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Analysis of Residential Fuel Cell System

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ABSTRACT: Fuel cells are now on the verge of dominating the 21st century commercially, revolutionizing the way we presently produce power. As fuel cells provide many advantages such as high efficiency, silent operation, no smoke stock pollution this adds up to energy savings for the consumer, energy security for country & cleaner environment. This paper discusses about the Dynamics of Fuel Cells for Electric Vehicle Propulsion, the practicalities like Fuel Processors, Balance of plant components, Efficiency, Emission and various other parameters to assess its feasibility. For more than 60 years automobile industries has been working on alternative power source vehicles & has place varieties of vehicles on the road. Though the most challenging task for automobile scientist is to provide a pollution free vehicle. These days the increase in demand of alternative fuels is due to, Conventional fuels causing GLOBAL WARMING crisis and Peak-oil causing energy crisis.

In the transportation sector, using PNGV (Partnership for a New Generation of Vehicles) body parameters (drag coefficient, cross sectional area, rolling resistance, and weight) for passenger vehicles instead of current body parameters uniformly improved the performance of all vehicles in terms of increased fuel economy and decreased greenhouse gas emissions. This analysis shows that only a direct hydrogen FCV will meet the PNGV fuel economy goals of 80 mpgge on realistic driving cycles.

KEYWORDS: Polymer Electrolyte Membrane, Fuel Cell Vehicle, Alkaline Fuel Cell, Membrane Electrode Assembly, PNGV.

I. INTRODUCTION

“I believe Fuel Cell vehicles will finally end the hundred year reign of the internal combustion engine as the dominant source of power for personal transportation. It’s going to be a winning situation all the way around – consumers will get an efficient power source, communities will get zero emissions and automakers will get another business opportunity – a growth opportunity.” **William C. Ford, Jr., Ford Motor Chairman**

The first fuel cell was built in 1839 by Sir William Groove, Welsh judge and gentleman scientist. Fuel cell can promote energy diversity and a transition to renewable energy sources. Hydrogen being the most abundant element on earth can be used directly. Fuel cells can also utilize fuel containing hydrogen, including methanol, ethanol, natural gas and even gasoline or diesel fuel. Neither hydrogen nor pure oxygen are feasible choices for general vehicles propulsion in view of their high cost and because of the technical difficulties and high costs to store practical quantities of these gases on vehicles. Like combustion-based automobiles engines automotive fuel cells must use ambient air as the source of the required oxygen, and they must be able to operate on widely available hydrocarbon fuels such as gasoline and other petroleum products which are easily stored on board vehicles. One key to meeting these stringent requirements is the development of the “membrane electrode assembly” or MEA. An MEA is an anode – PEM electrolyte – cathode composite structure in which each layer is made as thin as possible without losing the mechanical integrity of the composite structure or the electrochemical activity of the two electrodes. When hydrogen and oxygen are used as the primary fuels for the chemical reaction, the by-products of electrical production are pure water (H₂O) and heat. In this paper we explore the fuel choices issue, methanol reformer, hydrocarbon (gasoline) reformers, system complexity and feasibility.

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Heart of fuel cell is “stack”. This stack is actually made of many thin. Flat “Cells” layered together (fuel cell refers only to the individual cells). Each cell produces electricity & output of actually cells is combined to power the vehicle. Each cell contains several layers of different materials. Some layers help start the reaction that produce electricity; these are called catalysts. Each cell is supplied with hydrogen (from the fuel) & oxygen from the outside air. The hydrogen moves through the cell & encounters the first two catalyst layers. The catalyst causes the hydrogen molecules to release electrons & protons, creating the electrical current. The protons recreate through the electrolyte to the second catalyst layer where they react with oxygen to form water. Supplying hydrogen as either hydrogen gas or a hydrogen-rich reformat is a critical issue. A large number of fuel options for fuel cells can be used to provide hydrogen, each has advantages and disadvantages.

II. FUEL CELL

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. As the fig. 1 depicts- 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.

Fuel which is in gaseous form diffuses through the anode & is oxidized. This releases electrons to the external circuit. Oxidizer gas fuses through the cathode. Where the electrons coming from the anode through the external circuit resulting oxidations products are carried away reduce it. Fuel cell keeps the fuel molecules from mixing with the oxidizer. Transfer of electrons takes place through the path containing the load.

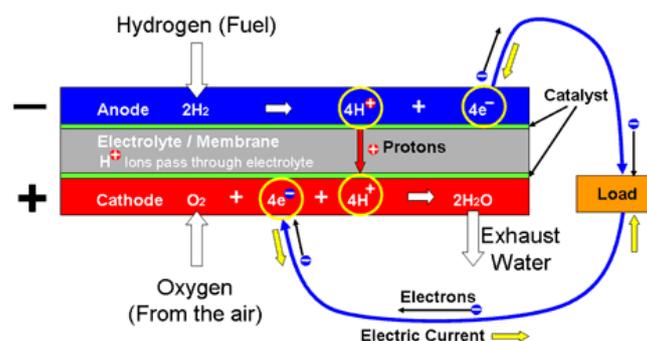


Fig. 1. Working of Fuel Cell

A fuel cell system, which includes a “fuel reformer”, can utilize the hydrogen from any hydrocarbon fuel – from natural gas to methanol, and even gasoline.

1. Alkaline Fuel Cell (AFC): Alkali fuel cells operate on compressed hydrogen and oxygen and generally use a solution of potassium hydroxide in water as their electrolyte. Operating temperatures inside alkali cells are around 150 to 200 °C.
2. Phosphoric Acid Fuel Cell (PAFC): The Phosphoric Acid Fuel Cell is the most mature fuel cell technology in terms of system development and commercialization activities. The phosphoric acid is contained in a Teflon bonded silicon carbide matrix. Platinum catalysed, porous carbon electrodes are used on both the fuel (anode) and oxidant (cathode) sides of the electrolyte.
3. Molten Carbonate Fuel Cell (MCFC): The Molten Carbonate Fuel Cell uses a molten carbonate salt mixture, usually lithium carbonate and potassium carbonate, as its electrolyte. The electrolyte is suspended in ceramic matrix.

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4. Proton Exchange Membrane (PEM): The Proton Exchange Membrane Fuel Cell offers an order of magnitude higher power density than any other fuel cell system, with the exception of the advanced aerospace alkaline fuel cell, which has comparable performance. From fig.2 the electrolyte in a PEM fuel cell is a solid acid supported within the membranes. The solid acid electrolyte is saturated with water so that the transports of ions can proceed

Chemical reactions for PEM fuel cell are:

Anode reaction (an oxidation reaction): $2H_2 \Rightarrow 4H^+ + 4e^-$

Cathode reaction (a reduction reaction): $O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$

Overall reactions (a redox reaction): $2H_2 + O_2 \Rightarrow 2H_2O$

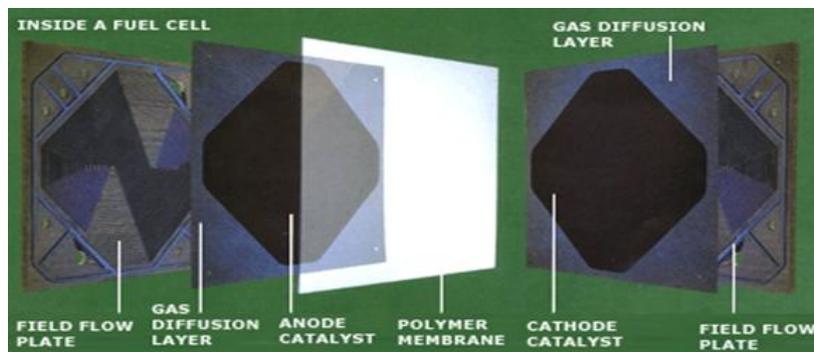


Fig. 2. Inside A Polymer Electrolyte Membrane (PEM) Fuel Cell Stack

III. FUEL CELL FOR ELECTRIC VEHICLE PROPULSION

As noted catalytic chemical fuel processor is required to convert these fuels to hydrogen-rich fuel gases that provide hydrogen fuel for operation of the PEM fuel cell stack described. Automotive fuel processors needs to provide not only all these capabilities, but they must be very compact and low in cost. The chemical principles and practical requirements governing automotive fuel processor used in the primary steps to convert methanol or gasoline as shown in fig. 3.

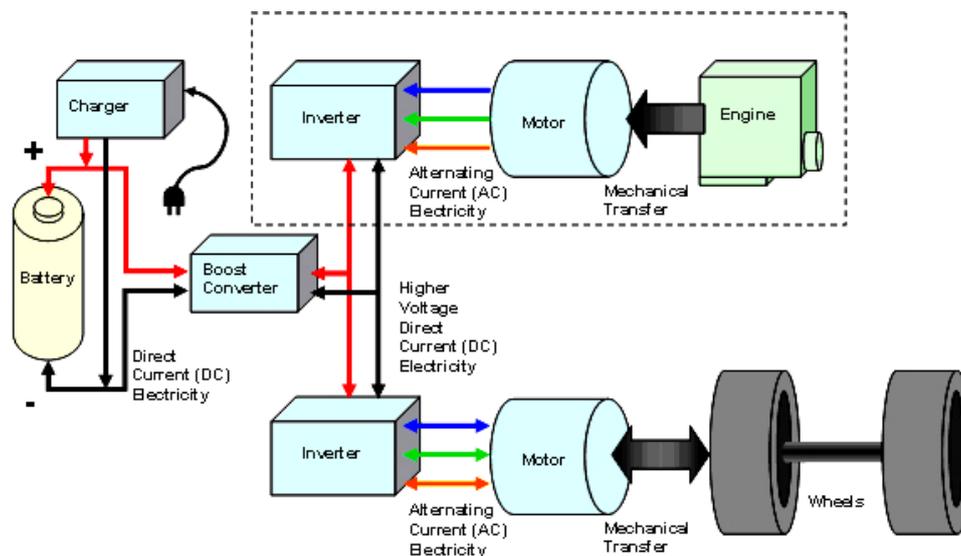


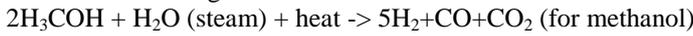
Fig. 3. Schematic of Fuel Cell Electric Engine

International Journal of Innovative Research in Science, Engineering and Technology

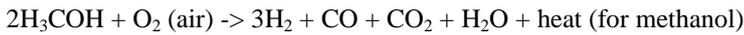
(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

a. Steam Reforming



b. Partial Oxidation



c. "Auto thermal Reforming", that is, combinations of reactions (a) and (b) in proportions such that released in the partial oxidation approximately balances and provides the heat required for steam reforming of methanol or gasoline.

$\text{CO} + \text{H}_2\text{O (steam)} \rightarrow \text{H}_2 + \text{CO}_2$ This reaction the CO content of the hydrogen rich gas stream through about 1%(10000 ppm) still far above the approximately 10 ppm tolerance limit of a typical anode catalyst.

$\text{CO} + \frac{1}{2} \text{O}_2 \rightarrow \text{CO}_2$, can be reduced by passing the processed fuel stream through "methanation" reactor according to: $\text{CO} + 3\text{H}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O}$.

BALANCE OF PLANT (BOP)

1. Air management system: It is the most important BOP component of a fuel cell power plant. The air management system equipment's for pressurized systems consists primarily of a compressor and expander and the electric drive motor for the compressor.
2. Water and thermal management: In a fuel cell, power plant the temperature of a number of critical components (particularly the stack and the different reactors of the fuel processor) have to be carefully controlled.
3. Controls: They are very important ingredients of each major fuel cell power plant subsystem and the integrated system. Parameters needing to be controlled include various mass flows, many temperature and pressures, turbine shaft speed and bypass, and a number of electrical parameters.

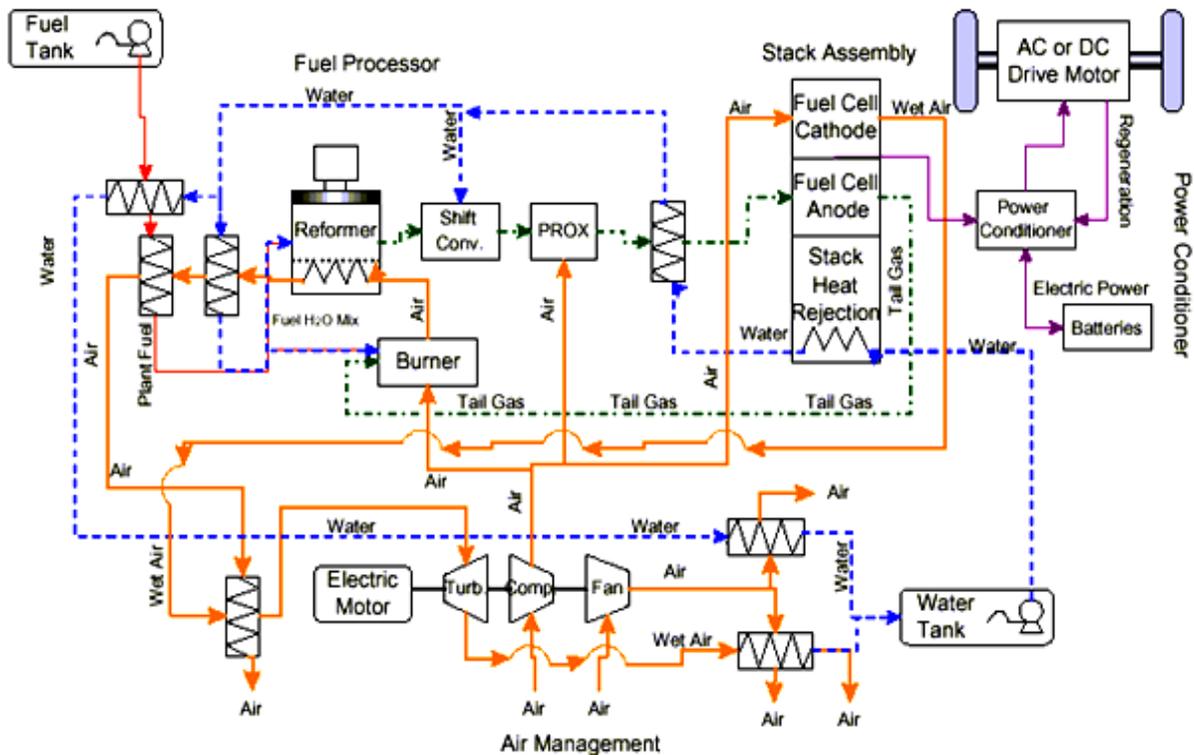


Fig. 4. Fuel Cell Electric Engine (Flow Diagram)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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IV. EXECUTIVE SUMMARY FOR PNGV TRANSPORTATION ANALYSIS

This analysis has demonstrated that converting to a lighter and more aerodynamic vehicle body does not significantly alter the relative merits of the fuel cell and hybrid electric vehicles relative to conventional passenger vehicles. The fuel economies of all vehicles (including ICEVs) improves more or less uniformly by almost 30%, but the relative improvements in performance of the alternative fueled vehicles compared to a more conventional internal combustion engine vehicle (ICEV) remain nearly constant. For example, the fuel economy of a direct hydrogen FCV on the 1.25 times accelerated EPA combined 55/45 city/highway driving schedule¹ is about 2.19 times higher than the corresponding ICEV with the AIV Sable. This fuel economy advantage increases only slightly to 2.23 times higher when both vehicles use a PNGV glider. From another perspective, the fuel economy of a direct hydrogen FCV improves by a factor of 1.29 (from 65.8 mpgge² with the AIV Sable up to 85.2 mpgge with the PNGV glider), while the conventional gasoline-powered ICEV improves by a factor of 1.27 (from 30.1 mpg to 38.2 mpg by converting to a PNGV glider). Both of these calculations assume no improvement in the efficiency of the power source -- the ICE and the fuel cell efficiencies are fixed -- only the vehicle glider characteristics change. While the fractional change in fuel economy is only slightly better with the FCV compared to the ICEV, the absolute fuel economies illustrate that fuel cell technology is required to reach the 80 mpg fuel economy goal of the PNGV, as shown in Figure 5. Both the pure FCV that has no battery or other peak power augmentation device and the battery-augmented direct hydrogen FCV would achieve over 82 mpgge on the 1.25 times accelerated combined driving cycle. The diesel-powered compression ignition direct injection (CIDI) vehicle in the parallel hybrid mode would reach almost 75 mpgge, close to the PNGV goal. All series hybrid electric vehicles (in either the thermostat on/off mode or the load following mode) and all fuel cell vehicles powered by either gasoline and methanol in the probable cases would achieve less than 60 mpgge.

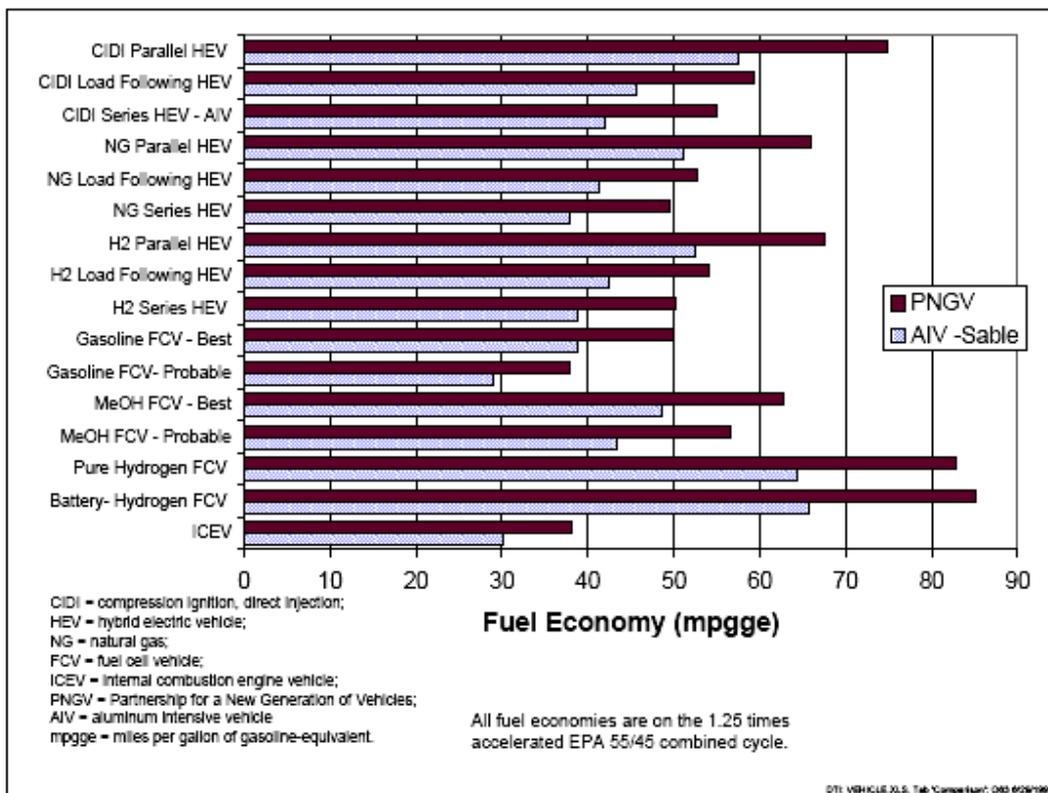


Fig. 5. Estimated Fuel Economy for Various Fuel Cell and Hybrid Electric Vehicles on the 1.25 Times Accelerated EPA Combined Driving Cycle

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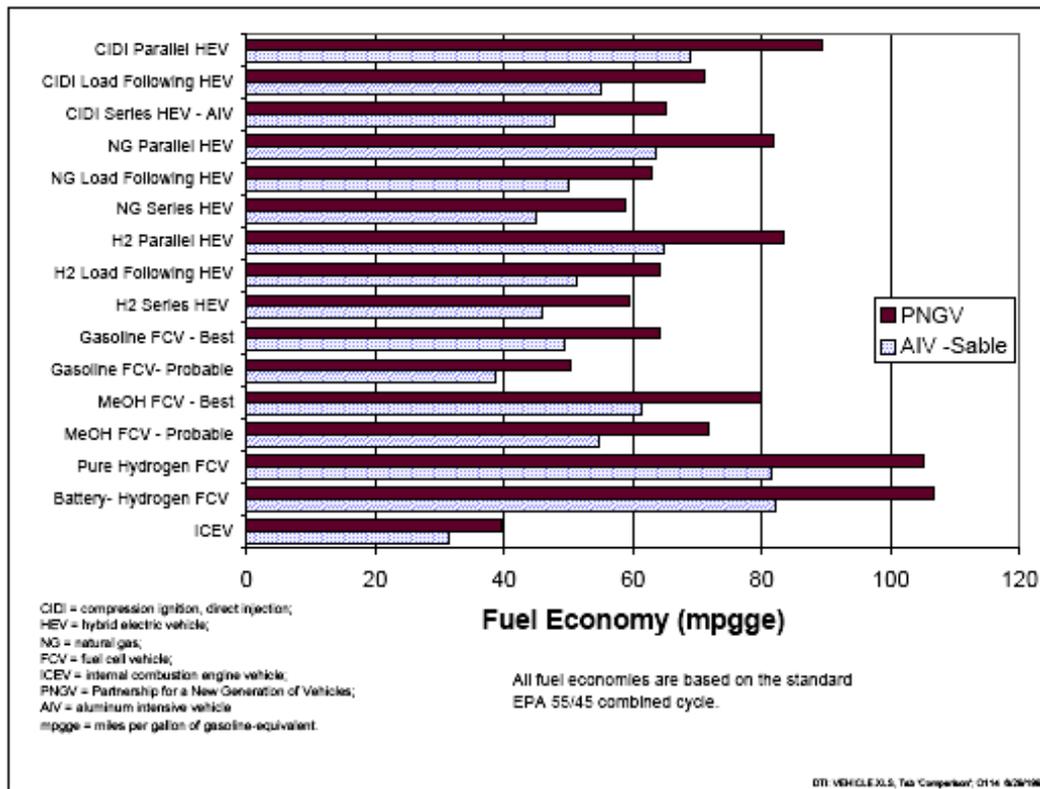


Fig. 6. Estimated Fuel Economy for Various Fuel Cell and Hybrid Electric Vehicles on the Standard EPA Combined Driving Cycle 1.25 Times Accelerated EPA Combined Driving Cycle

Both the hydrogen and the diesel parallel hybrid vehicles could achieve the 80 mpgge goal on the standard EPA 55/45 combined schedule without the 1.25 acceleration factor, as shown in Figure 6. However, this driving schedule does not reflect the speed and acceleration rate profiles of typical American drivers. These vehicles would meet the 80 mpgge goal on paper only. In any case, even with the unrealistic EPA combined cycle, the FCVs with onboard reformers would not meet the 80 mpgge goal, although the best-case methanol FCV would come very close at 79.8 mpgge. On this unrealistic driving cycle³, the direct hydrogen FCVs would achieve over 105 mpgge.

The environmental benefits of the alternative vehicles are generally proportional to fuel economy. Hence switching from the AIV Sable to the PNGV glider will also improve environmental benefits (both local emissions of criteria pollutants and greenhouse gas emissions) by the fuel economy factors - an improvement of 1.29 for the FCV and an improvement of 1.27 for the ICEV. However, the diesel parallel hybrid vehicle has a net greenhouse gas advantage over the direct hydrogen FCV when the hydrogen is derived from natural gas by conventional steam methane reforming, as shown in Figure 7. In addition, the natural gas parallel hybrid produces less greenhouse gas emissions than a hydrogen parallel hybrid, since more natural gas is consumed in making hydrogen than is used to directly fuel a hybrid vehicle. Thus there is no incentive from a climate change perspective in making a hydrogen hybrid vehicle -- storing natural gas directly on the vehicle not only reduces the volume of gas storage required, but also reduces net greenhouse gas emissions. The hydrogen hybrid vehicle would have an advantage in terms of local criteria pollutant emissions, as discussed in previous DTI reports (Thomas-1998a).

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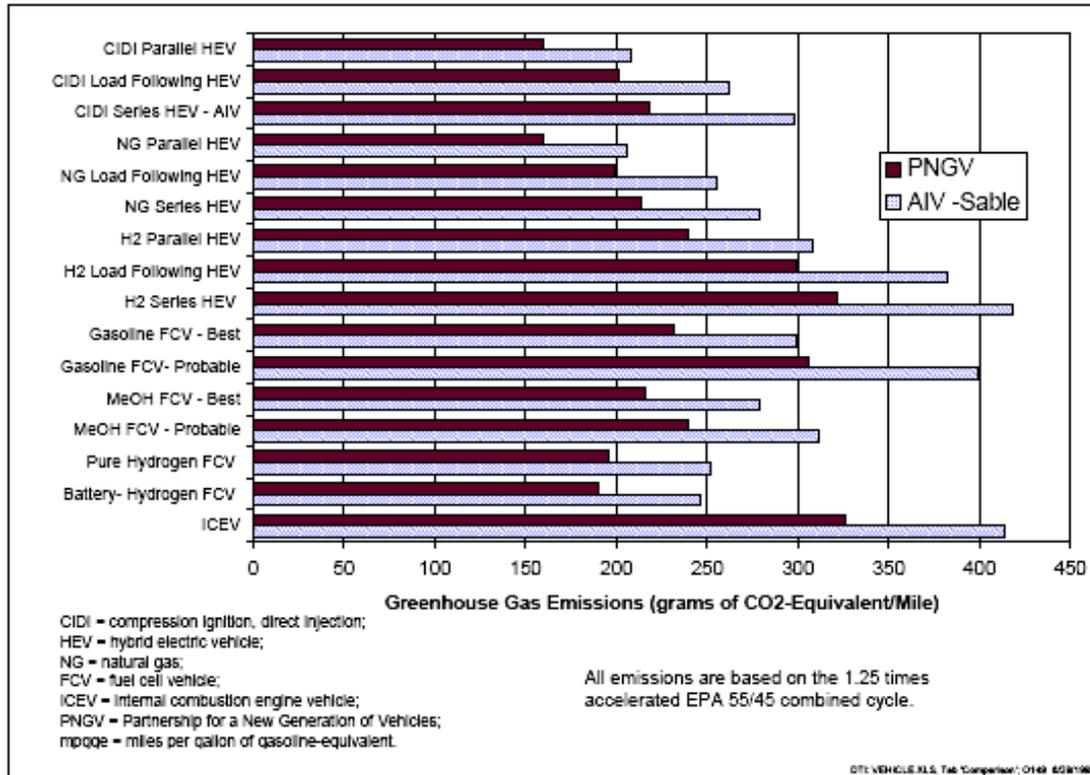


Fig. 7. Estimated Greenhouse Gas Emissions from Alternative Vehicles

Other Fuel Cell Types

- **Regenerative Fuel Cells (RFCs)** are attractive as a closed-loop form of power generation. Water is separated into hydrogen and oxygen by a solar-powered electrolyzer, and then is directed to the fuel cell, where electricity, heat and water are generated. The byproduct water is re-circulated back to the electrolyzer where the process begins again. PEM and SOFC regenerative fuel cell system systems are currently in development.
- **Zinc Air Fuel Cells (ZAFCs)** combine zinc pellets and air with an electrolyte to create electricity, generating significantly more power than lead-acid batteries of the same weight. ZAFC systems have potential use in transport applications.
- **Microbial Fuel Cells (MFCs)** use the catalytic reaction of microorganisms to convert virtually any organic matter (e.g. glucose, acetate, wastewater) into fuel. Enclosed in oxygen-free anodes, organic compounds are consumed by bacteria or other microbes. As part of the digestive process, electrons are pulled from the fuel and conducted into a circuit with the help of inorganic mediator chemicals. MFCs operate in mild conditions between 68-104⁰F. These systems are capable of efficiencies up to 50 percent, and will be suitable for small to miniature applications such as medical devices.

V. CONCLUSION

Hydrogen comes out as the strongest long term fuel to substitute for petroleum, as it is renewable fuel giving out clear energy and water vapour with little NO_x up on combustion with air. Hydrogen-air PEM fuel cell stack technology has advanced to the point where performance and operating characteristics meet the requirements for automobile propulsion. The integration of stacks, fuel processors and balance-of-plant components into complete fuel cell electric engines poses a number of very difficult technical challenges. Nevertheless, systems integration has reached the breadboard stage in leading research programs. The choice of a fuel to power the cell vehicle of tomorrow is critical,

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Vol. 4, Issue 8, August 2015

and a large no. of factors must be weighed. FCVs must compete other emerging technologies and be competitive on cost and performance. This choice needs to consider not simply the fuel processor technology, but safety and health consideration, overall infrastructure costs, fuel cost on a tax neutral basis, and acceptance by the public of new technologies.

We conclude that switching from the AIV Sable glider to the PNGV glider for a five-passenger vehicle will improve fuel economy by about 30% and will decrease greenhouse gas and local emissions by about 23% for almost all vehicles. The relative advantage of a direct hydrogen fuel cell vehicle over the ICEV with the same vehicle glider will increase only one or two percent with the lighter, more aerodynamic bodies. Therefore most of the relative conclusions with respect to fuel cell vehicles compared to conventional vehicles and to hybrid electric vehicles from previous DTI reports are equally valid as vehicle gliders improve in the future. Only direct hydrogen fuel cell vehicles will achieve the PNGV goal of 80 mpgge fuel economy over realistic driving schedules, although parallel hybrid electric vehicles could achieve 80 mpgge fueled by hydrogen, natural gas or diesel fuel operating on the rather anemic EPA combined driving schedule.

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