Alternative Fuels for IC Engines

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Abstract: - The main purpose of fuel is to store energy, which should be in a stable form and can be easily transported to the place of production. Almost all fuels are chemical fuels. We as a user use this fuel to perform mechanical work, such as powering an engine. The historical and the present- day civilization are closely interwoven with energy and in future, our existence will be more dependent upon energy. The conventional sources of energy, the single most important pre-requisite for power generation, are depleting fast. The world is heading towards a global energy crisis mostly due to running out of these energy sources; decreasing the dependency on fossil fuels is recommended. Yet, the sources of energy are infinite. The greatest task today is to exploit the non-conventional energy resources for power generation. Alternative energy sources provide many benefits. Renewable energy development can create quality jobs and promote economic development, especially in rural areas. If used to diversify utility resource portfolios, alternative energy technologies can provide a hedge against rising fuel prices and can be valuable risk management tools.

Keywords-

I. INTRODUCTION: WHY TO CONSIDER ALTERNATIVE ENERGY?

Alternative energy sources provide many benefits. Renewable energy development can create quality jobs and promote economic development, especially in rural areas. If used to diversify utility resource portfolios, alternative energy technologies can provide a hedge against rising fuel prices and can be valuable risk management tools. While some renewable energy resources are not always Available (that is, the wind does not always blow and the Sun does not always shine), the technologies perform reliably when the "fuel" is available. In this regard, they can add to the reliability of the electricity grid, especially for businesses in which power outages are extremely Costly. At the point of use, solar and wind technologies are emissions-free. This makes them attractive from an environmental standpoint. An additional environmental benefit could be the "bright fields" concept: installing clean energy technology-related businesses in environmentally blighted areas (brown fields). Finally, selected applications of energy efficiency and renewable energy technologies can enhance the disaster resiliency of communities and individual structures. For example, roof- or skid-mounted solar electric systems can provide needed power to hospitals, fire stations, police departments, gas stations, National Guard armories, etc. in the sunny days that follows destructive storms.

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- High cost of petroleum products and surge the cost of hydrocarbon fuels
- Increased demand for petroleum products.
- Strict emissions norms like EURO NORMS, BHARAT NORMS, KYOTO PROTOCOL, etc.
- Global warming and adverse Environment effect due to pollution from the automobile Fuels.

Alternative fuels, also known as non-conventional or advanced fuels, are any materials or substances that can be used as fuels, other than conventional fuels. Conventional fuels include: *fossil fuels* (petroleum (oil), coal, propane, and natural gas), and nuclear materials such as uranium. Some well known alternative fuels include biodiesel, bioalcohol (methanol, ethanol, butane), chemically stored electricity (batteries and fuel cells), [GreenNH3] non fossil, hydrogen, non-fossil methane, non-fossil natural gas, oil, and other biomass sources.

II. AN INTRODUCTION TO FUEL CELLS: GREEN ENERGY AN ALTERNATE FUEL FOR IC ENGINE.WHAT IS THE HISTORY OF FUEL W2CELLS?

Sir William Grove first demonstrated the technology behind fuel cells in 1839. The gas battery, later named the fuel cell, reversed the well-understood principal of electrolysis to generate an electrical current. Grove's invention was largely a curiosity as the age was captivated by the horseless carriage and the large reserves of petroleum that were being discovered. Fuel cells remained in obscurity until 1960 when the upstart government agency, The National Aeronautic and Space Administration (NASA), began looking for a practical power source for extended missions to space. Through research and development sponsored by NASA and private industry, the fuel cell is poised to become a replacement for the internal combustion engine and redesign the utility industry by making energy cleaner, cheaper and portable.

What is fuel cell?

A **fuel cell** is an electrochemical cell that converts energy from a fuel into electrical energy. Electricity is generated from the reaction between a fuel supply and an oxidizing agent. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained.

Fuel cells are different from conventional electrochemical cell batteries in that they consume reactant from an external source, which must be replenished – a thermodynamically open system. By contrast, batteries store electrical energy chemically and hence represent a thermodynamically closed system. Many combinations of fuels and oxidants are possible. A hydrogen fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. If pure hydrogen is used as a fuel, fuel cells emit only heat and water as a by-product.

Several fuel cell types are under development, and they have a variety of potential applications. Fuel cells are being developed to power passenger vehicles, commercial buildings, homes, and even small devices such as laptop computers.

III. HOW DOES A FUEL CELL OPERATES?

In principle, a fuel cell operates like a battery. Unlike a battery, a fuel cell does not run down or require recharging. It will produce energy in the form of electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat. Hydrogen fuel is fed into the "anode" of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron, which take different paths to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be utilized before they return to the cathode, to be reunited with the hydrogen and oxygen in a molecule of water.

IV. HOW DOES FUEL CELL GENERATE ELECTRICITY?

Fuel cells generate electricity through an electrochemical reaction, known as reverse electrolysis. This reaction combines hydrogen and oxygen to form water vapor, heat and electricity. All three of the by-products of this reverse electrolysis reaction can be further utilized by the fuel cell system. Waste heat can be utilized for space heating and cooling. The water vapor can be captured and used as the feedstock for additional hydrogen and the electricity is channeled into an external circuit where it is used by any electric appliance.

V. HOW FUEL CELLS WORK?

Fuel Cell Components & Function: A fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. A single fuel cell consists of an electrolyte sandwiched between two thin electrodes (a porous anode and cathode). While there are different fuel cell types, all work on the same principle: Hydrogen, or a hydrogen-rich fuel, is fed to the anode where a catalyst separates hydrogen's negatively charged electrons from positively charged ions (protons). At the cathode, oxygen combines with electrons and, in some cases, with species such as protons or water, resulting in water or hydroxide ions, respectively. For polymer exchange membrane (PEM) and phosphoric acid fuel cells, protons move through the electrolyte to the cathode to combine with oxygen and electrons, producing water and heat. For alkaline, molten carbonate, and solid oxide fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons. The electrons from the anode side of the cell cannot pass through the membrane to the positively charged cathode; they must travel around it via an electrical circuit to reach the other side of the cell. This movement of electrons is an electrical current. The amount of power produced by a fuel cell depends upon several factors, such as fuel cell type, cell size, the temperature at which it operates, and the pressure at which the gases are supplied to the cell. Still, a single fuel cell produces enough electricity for only the smallest applications. Therefore, individual fuel cells are typically combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells. Direct hydrogen fuel cells produce pure water as the only emission. This water is typically released as water vapour. Fuel cells release less water vapour than internal combustion engines producing the same amount of power.

What fuels do fuel cells use to produce electricity? One advantage of fuel cells is their fuel flexibility. With the proper reforming technology, fuel cells can extract hydrogen from a wide variety of currently available fossil fuels (e.g. Natural gas, methanol, coal, etc.). From fossil fuels, fuel cells utilize one natural element as their fuel, hydrogen, the most abundant element on Earth. In addition to fossil fuels, hydrogen can be generated renewably from water and other photo biological means.

Pure Hydrogen: Most fuel cell systems are fueled with pure hydrogen gas, which is stored onboard as a compressed gas. Since hydrogen gas has a low energy density, it is difficult to store enough hydrogen to generate the same amount of power as with conventional fuels such as gasoline. This is a significant problem for fuel cell vehicles, which need to have a driving range of 300-400 miles between refueling to be competitive gasoline vehicles. High-pressure tanks and other technologies are being developed to allow larger amounts of hydrogen to be stored in tanks small enough for passenger cars and trucks. In addition to onboard storage problems, our current infrastructure for getting liquid fuel to consumers can't be used for gaseous hydrogen. New facilities and delivery systems must be built, which will require significant time and resources. Costs for large-scale deployment will be substantial.

Hydrogen-rich Fuels: Fuel cell systems can also be fueled with hydrogen-rich fuels, such as methanol, natural gas, gasoline, or gasified coal. In many fuel cell systems, these fuels are passed through onboard "reformers" that extract hydrogen from the fuel. Onboard reforming has several advantages:There are also several disadvantages to reforming hydrogen-rich fuels: Onboard reformers add to the complexity, cost, and maintenance demands of fuel cell systems.High-temperature fuel cell systems can reform fuels within the fuel cell itself-a process called internal reforming-removing the need for onboard reformers and their associated costs. Internal reforming, however, does emit carbon dioxide, just like onboard reforming. In addition, impurities in the gaseous fuel can reduce cell efficiency.

Fuel Cell Systems. Most fuel cell systems consist of four basic components: Fuel processor: The fuel processor converts fuel into a form useable by the fuel cell. If hydrogen is fed to the system, a processor may not be required or it may only be needed to filter impurities out of the hydrogen gas. If the system is powered by a hydrogen-rich conventional fuel such as methanol, gasoline, diesel, or gasified coal, a reformer is typically used to convert hydrocarbons into a gas mixture of hydrogen and carbon compounds called "reformate." In many cases, the reformate is then sent to another reactor to remove impurities, such as carbon oxides or sulfur, before it is sent to the fuel cell stack.

This prevents impurities in the gas from binding with the fuel cell catalysts. This binding process is also called "poisoning" since it reduces the efficiency and life expectancy of the fuel cell. Some fuel cells, such as molten carbonate and solid oxide fuel cells, operate at temperatures high enough that the fuel can be reformed in the fuel cell itself. This is called internal reforming. Fuel cells that use internal reforming still need traps to remove impurities from the unreformed fuel before it reaches the fuel cell. Both internal and external reforming release carbon dioxide, but less than the amount emitted by internal combustion engines, such as those used in gasoline-powered vehicles. Energy Conversion Device - The Fuel Cell Stack :The fuel cell stack is the energy conversion device. It generates electricity in the form of direct current (DC) from chemical reactions that take place in the fuel cell. The fuel cell and fuel cell stack are covered under Fuel Cell Components and Function. Current Inverters &Conditioners: The purpose of current inverters and conditioners is to adapt the electrical current from the fuel cell to suit the electrical needs of the application, whether it is a simple electrical motor or a complex utility power grid. Fuel cells produce electricity in the form of direct current (DC). If the fuel cell is used to power equipment using AC, the direct current will have to be converted to alternating current. Both AC and DC power must be conditioned. Power conditioning includes controlling current flow (amperes), voltage, frequency, and other characteristics of the electrical current to meet the needs of the application. Conversion and conditioning reduce system efficiency only slightly, around 2 to 6 percent.Heat Recovery System: Fuel cell systems are not primarily used to generate heat. However, since significant amounts of heat are generated by some fuel cell systems-especially those that operate at high temperatures such as solid oxide and molten carbonate systems-this excess energy can be used to produce steam or hot water or converted to electricity via a gas turbine or other technology. This increases the overall energy efficiency of the systems.

VI. WHAT ARE THE BENEFITS OF FUEL CELLS?

- Environmental

Fuel Cells achieve high fuel efficiencies while emitting extremely low emissions.

- Engineering

Fuel cells operate on a wide variety of fuels, utilize electrochemical reactions and contain no moving parts. These features make them simple to operate, quiet and extremely reliable.

Why aren't fuel cells everywhere?

In the near future, fuel cells will play an increasing roll in everyday life. Soon fuel cell powered cars and trucks will be cruising the streets of your town emitting nothing more than harmless water vapor. Fuel cells will find their way into cell phones and laptop computers whose battery life is measured in days instead of hours. Your house or office will have a fuel cell that replaces a conventional furnace, providing heat and electricity free from the disruptions associated with the utility's electric grid. Most of the companies planning to manufacture fuel cells are still in the research and development stage of production. Once their systems satisfy the manufacturers' stringent requirements for performance and safety, the fuel cell systems will be available to the general public.

VII. IS HYDROGEN SAFE?

Hydrogen is a medium for storing energy. To be useful as energy carrier all fuels, such as gasoline and natural gas, have a characteristic of being volatile. Hydrogen's benefits differ from the fossil fuels commonplace in an advanced energy utilizing society such as in the United States.

Hydrogen is non-toxic. Gasoline and oil are extremely toxic and poisonous humans along with wildlife when unintentionally released into the environment. If a hydrogen spill occurred, the hydrogen would evaporate almost immediately leaving only water behind. Oil and gasoline, on the other hand, require immense cleanup efforts with the result being that most of the spilled toxic gasoline or oil seeps into the surrounding ecosystem wrecking irreparable harm.

Hydrogen has suffered from image problems in the past.

Hydrogen is commonly associated with two things; the Hindenburg disaster and the hydrogen bomb. Recently, researchers trying to determine the exact cause of the fire have investigated the Hindenburg accident. In 1937 the Hindenburg was destroyed attempting to land in an electrical storm outside of Lakehurst, NJ. Witness reported observing a blue glow on the top of the ill-fated airship. The blue glow is often indicative of extremely high electrical activity. The current school of thought indicates that the electricity around the skin of the ship probably ignited the skin. Addison Bain, a retired NASA safety expert, has analyzed the remaining fragments of the zeppelin's exterior fabric skin. His findings indicated that the skin was composed of either cellulose nitrate or cellulose acetate. Aluminum flakes were combined with these materials to reflect sunlight in order to keep the airship cool. The combination of cellulose nitrate and aluminum is commonly known today as the recipe for rocket fuel, as anyone who has watched a rocket launch knows, is highly flammable. The hydrogen contained in the airship did burn, but remember that hydrogen is lighter than air and the flames would have been streaking upwards not down onto the passenger cabin. All of the people who died in the disaster, died from falling to their death or burning to death from flaming, dripping diesel fuel. All of the survivors rode the airship down to the ground and safety. The size of the Hindenburg needs to be kept in mind. A passenger car or fuel cell operating on hydrogen would never have such a large amount of hydrogen stored in a flimsy cloth bag. All of the fuel cell systems and hydrogen storage techniques are engineered with safety being a paramount concern. The composite tanks used to store liquid and gaseous hydrogen are required to undergo rigorous safety testing before they are certified for hydrogen storage. The other reason hydrogen has received negative press in the past is its relationship to the hydrogen bomb. In order for hydrogen atoms to fuse tighter, like the reaction in a hydrogen bomb, special circumstances have to occur. Hydrogen will only fuse under extremely high heat and pressures that would never be found in a fuel cell system or hydrogen storage device.

Once transformed into a hydrogen-powered society, will the combined amount of water vapor from fuel cells cause environmental or climate problems?

The Union of Concerned Scientists have issued a report stating that, "If the entire U.S. passenger vehicle fleet were powered by hydrogen FCVs (fuel cell vehicles), the amount of water emitted annually (assuming no losses) would be 0.005% the rate of natural

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evaporation, water that is released by plants during photosynthesis, in the continental U.S."

VIII. DOES THE UNITED STATES GOVERNMENT SUPPORT FUEL CELL DEVELOPMENT?

By supporting the research and development of fuel cells, the United States Government is developing clean energy sources for our future while strengthening the United State's competitiveness on the world energy market. Many Governmental departments, including the Defense Department, the Department of Energy, Department of Transportation, etc? Have fuel cell programs in their respective areas. All of these programs are leading towards the commercialization of fuel cell technology through partnering with private industry. The Federal Government supports research and development through monetary contributions towards research that is considered risky by industry and by creating the initial markets for expensive new technology. For example, the Climate Change Fuel Cell program provides cost sharing regarding the purchase of a fuel cell system. Hydrogen and fuel cells only enjoy a fraction of the subsidies that the nuclear and fossil fuel industries receive each year.

Japan, Germany and Canada are all intensively developing fuel cell technology in their respective countries. Many of the manufacturers located in these countries enjoy governmental support that far surpasses what the United States Government is providing at home. These countries realize that fuel cells and hydrogen are the most likely replacement for our current energy system and with this in mind; they are trying to develop future industries today.

What are the Benefits of the Federal Government Supporting Fuel Cell Development?

By supporting fuel cell development, the United States Government will achieve the goals of strengthening our national energy security, improving environmental conditions and developing an industry. The United States is dependent on politically unstable and unfriendly regions of the globe for its supply of oil. Currently, the United States imports 50% of its oil. According to the Department of Energy this number is expected to grow to 65% by 2020. Fuel cells, with their characteristic fuel flexibility, allow the United States to dramatically reduce its dependence on foreign energy sources and reduce its unbalanced foreign trade debt. By eliminating or greatly reducing the emissions associated with fossil fuels, a noticeable improvement in the environmental conditions in many major metropolitan areas will occur. This results in a reduction of pollution-related medical conditions and a dramatic increase in the quality of life for residents of these areas. These two benefits combine to form incalculable monetary benefits. The United States has the opportunity to develop a new industry. Fuel cells and related industries can expand and improve the United States economy by creating new jobs in fuel cell manufacturing, sales, service and hydrogen production and storage. As costs fall, fuel cell technology becomes appealing to utilities in developing countries improving our exports and reducing our foreign trade deficit.

IX. AUTOMOTIVE BATTERIES VS. FUEL CELLS FOR TRANSPORTATION

Vehicles powered by fuel cells combine the attractive advantages of battery-powered cars and the convenience of an internal combustion engine. Fuel cells operate quietly and are zero to low emissions, comparable to a battery-powered vehicle. Fuel cell powered vehicles offer the range, power, responsiveness and rapid fueling that the internal combustion engine provides. Unlike battery-powered cars, fuel cells do *not* require lengthy recharge times and will *not* transfer the pollution from the tailpipe over the grid to a central generating facility. The batteries used in automobiles are extremely heavy which limits the vehicles range and capacity. The batteries are also composed of toxic materials and have a limited lifetime leading to disposal problems. Fuel cell vehicles operating on pure hydrogen produce only water vapor and heat as emissions while fuel cells reforming fossil fuels into hydrogen would be classified as ultra-low emission vehicles.

Hydrogen, when burned in a combustion engine is a huge improvement in terms of emissions when compared to fossil fuels. Burning hydrogen does release low amounts of nitrous oxide, a component of smog, into the atmosphere. This occurs whenever high temperature combustion occurs in the presence of oxygen. Other pollutants are also released as trace amounts of lubricants are burned in the process. The main reason to employ fuel cells instead of combusting hydrogen has to do with efficiency. Anytime a fuel is ignited and burned the overall efficiency is limited by the laws of physics, especially Carnot's Law, to around 10%. This is due to efficiency losses associated with heat and the additional steps necessary before the fuel is transformed into useable energy. A fuel cell directly converts the hydrogen fuel into electricity and is therefore inherently more efficient. A fuel cell skips the steps, associated with combustion generation, of first converting the fuel into heat, then mechanical energy and finally into energy. In an automobile engine 100 scf of hydrogen would power the car for about 6 to 12 miles. That same amount of hydrogen in a fuel cell powered car could travel 12 to 24 miles.

Below is an example calculation for determining the cost of operating a 1kW fuel cell on hydrogen. In this example a compressed hydrogen cylinder with a capacity of 200 cubic feet of hydrogen at normal temperature and pressure (NTP) is used. The purity of hydrogen consumed is 99%.

Calculation:

1. Compressed hydrogen cylinder - 200 cu.ft. Of hydrogen (NTP)
2. Cost of hydrogen cylinder is \$100 + \$14/month (rental) +\$20 (delivery)
3.1kW fuel cell system with a hydrogen consumption rate of 15 Standard Liter/min or 16.25 Normal Liter/min.
4. Number of hours of operation at 1kW = 200/16.25 = 12.3 hours

Costs: Example 1.

The cost of operating a 1kW fuel cell for 12.3 hours when only one cylinder is purchased per month is \$134. This is equivalent to \$10.89 per kWh.

Costs: Example 2.

When the number of hydrogen cylinders used is increased, then the cost is reduced. Assuming that 5 cylinders of hydrogen are consumed in one month, this gives 12.3 x 5 = 61.5 hours of operation. The cost of the cylinders is (5 x \$100) + (5 x \$14) + \$20 = \$590. This is equivalent to \$9.59 per kWh.

X. TYPES OF FUEL CELLS

Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications. A few of the most promising types include Polymer Electrolyte Membrane (PEM) Phosphoric Acid Direct Methanol Alkaline Molten Carbonate Solid Oxide Regenerative (Reversible)

What are the Different Types of Fuel Cells?

There are four main types of fuel cells distinguished by the electrolyte used in the individual cells. The different types of fuel cells are; polymer electrolyte membrane or proton exchange membrane (PEM), molten carbonate (MCFC), phosphoric acid (PAFC) and the solid oxide fuel cell (SOFC).

Polymer Electrolyte Membrane

Polymer electrolyte membrane (PEM) fuel cells-also called proton exchange membrane fuel cells-deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or onboard reformers. Polymer electrolyte membrane fuel cells operate at relatively low temperatures, around 80°C (176°F). Low temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to CO poisoning, making it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost. Developers are currently exploring platinum/ruthenium catalysts that are more resistant to CO. PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses. A significant barrier to using these fuel cells in vehicles is hydrogen storage. Most fuel cell vehicles (FCVs) powered by pure hydrogen must store the hydrogen onboard as a compressed gas in pressurized tanks. Due to the low energy density of hydrogen, it is difficult to store enough hydrogen onboard to allow vehicles to travel the same distance as gasoline-powered vehicles before refueling, typically 300-400 miles. Higher-density liquid fuels such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline can be used for fuel, but the vehicles must have an onboard fuel processor to reform the methanol to hydrogen. This increases costs and maintenance requirements. The reformer also releases carbon dioxide (a greenhouse gas), though less than that emitted from current gasoline-powered engines.

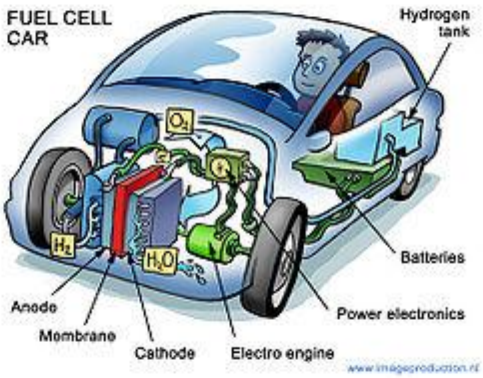
A. Power

Fuel cells are very useful as power sources in remote locations, such as spacecraft, remote weather stations, large parks, rural locations, and in certain military applications. A fuel cell system running on hydrogen can be compact and lightweight, and have no major moving parts. Because fuel cells have no moving parts and do not involve combustion, in ideal conditions they can achieve up to 99% reliability This equates to around one minute of down time in a two year period.

Since electrolyzer systems do not store fuel in them, but rather rely on external storage units, they can be successfully applied in large-scale energy storage, rural areas being one example. In this application, batteries would have to be largely oversized to meet the storage demand, but fuel cells only need a larger storage unit (typically cheaper than an electrochemical device).

One such pilot program is operating on Stuart Island in Washington State. There the Stuart Island Energy Initiative has built a complete, closed-loop system: Solar panels power an electrolyzer which makes hydrogen. The hydrogen is stored in a 500 gallon tank at 200 PSI, and runs a ReliOn fuel cell to provide full electric back-up to the off-the-grid residence.

1) Cogeneration



Configuration of components in a fuel cell car.

Micro combined heat and power (MicroCHP) systems such as home fuel cells and cogeneration for office buildings and factories are in the mass production phase. The system generates constant electric power (selling excess power back to the grid when it is not consumed), and at the same time produces hot air and water from the waste heat. MicroCHP is usually less than 5 kWe for a home fuel cell or small business. A lower fuel-to-electricity conversion efficiency is tolerated (typically 15-20%), because most of the energy not converted into electricity is utilized as heat. Some heat is lost with the exhaust gas just as in a normal furnace, so the combined heat and power efficiency is still lower than 100%, typically around 80%. In terms of exergy however, the process is inefficient, and one could do better by maximizing the electricity generated and then using the electricity to drive a heat pump. Phosphoric-acid fuel cells (PAFC) comprise the largest segment of existing CHP products worldwide and can provide combined efficiencies close to 90% (35-50% electric + remainder as thermal) Molten-carbonate fuel cells have also been installed in these applications, and solid-oxide fuel cell prototypes exist.

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Toyota FCHV PEM FC fuel cell vehicle.

a) Land vehicles

In 2003 President George Bush proposed the Hydrogen Fuel Initiative (HFI), which was later implemented by legislation through the 2005 Energy Policy Act and the 2006 Advanced Energy Initiative. These aimed at further developing hydrogen fuel cells and its infrastructure technologies with the ultimate goal to produce commercial fuel cell vehicles by 2020. By 2008, the U.S. had contributed 1 billion dollars to this project.

In May 2009, however, the Obama Administration announced that it will "cut off funds" for the development of fuel cell hydrogen vehicles, since other vehicle technologies will lead to quicker reduction in emissions in a shorter time. The US Secretary of Energy explained that hydrogen vehicles "*will not be practical over the next 10 to 20 years*", and also mentioned the challenges involved in the development of the required infrastructure to distribute hydrogen fuel. Nevertheless, the U.S. government will continue to fund research related to stationary fuel cells. The National Hydrogen Association and the U.S. Fuel Cell Council criticized this decision arguing that "*...the cuts proposed in the DOE hydrogen and fuel cell program threaten to disrupt commercialization of a family of technologies that are showing exceptional promise and beginning to gain market traction*."

There are numerous prototype or production cars and buses based on fuel cell technology being researched or manufactured by motor car manufacturers.

The GM 1966 Electro van was the automotive industry's first attempt at an automobile powered by a hydrogen fuel cell. The Electro van, which weighed more than twice as much as a normal van, could travel up to 70 mph for 30 seconds.

The 2001 Chrysler Natrium used its own on-board hydrogen processor. It produces hydrogen for the fuel cell by reacting sodium borohydride fuel with Borax, both of which Chrysler claimed were naturally occurring in great quantity in the United States. The hydrogen produces electric power in the fuel cell for near-silent operation and a range of 300 miles without impinging on passenger space. Chrysler also developed vehicles which separated hydrogen from gasoline in the vehicle, the purpose being to reduce emissions without relying on a nonexistent hydrogen infrastructure and to avoid large storage tanks. In 2005 the British firm Intelligent Energy produced the first ever working hydrogen run motorcycle called the ENV (Emission Neutral Vehicle). The motorcycle holds enough fuel to run for four hours, and to travel 100 miles in an urban area, at a top speed of 50 miles per hour. In 2004 Honda developed a fuel-cell motorcycle which utilized the Honda FC Stack.

In 2007, the Revolve Eco-Rally (launched by HRH Prince of Wales) demonstrated several fuel cell vehicles on British roads for the first time, driven by celebrities and dignitaries from Brighton to London's Trafalgar Square. Fuel cell powered race vehicles, designed and built by university students from around the world, competed in the world's first hydrogen race series called the 2008 Formula Zero Championship, which began on August 22, 2008 in Rotterdam, the Netherlands. More races are planned for 2009 and 2010. After this first race, Greenchoice Forze from the university of Delft (The Netherlands) became leader in the competition. Other competing teams are Element One (Detroit), HerUCLAs (LA), EUPLAtecH2 (Spain), Imperial Racing Green (London) and Zero Emission Racing Team (Leuven).

In 2008, Honda released a hydrogen vehicle, the FCX Clarity. Meanwhile there exist also other examples of bikes and bicycles with a hydrogen fuel cell engine.

A few companies are conducting hydrogen fuel cell research and practical fuel cell bus trials. Daimler AG, with thirty-six experimental units powered by Ballard Power Systems fuel cells completing a successful three-year trial, in eleven cities, in January 2007. There are also fuel cell powered buses currently active or in production, such as a fleet of Thor buses with UTC Power fuel cells in California, operated by SunLine Transit Agency. The Fuel Cell Bus Club is a global cooperative effort in trial fuel cell buses.

The first Brazilian hydrogen fuel cell bus prototype will begin operation in São Paulo during the first semester of 2009. The hydrogen bus was manufactured in Caxias do Sul and the hydrogen fuel will be produced in São Bernardo do Campo from water through electrolysis. The program, called "*Ônibus Brasileiro a Hidrogênio*" (Brazilian Hydrogen Autobus), includes three additional buses.

b) Airplanes

Boeing researchers and industry partners throughout Europe conducted experimental flight tests in February 2008 of a manned airplane powered only by a fuel cell and lightweight batteries. The Fuel Cell Demonstrator Airplane, as it was called, used a Proton Exchange Membrane (PEM) fuel cell/lithium-ion battery hybrid system to power an electric motor, which was coupled to a conventional propeller. In 2003, the world's first propeller driven airplane to be powered entirely by a fuel cell was flown. The fuel cell was a unique FlatStack stack design which allowed the fuel cell to be integrated with the aerodynamic surfaces of the plane.

c) Boats

The world's first Fuel Cell Boat HYDRA used an AFC system with 6.5 kW net output.

d) Submarines

The Type 212 submarines of the German and Italian navies use fuel cells to remain submerged for weeks without the need to surface.

e) Fueling stations

The first public hydrogen refueling station was opened in Reykjavík, Iceland in April 2003. This station serves three buses built by DaimlerChrysler that are in service in the public transport net of Reykjavík. The station produces the hydrogen it needs by itself, with an electrolyzing unit (produced by Norsk Hydro, and does not need refilling: all that enters is electricity and water. Royal Dutch Shell is also a partner in the project. The station has no roof, in order to allow any leaked hydrogen to escape to the atmosphere.

The California Hydrogen Highway is an initiative by the California Governor to implement a series of hydrogen refueling stations along that state. These stations are used to refuel hydrogen vehicles such as fuel cell vehicles and hydrogen combustion vehicles. As of July 2007 California had 179 fuel cell vehicles and twenty five stations in operation, and ten more stations have been planned for assembly in California. However, there have already been three hydrogen fueling stations decommissioned. South Carolina also has a hydrogen freeway in the works. There are currently two hydrogen fueling stations, both in Aiken and Columbia, SC. Additional stations are expected in places around South Carolina such as Charleston, Myrtle Beach, Greenville, and Florence. According to the South Carolina Hydrogen & Fuel Cell Alliance, the Columbia station has a current capacity of 120 kg a day, with future plans to develop on-site hydrogen production from electrolysis and reformation. The Aiken station has a current capacity of 80 kg. There is extensive funding for Hydrogen fuel cell research and infrastructure in South Carolina. The University of South Carolina, a founding member of the South Carolina Hydrogen & Fuel Cell Alliance, received 12.5 million dollars from the United States Department of Energy for its Future Fuels Program. Japan also has a hydrogen highway, as part of the Japan hydrogen fuel cell project. Twelve hydrogen fueling stations have been built in 11 cities in Japan. Canada, Sweden and Norway also have hydrogen highways implemented.

Other applications

- Providing power for base stations or cell sites Off-grid power supply
- Distributed generation
- Fork Lifts
- Emergency power systems are a type of fuel cell system, which may include lighting, generators and other apparatus, to provide backup resources in a crisis or when regular systems fail. They find uses in a wide variety of settings from residential homes to hospitals, scientific laboratories, data centers, telecommunication equipment and modern naval ships.
- An uninterrupted power supply (**UPS**) provides emergency power and, depending on the topology, provide line regulation as well to connected equipment by supplying power from a separate source when utility power is not available. Unlike a standby generator, it can provide instant protection from a momentary power interruption.
- Base load power plants
- Electric and hybrid vehicles.
- Notebook computers for applications where AC charging may not be available for weeks at a time.
- Portable charging docks for small electronics (e.g. a belt clip that charges your cell phone or PDA).
- Smartphones with high power consumption due to large displays and additional features like GPS might be equipped with micro fuel cells.
- Small heating appliances
- Space Shuttles

XI. FUEL CELL ECONOMICS

Use of hydrogen to fuel vehicles would be a critical feature of a hydrogen economy. A fuel cell and electric motor combination is not directly limited by the Carnot efficiency of an internal combustion engine.

Low temperature fuel cell stacks proton exchange membrane fuel cell (PEMFC), direct methanol fuel cell (DMFC) and phosphoric acid fuel cell (PAFC) use a platinum catalyst. Impurities create catalyst poisoning (reducing activity and efficiency) in these low-temperature fuel cells, thus high hydrogen purity or higher catalyst densities are required. Although there are sufficient platinum resources for future demand, most predictions of platinum running out and/or platinum prices soaring do not take into account effects of reduction in catalyst loading and recycling. Recent research at Brookhaven National Laboratory could lead to the replacement of platinum by a gold-palladium coating which may be less susceptible to poisoning and thereby improve fuel cell lifetime considerably. Another method would use iron and sulphur instead of platinum. This is possible through an intermediate conversion by bacteria. This would lower the cost of a fuel cell substantially (as the platinum in a regular fuel cell costs around $1500, and the same amount of iron costs only around $1.50). The concept is being developed by a coalition of the John Innes Centre and the University of Milan-Bicocca. PEDOT cathodes are immune to monoxide poisoning. Current targets for a transport PEM fuel cells are 0.2 g/kW Pt – which is a factor of 5 decrease over current loadings – and recent comments from major original equipment manufacturers (OEMs) indicate that this is possible. Recycling of fuel cells components, including platinum, will conserve supplies. High-temperature fuel cells, including molten carbonate fuel cells (MCFC's) and solid oxide fuel cells (SOFC's), do not use platinum as catalysts, but instead use cheaper materials such as nickel and nickel oxide. They also do not experience catalyst poisoning by carbon monoxide, and so they do not require high-purity hydrogen to operate. They can use fuels with an existing and extensive infrastructure, such as natural gas, directly, without having to first reform it externally to hydrogen and CO followed by CO removal.

Research and development

August 2005: Georgia Institute of Technology researchers use triazole to raise the operating temperature of PEM fuel cells from below 100 °C to over 125 °C, claiming this will require less carbon-monoxide purification of the hydrogen fuel.[

2008 Monash University, Melbourne uses PEDOT as a cathode.

2009 Researchers at the University of Dayton, in Ohio, have shown that arrays of vertically grown carbon nanotubes could be used as the catalyst in fuel cells.

2009: Y-Carbon has begun to develop a carbide-derived-carbon-based ultra capacitor with high energy density which may lead to improvements in fuel cell technology.

2009: A nickel bisdiphosphine-based catalyst for fuel cells is demonstrated.

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