Hydrogen Fleet Applications

Notes

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Introduction

There are many options available for fleet managers who wish to convert their fleets to alternative fuel vehicles. The previous section provided an overview of alternative fuel options and their benefits and drawbacks. This section will provide information specific to the use of hydrogen as an alternative fuel.

The use of hydrogen as a widespread alternative fuel is not yet a viable option, but its use in localized fleets is a current option. The biggest obstacle for the use of hydrogen is a nationwide production and distribution infrastructure. However, it is currently a main focus of research as a future widespread alternative fuel. There are two pathways for the use of hydrogen as a fuel: use as a fuel for a modified ICE or as the fuel for use with hydrogen fuel cells.

The goal of this section is to provide the necessary information for fleet managers to determine if their business fits the current niche for use with hydrogen fuel technologies.

Objectives

- Explain how to implement green fleets
- Learn about incentives for converting to hydrogen fleets
- Learn about the availability and cost of hydrogen
- Identify the advantages of using hydrogen
- Understand how to safely handle hydrogen

Greening of Fleets

There can be challenges to starting a green fleet, or converting an existing fleet to the use of alternative fuels. According to some industry experts, a successful plan to reduce fuel consumption and carbon emissions requires a long-term vision, incremental change, support from top management, and flexibility to make changes along the way.

There are compelling reasons why fleets should be green and deliberate steps on how to implement alternative fuels.[1]

Why use Green Fleets?

- **Reduce operating costs** by improving efficiency, reducing lifecycle costs, and reduce vulnerability to volatile fuel prices.
- **Reduce greenhouse gas emissions** by implementing the use of hydrogen in vehicles, which are the primary source of greenhouse and urban air pollution.
- **Improve corporate image** by branding business strategies and appealing to public concerns about energy conservation and ecological sensibilities.

How to Implement Green Fleets

- **Get buy-in** from all management and staff levels, and be sure to communicate information about the benefits, goals, and targets frequently.
- **Create long-term objectives** and tangible goals based on best practices in the industry (such as baselines, benchmarks, and progress reports).
- **Avoid setting reduction goals in absolute numbers** for growing fleets or fleets just starting because absolute goals can impede growth.
- **Anticipate obstacles**, such as driver resistance, lag time between original equipment manufacturers' technology and market availability, and slower return on investment.
- **Move slowly** and implement change over time.
- **Improve vehicle use** with selection analysis and education of drivers.
- **Track and report progress** and share successes with employees, shareholders and the public.

Hydrogen Fleets

As shown in **Figure 1**, hydrogen is the simplest element in the universe, consisting of only one proton and one electron. It is No. 1 on the periodic table of elements. It naturally occurs in gaseous form as a diatomic element, meaning it exists as bonded pairs. For this reason hydrogen is often represented with the chemical formula of H_2. It is a gaseous fuel that can be used to create mechanical energy through combustion.

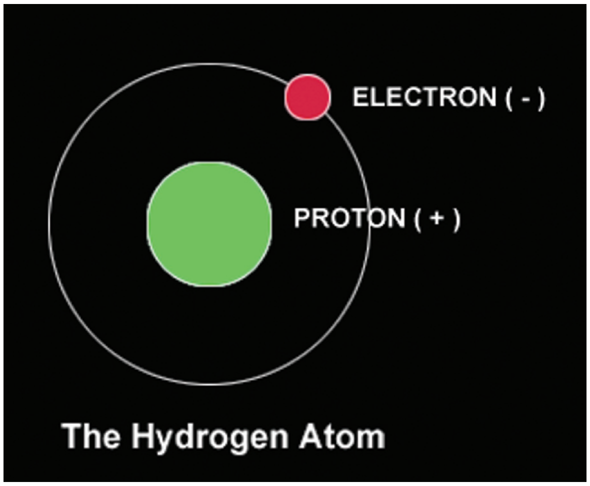

Figure 1: *The hydrogen atom has one proton and one electron. Source: NAFTC.*

The Alternative Fuels and Advanced Vehicles Data Center (AFDC) explains that very little hydrogen is present in Earth's atmosphere. Hydrogen is found mainly bonded with an oxygen atom in the form of water (H_2O), in hydrocarbons such as methane (CH_4), and in other organic matter.

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There are two main categories of hydrogen-powered vehicles, those that use internal combustion engines (ICEs) and those that use fuel cells to produce power. Similar to conventional vehicles powered by ICEs, hydrogen-powered vehicles have an internal combustion engine (ICE) that burns hydrogen (H_2) as fuel. Hydrogen gas also can be used as a fuel source for a fuel cell—a device that creates an electrical current to power a vehicle.

A mainstream distribution network does not currently exist for the use of hydrogen as a vehicle fuel. Hydrogen is most commonly produced by steam-methane reforming (the process of converting methane into hydrogen and carbon monoxide by causing a chemical reaction with steam). Methane, the primary component of natural gas, has the highest hydrogen-to-carbon ratio of any fuel, which is what makes it an affordable and effective method of hydrogen production. After steam-reformation, the hydrogen is typically stored either in a pressurized gas state or as a cryogenic liquid. It also must be stored in these states onboard vehicles in order to provide enough energy for vehicle operation comparable to conventional fuels.

Did You Know?

Natural gas reforming using steam accounts for about 95% of the approximately 9 million tons of hydrogen produced in the United States annually.

Source: AFDC, 2011

Hydrogen does require energy to be produced and processed to a usable form. This process often uses domestically produced methane along with domestically produced electricity, which provides for benefits to the U.S. economy and to energy security. When used by fleets for public transportation it can provide for significant localized emission reductions. The main byproduct of hydrogen use for ICEs or fuel cells is simply water, H_2O. The current state of hydrogen as a transportation fuel is mainly based on demonstration projects and initiatives. These projects are producing public fueling stations and special lease programs for hydrogen vehicles (see **Figure 2**).

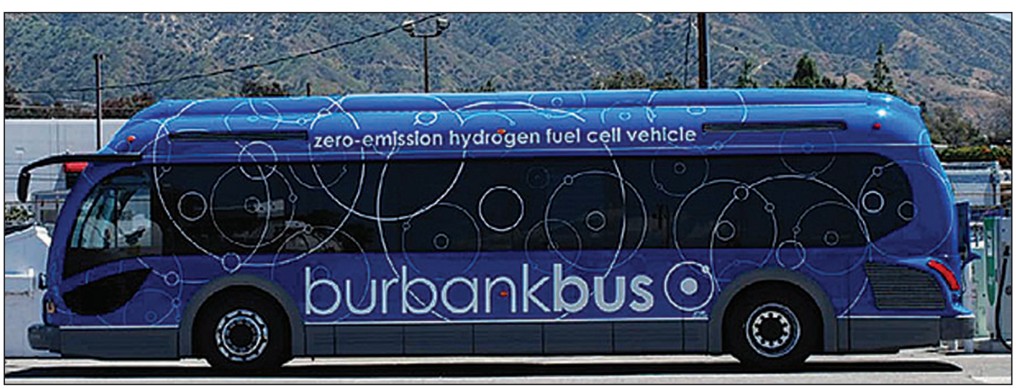

Figure 2: *Hydrogen fuel cell bus. Source: NREL.*

Incentives for Using Hydrogen in Fleets

Incentives propagate the growth and purchasing power within organizations that are needed for strong commercial markets. Incentives include partnership initiatives and pooled resources, financial subsidies, and informational tools. In the following section we will discuss incentives available that augment fleet managers' efforts to implement hydrogen use in their fleets.

Recent industry surveys have confirmed that fleet operations are voluntarily purchasing alternative fuel vehicles to meet specific EPAct regulations and mandates by the federal government. Many alternative fuel and advanced technology vehicles, however, cost more than their gasoline-powered counterparts, and determining how to pay for these more expensive vehicles has become a growing concern for fleet managers across the country. Fortunately, there is financial help available.

Despite the fluctuating economy and budget woes, there are a record number of grants and incentives available for funding alternative fuel vehicles. For example, in 2009, the U.S. Department of Energy (DOE) made nearly $300 million of American Reinvestment and Recovery Act (ARRA) funding available through the Clean Cities program. This single grant funding opportunity is responsible for putting more than 9,000 alternative-fuel and energy-efficient vehicles on the road.

Tax Incentives

The Internal Revenue Service (IRS) has several tax credits available for the development of hydrogen as a viable alternative fuel. These include incentives for production of hydrogen fuel, development of infrastructure, and fleet managers converting their vehicles to use hydrogen.

> **Tools to Help!**
> *Every state has some form of tax credit or rebate for using alternative fuels.*
> ***To find state-specific tax incentives, visit:*** *www.afdc.energy.gov/afdc/laws/search*

Federal Grant Funding

When it comes to grant opportunities, the federal government is by far the largest and most consistent source of funding. Many federal agencies offer funding opportunities, but the majority of funding for alternative fuel vehicles and transportation-related projects comes from a handful of federal agencies, such as the U.S. Department of Energy (DOE), Department of Transportation (DOT), Environmental Protection Agency (EPA), and U.S. Department of Agriculture (USDA). These agencies have information on their funding opportunities available on their respective websites.

Notes

State Grant Funding

Many states have developed aggressive grant funding programs during the past few years. While each state has different grant funding sources, the designated State Energy Office (SEO) is typically the largest alternative fuel vehicle grant funding source in each state. To make it easy to identify each state's SEO, the National Association of State Energy Officials (NASEO) publishes a directory of State Energy Offices online. The DOE's Alternative Fuels Data Center (AFDC) also publishes an interactive web-based map that allows users to click on any state in the country to get information on alternative fuel vehicle incentives and funding sources.[2] There is a multitude of state-level funding programs for clean air vehicle and transportation projects, but visiting the NASEO and AFDE websites will provide the starting points for any fleet manager interested in state-level funding programs.

Incentives for Hydrogen Production

An example of previous incentives for hydrogen production included the American Recovery and Reinvestment Act of 2009 that provided incentives for the production of hydrogen. A fueling tax credit (up to 30%) was available for hydrogen fueling stations from $30,000 to $200,000 in order to aid in growing the necessary fueling infrastructure. Changes were made such that companies not eligible for tax credits could apply for energy property grants for assistance in hydrogen development. A 30% tax credit was also available for investments in property that had the ability to manufacture hydrogen. In addition to incentives for direct hydrogen production, other incentives for technology that utilize hydrogen such as fuel cells have increased in availability. With an increase in products that utilize hydrogen, the overall demand will assist in the growth of production and distribution sites.

Hydrogen Availability and Cost

Hydrogen fuel is not yet widely available because of the challenges of cost-effective production, storage, and distribution. There is also little demand for hydrogen as a vehicle fuel outside of research and demonstration projects. As more hydrogen consuming technologies are developed the demand for hydrogen will increase, assisting in the availability and cost of hydrogen as vehicle fuel.

In the U.S. and around the world, the deployment of hydrogen energy technology primarily takes place through the use of demonstration systems. As of January 2012, there were 56 hydrogen fueling stations across the country[3] and nearly all were closed to public access.

With 35 hydrogen fueling stations, California is committed to using H_2 fuel, and is planning to build a network of H_2 fueling stations — a "Hydrogen Highway" —that will allow hydrogen-powered vehicles to be driven between San Diego and Sacramento, a corridor covering 500 miles. The first combined hydrogen and gasoline service station in the nation opened in November 2004 in Washington, DC.

To find the nearest hydrogen station, *visit the DOE's Alternative Fueling Station Locator at: www.afdc.energy.gov/afdc/locator/stations*

Demonstration projects show the viability of using hydrogen fuel in fleet applications and for commercial use. As the technology for producing hydrogen fuel improves, and more hydrogen-powered vehicles are produced, hydrogen fueling stations will become more prolific. The map below shows the hydrogen fuel stations currently operating in each state (see **Figure 3**).

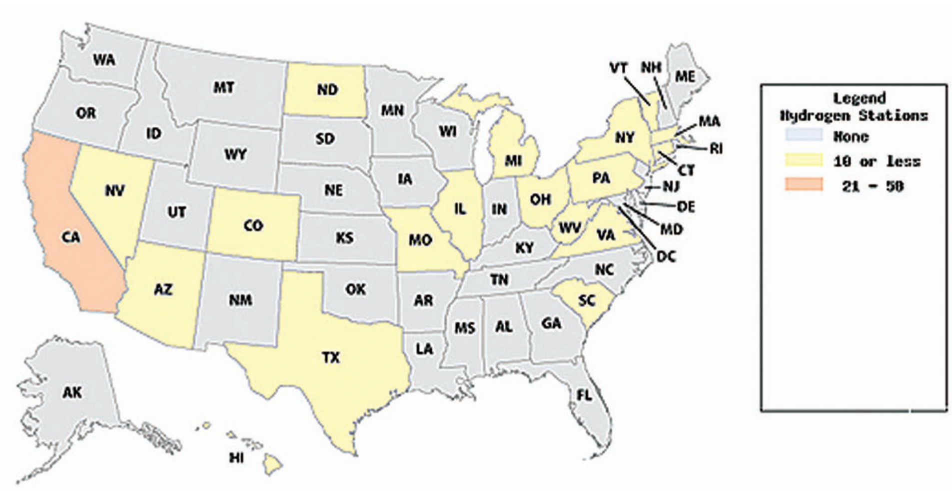

Figure 3: *Hydrogen fueling stations to date. Source: AFDC.*

Production: Steam-Methane Reforming

The most energy-efficient and most common way to produce H_2 gas for vehicle fuel is known as steam-methane reforming. This method requires heat (1022°F/550°C) and high pressure (225 psi) along with a catalyst to initiate and sustain the process. Methane is pumped into a heated pressurized storage tank and a small boiler, fired by some of the methane gas or other energy source, is used to produce high-pressure steam. In the heated storage tank, steam and methane are mixed together in the presence of a catalyst, such as nickel.

Notes

The steam combines with the methane to form carbon monoxide (CO) and release H_2. The CO created in this first step then reacts with more steam to produce carbon dioxide (CO_2), thereby releasing more H_2. The only waste products from the steam reforming process are CO_2, a small amount of CO, and heat.

The H_2 produced by the reforming process is purified and stored in pressurized tanks or as a cryogenic liquid for later use with vehicles.

Production: Electrolysis

Electrolysis of water, or water-splitting, is another promising technology for creating hydrogen fuel. Electrolysis is currently about half as efficient as steam reforming, but the development of an economical and efficient water splitting process would be a key technology for the future development of a hydrogen-based fuel system. One future method may utilize renewable energy sources such as solar, wind, and water power to electrolyze water for the production of pure hydrogen. This would then be used as vehicle fuel, providing for significant emissions reductions and a nearly carbon neutral energy process.

On-site Production

One of the least-expensive and most efficient approaches is to distribute fuels such as methanol and methane through existing pipeline systems and reform these into hydrogen fuel either at the fueling site or on board the vehicle. Developing hydrogen fuel on-site would eliminate the need for extensive transportation capabilities, but also would limit the deployment of hydrogen dispensers. Recent improvements in this technology include the opening of a hydrogen fueling station in August 2011, at the site of the Orange County Sanitation District waste treatment facility in Fountain Valley, California. This hydrogen station uses the methane from sewage as the basis for producing hydrogen![4]

If public fueling stations are available, they are often calibrated to dispense hydrogen by the kilogram instead of gallon. This is convenient because a kilogram of H_2 has approximately the same energy density of a gallon of gasoline. One gallon of gasoline carries about 129,000 Btu of chemical energy. A kilogram of hydrogen has about 133,000 Btu of chemical energy.

With buy-in from the government, energy suppliers, automakers, and the public, a hydrogen-based fuel system is economically viable. As it currently stands, 70% of the United States population lives within 60 miles of a hydrogen generating facility, though most people do not have access to that hydrogen. With an investment of $10-$15 billion, a hydrogen fueling station could be deployed within two miles of the top 100 metro areas. That investment would be roughly half the cost of the Alaskan pipeline when adjusted for inflation.[5]

Cost

The equivalent-per-gallon cost of hydrogen fuel has decreased over the past three years. Increase in availability is one of the contributing factors to the price decrease, as are technical improvements in the process to create hydrogen fuel. In 2009, hydrogen was more than six times as expensive as gasoline. By the beginning of 2012, the GGE of hydrogen was only $0.12 more than gasoline (see **Figure 4**). The national average is based on limited numbers of public fueling stations. In fact two of the reporting stations in 2012 offered hydrogen free to consumers; these were not included in the 2012 average.

Fuel	Area	2012 Cost	2009 Cost
Conventional Gasoline	National Average	$3.37	$1.86
Hydrogen	National Average	$3.49	$12.32

Figure 4: *Fuel type cost comparison, 2009-2012. Source: AFDC.*[6]

Hydrogen Cost Factors

- *Production*
- *Infrastructure development*
- *Transportation*
- *Storage*

Hydrogen Advantages

There are advantages and things to consider when using hydrogen as an alternative fuel. Below is a list of factors that affect decisions to use hydrogen in fleets.

Advantages

- Produced domestically
- Eliminates localized emissions of CO, HC, PM and CO_2 while producing only trace amounts of NO_x when used as fuel for ICEs
- Continues to create jobs in the research and development fields
- Will create new jobs in vehicle and fueling system production
- Harmless if spilled or released on land or water
- Nontoxic
- Offers the same performance as conventional vehicles
- Reduces U.S dependence on foreign oil

Things to Consider

- Limited availability in terms of fuel and vehicles
- Lower energy density based on volume means that fuel tanks are larger
- No available distribution network or infrastructure as is available for some other alternative fuels
- Current production uses CH_4, which is nonrenewable but domestically produced
- Uses energy from other polluting energy sources for production of pure hydrogen

Hydrogen Performance and Safety

Performance and safety are major factors to consider in the successful application of alternative fuels. Using alternative fuels in fleets should not sacrifice operating performance and should provide a safe alternative to conventional fuel.

Performance

Compared to conventional fuels, H_2 has a wide flammability range. A hydrogen-based, air-fuel mixture containing as little as 4% hydrogen will burn, and one containing up to 79% also will burn. Gasoline will burn only when the mixture contains between 1% and 7.6% fuel.[7] This means that H_2 will burn in an internal combustion engine over a broad range of fuel-air mixtures.

When hydrogen is burned in a dedicated and optimized hydrogen internal combustion engine, performance of the vehicle may be better than with a conventional gasoline engine. Hydrogen has a high flame speed and flame temperature. Because of this, alterations to the fuel management and timing systems are required for hydrogen to be used in a conventional ICE. Once proper modifications are complete, hydrogen fuel burns very well in any ICE, providing vehicle performance comparable to conventional vehicles. These vehicles will have no local emissions of CO, HC, PM (soot) or CO_2.

A well-designed fuel cell vehicle (FCV) can provide the same performance capability as a conventional vehicle. As with an electric vehicle, FCVs have the ability to have greater acceleration than a conventional vehicle because of the high torque characteristics of electric motors at low speeds. When used with fuel cells, hydrogen produces no local emissions beyond some waste heat and water. These vehicles are also attractive because they are quieter than conventional ICE counterparts.

Fuel cells will easily provide the energy necessary not only to move the vehicle, but also to power any accessories such as air conditioning, audio systems, and onboard navigation systems. However, a larger volume of hydrogen is necessary in order to travel the same distance as a vehicle would travel on a tank of conventional gasoline or diesel. Research is being completed on ways to store hydrogen to allow FCVs to achieve the range of conventional vehicles.

Hydrogen Performance Summary

- *Wide flammability range*
- *Can be used with high compression, efficient engines*
- *No local emission when used with fuel cells*
- *Only NO_x emissions when used with ICEs*
- *A well-designed H_2 vehicle will have comparable performance as compared to conventional vehicles*

Though a nationwide network for H_2 fuel distribution does not exist, H_2 can be stored and produced for fueling on-site for fleet operations. A special niche market for indoor fleets may arise from advancements in fuel cells. When hydrogen is used with fuel cells, no harmful emissions are produced and the vehicles are quiet, which is ideal for smaller indoor applications.

Safety

Hydrogen fuel is extremely safe for the environment. Compared to other fuels used in ICEs, hydrogen burns the cleanest. Unlike petroleum-based fuels, H_2 gas does not contain carbon — it does not add carbon to the atmosphere in the form of carbon monoxide (CO) and carbon dioxide (CO_2). Hydrogen does not produce harmful evaporative emissions (from fueling stations) or particulate matter (PM) soot.

Hydrogen is highly flammable and is therefore an excellent source for combustion. Hydrogen must be handled with the same caution as other combustible fuels. A hydrogen flame has a temperature of 2400°F (1316°C) and is usually invisible in daylight.

In addition to being flammable, hydrogen is buoyant. It is lighter than air and quickly rises in the atmosphere (or inside any space in which it is contained). One significant difference between hydrogen and gasoline or natural gas is that hydrogen dissipates more rapidly in a spill or leak because of its buoyancy.

Individuals who work with hydrogen systems need to be trained in the proper handling of the fuel. Proper handling includes preventing hydrogen leaks, taking proper action if leaks occur; removing the chance for leaked hydrogen to build up, and eliminating any potential sources of ignition. It should be noted that hydrogen leaks in confined spaces could lead to oxygen displacement.

Cylinder Inspections

Hydrogen is stored in cylinders under high pressure, on the order of thousands of psi. Regular cylinder inspections should be performed by an expert in order to maintain that they are functioning properly. High pressure hydrogen cylinders can be potentially dangerous, and if cylinders are damaged and not regularly inspected they can cause issues with the vehicle. With all of the safety aspects taken into consideration, there is minimal risk from a properly maintained cylinder.

The major components of a hydrogen-powered vehicle are much the same as those powered by other fuels. The major difference is in the fuel system, which would require service by trained technicians as previously described. Vehicles powered by hydrogen fuel cells are more electrically complex than conventional vehicles and are similar to electric drive (EV) vehicles. Service and maintenance of these systems should be completed by only trained technicians.

Placards and/or other markings are required on bulk shipments to help first responders recognize the material and respond appropriately in the event of an emergency. The DOT identifies gaseous hydrogen in transport with the hazardous material description identification number UN 1049 (see **Figure 5**) and liquid hydrogen is identified with the number UN 1966 (see **Figure 6**).

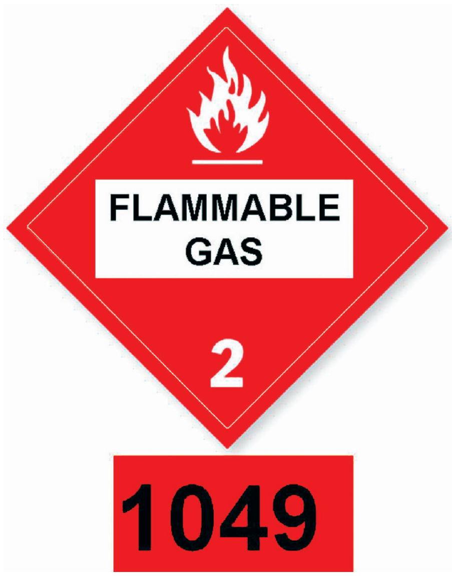

Figure 5: *Hazardous material description identification number UN 1049 placard for gaseous hydrogen. Source: DOT, PHMSA.*

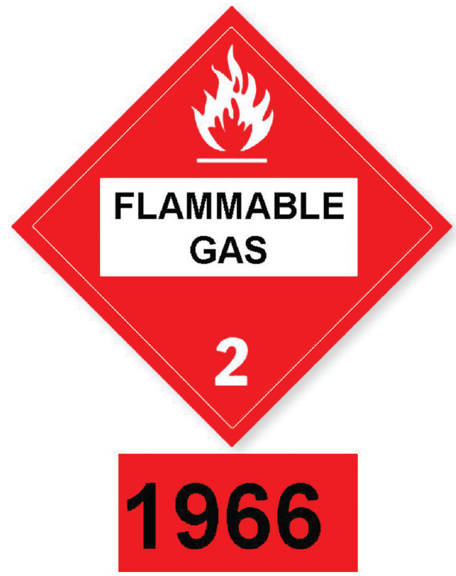

Figure 6: *Hazardous material description identification number UN 1966 for liquid hydrogen. Source: DOT, PHMSA.*

The National Fire Protection Association (NFPA) uses a diamond-shaped symbol to indicate the degree of hazard associated with a particular chemical or material. The diamond-shaped symbols are placed on chemical containers to provide flammability, instability, special hazard, and health hazard information. The NFPA 704 hazard placards used for gaseous and liquid hydrogen are shown in **Figures 7** and **8**; the “4” shown in both the gaseous and liquid hydrogen placards indicates flammability, and the “3” on the liquid placard the health issue related to a cryogenic substance. The “4” shown in the red area indicates that the flash point is below 73°F (23°C). The “3” shown in the blue indicates that liquid hydrogen may cause frostbite, and the “0” shown in the yellow area indicates that hydrogen poses no reactivity hazards.

Since H_2 is a gas (as it is used in a vehicle), an accidental release merely rises into the atmosphere, where it quickly combines with oxygen to produce water vapor. Hydrogen is usually transported as a cryogenic liquid. If the liquid were to spill, it would rapidly heat up, become a gas, and rise into the atmosphere. Unlike an oil or gasoline spill on land or at sea, a hydrogen spill presents very little danger of environmental damage.

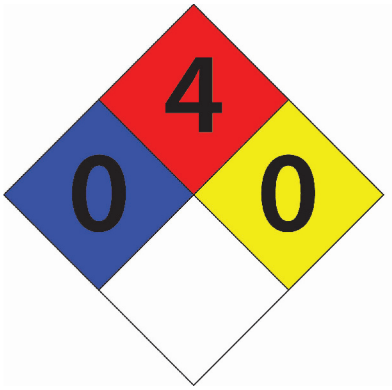

Figure 20: *NFPA 704 hazard placard for gaseous hydrogen. Source: NFPA.*

Figure 21: *NFPA 704 hazard placard for liquid hydrogen. Source: NFPA.*

Hydrogen is completely nontoxic and does not contain the carcinogens found in conventional fuel. In enclosed areas, there is very little danger with a small leak, and the danger is almost negligible in open areas because of the high buoyancy and diffusion rate of hydrogen. There is, however, a risk of asphyxiation when there is a large hydrogen leak in enclosed areas because hydrogen diffuses quickly, displacing the oxygen in a room.

> ***Hydrogen Safety Summary***
>
> - *Decreased greenhouse gas emissions*
> - *Dissipates quickly*
> - *Low risk of environmental damage in accidents*
> - *Nontoxic and noncarcinogenic*
> - *Technicians working with hydrogen as a pressurized gas or cryogenic liquid should be properly trained*

Summary

This material develops the understanding of hydrogen as an alternative fueling option for fleet managers and explains how to green fleets with hydrogen and incentives to implement its use. When compared to other alternative fuels, the widespread use of hydrogen as a fuel will not be immediate. Lack of production, distribution, and infrastructure are downsides to hydrogen as an alternative fuel. However, there is a niche market for the current state of hydrogen technologies. Hydrogen fuel can be produced on site for local fleet fueling and can offer lower emissions and lower sound levels for fleets with these needs. Continued involvement from consumers and fleets in demonstration projects will continue to push hydrogen technologies to the forefront of alternative fuels.

Test Your Knowledge

1) **True or False:** The cost of hydrogen for use as a vehicle fuel has significantly decreased in the past few years.

2) **True or False:** Steam reformation is a common method to produce pure H_2 from natural gas/ methane (CH_4).

3) **True or False:** Hydrogen may only be used with fuel cells to produce power for vehicle propulsion.

4) List two of the cost factors that are important when examining hydrogen as an alternative fuel.

5) **True or False:** Hydrogen has a greater energy density by mass when compared to conventional gasoline.

Answers: 1) True; 2) True; 3) False — hydrogen may be used in fuel cells and in ICEs to produce vehicle power; 4) Production, infrastructure development, transportation, or storage; 5) True.

Resources

U.S. DOE Fuel Cell Technologies Program

The U.S. Department of Energy's (DOE) Fuel Cell Technologies (FCT) Program offers information about current and past funding opportunities, selected past awards, and links to related opportunities from other DOE offices and federal organizations.

The mission of the FCT Program is to research, develop, and validate hydrogen production, delivery, storage, and fuel cell technologies. In carrying out this mission, the FCT Program selects research and development and other projects through open and competitive procurements and encourages collaborative partnerships among industry; universities; national laboratories; federal, state, and local governments; and non-government agencies.

Learn More about FCT
http://www1.eere.energy.gov/hydrogenandfuelcells/financial.html

- **Alternative Fuels Data Center** – Hydrogen (http://www.afdc.energy.gov/afdc/fuels/hydrogen.html) – Offers publications about the use of hydrogen as a fuel, a station locator, and other helpful information about the fuel.
- **Clean Cities 2012 Vehicle Buyer's Guide** (http://www.afdc.energy.gov/afdc/pdfs/51785.pdf) – Offers model-specific information about vehicles that utilize alternative fuels.
- **Fuel Cell and Hydrogen Energy Association** (http://fchea.org/) – Presents information about fuel cells and hydrogen as viable alternative fuels and how they can be used to solve the nation's fuel concerns.
- **Fuel Cell Today** (http://fuelcelltoday.com/) – Allows users to see practical applications of hydrogen when it is used in conjunction with fuel cells.
- **Fuel Economy** (http://fueleconomy.gov) – Official U.S. government source for information pertaining to the fuel economy ratings and fuel efficiency.
- **Gas Technology Institute** (http://www.gastechnology.org/) – Presents the organization's findings in relation to advanced hydrogen technologies.
- **Hydrogen Analysis Resource Center** (http://hydrogen.pnl.gov/cocoon/morf/hydrogen) – Contains information about hydrogen research and development in conjunction with the U.S. Department of Energy.
- **Hydrogen Car Info (**http://hydrogencarinfo.com/) – Provides up-to-date information on hydrogen cars, hydrogen fuel cell cars, and the hydrogen fuel cell industry.
- **Hydrogen Energy Center** (http://www.hydrogenenergycenter.org/) – Presents information about the projects that the center's volunteers are working on to help build a better energy future.

- **Hydrogen Fuel Cells** (http://hydrogen-fuel.org/) – Offers a basic overview of hydrogen as a fuel, hydrogen fuel cells, and the various uses of hydrogen as an energy source.
- **Hydrogen Highway** (http://hydrogenhighway.com/) – Provides information and news about hydrogen-powered vehicles and the hydrogen market.
- **International Association for Hydrogen Energy** (http://iahe.org/) – Discusses the future of hydrogen as a fuel.
- **The National Energy Lab** – Hydrogen (http://netl.doe.gov/technologies/hydrogen_clean_fuels/index.html) – Presents information about research being conducted to produce hydrogen from various sources.
- **U.S. Department of Energy – Clean Cities Program** (http://www1.eere.energy.gov/cleancities/) – Addresses the nation's energy security by supporting local actions and groups to reduce overall petroleum consumption in transportation.
- **U.S. Department of Energy (DOE)** (http://energy.gov/) – Agency that helps ensure America's security and prosperity by addressing energy related problems with emerging technologies.
- **U.S. Department of Energy (DOE) Vehicle Technologies Program** (http://www1.eere.energy.gov/vehiclesandfuels/) – Develops more efficient transportation technologies that help reduce domestic dependence on foreign petroleum.
- **U.S. Department of Transportation – Hydrogen Portal** (http://www.hydrogen.dot.gov/) – Offers information about the utilization of hydrogen as a fuel; provides important links to other hydrogen resources.
- **U.S. Environmental Protection Agency (EPA)** (http://www.epa.gov/) – Agency that acts to protect public health and the environment by writing and enforcing pertinent legislation.

Footnotes

1 Environmental Defense Fund, "Greening Fleets, A Roadmap to Lower Costs and Cleaner Corporate Fleets," http://business.edf.org/sites/business.edf.org/files/greening-fleets.pdf

2 U.S. Department of Energy, Alternative Fuels Data Center, ***State Incentives and Laws***, www.afdc.energy.gov/afdc/laws/state (updated June 15, 2011)

3 U.S. Department of Energy, Alternative Fuels Data Center, *Alternative Fueling Station Total Counts by State and Fuel Type*, http://www.afdc.energy.gov/afdc/fuels/stations_counts.html (updated March 3, 2012)

4 Liane Yvkoff, "Sewage-Powered Hydrogen Fueling Station Opens in CA," (CNET: Aug. 26, 2011), http://news.cnet.com/8301-11128_3-20097576-54/sewage-powered-hydrogen-fueling-station-opens-in-ca/

5 Britta Gross, Dr. Henk Mooiweer, Ian J. Sutherland, "Hydrogen Fueling Infrastructure Assessment," (December 2007), http://www.h2andyou.org/pdf/GM-SH%20HYDROGEN%20INFRA%20PAPER.pdf

6 U.S. Department of Energy, Alternative Fuels Data Center, *Alternative Fuels Price Reports*, http://www.afdc.energy.gov/afdc/price_report.html

7 U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Hydrogen Properties," Hydrogen and Fuel Cells (December 2001), http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/fcm01r0.pdf

Notes

CASE STUDY

Location: Oakland, CA
Company: Alameda-Contra Costa Transit District (AC Transit)
Study: **Hydrogen**

Left, hydrogen fuel cell bus on highway; Right, bus leaving fueling station. Photos courtesy of AC Transit.

AC Transit believes that hydrogen is the fuel of the future. It is a clean-burning, high-performance fuel that provides numerous benefits to fleet managers and the community as a whole. AC Transit has been using demonstration hydrogen fuel cell buses since 1999, and has witnessed dramatic improvements in the technology over the past 10 years. In 2010, AC Transit made a firm commitment to the technology by purchasing 12 hydrogen fuel cell buses.

Decision Points

For some time AC Transit has operated under the belief that hydrogen is the fuel of the future. It is fuel efficient, which is a benefit to the agency, and it produces zero tailpipe emissions, which benefits the quality of life of the residents of the AC Transit service area. Because the AC Transit public transportation system includes high-traffic urban areas, the reduction in emissions caused by a switch to hydrogen fuel cell buses reduce the overall emissions in areas with the highest concentration of pollutants.

AC Transit first began working with hydrogen fuel cell buses in 1999 through a series of demonstration projects. The performance of the vehicles led to a larger demonstration project in 2006, and the purchase of three hydrogen fuel cell buses. It was at this point, after observing the decreased maintenance requirements, the increasing quality of life, and the overall satisfaction of the riders and drivers that AC Transit began seeking funds to purchase its own hydrogen fuel cell buses. AC Transit built its first hydrogen fuel station, in conjunction with Chevron, to fuel the three buses already in its fleet in 2006.

In 2010, AC Transit purchased 12 hydrogen fuel cell buses. It also constructed a new hydrogen fuel station, this time in conjunction with Linde, and began plans to build a second station at the site of the previously decommissioned first station. The new buses were more durable than the previous ones utilized by AC Transit, which should reduce the maintenance costs associated with the buses.

Jaimie Levin, director of environmental technology and manager of the fuel cell program for AC Transit, acknowledges that there is still a significant cost gap between hydrogen fuel cell buses and conventional diesel buses. This is also true for the price of fuel. But AC Transit believes that an investment in the technology now will pay dividends in the future. The primary reason for the difference in cost is the lack of supply of the buses and the corresponding lack of demand for the fuel. AC Transit believes that by leading the way in purchasing hydrogen fuel cell buses, it is increasing the demand for hydrogen fuel, as well as demonstrating the efficacy of the technology for surrounding areas. Beginning in January 2012, AC Transit began loaning its buses to surrounding public transportation companies for additional demonstration programs. AC transit believes that by purchasing and sharing the technology, it will encourage the development of a region-wide hydrogen fuel cell program that will reap rewards for customers and the environment for the future.

QUICK FACTS

Fuel Type: Hydrogen fuel cell

Fuel Production: 66% Steam-methane reforming, 33% solar electrolysis

Number of Buses: 12

Operation: More than 11,000 hours

Driving Range: 220-240 miles

Fuel Cell Power: 120 kW

Fleet Facts

AC Transit owns and operates 12 third generation hydrogen fuel cell buses. These buses weigh 5,000 pounds less than the previous generation and are powered by a 120 kilowatt fuel cell system. The hydrogen fuel tanks are located in the roof and store enough fuel to give each bus a range of 220-240 miles before fueling. The buses also take advantage of a regenerative braking system. This system captures energy usually lost as heat during braking. The energy is stored onboard to assist the fuel cell system, which helps solve acceleration problems that have plagued previous iterations of the technology.

Most of the hydrogen used by AC Transit comes from a process called steam-methane reformation, a non-renewable source. When hydrogen becomes available in a renewable form, the third-generation buses will be able to be run on that as well.

Of particular importance to AC Transit was that its buses were tested in real-world conditions, not just on routes intended to maximize their performance. Rather, routes were selected to maximize the analysis of the performance by putting them in areas where they would be used most. This includes a focus on areas with high ridership and frequency of service on graded streets and an attempt to maximize, rather than minimize, load factors. The buses were operated under heavy demand in the cities of Oakland, Albany, and Berkeley.

Hydrogen fuel cell bus as is travels through the city. Photo courtesy of AC Transit.

Infrastructure

AC Transit has built two hydrogen fuel stations in conjunction with area fuel providers, though only one has been in operation at any given time. A second functioning fuel station will be constructed at the site of the previously decommissioned station in 2012, providing two operational hydrogen fuel stations within the AC Transit service area.

Approximately two-thirds of the hydrogen fuel used by AC Transit comes from a process called steam-methane reformation. This process involves reacting steam at a high temperature with methane to create hydrogen. This process does result in a release of greenhouse gases; however there is a 43% reduction in the release of greenhouse gases when compared to buses powered by diesel. Because this process utilizes fossil fuels, it is a non-renewable method for creating hydrogen fuel.

View of the hydrogen fueling station. Photos courtesy of AC Transit.

The other one-third comes from a 100% renewable process called solar electrolysis. Solar electrolysis uses solar energy to generate electricity to trigger a process to derive hydrogen from water, splitting the water molecules into the separate components of hydrogen and oxygen. The hydrogen is then collected and used as hydrogen fuel. This process does not yet produce sufficient fuel to service all of AC Transit's needs, but the process is renewable; it uses solar energy and water to develop hydrogen fuel.

Costs

As stated previously, there remains a significant cost gap between hydrogen fuel cell buses and standard diesel, buses. AC Transit estimates that the cost of a diesel bus is $1.5 million compared to a hydrogen bus at $3 million.

Some of the cost will be offset by a reduction in maintenance costs. As the fuel cost for hydrogen decreases, the savings in fuel economy will be realized as cost savings as well. The hydrogen buses used by AC Transit have doubled the fuel economy of the company's diesel buses.

Maintenance and Satisfaction

Overall satisfaction with the hydrogen fuel cell buses is high with AC Transit, its drivers, maintenance workers, and customers.

Initially AC Transit drivers noted that there was some "sluggishness" to the hydrogen buses when accelerating from 15-30 mph with the three vehicles purchased in 2006. This problem was solved with the purchase of the third-generation buses, which integrated regenerative braking systems. This added energy provided an extra boost of power and eliminated the sluggishness. Drivers rave about the performance of the vehicle. Driver quality of life has also improved as they are no longer inhaling diesel fumes when they drive the clean-burning hydrogen vehicles.

Fleet mechanics enjoy working with the new technology as well. Because hydrogen fuel and hydrogen fuel cell are clean burning, there is not the debris accumulation maintenance workers see in diesel engines. The fuel cells themselves have been extremely durable as well; with more than 11,000 hours of continuous operation, there is still no degradation in the cell's ability to produce electricity.

The customer base has been extremely satisfied with the hydrogen fuel cell buses, whether they are active bus riders or not. Riders appreciate that there are no fumes associated with the fuel cell buses, the bus runs more quietly, and that there is not a trade-off with performance. A recent survey randomly polled 500 bus riders and found overall satisfaction with the hydrogen buses to be in the high 80th percentile, while diesel buses are typically surveyed in the low 50th percentile.

Community members who live along bus routes but don't ride the bus also have expressed satisfaction with the hydrogen vehicles. Because they are clean-burning, the community is not exposed to the noxious fumes that are expelled by diesel buses. Community members also have cited the silence of the buses as a positive, though AC Transit has acknowledged that being completely silent can pose a public safety risk and have installed noise making devices including bells and wind chimes to alert pedestrians that there is an oncoming bus.

AC Transit has been very satisfied with the performance and customer satisfaction associated with the hydrogen fuel cell buses. The company's officials conducted a great deal of research before committing to the technology and it appears that the commitment has already been fruitful in the form of increased goodwill with the community.

Summary

Jaimie Levin believes that hydrogen fuel cell technology "has a lot of robustness to it. We see it in the long term as our future." It is this belief that led to AC Transit's willingness to pay a premium to adopt this technology as a way to demonstrate its viability to other agencies. The technology has met every one of AC Transit's goals; high-performance, zero emission, customer satisfaction, and environmentally friendly.

AC Transit views its purchase of hydrogen fuel cell buses and the construction of hydrogen fuel dispensing stations as a research and development project with the ultimate goal being nothing less than global fuel reduction.

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