

# International Journal of Innovative Research in Science, Engineering and Technology

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## Performance and Characterization of Hydrogen Fuel

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**ABSTRACT:** Hydrogen does not occur free in nature in useful quantities, but it is manufactured in a number of ways. It can be made from natural gas or it can be made by passing electric current through water with greater efficiency over an internal combustion engine. The same amount of hydrogen will take a fuel-cell car at least twice as far as a car running on gasoline.

### I. CARS PROPELLED BY HYDROGEN FUEL CELLS

There are companies which have been, and continue to work on, developing hydrogen fuel cells for cars. Many of these have invested billions of dollars into the study of cars that are more environmentally friendly. Honda has created the Honda FCX. This car omits only water vapor as it is:

- Propelled by electricity
- Generated by hydrogen fuel and an ultracapacitor (an energy storage device)

The BMW 7 Series Large Sedan is one car that BMW has come up with to promote its Clean Energy program. The car manufacturer announced that next year it will begin trials of a new 6.0-liter V12 gasoline-hydrogen-powered model of the 7 Series.

### ADVANTAGES OF HYDROGEN FUEL:

When hydrogen is burned, the only emission it makes is water vapor, so a key advantage of hydrogen is that when burned, carbon dioxide (CO<sub>2</sub>) is not produced. Clearly, hydrogen is less of a pollutant in the air because it omits little tail pipe pollution

### ALTERNATIVE METHODS TO PRODUCE HYDROGEN:

Wind, solar (photovoltaic cells), and nuclear hydrogen could be possibilities for alternative forms of producing hydrogen. Another form of technology is the use of electrolysis. This method uses an electric current to split water into oxygen and hydrogen.

### IN THE NEAR FUTURE:

Will we be seeing more cars run by hydrogen fuel in the near future?

Although once thought to be the fuel of the far-off future, hydrogen will be making a big debut next year and in the years to follow.

- ✓ Honda has plans to showcase a limited line of passenger cars powered by hydrogen fuel cells in 2008. They also have a new hybrid car that will be priced below \$25,000.
- ✓ GM has announced plans involving hydrogen vehicles.
- ✓ Mercedes will begin in 2010 with a small-scale production of the B-Class F-Cell vehicle.

Additionally, gas stations will have to get on board and supply hydrogen as well as gasoline at the pumps in order to make owning and driving these cars practical for the consumer.

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## II. VEHICLES

Buses, trains, PHB bicycles, canal boats, cargo bikes, golf carts, motorcycles, wheelchairs, ships, airplanes, submarines, and rockets can already run on hydrogen, in various forms. NASA uses hydrogen to launch Space Shuttles into space. There is even a working toy model car that runs on solar power, using a regenerative fuel cell to store energy in the form of hydrogen and oxygen gas. It can then convert the fuel back into water to release the solar energy.



The current land speed record for a hydrogen-powered vehicle is 286.476 mph (461.038 km/h) set by Ohio State University's Buckeye Bullet 2, which achieved a "flying-mile" speed of 280.007 mph (450.628 km/h) at the Bonneville Salt Flats in August 2008. For production-style vehicles, the current record for a hydrogen-powered vehicle is 333.38 km/h (207.2 mph) set by a prototype Ford Fusion Hydrogen 999 Fuel Cell Race Car at Bonneville Salt Flats in Wendover, Utah in August 2007. It was accompanied by a large compressed oxygen tank to increase power. Honda has also created a concept called the FC Spot, which may be able to beat that record if put into production.

## III. AUTOMOBILES

Many companies are currently researching the feasibility of building hydrogen cars, and some automobile manufacturers have begun developing hydrogen cars see list of fuel cell vehicles. Funding has come from both private and government sources. However, the Ford Motor Company has dropped its plans to develop hydrogen cars, stating that "The next major step in Ford's plan is to increase over time the volume of electrified vehicles". Similarly, French Renault-Nissan announced in 2009 that it is cancelling its hydrogen car R&D efforts. As of October 2009, General Motors CEO Fritz Henderson noted that GM had reduced its hydrogen program because the cost of building hydrogen cars was too high. "It's still a ways away from commercialization", he said. The "Volt will likely cost around \$40,000 while a hydrogen vehicle would cost around \$400,000. Most hydrogen cars are currently only available in demonstration models or in a lease construction in limited numbers and are not yet ready for general public use. The estimated number of hydrogen-powered cars in the United States was 200 as of October 2009, mostly in California. In February 2010 Lotus Cars announced that it was developing a fleet of hydrogen taxis in London, with the hope of them being ready to trial by the 2012 Olympic Games. London's deputy mayor, Kit Malthouse, said he hoped six filling stations would be available and that around 20-50 taxis would be in operation by then, as well as 150 hydrogen-powered buses.

### **BUSES:**

Fuel cell buses (as opposed to hydrogen fueled buses) are being trialed by several manufacturers in different locations. The Fuel Cell Bus Club is a global fuel cell bus testing collaboration.

Hydrogen was first stored in roof mounted tanks, although models are now incorporating onboard tanks. Some double deck models uses between floor tanks.

### **MOTORCYCLES AND SCOOTERS:**

ENV develops electric motorcycles powered by a hydrogen fuel cell, including the Crosscage and Biplane. Other

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manufacturers as Vectrix are working on hydrogen scooters. Finally, hydrogen fuel cell-electric hybrid scooters are being made such as the Suzuki Burgman Fuel cell scooter and the FHybrid.

### AIRPLANES:

The Boeing Fuel Cell Demonstrator powered by a hydrogen fuel cell Companies such as Boeing, Lange Aviation, and the German Aerospace Center pursue hydrogen as fuel for manned and unmanned airplanes. In February 2008 Boeing tested a manned flight of a small aircraft powered by a hydrogen fuel cell. Unmanned hydrogen planes have also been tested. For large passenger airplanes however, The Times reported that "Boeing said that hydrogen fuel cells were unlikely to power the engines of large passenger jet airplanes but could be used as backup or auxiliary power units onboard. July 2010 Boeing unveiled its hydrogen powered Phantom Eye UAV, powered by two Ford internal combustion engines that have been converted to run on hydrogen.

In Europe, the Reaction Engines A2 has been proposed to use the thermodynamic properties of liquihydrogen to achieve very high speed, long distance (antipodal) flight by burning it in a precooledjet engine.

### FORK TRUCKS:

A **HICE forklift** or **HICE lift truck** is a hydrogen fueled, internal combustion engine powered industrial forklift truck used for lifting and transporting materials. The first production HICE forklift truck based on the Linde X39 Diesel was presented at an exposition in Hannover on May 27, 2008. It used a 2.0 litre, 43 kW diesel internal combustion engine converted to use hydrogen as a fuel with the use of a compressor and direct injection. The hydrogen tank is filled with 26 liters of hydrogen at 350 bar pressure.

### ROCKETS:

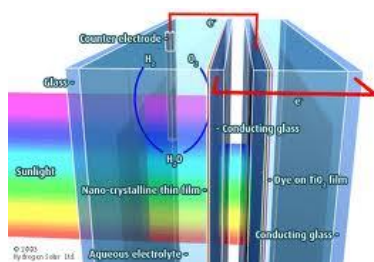
Rockets employ hydrogen because hydrogen gives the highest effective exhaust velocity as well as giving a lower net weight of propellant than other fuels. It performs particularly well on upper stages, although it has been used on lower stages as well, usually in conjunction with a dense fuel booster.

The main disadvantage of hydrogen in this application is the low density and deeply cryogenic nature, requiring insulation- this makes the hydrogen tanks relatively heavy, which greatly offsets much of the otherwise overwhelming advantages for this application.

The main advantage of hydrogen is that although the velocity change of a stage employing it is little different to a stage using denser fuel, the lift-off weight of the stage is less. Particularly when used for upper stages this permits a lighter rocket for any given payload.

## IV. INTERNAL COMBUSTION VEHICLE

Hydrogen internal combustion engine cars are different from hydrogen fuel cell cars. The hydrogen internal combustion car is a slightly modified version of the traditional gasoline internal combustion engine car. These hydrogen engines burn fuel in the same manner that gasoline engines do Francois Isaac de Rivaz designed in 1807 the first hydrogen-fueled internal combustion engine. Paul Dieges patented in 1970 a modification to internal combustion engines which allowed a gasoline-powered engine to run on hydrogen, Mazda has developed Wankel engines burning hydrogen. The advantage of using ICE (internal combustion engine) like Wankel and piston engines is the cost of retooling for



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production is much lower. Existing-technology ICE can still be applied for solving those problems where fuel cells are not a viable solution insofar, for example in cold-weather applications.

HICE forklift trucks have been demonstrated based on converted diesel internal combustion engines with direct injection

### FUEL CELL:

While fuel cells themselves are potentially highly energy efficient, and working prototypes were made by Francis Thomas Bacon in 1959 and Roger E. Billings in the 1960s, at least four technical obstacles and other political considerations exist regarding the development and use of a fuel cell-powered hydrogen car.

### FUEL CELL COST:

Currently, hydrogen fuel cells are costly to produce and are fragile. As of October 2009, *Fortune* magazine estimated the cost of producing the Honda Clarity at \$300,000 per car. Engineers are studying how to produce inexpensive fuel cells that are robust enough to survive the bumps and vibrations that all automobiles experience. Also, many designs require rare substances such as platinum as a catalyst in order to work properly. Such a catalyst can also become contaminated by impurities in the hydrogen supply. In the past few years, however, a nickel-tin nonmetal catalyst has been under development which may lower the cost of cells.

Fuel cells are generally priced in USD/kW, and data is scarce regarding costs. Ballard Power Systems is virtually alone in publishing such data. Their 2005 figure was \$73 USD/kW (based on high volume manufacturing estimates), which they said was on track to achieve the U.S. DoE's 2010 goal of \$30 USD/kW. This would achieve closer parity with internal combustion engines for automotive applications, allowing a 100 kW fuel cell to be produced for \$3000. 100 kW is about 134.

### FREEZING CONDITIONS:

Temperatures below freezing (32 °F or 0 °C) are a concern with fuel cells operations. Operational fuel cells have an internal vaporous water environment that could solidify if the fuel cell and contents are not kept above 0° Celsius (32°F). Most fuel cell designs are not as yet robust enough to survive in below-freezing environments. Frozen solid, especially before start up, they would not be able to begin working. Once running though, heat is a byproduct of the fuel cell process, which would keep the fuel cell at an adequate operational temperature to function correctly. This makes startup of the fuel cell a concern in cold weather operation. Places such as Alaska where temperatures can reach -40 °C (-40 °F) at startup would not be able to use early model fuel cells. Ballard announced in 2006 that it had already hit the U.S. DoE's 2010 target for cold weather starting which was 50% power achieved in 30 seconds at -20 °C.

### SERVICE LIFE:

Although service life is coupled to cost, fuel cells have to be compared to existing machines with a service life in excess of 5000 hours for stationary and light-duty. Marine PEM fuel cells reached the target in 2004. Current service life is 7,300 hours under cycling conditions. Research is going on especially for heavy duty like in the bus trials which are targeted up to a service life of 30,000 hours.

For more details on this topic, see Fuel cell.

### HYDROGEN:

Hydrogen does not come as a pre-existing source of energy like fossil fuel, but is first produced and then stored as a carrier, much like a battery. Hydrogen for vehicle uses needs to be produced using either renewable or non-renewable energy sources. A suggested benefit of large-scale deployment of hydrogen vehicles is that it could lead to decreased emissions of greenhouse gases and ozone precursors.

According to the United States Department of Energy "Producing hydrogen from natural gas does result in some greenhouse gas emissions. When compared to ICE vehicles using gasoline, however, fuel cell vehicles using hydrogen produced from natural gas reduce greenhouse gas emissions by 60%. While methods of hydrogen production that do not use fossil fuel would be more sustainable, currently renewable energy represents only a small percentage of energy

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**Vol. 4, Special Issue 13, December 2015**

generated, and power produced from renewable sources can be used in electric vehicles and for non-vehicle applications.

The challenges facing the use of hydrogen in vehicles include production, storage, transport and distribution. The well-to-wheel efficiency for hydrogen, because of all these challenges will not exceed 25%.

### PRODUCTION:

The molecular hydrogen needed as an on-board fuel for hydrogen vehicles can be obtained through many thermochemical methods utilizing natural gas, coal (by a process known as coal gasification), liquefied petroleum gas, biomass biomass gasification, by a process called thermolysis, or as a microbial waste product called biohydrogen or Biological hydrogen production. 95% of hydrogen is produced using natural gas, and 85% of hydrogen produced is used to remove sulfur from gasoline. Hydrogen can also be produced from water by electrolysis or by chemical reduction using chemical hydrides or aluminum. Current technologies for manufacturing hydrogen use energy in various forms, totaling between 25 and 50 percent of the higher heating value of the hydrogen fuel, used to produce, compress or liquefy, and transmit the hydrogen by pipeline or truck.

In either case, the scale of renewable energy production today is small and would need to be greatly expanded to be used in producing HYDROGEN for a significant part of transportation needs. As of December 2008, less than 3 percent of U.S. electricity was produced from renewable sources, not including dams In a few countries, renewable sources are being used more widely to produce energy and hydrogen. For example, Iceland is using geothermal power to produce hydrogen, and Denmark is using wind.

### STORAGE:

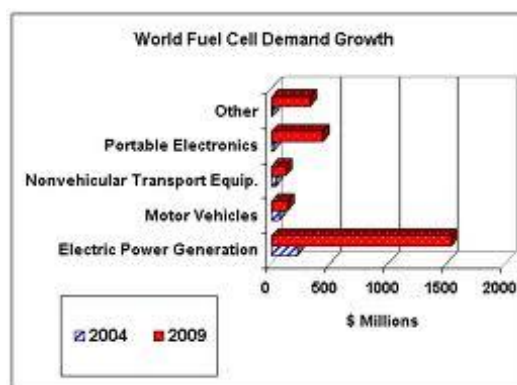
Compressed hydrogen storage mark

Hydrogen has a very low volumetric energy density at ambient conditions, equal to about one-third that of methane. Even when the fuel is stored as liquid hydrogen in a cryogenic tank or in a compressed hydrogen storage tank, the volumetric energy density (megajoules per liter) is small relative to that of gasoline. Hydrogen has a three times higher energy density by mass compared to gasoline (143 MJ/kg versus 46.9 MJ/kg). Some research has been done into using special crystalline materials to store hydrogen at greater densities and at lower pressures. A recent study by Dutch researcher Robin Gremaud has shown that metal hydride hydrogen tanks are actually 40 to 60-percent lighter than an equivalent energy battery pack on an electric vehicle permitting greater range for H2 cars.

### INFRASTRUCTURE:

The hydrogen infrastructure consists mainly of industrial hydrogen pipeline transport and hydrogen-equipped filling stations like those found on a hydrogen highway. Hydrogen stations which are not situated near a hydrogen pipeline get supply via hydrogen tanks, compressed hydrogen tube trailers, liquid hydrogen tank trucks or dedicated onsite production.

Hydrogen use would require the alteration of industry and transport on a scale never seen before in history. For



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**Vol. 4, Special Issue 13, December 2015**

example, according to GM, 70% of the U.S. population lives near a hydrogen-generating facility but has just about no access to hydrogen, despite its wide availability for commercial use. The distribution of hydrogen fuel for vehicles in the U.S. would require new hydrogen stations costing, by some estimates, 20 billion dollars. and 4.6 billion in the EU. Other estimates place the cost as high as half trillion U.S. dollars in the United States alone.

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.

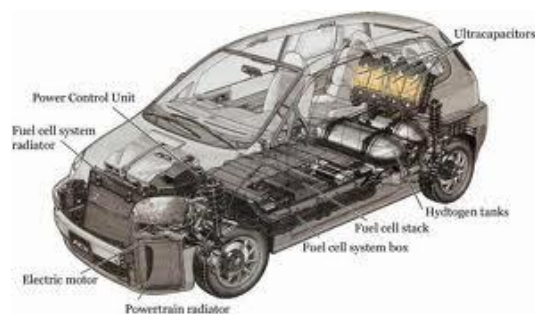
### CODES AND STANDARDS:

Hydrogen codes and standards are codes and standards(RCS) for hydrogen fuel cell vehicles. Additional to the codes and standards for hydrogen vehicles, there are codes and standards for hydrogen safety, for the safe handling of hydrogen and the storage of hydrogen. Codes and standards have repeatedly been identified as a major institutional barrier to deploying hydrogen technologies and developing a hydrogen economy. To enable the commercialization of hydrogen in consumer products, new model building codes and equipment and other technical standards are developed and recognized by federal, state, and local governments.

### COMPARISON WITH OTHER TYPES OF ALTERNATIVE FUEL VEHICLE:

Hydrogen vehicles are one of a number of proposed alternatives to the modern fossil fuel powered vehicle infrastructure.

### PLUG-IN HYBRIDS:



Plug-in hybrid electric vehicles, or PHEVs, are ICE-based hybrid vehicle that can be plugged into the electric grid. The PHEV concept augments standard hybrid electric vehicles with the ability to recharge their batteries from an external source while parked, enabling increased use of the vehicle's electric motors while reducing their reliance on internal combustion engines. The infrastructure required to charge PHEVs is already in place, and transmission of power from grid to car is about 93% efficient. This, however, is not the only energy loss in transferring power from grid to wheels. AC/DC conversion must take place from the grids AC supply to the PHEV's DC. This is roughly 98% efficient. The battery then must be charged, the Lithium Iron Phosphate battery is between 80-90% efficient in charging/discharging. This efficiency will impact twice, once discharging, once charging. The battery then needs to be cooled.

### NATURAL GAS:

ICE-based CNG or LNG vehicles (Natural gas vehicles or NGVs) use Natural gas or Biogas as a fuel source. Natural gas has a higher energy density than hydrogen gas, and its combustion creates only water and carbon dioxide as waste products. Natural gas powered vehicles have a lower carbon dioxide footprint. When using Biogas, NGVs become carbon neutral vehicles that run on animal waste. CNG vehicles have been available for several years, and there is sufficient infrastructure to provide both commercial and home refueling stations. In 2008, the ACEEE rated the Honda Civic GX, which uses compressed natural gas, as the greenest vehicle available.

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### BATTERY ELECTRIC VEHICLES:

As *Technology Review* noted in June 2008, "Electric cars—and plug-in hybrid cars—have an enormous advantage over hydrogen fuel-cell vehicles in utilizing low-carbon electricity. That is because of the inherent inefficiency of the entire hydrogen fueling process, from generating the hydrogen with that electricity to transporting this diffuse gas long distances, getting the hydrogen in the car, and then running it through a fuel cell—all for the purpose of converting the hydrogen back into electricity to drive the same exact electric motor you'll find in an electric car." Thermodynamically, each additional step in the conversion process decreases the overall efficiency of the process. Taking the Mini-E as an example, this can achieve a range of 156 miles (251 km) under optimum driving conditions but Mini have said most users can expect between 100–120 miles (160–190 km). However, most commutes are 30–40 miles (48–64 km) miles per day. Ed Begley, Jr., an electric car advocate, noted wryly, "The detractors of electric vehicles are right. Given their limited range, they can only meet the needs of 90 percent of the population." In addition, new Nickel-metal hydride and lithium batteries are non-toxic and can be recycled, and "the supposed 'lithium shortage' doesn't exist".



*Everyone is excited about hydrogen cars, but there is always the challenge of how they are going to fill up. Most cars are restricted by the distance that they can travel on a full tank and nothing more. Few places, especially on the East Coast, offer a refueling station to allow the cars to travel any further. If the hydrogen highway plan comes to fruition, that will finally change.*

### HIGH TEMPERATURE SOURCE:

*Hydrogen is a strong contender to the generation-next clean and green fuel. Scientists are always trying to eliminate or*



*minimize its drawbacks and maximize its benefits. They want to get rid of the intensive, high-energy process used when we need hydrogen as fuel. Because this process poses hurdle in the progress of hydrogen as clean and reliable alternative fuel. Scientists from the University of Tennessee, Knoxville, and Oak Ridge National Laboratory are looking towards the wonder known as photosynthesis for some answers. Photosynthesis is the process from which*

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Vol. 4, Special Issue 13, December 2015

plants generate energy and food in the presence of sunlight. Scientists think that photosynthesis might help providing answers so that we can utilize hydrogen as a fuel.

### STUDENTS RUN THEIR BOAT IN HYDROGEN:

A group of bright young Rensselaer students will soon take up the Hudson River, but with a difference. They are using a boat driven by clean and green hydrogen fuel. Their boat is the 22-foot New Clermont looked after by a three member crew. It is fitted with a pair of 2.2-kilowatt fuel cell units.



### NEW STORAGE TYPE:

It seems simple but if put it into practice then we can develop real potential for hydrogen fuels. A new method of “recycling” hydrogen-containing fuel materials could pave the way for commercially viable hydrogen-based vehicles. An article published in world’s leading chemistry journal *Angewandte Chemie*, makes a claim about recycling hydrogen-containing fuel materials. Los Alamos National Laboratory and University of Alabama researchers working within the U.S.

### V. THE LAST WORD (conclusion)

Many economists believe that although hydrogen cars may become more popular, it may be another decade before we see these vehicles in mass quantities on the market place. There is still more research to be done, and a number of hurdles to jump before hydrogen propelled vehicles are a common sight on all of our highways.

**Hydrogen vehicle** is an alternative fuel vehicle that uses hydrogen as its onboard fuel for motive power. The term may refer to a personal transportation vehicle, such as an automobile, or any other vehicle that uses hydrogen in a similar fashion, such as an aircraft. The power plants of such vehicles convert the chemical energy of hydrogen to mechanical energy either by burning hydrogen in an internal combustion engine, or by reacting hydrogen with oxygen in a fuel cell to run electric motors. Widespread use of hydrogen for fueling transportation is a key element of a proposed hydrogeneconomy.

Many companies are working to develop technologies that might efficiently exploit the potential of hydrogen energy for mobile uses. The attraction of using hydrogen as an energy.

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