SESSION 2633

Evaluating the Benefits of Hybrid Vehicles Concepts

Joshua Talbert, Frank Wicks and Richard Wilk
Union College
Schenectady, New York, 12308

Abstract

A decade ago it was generally expected that the electric vehicle would represent a clean and practical alternative to gasoline fueled vehicles. The subsequent failure of electric vehicles to be commercialized and used on a significant scale has been a combination of continued improvements of performance and decreased emissions from gasoline vehicles coupled with the fundamental limitations of electric batteries in terms of weight, energy storage capacity and charge and discharge rates.

The public's expectations for electric vehicles has now been replaced by the promise of high mile per gallon hybrid vehicles which are fueled by downsized gasoline engines which is combined with a battery based electric motor/generator. Electric drive will be used at low speeds, engine drive at moderate power requirement conditions and the combination of engine and electric will be used for high power requirement conditions such as acceleration or passing another vehicle while going up a hill. The gasoline engine will also charge the batteries when extra capacity is available and regenerative braking can recover the kinetic energy of the vehicle while braking or the potential energy of the vehicle while descending hills.

While the benefits are relatively easy to explain qualitatively, the quantification of the benefits of a such a hybrid system, relative to a conventional or downsized gasoline engine, if it does exist is much harder to quantify.

Any engineer should be skeptical of the claimed benefits until understood and demonstrated. Students should be taught the importance of critical thinking coupled with analysis. Accordingly, as a student summer project the authors have tried to critically evaluate the claimed benefits of a hybrid vehicle, along with identifying and evaluating potentially simpler techniques for regenerative braking and for providing extra power for other conditions.

Since the analysis of any potential benefits of a hybrid vehicle requires a model of the vehicle that provides the power requirements as a function of the driving conditions along with the ability to simulate a range of realistic driving patterns. A vehicle was instrumented with an accelerometer for on line computer data acquisition and computer to calculate engine and braking power throughout a driving cycle.

The results of this test and analysis indicate that the potential fuel conservation benefits of the currently commercialized hybrid vehicles are minimal. An alternative that was evaluated

Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition

to provide comparable benefits with a simpler system would be a downsized engine with a standby engine for high power requirement conditions. A simpler and possibly cost effective method for regenerative braking could use the existing battery and generator with a variable set point on the voltage regulator with the set point increased for regenerative braking conditions.

1. Background

Until two centuries ago all assisted land transportation was either by horse or other animal or else by slaves and servants transporting the more affluent. Starting in the early 1800s and then rapidly increasing over the century was rail transport powered by the steam engine. It was only about 1900 that powered personal transportation started with roughly equal portions of electric, steam and internal combustion engines. Nicolas Otto had demonstrated a four stroke per cycle internal combustion engine in 1876 that used a flame tube for ignition and required a gaseous fuel.

It required another generation of development and major advances including the development of electric spark ignition to replace the flame tube and the development of the carburetor which allows a high energy density liquid fuel in the tank that is vaporized by incoming air and which establishes a workable fuel to air ratio for combustion.

THE CAR

The advent of the practical internal combustion engine rapidly caused the demise of steam and electric vehicles. Steam engines were heavy, dangerous and took a long time from starting the fires in the boiler until sufficient steam pressure was produced. Electric cars were expensive and batteries limited the range. Ironically, it was the development of the electric starting system for the gasoline engine that eliminated the convenience advantage of the electric car.

With an internal combustion engine made practical with electric spark ignition and the carburetor the first decade of the 1900s saw hundreds of motor vehicle companies and models. However, they were generally too expensive for most people until Henry Ford after a decade of development introduced the Model T in 1908. It was standardized for mass production on assembly lines. It remained in production until 1927 when it was replaced by the Ford Model A.

Henry Ford had grown up on a Michigan farm where he complained the work never ended and appreciated the liberating value of the machine. Along with being a mechanical and manufacturing genius he was a social engineer who has been credited with establishing the middle class by doubling the pay of his factory workers to $5 per day and sharing half of the company's profits with the workers. Ford wrote in his book "Moving Forward" that the purpose of the machine is to transfer the heavy toil from the human back.

While there were hundreds of startup type car makers and models, the Ford Model T dominated the market for two decades. The cost steadily decreased while the Ford Motor
Company's profits increased due to continued improvements in manufacturing efficiency. What Henry Ford did not anticipate was the transition of a car from a revolutionary new mode of

transportation to a status symbol. He stayed with his conviction that every car be painted black, because color options would undermine the benefits of mass production.

This rigid standardization worked well until the 1920s. The middle class that Henry Ford had created wanted more variety. The introduction of paved highways created a new pleasure in travel. General Motors was first to capitalize on the combination of an increasing prosperity and the status value of a new car by introducing a significantly new model each year. Since then cars were marketed on the basis that prior year models were out of fashion rather than they had worn out.

The new model each year also provided opportunities for continued technical improvements that also supported the marketing. Hydraulic and power brakes, power steering, automatic transmissions, ultra long life, efficient and reliable engines, cleaner combustion, internal and external styling, air conditioning and low rolling resistance and long life tires and computer based engine management systems have made today's automobile far better than Henry Ford or any of the automobile pioneers could have imagined.

FUEL

The sun is the energy source for humans, animals, steam engines and all of our other hydrocarbon oxidation processes. Some like metabolism are slow, others like fire are fast and others explosive like in an internal combustion engine. The sun is also the source of our photovoltaic, hydro and wind power. However, some forms of solar energy are renewable such photovoltaic and others effectively nonrenewable within the human time scale.

With the exception of earth based nuclear reactors, it is the energy released in the form of radiation from the fusion of light atoms like hydrogen into heavier elements like helium in our sun that is the source of all our energy.

Food and fuels start with solar energy that converts water and carbon dioxide into hydrocarbon based vegetation. Animals enter the food chain and the animal fat stores the hydrocarbons.

Thus, horses are powered by the solar energy that has been converted during the year into hay and other forms of vegetation. Wood stores a few decades of solar energy. Decayed vegetation ranging from peat to coal store thousands of years of solar energy. Oils from whales, seals and fish were the liquid fuel sources before crude oil was first extracted from the earth at Oil City, Pennsylvania in 1859. Thus, crude oil from which gasoline is refined represents millions of years of stored solar energy via photosynthesis and the plant and animal food chain.

Henry Ford and others in his era realized that petroleum was a nonrenewable fuel and ultimately some form of coal or biomass alternative would be required. However, the amount of petroleum in the earth has been more than earlier predictions. The huge reserves at low and moderate prices has served well in extending the petroleum age. However, the resulting overwhelming dependence on oil for automobiles as well as for trains, ships, airplanes, heating, cooling, agriculture and electric power production results in major economic problems when the

Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition

price increases moderately and may well result in the most dreaded forms of social upheaval when the oil starts to run out.

The problem with oil is that it is so much better than any known alternatives that modern life as we know it can not be sustained without it. To a slightly lesser extent the problem with the gasoline fueled internal combustion engine automobile it is too desirable relative to the alternatives. There is a general faith and optimism that by the time that oil runs out the engineers and scientists will have invented some acceptable and hopefully better alternative. There are clearly alternatives, but no engineer or scientist has yet identified any alternative that comes close to the convenience of oil and that will not be much more expensive and far less flexible in its use.

There are a large myriad of suggestions about how to save non renewable fuels such as fuel cells, a solar driven hydrogen economy, super capacitors, super batteries, super flywheels, superconductivity for no loss electric transmission and machines, magnetically levitating trains, electric cars, and most recently hybrid cars which is the focus of this paper.

2. Hybrid Vehicle Assessment

The car driving and gasoline buying public has for long been subjected to many questionable claims. These range from a car engine that can run on water, a super carburetor that yields 100 miles per gallon that the oil companies conspired to keep off the market, an atomic powered car, a cold fusion powered car, Stirling engines, solar powered cars and most recently the hybrid gasoline and electric automobile that some companies have in production and most of the other companies have under development.

Enthusiasm for hybrid cars are supported by the specifications of the manufacturers along with the city and highway testing performed by the Environmental Protection Agency as shown in Table I.

Table I

Hybrids	Weight	Engine	Electric Motor	Battery	EPA Miles per Gallon
2000 Honda Insight Two Passenger	1850	73 hp 1 liter	13 hp	NiHydride	(61 city, 70 highway)
2001 Toyota Prius Four Passenger	2800	70 hp 1.5 liter	44 hp	NiCad 110 lbs	(45 city, 52 highway)

Dodge Durango SUV (Prototype)	175 hp 3.9 liter	70 hp

It is easy to qualitatively explain why a hybrid can be more efficient than a conventional gasoline powered vehicle. The electric system allows for a smaller and more fuel efficient engine by using supplemental electric power for acceleration, climbing hills and passing. The electric system and storage battery also allows for regenerative braking.

The eminent physicists Phillip and Phyllis Morrison who for many years have written the Wonders column in the Scientific American featured the Honda hybrid in the May, 2000 issue and presented a raving review of its performance and technology. The May 2000 issue of the ASEE Prism also featured the hybrid automobile with suggestions that the Honda Insight hybrid represented the vehicle of the future.

Further credibility for the future of hybrid vehicles comes from the Program for a New Generation of Vehicles (PNGV) which is a joint effort by the national laboratories and the automobile companies to combine their expertise and technologies to produce a 70 mpg family vehicle. A proposed vehicle will be an engine and electric hybrid fuel using advanced materials, aerodynamic drag reduction, tires, computers and storage technologies.

REASONS FOR SKEPTICISM

There are multiple constituencies that are excited about the hybrid vehicle. One is the technology driven consumer who once bought the biggest muscle car desires to be first to have the newest product. Another is the affluent environmentally conscience consumer who feels a social responsibility to buy a “Green or Environmentally Friendly” product. Also the national labs that have exciting technologies that were developed during the cold war and that are now technologies looking for an application.

While the authors agree that the production hybrid vehicles are technological marvels, the harder question is to quantify the benefits versus the costs. The desired method to perform the evaluation that we were not able to do but that we recommend would be to take the hybrid vehicle and remove the electric power components in terms of motors and batteries then compare the mpg performance in city and highway driving.

The Honda Insight has been designed to minimize power requirements by means of a reduced weight aluminum frame, sleek styling to reduce aerodynamic drag and low rolling resistance tires along with the small 1 liter engine, that still can produce an impressive 73 hp. With the reduced weight of the removed electric system the performance could be even better as a non hybrid. Thus, the hybrid feature would only serve some marketing purposes without representing any fuel saving.

The authors did develop a general mathematical model for the power requirements for a vehicle and the 73 hp engine alone provides excellent performance. A separate calculation of the benefits of regenerative braking shows that if the kinetic and potential energy of the vehicle that is absorbed by the brakes during any normal stop and go and down hill driving cycle is converted

Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition
Copyright @2001, American Society for Engineering Education

electric energy the value is only modest which is further deteriorated by recognizing limits on the rate at which it can be absorbed by a battery and a typical best case charge-discharge efficiency of 70%.

3. Conclusions and Recommendations

The authors concludes that a hybrid vehicle has the potential of modest performance gasoline performance benefits relative to a conventional gasoline car for some individual driving cycles, but the additional weight and complication can also be counterproductive.

Accordingly, the authors suggest that the Environmental Protection Agency should test and publish the city and highway performance of the same vehicle with the extra batteries and motors removed. This is especially important because some states have or are considering giving tax credits to individuals who buy alternative powered cars which raises questions of whether hybrids are or should be automatically given favorable status.

Recognizing that there is some potential benefit of electric vehicles the authors considered alternative methods for recovering some of this potential with less additional weight and complication.

Regenerative braking could be performed with the conventional electric system by lowering the set point on the voltage regulator below the fixed 13.85 volt setting when the brakes are applied. A high performance starting battery can produce 1000 cranking amps at 12 volts which corresponds to 12 kw or 16 hp. This would result in some of the cars kinetic energy being absorbed by the battery rather than the brakes. There are some plans to increase the voltage of future cars to 42 volts, which would further help this mode of regenerative braking.

Another possibility would be a car with two engines that might be 20 hp and 50 hp. Engines provide substantially more power per weight than an electric motor-generator and battery system. Both engines would be shut down for sustained stops. The smaller engine would provide more efficient city driving. The larger engine would be for highway speeds and both engines would operate for high power acceleration, hill climbing and passing requirements.