Plug in Hydrogen Vehicle

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Abstract

Vehicles are one the major causes of CO_2 emissions contributing to global warming. While there is a push towards a hydrogen economy we need good solutions that can facilitate the transition from a hydrocarbon to a hydrogen infrastructure. Since hydrogen is easily created from water using electricity, a device that could create and compress hydrogren onboard a vehicle would bridge the gap for a transisition period. With a few modifications, to allow a combustion engine to run on both hydrogen and gasoline, a vehicle could either be plugged in or filled with hydrogen from a station. This would effectively create a zero emissions vehicle that could still be filled with gasoline for extended trips. It is unknown to what extent an average new vehicle engine would need to be modified, but in principle it comes down to finding the right compression ratios and control systems. These are therefore purly modifications and not complete propulsion system redesigns like current hybrids. As a result it should be very cost effective and easily implemented method of creating a hybird on a pre-exsisting platform.

The hydrogen hybrid project proposal is intended to examine the steps in determining weather full scale development is feasible. It will attempt to proposed the methods of evaluating such a system that would determine if the added benefits outweight the potnetial cost. It will be comprised of two development paths. The first path is to determine the feasibility and required modifications to turn an average gasoline engine into an efficient hydrogen multifuel engine. If this initial development proves to be promising then research into determining the feasibility of creating an onboard hydrogen production system. If the onboard hydrogen production is not viable their is an alternative available, which is to research the development of home based hydrogen production stations that owners would have installed in their homes or garages similar to the proposed high current recharging stations for electric vehicles. Another potential development for home refilling rather than recharging is the possibility of examining if a "peer-to-peer" refueling system could work for the consumer.

The project hopes to promote the usage of hydrogen and ensure that it is created from the most enviromental sources available. The fortunate driving force is that oil will likely continue to get more expensive as supplies are more tightly controlled. The other side is that as wind turbines and solar panels enter heavy mass manufacturing that the cost will be driven down. Very soon the cost of installing photovoltaic at a consumer level may become cheaper than purchasing electricity from the utilites and have amortization periods of less than ten years as opposed to the twenty to thirty they are currently.

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Chapter 1

Introduction

General Motors is at the forefront of developing technology that could vastly change the world. The Chevrolet Volt project is easily the most widely publicized enviromental car project since the "Impact" EV1 project which tested the market for enviromental vehicles. It became obvious to GM that battery technology at the time was to costly for too little range. On top of that the battery replacement cost was something consumers were not willing to deal with. The cost to distance ratio is getting to the point where it is technically feasible to build a plugin hybrid vehicle with sufficient range to just start entering the market, but the cost of the battery is still a significant drawback to the middle class. It is currently estimated that the Volt will cost upwards of $35000 USD [3] and being a small to midsize sedan this places it significantly above an average competitor. Other companies such as Th!nk have a battery rental program [4] where you purchase the electric car but lease the battery. Bob Lutz who is leading the development of the Chevrolet Volt has speculated that they may lease the battery to drive down the cost. Effectively it eliminates the need for the consumer to absorb the battery maintence and replacement costs but it makes the car more expensive on a whole life cost rather than a one time purchase cost. The leasing does have a positive impact and that is that they will be able to recycle the batteries and keep the lithium market stable for future generations of their plugin and battery electric vehicles.

GM is currently building vehicles that are flex fuel enabled which is one of the greatest achievements that can allow for vehicles to have a reduced carbon footprint. The way it works is that a plant uses more CO_2 to grow than releases when refined and burnt as ethanol in a combustion engine. This actively fights global warming but their is a significant drawback to it; ethanol production ineffectively utilizes land compared to alternative methods. This is an issue in todays global climate where places in the world are experiencing a food shortages.

On average the raw energy output of a photovoltaic cell is 50 [7] times more efficient than energy ouput of ethanol[1] with older technology, and 100 times more effective with newer technology. This however does not take into account the cost of the solar cell or installation which at present is a significant draw

[1] These are raw numbers based ethanol energy and powe output of the solar cell and does not include the efficiency of a combustion engine nor does it include efficiency of electric motors or controlls.

back. Based on a 170 watt solar panel at consumer price of 800 dollars it could take up to approximately 30 years to amortize the solar panel cost. Wind power takes significantly less time to amortize but require extended maintence due to the moving parts which offset the lower cost.

Even with the inefficiencies of the internal combustion engine, if the electricity generated could be directly channeled into a combustion engine it should theoritcally yeild a better usage of land in a given area.

One possible method of implementing such a proposal is to run a combustion engine on hydrogen created from green electricity. The main driving factor of hydrogen is the simplicity of its creation. Where there is water and a source of power then hydrogen can be made. Hydrogen would not be a fuel so much as it is an energy carrier, but in order to run a hydrogen vehicle an infrastructure needs to exsist to fuel it.

An alternative exsist in making an engine that can operate on multiple fuel types. BMW has already done this with its Hydrogen 7 vehicle with a V12 engine. BMW currently lends the Hydrogen 7 to celebrities to raise awareness for the enviroment. If the requirement for this infrastructure was elimnated then a vehicle like the Hydrogen 7 could serve as a catalyst for people to install the infrastructure as it was necessary. This is the basis of the plug-in hydrogen hybrid; eliminate the inconvience of a "gas station" and replace it with being able to fuel at home.

This is a solution to the so called "catch 22" of having a vehicle with no fuel, or a fueling station with no vehicles in the market. It would enable companies to create hydrogen transition vehicles with waiting for the infrastructure allowing one item to be created first. In the end it is a solution to the promise of clean vehicles which nobody has been able to deliver on.

The problem is how to make the vehicle useful to the consumer with low added cost. Current hybrids add significant cost and to make it cost beneficial to a consumer the vehicles must be driven anywhere from 150000km to 300000km. This is effectively considered the end of life of most vehicles so it means that when the vehicle is no longer useful and has had no cost benefit to the owner. This is continually changing with rising fuel prices. A hybrid system should add enough gains to pay for itself over the average lease or purchase period for a vehicle. Even with the drastic cost increase for a hybrid the amortization period should hold steady by increasing overall efficiency and show apprciable gains to the consumer in a reasonable time frame.

In the mean time making efficient usage of electricity is necessary and fuel cells are significantly more efficient compared to the combustion engine. Currently fuel cells are very costly due to the required proton exchange membranes and platnium catalyst materials. Manufacturing is not nearly to the scale required for vehicles yet and best estimates put it at ten to twenty years away. Fuel cells may remain the future but the enviroment is unable to wait for mass manufacturing to catch up in a consumer driven market.

The possible solution would be in a simple system that produces and stores hydrogen onboard a vehicle when plugged in to any electrical supply that would give the consumer similar range to that of the Chevorlet Volt's targeted electric only range of 40 miles or 60-70 kilometers on batteries. It should be a low cost option that does not compromise the vehicle and ensures that it can still be built on the exsisting production lines.

Chapter 2

Overview

2.1 Internal Combustion Engine

Hydrogen fuel cell system efficiency is approximately 50-70%[5] in a best case scenario while a combustion engine efficiency will average approximately 20%. Assuming similar transmission loses[1] and an electric motor and controller losses puts a best case Proton Exchange Membrane fuel cell at 30-50% efficiency. This gives fuel cells approximately 2 times the efficincey over a combustion engine. This is a significant amount as it could mean the difference between a 30mpg car and a 60mpg car of identical dimensions. This could mean the difference between being more cost effective to use electricty to being more cost effictive to use gasoline.

Pursuing such an inefficient system may on the surface seem like a poor choice when compared purly to the technical benefits of fuel cells but in reality its a sacrifice to ensuring fuel cells are here in the near future. Fuel cell vehicles need the hydrogen delievery infrastructure to be well developed in order to have a hydrogen only vehicle. Fuel cells are not flexible to the fuel they use and are very sensitive. As a result if the hydrogen infrastructure is only developed within a city the vehicle cannot risk leaving that city. The alternative is to have an onboard engine and generator. This would be another transition technology but would add significant weight driving down efficieny of vehicle. The best way to manage this would be with the smallest engine possible. However given that the initial fuel cell vehicles will likely be of significant cost without a gasoline engine, this would further delay its entry into the market.

In a worse case scenario of running out of fuel it will initially be improbable for the driver to walk to a fuel station and get a compressed cylinder of hydrogen which they will carry back to the car. The combined risks and limited mobility could relegate fuel cell vehicles to similar applications as golf carts and neighbourhood electric or low speed vehicles. This would constitute a significant delay in mass market adoption of a much needed technology.

The benefits of the hydrogen hybird system are limited on a personal level but would have local, national, and global implications that would sevre as a catalyst for the emerging hydrogen economy. It is a project that uses an

[1]Electric may be less depending on configuration. Wide speed brushless DC and AC induction motors can utilize a single speed transmission reducing shifting loses

inefficient system to have small gains today that will lead to wider and faster adoption in the future.

2.2 Vehicle Selection

Any midsized sedan makes a very good plateform for testing a hydrogen plugin system. Being a midsize family sedan it has sufficient cargo space to be used for experimentation without compromising its ability to be used for day to day activities. Estimates of 1/5 to 1/10 utilization of the cargo space would mean that their would be sufficient space for safety devices and measuring equipment for testing and experimentation. A well developed platform which is mature and stable would be ideal. This would elminate general risks of reliability of the vehicle in relation to other components such as braking and suspension.

After research into the documented requirements for hydrogen combustion, such as intake geometry and compression ratio, a suitable vehicle could be selected. Later experimentation could be performed on any efficiency benefits from turbo charging or super charging when utilizing hydrogen to control air to fuel ratios better.

2.3 CO_2

One of the obvious questions to such a project is weather or not it will actually reduce CO_2 emissions or will it just move it from the tailpipe to a smoke stack. Unfortunately their is no conculsive answer that will be correct in every location in world. In some areas that utilize photovoltaic, wind power, and hydro genereation dams their is no CO_2 emissions; A plugin hydrogen vehicle now becomes a true Zero Emissions Vehicle. However if the electricity is generated by a Coal fired plant or by a naturual gas plant then the emissions will not be significantly changed.

General Electric recently introduced its H-System which has plant efficency of up to 60%. When compared to a small combustion engine that is a 2-3 times efficiency increase leading to less carbon based emissions. Considering that a combustion engine is then 1/3 to 1/4 as efficient as the H-System the benefits for the hydrogen hybird are negligible if any. In this case a fuel cell would be needed in order to reduce emissions overall. Unfortunately if electricity comes from older power generation plants it may be better to utilize gasoline rather than the hydrogen as the lower efficieny means that emission will be even higher.

Chapter 3

Hydrogen, Costs, and Refueling

3.1 Required Hydrogen

In order to make a few general calculations on the amount of required hydrogen a few assumptions will need to be made. These assumptions will need to be verified by testing as the assumptions refer to issues that have not been tested before.

1. The efficiency of the engine combusting gasoline is similar to that of combusting hydrogen
2. All of the hydrogen stored in the tank can be utilized dow to 1 atm of presure
3. 40 mile plugin range is an acceptable number to customer

The efficiency of a gasoline engine combusting hydrogen is likely to vary depending on many factors. One production engine may be very receptive of using hydrogen, while another man show drastic decreases in efficiency. However we can assume that energy released to be approximately the same, thus heating a similar amount of air in the engine as the gasoline. The molecular weights and constituents that leave the engine are different but this can still be approximated to the Otto cycle calculations.

Gasoline contains 27.7 MJ/liter [6] of energy while Hydrogen at 700 Bar (10000psi) contains 5.6 MJ/liter. For a 30mpg combine cycle car to go 40 miles would require 1.34 gallons or 5.1 liters of gasoline. This translates into 25.22 liters of 700bar hydrogen to have the same energy. At a lower pressure of 350 bar this area doubles to 50.44 liters.

This would require a 25.23cm x 100cm cylinder approximately to accomadate the 50 liters of volumetric hydrogen required. This tank could easily fit into the trunk of a midsize sedan with a minimal impact on cargo space.

3.2 Cost of Hydrogen

The best way to compare the cost of a plugin hydrogen vehicle would be to compare how much energy a person would get at what cost. Utilizing data from the Energy Information Administration official statistics the average United States kilowatt hour cost 10.31 cents. 1 killowatt/hour = 3.6 Megajoules of energy.

$$c/MJ = Cost/Energy \tag{3.1}$$

For gasoline according to the Energy Information Administration on April 20, 2008 averages 338.9 cents per gallon or 89.29 cents per liter which works out to:

$$c/MJ = 89.3c/27.7MJ = 3.22c/MJ \tag{3.2}$$

While the price electricity works out to:

$$c/MJ = 10.31c/(3.6 * 0.7 * 0.90)^1 = 4.54c/MJ \tag{3.3}$$

This effectively proves that utilizing average grid costs to utilize a plug in hydrogen vehicle is inefficient and does not improve cost to the consumer. Based on the method the electricity is generated the vehicle may become pollution free but would still remain less appealing. However in cities that use a time based price scheme that offers cheaper electricity off of peak hours it can be beneficial to consumer and the enviroment. According to California Cars Inititive prices can be as low as 2 cents/kilowatt. Once electricity at night reaches 7.3 cents a killowatt/hour then hydrogen fueling becomes cost effective.

While this is the average US fuel cost on April 20th, Gasoline is continually on the rise while enviromental alternatives are on fall. This is simply based on availability and manufacturing. Oil is limited in quantity and is at the behest of countries that have oil. If a large enough supplier refuses to increase production then supply is less than demand and thus prices rise. Economically speaking people will seek ways to mitigate this on their own level but response is slow and leads to social unrest.

Alternative means of creating energy are in theory free. Wind, solar, tidal, hydro, wave, and geothermal are some of the emerging technologies that can close the energy gap. These are all based on the energy that the earth is bombarded with daily and by using them it will lower the temperature of the earth on a very miniscule level. The problem with CO_2 is that it traps excessive energy in the earth, these methods counteract that by removing energy thus balancing the earth's climate over a longer period. The way to do this is with super scale infrastructure. At the personal level being able to utilize wind or solar power at a persons home could quickly lead to offsetting the cost of fuel.

The limiting factor for enviromental energy is not the earth, but manufacturing. Almost any generating device can be made entirly of renewable or recyclable material, its just that manufacturing capacity has not been high enough to drive the costs down to an effective level. As small scale wind turbines prices drop

[1] 3.6 = Megajoules per killowatt hour, 0.7 = approximate electrolyzer efficiency, 0.9 = approximated compressor efficiency

it becomes plausible to install one on ones property to directly fuel a persons vehicle.

According to Newfoundland Hydro, during a presentation at Memorial University on wind power, the reason that they burn Bunker C fuel in the winter is that they can only use levy systems to time shift water for approximately one month. Night time and summer has such low demand that if they were to install wind turbines that it would reduce their profits. The hydro system is constant and can supply as much power as needed to the province until the levi system runs to even at which point the bunker C plant is started. The approximate quoted figures is that hydro is 1-3 cent/KWh over the lifetime of a dam while wind is approximately 6 cent/KWh. In the summer this would cause installations to back up levi's because of the wind power. While this problem is unique to the isolated grid of Newfoundland it provides an understanding for the basis of why manufacturing is not peaking fast enough which is that average demand is not steady enough to warrent enviromental installations. Other methods that produce CO_2 are still more cost effective or under certain circumstances the exsisting method is more profitible. This will likely change in the coming years as the price of any oil based product rises.

In places where coal fired plants are the primary sources, charging at night allows the power plant to not waste energy as they can not be shut down or started easily and normally run in a lowered capacity and in some cases lower efficiency mode because of the reduced demand. Wind and hydro power still work at night allowing for the better utilization of wasted energy making a hydrogen plugin a cost effective solution. Wind energy would be used first as this must be captured immediately while hydro power can be "stored" using levy systems if available. In an advanced enviromental power generation setup the most intermittant powers would be used first and the secondary systems tailor to the current draws that are expected. Using solar first as it peaks during the day, wind to be the average supplement and hydro power as the backup utilizing a large levy system.

3.3 Cost Offset Methods

While the last section proved that only off peak electricity could make a cost impact by utilizing grid electricity an alternative method exsists. The electrolyzer can be made to handle a very wide variety of voltages ranging from the 10's to the 100's of volts. As a result photovoltaic and small wind turbines become a useful solution as they no longer require costly grid intertie systems. Utilizing a special 5 prong plug could power the compressor from the A/C grid and the electrolyzer from whatever alternative electrical source the consumer has available.

The system could also be modified to automatically switch to either grid or alternative mode without any user intervention so that when enough energy is coming from the alternative means the grid is only used for the compressor and when insufficient alternative energy is available the system could fall back to grid power to refill the hydrogen.

The costs of repaying an installation of any kind varies and individual cost comparisons would need to be conducted.

3.4 Automatic Refilling

One of the proposed methods of reducing operating costs for the Chevrolet Volt is to utilize a smart charging method. This would mean utilizing a simple programable logic device to monitor time, expected daily driving, actual driving, last drive distance, and even location to decide when to switch from battery power to gasoline power and when to charge from the grid when plugged in. A simpler system may be used for the hydrogen plugin. The motivating factor for the Volt is to reduce wear on the battery and to increase mileage while the motivating factor for a hydrogen plugin will be to reduce emissions and provide mileage gains and reduce cost.

A similar method can be used with a plugin hydrogen vehicle. A calculation can be setup and the vehicle can be programed only to fill up the hydrogen system when it provides an improved effective miles per gallon cost number. The method would be targeted to use low cost power as well as having a positive influence on the enviroment.

3.5 Alternative Compressor

An alternative to the onboard compressor would be to have a user installable station that actively makes hydrogen and store it in a larger tank that is installed in a home or garage. The tank would be sufficiently large to hold more hydrogen than the vehicle can hold. When the consumer gets home they can now refill the hydrogen tank in vehicle in a matter of seconds. While this adds cost it combines the convience of short refueling time with the enviromental and cost benefits. Assuming the average consumer drives 64 kilometers a day the onboard hydrogen tank is sufficient. However if another trip is needed then prestored low cost hydrogen made during non-peak hours can be used during peak hours. The system will automatically refill itself at home during off peak time.

This method actively encourages an infrastructure to exsist as a standardized filling method would be required. A system of "peer to peer" hydrogen sharing as well as electrical load leveling can be utilized with this system discussed in the next section.

3.5.1 Consumer to Consumer Filling

In the event that a low cost plug-in filling station for the home user could exsist it would be possible to implement a "peer to peer" fuel station approach similar to file sharing methods that exsist on the web.

While online file sharing methods involve transfering data back and forth to between computers, a consumer to consumer fuel model can exsist in a similar fashion. Assuming one centralized company has control of the filling stations and consumers locate the filling stations on their own property but in such a way as the general public can use them then a distributed fueling network could exsist.

If Person A were to use Person B's fill station then Person A would be charged a small markup on the cost of creating and storing hydrogen at Person B's fill station. Person B could be either credited the money or could fill up at Person A's or any other person's fill station that has been marked for public usage. This would provide an incentive to keep the fill stations public and also create an infrastructure for filling.

The electrical companies my even subsidize such a project as these small fill stations could be used as load leveling devices during the day and as an electrical load at night to keep levies from backing up in the summer or wasting power from fossil fuel burning plants due to decreased demand. Once mass manufacture of hydrogen fuel cells peak, fill stations could be developed that intergrate fuel cells to act as positive load leveling by feeding electricity back into the grid with minimal losses in power. This would allow distributed amounts of energy to be stored at night and utilized during the day. It would effectively strengthen the electrical grid by allowing heavier loads during the day without increasing main plant output.

Chapter 4

Development Stages

4.1 Research and Design

The first stage in developing a hydrogen plugin will require a significant amount of research. This would require developing a plan to decide what engine would be most suitable and what would need to be modified. Research into hydrogen combustion engines is rather mature as systems exsist for stationary installation in remote areas. It uses wind turbines to generate hydrogen and then combusts the hydrogen in a standard combustion engine to run a generator when no wind power is available.

Two tasks need to develop independantly. One developing the electrolyzer and compressor system, the other developing the hydrogen storage and injection system. At this stage no readily available electrolyzer or compressor systems exsist so this part of the project would require longterm commitement to design and developing a prototype. The other side can develop independantly utilizing purchased hydrogen gas stored in rented cylinders for experiementation.

Once the engine is selected the manifold will need to be modified for hydrogen injection without compromising the exsisting injectors or engine management system. The manifold modifications are relatively simple as compressed natural gas injectors are readily available and can be used. The main problem is making sure that the current engine management system can be modified so that if another system is controling the hydrogen aspect of the vehicle that the gasoline system is disabled. An absolute worse case scenario is a replacing of the computer with an openly modifiable aftermarket system.

However a simple test setup can easily be performed by drilling a small hole in the maniforld and connecting it directly to a presurized hydrogen supply. Given that throttle's are no longer directly connected to the butterfly valve of the manifold and rather are connected to a throttle position sensor; if the engine has an alternative gaseous fuel source which increases combustion intensity would drive up the engine speed, as a result the computer would not inject as much gas.[1] This could be measured by flow meters installed on the presurized fuel line and the return line and checked to ensure gasoline delivery drops as hydrogen delievery increases. One of the main issues with attempting this is that gasoline

[1]Some engines can operate by not injecting any gasoline while slowing down using the engine as a brake

engines run best when the air to fuel ratio is stichometricly balanced while with hydrogen a lean mixture of air is required to reduce NOx emissions.

Research into correct air to fuel mixtures for hydrogen will be essential as exact air to hydrogen mixtures combust hotter than gasoline and can lead to the creations of nitric's. It is therefore perferable to run hydrogen with an excessive amount of air so that it can disipate heat better.

4.2 Vehicle Preperation and Research

The first task after the research stage, which should have resulted in finding the required compression ratios, fuel-air mixture, etc, is to chose a small engine to start testing. The engine should be simple and representative of the aproximate target vehicle classification but should be of low replacement cost. This may include a single cylinder engine from a motorcycle or dirtbike so long as the required specifications are similar.

The engine should be stripped to its bare essential components such as having carburtor or injectors removed and replaced with a continous feed hydrogen injector for testing. This test setup can then facilitate testing for best fuel air ratio, efficiency, NOx emissions and eventually even long term wear in accelerated testing. It can serve to see what improvements and modifications would need to be made to a full size engine in regards to piston rings, intake, etc.

Once the testing is complete on this test bed the project can move towards modifying a full size engine to hydrogen only running. This will give a chance to make improvements and find a compromise between the required hydrogen and gasoline mode operation. This stage should begin to show improvements of efficency at various engine speeds and loads and develop a specific engine characteristic map.

The final stage would determine the feasibility of dual fuel system of gasoline and hydrogen and what modifications would need to be made to an engine. This can either start with taking the full size test engine back to stock condition and determining modifications required for it to use hydrogen or take the approach of starting with a new engine in the case of any damage or accelerated wear that has been discovered.

4.3 Hydrogen Generation

An appropriate method of generating hydrogen with electricity needs to be found. Though it is commonly known how to use impurities in water to make it conduct electricty and hence create hydrogen are known, it is not commonly required to make a system that produces hydrogen at a rate comparable to charging batteries in an electric vehicle. The amount of water that is required and the acceptable replenishment time frame needs to be determined at some point. Initially engineering should drive this at a minimum of replenishing 64 km of range per water refill. At a latter point surveys and field testing could conclude what the customer wants.

The required surface area at the required rate of recharge needs to be determined while keeping the physical size as small as possible. This is done by setting up an experiement utilizing thin sheets of metal fully submerged in a water + KOH solution with chambers at 1 atm of pressure to determine how much hydrogen is generated over how much time at given voltages and currents for given surface area, plate seperation, material, etc. Many experiments would need to be performed repeatidly to measure each condition to find the smallest apparatus that could be placed onboard a vehicle.

The result of these experiements my prove that an onboard electrolyzer with the determined rate of generation could be to large or require difficult issues to resolve. In this case the research for onboard electrolyzer should be abandoned and then proceed to an offboard garage installation as well as the viability of a consumer network system for electrolyzers.

In the case of onboard electrolyzers being sufficient research should proceed to an onboard compressor and specifications for the tanks shape and size as well as external refilling system and valves. The compressor is going to require high safety factors due to the repeated fatigue loading on the compressors walls. If the onboard system is abandoned than the emphasis should move towards making the compressor as cost effective as possible and convient to install.

4.4 Testing

Once all parts of the system are fully determined and working independantly the system should be intergrated together. While the design of each component would be know the required specifications for the other components thoughout the process and the actual combinations of each system may be difficult. It may require re-engineering of the shape of the elecrolyzer or compressor or the location of the compressed cylinders.

4.5 Mild Hybrid Condition

Once an engine is developed and can utilize hydrogen in direct conjunction with gasoline then a mild hybrid condition could be created. A normal gasoline only hybird gains efficiency by reclaiming normally wasted energy in two ways. The first is by attempting to elminate having the engine run at high and inefficient speeds. The second is by reclaiming braking energy. The energy it takes to deccelerate a moving body is equivalent to the energy it takes to accelerate it to an identical speed. Aerodynamic, rolling resistance, and transmission loss's are unreclaimable reducing the amount of energy available.

The gains that current hybrids make is likly near the theoritical peak of what is reclaimable due to the high efficiency of the motors, generators, and battery systems. The main drawback is that the vehicle now has to have heavy batteries installed making the vehicle heavier and requiring more power to accelerate it.

Under the assumption of having an onboard electrolyzer it may be possible to configure the engine control and management unit to shut off fuel systems and utilizing a modified alternator as an electrical braking system feeding power directly into the electrolyzer. It is assumed that the electrolyzer will be of sufficient surface area to support full recharge of the pressurized tanks in a similar time to that of a battery based plug in hybrid. This would indicate that the electrolyzer would be a suitable high current device that could draw enough current to make a modified alternator into an engine braking system.

Depending on the setup it may be best to have a low pressure holding system that can feed into the hydrogen system after the high pressure regulators so that the compressor would not have to start. This makes a very useful system as under hybrid conditions their is no wasted energy from the compressor compressing the gas.

Chapter 5

Other Applications

Formula One racing has imposed an engine development ban [1] which will be lifted with the intention of using smaller lower cost engines as well as stimulate the development hybrid systems. In Formula One racing the vehicles constantly brake and accelerate as they have to slow for turns and speed up for other sections. This means that Formula One vehicles are in the prime type of enviroment for a regen braking mild hybrid systems.

However with the 605kg weight restiction for the vehicles, the addition of batteries is a very unlikley occurance. With the hydrogen hybird system (without a compressor and just a low pressure holding system) energy recovered from braking could then create and store hydrogen and oxygen. The difference with the Formula One application is that the oxygen would be stored as well and both injected into the manifold in the correct stiocometric ratio of two parts hydrogen to every one oxygen.

Reasoning for this is that under braking hydrogen could be created but the engine system is naturally aspirated and would thus take away from gasoline usage.[1] Therefore adding hydrogen without reducing the amount of atomized liquid fuel would cause incomplete combustion and be very detrimental to Formula One engines. By keeping the oxygen generated and injecting it along with the hydrogen means that more energy is released in the combustion cylinder for the same volume.

This in turn would mean that the drivers could utilize a boost system that is acutated when needed from the steering wheel electronics. Other hybird boost systems have been proposed [2] but have been accused of adding high cost to Formula One development. The hydrogen system would be require to utilize an alternator for braking and would likely only be applied to the rear of the car. The engines of Formula One vehicles are limited to 19000 rpm and normally run near these speeds. This gives the electrical generation system an advantage as an alternator system connected directly to the engine crankshaft rotates very fast. The voltage generated from a set of coils is proportional to the speed of a field passing the coil. Since the speed if very fast compared to conventional engines this means that to generate the same voltage to store energy of a conventional hybrid, the formula hybrid system could utilize a significantly smaller alternator.

[1] This could be utilized as an improvement as well because it could reduce fuel consumption in general

Chapter 6

Conclusion

While nowhere as efficient as a hydrogen fuel cell vehicle a hydrogen combustion engine is a viable method of generating mechanical power. This project is targeted at determining how much modifications to a current production vehicle would be required in order to generate a range extended plug in hydrogen combustion engine based vehicle. Research is required to determine efficencies of each subsystem as it is designed. These numbers, once verified, would provide a basis for weather or not such a system would be viable at reducing vehicle emissions, specifically that of CO_2, and more importantly to the consumer if it would provide a cost savings. The underlying goal is to provide a long term basis for global hydrogen adoption while providing a small cost benefit to the consumer. This would facilitate the easier transisiton to the more appealing hydrogen fuel cell vehicles.

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