Chapter II.

INTERNAL COMBUSTION

A. Introduction

There is no one in emergency service today that didn't grow up behind the steering wheel of an internal combustion engine (ICE). We are as familiar with this technology and the associated hazards as we are with breathing. As we've gotten older and wiser, we have watched as the automotive industry has grown as well.

In response to the rising numbers of deaths and injuries due to vehicle impacts to other vehicles or inanimate objects—the industry has developed standards for occupant safety. Many of these safety features like, air bags, pretensioned seatbelts, and pneumatic bumpers, continues to have a profound effect on emergency responders.

Similarly, as the cost of fuel has risen, the automotive industry has responded by offering a plethora of alternative fuel and energy technologies. Alternative fuel vehicles challenge emergency responders to redefine our standard operating procedures to manage these new technologies and fuels.

The key word here is "fuels." We should be aware and recognize that all fuels burn and pose fire and explosion risks if their combustion is not controlled. So safety is always an issue with fuels used in ICEs.

Rising fuel costs will continue to draw people towards alternative fuel vehicle options.

Most people use hydrocarbon fuels such as gasoline, propane, and natural gas often times without thinking about it. Tens of millions of people pump gasoline into their cars every day. It is commonplace for us to turn on the tap to get hot water, to light our stoves, or to heat our homes. We usually do not think about the use of the fuels that supply these conveniences, but when we do it is more often than not when the utility bill comes in every month. Other than cost, we readily accept the risks associated with the use of these fuels because systems that use them achieve sufficient levels of safety.

The challenge for emergency responders is to properly identify the fuel system and take action according to the hazards they present. The fuels that are most often associated with fleet vehicles include natural gas and propane. But bio-fuels like ethanol and biodiesel are appearing not only in fleet but in consumer vehicles as well. With the push towards hydrogen in fuel cell vehicles, OEM's are researching the use of hydrogen as a viable fuel in ICE vehicles—knowing that the infrastructure that supports the delivery of hydrogen to the consumer is only around the corner.

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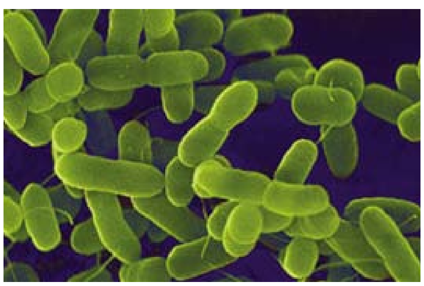
This section explores the benefits, hazards, and infrastructures that support each of these alternative fuel types including fuels like ethanol and biodiesel, natural gas, propane and hydrogen.

B. Ethanol

Worldwide pressure on petroleum producers and consumers has driven the demand for cleaner burning and more economical fuel sources. Pure ethanol and ethanol blended fuel is receiving international attention as the revolutionary solution to meet this new market demand and stricter environmental regulations.

So much so that, today, there are over 110 bio-refineries in the United States and Canada alone. It estimated that soon there will be over 180 bio-refineries with production exceeding 12 billion gallons per year in North America.



E.Coli Bacteria

In Brazil, sugarcane is used exclusively as a feedstock in the manufacture of ethanol. In North America, however, corn is the primary source of ethanol fuel with some controversy regarding the diversion of a food source to a fuel source. Researchers are also exploring other biotic material such as algae and e-coli bacteria as a potential sustainable feedstock. Researchers are also investigating the use cellulosic ethanol by doubling the efficiencies of enzymes that are used to breakdown any plant matter into ethanol. The result of this research would allow a wider range of plant material to be used as feedstock in the production of ethanol in the future.

Ethanol fuels pose unique hazards and risk not typically associated with conventional petroleum products. Unlike gasoline and diesel, ethanol fuels are water soluble, conductive to electricity, have a wider flammable range, and react less effectively to standard firefighting foam. Firefighters and emergency personnel must address these and other concerns before responding to fires and spills. Ethanol fuels must also be stored, transported, and generally handled differently than other hydrocarbons.

A select number of fueling stations offer the option of using E-85 or Biodiesel in California.

Ethanol Properties

Alcohol fuels offer both advantages and disadvantages to vehicle performance. Ethanol falls short of BTU energy content compared to gasoline. This translates to an estimated 27% to 30% loss of vehicle miles-per-gallon traveled compared to the same volume of gasoline. On the positive side, with ethanol's higher octane ratings, vehicle operators are impressed with improved torque and horsepower over much of the engine speed and range.

Ethanol is a colorless liquid with a gasoline odor. The flammability range of ethanol is 3% to 19% with an auto ignition temperature of 793° F. Like gasoline, released vapors are heavier than air and can pool in low laying areas or travel a distance, ignite and flash back. Ethanol may react vigorously with heat and oxidizing materials such as; nitrates, peroxides and acids. It is advisable to isolate ethanol fumes from heat, sparks, and hot metal surfaces. While ethanol is a low emission fuel, combustion may produce carbon monoxide, carbon dioxide, aldehydes and ketones.

Ethanol is a colorless liquid with a gasoline odor.

The health effects of ethanol when inhaled or ingested may produce central nervous system depression characterized by headaches, nausea, dizziness, loss of balance and coordination, and stupor. Vapors or spray mists may be irritating to nasal and respiratory tract. This product may be irritating to skin and eyes resulting in redness, itching or burning. Aspiration of ethanol can induce chemical pneumonia.

The yellow gas cap is an indication that this vehicle can be using gasoline or E-85.

Vehicle Identification

Many blended gasoline/alcohol fuels are being dispensed across California and the country as E-85. E-85 is an 85% alcohol and 15% gasoline blend. Special badging or insignia can be found on the right rear and right rear quarter panel of the vehicle identifying it as a Flex-fuel vehicle. Some manufacturers also used yellow gas caps to help identify that the vehicle uses both gas and ethanol. Driver/operators have the option to use either all gasoline or a blend of gasoline and ethanol when filling their tanks.

Vehicle Operation

Ethanol vehicle operation is the same as any other internal combustion vehicle that you are already familiar with. Shut-off the engine using the ignition key. Set the parking break and chock the wheels when working around ICE vehicles.

Many fleet vehicles offer the driver the flex-fuel option; using regular gasoline or E-85

Ethanol Vehicle Refueling

Ethanol is delivered by tanker truck to service stations and stored in underground tanks. Consumers use standard gasoline service pumps

A Jello shot made from pure grain alcohol demonstrates the characteristic blue flame that would be barely visible in the daylight.

—Courtesy of myscienceproject.com

to fill their vehicles. The standard service station safety features apply-breakaway hoses, an emergency shut-down switch, and protection of the pump island from vehicle collisions.

Emergency Response Considerations

When alcohol burns it produces a very pale light. In the daytime, burning alcohol fuel can hardly been seen other than a shimmer in the air as minimal smoke is produced with the burning of other hydrocarbons present in the fuel and air. Use a thermal image camera to verify an alcohol fuel fire.

Alcohol fuels do not react to standard firefighting extinguishment methods. Water dilutes the alcohol increasing the size of a running fuel fire. The best firefighting agent for alcohol fires is Alcohol Resistant Aqueous Film Forming Foam (AR-AFFF). The International Association of Fire Chiefs and the Ethanol Emergency Response Coalition tested a range of firefighting foams at the Ansul Fire Technology Center, in Marinette, Wisconsin in February 2007. AR-AFFF was determined to be the most effective fire extinguishing agent over standard AFFF, Class A foam, emulsifiers, conventional flouro-protein foam, and Alcohol-resistant film-forming flouro-protein (AR-FFFP) foam when tested against E-10 and E-85/95 fuels using the UL162 test methodology.

To stay current on this fuel technology, it is recommended that you visit the "Ethanol Emergency Response Coalition" web-site for new or updated information on this fuel technology *http://www.ethanolresponse.com/*

Biodiesel is yellow in color with a slight cooking oil scent.

C. BIODIESEL

Pure biodiesel is referred to as B100 Biodiesel, which is a non-toxic, biodegradable, renewable, carbon-neutral, sulfur-free, domestically "grown" biofuel. B100 Biodiesel is refined from many American-grown fuel/energy crops such as soybeans, canola, rape-seed and even palm trees.

Biodiesel is yellow in color with a slight cooking oil scent. Not surprising when you consider that biodiesel is made primarily from soybeans or recycled vegetable oils and fats. It can be made from any triglyceride oil, including the vegetable oil used in kitchens, in a process called transesterification. Transesterification is a catalytic process where vegetable oils or animal fats react with an acid (methanol or ethanol) to produce biodiesel.

It can be blended with regular diesel or can be the sole fuel source. Biodiesel is an effective alternative fuel for diesel engines. Older diesel engines may require fuel system modifications since biodiesel could cause rubber seals to deteriorate. The biodiesel market is expected to grow to over 40 million gallons this year. Presently there are over 100 major fleets that use biodiesel; many are federal government agencies like NASA, the National Park Service, and the military.

Municipalities using biodiesel realize the additional benefit as an inexpensive way to meet their EPA clean air mandates. A case in point can be found in the partnership developed in Arizona between the Rio Rico Fire District and the University of Arizona. Together this partnership is collecting waste oil from local restaurants and converting it, at two fire stations, into biodiesel to run about 20 vehicles including fire engines and ambulances. This partnership is being funded by the EPA with a $90,000 grant.

This Engine is powered with biodiesel made on site at the Rio Rico Fire Station in Arizona.

—Courtesy of Rio Rico Fire Deparment

A 2006 study conducted by the U.S. Department of Energy's National Renewable Energy Laboratory found that for large vehicles, burning a mixture of 20 percent biodiesel to 80 percent petroleum diesel, known as B-20, reduced emissions of particulate by 16.4 percent, carbon monoxide by 17.1 percent and total hydrocarbons by 11.6 percent.

Biodiesel Properties

The good news is that biodiesel is nontoxic. The acute oral lethal dose is greater than 17.4 g/Kg body weight. By comparison, table salt (NaCL) is nearly 10 times more toxic. A 24-hr. human patch test with undiluted biodiesel produced a very mild irritation. The irritation was less than the result produced by 4 percent soap and water solution.

Biodiesel is non-toxic. Nevertheless, protect the aquatic environment by preventing fuel from entering storm drains and waterways

Additional environmental concerns shows that a 96-hr. lethal concentration for bluegill of biodiesel grade methyl esters was greater than 1000 mg/L. Lethal concentrations at these levels are generally deemed "insignificant" according to NIOSH (National Institute for Occupational Safety and Health) guidelines in its Registry of the Toxic Effects of Chemical Substances.

Biodiesel degrades four times faster than petroleum diesel. Within 28 days, pure biodiesel degrades 85 to 88 percent in water. Dextrose (a test sugar used as the positive control when testing biodegradability) degraded at the same rate.

Blending biodiesel with diesel fuel accelerates the diesel fuels biodegradability. For example, blends of 20 percent biodiesel and 80 percent diesel fuel degrade twice as fast as #2 diesel alone.

The flash point of a fuel is defined as the lowest temperature at which the vapor above a combustible liquid can be made to ignite in air. The flashpoint of biodiesel is 266° Fahrenheit, well above petroleum based diesel fuel's flash point of around 125° Fahrenheit. Testing has shown the flash point of biodiesel blends increases as the percentage of biodiesel increases. Therefore, biodiesel and blends of biodiesel with petroleum diesel are safer to store, handle, and use than conventional diesel fuel.

To mitigate a release or spill, emergency responders should isolate the fuel from potential ignition sources such as; flares, smoking or flames in the hazard area. Stop the leak if you can do it without risk. Keep unnecessary people away; isolate hazard area and deny entry. Isolate for half mile in all directions if tank truck or storage tank is involved in fire. Water spray may reduce vapor but may not prevent ignition in closed spaces.

Any diesel vehicle can be fueled with biodiesel including these long haul trucks.

Although this product is not considered to be a water pollutant, releases of this product should be prevented from contaminating soil and water, and from entering drainage and sewer systems. Contain liquid to prevent further contamination of soil, surface water or groundwater. Soak up small spills using absorbent material such as paper, rags, or sawdust and place into containers for later disposal.

Vehicle Identification

Most diesel vehicles can switch to biodiesel without any changes to the vehicle. There are no standards that require vehicle owners to provide badging or signage for the fuel that they have on board.

Vehicle Operation

Biodiesel vehicle operation is the same as any other internal combustion vehicle that you are already familiar with. Shut-off the engine using the ignition key. Set the parking break and chock the wheels when working around ICE vehicles.

Biodiesel Vehicle Refueling

Biodiesel is delivered by tanker truck to service stations and stored in underground tanks. Consumers use standard service pumps to fill their vehicles. The standard service station safety features apply, breakaway hoses, an emergency shut-down switch, and protection of the pump island from vehicle collisions.

Emergency Response Considerations

Combustion of biodiesel fuel produces carbon monoxide, carbon dioxide along with thick smoke. It is recommended that dry chemical, foam, CO2, or water spray (fog) is used for extinguishment. Caution must be exercised as a water stream may splash the burning liquid and spread the fire. Water spray should be used to cool drums of biodiesel exposed to fire.

A characteristic of biodiesel is that, like linseed oil, biodiesel soaked rags or spill absorbents can cause spontaneous combustion. Biodiesel soaked rags or spill absorbents should be stored in approved safety containers and disposed of properly. Oil soaked rags may be washed with soap and water and allowed to dry in well ventilated area. Firefighters should use self-contained breathing apparatus to avoid exposure to smoke and vapor.

In an accidental spill, remove sources of ignition, contain spill to smallest area and if possible stop the leak. You can pick up small spills with absorbent materials and dispose of these materials properly to avoid spontaneous combustion. It maybe good to know the Specific Gravity of biodiesel is 0.88 or slightly lighter than water. Which means that biodiesel can float on the surface of the water and can quickly get into storm drains and natural waterways.

"In an accidental spill, remove sources of ignition, contain spill to smallest area and if possible stop the leak."

To recover large spills for salvage or disposal, wash hard surfaces with safety solvent or detergent to remove remaining oil film. The greasy nature of the oily film will result in an unsafe slippery surface.

To stay current on this fuel technology, it is recommended that you visit the "National Biodiesel Board" web-site for new or updated information on this fuel technology. *http://www.biodiesel.org*

D. NATURAL GAS (CNG & LNG)

Natural gas is the fuel many people use to heat their homes and cook their food. But natural gas also has a proven safety record as a vehicle fuel. Unlike gasoline, natural gas is nontoxic, non-corrosive, and contains almost no smog-forming hydrocarbons. With its high ignition temperature and narrow explosive range, natural gas is much less likely than gasoline to ignite accidentally.

Natural gas vehicles, or NGVs, offer another solution to the pressing problems of air pollution, ocean and ground water contamination, and questionable global oil supply. NGVs meet low emission standards well ahead of state mandated phase-in schedules. Natural gas has a reputation as a reliable domestic fuel. With vast reserves still avail-

CNG distribution centers in California.

able in the continental U.S., natural gas is well positioned to serve our transportation energy needs for years to come.

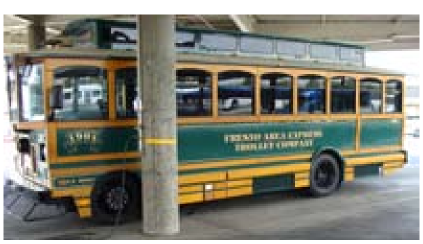
NGVs are powered by a clean and reliable domestic fuel that is available through a rapidly expanding retail infrastructure. With over 80,000 miles of distribution pipeline within California alone, natural gas is already available in most communities. The number of compressed natural gas (CNG) fueling stations has grown in California from a mere handful in 1990 to several hundred today. Across the country there are more than 1,300 fueling stations, with more stations being built each week.

Over 40 different manufacturers have at one point produced light, medium and heavy duty vehicles and engines. There are over 109,000 NGVs on U.S. roads and over one and a half million worldwide. New vehicles are available mostly to fleet vehicle operators. Fleet vehicles include: state and local government, transit, taxi, school, refuse trucks, street sweepers, postal, and freight delivery vehicles.

The driving cost and range of NGVs compares well to gasoline and diesel vehicles, with fuel efficiency for light duty vehicles of 25 to 30 miles per gallon. Fleets that have switched to NGVs have found their overall operating costs comparable to or lower than conventional vehicles.

Natural gas burns cleaner than other fuels, reducing routine maintenance costs and has lower emissions. The use of natural gas can help eliminate U.S. dependence on foreign oil, increasing national security and lowering the foreign trade deficit.

Natural gas is an abundant, domestically available product. Natural gas is primarily methane (CH4). It originates through conversion of organic material by micro-organisms (biogenesis), thermal decomposition of buried organic matter (thermogenesis), or deep crustal processes (abiogenesis). When formed by thermogenesis or abiogenesis, buoyant methane migrates upward through rock pores and fractures, then, either accumulates under impermeable layers or eventually reaches the surface and dissipates into the atmosphere.



Natural gas mass transit vehicles are easy to identify with their characteristic hump on the roof, where the CNG cylinders are stored.

Because natural gas is lighter than air, it doesn't pool on the ground as do gasoline, diesel, ethanol and propane fuels. The fuel storage cylinders for natural gas are stronger than gasoline tanks and can withstand crash, bonfire, and gun-shot tests.

There are two distinct fuel storage techniques for NGVs: Compressed Natural Gas (CNG) and Liquefied Natural Gas" (LNG). Even though natural gas is a safe and reliable fuel, the two fuel storage techniques warrant different safety precautions and awareness by emergency response personnel.

Natural Gas Properties

Natural gas is compressed so that it can be used as a practical and portable fuel supply. CNG is comprised mostly of methane with 5 to 20 percent of other vapors such as ethane, propane, and butane. A methane molecule is comprised of four hydrogen and one carbon atom and is considered a "simple" hydrocarbon (CH4). Comparatively, gasoline and diesel are considered "complex" hydrocarbons.

Compressed Natural Gas

CNG is naturally colorless and odorless. To aid in detection of gas leaks, producers add an odorant, mercaptan, which smells like sulfur or rotten eggs. This smell can be detected before the gas reaches its lower flammability limits. Natural gas is non-toxic and presents no exposure hazard. However, natural gas can displace the atmosphere and can pose an asphyxiation hazard in enclosed spaces. Fortunately, natural gas can be ventilated to the outside and dispersed into the atmosphere.

Card-lock facilities like this one in Chico, California service the area's CNG fleet vehicles.

CNG is stored under high pressure, and its storage cylinders are thicker than other types of fuel tanks. If a high-pressure fuel system component fails, gas can be released suddenly and forcefully. CNG systems are commonly pressurized up to 3600 psi—almost 30 times the pressure in an air-brake system. This is similar to the pressure of a self-contained breathing apparatus (SCBA).

> ***"When ignited, CNG produces a flame that is visible under most conditions."***

Natural gas is lighter than air and will rise if released into the atmosphere. Vapors from gasoline, diesel, ethanol, or propane, on the other hand, are heavier than air and tend to settle in low lying areas. The buoyancy of natural gas provides emergency responders with the option of allowing the gas to release itself to the atmosphere without harm to the environment, or of allowing a gas-fueled fire to burn itself out.

All fuels are flammable when vaporized and mixed with air. When CNG is released to the atmosphere, it is already in vapor form. When ignited, CNG produces a flame that is visible under most conditions. Under certain conditions, as in an unventilated confined area, CNG can also explode.

To be a fire or explosion hazard the air/fuel vapor ratio must be within the flammable range. For natural gas, the flammable range occurs when the fuel/air mixture is between 5 and 15 percent. Below 5 percent, the fuel/air mixture is too lean to burn; above 15 percent the fuel/air mixture is too rich to burn.

As a safety measure, many CNG installations have combustible gas detectors located on the ceiling—in some cases in the fuel compartment of the vehicle—to detect gas rising from a leak. These detectors sound an alarm when the mixture reaches one-fifth of the lower flammability limit.

Commercial LNG facilities, like this one, refuel a variety of LNG fleet vehicles.

Liquefied Natural Gas

The characteristics of LNG are similar to those of CNG. The difference is that LNG is stored as a liquid under pressure at low temperature in a cryogenic storage tank. Unlike CNG, odorant is not added to LNG. Therefore you cannot rely on the characteristic smell ("rotten eggs") of natural gas to detect a leak.

As a cryogenic liquid, LNG will burn or cause frostbite on exposed skin. Just as natural gas is lighter than air, LNG is lighter than water. LNG will form ice crystals on water and float on the surface.

LNG vapors are lighter than air— but only after it warms to above –160 degrees (F). At –160 degrees (F) the vapor is the same weight as air. From –260 to –160 degrees (F) the vapor cloud is heavier than air.

Any gas when cooled or sufficiently compressed becomes a liquid. Steam, for example, turns to water below 212 degrees (F) under standard pressure. Methane, on the other hand, turns to liquid at –258 degrees (F).

The advantages of storing natural gas as a liquid include:

- ❖ Lower level of impurities, which in turn provides a more consistent and controlled mixture of gas to air in the engine.
- ❖ Lower storage pressure. LNG tanks are stored at 230 psi, rather than the 3,600 psi used for compressed natural gas.
- ❖ Greater storage density. LNG holds 2-3 times more than CNG.

LNG

LNG is stored in a double walled, stainless steel tank, much like a thermos. It is possible to store at least three times as much natural gas in the same volume of space as compressed gas. LNG cylinders have been subjected to the same rigorous safety tests that CNG cylinders undergo, including burn, crash, and gunshot tests and perform as well. LNG cylinders are built to DOT4L specifications according to NFPA 57.

Should a failure occur in both walls of a LNG tank, so that LNG flows out, it will pool as a liquid and form a vapor cloud that will dissipate into the atmosphere. A small leak or dribble from a refueling operation gives the liquefied natural gas a liquid mercury like character with silver beads of natural gas dancing around the pavement until they quickly dissipate into the atmosphere.

Because of the physical differences between LNG and liquefied petroleum gas (Propane or LPG), along with the differences in storage techniques, Boiling Liquid Expanding Vapor Explosion (BLEVEs) is less of a concern for LNG storage cylinders. There have been no recorded cases of catastrophic failure, or of BLEVE's associated with liquefied natural gas.

Water should not be sprayed on a liquefied natural gas spill. The reaction of water to the cryogenic liquid could cause the liquid to splatter violently over a wide area. When water is applied, it warms the liquid, increasing the amount of vapor production.

When water is applied to a LNG fire the increase in vapor volume increases the intensity of the fire. If the fuel cannot be allowed to safely burn itself off then a high flow Purple K fire extinguisher should be used. High expansion foam can be used to cover the surface of a 2 dimensional LNG fire to reduce the intensity of the fire.

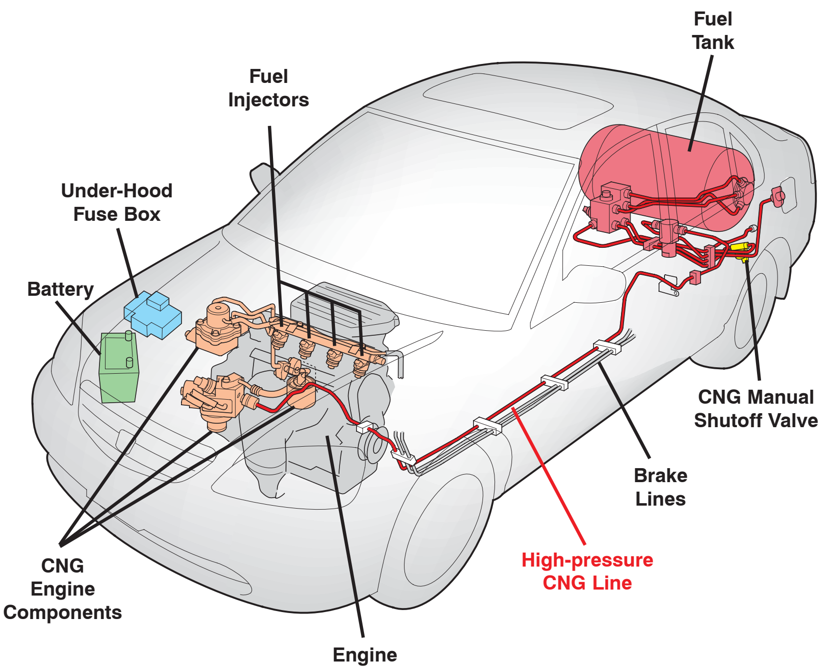
Every effort should be made to insure that the cryogenic liquid is not allowed to flow into storm or sewer drains. You can contain the liquid with an earth or sand dike.

Vehicle Identification

Emergency responders can expect to encounter a wide range of vehicle types that use natural gas as their primary or secondary fuel source; passenger vehicles, mass transit vehicles, refuse disposal vehicles, and freight vehicles.

In the transition from gasoline or diesel fuel, many of these vehicles may contain both gasoline tanks and natural gas cylinders that can be easily switched at the discretion of the vehicle operator. In either case—bi-fuel or all natural gas—the emergency responder must first identify the vehicles fuel system before committing to a specific fire or rescue operation.

Many production NGVs are modifications of the same make and model (gasoline or diesel) vehicles that you see on the road every day. So how do you distinguish NGVs involved in an incident from their standard fuel counterparts? When an NGV is delivered to the customer, it comes equipped with a distinctive diamond shaped insignia with "CNG" or "LNG" printed in the middle. These decals are typically located on the



rear or side/rear of the vehicle and on exposed cylinders.

These natural gas industry approved symbols were designed to aid emergency response personnel by identifying the type of fuel being used. However, you should recognize that there is no guarantee the customer will keep the insignia on the vehicle or that the insignia will be easily identified after a vehicle collision or fire.

Vehicle Operation & Shutdown

Natural gas vehicles, both CNG and LNG, operate much as their gasoline and diesel fuel counterparts. Some vehicles use both gasoline and CNG as a Flex-Fuel or Bi-Fuel vehicle. In either case, an ignition key is used to turn on the engine and allow the fuel to flow from the CNG cylinder or LNG container to the fuel regulator and on to the combustion engine. The fuel regulator reduces the fuel pressure on CNG vehicles from 3,600 psi to a range of 60 to 120 psi, depending on make and model of the vehicle. For LNG vehicles, the fuel is regulated from 230 psi to a range of 75 to 120 psi.

The fuel regulator regulates the pressure delivered to the engine. The fuel regulator can be located close to the CNG cylinder or LNG container, or it can be located within the engine compartment. If the regulator is near the fuel tank, downstream natural gas will be at relatively low pressures. If the regulator is near the engine, pressures from the tank to the regulator will be relatively high. The fuel flows from the cylinder or container to the regulator — then to the engine compartment and engine. Fuel is routed from the cylinder through stainless steel tubing and high-pressure fittings either under or through the vehicle chassis. There is no circumstance where the stainless steel fuel lines transverse the posts, roof or passenger compartment of the vehicle. Realizing that high-pressure fuel lines are present, caution should be exercised during extrication emergencies to ensure that the fuel lines are not inadvertently severed.

To shut down an NGV, you turn the ignition key to the “off” position, which simultaneously turns off the engine and stops the flow of fuel from the cylinder. NGVs have a manual shutoff valve at the cylinder or container. To insure that a CNG or LNG cylinder or container is no longer flowing fuel, or to stop a fuel leak, locate the cylinder or container shut-off valve under the vehicle chassis or close to the fuel cylinder. The shut-off valve requires a quarter turn to shut off the flow of fuel from the cylinder. The location of the fuel shut-off valve can vary from make and model of vehicle. Typically, it is near and under the cylinder itself.

Fuel Cylinders

Fuel cylinder construction is the same for all gaseous fuels, natural gas, propane, and hydrogen. CNG cylinders are similar in design and construction to the air tanks used in Self Contained Breathing Apparatus (SBA's). However, instead of pressurized air, CNG cylinders contain pressurized natural gas. The high-pressure gas exerts forces on the walls of the cylinders. To withstand these forces, cylinders are made of thick-walled, high strength materials such as steel, aluminum, or composites.

Cylinders come in a variety of construction materials; steel, aluminum, and fiber wrapped.

Cylinders are made to withstand much higher pressures than the normal service pressure. For example, a cylinder rated for service at 3,600 psi is designed to withstand pressures in excess of 8,100 psi. Regardless of this design potential, cylinders should never be pressurized above their maximum fill pressure (generally, 1.25 times the service pressure).

Cylinders used for natural gas, propane or hydrogen, are all made to withstand 1.25 times the service pressure.

The typical CNG cylinder has a cylindrical shaped sidewall with hemispherical domes on the ends. The cylinder ends typically contain a metal port that can be used for inserting a valve, end plug, or other part. The expected life span of a cylinder is normally 15-20 years.

The four types of CNG cylinders are:

Type 1: An all metal cylinder made of steel or aluminum.

Type 2: A cylinder with a metal liner made of steel or aluminum and a hoop-wrapped fiber overwrap.

Type 3: A cylinder with a thin metal liner and fully wound-fiber overwrap.

Type 4: A cylinder with a plastic liner and a fully wound-fiber overwrap.

In composite-wrapped cylinders, the composite fiber overwrap plays a key role in resisting the high gas pressure forces pushing against the cylinder liner wall. As gas pressure increases, it produces tension on the fibers and causes them to stretch slightly. Fibers can easily handle normal gas pressure. However, going beyond the maximum fill pressure may put too much stress on the fibers leading to fiber breakage and possible cylinder failure.

For safety, the CNG cylinders are equipped with pressure relief devises (PRD). The devise is set at a predetermined temperature which will vent the CNG before any chance of explosion.

A vehicle fire and inoperative pressure relief device (PRD), allowed this cylinder to fail.

–Courtesy of Seattle F.D. Washington

On most vehicles a vent tube is attached to the PRD which will vent pressurized gas to the outside of the vehicle. When a cylinder is involved in a vehicle fire the compressed gas will expand and will open the PRD and allow the cylinder to vent. The cylinder will continue to vent until all of the gas is expelled. For LNG containers, the PRD will vent-off excess pressure then the PRD will re-seat itself. It is important to not fill the LNG vent tube with water as the escaping gas will freeze, blocking the vent tube.

The pressure relief device releases gas when the cylinder is exposed to a fire, to insure that the cylinder will not explode. It can also release pressure when the tank pressure increases beyond its rated capacity. The vent tube can be located at the rear or the side (rear) of the vehicle, depending on manufacturer. It is important for emergency response personnel to identify the location of the relief device vent before they begin any operation around the vehicle. When PRDs operate they vent the entire contents of the cylinder(s) they are protecting. When a PRD operates you may hear a loud, high-pitched whistle.

This Hydrogen cylinder is undergoing the bonfire test.

A number of standards have been developed for natural gas cylinders, including NGV2 Standard, (ANSI/CSA NGV2 "Basic Requirements for Compressed Natural Gas Vehicle Fuel Containers"). This is a voluntary industry standard which contains ten design qualification tests, including pressure cycle, environmental pressure, burst, impact, bonfire, and gunshot.

The FMVSS 304 standard (49 CFR 571.304 – "Compressed Natural Gas Fuel Container Integrity") is a mandatory Federal (NHTSA/ DOT) Motor Vehicle Safety Standard applicable to all CNG cylinders sold for motor vehicles in the US. FMVSS is similar to an older version of NGV2 but has fewer design qualification tests. Transport Canada and the International Organization for Standardization (ISO) have cylinder standards similar to NGV2.

For the fire service, NFPA 52 "Compressed Natural Gas CNG Vehicular Fuel Systems," along with FMVSS 303, ensure that pressurized CNG fuel tanks are shielded from damage by road hazards and mounted to minimize damage from a collision. To this end, fuel tanks cannot be mounted in front of the front axle or behind the rear axle. The tanks must be securely fastened to the vehicle and shielded from direct heat generated by the vehicle exhaust system. Pressure relief devices (PRD) must be vented to the outside of the vehicle.

Depending the on the make, model, and vehicle manufacturer, natural gas containers may be found in the rear, trunk, pick-up bed, as side tanks, or on top of the vehicle. In passenger vehicles and small trucks, the CNG cylinders are typically found in the rear of the vehicle, mounted in the pickup bed, the vehicle trunk, or under the rear of the vehicle where a gasoline tank had previously been mounted. Large heavy duty vehicles may replace their saddle-mount diesel tanks with LNG containers, while buses may have LNG containers under the passenger compartment or CNG cylinders on top of the vehicle.

CNG Vehicle Refueling

Natural gas is delivered to the refueling site from an intricate network of transmission and distribution pipelines that crisscross the country. Typically, distribution or feeder lines deliver product to site at, or below, 60 psi. Pressure in the transmission pipeline runs 60 psi or greater.

From the pipeline natural gas is scrubbed, dried, and compressed before it is pumped to the customers vehicle.

Natural gas is then run through several stages before it is delivered to the customer. From the feeder line the gas is sent through a dryer to remove moisture and then through a filter to remove particulate matter. The natural gas is then compressed to 3,600 psi and stored in above ground storage tanks. The storage tanks can hold 10,000 cubic feet or 300 gallons of product.

The refueling customer typically has a plastic card that unlocks and provides access to the natural gas dispenser. The customer then attaches the hose to the vehicle and begins the refueling operation. Once fuel has been transferred the dispenser automatically stops the flow of fuel.

Emergency response plans of any refueling station should include the locations of emergency shut-down switches.

The NFPA Standards for natural gas fuel systems include:

- ❖ NFPA 52, "Compressed Natural Gas (CNG) Vehicular Fuel Systems Code"
- ❖ NFPA 57, "Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code"

Each of these standards specifies that refueling stations have manual and automatic shut-off valves. A number of methods are designed to shut off the flow of natural gas:

1. *A manual shut-off switch is located at the main CNG dispensing location. Customers are trained to shut down the dispenser if they feel a problem or hazard exists. If the dispenser detects a problem it will automatically shut down.*
2. *Breakaway protection is provided in the event of a vehicle pulling away from the refueling station while the fueling hose is still connected to the vehicle. The breakaway device stops the flow of natural gas to the dispenser.*
3. *A manual emergency shut-down switch is located at a remote location from the dispenser. The location is clearly marked with a red sign and white lettering. The emergency switch will stop the flow of fuel to the dispenser.*
4. *For emergency response personnel, a curbside shut-off valve is provided. The emergency shut-off valve will turn off the gas supply to the dispenser.*

It is important that emergency response personnel identify and locate the curbside valve before responding to an emergency at the facility.

5. *Another emergency shut-off switch is located on the compressor control panel. Typically a trained gas company employee would use this switch and any of the valves located in the compressor and storage area while performing maintenance. The switch shuts down power and the flow of gas to the compressor.*

When pre-planning a natural gas fueling station, be sure to review the gas company's EPA mandated MSDS sheets (See Appendix A) and emergency action plan. These documents specify the locations of the main electrical power as well as emergency shutoff valves and switches. Preplans of the fueling facility should include the location of fuel storage areas, compressors, along with manual, curbside and emergency shut-off valves and switches.

"Preplans of the fueling facility should include the location of fuel storage areas, compressors, along with manual, curbside and emergency shut-off valves and switches."

Emergency response to refueling stations must include the use of full structural firefighting clothing and SCBAs. You can protect and extinguish a fire involving a vehicle or threatening exposures using water and foam. If the venting CNG is on fire and it doesn't threaten lives or exposures you can let the fire continue to burn until a gas company employee arrives to lend assistance. With LNG facility fires you could also allow the fuel to burn off. You should not put water on a LNG fuel leak. If the area around above ground fueling containers, are involved in a fire, and if there is no liquefied natural gas, carefully approach the tanks and use water to cool the tanks and/or to protect surrounding exposures.

CNG Residential Refueling

Though not yet common, several companies are marketing compressors that take the natural gas piped to a residential site and compress it to refuel a CNG vehicle. The residential fueling facility (RFF or vehicle refueling appliance—VRA) is an assembly used for compression and delivery of natural gas into vehicles. The RFF includes all associated equipment such as hoses and couplings. Similar to commercial refueling stations, RFF systems have manual and automatic safeguards that shutoff both the flow of fuel and electrical power as mandated by NFPA 52.

Residential refueling offers flexibility to CNG vehicle operators.

All related equipment for an RFF is designed to minimize the possibility of physical damage and vandalism. The systems can be allowed either indoors or outdoors, but outdoor installation is preferable. With indoor installations, a gas detector set to alarm at one fifth the flammable limit is required, and the compression unit must be located to allow venting to the outdoors.

The ability for homeowners to fuel their vehicles in their own driveways suggests that emergency responders should be prepared to deal with natural gas emergencies not only on the highway, but at commercial refueling stations and in residential settings. To find out if you have residential refueling in your jurisdiction, contact the local building department and ask for any codes or ordinances that allow such devices. Also, inquire about recently issued permits and the location of residences that have installed RFF systems.

LNG Refueling

LNG relies on tanker trucks to get the fuel to the refueling station. A tanker truck has the capacity of delivering up to 10,000 gallons per load. It is estimated that at least 200,000,000 gallons of LNG are trucked into California every day. And, every year this capacity keeps increasing.

LNG re-fueling is handled by skilled professionals. Note the Protective gear, rubber apron, gloves, and face shield to protect the operator from cryogenic burns.

The delivery truck transfers the LNG to an on-site storage tank or vehicle for mobile refueling operations. Refueling operators wear rubber aprons, work boots, leather welding gloves, safety glasses and face shields to protect themselves from the cryogenic liquid. Fuel is transferred from the storage tank to the vehicle through a vapor shielded dispenser. An emergency shut-off switch is located in the dispenser panel and at a safe remote location between 30 and 75 feet away.

Ice crystals around the LNG tank valves during re-fueling is normal.

Cryogenic LNG containers, consists of two nested tanks that form a thermos-like insulating vessel to keep the liquid from reaching its boiling point at the designed storage pressure. The space between the inner and outer tank is vacuum sealed and filled with an insulating material to keep the liquid below its boiling point. After LNG flows from the tank, it is heated by a heat exchanger to form vapor, which is then regulated to the proper pressure before it enters the engine.

Ice crystals on the exterior of the tank indicate a tank failure.

Large vehicles with sidesaddle tanks can hold up to 170 to 180 gallons of LNG. If opened to the atmosphere this volume of LNG would quickly dissipate into the atmosphere often times before emergency response personnel can get to the scene. It is common to see ice, frost or ice crystals on the outside of the container valve and hoses. Ice or frost on the container, however, would indicate a container failure. A slight loss in vacuum pressure would be indicated by sweat forming on the exterior of the tank. In either case, the LNG vapor would begin to boil off and the pressure relief valve would expel excess natural gas to the atmosphere.

It is important to note that LNG pressure relief devices will re-seat after pressure is sufficiently lowered. Importantly, vapor clouds around an LNG vehicle, does not always indicate a leak or a problem. When dealing with a cryogenic liquid, it should be recognized that one cannot see natural gas vapors. The vapors that are visible will be the moisture in the air as it is cooled by the cryogenic fluid or metal cylinders, valves, and lines that contain liquefied natural gas.

In an emergency involving LNG fuel leaks the immediate area should be evacuated and the surrounding exposures should be protected with hose streams until the gas completely vents to the atmosphere. You can use hose streams to direct the dispersal of the vapors away from exposures. If the vapor catches on fire protect exposures with hose streams and let the vapors burn off. If it is necessary to extinguish the fire, do not use water! Instead use a high flow Purple K extinguishing agent.

Emergency Response Considerations

As a flammable gas, CNG leaks and fires can occur during fueling, maintenance, repair or as a result of traffic collisions. Open flames will cause CNG to ignite, which disallows smoking, welding, grinding or any other open flame operations around CNG facilities or vehicles. CNG also can be ignited by sparks from electrical equipment, static electricity, and contact with hot surfaces. CNG fires can be fought using foam or water. However, water should not be used when fighting LNG fires.

Live-fire training on the rim of the Grand Canyon, demonstrates the characteristics of an LNG fire.

One recommended strategy when dealing with NGV emergencies is to allow the gas vapors to dissipate into the atmosphere or to burn off all the fuel when no lives or exposures are threatened.

A leak from the high-pressure side of a CNG fuel system could produce a high-velocity cold gas jet. As the jet travels, the concentration of the gas drops as it mixes with ambient air. A release could cause injury from flying debris, the high jet momentum, or exposure to the extremely cold gas near the release point. The high velocity jet can create high intensity noise alerting emergency response personnel to a gas leak problem and/or its location.

If the gas jet comes in contact with a spark, a jet fire or “torch fire” at very high temperatures can cause serious burns and structural damage. Remember, however, that the gas-to-air mixture has to be within the 5 to 15 percent range for ignition to take place. The ideal response to a natural gas leak is to isolate potential sources of ignition from coming into contact with the gas plume until it is safely dissipated into the atmosphere. With a torch fire protect surrounding exposures from radiant heat or direct flame impingement with fog streams allowing the torch fire to burn itself out.

The greatest danger for natural gas is in enclosed spaces. Natural gas can displace oxygen in the atmosphere making it a potential asphyxiant hazard. In enclosed spaces, and in the proper flammable range, natural gas can explode when in contact with an ignition source.

Emergency response to CNG and LNG can be pre-planned with the following actions:

1. *Use gas detectors to determine a leak in the fuel system.*
2. *Isolate the fuel from potential sources. This can be accomplished by shutting-off the fuel valves on the vehicle or at the refueling station, or by directing the vapor cloud away from buildings and other potential sources of ignition with a fog stream.*
3. *If the fuel is on fire, protect surrounding exposures with hose streams and allow the fuel to burn it self off.*
4. *Use foam or water to extinguish a CNG fire if necessary.*
5. *Use a high volume of Purple K to extinguish a LNG fire, being careful of flashback after the fire has been extinguished.*
6. *Use high expansion foam on the surface of a LNG fire to reduce the fire's intensity.*
7. *Avoid contact with the high velocity jet in a CNG Leak*
8. *Avoid contact with LNG liquid.*
9. *Use sand or dirt to create a berm around a LNG fuel leak making sure that the fuel does not flow into sewer or storm drains.*

LNG will cause first degree burns or frostbite if not treated immediately. If a person has LNG on their clothes, defrost the fabric with water before trying to remove the clothing. Otherwise, frozen fabric will adhere to the skin—increasing the damage to the injured area.

"LNG will cause first degree burns or frostbite if not treated immediately."

Consult original equipment manufacturer for the location of the fuel shut-off valve.

Coalition Interest

This section was originally funded by the California Office of Traffic Safety and the California Energy Commission with assistance by the California Natural Gas Coalition and Pacific Gas and Electric (PG&E). To stay current on this fuel technology, it is recommended that you visit the "California Natural Gas Vehicle Coalition" web-site for new or updated information on this fuel technology *http://www.cngvc.org.* It is highly recommended that you go to the original equipment manufacturer for specific emergency response guidelines for specific makes and models of vehicles.

E. PROPANE

Propane gas and liquefied petroleum gas (LPG), is the nation's third most common vehicular fuel, after gasoline and diesel. There are over 270,000 on-road vehicles in the United States and more than 10 million worldwide that operate on propane. A large number of these are used in fleets that include light-to heavy-duty trucks, buses, taxicabs, police cars, and rental and delivery vehicles.

Unlike CNG fueling stations, LPG fueling stations require a trained to technician to transfer fuel to the vehicle.

Propane is safer (slower burning, higher ignition temperature) than gasoline, and because of its relatively simple chemical makeup it is potentially cleaner burning. Oil & filter changes can be extended when engines are run exclusively on propane. Likewise, longer engine life (often 180,000-200,000 miles) is expected.

Winter start-ups are easier with gaseous propane, but during hot weather, propane displaces already thin intake air which leads to a hot start and a potential loss of power. Propane lacks lubricity, so some OEMs use hardened valves/seats and guides; nor does propane provide for intake cooling, as do vaporizing liquid fuels.

In many ways propane and liquefied petroleum gas is somewhat similar in use to CNG and LNG. Vehicle operation and shut-down procedures are the same. The differences lay in the characteristics of these two fuel types along with their differences in storage techniques that emergency responders must be aware of.

Propane Properties

LPG contains about 90% propane, with small concentrations of ethane, butane, propylene, and other gases. Propane and butane are both a

Most propane vehicles are used in fleet operations, and are available from vehicle manufacturers as an option.

derivative of crude oil extraction processes and are classified as liquefied petroleum gasses (LPG). Thirty percent of the propane produced today is extracted from crude oil and 70 percent is processed from natural gas. Like CNG, LPG is colorless and odorless in its natural state. Mercaptan, an odorant, is added to LPG to aid in leak detection.

At atmospheric pressure, propane remains a vapor down to –44º F. Under moderate pressure (typically well below 200 psi at 70º F) propane shrinks to a liquid 270 times more dense than when gaseous, making it ideal for compact on-board vehicle storage. If vented, propane boils off as a gas.

LPG is stored under pressure as a liquid. Because its boiling point is -44°F, liquid LPG expands rapidly into a vapor under normal outdoor temperatures and without containment. Liquid propane leaks are generally more dangerous than propane gas leaks because a small volume of spilled liquid propane can boil off into a large volume of propane vapor. LP gas expands 1.5 times for every 10 degree rise in temperature. In a closed container this increases the volume of liquid gas and increases container pressure. A pressurized tank or cylinder exposed to fire creates the potential for a BLEVE (Boiling Liquid Expanding Vapor Explosion).

"A pressurized tank or cylinder exposed to fire creates the potential for a BLEVE (Boiling Liquid Expanding Vapor Explosion)."

Unlike CNG, LPG is 1.5 times heavier than air. If a leak in the fuel system occurs the gas readily dissipates. However, under the right conditions, propane gas can settle in low unventilated areas and become concentrated when there is no air movement.

The flammable limit for LPG is between 2.15 percent and 9.6 percent — slightly less than the percentage for CNG. The ideal combustion ratio for propane is 24 parts of air to one part propane.

Vehicle Identification

Similar to CNG and LNG, propane is marked in a blue diamond and the decal is affixed to the rear bumper of the vehicle.

Vehicle Operation

Propane vehicle operation is the same as any other internal combustion vehicle that you are already familiar with. Shut-off the engine using the ignition key. Set the parking break and chock the wheels when working around ICE vehicles.

Vehicle Refueling

Propane is distributed by rail and truck to local retailers. Modern propane dispensing equipment is designed for refueling at a rate of about

Refueling stations that offer propane are easily identified with above ground storage tanks.

Isolate fuel from potential ignition sources by shutting off fuel valves or by directing the vapor away from exposures using a fog stream.

From a emergency responders perspective what can go wrong, will go wrong, as evidenced by this truck driving over a propane tank.

12-18 gallons/minute. Propane refueling sites are found at public fill stations and truck stops, at equipment rental outlets, and at RV dealers and some campgrounds. Prices vary widely. Some bulk suppliers of propane offer direct retailing. LPG for rural domestic and farm use is normally trucked in and stored on site.

Liquid propane is pumped to the vehicle under pressure by a trained technician and is stored in steel tanks at 200 psi. Propane's "storage ratio" to gasoline is roughly 1.1 to 1, thus a bi-fuel propane vehicle tank doesn't take up as much cargo space as tanks for CNG. Propane tanks are filled to 80% to allow for expansion. If exposed to summer heat and sunshine, propane tank temperatures and pressures can rise radically. These conditions are handled by the tank's 20% expansion volume, pressure relief valves and the vehicle's fuel pressure regulator(s).

While the actual content of propane can vary, LPG intended as a vehicle fuel should be of the highest quality (>88% propane minimum) with little sulfur, paraffin, or olefin content. There is, as of yet, no national distribution system for propane as a vehicle fuel.

LPG Emergency Response

When responding to an LPG vehicle incident, wear full structural firefighting clothing, approach the vehicle and tanks from the side, and direct hose streams to the top of LPG tanks to keep the vapor space cool. Whenever possible, avoid approaching the pressurized tanks from their ends in case of a tank BLEVE. The configuration of LPG fuel tanks varies by manufacturer. On the 22-foot shuttle buses, they are typically mounted horizontally, side-by-side underneath the floor, behind the batteries.

Emergency response to LPG emergencies can be pre-planned with the following actions:

1. *Use gas detectors to determine a leak in the fuel system.*

2. *Isolate the fuel from potential sources. This can be accomplished by shutting-off the fuel valves on the vehicle or at the refueling station, or by directing the vapor cloud away from buildings and other potential sources of ignition with a fog stream.*

3. *If the fuel is on fire, protect surrounding exposures with hose streams and allow the fuel to burn it self off.*

4. *Use foam or water to extinguish a LPG fire if necessary.*

5. *Avoid contact with the high velocity jet in a LPG Leak.*

8. *In confined space, allow LPG to ventilate before entering the space.*

Information updates

To stay current on this fuel technology, it is recommended that you visit the "Propane Education and Research Council" web-site for new or updated information on this fuel technology, *http://www.propanesafety.com*. It is highly recommended that you go to the original equipment manufacturer for specific emergency response guidelines for specific makes and models of vehicles.

F. HYDROGEN

BMW has designed an internal combustion engine that uses hydrogen for the fuel.

Hydrogen was first recognized as a distinct element in 1766 by the English chemist, Henry Cavendish, who called it inflammable air. His new discovery was found to form water on combustion with air, which led to it being named hydrogen, which means 'water former.' Hydrogen was little used until early in the nineteenth century when 'town gas,' a mixture of hydrogen, methane, carbon dioxide, and carbon monoxide made from coal was used for cooking and lighting.

Today, hydrogen is an important chemical commodity. In the U.S. alone, more than eight million tons are produced annually, mostly by steam reforming natural gas. Hydrogen has been transported safely both as a cryogenic liquid and as a compressed gas by rail, barge, truck, and pipeline for use in the aerospace, food, petrochemical, and semiconductor industries. These industries have an excellent safety record with hydrogen because they understand the risk and how to manage it.

Hydrogen is not only used in internal combustions engines, but also in fuel cell processes to generate electricity. BMW's Hydrogen 7 is one of several hydrogen fueled prototype passenger vehicles that can be ready for distribution.

Hydrogen vehicles, and fuel cell vehicles that rely on hydrogen, are stymied by the "chicken and the egg" syndrome. Vehicle manufacturers cannot mass produce vehicles to make them affordable without a reliable fuel supply. On the other hand, the refueling infrastructures are not being built, because there is no vehicle demand for the fuel. The only solution to this "which will come first" problem is for the Federal government to muster the resources and build the infrastructure necessary for the growth and acceptance of this technology.

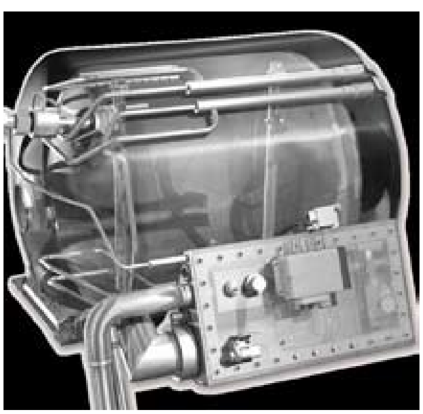
Nevertheless, hydrogen as a fuel is as promising as any of the other alternative fuel choices. There are over 200 vehicles that rely on gaseous hydrogen, with 22 that utilize liquid hydrogen, on California roadways today—enough vehicles for emergency responders in major metropolitan areas like Los Angels, San Diego, San Francisco and Sacramento to become familiar with this technology.

"Hydrogen is most commonly used as a gas compressed to 2,400 psi or as a cryogenic liquid at below -253 degrees Celsius."

Hydrogen Properties

Hydrogen is most commonly used as a gas compressed to 2,400 psi or as a cryogenic liquid at below -253 degrees Celsius (20 degrees above absolute zero).

When volume is a consideration, hydrogen may be stored as a liquid. One and a half million cubic feet of hydrogen as a liquid can be stored in the same space it takes to store 100,000 cubic feet of hydrogen as a gas. Typically you would find hydrogen storage at electronic plants, NASA, and food processing facilities.



BMW H2 Tank

The properties of hydrogen make it an acceptable fuel choice:

- Hydrogen has no color, no odor (and cannot be odorized), no taste or flavor.
- Hydrogen is less flammable than gasoline. The self-ignition temperature of hydrogen is 550 degrees Celsius. Gasoline varies from 228-501 degrees Celsius, depending on the grade.
- Hydrogen disperses quickly. Being the lightest element (fifteen times lighter than air), hydrogen rises and spreads out quickly in the atmosphere. When a leak occurs, hydrogen gas quickly becomes so sparse that it cannot burn. Even when ignited, hydrogen burns upward, and is quickly consumed. By contrast, materials such as gasoline, diesel, ethanol and propane vapors are heavier than air, and will not disperse as quickly, remaining a flammable threat for much longer.
- Hydrogen is a non-toxic, naturally-occurring element in the atmosphere. By comparison, gasoline and diesel is poisonous to humans. Hydrogen can, like any other gas, displace oxygen in confined areas making it an asphyxiant hazard.
- Hydrogen combustion produces water vapor and heat. When pure hydrogen is burned in pure oxygen, only pure water is produced. A scenario, which only occurs in laboratories and the space shuttle. In any case, when a hydrogen engine burns, it actually cleans the

ambient air, by completing combustion of the unburned hydrocarbons that surround us. Compared with the toxic compounds (carbon monoxide, nitrogen oxides, and hydrogen sulfide) produced by petroleum fuels, the products of burning hydrogen is obviously much safer.

- Hydrogen can be stored safely. Cylinders currently in use for storage of compressed hydrogen (similar to compressed natural gas tanks) undergo and have survived intact through testing including; shot test with six rounds from a .357 magnum, detonation test with a stick of dynamite next to the cylinder, and subjecting them to fire at 1500 degrees F. It is not likely that a typical gasoline tank wouldn't survive any of these tests.
- Hydrogen has three times the energy content per pound as gasoline or diesel fuel, and has 71% less greenhouse gas emissions per energy unit over the whole fuel production cycle relative to gasoline.

As an asphyxiant, it should be noted that before suffocation could occur, the lower flammability limit of hydrogen in air would be exceeded possibly causing both an oxygen-deficient and explosive atmosphere. Exposure to moderate concentrations may cause dizziness, headache, nausea and unconsciousness.

Exposure to atmospheres containing 8-10% or less oxygen will quickly bring about unconsciousness without warning leaving individuals unable to protect themselves. Lack of sufficient oxygen may cause serious injury or death.

Hydrogen Vehicle Identification

The BMW Hydrogen 7 vehicle will undoubtedly set the industry standard when hydrogen ICE vehicle become more prevalent as the first commercially available ICE hydrogen vehicle. The BMW Hydrogen 7, like all alternative vehicles, is clearly labeled and/or badged. BMW utilizes both gasoline and hydrogen fuel capabilities in their internal combustion engine (ICE). When one or the other fuel runs out, the vehicle automatically switches over to the other. This vehicle has a range of 310 miles on gasoline and an extra 125 miles on Hydrogen.

Hydrogen Vehicle Operation

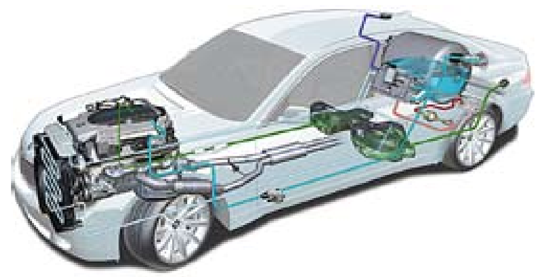
Hydrogen vehicle operation is the same as any other internal combustion vehicle that you are already familiar with. Shut-off the engine using the ignition key or power button. Set the parking break and chock the wheels when working around ICE vehicles.

BMW's Hydrogen 7 uses an insulated cryogenic tank to hold 18 lbs of liquid hydrogen. The design of this tank is equal to 57 feet of normal

H2 warning systems are standard in BMW.

insulation material. Hydrogen in the storage tank will boil off over time. The boil off management system will burn excessive hydrogen gas in a catalytic converter. It takes only nine days for 1/3 of the liquid hydrogen in the tank to become a water vapor.

Due to the risk of hydrogen vapors, parking the BMW Hydrogen 7 in an enclosed space is not an option. BMW has a number of safety features built in to their hydrogen vehicle including: driver warning systems in the case of a hydrogen system malfunction, gas detectors, and pressure relief vent openings on the roof of the vehicle. In the event of an overturned vehicle, hydrogen will also be relived from the underside of the vehicle. The hydrogen system is further monitored through a GPS signal.



The vent tubes run through the rear C support on both sides of the vehicle. BMW points out that during extrication the A and B pillars can be severed and the roof folded back without cutting the C pillars. For the rescue team this means a roof flap is the only available extrication option as roof removal is not recommended. Fuel lines to the engine compartment do not run through the passenger compartment, but within the undercarriage of the vehicle.

There are three batteries in the trunk. Two support the hydrogen boil-off, leak detection and warning systems. These batteries should never be controlled by firefighters. There is however, a single 12 volt battery that supports normal electrical functions of the vehicle. This battery can and should be controlled during extrication operations. BMW has placed labels on all three batteries with safety instructions.

The door lock pins on the interior door panel flash red in the event of a hydrogen release inside the vehicle cab. Proper actions include removing side window glass and placing a power blower for hydrogen gas removal.

You can expect to see additional improvements being made by BMW in hydrogen boil-off management and fuel tank efficiency in the future.

Hydrogen Refueling

Hydrogen fuel stations are in the planning and development process in key metropolitan areas of California with a focus on

San Francisco Bay Area, Sacramento, Los Angeles and Orange County. Hydrogen stations are not a "one-size-fits-all" technology. Some stations can make hydrogen fuel on site by reforming natural gas or electrolyzing water. Other stations dispense hydrogen made at a central production facility which is then trucked to the on-site storage tank. Some stations will only dispense hydrogen fuel while others will dispense it along side other fuels. For larger applications like fleet vehicles, an on-site stationary fuel cell system can make electricity and heat for buildings, as well as hydrogen for fleet vehicles.

Hydrogen Emergency Response

The protocols for fighting a hydrogen fire are similar to the basic rules for fighting any fire fueled by a flammable gas. The first thing to do is to eliminate the ignition source and/or isolate the fuel. If this is not an option, the fuel source is generally allowed to burn itself out while protecting exposures to minimize the risks of injury and danger to the surrounding area.

Hydrogen fires have a pale blue to invisible flame and generate little smoke. However, combustible material in or near the hydrogen flame, and particles in the air will likely render a visible flame and give off smoke. Use ultra-violet and/or infra red (IR) detectors, if available, to scan for invisible hydrogen flames. If no flames are present, scan the vehicle with a hydrogen leak detector (combustible gas detector rated for hydrogen), if available. Hydrogen is easily ignited with low-ignition energy such as static electricity. Pressure in containers can build-up and may rupture. Do not extinguish hydrogen fires unless the leak feeding the flame can be stopped. If safe to do so, allow the gas to burn out and protect exposures.

Because the hydrogen is vented through the BMW's "C" pillars the manufacturer recommends a roof fold to extricate occupants.

To stay current on this fuel technology, it is recommended that you visit the "Hydrogen 2000" web-site for new or updated information on this fuel technology. *http://www.hydrogen2000.com.* It is highly recommended that you go to the original equipment manufacturer for specific emergency response guidelines for specific makes and models of vehicles.