hydrogen storage facility.

Caption: Hydrogen dispenser.
Photo courtesy of NextEnergy

Image 2: Photo of a hydrogen pump at a compressed hydrogen storage facility.

Caption: Hydrogen dispenser.
Photo courtesy of Sacramento Municipal Utility District

Supplementary Content

To view references for related hydrogen codes and standards and learn more about hydrogen dispensing, visit the following links:

- Hoses and connectors for hydrogen dispensing (see page 12 of appendix for references)
- Liquid hydrogen dispensers (see page 12 of appendix for references)
- Gaseous hydrogen dispensers (see page 12 of appendix for references)
- Vehicle connectors for hydrogen dispensing (see page 12 of appendix for references)
- Electrical equipment for hydrogen dispensing (see page 12 of appendix for references)
- Fuel lines for hydrogen dispensing (see page 13 of appendix for references)

Slide 9 of 27

Balance-of-Plant Components

"Balance-of-plant" is the name given to the components of a hydrogen fueling station that aren't part of the major functional systems.

National codes and standards address balance-of-plant components like:

- Piping and tubing
- Valves and fittings
- Pressure relief
- Venting and other equipment

Image

Image 1: Photo of four red compressed hydrogen bottles at a compressed hydrogen storage facility.

Image 2: Photo of piping showing where the hydrogen feed comes up from the floor to the station at a compressed hydrogen storage facility.

Image 3: Photo of piping showing where the hydrogen feed runs from an aboveground conduit into belowground piping at a compressed hydrogen storage facility.

Caption: Hydrogen valves and piping.

Photos courtesy of NextEnergy

Supplementary Content

To view references for related hydrogen codes and standards, visit the following links:

- Piping and tubing (see page 14 of appendix for references)
- Valves and fittings (see page 14 of appendix for references)
- Pressure relief (see page 15 of appendix for references)
- Venting and other equipment (see page 15 of appendix for references)

Operation Approval

A "permit of occupancy" issued from the local building department marks the conclusion of the construction approval process.

Operation approval, however, is an ongoing process that addresses safe operating conditions, maintenance, and record-keeping. Fire safety and inspection officials usually grant these approvals.

Image

Graphic showing three general steps in the order of the permitting process: project considerations, construction approval, and operation approval. Operation approval is accentuated with a red square around it.

Supplementary Content

To view references for related hydrogen codes and standards, visit the following links:

- Operation approvals for vehicle access (see page 17 of appendix for references)
- Operation approvals for fuel delivery access and unloading (see page 17 of appendix for references)
- Operation approvals for ignition control (see page 17 of appendix for references)
- Operation approvals for fire safety and emergency planning (see page 17 of appendix for references)
- Operation approvals for personnel issues and training (see page 18 of appendix for references)
- Operation approvals for dispensing (see page 18 of appendix for references)
- Operations approvals for signage (see page 18 of appendix for references)

Safety

The bottom line at a hydrogen fueling station, just like at any transportation fuel facility, is the safety of employees, customers, and passersby. Codes and standards are designed to reduce the probability of an unintentional hydrogen release, the consequences of any such incident, and the severity of a hydrogen-related fire.

Toward this end, hydrogen fueling stations incorporate fire suppression systems, alarms, sensors, gas detectors, and other safety equipment, all of which must be tested regularly. In addition, safety signs must be properly posted at all stations.

Image

Graphic of two red signs that have a white-outlined symbol of fire at the top and a number “2” at the bottom. The sign on the left reads, “1966” in the center, and the sign on the right reads, “Flammable Gas” in capital letters in the center and has an additional orange rectangle underneath that reads, “1966.”

Caption: Hydrogen signage.

Supplementary Content

To view references for related hydrogen codes and standards, visit the following link:

- Fire safety for equipment (see page 20 of appendix for references)

Slide 12 of 27

Safe Operating Practices

To minimize the known hazards associated with handling hydrogen, safe operating practices have been established. An operations safety plan, which is part of standard safe operating practices, explains what to do if there's an incident.

Image

Photo of the back of a fuel cell bus with a line of fuel filling the tank. The back end is open, exposing the hydrogen fuel cell.

Caption: Fuel cell bus powered by compressed gaseous hydrogen.
Photo courtesy of Santa Clara Valley Transportation Authority

Supplementary Content

To view references for related hydrogen codes and standards and learn more about safety planning, visit the following links:

- Operation approvals for fire safety and emergency planning (see page 21 of appendix for references)
- Safety planning guidance for hydrogen projects (PDF 157 KB)

Slide 13 of 27

Annual Inspections

These inspections, which are required to ensure the continued safety of the hydrogen fueling facility, are usually included in the operation approvals.

Annual inspections may focus on:

- Specific operating equipment, subsystems, and systems inspections
- Fire protection and safety systems inspections
- Record-keeping inspections
- Operator training and performance

Image

Graphic of two signs for hydrogen, one for gaseous hydrogen and one for liquid hydrogen. Each is shaped like a two-dimensional diamond with four colored squares and numbers inside. The sign on the left, for gaseous hydrogen, has a four in the red square, a zero in the yellow square, nothing in the white square, and a zero in the blue square. The sign on the right, for liquid hydrogen, has a four in the red square, a zero in the yellow square, nothing in the white square, and a three in the blue square.

Caption: NFPA hazard placards (like the ones above) rate the health, flammability, and instability characteristics of a material. These ratings are intended to provide information for emergency responders.

Supplementary Content

To view references for related hydrogen codes and standards, visit the following link:

- Hydrogen fueling station annual inspections (see page 22 of appendix for references)

Slide 14 of 27

Hydrogen Fueling Station Layout

The information below provides an example of a typical hydrogen fueling station layout along with some of the setback requirements, codes, and standards that govern the design, construction, and operation of such a station.

The animation is a map-like drawing of an example hydrogen fueling station. A food market and two parking lots are located in the upper-right corner of the lot. A car wash, a parking lot, and a trash enclosure are located on the left side of the lot. A fuel-dispensing island with a canopy is located in the bottom-right corner of the lot. A secondary street is located along the right side of the lot, and a primary street is located along the bottom of the lot.

Setback distances are indicated by colored regions and are summarized in a setback table titled "2010 National Fire Protection Association (NFPA) Setbacks":

- NFPA 55, Table 11.3.2.2 – Minimum distance from liquefied hydrogen systems to exposures:
  - Walls adjacent to system constructed of combustible material (1,500 liter liquid hydrogen storage tank) – 50-foot setback
- NFPA 55, Table 11.3.2.2.1(a) – Minimum distance from outdoor gaseous hydrogen systems to exposures:
  - Air intake openings – 30-foot setback
  - Wall openings – 30-foot setback
  - Lot line – 30-foot setback
  - Parked vehicles – 15-foot setback
  - Building (with combustible walls) – 10-foot setback
- NFPA 52, Table 9.3.1.4 – Separation distances for outdoor gaseous hydrogen dispensing systems:
  - Building, line of adjoining property that can be built on, any source of ignition (only pertains to dispersing equipment) – 10-foot setback
  - Nearest public street or public sidewalk (only pertains to dispersing equipment) – 10-foot setback
  - Storage containers (only pertains to dispersing equipment) – 3-foot setback

Setbacks are applicable to a 7,000 psi hydrogen system.

A "construction approvals" button links to the references for related hydrogen codes and standards (see page 23 of appendix for references).

An “operation approvals” button links to references for related hydrogen codes and standards (see page 27 of appendix for references).

Slide 15 of 27

Specialty Vehicles—Fuel Cell Forklifts

Many organizations—grocers, tire and hardware companies, and others—have begun to realize the value of using fuel cells to support their operations. Federal agencies across the country are incorporating advanced energy technologies, including fuel cells, into their facilities.

For specialty vehicles such as forklifts, fuel cells can be a cost-competitive alternative to traditional lead-acid batteries because:

- Batteries have a limited range, take substantial time to recharge and cool before reuse, and are prone to voltage drops as power discharges.
- Unlike battery powered vehicles, fuel cell vehicles can be rapidly refueled, eliminating the time and cost associated with swapping batteries.
- The voltage delivered by the fuel cell is constant as long as hydrogen fuel is supplied. Using fuel-cell-powered forklifts can boost productivity by eliminating trips to the battery changing station. And with no need for battery chargers, storage, or changing areas, more warehouse space is available for other uses.

Fueling infrastructure—including indoor fueling facilities—for these growing markets will be needed.

Image

Photo of forklift in front of an airplane.

Caption: This fuel-cell-powered forklift operates at an airport.
Photo courtesy of Hydrogenics

Supplementary Content

To learn more, visit the following links:

- Early Markets: Fuel Cells for Material Handling Equipment fact sheet (PDF 402 KB)
- Early Market Applications page on the FCT Web site

On-Site Hydrogen Generation for Indoor Fueling Facilities

Some facilities generate hydrogen on site using a steam methane (natural gas or biogas) reforming (SMR) process.

The hydrogen generation and storage equipment consists of the following components:

1. Hydrogen generation equipment—Water and gas (natural gas or biogas) purification system, steam reformer, and hydrogen purification system

2. Storage equipment—Hydraulic compressor and cascade storage system

Image

Photo of a large rectangular structure with vents near its base and pipes near its roof.

Caption: Natural gas reformer.
Photo courtesy of National Renewable Energy Laboratory

Supplementary Content

To learn more, visit the following links:

- Natural Gas Reforming page on the FCT Web site
- Renewable Liquid Fuels Reforming page on the FCT Web site
- Hydrogen Production page in the Alternative Fuels and Advanced Vehicles Data Center (AFDC)

Slide 17 of 27

Delivered Hydrogen for Indoor Fueling Facilities

Instead of generating hydrogen on site, some fueling facilities have hydrogen delivered by a vendor. Such sites often have a combined liquid/gaseous hydrogen storage system outside the facility. Liquid hydrogen is vaporized to make gaseous hydrogen for use in specialty vehicles. The gaseous hydrogen is then piped into the facility for dispensing.

Image

Graphic of an indoor hydrogen fueling facility with a hydrogen dispenser on the inside of an exterior building wall. Outside the facility, a fence surrounds a gaseous hydrogen storage system consisting of three horizontal cylinders connected at the ends and a cylinder-shaped liquid hydrogen storage system.

Supplementary Content

To learn more, visit the following links:

- Hydrogen Infrastructure Development page in the AFDC
- Hydrogen Storage fact sheet (PDF 465 KB)
- Code Compliance Analysis for Indoor Hydrogen Fueling presentation (PDF 135 KB)

Hydrogen Dispensing at Indoor Fueling Facilities

Hydrogen is piped through the exterior wall to the dispenser, which is usually located inside the facility on the wall closest to the hydrogen storage containers.

The hydrogen fueling dispenser can be electronic or mechanical.

Image

Three photos at an indoor hydrogen fueling facility: the first photo shows pipes leading to the base of a building wall and up its side; the second photo shows a dispenser system consisting of two white boxes attached to a wall near a danger sign; and the third photo shows a fueling nozzle.

Caption: Hydrogen piping, dispenser system, and fueling nozzle.
Photos courtesy of National Renewable Energy Laboratory

Supplementary Content

A mechanical dispenser is not subject to the electrical classification and equipment requirements for dispensing operations in NFPA 52 and NFPA 70 (National Fire Protection Association).

To view references for related codes and standards, visit the following links:

- Liquid Hydrogen Dispensers (see page 29 of appendix for references)
- Gaseous Hydrogen Dispensers (see page 29 of appendix for references)

Slide 19 of 27

Indoor Fueling Facility Layout

This animation provides an example of an indoor fueling facility along with some of the setback requirements, codes, and standards that govern the design, construction, and operation of such a facility. This facility uses an electronic dispenser and a combined liquid/gaseous hydrogen storage system.

Image

The animation is a map-like drawing of an indoor hydrogen fueling facility with outdoor hydrogen storage. A fuel dispenser and controller for the dispenser are located inside a warehouse near two vehicle protection barriers. Three gaseous hydrogen storage tanks and one liquefied hydrogen storage tank are located outside the warehouse. Vegetation surrounds one corner of the drawing.

Setback distances are indicated by colored regions and are summarized in a setback table titled "2010 National Fire Protection Association (NFPA) Setbacks":

- NFPA 55, Table 11.3.2.2 – Minimum distance from liquefied hydrogen systems to exposures:
    - Walls adjacent to system constructed of combustible material (1,500 liter liquid hydrogen storage tank) – 50-foot setback
- NFPA 55, Table 10.3.2.2.1(a) – Minimum distance from outdoor gaseous hydrogen systems to exposures:
    - Air intake openings – 30-foot setback
    - Wall openings – 30-foot setback
    - Lot line – 30-foot setback
    - Parked vehicles – 15-foot setback
    - Building (with combustible walls) – 10-foot setback

Setbacks are applicable to a 7,000 psi hydrogen system.

A “construction approvals” button links to the references for related hydrogen codes and standards (see page 30 of appendix for references).

An “operation approvals” button links to references for related hydrogen codes and standards (see page 31 of appendix for references).

Summary

Congratulations! You've completed the Hydrogen Fueling Stations section of this course. In this section, you learned about hydrogen fueling stations, which resemble those that dispense gasoline. And many of the hydrogen fueling stations of the future will expand on the existing fueling stations of today. In some cases, developers will simply add hydrogen pumps to the gasoline or natural gas pumps that are already in place. Other hydrogen fueling stations will be designed and constructed to offer only hydrogen.

And like other fueling stations, hydrogen stations must be designed, constructed, and operated to work with the properties of the fuel they offer. Some special equipment needs and unique site and safety considerations rest on hydrogen's unique properties. Developers and code officials alike are becoming more familiar with the basic properties, uses, and safety considerations of hydrogen, along with the methods used for acquiring, storing, and dispensing the fuel. This familiarity will build, in turn, a comprehensive understanding of the construction and safety considerations for hydrogen fueling stations, as well as the related codes and standards.

Now, take the quiz.

Slide 21 of 27

Note: Slides 22 through 27 contain electronic quiz questions that are only available in the Flash version of the course. To have someone contact you so you can answer the quiz questions verbally and receive a certificate of completion, send an e-mail to Hydrogen Education at hydroedu@nrel.gov with "Verbal Quiz Request" in the subject line.

Fuel Cell Facilities

Fuel cell systems are entering the commercial market in many places across the country. These systems can be broadly divided into two groups: power-only and cogeneration.

Power-only examples include fuel cells for backup power for critical uses such as telecommunications and emergency response radio towers.

Cogeneration examples that also provide water or space heating include continuous base-load power to supplement grid power for power-quality-sensitive loads such as high-tech manufacturing and peak shaving by high-volume electricity users like data centers.

Images

Image 1: Photo of a fuel cell surrounded by thin metal poles in a snowy location.

Caption: This fuel cell system supplies backup power for a remote radio tower in Berry Hill, New York.

Photo courtesy of Battelle

Image 2: Photo of five fuel cells at a snow-covered mail processing center. The background is filled with more fuel cells and a mountain landscape on the horizon.

Caption: This 1000-kW fuel cell system provides electricity and heat for the mail processing center in Anchorage, Alaska.

Photo courtesy of U.S. Postal Service

Supplementary Content

To learn more, visit the Fuel Cell Systems page on the Fuel Cell Technologies (FCT) Program Web site.

Slide 1 of 21

Backup Power Systems

Backup or uninterruptible power systems fueled by hydrogen are generally relatively small (less than 15 kW).

Typically serving as backup during grid failures, these systems usually use polymer electrolyte membrane (PEM) fuel cells that operate at relatively low temperatures. The hydrogen is most often stored in pressurized cylinders, with fuel delivered by swapping full cylinders for empty ones.

Image

Photo of a fuel cell with four short red posts in front of it and an electrical shed in the background.

> **Caption**: Verizon Communications operates this fuel cell installation at the Albany International Airport in Albany, New York.
> *Photo courtesy of Plug Power*

Supplementary Content

To learn more, visit the following links:

- Types of Fuel Cells page on the FCT Web site
- Telecommunications Backup Power page on the Permitting Hydrogen Facilities Web site

Slide 2 of 21

Components of Typical Backup Power Systems

Graphic of a backup power system that uses a polymer electrolyte membrane (PEM) fuel cell stack to provide power for the load. The process requires two primary elements (air and stored hydrogen) and results in two products (power and a mixture of air and water). To generate power, the PEM fuel cell stack involves three primary processes: humidifying air, regulating hydrogen, and cooling the fuel cell.

The process of humidifying the air starts when air passes through the air filtration and the blower to the membrane humidifier. The humidified air moves from the membrane humidifier to the PEM fuel cell stack. The process of regulating hydrogen starts when stored hydrogen passes through the pressure regulator, into the membrane humidifier, and then into the PEM fuel cell stack. The process of cooling the fuel cell starts by passing coolant through the PEM fuel cell stack. The warmed coolant exits the PEM fuel cell stack through the coolant pump and enters the radiator. Fresh coolant exits the radiator and travels back to the PEM fuel cell stack to repeat the cooling process.

The PEM fuel cell stack releases air and water as a byproduct mixture on two sides. On the humidified air side, the stack releases an air and water mixture that passes through two membrane humidifiers before entering the dilution mixer. These byproducts then exit the power system as air and water. On the regulated hydrogen side, the stack releases an air and water mixture that splits into two directions. Some of this byproduct mixture re-enters the powering process through a recirculation pump. The rest of this byproduct mixture passes through the purge valve before entering the dilution mixture. The byproducts then exit the power system as air and water. The load takes power from the PEM fuel cell stack, uses what is necessary, and returns what is not used.

Supplementary Content

Hydrogen Storage (for Backup Power Systems)

Backup power systems with polymer electrolyte membrane (PEM) fuel cells are usually fueled by one or more six-packs of delivered compressed hydrogen storage containers. Each container weighs about 137 pounds (lb) and holds either 196 or 261 standard cubic feet (scf) of hydrogen at a pressure of up to 2,400 pounds per square inch (psi). Each six-pack can power a typical 5-kW fuel cell for nearly 12 hours. The hydrogen can also be stored in permanent fuel tanks.

PEM Stack (Remote Monitoring)

Unlike batteries and generators, fuel cells can be monitored remotely. During an extended power outage, system managers can wait to service a facility until fuel is actually running low. Sometimes described as “moving refueling from an art to a science,” this can greatly reduce maintenance costs and allow facility managers to devote resources to the highest priority locations during outages.

Recirculation Pump

A recirculation pump takes byproducts released by the stack and reintroduces them into the fuel cell through the membrane humidifier.

Membrane Humidifier

Membrane humidifiers transfer water from the spent cathode exhaust through a membrane to the incoming hydrogen. The pressure drop across the membrane humidifier is controlled to prevent excessive mixing of the reactants. A membrane humidifier uses the energy from the spent air to raise the temperature and concurrently humidify the incoming air.

Dilution Mixer

The dilution mixer takes products from the membrane humidifier and purge valve and releases exhaust.

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Supplementary Base-Load Power Cogeneration Systems

These large fuel cell systems have high operating temperatures so they can produce useful heat (or cooling) in addition to electricity. They are generally larger (100 kW to several megawatts [MW]), more complex systems that run continuously, ensuring consistent power quality as well as backup if the power goes out.

Systems like this can use phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), or solid oxide fuel cells (SOFC) with associated reformer units that allow them to run on natural gas or other hydrocarbon fuel.

Image

Photo of a stationary fuel cell at the back of a building. The fuel cell reads, "UTC Power" on the front in blue letters.

> **Caption**: This supplementary base-load fuel cell supplies heating and cooling as well as electricity for a Whole Foods store in Connecticut.
> *Photo courtesy of UTC Power*

Supplementary Content

To learn more about PAFC, MCFC, and SOFC fuel cells, visit the Types of Fuel Cells page on the FCT Web site.

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Components of Typical Supplementary Base-Load Power Cogeneration Systems

Most supplementary base-load power systems use phosphoric acid, molten carbonate, or solid oxide fuel cells. As the diagram shows, these large, continuous-operation systems generally include exhaust burners and exhaust and coolant condensers, as well as cogeneration system connections.

Image

Graphic of a cogeneration power system that shows how three elements (air, fuel, and water) generate two products (AC power and water at about 80°C). The system is composed of six basic parts: an exhaust cooler, a burner, a fuel reformer, a fuel cell, a coolant cooler, and an inverter. The exhaust cooler uses water at about 60°C from buildings to cool warm exhaust from the burner and releases cold exhaust into the air and warmed water at about 62°C to the coolant cooler. The burner takes air, depleted air from the fuel cell, fuel, and depleted reformate from the fuel cell and releases warm exhaust to the exhaust cooler and heat to the fuel reformer.

The fuel reformer takes fuel, air, water and heat from the burner to release reformate to the fuel cell. The fuel cell takes reformate from the fuel reformer and air to release depleted air to the burner and DC power to the inverter. The fuel cell also takes cold coolant from the coolant cooler and releases hot coolant to the coolant cooler. The coolant cooler takes hot coolant from the fuel cell and water from the exhaust cooler at about 62°C to release cold coolant to the fuel cell and water at about 80°C to buildings. The inverter inverts DC power from the fuel cell to send AC power to buildings.

Supplementary Content

Fuel Reformer for Supplementary Base-Load Power Systems

Reformers generate hydrogen from hydrocarbon fuels. A fuel reformer or fuel processor produces relatively pure hydrogen from natural gas; lower purity methane similar to methane from landfills or anaerobic digesters; or any hydrocarbon fuel readily available or easily transportable (i.e., liquefied petroleum gas or diesel).

Converting liquid or gaseous light hydrocarbon fuels to hydrogen and carbon monoxide is commonly called reforming. Higher operating temperatures allow molten carbonate and solid oxide fuel cells to operate directly on methane while using a fuel cleanup or conditioning unit. Systems without separate reformers can divert some hydrogen to fuel vehicles or equipment (i.e., forklifts operating on fuel cells). Such systems cogenerate power, heat, and fuel.

Inverter (Power-Conditioning Equipment)
Fuel cells generate direct current (DC). If a fuel cell power system serves a facility that runs on direct current, only current and voltage controls are needed for power conditioning.

Most supplementary base-load fuel cell power systems, however, serve alternating current (AC) facilities. In these cases, power-conditioning equipment includes DC-to-AC inversion as well as current and voltage controls. Frequency-control equipment is also necessary for maintaining an acceptable level of harmonics output. Even if alternating current power inversion is required, direct current will likely also be used for the system itself. Running blowers, pumps, controls, and other auxiliary equipment on direct current before it's inverted is usually more efficient.

Cogeneration System
In any electrical generation system, inefficiencies take the form of waste heat. And supplementary base-load fuel cell power systems operate at such high temperatures that their waste heat is hot enough to be easily captured for useful work. Most commonly, that waste heat is used for domestic hot water or space heating. It's also possible to convert heat into cooling via absorption or desiccant cooling systems.

Such cogeneration or combined heat and power systems can dramatically increase the already high efficiency of supplementary base-load power systems. For this reason, they're a major advantage for distributed electrical generation systems.

Burner
As a component of a typical supplementary base-load power cogeneration system, a burner helps increase output by reheating gas turbine exhaust with little or no additional air. For this reason, burners can raise the efficiency of gas turbine cogeneration.

Fuel Cell
A device that uses hydrogen and oxygen to create electricity through an electrochemical process.

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Construction Approval

Designers and developers of stationary fuel cell systems should follow all the design principles appropriate to facilities involving flammable fuels, compressed gases, and electrical and water supply equipment, but be cognizant of the specific properties of hydrogen as well.

Special stationary hydrogen facility safety systems commonly include pressure relief devices such as rupture disks, pressure relief valves, and safety vents; leak and flame detection; monitoring; controlled access; and emergency stops.

Here are some specific design and installation considerations:

- Fire safety
- Compressed hydrogen gas storage
- Electrical equipment
- Fuel lines
- Balance-of-plant equipment

Image

Graphic showing three general steps in the order of the permitting process: project considerations, construction approval, and operation approval. Construction approval is accentuated with a red square around it.

Supplementary Content

To view references for related codes and standards, visit the following links:

- Setbacks and footprints for fuel cell systems (see page 33 of appendix for references)
- Fuel cell weather protection (see page 33 of appendix for references)
- Storage containers for compressed hydrogen storage (see page 33 of appendix for references)
- Equipment location for compressed hydrogen storage (see page 34 of appendix for references)
- Design standards (see page 34 of appendix for references)
- Fuel cell equipment specifications (see page 35 of appendix for references)

Fire Safety

The ability to prevent or quickly suppress fires is important for any system that uses liquid or gaseous fuel.

Hydrogen is no more dangerous than other fuels, but it is different. Because hydrogen is colorless and odorless and its flames are virtually invisible in daylight, sensors and other equipment or design considerations—while unnecessary for other facilities—are often required.

On the other hand, hydrogen is nontoxic and as the lightest gas, it disperses rapidly upward if released, so open, outdoor locations greatly reduce potential hazards.

Image

Photo of a fire truck.

Caption: Fire safety is of concern when using flammable gases.

Photo courtesy of HAMMER

Supplementary Content

To view references for related codes and standards, visit the following links:

- Construction for fuel cell fire safety (see page 38 of appendix for references)
- Equipment for fuel cell fire safety (see page 38 of appendix for references)
- Signage for fuel cell fire safety (see page 38 of appendix for references)

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Compressed Hydrogen Gas Storage

For fuel cell backup power systems, hydrogen storage is a primary safety consideration. Hydrogen is stored in standard prefilled cylinders, which are delivered to the site, or in pressurized tanks that are refilled by delivery tankers.

Images

Image 2: Photo of nine red compressed hydrogen bottles at a compressed hydrogen storage facility.
Image 2: Photo of a vent stack at a compressed hydrogen storage facility.

Caption: Typical prefilled cylinders and pressurized tanks.
Photos courtesy of NextEnergy

Supplementary Content

To view references for related codes and standards, visit the following links:

- Storage containers for compressed hydrogen storage (see page 39 of appendix for references)
- Equipment location for compressed hydrogen storage (see page 39 of appendix for references)
- General safety requirements for compressed hydrogen storage (see page 39 of appendix for references)

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Electrical Equipment

In addition to the power-conditioning equipment discussed earlier, fuel cell installations include a variety of electrical equipment and connections, all of which must be considered in developing safe system design and operating procedures.

Smaller telecommunications installations will house power-conditioning equipment—as well as fuel cells and hydrogen cylinders—in cabinets such as these. Larger installations will house power-conditioning equipment inside buildings, along with telecommunication equipment.

Image

Photo of a stationary fuel cell system on the left with a hydrogen storage unit on the right.

Caption: Stationary fuel cell system (left) and hydrogen storage unit (right).

Photo courtesy of Plug Power, Inc.

Supplementary Content

To view references for related codes and standards, visit the following links:

- Electrical equipment for fuel cell systems (see page 41 of appendix for references)
- Equipment for fuel cell fire safety (see page 41 of appendix for references)

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Fuel Lines

Piping that carries the fuel from the storage tank to the fuel cells is another important safety element. And large supplementary fuel cell systems will have fuel lines bringing natural gas or other fuel to the system. These fuel lines are subject to appropriate regulations and design considerations for those kinds of pipelines.

Image

Photo of three red compressed hydrogen bottles enclosed in a fenced-in area at a compressed hydrogen storage facility.

Caption: Fuel lines from hydrogen tanks.

Photo courtesy of NextEnergy

Supplementary Content

To view references for related codes and standards, visit the following link:

- Fuel lines for hydrogen dispensing (see page 42 of appendix for references)

Slide 10 of 21

Balance-of-Plant Components

Fuel cell systems include a variety of peripheral and safety equipment, all subject to appropriate safety and environmental regulations.

Large supplementary power systems also discharge cooling water associated with heat removal from the reformer and the fuel cell itself.

Image

Photo of the fuel cell components at the City of Tulare's wastewater treatment plant. The plant includes a gas chiller, a flare, a packed wash, a tower, a 450-kW Waukesha engine generator, a solar PV carport, three 300-kW fuel cells, a compressor skid, two siloxane removal units, and two H_2S removal units.

Caption: Components of the fuel cell system at the City of Tulare Wastewater Treatment Plant. *Photo courtesy of the City of Tulare*

Supplementary Content

To view references for related codes and standards, visit the following links:

- Piping and tubing for fuel cell systems (see page 43 of appendix for references)
- Pressure relief for fuel cell systems (see page 43 of appendix for references)
- Valves and fittings for fuel cell systems (see page 43 of appendix for references)
- Venting and other equipment for fuel cell systems (see page 44 of appendix for references)

Operation Approval

Fire codes generally require fuel cell power systems to be serviced once a year and many vendors find that sufficient to keep fuel cell backup power systems running at peak performance. Because the fuel cell itself has no moving parts (there are generally fans and other moving parts in the balance of the system), backup power fuel cell maintenance focuses on resupplying hydrogen fuel.

Large supplementary systems are directly connected to natural gas or other fuel supplies, so no fuel transportation or delivery is involved. These systems are, however, major pieces of equipment that should be regularly inspected for any needed maintenance.

Such systems also typically supply cogeneration heating or cooling as well as electricity, so all of these connections and auxiliary systems are subject to codes and standards and may require more frequent inspection and maintenance.

Specific operation considerations for stationary fuel cells include hydrogen delivery, fire and emergency planning, and periodic inspections.

Image

Graphic showing three general steps in the order of the permitting process: project considerations, construction approval, and operation approval. Operation approval is accentuated with a red square around it.

Supplementary Content

To view references for related codes and standards, visit the following links:

- Signage for fuel cell systems (see page 45 of appendix for references)
- Personnel issues and training for fuel cell systems (see page 45 of appendix for references)

Delivery of Hydrogen for Fuel Cells

Most backup-power fuel cell installations are fueled by one or more six-packs of compressed hydrogen storage containers, but some may have permanent storage tanks.

When the hydrogen fuel supply runs low, a self-checking alarm remotely alerts the operator that the storage containers need to be replenished. The operator then makes arrangements to resupply via "hot swapping" or "bumping."

In a hot-swap resupply, prefilled hydrogen storage containers are delivered to the fuel cell site and swapped one at a time with the depleted containers without disrupting backup operations. Bumping involves refilling permanent storage tanks at the site. A hydrogen tanker delivers hydrogen gas and replenishes the existing storage supply.

National codes and standards are in place to address hydrogen delivery; additional local regulations may apply as well.

Image

Photo of green hydrogen-storage containers.

Caption: Typical containers used for compressed hydrogen storage.

Photo courtesy of National Renewable Energy Laboratory

Supplementary Content

To view references for related codes and standards and learn more about fuel cells, visit the following links:

- Delivery of hydrogen for fuel cell systems (see page 46 of appendix for references)
- Hydrogen Portal page on the U.S. Department of Transportation Web site

Fire and Emergency Planning

Effective planning for fires or other emergencies is one of the most important safety measures for any facility. It's particularly important for fuel cell facilities because emergency personnel may not be familiar with the fuels and equipment at such facilities. Site operations personnel should work with emergency responders to make sure they have the information they need to respond to a potential or actual incident.

Image

Photo of a firefighter wearing an oxygen tank and holding an electronic device.

Caption: Fire and emergency planning is critical for effective fuel cell use safety.

Photo courtesy of HAMMER

Supplementary Content

To view references for related codes and standards, visit the following link:

- Fire and emergency planning for fuel cell systems (see page 47 of appendix for references)

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Periodic Inspections for Stationary Fuel Cell Power Systems

Codes and standards that govern periodic inspections are probably the most important general operation regulations for stationary fuel cell systems.

Periodic inspections may focus on:

- Specific operating equipment, subsystems, and systems
- Fire protection and safety systems
- Record-keeping
- Operating staff training

Image

Graphic of the cover of the *Emergency Response Guidebook*.

Caption: Review of emergency response procedures is one important element of periodic inspections for fuel cell systems.

Supplementary Content

To view references for related codes and standards, visit the following link:

- Periodic inspections for fuel cell systems (see page 48 of appendix for references)

Slide 15 of 21

Layout of Telecommunications Site Using Fuel Cell for Backup Power

The information below provides an example of a typical telecommunications site layout that uses hydrogen fuel cells for backup power along with some of the setback requirements, codes, and standards that apply to such a site.

The animation is a map-like drawing of an example telecommunications site that includes a telecommunications tower, a battery backup cabinet, an equipment cabinet, a fuel cell, and gaseous hydrogen storage. The telecommunications tower stands in a fenced-in area. Connected to the right of the tower are its battery backup cabinet and equipment cabinet. To the right of that is the fuel cell and hydrogen storage. A secondary street is located along the right side of the lot, and a primary street is located along the bottom of the lot.

Setback distances are indicated by colored regions and are summarized in a setback table titled "2010 National Fire Protection Association (NFPA) Setbacks:

- NFPA 55, Table 10.3.2.2.1(a) – Minimum distance from outdoor gaseous hydrogen systems to exposures
    - Buildings on same property—5-foot setback
    - Dry vegetation and combustible materials—10-foot setback
    - Overhead utilities—10-foot setback

Setbacks are applicable to a 3,500 psi hydrogen system.

A "construction approvals" button links to the references for related hydrogen codes and standards (see page 49 of appendix for references).

An "operation approvals" button links to references for related hydrogen codes and standards (see page 53 of appendix for references).

Summary

Congratulations! You've completed the Fuel Cell Facilities section of this course. In this section, you learned about stationary fuel cell applications. Whether small backup-power-only systems or large supplementary base-load power cogeneration systems, these systems involve hydrogen or other flammable fuels and various potentially hazardous components. They must be designed, constructed, and operated in accordance with established safety principles and the specific and unique properties of hydrogen. Additional federal, state, and local requirements may also apply.

Developers and code officials alike are becoming more familiar with fuel cells and with the basic properties, uses, and safety considerations of hydrogen, along with the methods for acquiring, storing, and dispensing the fuel.

Now, take the quiz.

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Note: Slides 18 through 21 contain electronic quiz questions that are only available in the Flash version of the course. To have someone contact you so you can answer the quiz questions verbally and receive a certificate of completion, send an e-mail to Hydrogen Education at hydroedu@nrel.gov with "Verbal Quiz Request" in the subject line.

Thank you for completing the Introduction to Hydrogen for Code Officials online training course and taking the quiz. This course was intended to provide introductory information about hydrogen and fuel cell technologies and applications as well as the codes and standards applicable to hydrogen fueling stations and fuel cell facilities. For more information about these topics, please visit the Library.

Publications

The following publications provide information about hydrogen and fuel cell technologies and applications. These documents are available as Adobe Acrobat PDFs. Download Adobe Reader.

Comparison of Fuel Cell Technologies (PDF 38 KB)
A table comparing the properties, advantages, and disadvantages of various fuel cell technologies.

Early Markets: Fuel Cells for Material Handling Equipment (PDF 694 KB)
A fact sheet that introduces the use of fuel cells for powering forklifts.

Early Markets: Fuel Cells for Backup Power (PDF 521 KB)
A fact sheet that covers the use of fuel cells for powering emergency-response radio towers.

Hydrogen Distribution and Delivery Infrastructure (PDF 365 KB)
A fact sheet that presents an overview of hydrogen distribution and delivery methods.

Hydrogen Fuel Cells (PDF 403 KB)
A fact sheet that provides an overview of hydrogen fuel cell technologies.

Publications (continued)

Hydrogen Fueling—Coming Soon to a Station Near You (PDF 1.6 MB)
A fact sheet that gives an overview of hydrogen fueling station permitting, codes, and standards. It also offers information about existing stations, including contacts for the people who were involved with permitting these stations.

Hydrogen Production (PDF 331 KB)
A fact sheet on the basics of hydrogen production technologies.

Hydrogen Safety (PDF 386 KB)
A fact sheet that summarizes hydrogen's properties and discusses how to handle it safely.

Hydrogen Storage (PDF 439 KB)
A fact sheet that introduces hydrogen storage technologies.

Slide 2 of 2

Related Links

Explore the following links to learn more about hydrogen and fuel cell technologies, federal research programs, codes and standards development, and the permitting process for hydrogen applications.

Introductory Hydrogen Information

Alternative and Advanced Fuels: Hydrogen
A Web site maintained by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy (EERE) Alternative Fuels and Advanced Vehicles Data Center.

California Fuel Cell Partnership
The California Fuel Cell Partnership includes auto manufacturers, energy providers, fuel cell companies, and government agencies involved in advancing and evaluating new vehicle technologies. The site features an online resource center with education information and tools.

Increase Your H2IQ
A Web site of the EERE Fuel Cell Technologies Program. Image: Graphic of the Increase Your H_2IQ Program.

Fuel Cells 2000
An online information center that includes fuel cell reference charts, a library, fuel cell photos, and more.

Slide 1 of 4

Related Links (continued)

National Hydrogen Association

The National Hydrogen Association serves as a catalyst for information exchange and cooperative projects among industry, government, and research organizations. The site features basic information about hydrogen and fuel cell technologies.

Federal Research Programs

DOE Hydrogen Program

Program that facilitates the research, development, and validation of fuel cell and hydrogen production, delivery, and storage technologies.

DOE EERE Fuel Cell Technologies (FCT) Program

Program that supports the larger DOE Hydrogen Program with a focus on renewable technologies.

DOE EERE FCT Safety, Codes, and Standards Program

Information about the FCT Program's safety, codes, and standards efforts, which a focus on the development of safe practices and procedures for operating, handling, and using hydrogen and hydrogen systems.

U.S. Department of Transportation (DOT) Hydrogen Portal

Web site that offers safety, codes, and standards information and links to hazardous material Web sites for the various DOT agencies.

Slide 2 of 4

Related Links (continued)

Codes and Standards Development

As the use of hydrogen and fuel cell systems expands, additional codes and standards are needed to ensure the safe design, construction, and operation of these systems. The following organizations and resources support this effort.

Hydrogen Codes and Standards Portal

American National Standards Institute's portal to information about codes, standards, and regulations. You can register here to receive customized notifications about codes and standards development activities.

Hydrogen Industry Panel on Codes

Web site of a group that helps harmonize the development of codes and standards governing the storage, dispensing, use, and handling of gaseous and liquid hydrogen.

Standards Development Organizations

Information on the roles of the various organizations that are cooperating to develop codes and standards for the commercialization of emerging hydrogen and fuel cell technologies.

U.S. Fuel Cell Council

Primer on the development of codes and standards for fuel cells.

Related Links (continued)

Permitting, Codes, and Standards Information

Codes and Standards Resources
Resources for helping project developers and code officials prepare and review code-compliant projects, including templates that identify the organizations responsible for developing alternative fuel codes and standards as well as lists of national codes and standards related to alternative fuel vehicles and infrastructure.

Hydrogen/Fuel Cell Codes and Standards
Matrix of national and international codes and standards for hydrogen and fuel cells.

Introduction to Hydrogen Safety for First Responders
Online course that helps fire, law enforcement, and emergency medical personnel learn about hydrogen basics, transport and storage, vehicles, dispensing, stationary facilities, codes and standards, and emergency response.

Permitting Hydrogen Facilities
DOE Web site that identifies model codes and standards to help local permitting officials deal with proposals for hydrogen fueling stations, fuel cell use for telecommunications backup power, and other hydrogen projects.

Regulators' Guide to Permitting Hydrogen Technologies
Guide to hydrogen's use as a fuel, the regulatory process, and codes and standards for stationary fuel cells in commercial buildings and hydrogen fueling stations.

Glossary

Adsorber
Solid material used to capture either a gas or liquid.

Anaerobic digestion
A series of processes in which tiny organisms break down biodegradable material in the absence of oxygen.

Anode
The electrode at which oxidation (a loss of electrons) takes place. For fuel cells and other galvanic cells, the anode is the negative terminal; for electrolytic cells (where electrolysis occurs), the anode is the positive terminal.

Atom
The smallest particle of an element that can exist either alone or in combination.

Autoignition
The spontaneous ignition of gases or vapors given off by a heated material.

Autoignition temperature
Minimum temperature at which a substance must be heated without applying flame or spark. Materials should not be heated to greater than 80% of this temperature.

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Glossary (continued)

Base load

The minimum amount of power that a utility or distribution company must make available to its customers, or the amount of power required to meet minimum demands based on reasonable expectations of customer requirements. Base-load values usually vary from hour to hour.

Biomass

Organic matter, including crop or forest residues, organic municipal solid wastes, and special crops that can be grown specifically for energy production.

Bio-oil

A carbon-rich liquid that can be derived from solid biomass through pyrolysis. The liquid can then be used to produce chemicals and fuels.

Boiloff

The vapor loss from a volatile liquid such as hydrogen in its liquid form.

Buoyancy

The tendency of a body to float or to rise.

Burner

As a component of a typical supplementary base-load power cogeneration system, a burner helps increase output by reheating gas turbine exhaust with little or no additional air. For this reason, burners can raise the efficiency of gas turbine cogeneration.

Glossary (continued)

Captive use

The practice of producing hydrogen on the site where it is to be used.

Catalyst

A chemical substance that increases the rate of a reaction without being consumed. After the reaction, it can potentially be recovered from the reaction mixture chemically unchanged. The catalyst lowers the activation energy required, which allows the reaction to proceed more quickly or at a lower temperature. In a fuel cell, the catalyst facilitates the reaction of oxygen and hydrogen. In polymer electrolyte membrane fuel cells, it is usually made of platinum powder very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen. The platinum-coated side of the catalyst faces the membrane in the fuel cell.

Cathode

The electrode at which reduction (a gain of electrons) occurs. For fuel cells and other galvanic cells, the cathode is the positive terminal; for electrolytic cells (where electrolysis occurs), the cathode is the negative terminal.

Checklist analysis

A systematic evaluation against pre-established criteria in the form of one or more checklists.

Glossary (continued)

Cogeneration

A form of energy generation where the waste heat from electricity generation is passed through a second cycle to extract the energy from the heat. Also known as combined heat and power (CHP).

Compressor

A device used for increasing the pressure and density of gas.

Density

The amount of mass in a unit volume. The density of gases varies with temperature and pressure.

Dilution Mixer

The dilution mixer takes products from the membrane humidifier and purge valve and releases exhaust.

Electrochemical process

A process that uses electricity to cause a chemical transformation.

Electrolysis

A process that uses electricity passing through an electrolytic solution or other appropriate medium to cause a reaction that breaks chemical bonds.

Glossary (continued)

Electrolyte
A substance that conducts charged ions from one electrode to the other in a fuel cell, battery, or electrolyzer.

Electrolyzer
A device that uses electricity to break water down into hydrogen and oxygen.

Electron
A stable atomic particle that has a negative charge; the flow of electrons through a substance constitutes electricity.

Embrittlement
The process by which various metals—most importantly high-strength steel—become brittle and crack after being exposed to hydrogen.

Energy
The quantity of work a system or substance is capable of doing, usually measured in British thermal units or joules.

Energy carrier
A means by which energy can be delivered and stored in a usable form. Energy carriers such as hydrogen and electricity are not primary energy sources. They must be produced from primary energy sources such as light, wind, and fossil fuels.

Glossary (continued)

Energy content

The amount of energy for a given mass of fuel.

Ethanol

A liquid biofuel made by converting the carbohydrate portion of biomass into sugar, which is then converted to ethanol through a fermentation process similar to brewing beer. Ethanol is the most widely used biofuel today.

Event tree analysis (ETA)

An inductive procedure that shows all possible outcomes resulting from an accidental (initiating) event in a complex system.

Failure mode and effects analysis (FMEA)

A deductive risk analysis method that helps identify and rank the type, severity, and priority of potential failures of a design or construction process.

Fault tree analysis (FTA)

A deductive analysis method that results in a systematic description of the combinations of possible occurrences in a system that can result in failure. The method, which is applied as a diagnosis and development tool, is especially helpful in early design stages.

Flammability range

The flammability range of a gas is defined in terms of its lower flammability limit and upper

Glossary (continued)

flammability limit. Between the two is the flammable range in which the gas and air are in the right proportions to burn when ignited. Below the lower flammability limit, there is not enough fuel to burn. Above the higher flammability limit, there is not enough air to support combustion.

Fuel
A material used to create heat or power through chemical conversion in processes such as burning or electrochemistry.

Fuel cell
A device that uses hydrogen and oxygen to create electricity through an electrochemical process.

Fuel reformer
A device that uses heat and catalysts to "crack" hydrocarbons and release the hydrogen they contain. A reformer produces a mixture of gases that must then be purified to produce hydrogen pure enough for use in a fuel cell. Also called a fuel processor.

Galvanic
Of, relating to, or producing a direct current of electricity.

Hazard and operability analysis (HAZOP)
A methodology for identifying and dealing with potential problems in design, manufacturing, or

Glossary (continued)

industrial processes, particularly those that would create a hazardous situation or a severe impairment of the process.

Heat value
The amount of heat that can be obtained from a fuel.

Ignition energy
The amount of external energy that must be applied to ignite a combustible fuel mixture.

Ion
An atom or molecule that carries a positive or negative charge because of the loss or gain of electrons.

Liquefaction
The process of making or becoming liquid.

Membrane Humidifier
Membrane humidifiers transfer water from the spent cathode exhaust through a membrane to the incoming hydrogen. The pressure drop across the membrane humidifier is controlled to prevent excessive mixing of the reactants. A membrane humidifier uses the energy from the spent air to raise the temperature and concurrently humidify the incoming air.

Glossary (continued)

Methane

See natural gas.

Molecular weight

The weight of a molecule that may be calculated as the sum of the atomic weights of its constituent atoms.

Molecule

The smallest particle of a substance that retains all the properties of the substance. It is composed of atoms.

Natural gas

A naturally occurring gaseous mixture of simple hydrocarbon components (primarily methane) used as a fuel.

Oxidation

The loss of one or more electrons by an atom, molecule, or ion.

Polymer

A natural or synthetic compound composed of repeated links of simple molecules.

Power conditioning

The isolation of sensitive equipment from the effects of electrical noise and voltage fluctuations.

Glossary (continued)

Primary energy source
Source of energy found in nature, such as the sun, wind, and fossil fuels.

Probabilistic risk assessment (PRA)
A systematic approach to evaluating how the pieces of a complex system work together to ensure safety, allowing analysts to quantify risks.

Proton
A subatomic particle in the nucleus of an atom that carries a positive electric charge.

Pyrolysis
A process in which the biomass is broken down into liquid in an oxygen-free, high-temperature environment.

Radiosonde
A miniature radio transmitter that's carried aloft (like an unmanned balloon). Its instruments use precise tone signals or other suitable methods to broadcast the atmospheric humidity, temperature, and pressure every few seconds.

Recirculation Pump
A recirculation pump takes byproducts released by the stack and reintroduces them into the fuel cell through the membrane humidifier.

Glossary (continued)

Setback

The absolute minimum distance that must be maintained between any energy facility and a dwelling, rural housing development, urban center, or public facility.

Six-packs

Compressed hydrogen storage containers that each hold 139 or 261 scf of hydrogen at a pressure of 2,400 psi. Together, they can power a fuel cell for 24 to 96 hours.

Steam reforming

The process of reacting a fuel such as natural gas or ethanol in the presence of steam to produce hydrogen.

Synthesis gas

A mixture of hydrogen and carbon monoxide; also known as syngas.

What-if analysis

A process in which key quantitative assumptions and computations (underlying a decision, estimate, or project) are changed systematically to assess their effect on the final outcome. Employed commonly in evaluation of the overall risk or in identification of critical factors, it attempts to predict alternative outcomes of the same course of action. Also called sensitivity analysis.

Thank you for completing the

Introduction to Hydrogen for Code Officials

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Survey

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Operation Approvals for Fire Safety and Emergency Planning

International Fire Code (International Code Council, 2009)

- 404 Fire Safety and Evacuation Plan
- 406 Employee Training and Response Procedures
- 407 Hazard Communication
- 906 Portable Fire Extinguishers
- 907 Fire Alarm and Detection Systems
- 2209.3.2.6.2 Fire-Extinguishing Systems
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
- 2209.5.1 Protection from Vehicles
- 2209.5.2 Emergency Shutoff Valves
- 2209.5.3 Emergency Shutdown Controls
- 2209.5.4 Venting of Hydrogen Systems

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 7.3.5 Fixed Fire Protection

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

- 9.2 General System Requirements
- 9.11 Installation of Emergency Shutdown Equipment

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

- 4.1 Permits
- 4.2 Emergency Plan
- 7.1.10 Separation from Hazardous Conditions

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Fueling Station Design

International Fire Code (International Code Council, 2009)
35 Flammable Gases and Flammable Cryogenic Fluids
2209.1 General
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
7.3 Motor Fuel Dispensing Facilities
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.3 System Siting
14.3 Facility Design
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
7.1.10 Separation from Hazardous Conditions

Equipment Design

International Fire Code (International Code Council, 2009)
2209.2 Equipment
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2 General System Requirements

Barrier Wall Design

Gaseous Hydrogen Equipment
International Fire Code (International Code Council, 2009)
2209.3.1.1 Barrier Wall Construction – Gaseous Hydrogen
Liquid Hydrogen Equipment
International Fire Code (International Code Council, 2009)
2209.3.2.5.1.1 Location on Property
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
8.7.2.1 Fire Barriers
8.7.3.1 Fire Barriers

Weather Protection

International Fire Code (International Code Council, 2009)
2209.3.2.2 Weather Protection
2704.13 Weather Protection

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Setbacks and Footprints for Outdoor Gaseous Hydrogen Systems

International Fire Code (International Code Council, 2009)
2209.3.1 Separation from Outdoor Exposure Hazards
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.3.1 General
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
10.3.2 Specific Requirements
10.3.2.2 Minimum Distance

Setbacks and Footprints for Liquid Hydrogen Systems

International Fire Code (International Code Council, 2009)
2209.3.1 Separation from Outdoor Exposure Hazards
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
14.3.2.1.1 Siting
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
11.3.2 Specific Requirements
11.3.2.2 Minimum Distance

Hydrogen Fueling Stations Module – Slide 5 of 27

Operation Approvals for Fire Safety and Emergency Planning

International Fire Code (International Code Council, 2009)
- 404 Fire Safety and Evacuation Plan
- 406 Employee Training and Response Procedures
- 407 Hazard Communication
- 906 Portable Fire Extinguishers
- 907 Fire Alarm and Detection Systems
- 2209.3.2.6.2 Fire-Extinguishing Systems
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
- 2209.5.1 Protection from Vehicles
- 2209.5.2 Emergency Shutoff Valves
- 2209.5.3 Emergency Shutdown Controls
- 2209.5.4 Venting of Hydrogen Systems

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
- 7.3.5 Fixed Fire Protection

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
- 9.2 General System Requirements
- 9.11 Installation of Emergency Shutdown Equipment

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 4.1 Permits
- 4.2 Emergency Plan
- 4.7 Personnel Training
- 4.8 Fire Dept. Liaison
- 7.1.10 Separation from Hazardous Conditions
- 10.5 Operation and Maintenance

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Fueling Station Design

International Fire Code (International Code Council, 2009)
35 Flammable Gases
2209.1 General
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
7.3 Motor Fuel Dispensing Facilities
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.3 System Siting
14.3 Facility Design
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
7.1.10 Separation from Hazardous Conditions

Equipment Design

International Fire Code (International Code Council, 2009)
2209.2 Equipment
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2 General System Requirements

Barrier Wall Design

Gaseous Hydrogen Equipment
International Fire Code (International Code Council, 2009)
2209.3.1.1 Barrier Wall Construction – Gaseous Hydrogen
Liquid Hydrogen Equipment
International Fire Code (International Code Council, 2009)
2209.3.2.5.1.1 Location on Property
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
8.7.2.1 Fire Barriers
8.7.3.1 Fire Barriers

Weather Protection

International Fire Code (International Code Council, 2009)
2209.3.2.2 Weather Protection
2704.13 Weather Protection
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.3.2.1.1 **Weather Protection**

Compression Systems and Equipment

International Fire Code (International Code Council, 2009)
2209.2 Equipment
2209.3 Location on Property

2209.5.3.1 System Requirements
2209.5.4.2.1 Minimum Rate of Discharge

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2 General System Requirements
9.3 System Siting
14.10 Stationary Pumps and Compressors

Vaporizers

International Fire Code (International Code Council, 2009)

2209.2 Equipment
2209.3 Location on Property
3203.1.3 Foundations and Supports
3203.2.2 Vessels or Equipment Other than Containers
3203.5.3 Securing of Vaporizers

International Fuel Gas Code (International Code Council, 2009)

708 Design of Liquefied Hydrogen Systems Associated with Hydrogen Vaporization Operations

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

11.2.5 Liquefied Hydrogen Vaporizers

Canopy Tops

International Fire Code (International Code Council, 2009)

2209.3.2.6 Canopy Tops
2209.3.3 Canopies

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.3.2 Outdoors

Fire Safety for Construction

International Fire Code (International Code Council, 2009)

911 Explosion Control
2209.5 Safety Precautions

International Fuel Gas Code (International Code Council, 2009)

706.3 Outdoor Gaseous Hydrogen Systems

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.13 Stray or Impressed Currents and Bonding

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.10 Separation from Hazardous Conditions

Fire Safety for Equipment

International Fire Code (International Code Council, 2009)

404 Fire Safety and Evacuation Plan
406 Employee Training and Response Procedures
407 Hazard Communication
906 Portable Fire Extinguishers
907 Fire Alarm and Detection Systems

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
2209.5 Safety Precautions

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2.5 Equipment Security and Vehicle Protection
9.2 General System Requirements
9.3.3 Indoors
9.15 Fire Protection
14.3.4 Indoor Fueling
14.5 Liquid Hydrogen Vehicle Dispensing Systems

Fire Safety Signage

International Fire Code (International Code Council, 2009)
2204.3.5 Emergency Procedures
2209.5.2.1 Identification

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.3.3.11 Warning Signs

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
6.11 Hazard Identification Signs
10.2.5 Marking
11.3.1.3 General

Gaseous Hydrogen Safety

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)
9 Maintenance

International Fire Code (International Code Council, 2009)
2204 Dispensing Operations
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
9.2.2 Tank Filling and Bulk Delivery
9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities
9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.14 System Operation
9.15 Fire Protection
9.16 Maintenance System

Liquid Hydrogen Safety

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)
9 Maintenance

International Fire Code (International Code Council, 2009)
2204 Dispensing Operations

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
9.2.2 Tank Filling and Bulk Delivery

9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities
9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

14.5 Liquid Hydrogen Vehicle Dispensing Systems
14.15 Maintenance

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Liquid Hydrogen Storage Equipment Location

International Fire Code (International Code Council, 2009)
- 2209.3 Location on Property
- 3203.5.4 Physical Protection
- 3203.6 Separation from Hazardous Conditions
- 3204.3.1.1 Location
- 3204.4.2 Location
- 3504 Storage

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 11.3.1 General
- 11.3.2 Specific Requirements

Liquid Hydrogen Storage Containers

Aboveground Containers

International Fire Code (International Code Council, 2009)
- 2703.2 Systems, Equipment, and Processes
- 3203.1 Containers
- 3204.3.1 Stationary Containers

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
- 5.3 Design and Construction of Containers

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 11.3.2 Specific Requirements
- 11.4.2 Aboveground Tanks

Underground Containers

International Fire Code (International Code Council, 2009)
- 2703.2 Systems, Equipment, and Processes
- 3203.1 Containers
- 3203.5 Security
- 3203.6 Separation from Hazardous Conditions
- 3204.4 Underground Tanks

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 11.4.3 Underground Tanks

Liquid Hydrogen Storage General Safety Requirements

International Fire Code (International Code Council, 2009)
- 2209.5 Safety Precautions
- 2211.7 Repair Garages for Vehicles Fueled by Lighter-than-Air Fuels
- 2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers
- 3003 General Requirements
- 3203 General Safety Requirements
- 3503 General Requirements

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
- 14.3 Facility Design

Appendix: Supplementary Content – References for Related Hydrogen Codes and Standards

Compressed Hydrogen Gas Storage Equipment Location

International Fire Code (International Code Council, 2009)
2209.3 Location on Property
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.3 System Siting
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
10.3.2 Specific Requirements

Compressed Hydrogen Gas Storage Containers

CGA PS-20, Direct Burial of Gaseous Hydrogen Storage Tanks (Compressed Gas Association, 2006)
CGA PS-21, Adjacent Storage of Compressed Hydrogen and Other Flammable Gases (Compressed Gas Association, 2005)
International Fire Code (International Code Council, 2009)
2703.2.1 Design and Construction of Containers, Cylinders, and Tanks
3003.2 Design and Construction
3503.1.2 Storage Containers
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
5.3 Design and Construction of Containers, Cylinders, and Tanks

Compressed Hydrogen Gas Storage General Safety Requirements

International Fire Code (International Code Council, 2009)
2209.5 Safety Precautions
2211.7 Repair Garages for Vehicles Fueled by Lighter-than-Air Fuels
2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers
3003 General Requirements
3503 General Requirements
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2.5 Equipment Security and Vehicle Protection
9.2 General System Requirements
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
7.1.8 Security

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On-Site Hydrogen Production Equipment and Specifications

International Fire Code (International Code Council, 2009)
2209.3.1 Separation from Outdoor Exposure Hazards
International Fuel Gas Code (International Code Council, 2009)
703.1 General Requirements
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
5.2 System Approvals

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Hoses and Connectors for Hydrogen Dispensing

International Fire Code (International Code Council, 2009)
2209.2 Equipment
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
5.10 Hose and Hose Connections

Liquid Hydrogen Dispensers

International Fire Code (International Code Council, 2009)
2206.7.4 Dispenser Emergency Shutoff Valve
2206.7.5 Dispenser Hose
2206.7.6 Fuel Delivery Nozzles
2209.2 Equipment
2209.3 Location on Property
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
6.3 Requirements for Dispensing Devices
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
14 Liquid Hydrogen Fueling Facilities

Gaseous Hydrogen Dispensers

International Fire Code (International Code Council, 2009)
2209.2 Equipment
2209.3 Location on Property
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2 General System Requirements
9.3 System Siting

Vehicle Connectors for Hydrogen Dispensing

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
5.11 Vehicle Fueling Connection

Electrical Equipment for Hydrogen Dispensing

International Fire Code (International Code Council, 2009)
2201.5 Electrical
2205.4 Sources of Ignition
2209.2.3 Electrical Equipment
2211.3.1 Equipment
2211.8.1.2.4 Grounding and bonding
2703.9.4 Electrical Wiring and Equipment

3003.8 Wiring and Equipment
3003.16.14 Classified Areas
3203.7 Electrical Wiring and Equipment
3503.1.5.1 Bonding of Electrically Conductive Materials and Equipment

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

6.7 Emergency Electrical Disconnects
8 Electrical Installations

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.12 Installation of Electrical Equipment
9.13 Stray or Impressed Currents and Bonding

Fuel Lines for Hydrogen Dispensing

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

3.0 Piping System Criteria

International Fire Code (International Code Council, 2009)

2201 Scope
2209.3.2.3 Indoors
2209.3.2.6 Canopy Tops
3501.1 Scope

International Fuel Gas Code (International Code Council, 2009)

101.2.1 Gaseous Hydrogen Systems
704 Piping, Use, and Handling
705 Testing of Hydrogen Piping Systems

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.8 Fuel Lines

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Piping and Tubing

ASME B31.12, Hydrogen Piping and Pipelines (American Society of Mechanical Engineers, 2008)
ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)
F323.4(5) Specific Material Considerations-Metals
IX K305 Pipe
CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)
3.1 General
3.2 Piping Materials
5.0 Installation
5.1 Piping Installation General
5.2 Piping Installation Above Ground Installation
5.3 Piping Installation Underground Installation
International Fire Code (International Code Council, 2009)
2201.1 Scope
2209.3.2.3 Indoors
2209.3.2.6 Canopy Tops
3501.1 Scope
International Fuel Gas Code (International Code Council, 2009)
101.2.1 Gaseous Hydrogen Systems
704 Piping, Use, and Handling
705 Testing of Hydrogen Piping Systems
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.9 Installation of Piping and Hoses
9.10 System Testing
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
11.2.3 Piping, Tubing, and Fittings

Valves and Fittings

ASME B31.12, Hydrogen Piping and Pipelines (American Society of Mechanical Engineers, 2008)
ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)
IX K306 Fittings, Bends, and Branch Connections
IX K307 Valves and Specialty Components
CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)
3.3.2 Isolation Valves
3.3.3 Emergency Isolation Valves
3.3.4 Excess Flow Valves
3.3.5 Check Valves
3.3.7 Gasket and Sealing Materials
3.3.8 Additional Requirements
5.0 Installation
5.1 Installation General

International Fire Code (International Code Council, 2009)
- 2209.5.2 Emergency Shutoff Valves
- 2211.8.1.2.4 Grounding and bonding
- 2703.2.2 Piping, Tubing, Valves, and Fittings
- 2703.9.3 Protection from Vehicles
- 2703.10.1 Valve Protection
- 2705.1.10 Liquid Transfer
- 3003.6 Valve Protection
- 3005.3 Piping Systems
- 3005.4 Valves
- 3203.2.6 Shutoffs Between Pressure-Relief Devices and Containers
- 3205.1.2 Piping Systems
- 3205.3.2 Emergency Shutoff Valves
- 3503.1.3 Emergency Shutoff

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
- 5.9 Valves

Pressure Relief

CGA S-1.3, PRD Standards Part 3 - Stationary Storage Containers for Compressed Gases (Compressed Gas Association, 2005)
- 5.3.2 Non-Liquid Compressed Gases

International Fire Code (International Code Council, 2009)
- 2209.2.1 Approved Equipment
- 2209.5.4.2 Pressure-Relief Devices
- 3003.3 Pressure-Relief Devices
- 3203.2 Pressure-Relief Devices
- 3203.3 Pressure-Relief Vent Piping
- 3203.5.4 Physical Protection
- 3203.8 Service and Repair
- 3205.1.2.3.2 Shutoff Valves on Piping

International Fuel Gas Code (International Code Council, 2009)
- 703.3 Pressure-Relief Devices

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
- 5.4 Pressure-Relief Devices
- 5.6 Pressure Gauges
- 5.7 Pressure Regulators
- 9.6 Installation of PRDs on Fueling Systems
- 9.7 Installation of Pressure Gauges
- 14.8 Pressure-Relief Devices

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 7.1.5.5 Pressure-Relief Devices
- 10.2.2 Pressure-Relief Devices

Venting and Other Equipment

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)
- 6.0 Vent System

6.2 Sizing
6.3 Design
6.4 Materials
6.5 Components
7 Installation

International Fire Code (International Code Council, 2009)

2209.5.4 Venting of Hydrogen Systems
2211.8.1.2 Atmospheric Venting of Hydrogen from Motor Vehicle Fuel Storage Containers
3003.16.8 Connections
3005.5 Venting
3203.3 Pressure-Relief Vent Piping
3204.4.5 Venting of Underground Tanks

International Fuel Gas Code (International Code Council, 2009)

703.4 Venting

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.5 Vent Pipe Termination
9.3.3 Indoors

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.2.2 Pressure-Relief Devices

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Operation Approvals for Vehicle Access

International Fire Code (International Code Council, 2009)
105.6.8 Compressed Gases
105.6.10 Cryogenic Fluids
105.6.39 Repair Garages and Motor Fuel-Dispensing Facilities
404.3.2 Fire Safety Plans
3205.4 Filling and Dispensing
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
6.3.7 Requirements for Dispensing Devices
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2.5 Equipment Security and Vehicle Protection
14.3.1 General
14.5 Liquid Hydrogen Vehicle Dispensing Systems
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
10.3 Location of Gaseous Hydrogen Systems

Operation Approvals for Fuel Delivery Access and Unloading

International Fire Code (International Code Council, 2009)
105.6.8 Compressed Gases
105.6.10 Cryogenic Fluids
2205.1 Tank Filling Operation for Class I, II, or IIIA Liquids
3205.4 Filling and Dispensing
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
6.3.7 Requirements for Dispensing Devices
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2.5 Equipment Security and Vehicle Protection
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
10.3 Location of Gaseous Hydrogen Systems

Operation Approvals for Ignition Control

International Fire Code (International Code Council, 2009)
2209.3.2.3.3 Ignition Source Control
3503.1.4 Ignition Source Control
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
4.9 Ignition Source Controls
7.6.3 Ignition Source Control

Operation Approvals for Fire Safety and Emergency Planning

International Fire Code (International Code Council, 2009)
404 Fire Safety and Evacuation Plan
406 Employee Training and Response Procedures

407 Hazard Communication
906 Portable Fire Extinguishers
907 Fire Alarm and Detection Systems
2209.3.2.6.2 Fire-Extinguishing Systems
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
2209.5.1 Protection from Vehicles
2209.5.2 Emergency Shutoff Valves
2209.5.3 Emergency Shutdown Controls
2209.5.4 Venting of Hydrogen Systems

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

7.3.5 Fixed Fire Protection

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2 General System Requirements
9.11 Installation of Emergency Shutdown Equipment

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.1 Permits
4.2 Emergency Plan
7.1.10 Separation from Hazardous Conditions

Operation Approvals for Personnel Issues and Training

International Fire Code (International Code Council, 2009)

406 Employee Training and Response Procedures
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.7 Personnel Training
4.8 Fire Department Liaison

Operation Approvals for Dispensing

International Fire Code (International Code Council, 2009)

2204.2 Attended Self-Service Motor Fuel-Dispensing Facilities
2204.3 Unattended Self-Service Motor Fuel-Dispensing Facilities
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

6.2 General Requirements
6.3 Requirements for Dispensing Devices

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

14.5 Liquid Hydrogen Vehicle Fuel Dispensing Systems

Operation Approvals for Signage

International Fire Code (International Code Council, 2009)

2204.3.5 Emergency Procedures

2209.3.2.3.2 Smoking
2209.3.2.6.3 Signage
2209.5.2.1 Identification

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.3.3.11 Warning Signs

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.10 Signs

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Fire Safety for Equipment

International Fire Code (International Code Council, 2009)
- 404 Fire Safety and Evacuation Plan
- 406 Employee Training and Response Procedures
- 407 Hazard Communication
- 906 Portable Fire Extinguishers
- 907 Fire Alarm and Detection Systems
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
- 2209.5 Safety Precautions

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
- 9.2.5 Equipment Security and Vehicle Protection
- 9.2 General System Requirements
- 9.3.3 Indoors
- 9.15 Fire Protection
- 14.3.4 Indoor Fueling
- 14.5 Liquid Hydrogen Vehicle Dispensing Systems

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Operation Approvals for Fire Safety and Emergency Planning

International Fire Code (International Code Council, 2009)

404 Fire Safety and Evacuation Plan
406 Employee Training and Response Procedures
407 Hazard Communication
906 Portable Fire Extinguishers
907 Fire Alarm and Detection Systems
2209.3.2.6.2 Fire-Extinguishing Systems
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
2209.5.1 Protection from Vehicles
2209.5.2 Emergency Shutoff Valves
2209.5.3 Emergency Shutdown Controls
2209.5.4 Venting of Hydrogen Systems

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

7.3.5 Fixed Fire Protection

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.16 General System Requirements
9.10.5 Installation of Emergency Shutdown Equipment

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.1 Permits
4.2 Emergency Plan
7.1.10 Separation from Hazardous Conditions

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Hydrogen Fueling Station Annual Inspections

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)
7.0 Maintenance and Repair

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)
9 Maintenance

International Fire Code (International Code Council, 2009)
406.2 Frequency
901.6.2 Records
907.2 Inspection, Testing, and Maintenance
2206.2.1.1 Inventory Control for Underground Tanks
3204.5.2 Corrosion Protection
3205.4 Filling and Dispensing

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2.15 General System Requirements

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Hydrogen Fueling Station Construction Approvals

ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)
F323.4(5) Specific Material Considerations—Metals
IX K305 Pipe
IX K306 Fittings, Bends, and Branch Connections
IX K307 Valves and Specialty Components

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)
3.0 Piping System Criteria
3.1 General
3.2 Piping Materials
3.3.2 Isolation Valves
3.3.3 Emergency Isolation Valves
3.3.4 Excess Flow Valves
3.3.5 Check Valves
3.3.7 Gasket and Sealing Materials
3.3.8 Additional Requirements
5.0 Installation
5.1 Installation General
5.1 Piping Installation General
5.2 Piping Installation—Above Ground Installation
5.3 Piping Installation—Underground Installation

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)
6.0 Vent System
6.2 Sizing
6.3 Design
6.4 Materials
6.5 Components
7 Installation
9 Maintenance

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association, 2006)
4.1 Transportation Regulating Authorities
4.2 Container Regulations
4.3 Container Filling Regulations
4.4 Regulating Authorities of Employee Safety and Health
6.2 Flammable Gases

CGA PS-20, Direct Burial of Gaseous Hydrogen Storage Tanks (Compressed Gas Association, 2006)

CGA PS-21, Adjacent Storage of Compressed Hydrogen and Other Flammable Gases (Compressed Gas Association, 2005)

CGA S-1.3, PRD Standards Part 3 - Stationary Storage Containers for Compressed Gases (Compressed Gas Association, 2005)
5.3.2 Non-Liquid Compressed Gases

International Fire Code (International Code Council, 2009)
404 Fire Safety and Evacuation Plan

406 Employee Training and Response Procedures
407 Hazard Communication
906 Portable Fire Extinguishers
907 Fire Alarm and Detection Systems
911 Explosion Control
2201 Scope
2201.1 Scope
2201.5 Electrical
2204 Dispensing Operations
2204.3.5 Emergency Procedures
2205.4 Sources of Ignition
2209.2 Equipment
2209.2.1 Approved Equipment
2209.2.3 Electrical Equipment
2209.3 Location on Property
2209.3.1 Separation from Outdoor Exposure Hazards
2209.3.2.3 Indoors
2209.3.2.6 Canopy Tops
2209.3.3 Canopies
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
2209.5 Safety Precautions
2209.5.2 Emergency Shutoff Valves
2209.5.2.1 Identification
2209.5.3.1 System Requirements
2209.5.4 Venting of Hydrogen Systems
2209.5.4.2 Pressure-Relief Devices
2209.5.4.2.1 Minimum Rate of Discharge
2211.3.1 Equipment
2211.7 Repair Garages for Vehicles Fueled by Lighter-than-Air Fuels
2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers
2211.8.1.2 Atmospheric Venting of Hydrogen from Motor Vehicle Fuel Storage Containers
2211.8.1.2.4 Grounding and Bonding
2703.2.1 Design and Construction of Containers, Cylinders, and Tanks
2703.2.2 Piping, Tubing, Valves, and Fittings
2703.9.3 Protection from Vehicles
2703.9.4 Electrical Wiring and Equipment
2703.10.1 Valve Protection
2705 Use, Dispensing, and Handling
2705.1.10 Liquid Transfer
3003 General Requirements
3003.2 Design and Construction
3003.3 Pressure-Relief Devices
3003.6 Valve Protection
3003.8 Wiring and Equipment
3003.16.8 Connections
3003.16.14 Classified Areas
3005.3 Piping Systems
3005.4 Valves

- 3005.5 Venting
- 3005.7 Transfer
- 3203.1.3 Foundations and Supports
- 3203.2 Pressure-Relief Devices
- 3203.2.2 Vessels or Equipment Other than Containers
- 3203.2.6 Shutoffs Between Pressure-Relief Devices and Containers
- 3203.3 Pressure-Relief Vent Piping
- 3203.5.3 Securing of Vaporizers
- 3203.5.4 Physical Protection
- 3203.7 Electrical Wiring and Equipment
- 3203.8 Service and Repair
- 3204.4.5 Venting of Underground Tanks
- 3205.1.2 Piping Systems
- 3205.1.2.3.2 Shutoff Valves on Piping
- 3205.3.2 Emergency Shutoff Valves
- 3501.1 Scope
- 3503 General Requirements
- 3503.1.2 Storage Containers
- 3503.1.3 Emergency Shutoff
- 3503.1.5.1 Bonding of Electrically Conductive Materials and Equipment
- 3504 Storage
- 3505 Use

International Fuel Gas Code (International Code Council, 2009)

- 101.2.1 Gaseous Hydrogen Systems
- 703.3 Pressure-Relief Devices
- 703.4 Venting
- 704 Piping, Use, and Handling
- 705 Testing of Hydrogen Piping Systems
- 706.3 Outdoor Gaseous Hydrogen Systems
- 708 Design of Liquefied Hydrogen Systems Associated with Hydrogen Vaporization Operations

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 6.7 Emergency Electrical Disconnects
- 8 Electrical Installations
- 9.2.2 Tank Filling and Bulk Delivery
- 9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities
- 9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association, 2010)

- 5.3 Design and Construction of Containers, Cylinders, and Tanks
- 5.4 Pressure-Relief Devices
- 5.5 Vent Pipe Termination
- 5.6 Pressure Gauges
- 5.7 Pressure Regulators
- 5.8 Fuel Lines
- 5.9 Valves
- 5.10 Hose and Hose Connections
- 5.11 Vehicle Fueling Connection

9.2 General System Requirements
9.2.3 Equipment Security and Vehicle Protection
9.2.4 Out of Service Bulk Storage
9.2.5 Equipment Security and Vehicle Protection
9.2.6 Cargo Transport Unloading
9.2.7 Control Device Icing
9.2.8 Vehicle Ignition Classification
9.2.9 Fueling Connection Leak Prevention
9.2.10 Compression and Processing Equipment
9.2.11 Reference to NFPA 37 for Compressor Installations
9.2.12 Electrical Classification for Compressors
9.2.13 Liquid Carryover Prevention
9.2.14 Detection for Dispensing Equipment
9.2.15 General System Requirements
9.2.16 General System Requirements
9.3 System Siting
9.3.1 General
9.3.1.3 General
9.3.2.3 Outdoors
9.3.3 Indoors
9.3.3.12 Warning Signs
9.3.3.3 Indoors
9.6 Installation of PRDs on Fueling Systems
9.7 Installation of Pressure Gauges
9.9 Installation of Piping and Hoses
9.11 Installation of Emergency Shutdown Equipment
9.12 Installation of Electrical Equipment
9.13 Stray or Impressed Currents and Bonding
9.14 System Operation
9.15 Fire Protection
14.2.4 Indoor Fueling
14.4.3 Liquid Hydrogen Vehicle Dispensing Systems
14.8 Pressure-Relief Devices

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4 General Requirements
6.12 Hazard Identification Signs
7.1.2.5 Pressure-Relief Devices
7.1.4 Security
7.1.6 Separation from Hazardous Conditions
7.3.1.10 Use and Handling
10.2.1 Pressure-Relief Devices
10.2.2 Pressure-Relief Devices
10.2.4 Marking
10.3.2 Specific Requirements
10.3.2.1 Specific Requirements
10.3.2.2 Minimum Distance
11.2.3 Piping, Tubing, and Fittings
11.2.5 Liquefied Hydrogen Vaporizers

11.3.1.4 General

SAE J2600, Compressed Hydrogen Surface Vehicle Refueling Connection Devices (Society of Automotive Engineers, 2002)

Hydrogen Fueling Station Operation Approvals

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

7.0 Maintenance and Repair

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

9 Maintenance

International Fire Code (International Code Council, 2009)

105.6.8 Compressed Gases
105.6.10 Cryogenic Fluids
105.6.39 Repair Garages and Motor Fuel Dispensing Facilities
404 Fire Safety and Evacuation Plan
404.3.2 Fire Safety Plans
406 Employee Training and Response Procedures
406.2 Frequency
407 Hazard Communication
901.6.2 Records
906 Portable Fire Extinguishers
907 Fire Alarm and Detection Systems
907.2 Inspection, Testing, and Maintenance
2204 Dispensing Operations
2204.2 Attended Self-Service Motor Fuel Dispensing Facilities
2204.3 Unattended Self-Service Motor Fuel Dispensing Facilities
2204.3.5 Emergency Procedures
2205.1 Tank Filling Operation for Class I, II, or IIIA Liquids
2206.2.1.1 Inventory Control for Underground Tanks
2209.3.2.3.2 Smoking
2209.3.2.3.3 Ignition Source Control
2209.3.2.6.2 Fire Extinguishing Systems
2209.3.2.6.3 Signage
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel Dispensing Facilities
2209.5.1 Protection from Vehicles
2209.5.2 Emergency Shutoff Valves
2209.5.2.1 Identification
2209.5.3 Emergency Shutdown Controls
2209.5.4 Venting of Hydrogen Systems
3204.5.2 Corrosion Protection
3205.4 Filling and Dispensing
3503.1.4 Ignition Source Control

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

6.2 General Requirements

- 6.3 Requirements for Dispensing Devices
- 6.3.7 Requirements for Dispensing Devices
- 7.3.5 Fixed Fire Protection
- 9.2.2 Tank Filling and Bulk Delivery
- 9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities
- 9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

- 9.2.3 Equipment Security and Vehicle Protection
- 9.2.15 General System Requirements
- 9.2.16 General System Requirements
- 9.3.3.12 Warning Signs
- 9.10.5 Installation of Emergency Shutdown Equipment
- 9.13 System Operation
- 9.14 Fire Protection
- 9.15 Maintenance System
- 14.2.1.6 General
- 14.4.1 Liquid Hydrogen Vehicle Dispensing Systems
- 14.4.2 Liquid Hydrogen Vehicle Dispensing Systems
- 14.4.3 Liquid Hydrogen Vehicle Dispensing Systems
- 14.4.5 Liquid Hydrogen Vehicle Dispensing Systems
- 14.4.11 Liquid Hydrogen Vehicle Dispensing Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

- 4.1 Permits
- 4.2 Emergency Plan
- 4.6 Personnel Training
- 4.7 Fire Department Liaison
- 4.8 Ignition Source Controls
- 4.9 Signs
- 6.12 Hazard Identification Signs
- 7.1.6 Separation from Hazardous Conditions
- 7.6.3 Ignition Source Control
- 10.2.4 Marking
- 10.3 Location of Gaseous Hydrogen Systems
- 11.3.1.4 General

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Liquid Hydrogen Dispensers

International Fire Code (International Code Council, 2009)
2206.7.4 Dispenser Emergency Shutoff Valve
2206.7.5 Dispenser Hose
2206.7.6 Fuel Delivery Nozzles
2209.2 Equipment
2209.3 Location on Property
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)
6.3 Requirements for Dispensing Devices
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
14 Liquid Hydrogen Fueling Facilities

Gaseous Hydrogen Dispensers

International Fire Code (International Code Council, 2009)
2209.2 Equipment
2209.3 Location on Property
2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
9.2 General System Requirements
9.3 System Siting

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Indoor Fueling Facility Construction Approvals

ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)
F323.4(5) Specific Material Considerations—Metals
IX K305 Pipe
IX K306 Fittings, Bends, and Branch Connections
IX K307 Valves and Specialty Components

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)
3.0 Piping System Criteria
3.1 General
3.2 Piping Materials
3.3.2 Isolation Valves
3.3.3 Emergency Isolation Valves
3.3.4 Excess Flow Valves
3.3.5 Check Valves
3.3.7 Gasket and Sealing Materials
3.3.8 Additional Requirements
5.0 Installation
5.1 Piping Installation General
5.1 Installation General
5.2 Piping Installation—Above Ground Installation
5.3 Piping Installation—Underground Installation

International Fire Code (International Code Council, 2009)
906 Portable Fire Extinguishers
907 Fire Alarm and Detection Systems
2209.3.2.3 Indoors
2209.3.2.6.3 Signage
2209.5 Safety Precautions
2209.5.1 Protection from Vehicles
2209.5.2 Emergency Shutoff Valves
2209.5.2.1 Identification
2209.5.3 Emergency Shutdown Controls
2209.5.3.1 System Requirements
2209.5.4 Venting of Hydrogen Systems
2209.5.4.2 Pressure-Relief Devices
2209.5.4.2.1 Minimum Rate of Discharge
2703.2 Systems, Equipment, and Processes
2703.2.2 Piping, Tubing, Valves, and Fittings
3005.3 Piping Systems
3005.4 Valves
3005.5 Venting

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)
5.2 System Approvals
5.3 Design and Construction of Containers, Cylinders, and Tanks
5.4 Pressure-Relief Devices

5.5 Vent Pipe Termination
5.6 Pressure Gauges
5.7 Pressure Regulators
5.8 Fuel Lines
5.9 Valves
5.10 Hose and Hose Connections
5.11 Vehicle Fueling Connection
9.2 General System Requirements
9.2.3 Equipment Security and Vehicle Protection
9.2.4 Out of Service Bulk Storage
9.2.5 Equipment Security and Vehicle Protection
9.2.6 Cargo Transport Unloading
9.2.7 Control Device Icing
9.2.8 Vehicle Ignition Classification
9.2.9 Fueling Connection Leak Prevention
9.2.10 Compression and Processing Equipment
9.2.11 Reference to NFPA 37 for Compressor Installations
9.2.12 Electrical Classification for Compressors
9.2.13 Liquid Carryover Prevention
9.2.14 Detection for Dispensing Equipment
9.2.15 General System Requirements
9.2.16 General System Requirements
9.3 System Siting
9.3.1 General
9.3.1.3 General

9.3.3 **Indoors**

9.3.3.3 Indoors
9.3.3.12 Warning Signs
9.6 Installation of PRDs on Fueling Systems
9.7 Installation of Pressure Gauges
9.9 Installation of Piping and Hoses
9.11 Installation of Emergency Shutdown Equipment
9.12 Installation of Electrical Equipment
9.13 Stray or Impressed Currents and Bonding
9.14 System Operation
9.15 Fire Protection

Indoor Fueling Facility Construction Approvals

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

7.0 Maintenance and Repair

International Fire Code (International Code Council, 2009)

404 Fire Safety and Evacuation Plan
404.3.2 Fire Safety Plans
406 Employee Training and Response Procedures
406.2 Frequency of Training
407 Hazard Communication

901.6.2 Records
906 Portable Fire Extinguishers
907 Fire Alarm and Detection Systems
907.2 Inspection, Testing, and Maintenance
2209.3.2.3 Indoors
2209.3.2.3.2 Smoking
2209.3.2.3.3 Ignition Source Control
2209.3.2.6.3 Signage
2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers
2211.8.1.2 Atmospheric Venting of Hydrogen from Motor Vehicle Fuel Storage Containers
2211.8.1.2.4 Grounding and Bonding
3005.3 Piping Systems
3005.4 Valves
3005.7 Transfer

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.3 Equipment Security and Vehicle Protection
9.2.15 General System Requirements
9.2.16 General System Requirements
9.3.3.12 Warning Signs
9.10.5 Installation of Emergency Shutdown Equipment
9.13 Stray or Impressed Currents and Bonding
9.14 System Operation
9.15 Fire Protection

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Setbacks and Footprints for Fuel Cell Systems

International Fire Code (International Code Council, 2009)
- 2703.9.8 Separations of Incompatible Materials
- 3003.7 Separations from Hazards
- 3004 Storage of Compressed Gases
- 3504.2.1 Distance Limitation to Exposures

International Fuel Gas Code (International Code Council, 2009)
- 706 Location of Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 10.3.2 Specific Requirements

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
- 6.4.1 Gaseous Hydrogen Storage

Fuel Cell Weather Protection

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
- 1.6 Enclosures and Associated Construction

International Building Code (International Code Council, 2009)
- 1609 Wind Loads
- 1612 Flood Loads
- 1805 Footings and Foundation

International Fire Code (International Code Council, 2009)
- 2703.2.8 Seismic Protection
- 2703.9.6 Protection from Light
- 2703.9.7 Shock Padding
- 3003.15 Lighting

International Fuel Gas Code (International Code Council, 2009)
- 302 Structural Safety

International Mechanical Code (International Code Council, 2009)
- 302 Protection of Structure

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 7.1.4.3 Physical Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
- 5.1.1 (2) General Siting

Storage Containers for Compressed Hydrogen Storage

International Fire Code (International Code Council, 2009)
- 2703.2.1 Design and Construction of Containers, Cylinders, and Tanks
- 2703.2.4 Installation of Tanks
- 2703.2.5 Empty Containers and Tanks
- 2703.9.9 Shelf Storage

2704 Storage
3003.1 Containers, Cylinders, and Tanks
3003.2 Design and Construction
3003.4.1 Stationary Compressed Gas Containers, Cylinders, and Tanks
3003.4.2 Portable Containers, Cylinders, and Tanks
3003.6.1 Compressed Gas Container, Cylinder, or Tank Protective Caps or Collars
3004 Storage of Compressed Gases
3503.1.2 Storage Containers

International Fuel Gas Code (International Code Council, 2009)
703.2 Containers, Cylinders, and Tanks

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
7.1.3 Listed and Approved Hydrogen Equipment
7.1.5 Containers Cylinders and Tanks

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
6.4.1 Gaseous Hydrogen Storage

Equipment Location for Compressed Hydrogen Storage

International Fuel Gas Code (International Code Council, 2009)
303 Appliance Location

International Mechanical Code (International Code Council, 2009)
303 Equipment & Appliance Location

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
10.3 Location of Gaseous Hydrogen Systems

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
6.4.1 Gaseous Hydrogen Storage
6.4.3 Hydrogen Piping

Design Standards

Model code provisions related to fuel cell general design issues include:

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
1.2 Power Systems Design
1.3 General Design Requirements
1.4 Materials
1.6 Enclosures and Associated Construction

International Fuel Gas Code (International Code Council, 2009)
302 Structural Safety
633 Stationary Fuel Cell Power Systems
635 Gaseous Hydrogen Systems

International Mechanical Code (International Code Council, 2009)
302 Protection of Structure
924 Stationary Fuel Cell Power Systems
926 Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.1 Listed and Approved Hydrogen Equipment
7.1.4.3 Physical Protection
10.2 Design of Gaseous Hydrogen Systems

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

4.2 Prepackaged, Self-Contained Fuel Cell Power Systems
4.3 Pre-Engineered Fuel Cell Power Systems
4.4 Engineered and Field-Constructed Fuel Cell Power Systems
5.1.1 (2) General Siting
6.4.1 Gaseous Hydrogen Storage

International Building Code (International Code Council, 2009)

1609 Wind Loads
1612 Flood Loads
1805 Footings and Foundation
International Fire Code (International Code Council, 2006)
2703.2.8 Seismic Protection
2703.9.6 Protection from Light
2703.9.7 Shock Padding
3003.15 Lighting

Fuel Cell Equipment Specifications

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.3 Labeling Requirements
7.3.1.4 Piping Systems
7.3.1.5 Valves
10.2.1 Pressure-Relief Devices
10.2.1.1 Venting Requirements
10.2.4 Marking
10.3 Location of Gaseous Hydrogen Systems
10.4.1.2 Electrical Equipment Location
10.6 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

5.2 Outdoor Installations
6.1.2 General
6.4.1 Ventilation Air
6.4.1 Gaseous Hydrogen Storage
6.4.3 Hydrogen Piping
6.4.3.1 Hydrogen Piping
6.4.3.2 Hydrogen Piping
6.4.3.5 Hydrogen Piping
6.4.3.7 Hydrogen Piping
7.1.1 General
7.2.2 When Natural ventilation Permitted
7.3 Exhaust Systems
8.1.2 Fuel Cell Fire Protection and Detection
8.1.3 Electrical Equipment and Components

9.2 Outdoor Installations
703.4 Venting
703.6 Electrical Wiring and Equipment

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)

1.12.1 Manual Valves
1.12.2 Automatic Valves
1.12.3 Pressure Regulators
1.15 Electrical Equipment and Wiring
1.5 General Construction and Assembly
1.6 Enclosures and Associated Construction
1.8.1 Metallic Piping
1.9 Drain, Venting and Ventilation Exhaust Systems
1.19.1 Materials for Markings
1.19.2 FC Labeling Requirements
1.19.4 - 1.19.7 Electrical Diagrams

International Fire Code (International Code Council, 2009)

2703.2.2 Piping, Tubing, Valves, and Fittings
2703.3 Release of Hazardous Materials
2703.4 Material Safety Data Sheets
2703.9.2 Security
2703.9.3 Protection from Vehicles
2703.9.4 Electrical Wiring and Equipment
2703.9.5 Static Accumulation
3003.16.13 Accessway
3003.3 Pressure-Relief Devices
3003.4 Gas Marking
3003.4.3 Piping Systems
3003.5 Security
3003.6 Valve Protection
3003.8 Wiring and Equipment
3003.10 Unauthorized Use
3003.12 Leaks, Damage, or Corrosion
3003.13 Surface of Unprotected Storage or Use Areas
3003.14 Overhead Cover
3005.3 Piping Systems
3005.4 Valves
3005.5 Venting
3203.4 Liquid Marking
3503.1.3 Emergency Shutoff
3503.1.4 Ignition Source Control
3503.1.5 Electrical

International Fuel Gas Code (International Code Council, 2009)

303 Appliance Location
305 Installation
409 Shutoff Valves
703.3 Pressure-Relief Devices
703.4 Venting

703.5 Security
703.6 Electrical Wiring and Equipment
704 Piping, Use and Handling

International Mechanical Code (International Code Council, 2009)

303 Equipment & Appliance Location
304 Installation
305 Piping Support
401 General
501 Exhaust Systems
502 Required Systems
510 Hazardous Exhaust Systems

General Safety Requirements for Compressed Hydrogen Storage

International Fire Code (International Code Council, 2009)

2703.4 Material Safety Data Sheets
2703.9.2 Security
2703.9.3 Protection from Vehicles
3003.5 Security
3003.10 Unauthorized Use
3003.12 Leaks, Damage, or Corrosion
3003.13 Surface of Unprotected Storage or Use Areas
3003.14 Overhead Cover
3503.1.3 Emergency Shutoff
3503.1.4 Ignition Source Control

International Fuel Gas Code (International Code Council, 2009)

409 Shutoff Valves
703.5 Security

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.3 Location of Gaseous Hydrogen Systems

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

6.4.3.2 Hydrogen Piping
6.4.3.5 Hydrogen Piping
6.4.3.7 Hydrogen Piping
6.4.3.1 Hydrogen Piping

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Construction for Fuel Cell Fire Safety

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
- 1.5 General Construction and Assembly
- 1.6 Enclosures and Associated Construction

International Fuel Gas Code (International Code Council, 2009)
- 305 Installation

International Mechanical Code (International Code Council, 2009)
- 304 Installation

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
- 5.2 Outdoor Installations
- 9.2 Outdoor Installations

Equipment for Fuel Cell Fire Safety

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 10.6 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
- 8.1.2 Fuel Cell Fire Protection and Detection

Signage for Fuel Cell Fire Safety

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
- 1.19.1 Materials for Markings
- 1.19.2 FC Labeling Requirements
- 1.19.4 - 1.19.7 Electrical Diagrams

International Fire Code (International Code Council, 2009)
- 3003.4 Gas Marking
- 3003.16.13 Accessway
- 3203.4 Liquid Marking

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 7.1.7 Labeling Requirements
- 10.2.5 Marking

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
- 6.1.2 General

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Storage Containers for Compressed Hydrogen Storage

International Fire Code (International Code Council, 2009)
- 2703.2.1 Design and Construction of Containers, Cylinders, and Tanks
- 2703.2.4 Installation of Tanks
- 2703.2.5 Empty Containers and Tanks
- 2703.9.9 Shelf Storage
- 2704 Storage
- 3003.1 Containers, Cylinders, and Tanks
- 3003.2 Design and Construction
- 3003.4.1 Stationary Compressed Gas Containers, Cylinders, and Tanks
- 3003.4.2 Portable Containers, Cylinders, and Tanks
- 3003.6.1 Compressed Gas Container, Cylinder, or Tank Protective Caps or Collars
- 3004 Storage of Compressed Gases
- 3503.1.2 Storage Containers

International Fuel Gas Code (International Code Council, 2009)
- 703.2 Containers, Cylinders, and Tanks

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 7.1.1 Listed and Approved Hydrogen Equipment
- 7.1.2 Containers, Cylinders and Tanks

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
- 6.4.1 Gaseous Hydrogen Storage

Equipment Location for Compressed Hydrogen Storage

International Fuel Gas Code (International Code Council, 2009)
- 303 Appliance Location

International Mechanical Code (International Code Council, 2009)
- 303 Equipment & Appliance Location

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
- 10.3 Location of Gaseous Hydrogen Systems

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
- 6.4.1 Gaseous Hydrogen Storage
- 6.4.3 Hydrogen Piping

General Safety Requirements for Compressed Hydrogen Storage

International Fire Code (International Code Council, 2009)
- 2703.4 Material Safety Data Sheets
- 2703.9.2 Security
- 2703.9.3 Protection from Vehicles
- 3003.5 Security
- 3003.10 Unauthorized Use
- 3003.12 Leaks, Damage, or Corrosion

3003.13 Surface of Unprotected Storage or Use Areas
3003.14 Overhead Cover
3503.1.3 Emergency Shutoff
3503.1.4 Ignition Source Control

International Fuel Gas Code (International Code Council, 2009)

409 Shutoff Valves
703.5 Security

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.3 Location of Gaseous Hydrogen Systems

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

6.4.3.2 Hydrogen Piping
6.4.3.5 Hydrogen Piping
6.4.3.7 Hydrogen Piping
6.4.3.1 Hydrogen Piping

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Electrical Equipment for Fuel Cell Systems

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
1.15 Electrical Equipment and Wiring
International Fire Code (International Code Council, 2009)
2703.9.4 Electrical Wiring and Equipment
2703.9.5 Static Accumulation
3003.8 Wiring and Equipment
3503.1.5 Electrical
International Fuel Gas Code (International Code Council, 2009)
703.4 Venting
703.6 Electrical Wiring and Equipment
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
6.6 Electrical Equipment
NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
8.1.3 Electrical Equipment and Components

Equipment for Fuel Cell Fire Safety

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
10.6 Fire Protection
NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
8.1.2 Fuel Cell Fire Protection and Detection

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Fuel Lines for Hydrogen Dispensing

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)
3.0 Piping System Criteria
International Fire Code (International Code Council, 2009)
2201 Scope
2209.3.2.3 Indoors
2209.3.2.6 Canopy Tops
3501.1 Scope
International Fuel Gas Code (International Code Council, 2009)
101.2.1 Gaseous Hydrogen Systems
704 Piping, Use, and Handling
705 Testing of Hydrogen Piping Systems
NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2006)
5.8 Fuel Lines

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Piping and Tubing for Fuel Cell Systems

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
1.8.1 Metallic Piping
International Fire Code (International Code Council, 2009)
2703.2.2 Piping, Tubing, Valves, and Fittings
3003.4.3 Piping Systems
3005.3 Piping Systems
International Fuel Gas Code (International Code Council, 2009)
704 Piping, Use and Handling
International Mechanical Code (International Code Council, 2009)
305 Piping Support
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
7.3.1.3 Piping Systems
NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
6.4.1 Ventilation Air
6.4.3 Hydrogen Piping

Pressure Relief for Fuel Cell Systems

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
1.12.3 Pressure Regulators
International Fire Code (International Code Council, 2009)
3003.3 Pressure-Relief Devices
International Fuel Gas Code (International Code Council, 2009)
703.3 Pressure-Relief Devices
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
10.2.1 Pressure-Relief Devices
NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
6.4.1 Gaseous Hydrogen Storage

Valves and Fittings for Fuel Cell Systems

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
1.12.1 Manual Valves
1.12.2 Automatic Valves
International Fire Code (International Code Council, 2009)
2703.2.2 Piping, Tubing, Valves, and Fittings
3003.6 Valve Protection
3005.4 Valves
NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.3.1.3 Piping Systems
7.3.1.4 Valves

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

6.4.1 Gaseous Hydrogen Storage

Venting and Other Equipment for Fuel Cell Systems

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)

1.9 Drain, Venting and Ventilation Exhaust Systems

International Fire Code (International Code Council, 2009)

2703.3 Release of Hazardous Materials
3005.5 Venting

International Mechanical Code (International Code Council, 2009)

401 General
501 Exhaust Systems
502 Required Systems
510 Hazardous Exhaust Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.2.2.1 Venting Requirements

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

7.1.1 General
7.2.2 When Natural ventilation Permitted
7.3 Exhaust Systems

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Signage for Fuel Cell Systems

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)

1.19.1 Materials for Markings
1.19.2 FC Labeling Requirements
1.19.4 - 1.19.7 Electrical Diagrams

International Fire Code (International Code Council, 2009)

2703.5 Hazard Identification Signs
2703.6 Signs

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.7 Labeling Requirements
10.2.5 Marking

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

6.1.2 General
6.4.1 Gaseous Hydrogen Storage
6.4.3 Hydrogen Piping

Personnel Issues and Training for Fuel Cell Systems

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association, 2006)

4.4 Regulating Authorities of Employee Safety and Health

International Fire Code (International Code Council, 2009)

406 Employee Training and Response Procedures

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.6 Personnel Training
4.7 Fire Department Liaison

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Delivery of Hydrogen for Fuel Cell Systems

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association, 2006)
4.1 Transportation Regulating Authorities
4.2 Container Regulations
4.3 Container Filling Regulations
6.2 Flammable Gases

International Fire Code (International Code Council, 2009)
105.6.8 Compressed Gases
404.3.2 Fire Safety Plans
2705 Use, Dispensing, and Handling
3005.7 Transfer
3505 General Use

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
7.3.10 Use and Handling
8.3.5 Overfilling
10.3 Location of Gaseous Hydrogen Systems

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Fire and Emergency Planning for Fuel Cell Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)
10.6 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)
8.2 Fire Prevention and Emergency Planning

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Periodic Inspections for Fuel Cell Systems

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)

1.18.2 Maintenance Manual

International Fire Code (International Code Council, 2009)

2703.2.6 Maintenance

3003.9 Service and Repair

International Fuel Gas Code (International Code Council, 2009)

707 Operation and Maintenance of Gaseous Hydrogen Systems

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Construction Approvals for Telecommunications Site Using Fuel Cell for Backup Power

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)

- 1.2 Power Systems Design
- 1.3 General Design Requirements
- 1.3.2 Protection from Environmental Conditions
- 1.3.3 Electrical Safety
- 1.3.5 Steam Backflow
- 1.3.6 FC System Purging
- 1.3.7 Safe Handling During Moving
- 1.3.8 Shock and Vibration Protection
- 1.3.9 Requirements for Not-Listed Equipment
- 1.3.11 Temperature Limits
- 1.4 Materials
- 1.5 General Construction and Assembly
- 1.6 Enclosures and Associated Construction
- 1.8.1 Metallic Piping
- 1.9 Drain, Venting, and Ventilation Exhaust Systems
- 1.12.1 Manual Valves
- 1.12.2 Automatic Valves
- 1.12.3 Pressure Regulators
- 1.15 Electrical Equipment and Wiring
- 1.19.1 Materials for Markings
- 1.19.2 FC Labeling Requirements
- 1.19.4 - 1.19.7 Electrical Diagrams

International Building Code (International Code Council, 2009)

- 307.1.1 Maximum Allowable Quantities
- 414.1 General
- 414.2 Control Areas
- 414.4 Hazardous Materials Systems
- 414.6 Outdoor Storage, Dispensing, and Use
- 907 Fire Alarms and Detection Systems
- 1609 Wind Loads
- 1612 Flood Loads
- 1805 Footings and Foundation

International Fire Code (International Code Council, 2009)

- 401 General Emergency Planning and Preparedness
- 406 Employee Training and Response Procedures
- 2703.1 Hazardous Materials
- 2703.1.1 Maximum Allowable Quantities per Control Area
- 2703.1.3 Quantities Not Exceeding the Maximum Allowable Quantity per Control Area
- 2703.1.4 Quantities Exceeding the Maximum Allowable Quantity per Control Area
- 2703.2 Systems, Equipment, and Processes

2703.2.1 Design and Construction of Containers, Cylinders, and Tanks
2703.2.2 Piping, Tubing, Valves, and Fittings
2703.2.3 Equipment, Machinery, and Alarms
2703.2.4 Installation of Tanks
2703.2.5 Empty Containers and Tanks
2703.2.8 Seismic Protection
2703.2.9 Testing
2703.3 Release of Hazardous Materials
2703.4 Material Safety Data Sheets
2703.8 Construction Requirements
2703.8.1 Buildings
2703.8.2 Required Detached Buildings
2703.8.3 Control Areas
2703.8.4 Gas Rooms
2703.8.5 Exhausted Enclosures
2703.8.6 Gas Cabinets
2703.8.7 Hazardous Materials Storage Cabinets
2703.9 General Safety Precautions
2703.9.1 Personnel Training and Written Procedures
2703.9.1.1 Fire Department Liaison
2703.9.2 Security
2703.9.3 Protection from Vehicles
2703.9.4 Electrical Wiring and Equipment
2703.9.5 Static Accumulation
2703.9.6 Protection from Light
2703.9.7 Shock Padding
2703.9.8 Separations of Incompatible Materials
2703.9.9 Shelf Storage
2703.12 Outdoor Control Areas
2704 Storage
2705 Use, Dispensing, and Handling
3003.1 Containers, Cylinders, and Tanks
3003.2 Design and Construction
3003.3 Pressure-Relief Devices
3003.4 Gas Marking
3003.4.1 Stationary Compressed Gas Containers, Cylinders, and Tanks
3003.4.2 Portable Containers, Cylinders, and Tanks
3003.4.3 Piping Systems
3003.5 Security
3003.6 Valve Protection
3003.6.1 Compressed Gas Container, Cylinder, or Tank Protective Caps or Collars
3003.7 Separations from Hazards
3003.8 Wiring and Equipment
3003.10 Unauthorized Use
3003.11 Exposure to Fire
3003.12 Leaks, Damage, or Corrosion
3003.13 Surface of Unprotected Storage or Use Areas
3003.14 Overhead Cover

3003.15 Lighting
3003.16.13 Accessway
3004 Storage of Compressed Gases
3005 Use and Handling of Compressed Gases
3005.1 Compressed Gas Systems
3005.2 Controls
3005.3 Piping Systems
3005.4 Valves
3005.5 Venting
3005.6 Upright Use
3005.7 Transfer
3005.9 Material-Specific Regulations
3005.10 Handling
3203.4 Liquid Marking
3503.1 Quantities Not Exceeding the Maximum Allowable Quantity per Control Area
3503.1.2 Storage Containers
3503.1.3 Emergency Shutoff
3503.1.4 Ignition Source Control
3503.1.5 Electrical
3503.2 Quantities Exceeding the Maximum Allowable Quantity per Control Area
3504.2 Outdoor Storage
3504.2.1 Distance Limitation to Exposures
3505 General Use

International Fuel Gas Code (International Code Council, 2009)

301 General
302 Structural Safety
303 Appliance Location
305 Installation
409 Shutoff Valves
633 Stationary Fuel Cell Power Systems
635 Gaseous Hydrogen Systems
703.2 Containers, Cylinders, and Tanks
703.3 Pressure-Relief Devices
703.4 Venting
703.5 Security
703.6 Electrical Wiring and Equipment
704 Piping, Use, and Handling
705 Testing of Hydrogen Piping Systems
706 Location of Gaseous Hydrogen Systems

International Mechanical Code (International Code Council, 2009)

301 General
302 Protection of Structure
303 Equipment and Appliance Location
304 Installation
305 Piping Support
401 General
501 Exhaust Systems
502 Required Systems

510 Hazardous Exhaust Systems
924 Stationary Fuel Cell Power Systems
926 Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.1 Listed and Approved Hydrogen Equipment
7.1.2 Containers, Cylinders, and Tanks
7.1.3 Listed and Approved Hydrogen Equipment
7.1.4.3 Physical Protection
7.1.6 Separation from Hazardous Conditions
7.3.1.4 Valves
7.6 Flammable Gases
10.2 Design of Gaseous Hydrogen Systems
10.2.1 Pressure-Relief Devices
10.2.1.1 Venting Requirements
10.2.5 Marking
10.3 Location of Gaseous Hydrogen Systems
10.3.2 Specific Requirements
10.4.1.2 Electrical Equipment Location
10.6 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

4.2 Prepackaged, Self-Contained Fuel Cell Power Systems
4.3 Pre-Engineered Fuel Cell Power Systems
4.4 Engineered and Field-Constructed Fuel Cell Power Systems
5.1.1 General Siting
5.1.1 (2) General Siting
5.1.2 General Siting
5.1.3 General Siting
5.2 Outdoor Installations
6.1.2 General
6.4.1 Gaseous Hydrogen Storage
6.4.1 Ventilation Air
6.4.3 Hydrogen Piping
6.4.3.2 Hydrogen Piping
6.4.3.5 Hydrogen Piping
6.4.3.7 Hydrogen Piping
6.4.3.1 Hydrogen Piping
7.1.1 General
7.2.2 When Natural ventilation Permitted
7.3 Exhaust Systems
8.1.2 Fuel Cell Fire Protection and Detection
8.1.3 Electrical Equipment and Components
9.2 Outdoor Installations
9.5 Fire Protection

Operation Approvals for Telecommunications Site Using Fuel Cell for Backup Power

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)

1.18.2 Maintenance Manual
1.19.1 Materials for Markings
1.19.2 FC Labeling Requirements
1.19.4 - 1.19.7 Electrical Diagrams

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association, 2006)

4.1 Transportation Regulating Authorities
4.2 Container Regulations
4.3 Container Filling Regulations
4.4 Regulating Authorities of Employee Safety and Health
6.2 Flammable Gases

International Fire Code (International Code Council, 2009)

105.6.8 Compressed Gases
404.3.2 Fire Safety Plans
406 Employee Training and Response Procedures
2703.2.6 Maintenance
2703.5 Hazard Identification Signs
2703.6 Signs
2705 Use, Dispensing, and Handling
3003.4 Gas Marking
3003.9 Service and Repair
3003.16.13 Accessway
3005.7 Transfer
3203.4 Liquid Marking
3505 General Use

International Fuel Gas Code (International Code Council, 2009)

707 Operation and Maintenance of Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.6 Personnel Training
4.7 Fire Department Liaison
7.1.3 Listed and Approved Hydrogen Equipment
7.3.1.10 Use and Handling
8.3.5 Overfilling
10.2.5 Marking
10.3 Location of Gaseous Hydrogen Systems
10.6 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

6.1.2 General
6.4.1 Gaseous Hydrogen Storage
6.4.3 Hydrogen Piping
8.2 Fire Prevention and Emergency Planning