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Chapter 1

THE PLUG-IN HYBRID ELECTRIC VEHICLE PHEV: DIFFERENCES WITH THE BATTERY ELECTRIC VEHICLE EV

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ABSTRACT

This chapter discusses plug-in hybrid electric vehicles (PHEV) and pure electric vehicles (EV) for the transition from Fossil Fuel Based to a Zero CO_2 society and is broken into the following sections:

1) Introduction of the PHEV and The objective of Vehicle Electrification
2) The limitations of Electric Drive now and into the foreseeable future.
3) The urgency of conversion to renewable energy to replace fossil fuel use in transportation and society.
4) The need for dual or triple fuel systems until new technology is created.
5) Using the PHEV to improve the existing Electric generation and distribution system
6) A road Map for Integrating the PHEV into a no fossil fuel, completely renewable energy society with no loss of function or convenience and yet lower costs.
7) Conclusions.

Keywords: Global warming, fossil fuel, renewable energy, PHEV (Plug-In Hybrid Electric Vehicle), Pure Battery Electric Vehicle (EV), sustainable energy supply, minimizing CO_2 and greenhouse gases, technology solution, Natural Gas-NG, Corporate and private benefits of new energy use.

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INTRODUCTION

The Electric Vehicle, or EV, is a focus of this book but this chapter looks at an alternative but parallel path to allow us to solve the most pressing problem on the Planet—Global Warming from creating CO_2 – in the shortest time frame with a minimum of new technology. This chapter shows alternative emphasis in the near-term and midterm until new, currently un-imagined technology is created. Technology is limited to the known physical elements, physics, and chemical concepts developed and discovered in the last 500 years. Yes, there is probably more to be discovered but we may not have the time to discover and develop these new technologies for mass use in the next 50 to 100 years.

Based on this focus, what can we do now to transition to a Renewable Energy Society in the shortest possible time? Part of the answer can be found by reviewing the evolution of energy development and use.

We began in earnest to transition from an agricultural society based on animal and human power to a machine oriented society without the use of biological slaves about 200 years ago with the creation of the steam engine. This Steam Machine could use cellulose or fossil fuel. It was a true multi-fuel machine that was used to transition from biologically renewable energy sources to a more energy dense material found in the ground but created by the sun thousands-to-millions of years ago and concentrated by the earth—fossil fuel. This provided the beginning of the fossil fuel age, but the transition was possible because of the multi-fuel capability of the steam engine. The transition was un-noticeable even as new power-developing sources were discovered. Otto, Diesel, Atkinson and others spearheaded these discoveries in the late 1800's. All these inventors created engines that used a further concentrated energy-dense material derived from oil or coal to provide transportation machines that were light weight and cost effective. The steam engine continued until recently for long haul and freight transportation where weight and performance was not as important. Coal steam is still used to generate stationary electricity for most of the world today. These large stationary machines are also multi-fuel, being easily switched from coal to natural gas and even garbage.

Now let's get back to vehicles and converting them from gasoline and Diesel to using electricity. We currently use electricity for many transportation systems "successfully" on fixed routes. These are the trains and trolley systems that exist around the world. The word "successfully" is questioned because we have not looked at the efficiency and resource expenditure for these systems. If we consider the amount of conducting material needed for an electric train and the number of people carried per day, it is large because the electricity is used in peak pulses when a train needs it as it passes by a source. Since these trains go by infrequently the energy distribution system needs to be designed for the peak power but the average power is much less, maybe as low as 10%. Thus they are an inefficient use of energy supply resources. To improve this efficiency then it is necessary to find a way to level the load so that electric energy can be delivered at a low power but can supply a high power when needed as the train or vehicle goes by. This can be done with Electric Energy Storage by capacitors or batteries. The storage can be stationary on the ground or mobile in the vehicle. Either way, energy storage is needed to be able to use electricity more efficiently to drive our machines instead of liquid fuel. One of the questions addressed is, "Is it wise for us to move toward an All Electric society?" For example, it makes little sense with our current knowledge of physics and chemistry to consider a 5000 passenger oceangoing craft being powered by batteries. The same goes for aircraft. Thus, society, as we know it, must have some liquid fuel to be competitive to what we have become dependent. The only issue is to stop using fossil-based liquid fuels.

Thus, the objective of electrification can be listed with the following attributes:

1) Improve energy efficiency from renewable sources to the end use in transportation and industry.
2) Reduce liquid forms of energy use as much as possible, but in a coordinated transition so as not to disturb global economic health.
3) Create as much renewable energy as possible, using solar, wind, water and biofuels.
4) Create a transition road map that allows the world's general public to seamlessly transform from fossil fuel consumption to 100% renewable energy consumption in the shortest possible time, beginning with the existing fossil fuel and electric distribution infrastructure.
5) Create transition products that are cheaper and more functional than fossil fuel-only vehicles, and provide for lower running costs.

These attributes can be achieved entirely by the PHEV, but there is certainly space for battery-only vehicles, or EVs. In addition, as we reduce the use of fossil fuel we will need to address the fossil fuel industry that currently has a financial and physical monopoly on our oil dependent world.

LIMITATIONS OF EVS

The advantage of gasoline- and Diesel-fueled vehicles lies in the energy density of the fuel. Part of that density comes from the fact that some of the energy comes from the atmosphere in the form of oxygen. When electricity is created from fossil fuel it can only be created at less than 50% and, when transported to the end use by the distribution system, it could be as low as 30% to 35%. If the fossil fuel is consumed in today's gasoline or Diesel vehicles, it could be as efficient as 30% to 35%. But for passenger cars it is much lower at around 20% to 25% due to the demanded performance and acceleration. If EVs are designed to have the same performance as conventional gasoline and Diesel cars then they also suffer from low energy efficiency from the electric plug to the wheels of the car. Thus, many people have argued that the EV fueled by fossil fuel electric generation is a lot of expense for little or no gain in energy efficiency. In addition, to achieve a comparable range requires a lot of batteries with a real price to be paid in weight and costs using today's battery technology. Of course this could be improved, but that is only a small portion of the problem!

The more important issue currently ignored is how to transfer the equivalent energy required to travel 350 miles (500 km) in 5 to 10 minutes? A simple calculation illustrates the concern. If a vehicle requires 0.3 kWh/mile travelled and it goes 350 miles then it requires 105 kWh of batteries. If we wish to put this much energy into the batteries in 10 minutes, or $1/6^{th}$ hour, then it will take 630 kW of power. But the batteries at this charge level are currently less than 50% efficient, meaning that we need more than 1000 kW of power to feed the batteries in 10 minutes, or over 1 mega-Watt or more for one vehicle for 5 to 10 minutes. Such an electrical system would require about 20% of a typical electric power plant for 10 minutes with the electric wires and transformers necessary to get that power to the vehicle charge station to be used only for 5 or 10 minutes out of perhaps an hour or more. Think of how frequently our gasoline stations are used on the average and yet we have almost every car using gasoline today. It is less than 50% and, in the beginning, 75 years ago, it was less than 5%. Another difference is that a tanker truck can put a store of energy into the ground at the gas station to be used for 2 weeks to a month. Thus, an obvious solution is to put a large battery at the filling station that can supply this megawatt of power for five minutes, or so, and then be charged slowly over many hours at low power. If such a battery were to be developed where such a charge rate can be done with an efficiency of 90% instead of 50% or less, then the idea is to put in a large set of batteries that can be charged from the electric grid at a low power and can be used to discharge quickly into the vehicle's battery. No such technology or delivery system exists today that is comparable to our current system of filling stations that utilize tanker trucks to fill underground storage tanks.

Another fundamental problem is the way electric energy is stored in batteries (Electrochemically, which has internal resistance where the transfer loss goes up proportional to the square of the rate) and the way liquid energy can be stored in bulk with energy transferred to a vehicle with little or no loss. Until technology of electric energy transfer is solved there will always be a loss. This makes electric drive energy much less efficient than liquid fuel in all Fast- or Quick-Charge situations. To improve this situation requires technology we currently do not have, and no one is attacking the problem. The current Quick Charge Stations being installed around the US and Europe are not really good investments and could not happen economically without direct government support. Such support is being made available because people are pushing for a solution without a full understanding of the consequences. Money is being made available for such experiments because politicians do not understand the consequences of Quick Charge. The manufacturers have no reason to tell the truth about overall efficiency, and the electric power companies care less about efficiency because they make more money the more energy they sell! A possible solution would be to have a truly independent technology monitoring body, made up of technology people, who are paid and protected enough to not be influenced by special interest lobbyist from all sectors of the energy industry.

A bigger issue of the EV is range, or how far it can go. Current batteries are all affected by ambient temperature variations. This one parameter will vary the range by as much as 30% or more. Another parameter that affects range is internal temperature caused by use and quick charging and discharging. This could also affect battery longevity. Battery cell balancing is another matter that may further discount range capability when rapidly charging and discharging. Thus at any one time the actual range available can vary by a factor of 2 or more. Compare this to gasoline or Diesel vehicles where the maximum variation for the worst conditions may be $\pm$10%. Anyone owning an EV now knows about these wide variations in capability and if he can live with and understand the limitations then he could be happy. But what of the average person who owns a conventional liquid fuel vehicle with the current convenience and availability of the fueling infrastructure? There is no comparison today. Regardless of the money thrown at the issue to make it acceptable, while ignoring physics and efficiency, the truth will eventually come out and the current experiments will be supplanted by as yet unknown technology, or abandoned due simply to the logic of the amount of energy required to charge batteries and the cost of the infrastructure. The future of the world will depend on the average energy consumption per person. It is our objective to find the best way to minimize this consumption and make sure it all comes from renewable sources as our finite world continues.

Now let's look at the EV's internal technology. All EVs constructed by the major car companies are well designed and use the best available technology, yet they hardly compare to the liquid fuel alternatives that are a small fraction of the cost. Of course there are applications where the EV is 100% satisfactory and those applications and the people who use them should be commended for spending the money and time to drive such vehicles. However, for the average consumer the EV is far from satisfactory since it lacks so many of the essential technical features of the existing, much lower-cost liquid fueled vehicles. Thus there will be a market for EVs but it cannot be anywhere near a double-digit percentage of the overall vehicle market until major breakthroughs discussed above are completely addressed and become competitive with liquid fuel counterparts. To put things in perspective, the Tesla long-range vehicle has 85 kWh of batteries. Yes these batteries can drive the vehicle 300 miles but under very carefully controlled conditions. We must remember that 85 kWh of energy is equivalent to about 2.5 gallons of gasoline. So if you had a gasoline car with such a tank size, would you attempt a 300 mile trip?

THE URGENT NEED TO STOP USING FOSSIL FUEL FOR TRANSPORTATION, INDUSTRY AND SOCIAL APPLICATIONS

Regardless of the down sides of the EV, we must continue to try new technology because the world is finite and may not last forever. Mankind, using fossil fuel, or stored energy from the sun millions of years in the past, is changing the climate quicker than at any time in the history as we know it. Recent Public Broadcasting Service (PBS) documentaries and books by Climatologists the world around, all confirm the findings. So it is clear that we must stop using fossil fuel without disturbing society, as we now know it. Dire consequences in heat and violent weather will disrupt the planet to conditions not tolerable by our species. The point is that we humans cannot evolve as fast as the climate is changing, so we will become the dinosaurs of the past. But the destruction will come from within rather than from meteors from outside our planet. But how can we do this without large disruption in society. By the way, the richest segment of our society is the oil industry because the world is currently completely dependent on it to support our convenient and productive lifestyle. Thus we need to find a solution that addresses every part of current society so that everyone benefits and can continue to profit equally.

OIL DEPLETION CAUSES GLOBAL WARMING-PHEVS CAN BE PIVOTAL IN THE SOLUTION WITH NO NEW TECHNOLOGY NEEDED

The best solution would be to stop using fossil material for fuel, which is creating CO_2 and other greenhouse gases contributing to the rapid warming of the planet. If the fossil material were developed into recyclable structural materials for the construction industry, replacing wood and other materials, we could begin to restore some of our forests to absorb the excess CO2 being generated and start to use recyclable fossil materials to create new buildings and houses. Then after the products become obsolete or worn out they can be recycled simply by adding primarily concentrated heat energy from the sun through solar, wind or water sources.

We have been using fossil material now for roads and plastics of all kinds already. What is suggested here is simply that this segment of the fossil extraction industry be greatly expanded with the potential to become more valuable than selling the fossil material for destruction of itself and the planet by using it for energy. Policies to make this happen would be needed and it must be shown to the energy industry that making this change is good for their long term future, and could insure them of a continued business model for more years than if they were to use their current extracted material for energy. Their business model may have to change slightly but they have the resources to do that, they only need the thrust and motivation to move in such a direction.

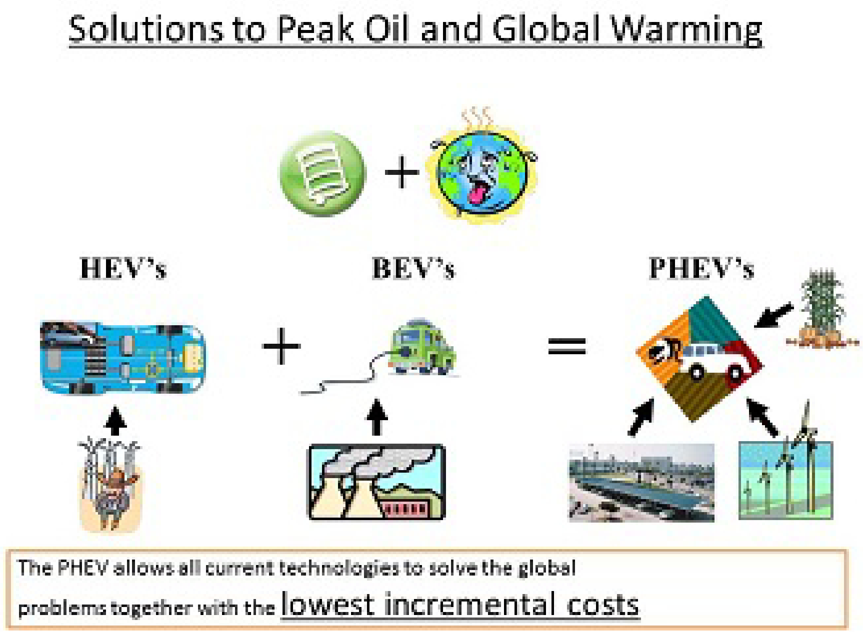


Figure 1. The PHEV can use renewable energy with zero CO_2 emissions.

Since the world is driven by profits, rules and regulations must be created *to* allow this to occur. Also, new material technology is needed to allow mass production of standard shapes used in the construction business.

Refinement of the fossil material will take energy but ultimately this should come from renewable solar, wind, or water, and maybe nuclear energy. This way the current fossil fuel industry can continue its profit making, while benefiting society by creating planet-saving materials and reducing the greenhouse gas emissions gradually, in a controlled rate, to essentially zero, over time.

THE NEED FOR DUAL OR TRIPLE ENERGY USE MACHINES FOR A TRANSITIONING SOCIETY

As we discussed in the Introduction, the evolution from steam to gasoline and Diesel was essentially seamless because the steam engine was a multi-fuel machine. The gasoline engine was not. Diesel engines were designed by Rudolf Diesel to initially burn essentially any combustible material from coal to wood pulp. But it was soon discovered that a liquid fuel contained much more energy and could be handled and distributed much easier than coal or wood. The steam engine, however, when converted to Diesel fuel or oil also became better and more efficient. So the various forms of power production continued with gradual improvements until relatively recently. Thus, the same holds true today–flexible fueled systems allow the transition to new technology in a seamless fashion.

To transition to the use of renewable energy from gasoline and Diesel machines dependent on liquid fossil fuels, could be done in a number of ways. People have suggested a transition directly to biofuels. The problem is that the current liquid energy consumption rate is so high that we could not grow enough fuel to satisfy the energy currently consumed by society. Biofuels have been shown to be producible at a reasonable price competitive with current oil-derived gasoline and Diesel fuel. The main problem is developing enough to satisfy demand. Currently, gasoline in California, due to emissions regulations, is mixed, with up to 10% ethanol. Thus, already 10% of the gasoline sold there is biofuel. So this is likely sustainable. But to make it 100% biofuel would not be possible today or into the future because fuel growth will compete with food growth.

If, however, we create a vehicle that can use 90% electricity and 10% liquid or gaseous fuel, we can transition to a renewable energy society seamlessly without having to create more biofuel. The Chevrolet Volt, the new Ford C-Max and Ford Fusion Energi models, and Toyota Prius Plug-In are PHEVs. Other companies are beginning to follow suit. These vehicles are all designed to use as much electric energy as possible. Their control policy is to assume a fully charged vehicle at the beginning of a trip then deplete the electric batteries to a minimum when a gasoline or Diesel engine is asked to take over carrying the load. The electric battery and motor then are used to provide extra performance to the vehicle. This philosophy allows the liquid-fueled engine to be downsized and run much more efficiently. The amount of down size is dependent on the size of the battery and thus the power of the electric motor.

The author has designed and constructed over ten such vehicles based on various technologies in the powertrain. Some of the vehicles had liquid-fueled engines that were downsized by a factor of 5 (from 3.0 liters to 0.6 liters) and yet had comparable performance to the original vehicle because the electric motor and the gasoline engine powers were designed to be additive.

The result was an All Electric Range (AER) of about 60 miles (100 km) and a performance equal to the conventional car. When the batteries are depleted to the Minimum State of Charge (SOC) after traveling 60 miles (100 km), the engine comes on to maintain the battery SOC, but does not charge the battery above the Minimum SOC. Thus allowing the batteries to be filled from an external source when the vehicle comes to a stop.

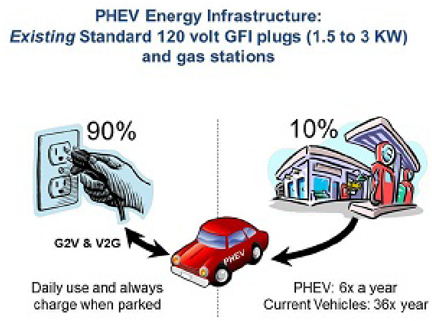


Figure 2. PHEV uses 90% electricity from low power chargers and 10% liquid fuel for long trips a year.

This policy not only allows the use of electricity first, then the gasoline engine to drive the vehicle, but to also add electric energy from the battery/electric motor system to provide acceleration and collect regeneration of energy from deceleration of the vehicle. In this mode the electric energy is cycled in and out of the batteries as needed to maintain the vehicle at the drivers command. This mode is sometimes called the Charge Sustaining (CS) mode. There are many different powertrain configurations to accomplish these three basic modes, All Electric, Regeneration and CS. We will not be discussing the specific configurations except to say that the best configurations are ones that are simple but allows the operation of all the modes at the best possible efficiency. The amount of AER is dependent on the size of the batteries or kWh of energy stored. The commercial vehicles currently being manufactured have enough batteries for AER of 12 miles-20 km, 20 miles-30 km and 40 miles-60 km. Of course, they could be increased to 60 miles-100 km, as was done by the author. If the same battery technology were to be used, then the power available from the battery pack will be proportional to the battery size. Then if all the vehicles are to have the same performance, the gasoline engine power can be so adjusted to make the total power the same as the conventional all gasoline vehicle. Thus, the larger the batteries, the smaller the liquid fueled engine required. This has the effect of increasing the fuel economy or decreasing the fuel consumption without affecting performance. To counterbalance the positive effect on fuel consumption is the added weight of the batteries and the top sustained speed of the vehicle. Notice the top speed may be the same but the sustained speed is lower due to the smaller engine. In addition, the battery costs today are higher than almost all other components in the PHEV. The manufacturers at any time point in the technology development must reach a compromise. So we see the Japanese manufacturers choosing a small battery pack and a larger engine, Ford Choosing a 20-mile AER and a smaller engine and General Motors choosing a 40-mile AER and a small, efficient engine. It is obvious that the overall vehicle cost would be affected by the battery size and powertrain complexity.

The main advantage of a larger battery pack is the displacement of liquid fuel with electricity. Obviously, the larger the battery pack, the less liquid fuel will be used if all vehicles performed equally and were driven similarly with the energy from the battery pack coming from a wall plug or an external source. The key difference between charging PHEV batteries, as opposed to the EV batteries, is the *rate of charge* needed and desired. The PHEV in general, can be charged much slower and be fully effective.

The US Society of Automotive Engineers, SAE, have established standards on charging batteries for safety and other reasons. The standard is referred to by the number J1772 for charging at a rate up to about 10 kW. In addition they have set two levels of charging depending on the power capacity of the electrical outlet. Around the world, for domestic and light duty electricity use, there are essentially two levels of electrical outlets. Less than 2 kW is called Level 1 and less than 10 kW but more than 2 kW, is called Level 2. The low power Level 1 outlets are distributed around the world and essentially in every home, business and industry. Level 2 outlets are used for large electric stoves, electric heaters and clothes dryers, and pumps for swimming pools, etc. By far, there are more Level I plugs in society than Level 2. It is the accessibility and availability of off-the-shelf components that is critically important to charge these PHEVs at the beginning of new technology introduction. So Level 1 charging systems are preferred. The problem has been that more money can be made by a charge station business in Level 2 and above, than in Level 1.

The PHEV is a dual or triple fuel vehicle being able to use electricity from an outside source and liquid or gaseous fuel from one or more sources. This gives the PHEV a big advantage over the EV because it does not have to be electrically capable to carry out a driving mission; there is also gasoline or other energy on board. Thus easing a phenomenon of single-fueled vehicles called Range Anxiety. Gasoline vehicles also experienced this phenomenon before 1920, when there were few gasoline stations and gasoline was mostly distributed in small glass bottles by drug or hardware stores. The fall back in those days was the horse. Today, in most countries around the world, gasoline stations are abundant enough and the range of the gasoline vehicle is far enough to essentially make the liquid fueled vehicle convenient and productive. In fact, some will say that the gasoline vehicle is what led us to our current level of productivity. Thus, as we introduce new vehicle technology it must be as good or better than the current gasoline vehicle in every dimension of measure, and be comparable in cost. The multi-fuel aspect of the PHEV could do just that.

The PHEV will uses electricity to displace liquid fuel if the user plugs the vehicle in when parked. If we look at the typical use of the conventional gasoline vehicle we find from the US National Highway Traffic Safety Administration (NHTSA) that the average driver across the US travels about 30 miles a day and drives his vehicle for about 3 hours. This means he has 21 hours to charge the vehicle. The PHEV will use about 0.3 kWh of energy per mile of travel. So, in 21 hours, using Level 1 plugs at 1.5 kW can provide about 31 kWh of energy, or a range of about 100 miles per day. Thus, Level 1 plugs are capable of supplying 3 times the average mileage required by the normal driver if the vehicle were plugged in every time it is stopped and the batteries are large enough. Hence for PHEVs, the much lower cost Level 1 plugs would more than satisfy today’s average driver’s need to displace liquid fuel with electricity.

The PHEV then, has little or no need for high-cost level 2 and even less need for much higher cost quick-charge concepts. Of course the amount of liquid fuel displaced is dependent on the battery size. The average US driver travels 30 miles (50 km) round trip a day to-and-from work. So a driver travels 15-or-less miles at a time and then stops for up to 8 hours, thus the battery only has to provide 15 miles of range (25 km) at a time, and be charged twice a day. Such a battery then will be cycled twice a day, and if the car is used for 4 years, the battery will have experienced approximately 2400 cycles, or about the limit of current battery life cycle. On the other hand, if the battery were capable of 30 miles and the person drives 15 miles and charges twice a day, the batteries experience only one cycle per day and the batteries should last 4800 cycles, or about 9 to 10 years. (This is the strategy of the General; Motors Chevrolet VOLT) The down side is that the batteries cost 1/3 more. Thus, the Federal government has provided an incentive for the larger battery, and the State of California provides additional incentive, plus High Occupancy Vehicle (HOV) lane access to allow the driver to drive in the free-flowing HOV lane with only one occupant in the vehicle. This has turned out to be a very popular incentive for people to purchase the PHEV with 30 to 40 miles of AER. This is less than 1/3 the batteries of Pure Electric vehicles with the same capabilities.

Depending on government subsidy is not a sustainable business model but it helps to get the technology into the hands of the general public until the volume drives the battery price down to the point where these PHEVs can be comparable in price as the standard gasoline- or Diesel-fueled vehicle.

So why would the driver of a PHEV plug his vehicle into the electric grid? The base cost of electricity around the world is about US $0.10 to $0.12 per kWh. Gasoline is at approximately $4.00 per gallon in the US (more like $9.00/gallon in Europe), with current gasoline vehicle fuel economy at about 30 mpg, making fuel cost about 13 cents per mile. When driving on electricity, the energy needed is about 0.3 kWh/mile and the cost is about 7 cents per mile, or close to ½ to ¼ the cost of using gasoline. At the current time, most places do not charge for electricity because it would only amount to about 15-to-18 cents an hour. Collecting this is not worth the paperwork for short-term parkers, so it is often free. This provides further incentive to purchase such a vehicle today. On the other hand, with Level 2 charging, it is about 72 cents per hour, making it more difficult to justify free charging. As mentioned above, Level 1 charging is completely adequate for the PHEV.

It should be pointed out that the Japanese PHEVs by Toyota, Honda and Nissan have elected an AER of just 12 miles (20 km). The reason for the smaller battery pack is clear, the average driver in Japan drives a distance of less than 20 km to work, and assuming the vehicle is parked for at least 8 hours at work, then the vehicle can easily accumulate 10 kWh of energy, providing a range capability of 50 km. This is about 5 times what is needed in Japan. The down side is that the engine cannot be downsized as much, even with higher-power batteries because there is not enough energy to account for un-anticipated needs, such as long, steep highway grades where the small battery pack boost will dissipate before the grade needs are met; the vehicle will slow down making it less acceptable by the general public. Never-the-less, the step to PHEVs is headed in the right direction, and as battery costs come down due to higher volume then the battery pack size can be increased and the engine further downsized for better fuel economy in Charge Sustaining or CS mode.

The vehicles constructed by the author have shown that the liquid-fueled engine could be downsized to 1/5 to 1/3 the conventional vehicle and still maintain the performance of the comparable all gasoline vehicle. The battery packs in these vehicles were sized for 60 miles or 100 km AER. The charge-sustained highway fuel economy was close to 3X the conventional car, or the vehicle consumed about 1/3 the fuel of the comparable conventional car at sea level whise sustaining the charge in the traction batteries. A down side of this drastic engine downsize is the performance at high altitude. Thus the engine needs altitude compensation by turbo or super charging the intake air. This is well known technology and there are multiple sources for this. In addition, a turbo system can be designed to regulate the engine intake air to sea level pressure by the use of an electric generator providing a turbo compounding effect at sea level further increasing the engine efficiency and reducing fuel consumption. This works well with the downsized engine because when it is run, it is run at high load providing high exhaust heat energy and the ability to extract energy from the exhaust stream.

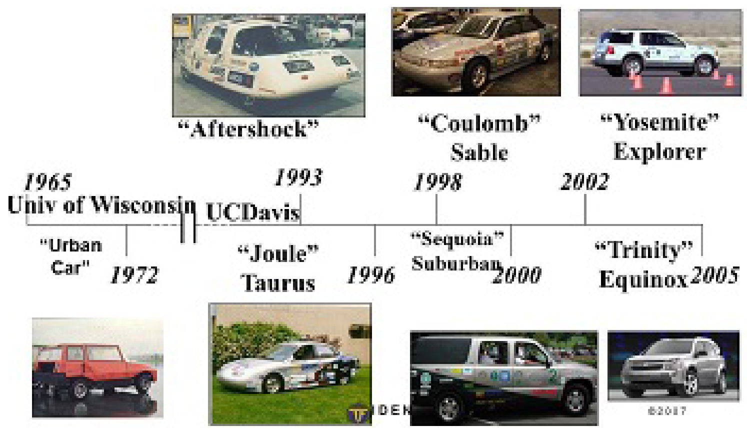


Figure 3. Some production cars and Sport Utility Vehicles (SUVs) modified to PHEV with 60 mile AER by the author.

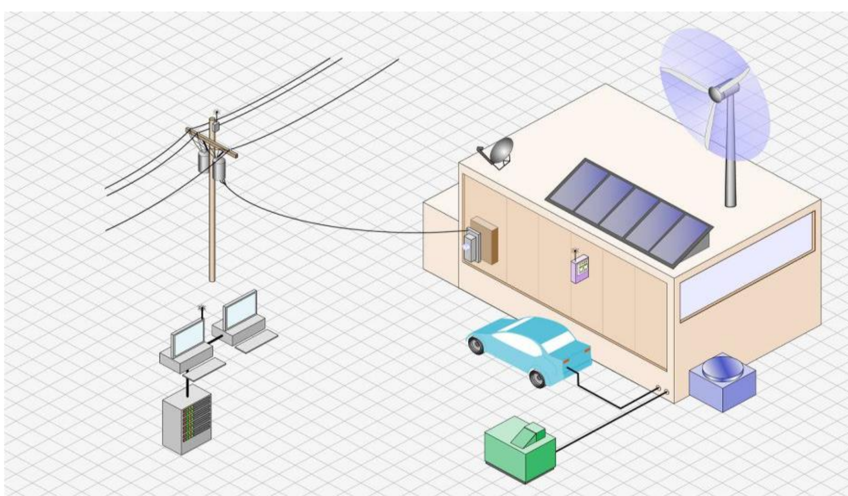
IMPROVING THE ELECTRIC POWER DISTRIBUTION SYSTEM WITH THE PHEV

This is an area that is not well addressed. If charging, as argued above with Level 1 at less than 2 kW, then 1000 cars distributed in society could consume 2 MW of power. Power plants must regulate their power according to demand because if extra power is generated, it must be dissipated or used in storage somewhere.

PHEVs distributed in society today all have battery systems that are intelligent, so it is a simple matter to allow communication between the battery pack and the power generation system, which have compatible needs. These batteries can be used to take load when there is excess energy available and not take load when the electric power system is overburdened. A simple on-off signal to the charger is all that is needed at this stage. The central power distribution system can cycle the energy to various chargers on line in a sequence that is equitable. For example, if a vehicle signs up for such service maybe the electric rate can be reduced to ½ or so because the electric system receives a valuable benefit. The power companies benefit because they are getting revenue with energy that would have been wasted otherwise due to short term over capacity, and they can use this variable load distributed in society to regulate substations where peak demand may be occurring. If a driver finds he is in the wrong neighborhood to take advantage of this low rate then he can sign up for regular service or move his vehicle's parking location to a more favorable spot.

The net result of this strategy of electric power distribution and management is to utilize the existing electric distribution lines already in place to a higher utility factor. For example, most American homes have 200 amp service at 220 volts, or about 40 kW capability. This capacity is rarely used, and it is calculated that less than 20% of this peak capacity is used in the common American home. This implies that we have installed far greater capacity than is being utilized. By using battery charging in vehicles distributed throughout society we can increase this utilization factor with *no new power-line facilities* by simply allowing the charging system to go off for those times when the local electric grid is highly loaded. For the EV this may not work well since they are one energy source vehicles and already suffer range anxiety, thus they would want high power charging every time they are parked, lowering the utility factor and efficiency of the power lines further. Since PHEVs are on Level 1 low power charge, this Level 1 charging system can become a dream for power-line regulation purposes. The driver of the PHEV may use his secondary energy source, gasoline, a little more periodically. If he is properly compensated so that everyone wins, then such a system can work and it is low-to-no cost to society and the owner or driver of the PHEV.

A further extension of this concept is to design a bidirectional charger that can take power from the batteries and feed power back to the AC lines in proper phase as needed by the power company. This power regulation scheme can be used to compensate for sudden changes in the local electricity demand and the batteries are then used for power line compensation to maintain high efficiency power transfer from the main power plant. Because each battery system is being charged or, in this case, discharged at 1 to 2 kW the regulation of a large load would take many vehicles in a local area. A computer algorithm can be designed to take this distributed resource and allocate it properly to regulate the local grid and greatly improve energy transfer efficiency with no additional resources! The objective would be to improve the grid at the same time providing the customer energy over a period of time such as 4 to 8 hours. People have called this concept "Vehicle-to-Grid," or V2G, energy feedback. Thus, the PHEV at Level 1 charging can be implemented and benefit society with essentially no new power resources because it is getting it's energy from higher utilization of existing resources, thus increasing the efficiency of the electric power system. In addition, the batteries may benefit from the low-level charge-discharge exercise.



From Southern California Edison.

Figure 4. Total energy management system at work and home with energy stored in PHEV's, most energy can come from renewable sources.

We have shown in this section that the PHEV can be used to greatly improve the Electric Distribution System and the savings can be shared between the customer and the utility, so everyone benefits. In addition, we have indicated that the current Electric grid systems all over the world (even in places like India) have over capacity that is not used. In fact the USDOE Pacific North West Laboratory has calculated that this over capacity in generation and distribution in the US could, under proper management and integration, support 80% of cars on the road today if they were all PHEVs, with no change in the electric power lines.

On the other hand, if we had to go to high power charging with Level 2 and above, for EVs, etc., then new infrastructure would be needed at great expense.

The message of this chapter is that with the PHEV concept, there is no new electrical infrastructure needed. And as far as liquid fuel infrastructure, these vehicles can begin on fossil fuel and transition to biofuel that will be distributed by the same liquid fuel infrastructure we have today. These advantages are lost with the EV concept.

Alternative fuel concepts such as hydrogen, methanol, etc., have been tried in the past and each time they failed after huge amounts of money and time were spent. Why? Simple. The energy distribution system was not there, and to construct a new energy infrastructure means a huge public investment. There is never a good time for such investments so these proposals all die a natural death. Hydrogen is on its last legs now because in addition to the lack of infrastructure and generation from renewable sources, Hydrogen Fuel cell energy "Source-to-Wheels" efficiency has been "brushed under the rug". For example, it is a simple matter to compute the generation of energy from a windmill and trace the electricity path to powering the wheels of a car using a EV or PHEV, and then compare that to taking the same wind energy and forming hydrogen from water then transporting it to a distribution system, and finally using it in a fuel cell at "high efficiency". The current PHEVs and EVs on the road today would be able to go 300%-to-500% farther than the best hydrogen vehicle today at a fraction of the cost. In addition, the batteries in the PHEV or EV can be used to benefit the grid as discussed above, further lowering the system costs.

A ROAD MAP TO AN ALL RENEWABLE ENERGY SOCIETY BASED ON LONG-RANGE PHEVS AND EVS

We just mentioned above that PHEV and EV batteries can be used to level the load and better utilize the current grid. In this section let us look at what is needed to transform from a 100% fossil fuel-dependent Society to one that can use 100% renewable energy in the shortest possible time.

It is obvious from the above discussion that nothing will change if we do not address the entire energy sector, both production and consumption/utilization together. We have not discussed renewable energy production and how it can be used in PHEVs and EVs of the future. We did say above that it is a simple matter to use battery energy storage to level the grid and to provide energy back to the grid in times of need. Once this feature is developed, then the technology can be extended to address renewable energy.

All renewable energy systems are discontinuous. For example solar energy only generates for less than 12 hours, and wind blows intermittently, daily and seasonally. Even waterpower is dependent on last year's rainfall, etc. To take these variable sources and integrate them into the electric grid means that we are varying the power output of the grid even more than we are with load. This generally means new power lines and more infrastructure to accommodate the large wind and solar farms located in remote locations. In addition to these large, efficient wind and solar farm installations, we can utilize the batteries and energy storage capability of the PHEV and EV to level the renewable energy sources and relieve the grid from trying to accommodate the added renewable energy by throttling the fossil electric power generation and reducing the fossil or other fuel generation system efficiency due to throttling.

A proposal in a recent paper by Sterling Watson now at MIT, stated that if every new car sold were a Chevrolet Volt and it was sold with a windmill or a set of solar panels, (the car would be sold with “fuel” for the life of the car), and if everyone bought one of these cars or something similar with a renewable energy generator, in a period of about 15 years we can be completely off of fossil fuels, if we supply 10% or so of our energy from liquid biofuel sources. As we mentioned above, this 10% biofuel is already in the gasoline being sold in California by law. Thus, in California we can today begin to use only the ethanol in our fuel and forget about the gasoline with little or no change in any of the energy infrastructure. Then if the energy were generated by local distributed renewable wind and solar and stored in the batteries of the PHEV or EV with G2V (Grid-to-Vehicle) and V2G capability, it can be used by the vehicle, or local homes, or industry. We would suddenly be transitioned to a renewable society with no loss in performance or convenience. Since cars last about 15 years, then, this is the minimum time for this transition. In the paper by Watson and Frank, he they found that the energy for industry would have to come from large wind and solar farms. So simultaneous with the introduction of the PHEVs and EVs, would be the construction of the large energy farms and biofuel production farms. Biofuels are needed for things like aircraft and ships. We currently use oil and jet fuel for these purposes, but biofuels could easily be substituted with no loss in productivity.

Figure 5. Sustainability road map.

The batteries of the PHEV and EV are not worn out after 10 to 15 years of use but they may have degraded in power and energy capacity. None-the-less, they have additional life left for other uses than transportation. These vehicle batteries could be used in homes, business offices and industry to store renewable energy where they can provide a steady load for 24/7 to run buildings and to charge vehicles. Thus, PHEV and EV batteries can be used to provide the total energy store necessary to take energy from both local- and centrally-generated wind and solar facilities, and the energy can be managed for vehicle needs, while also supplying enough energy for all stationary use, as well. The question is where should these generators sit? It is suggested in the paper that they simply sit at the place of residence and at the work place.

Ultimately, such small energy generators will have to be managed by someone other than the home owner or the industrial user. The logical energy managers are simply the existing electric power companies. Many of these companies are called home or stationary energy managers, like Pacific Gas and Electric (PGE). Since energy management is their game, then managing a distributed collection of energy sources could easily be done with today's computer technology. This gives the company much more work, but then management and costs of it's traditional sources of energy from coal, natural gas, water and nuclear would be less or greatly reduced. This allows them to grow and provides additional revenue. The idea is to ultimately reduce coal and natural gas to zero. This gives the existing energy companies a lucrative new business and allows growth for the foreseeable future, as the technology evolves.

CONCLUSION

We have tried to convey a scenario using mostly PHEVs, but also some EVs, where there are no losers and all winners in order to solve the problem of transitioning off of fossil fuels in an acceptable and easily integrated fashion for everyone. This applies to all involved in the energy business, from the individual, to large corporations designing and selling cars and trucks, and the energy industry's oil and gas production and electric energy generation and distribution companies. We are suggesting that all these industries be provided incentives to grow into the new paradigm. The key is that we stop using fossil material for energy and start using fossil material for everlasting products that can be recycled many times *without* being destroyed by combustion and turned into CO_2 or other greenhouse gases.

Our planet is quickly becoming a place no longer habitable by our species. If we do not begin the amelioration of our actions of the past we will essentially extinguish ourselves with essentially no survivors. This scenario is common to all species on earth. The classic high school experiment where a small dish of nourishment is injected with bacteria and allowed to grow and flourish illustrates the potential outcome of the world. In so many days the colony of bacteria grows and grows happily until all resources are consumed then the entire colony suddenly dies. We, as "intelligent" bacteria, have the means to change this scenario because we know a lot about our finite world and we have the technology to affect this change. The question is, can we act fast enough to catch ourselves before the start of the inevitable catastrophic collapse. The bacteria surely couldn't act fast enough and other past living species couldn't act fast enough. The bigger question is, with our knowledge of physics and chemistry do we have the financial and political "will" to work together to stem the tide of exponential growth before it is too late for everyone? We have suggested that it is possible with the technology we currently have in PHEVs, biofuels, and renewable energy from the sun, wind and water. But all these related industries, government, society at large, and the investment community must act together, pushing in one concerted and coordinated direction for everyone's benefit. Then, perhaps, we can avoid the inevitable, sudden collapse for the next 10,000 years or so.

The key is to use the fastest possible way to electrification using renewable, non-greenhouse gas-generated energy, and the road map outlined above. Remember that the end game is not yet visible since we do not currently have the technology with the same energy density and convenience that fossil fuel offers. If we wait until it is developed and distributed worldwide it will be too late. So we must have a road map that will take us from our current social and energy infrastructure and transition seamlessly to the unknown future. The PHEV allows us this beginning. Keep in mind, however, that because we don't know the ultimate end game technology, since it has not yet been invented, that is the PHEV running on biofuels and renewable low-cost electric energy may, in fact, be the end game. It meets the worldwide objective of ZERO CO_2 in the shortest possible time frame. Time to transition to Zero CO_2 is a matter of adoption rate with a minimum time of 15 years simply because that is the average lifetime of vehicles in general. No other technology can claim this seamless and affordable transition from our current Fossil Fueled Society.

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