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A Fifteen Year Roadmap Toward Complete Energy Sustainability

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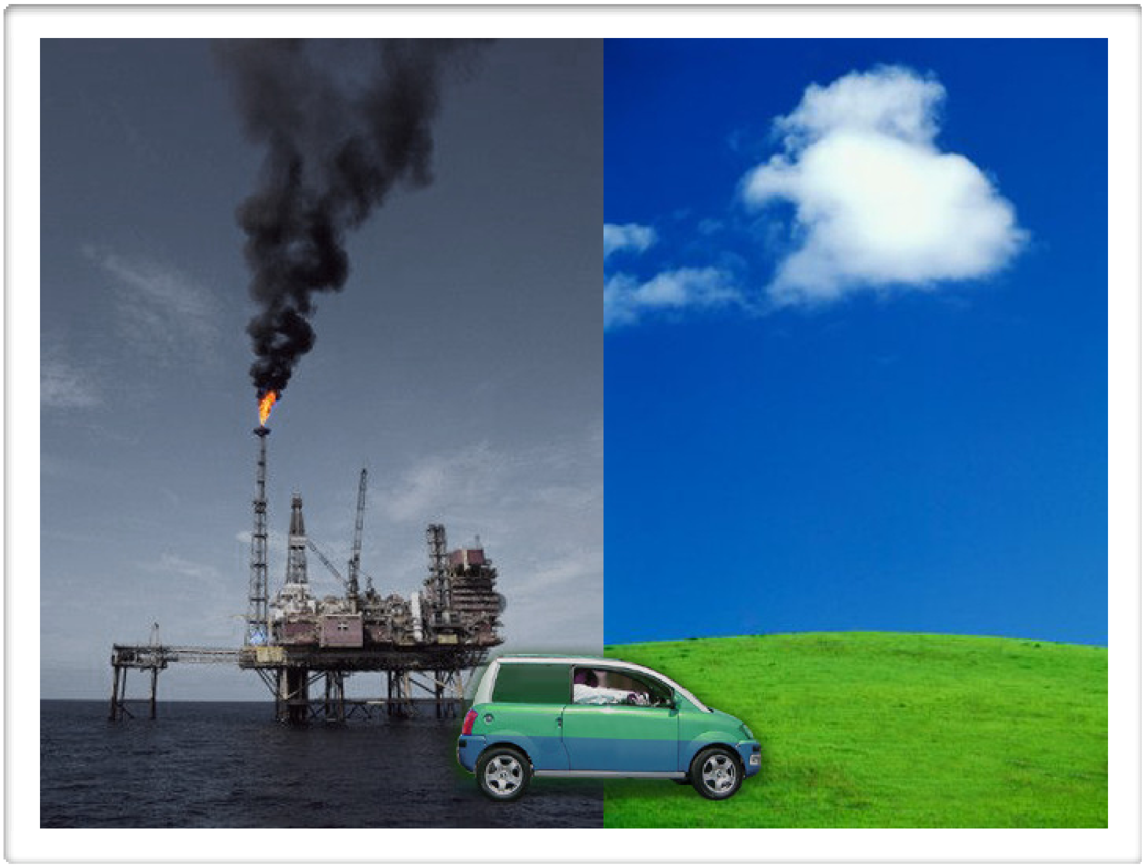

STERLING WATSON, EFFICIENT DRIVETRAINS INC.

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Abstract

The purpose of this paper is to show that we can transition from fossil fuel dependency to a sustainable society dependent only on renewable energy, in the form of renewable electricity and biofuels. In truth, all energy is renewable, but fossil fuels are renewable with a cycle time of hundreds of millions of years. As the rate of oil removal from the earth reaches its peak, we must find an alternative to fossil fuel energy. We will show that we can use renewable energy with a cycle time of less than one year to power our entire society.

We will present a road map of how this can be accomplished in only fifteen years with a reasonable rate of investment, using the example of the typical American state of Hawaii. We are choosing Hawaii because its energy usage can be easily measured by accounting for imported fossil fuel. Hawaii is isolated from traditional energy resources because it is geologically very young. If we can show that Hawaii can become fossil fuel independent, then any state in the US can also become fossil fuel independent.

With this scenario, the oil and coal companies would be put out of business. Our objective is rather to enhance their business by asking them to create a more valuable product for society. Rather than using the fossil material for energy, it can be transformed into recyclable plastic materials for construction, or other products beneficial to society. In this manner, we can solve the depletion of our forests while creating a recyclable product useful to society forever. In addition, we don't have to sequester the carbon dioxide that results from burning fossil fuel. Thus, we should be investing in developing commercial materials and products from oil and coal to benefit society rather than investing in carbon sequestration research.

By transitioning the United States to a society run on renewable energy, we will also solve our national security problem caused by our dependency on foreign oil. If we can do this in the United States, then the rest of the world can follow our example and become fossil fuel independent.

This transition from fossil fuels to renewable energy can be accomplished while improving our lifestyle at a very small incremental cost. This will require homes, industry, and transportation to transition to over ninety percent electric energy. Because electric energy storage is twenty times heavier than liquid fuel and the flow rate of the existing electric infrastructure (1 kW) is one thousand times slower than the flow rate of liquid fuel, certain elements of our society, such as air transportation and long-distance ground travel, cannot be fully electrified today. However, these elements can be powered by liquid biofuels.

Complete energy sustainability needs to account for these physical attributes of electricity and liquid fuel. This paper will show that we can adapt these characteristics to our existing society without affecting lifestyle, while using renewable energy from the wind and biomass derived in Hawaii.

Introduction

Throughout the last two hundred years, humankind has used fossil fuels to power society, and is now depleting these resources at an unsustainable rate. Not only are we exhausting these resources, but we are transforming the fossil material into carbon dioxide. This is creating global warming and returning the earth to the condition it was in billions of years ago, when the atmosphere consisted primarily of carbon dioxide, and atmospheric temperatures were much higher than they are today.

It is clear that we must stop burning fossil fuels, but our society is currently dependent on the energy that we derive from them. The objective of this paper is to show that we can transition from fossil fuel derived energy to renewably derived energy in a short period of time, if we invest our human effort appropriately.

Because renewable energy sources such as solar and wind suffer from intermittency, we need a way to store this energy to provide continuous flow as is needed by our society. Our solution is to use the ground transportation sector as a means of storing energy for the rest of society. Thus, we have to shift ground transportation from being predominantly dependent on oil to being primarily dependent on electricity, without a sacrifice in any of the performance parameters. These performance parameters include acceleration and speed as well as the convenience of energy replenishment.

Recently, electric vehicles and extended-range electric vehicles (or plug-in hybrids) have been shown to have acceleration and velocity performance comparable to conventional gasoline and oil powered automobiles.[1] However, the electric vehicle requires high electric power to restore energy in the car. This high power requires new, expensive infrastructure investment. The plug-in hybrid, on the other hand, does not have to be electrically charged at high power because it uses both electric energy and liquid fuel energy. This addresses the thousand-to-one difference in fueling rate between electric and liquid fuel energy. This liquid fuel energy can be bio-derived, or taken from fossil fuel sources as a backup.

The plug-in hybrid electric vehicle (PHEV) is the ideal vehicle for a society transitioning from fossil fuel to renewable energy. If we can show that the PHEV along with solar and wind generation can make a particular modern US city or island completely free of fossil fuel while making no sacrifice in lifestyle or productivity, then we can show that the entire nation can be made fossil fuel-free today without changing the energy distribution infrastructure. This simultaneously provides a solution to global warming and the peak in oil production. We can also propose alternative uses for fossil materials that will benefit humankind forever by using oil and coal to produce recyclable plastic, instead of energy.

We will present a road map of how to move from our existing fossil energy-dependent society to a completely self-sustaining society without any sacrifice in quality of life or productivity. This can be accomplished by simply introducing one critical product into society—a bidirectional charger for batteries to smooth the intermittency of energy generated from solar and wind.[2] The bidirectional charger will automatically generate the desire to use direct solar and wind to supply both transportation and stationary energy use in the entire society, because the cost of these re-

[1] Tesla electric car demonstrates that electric cars can have acceleration and range comparable to today's automobiles.

[2] A bidirectional charger is defined as a charger which can take alternating current (AC) electric energy and charge a direct current (DC) battery and then be able to convert the stored DC electric energy back into synchronized AC energy.

newable energy sources is less than one quarter the cost of today's fossil fuel energy. This will require producing and installing many times more batteries than we currently have in society. We propose that the increased battery supply be in the plug-in hybrid vehicles. Once that is satisfied, integrating the PHEVs' stored electric energy into the home, business, and industry becomes a natural next step because the movement will be driven by lower cost.

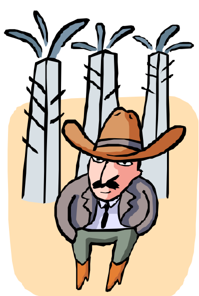
The islands of Hawaii are a good example of a modern American state with information on all energy consumed on the islands as well as information on solar and wind resources. In this paper, we will compile diurnal energy use and show how it can be completely supplied by solar or wind, and we will show how the batteries of plug-in hybrids or electric vehicles can be used to level the intermittency of solar and wind power.

As society begins to transition off of fossil fuels, the companies that provide fossil fuels will need to transition their business to something of higher value than energy. We will propose that fossil material removed from the ground be used to produce forever recyclable product rather than energy. This constantly reused material then has a much higher value than energy, which is used only once. This will thus address the carbon dioxide problem caused by burning fossil fuels since we will no longer burn the fossil material.

In the rest of this paper, we will detail the claims in this introduction and create a roadmap toward a completely energy sustainable society using the example of the Hawaiian Islands.

Current Energy Use in Hawaii

Nearly ninety percent of all electricity currently generated in Hawaii comes from petroleum, and the rest is currently generated from coal, hydroelectricity, geothermal, wind, and other renewable sources.[3]



In 2007, according to the Energy Information Administration (EIA), the total petroleum imported was 52,897 thousand barrels.[4] Motor gasoline was 21 percent, jet fuel was 24 percent, distillate fuel was 18 percent, and liquefied petroleum gases were one percent of the total petroleum imported. The balanced 38 percent was either lost or used for residual plastic and asphalt or tar.

Electric energy in Hawaii is currently estimated to be about 32 percent efficient, including the small amount of electricity generated by coal. This 32 percent is derived from calculating the electric generation efficiency (40 percent) times the transmission efficiency (80 percent). This number correlates with Hawaii's total electric energy use, which is calculated from the total amount of electricity generated divided by the amount of energy in the imported oil used for electricity.

The low efficiency of creating electricity from fossil fuel means that we are importing 68 percent more energy than is actually used in Hawaii. This 68 percent of the imported energy is wasted in heat and creates greenhouse gases. Thus, if renewable energy is to replace fossil fuel, we only need to generate 32 percent of the energy currently imported.

[3] http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=HI

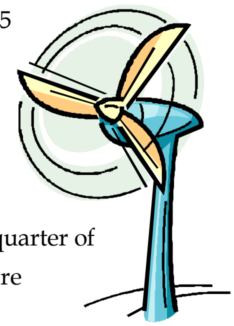
[4] http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=HI

Imported energy is distributed into homes, businesses, and industry. On average, each home uses 18.51 kWh per day, each business uses 109.11 kWh per day, and each industry uses 3,478.67 kWh per day.

These calculations indicate that the total electricity used in the entire state of Hawaii is about 38 million kWh per day.

Transportation Oil Consumption (Cars and Trucks)

Each year, cars and trucks in Hawaii use 11,348,000 barrels of motor gasoline, amounting to 476,616,000 gallons. This implies that each car, on average, uses 422 gallons per year, and then according to average miles driven by cars in Hawaii, the average fuel economy is 17.78 miles per gallon. When considering that this gasoline was derived from imported oil, this amounts to 15.78 miles per gallon of crude oil. Translated into energy, this is 2.57 kWh per mile using crude oil.



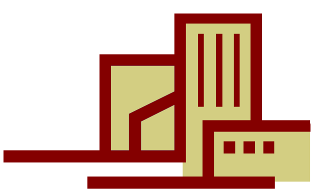
On the other hand, the average electric vehicle, including cars and trucks, conservatively uses 0.5 to 0.7 kWh per mile (based on research done at UC Davis). Of course, this is electricity at the wall plug. If this electricity is derived from imported oil, then the fuel economy per mile of crude oil becomes 1.6 to 2.2 kWh per mile using crude oil electricity. This number is only a little better than that of the internal combustion engine.

However, if we use wind or other renewable energy, we only need to generate one-fifth to one quarter of the amount of energy imported from crude oil. Clearly, electric cars in Hawaii will be much more beneficial if the electricity generated is from solar or wind.

We conclude that electric cars are not useful for the Hawaiian society unless the electricity is derived from solar, wind, or other renewables. Otherwise, they are of little benefit to offsetting fossil fuel use in Hawaii.

Residential, Commercial, and Industrial Energy Use

The total number of housing units in Hawaii in 2007, including private homes and apartments, was 506,737.[5] From the EIA, the total amount of oil energy imported for the residential sector in 2007 was about 38 trillion Btu. When this energy is converted to electricity at 40 percent efficiency, this results in 4 billion kWh per year. Based on the number of residential units, the average home uses 18.5 kWh per day, assuming the transmission efficiency is 80 percent.



The total number of firms in 2002 was 99,224, according to the US Census Bureau.[6] Assuming twenty percent of these firms are classified as industrial and the other eighty percent are classified as commercial, there are 19,845 industries and 79,379 commercial firms.[7] From the EIA, the total amount of oil energy imported in 2007 for the industrial sector was about 68 trillion Btu, and the total amount of oil energy imported for the commercial sector was about 42 trillion Btu. Assuming the electricity efficiency for firms is the same as the efficiency for residences, i.e. the conversion efficiency 40 percent and the transmission efficiency is 80 percent, then the average industrial firm in Hawaii uses 912 kWh per day and the average commercial firm uses 136 kWh per day.

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[5] http://quickfacts.census.gov/qfd/states/15000.html

[6] http://quickfacts.census.gov/qfd/states/15000.html

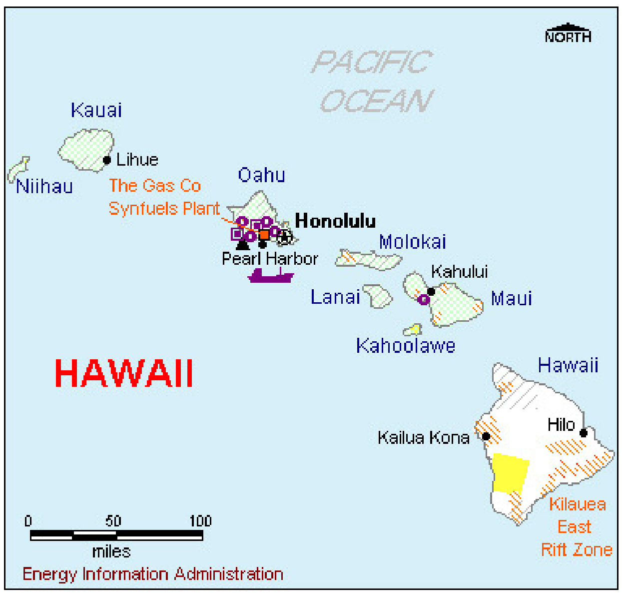
[7] We are assuming that industry is volume manufacturing and that commercial is primarily sales.

Jet and Shipping Fuel

Jet and shipping fuel represent the balance 10.7 million barrels of oil a year, amounting to roughly a quarter of all imported oil to Hawaii. This large fraction is the result of Hawaii's large amount of aircraft traffic. Since we are looking at making Hawaii energy independent except for aircraft and shipping energy, we will not include this in our analysis.

Choosing a Typical American State

We are choosing Hawaii because it is a self-contained island in which all modern energy is imported, with data for

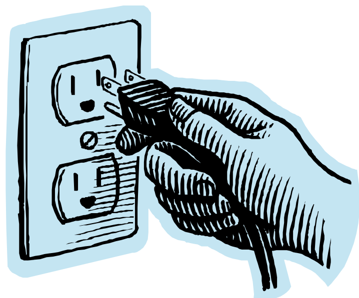


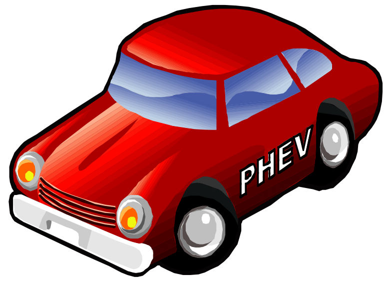
how much is imported and how it is used. We know that nearly all Hawaiian electricity comes from fossil fuels.

We realize that the state of Hawaii has some of the lowest per capita energy consumption in the United States, which makes it an ideal place to start the conversion to renewable energy.

Introducing the Plug-In Hybrid Concept for Transportation

In the above section, we talked about switching transportation from use of gasoline to use of electricity. The question is how to do this without impacting a change in our current energy distribution infrastructure. The energy infrastructure is ninety percent made up of household electric plugs at 120 volts and 15 amp circuits (or 1.8 kW), as well as gasoline and diesel stations.

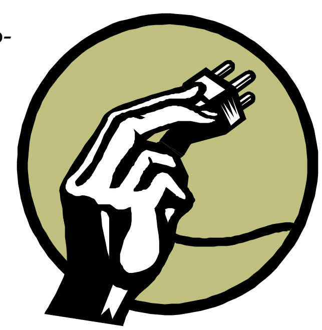




We will show that we can transition from gasoline or diesel to electricity using the plug-in hybrid electric vehicle (PHEV). UC Davis has constructed plug-in hybrids for the past thirty years, but Toyota and General Motors are just now introducing plug-in hybrids into the marketplace. General Motors calls their PHEVs extended range electric vehicles, or EREV, and Toyota calls their vehicles PHEVs. The concept of the plug-in hybrid is being introduced by all major car companies. We will show in more depth how to use the plug-in hybrid to transition society from gasoline and diesel to renewable energy.

The plug-in hybrid has the capability of using wall-plug supplied electricity to charge the batteries while it is parked, as well as the capability to use gasoline or liquid fuel if necessary. Because the average car is only used three hours per day, it is therefore parked for twenty-one hours a day. During this time, the batteries can be charged by using conventional 120 volt wall sockets at 1.8 kW per socket. This is possible because the average PHEV driven twenty miles a day will require a maximum of only 10 kWh, and this can be obtained from the wall in about six hours. For long trips, the PHEV can run on liquid fuels derived from bio-sources or gasoline, making gasoline and coal-fired electricity backup energy sources. This strategy shows that we can transition to electric energy transportation in one step, without any sacrifice in the way we use automobiles and conduct commercial business.

If renewable electric energy and biofuels such as plant-grown biodiesel or ethanol are used, no gasoline will be needed for transportation. Thus, a specification for a PHEV to benefit society is the following:

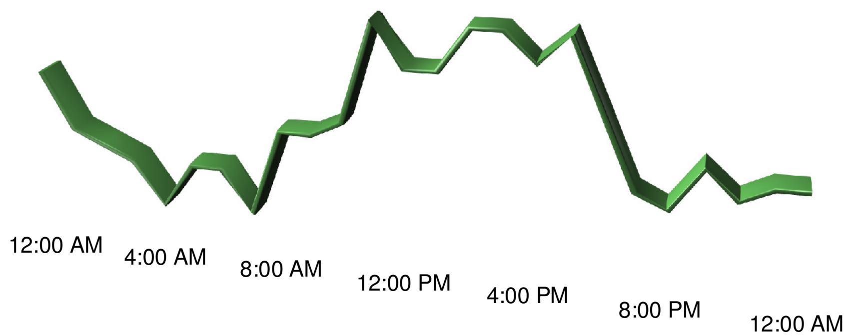


> The car should be capable of running on electricity for daily driving. In the continental United States, the average miles driven per day is thirty miles. In Hawaii, this number is likely to be smaller. The Chevrolet Volt has an all-electric range of forty miles, and the proposed Toyota Prius plug-in hybrid has an all-electric range of twelve to fifteen miles. Both cars can be used in Hawaii using only electricity if they are plugged in every time they are parked. The advantage would go to the plug-in hybrid Prius because if the daily travel is less than thirty miles, the maximum one-way trip is around fifteen miles. The objective is to replace gasoline with electricity, which can be done with a car with forty miles all-electric range plugged in once a day, or a car with fifteen miles all-electric range plugged in twice a day. In Hawaii, the average mileage is about twenty miles per day, which would require roughly six kilowatt-hours per day charging once per day. If we plug the car in every time we park, the car can have an even smaller all-electric range. In addition, since all cars should be capable of running on high-percentage biofuels in the future, then we can easily have a society that runs on electricity supplemented by a small amount of biofuel with no fossil fuel at all.

Solar and Wind Charging

We can derive renewable electricity from either solar or wind, but wind is less expensive than solar and Hawaii has an abundance of wind. For Hawaii, we will focus on wind power, but other locations in the world may focus on solar or combinations of solar and wind power.

Hourly Wind Speeds for Honolulu 8/28/09



From the National Weather Service, we created a graph of the wind speeds on a typical day in Honolulu.[8] From this information we can calculate the total number of kilowatt-hours needed to replace oil on the island. This information gives the wind speed from which we want to calculate the amount of wind turbine power needed to satisfy the daily electrical load and transportation electricity in all of Hawaii.

Wind generation can be done both locally and centrally. Local wind turbines would be installed on homes, businesses, and industries. Central wind farms would be installed in remote areas with more steady prevailing wind.

From the above energy use calculations, wind would have to supply about 38.7 million kWh per day for homes, businesses, and industries. If the average distance a car goes is 20 miles per day and the average of all car sizes uses 0.3 kWh per mile, the overall average use will be 6 kWh per day. Including trucks, this number will increase to about 7 kWh per vehicle per day. This means that the amount of energy used by all 1.13 million vehicles per day will be about 8 million kWh. Adding this number to the amount of energy used by homes, businesses, and industries, the total amount of energy needed to be generated by wind each day is 46.7 million kWh.

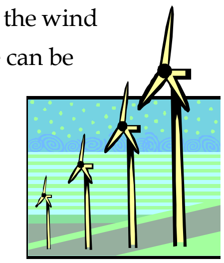
Since all of this energy needs to be generated by wind, we have to calculate the number of wind turbines needed to generate all 46.7 million kWh. This number divided by 24 hours gives an average power of 1.95 million kW needed. From our wind profile data, we find that the average wind speed is 10 miles per hour and the peak is 17 miles per hour. According to the power curve data from a Northwind 100 turbine, we find that the wind turbines can be sized

[8] http://www.weather.gov/data/obhistory/PHNL.html (National Oceanic and Atmospheric Administration NOAA)

for average speed of about 10 miles per hour.[9] Around the average speed, the power varies linearly with wind speed. The variation of wind energy is about 17 percent. This data will allow us to size the number of wind turbines needed to supply the entire electrical needs of the island, including transportation.

There have to be enough batteries in PHEVs to store 17 percent of the 46.7 million kWh, which is about 8 million kWh. 8 million kWh divided by 1.13 million vehicles is about 7 kWh per vehicle. The Chevrolet Volt has 15 kWh of batteries, more than enough for a car that uses 6 kWh per day and stores 7 kWh of wind energy.

The average wind power is 1.95 million kW, and the peak power is 70 percent more according to the wind profile. This gives a peak wind power of 3.3 million kW. If we assume that a small 2 kW turbine can be installed on each home, homes will produce approximately one million kW in total. If we assume that a 10 kW turbine can be installed on each firm, and there are about 100,000 firms, the firms will generate another million kW in total. The remaining amount of wind power needed, 1.3 million kW, can come from wind farms with 1 MW wind turbines.



If we want to install all of these turbines in fifteen years, which is our suggested roadmap, this means that we should construct 87 one MW wind turbines in wind farms per year, 33,000 two kW wind turbines for homes per year, and 7,000 ten kW wind turbines for firms per year. This then sets the policy to convert the entire island of Hawaii to wind power in fifteen years, including transportation, homes, business, and industry.

PHEV Energy Storage Requirements and Numbers for Hawaii

There are 1.13 million vehicles in Hawaii, and if we are to convert all of them to PHEVs, we would have to replace the vehicle fleet at the rate of 75,000 vehicles per year. This implies about 75,000 Chevrolet Volts per year.

The Chevrolet Volt has a 15 kWh battery, and people on the island travel about 20 miles a day using 6 kWh. We calculated above that each of these vehicles would have to store about 7 kWh of wind energy and then give back to the grid about 7 kWh of electric energy. In the worst case, if the travel energy and the wind energy happen to coincide, we would need to store about 13 kWh of wind energy in the batteries. This is well within the 15 kWh capability of the Chevrolet Volt. In the best case, when the wind variation and the travel energy use dovetail, a much smaller battery pack could be used. Because the wind blows most during the day when the car is being used, this reduces the amount of battery required from 13 kWh to a much smaller number. This means that a smaller battery PHEV such as the Toyota Prius may well be a better choice for a vehicle to transition Hawaii off of fossil fuel.

The PHEV can thus be used to level wind power and supply electric energy for all of society. Since the batteries in the PHEV were paid for by the customer of the PHEV and he or she is supplying energy for all of society, the use of those batteries should be paid for. Our suggestion is that perhaps the electric energy used from the central electric system should be given to the PHEV free of charge. This means that the PHEV could conceivably travel daily with no cost for energy.

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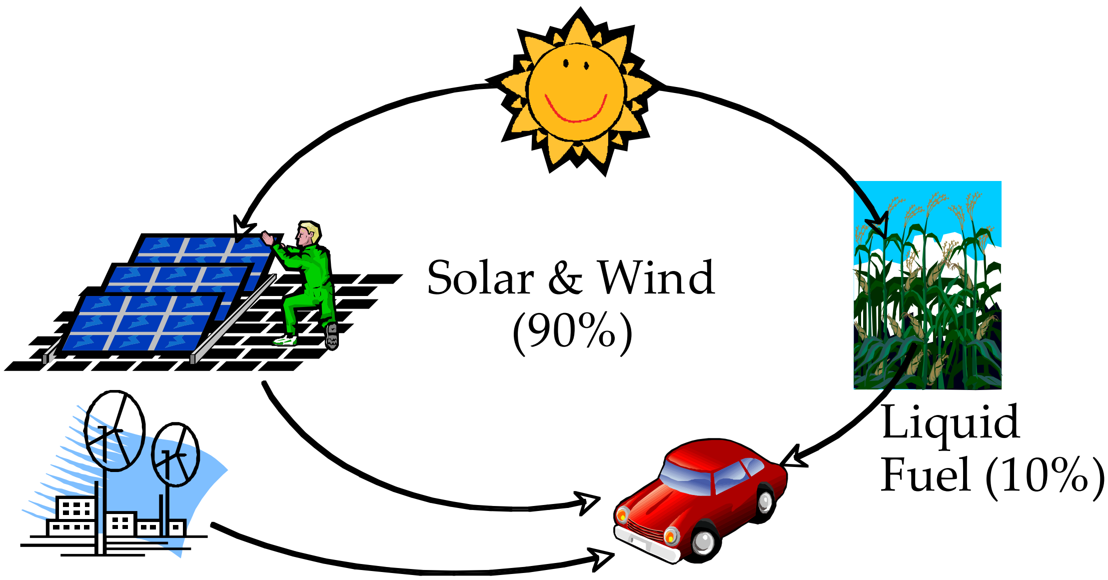
[9] http://energyconcepts.us/wp-content/uploads/2008/09/nwind100_specs.pdf

The PHEV uses a minimum amount of batteries but is more efficient than a regular hybrid (HEV) because it can be designed with a smaller engine due to its larger battery pack and electric motor. The PHEV not only uses electric energy, but when using liquid fuel it consumes less than one half the liquid fuel used by conventional cars.

PHEV Integrated into the Society

In this section we will discuss the advantages of the plug-in hybrid for society. We want to show that it is the starting point for transforming society from fossil-fuel use to using renewable electricity. To begin our discussion, we will discuss the features of the plug-in hybrid that distinguish it from conventional cars and all-electric cars or battery-electric cars (BEV).



The PHEV can use either electric energy or liquid fuel energy, and is not dependent on a single energy source as the conventional car is dependent on gasoline and the BEV is dependent on electricity. These single-energy source vehicles cannot run if the energy source is not available. On the other hand, the PHEV can run on either available energy source, and the switch from electricity to liquid fuel can be done automatically. This dual fuel capability can be extended to renewable electricity and biofuels. Biofuels are practical in the PHEV because the PHEV only uses 10 percent liquid fuel and 90 percent electricity from the existing grid or directly from renewable energy sources such as solar and wind. The advantage of the PHEV is that we can grow the small amount of biofuels needed for it whereas we cannot grow the large amount of biofuels needed for conventional cars because the PHEV uses less than 10 percent of the fuel used by the conventional car.

The PHEV can be charged by the conventional electric grid or directly by solar or wind. If it is charged by solar or wind, the solar or wind generator should be hooked to the home, industry, or grid so that if the vehicle is not parked and charging or if it is fully charged, the wind generator or electricity can then be used directly to supply power to the home or industry, or to others on the grid.

We will discuss the efficiency of using wind and solar electricity in a PHEV for transportation compared with using grid electricity for charging. Grid electricity in Hawaii is currently generated from fossil fuel. We calculated above that it takes about 2.57 kWh of fossil fuel electricity to drive an electric car or PHEV one mile. However, if solar or wind is used to charge the batteries, it would only take 0.3 kWh to drive that same car one mile. This means that solar or wind generation is eight times more efficient and effective than using fossil-fuel derived energy. Therefore, we only need to generate one-eighth the energy currently imported for automobiles.

Using the PHEV to make Hawaii Independent from Oil

In this section we will show how the plug-in hybrid will be the base for making the state of Hawaii energy independent. From the calculations above, we find that we have to store 17 percent of 46.7 million kWh, or about 8 million kWh, and we divided this number into 1.13 million vehicles, each storing about 7 kWh. This amount of energy will be absorbed when the wind is blowing at its highest, and given back to the grid when it is at its minimum. This energy cycling may occur at any time during the day or night through the bidirectional charger mentioned in the introduction. In this way, the amount of energy available on the general electric grid is stabilized by the PHEV batteries, creating a constant supply of electric energy to meet Hawaii's daily needs. For this to happen, we require ultimately that every vehicle in Hawaii be a PHEV. Assuming cars are replaced every fifteen years, if we begin today we can replace the entire fleet of conventional cars in Hawaii to PHEVs in fifteen years.

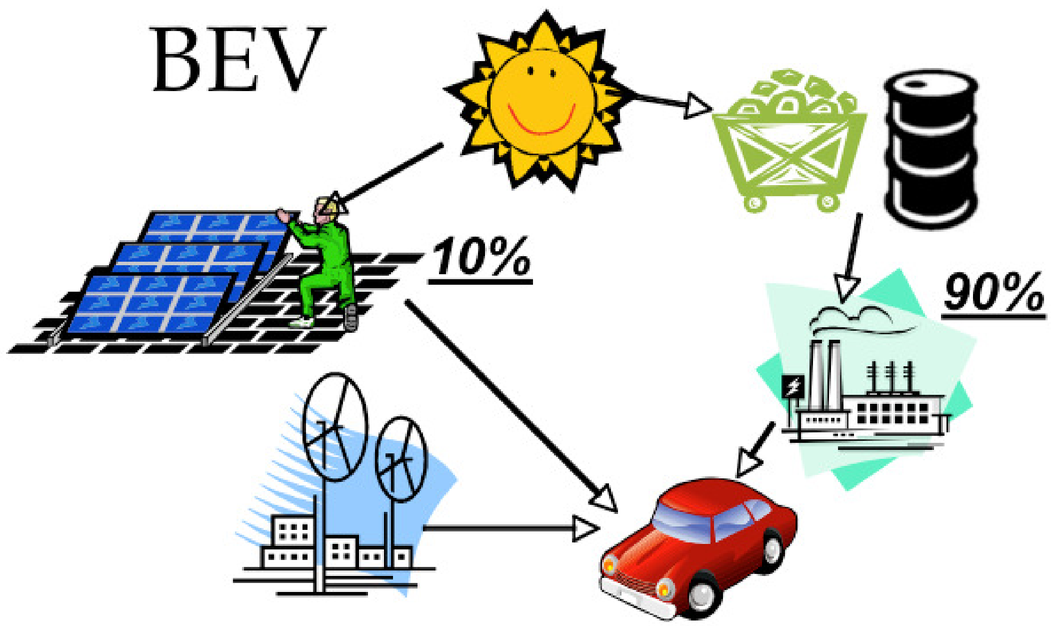
Our strategy will be to import into Hawaii as many PHEVs as we can. These PHEVs will come with different battery sizes, some with a fifteen mile all electric range and some with as much as a forty to sixty mile range. Some examples are the Chevrolet Volt with a forty mile all electric range and the plug-in hybrid Toyota Prius with a twelve to fifteen mile all electric range. Other companies may introduce other variations. We anticipate that a typical home will have two PHEVs, one with a short range, which is used around town, and one with a long range, used for a daily commute to and from work. By buying two vehicles of different battery size, we will minimize the upfront costs of the PHEVs. With two such vehicles, renewable energy generators can be distributed according to each vehicle's energy needs, so perhaps the short range vehicle can be charged at home while the long range vehicle is charged at work.

These vehicles can be integrated into the existing vehicle fleet a year at a time, or continuously over a fifteen-year period, and the rate of introduction will generally be equivalent to vehicle replacement times. In other words, the public would not replace an existing vehicle until it is worn out, which is about fifteen years. This rollout period for the plug-in hybrid replacing the entire fleet in a fifteen year period is reasonable due to the buying habits of the public and the life of the cars.

The Advantages of the PHEV Over Other Alternative Energy Vehicles

Battery Electric Vehicles (BEV)

As mentioned above, the BEV is a single energy source vehicle. It uses only batteries, and may have between three and ten times as many batteries as a PHEV. The cost of these batteries makes the BEV much more expensive than a PHEV. In addition, the BEV due to its single energy source will be required to charge quickly. This means high powered charging systems must be distributed in society. This high power charging infrastructure can be very costly. When choosing the ideal vehicle to transition society, we have to keep in mind our goal of displacing oil as quickly as possible. The BEV cannot displace oil as quickly as the PHEV because its upfront cost will be so high due to the batteries. Additionally, battery material is rare at this moment. We can build as many as ten times as many PHEVs as BEVs with the same amount of battery material, therefore displacing up to ten times more fossil fuel using PHEVs



than BEVs.

Due to the fact that BEVs will frequently require fast or high-power charging, which cannot be done by solar or wind electricity, the amount of energy from solar or wind that a BEV uses will be low by comparison to fossil-fuel generated electricity.

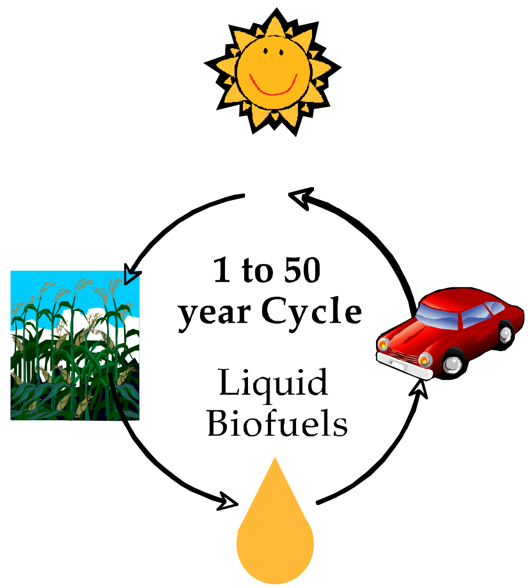
One BEV concept, called battery swapping, makes the battery supply problem even worse, because one battery pack must be in the car while another is charging, requiring more than twice as many batteries. This means that the PHEV will displace up to twenty or more times the amount of fuel as a battery swapping BEV.

Natural Gas Vehicles

The natural gas vehicle uses natural gas, which is a fossil fuel, making the vehicle not a truly CO_2 free concept. Of course, the natural gas can be derived from biological sources and from that standpoint it could be considered a renewable energy. However, there is no infrastructure to create the amount of natural gas to power very many cars at this time.

Liquid Biofuel Vehicles

Conventional cars use up to ten times more liquid fuel than a PHEV. To grow and refine this much liquid fuel is unreasonable because we will be displacing land for food production, creating a severe impact on society and driving the cost of food up to unaffordable levels. Using biofuels for conventional vehicles is not sensible unless we can reduce the amount of biofuels needed by an order of magnitude. There are some vehicles, such as aircraft and long-haul trucks, where liquid fuels cannot be substituted. We should grow the amount of liquid fuel needed to supply these applications as well as all PHEVs.



Liquid biofuels are perfect for the PHEV as a replacement for gasoline or diesel. This is because the PHEV uses only 10 percent or less of liquid fuel and the current reformulated gasoline in the United States is already 10 percent biofuel. This means we wouldn't have to alter our source of biofuels to begin the introduction of PHEVs. Because the biofuel supply is already stabilized, we would not be affecting food production either.

Hydrogen-Powered Vehicles

The first problem with hydrogen-powered vehicles is energy density of storage, because hydrogen is such a light material that it is difficult to store large amounts of its energy in a given space and a given weight. Hydrogen cannot compete with liquid fuels in energy density. The PHEV is both a BEV and a conventional car, so it has the advantages of both while having none of the disadvantages. If hydrogen is generated from renewable energy, we lose a large amount of electricity to the hydrogen-generating process rather than using the electricity directly in a PHEV or BEV. We then have to compress and store the energy and use the hydrogen in either an internal combustion engine or a fuel cell. When we multiply and add up all the losses we find that the electricity used for driving a vehicle in the hydrogen path will only go one-eighth as far as electricity used to charge batteries in a PHEV. The hydrogen vehicle can be constructed but it suffers from several technologies that are not yet here: the generation of hydrogen, the storage and transportation of hydrogen, the cost of a hydrogen engine itself, and the distribution of hydrogen. All these problems must be solved to make hydrogen an effective pathway for energy.

Conclusion

In this paper, we wanted to show that we can take a modern American state and transform it to a sustainable energy society within a period of fifteen years. To do this, we found a state where data had been collected that was clearly defined in terms of the amount of energy imported and the way that energy was used. From the EIA website, we found that the total amount of energy imported into Hawaii per year is 344 $x10^{12}$ (trillion) Btu, or about 97.4 $x10^{9}$ (billion) kWh. That energy is divided into the residential (10.8 billion kWh), commercial (12.5 billion kWh), industrial (20.8 kWh), and transportation (53.2 billion kWh) sectors.

For transportation we have separated out jet and shipping fuel. Of the amount of petroleum imported, 21 percent is used for motor gasoline, 17.6 percent is used for distillate fuel, 0.8 percent is used for liquefied petroleum gases, 24 percent is used for jet fuel, and the remaining 38 percent is lost to process heat and products such as plastics and road building material. Only 21 percent of the total amount of petroleum imported ends up useful for ground transportation in Hawaii. To calculate the number of kWh needed to transport vehicles from this fuel, we looked at the data from the EIA website. We know the total gallons used by all vehicles in Hawaii each year is 476.6 million, and there are 1.13 million total vehicles, so the average car uses 422 gallons per year. Assuming the average vehicle drives 7,500 miles per year, the average fuel economy is 17.78 miles per gallon. Assuming the gasoline refining process from crude oil is 87 percent efficient, this results in 15.74 miles per gallon of crude oil as the actual average efficiency. This amounts to 2.57 kWh per mile for the average vehicle from crude oil. We know from electric vehicle experiments that the average electric vehicle uses about 0.3 kWh per mile.[10] We conclude that we have to generate less than one-eighth of the number of kWh of energy imported for creating gasoline. If we are to power all vehicles by renewable electricity, we only need to generate one-eighth of the 19.3 billion kWh currently from imported oil. So, only 2.4 billion kWh of electric energy are needed.

The residential, commercial, and industrial sectors use electricity from oil that is about 32 percent efficient, taking into account 40 percent efficient generation and 80 percent efficient transmission. This means that the total kWh of oil imported for electric generation is three times more than what is actually used, so we only need to generate by wind 14 billion kWh per year, one-third the amount of kWh from imported oil. Thus the total electricity from renewable sources needed for transportation, residential, commercial, and industrial is 16.4 billion kWh per year for the entire state, without any loss in social performance.

The total amount of electricity needed to be generated is 16.4 billion kWh per year or 46.7 million kWh per day for the entire state. This can be accomplished by installing 2 kW wind turbines on 500,000 homes, 10 kW wind turbines on 100,000 firms, and 1,300 one MW wind turbines in wind farms. Our objective is to accomplish this in fifteen years, which means that we need to install 2 kW wind turbines on 33,000 homes per year, 10 kW turbines on 7,000 firms per year, and 87 one MW wind turbines in wind farms per year. This is doable through investment by the government and the electric utility companies.

We calculated above that the Chevrolet Volt with 40 miles all electric range and 15 kWh of batteries is more than enough to satisfy the needs of Hawaii. To accomplish a sustainability in Hawaii in 15 years we would have to sell 75,000 vehicles per year. From the above calculations, we showed that the maximum daily wind variation was 7 kWh. If the wind and the travel habits are coordinated, then a PHEV with minimum energy storage of 7 kWh could be used for Hawaii. This is very close to the Toyota Prius PHEV. We conclude that PHEVs between the proposed Toyota Prius PHEV with 5 kWh and the Chevrolet Volt with 15 kWh would be adequate for Hawaii and can be used to balance the wind load and provide steady power to the entire island of Hawaii in fifteen years.

What we have shown in this paper is that we already have the technology to transfer our society off of fossil fuels within fifteen years, if we have the will to do so. If Hawaii can become completely sustainable and fossil fuel-free, so

[10] Tesla claims about 0.2 kWh per mile

can any city, state, or nation. Using clean, renewable energy combined with the plug-in hybrid, we can simultaneously solve the imminent problems of climate change and the peak in oil removal.

Reference Material

[3,4] **US Energy Information Administration Hawaii Data**

http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=HI

[5,6] **Hawaii QuickFacts from the US Census Bureau**

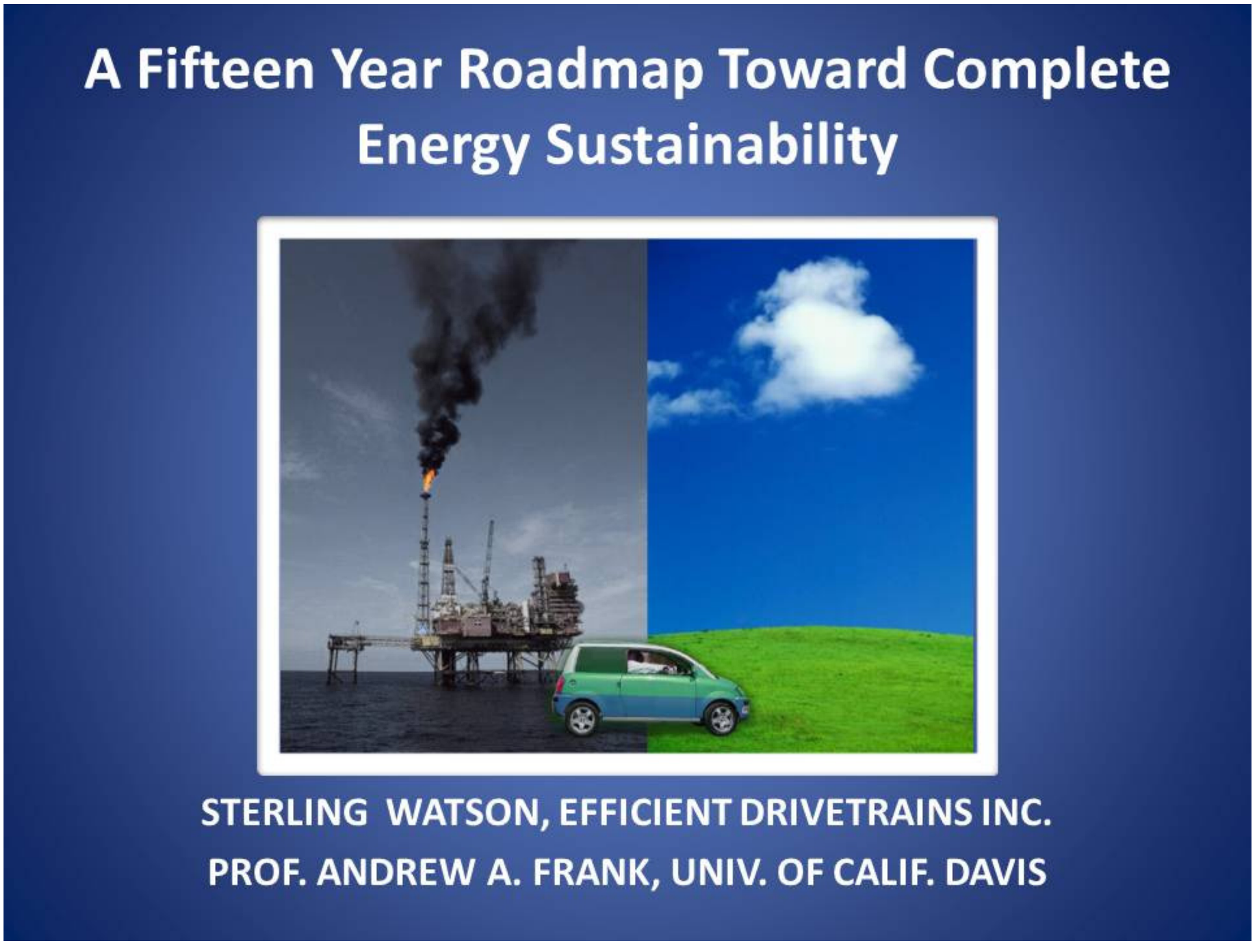
http://quickfacts.census.gov/qfd/states/15000.html

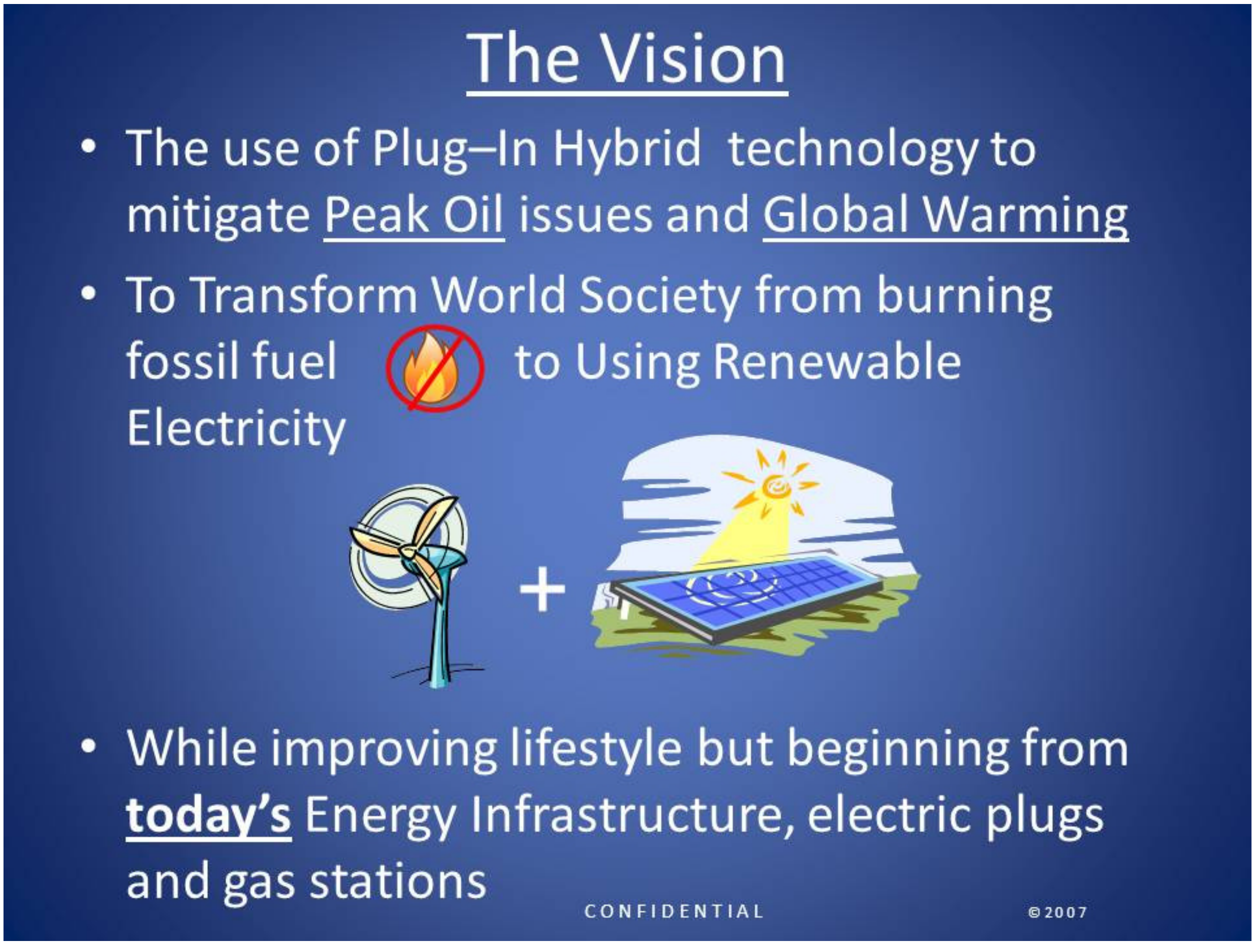
[8] **National Weather Service: Honolulu International Airport**

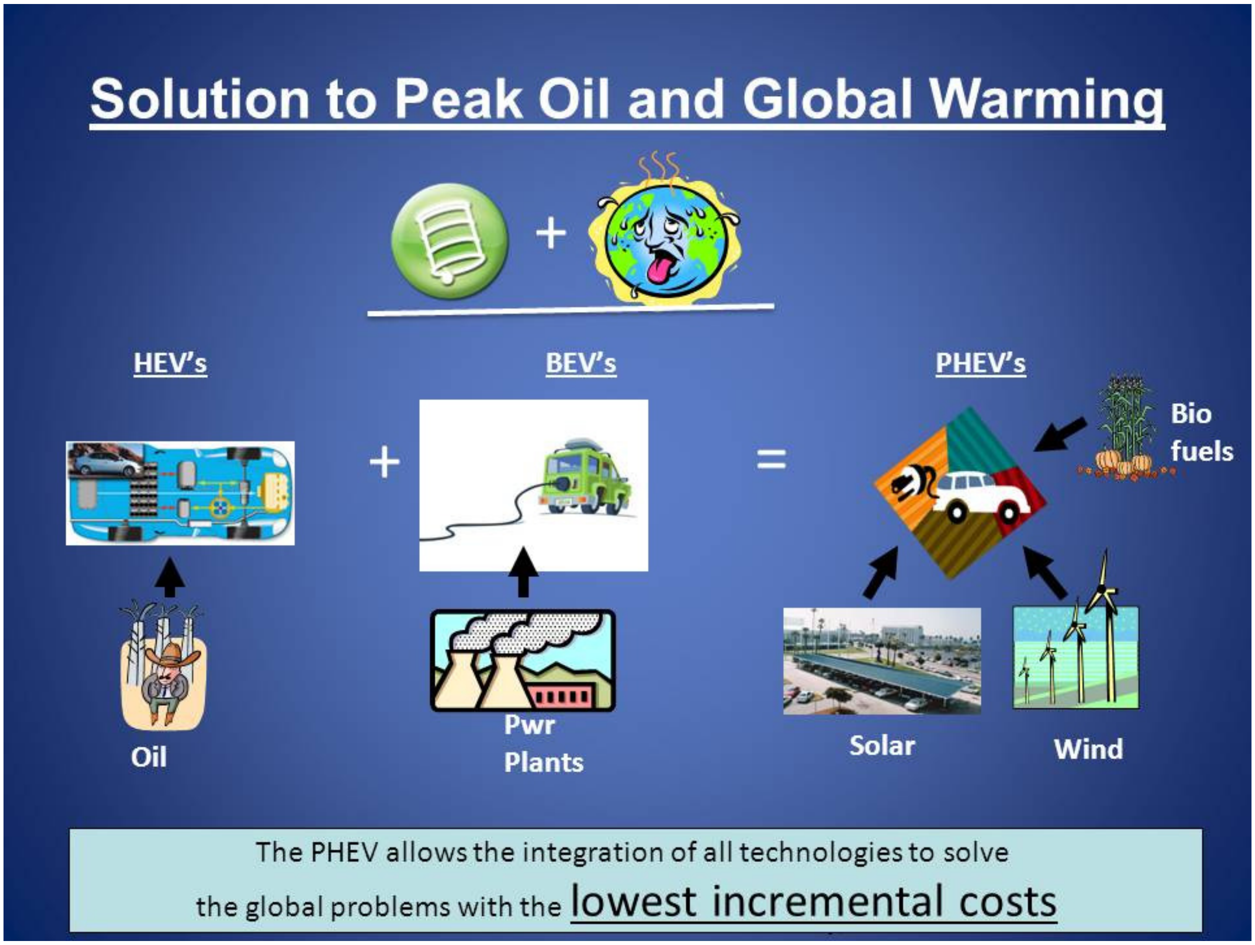
http://www.weather.gov/data/obhistory/PHNL.html

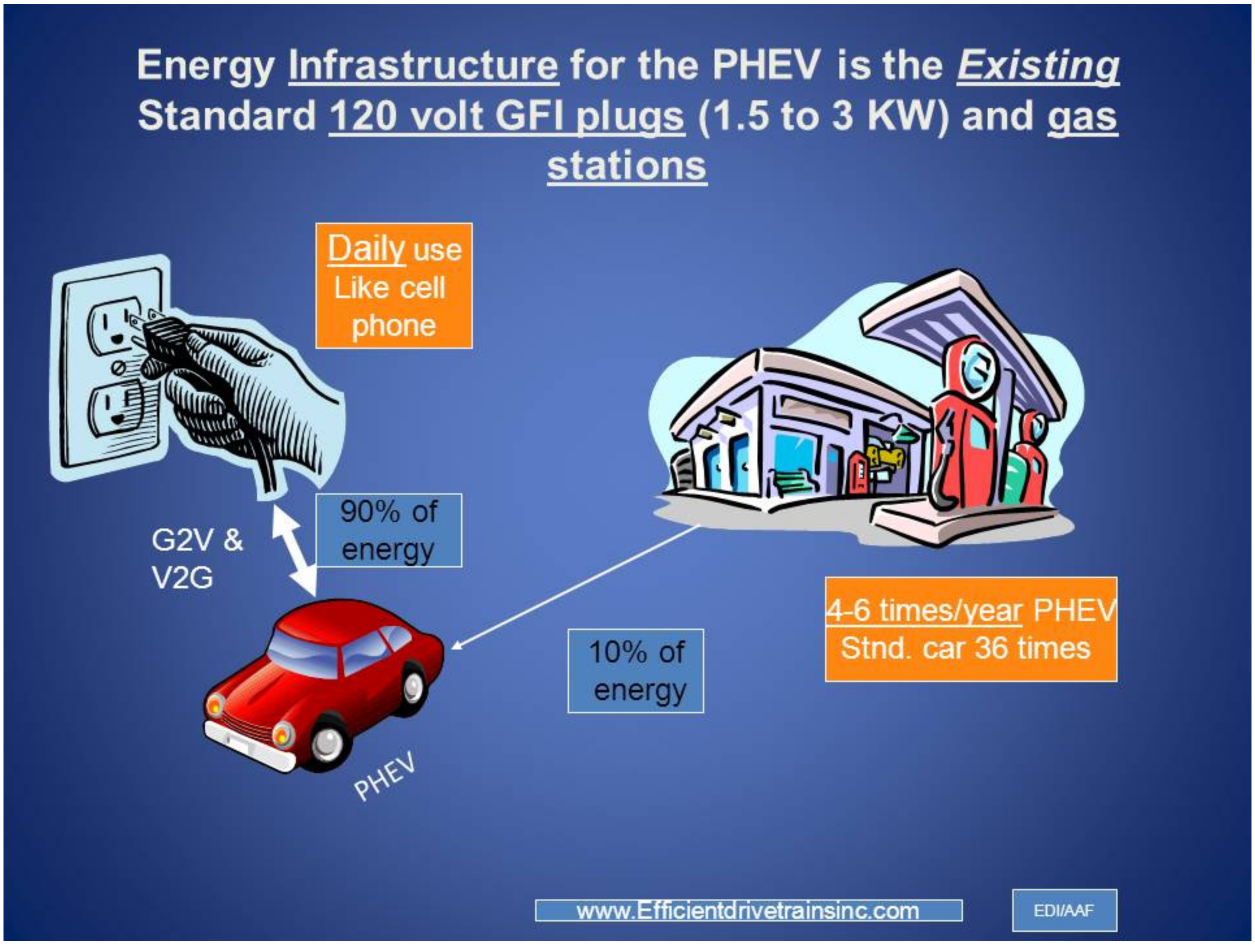
[9] **Northwind 100 Specifications**

http://energyconcepts.us/wp-content/uploads/2008/09/nwind100_specs.pdf

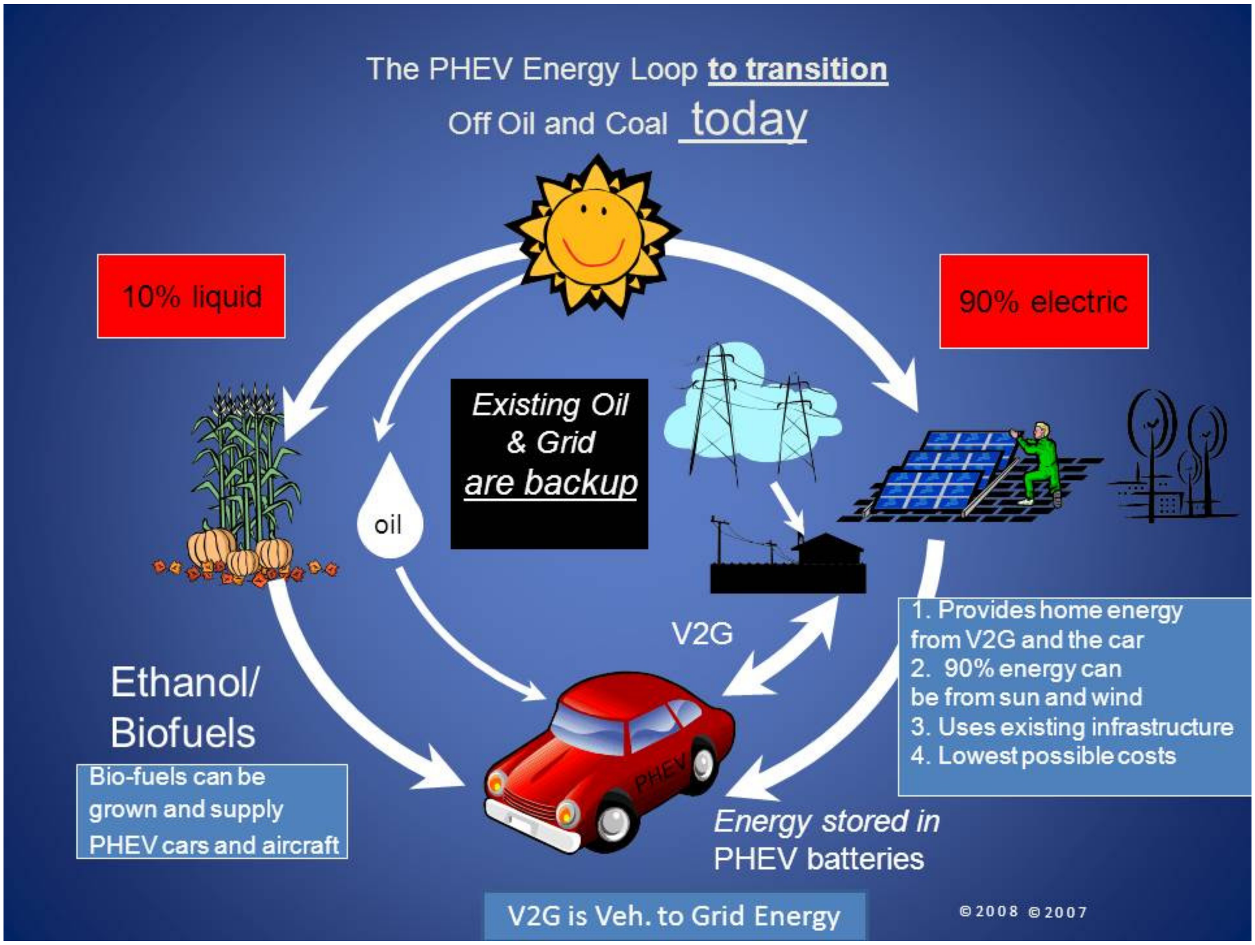

A Fifteen Year Roadmap Toward Complete Energy Sustainability
STERLING WATSON, EFFICIENT DRIVETRAINS INC.
PROF. ANDREW A. FRANK, UNIV. OF CALIF. DAVIS

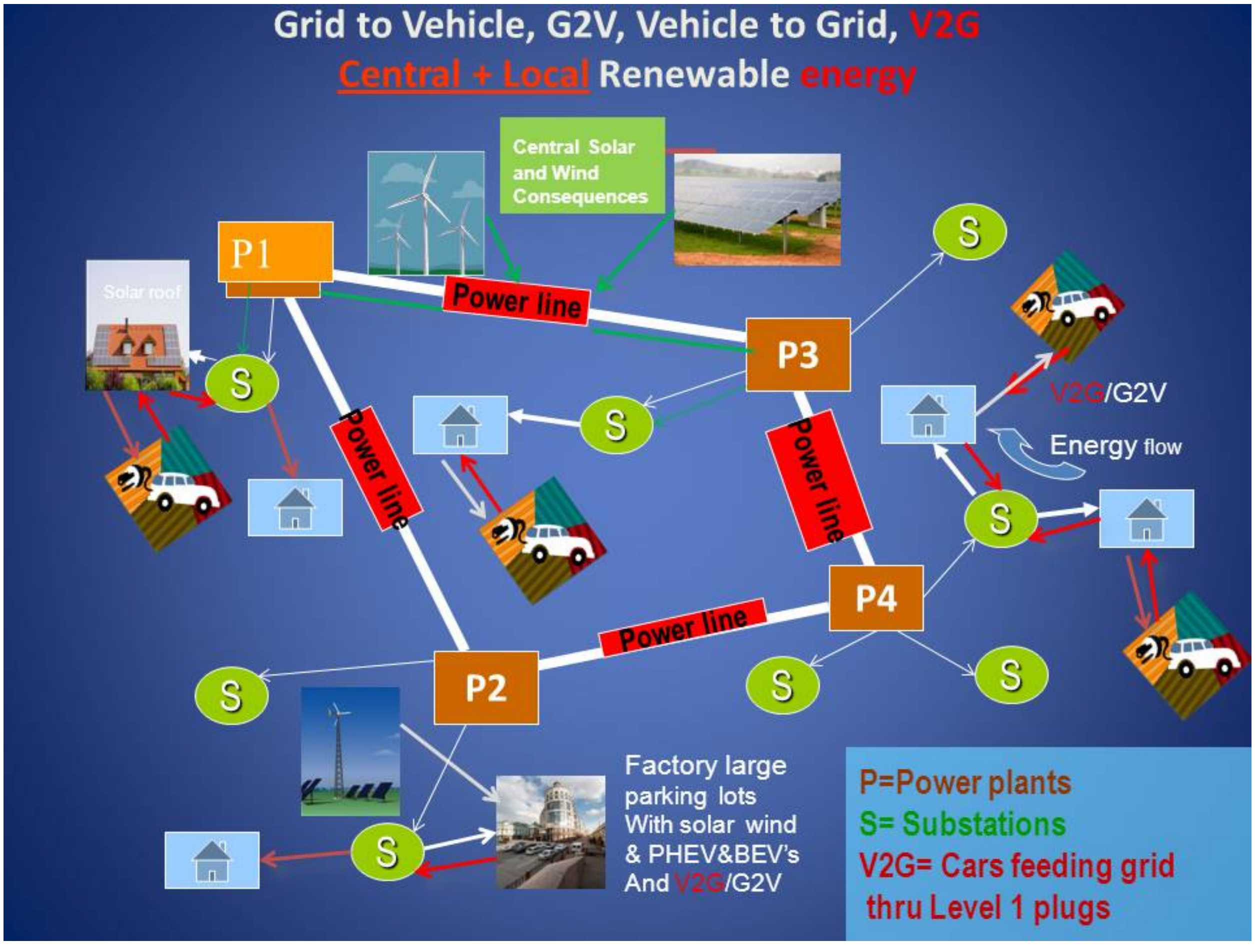

The Vision
The use of Plug–In Hybrid technology to mitigate Peak Oil issues and Global Warming
To Transform World Society from burning fossil fuel to Using Renewable Electricity
+
While improving lifestyle but beginning from today's Energy Infrastructure, electric plugs and gas stations
CONFIDENTIAL
©2007

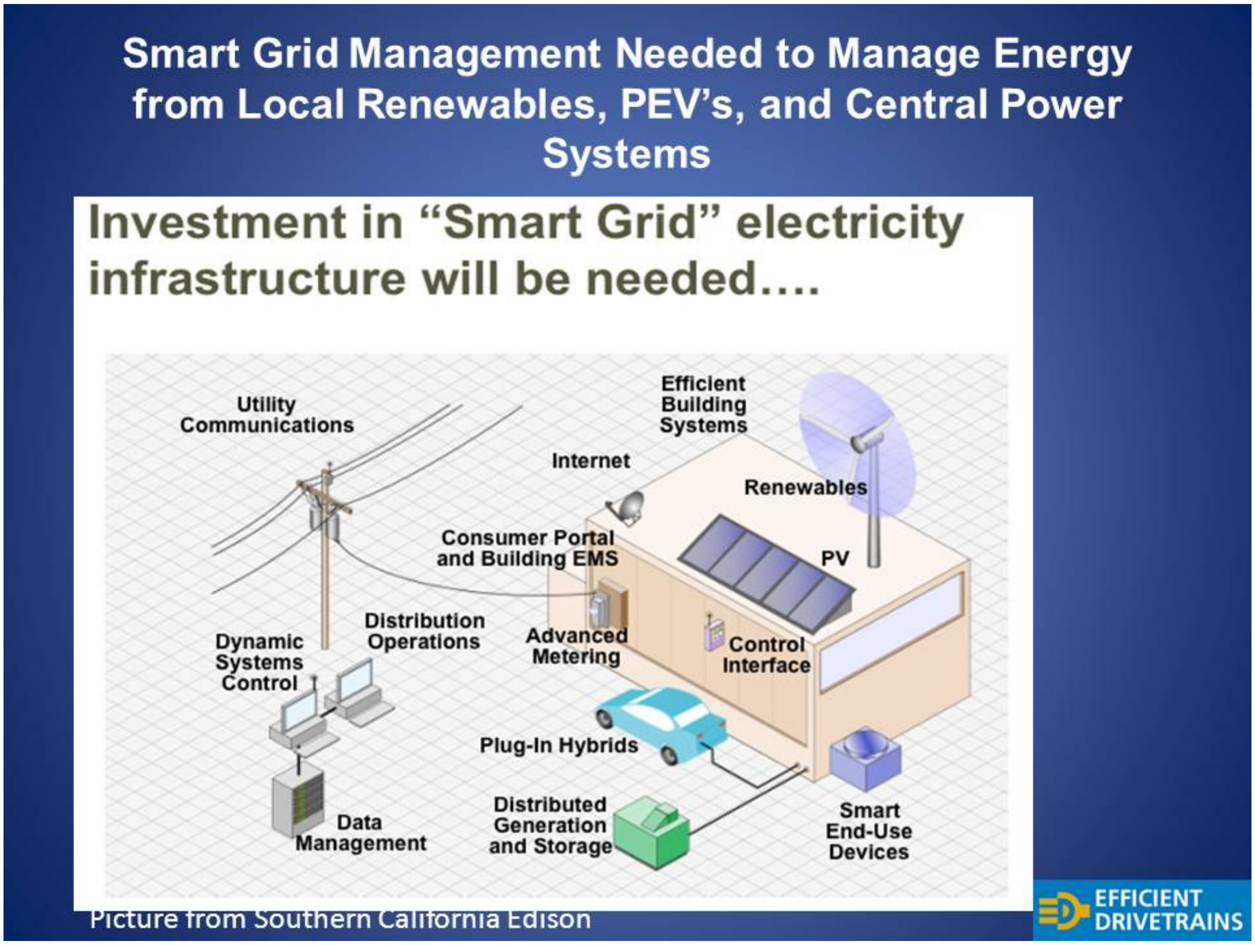

Solution to Peak Oil and Global Warming
+
HEV's
BEV's
PHEV's
+
=
Bio
fuels
Oil
Pwr
Plants
Solar
Wind
The PHEV allows the integration of all technologies to solve
the global problems with the lowest incremental costs


Energy Infrastructure for the PHEV is the Existing Standard 120 volt GFI plugs (1.5 to 3 KW) and gas stations
Daily use Like cell phone
90% of energy
G2V & V2G
PHEV
10% of energy
4-6 times/year PHEV Stnd. car 36 times
www.Efficientdrivetrainsinc.com
EDI/AAF

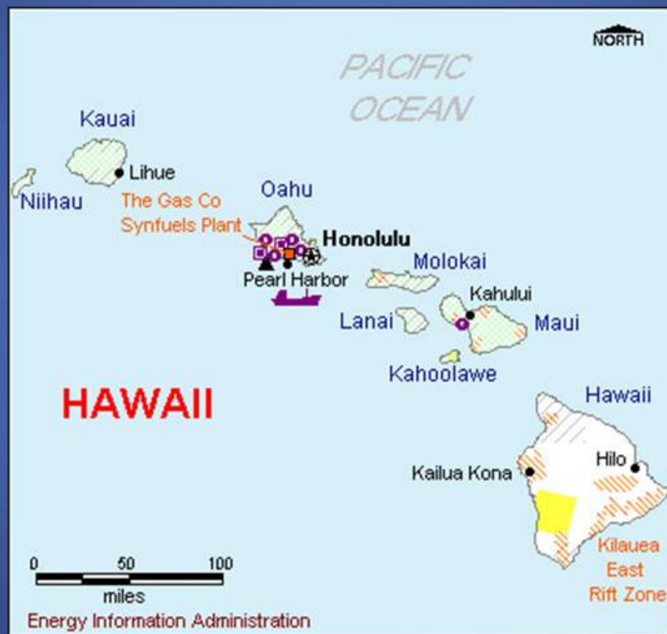

The new Chevy Volt is a PHEV


The PHEV Energy Loop to transition
Off Oil and Coal today
10% liquid
90% electric
Existing Oil & Grid are backup
oil
V2G
Ethanol/ Biofuels
Bio-fuels can be grown and supply PHEV cars and aircraft
1. Provides home energy from V2G and the car
2. 90% energy can be from sun and wind
3. Uses existing infrastructure
4. Lowest possible costs
PHEV
Energy stored in PHEV batteries
V2G is Veh. to Grid Energy
©2008 ©2007

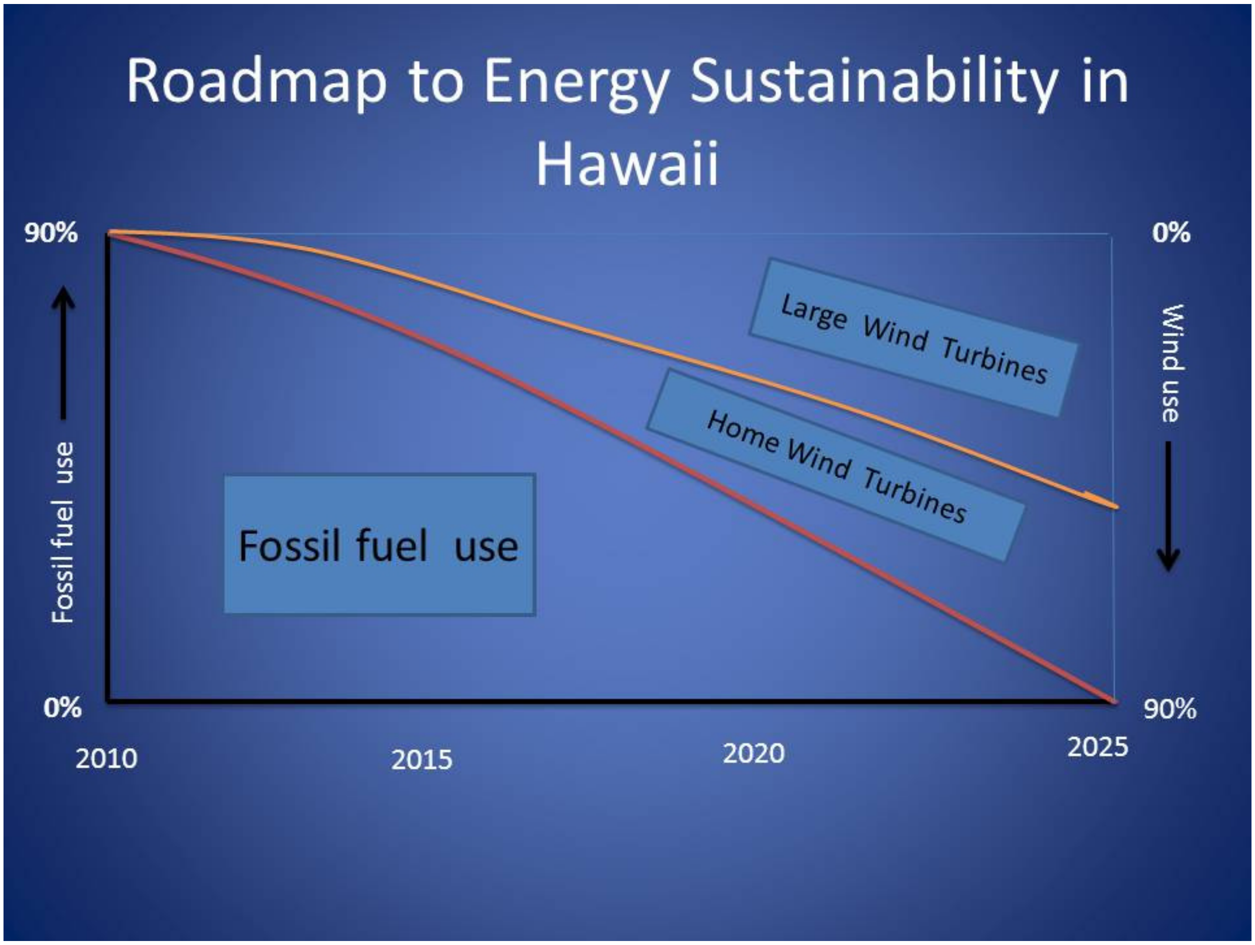

Grid to Vehicle, G2V, Vehicle to Grid, V2G
Central + Local Renewable energy
Central Solar and Wind Consequences
P1
Solar roof
Power line
P3
P2
P4
S
V2G/G2V
Energy flow
Factory large parking lots With solar wind & PHEV&BEV's And V2G/G2V
P=Power plants
S= Substations
V2G= Cars feeding grid thru Level 1 plugs

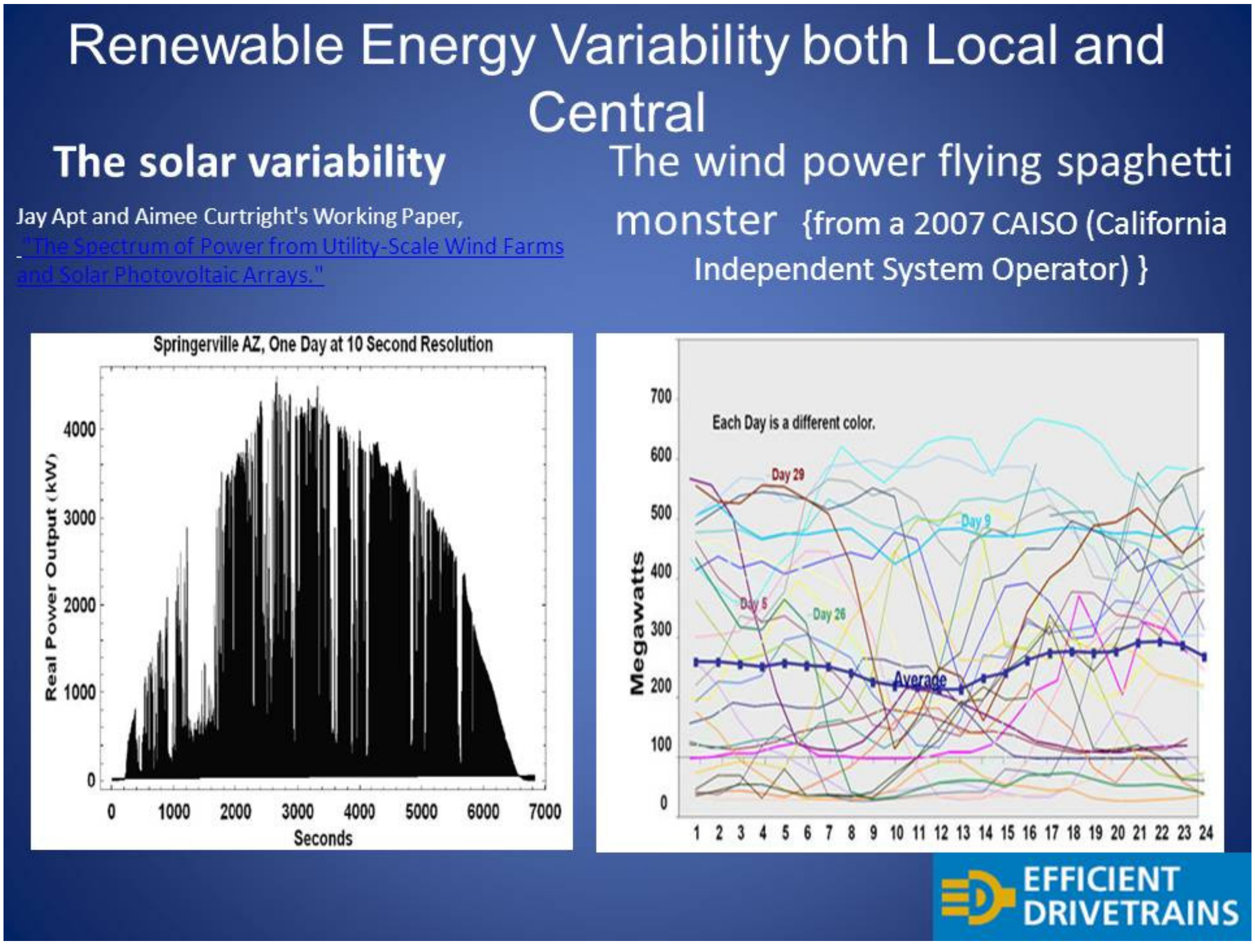

Smart Grid Management Needed to Manage Energy from Local Renewables, PEV's, and Central Power Systems
Investment in "Smart Grid" electricity infrastructure will be needed….
Utility Communications
Efficient Building Systems
Internet
Renewables
Consumer Portal and Building EMS
PV
Distribution Operations
Dynamic Systems Control
Advanced Metering
Control Interface
Plug-In Hybrids
Data Management
Distributed Generation and Storage
Smart End-Use Devices
Picture from Southern California Edison
EFFICIENT DRIVETRAINS

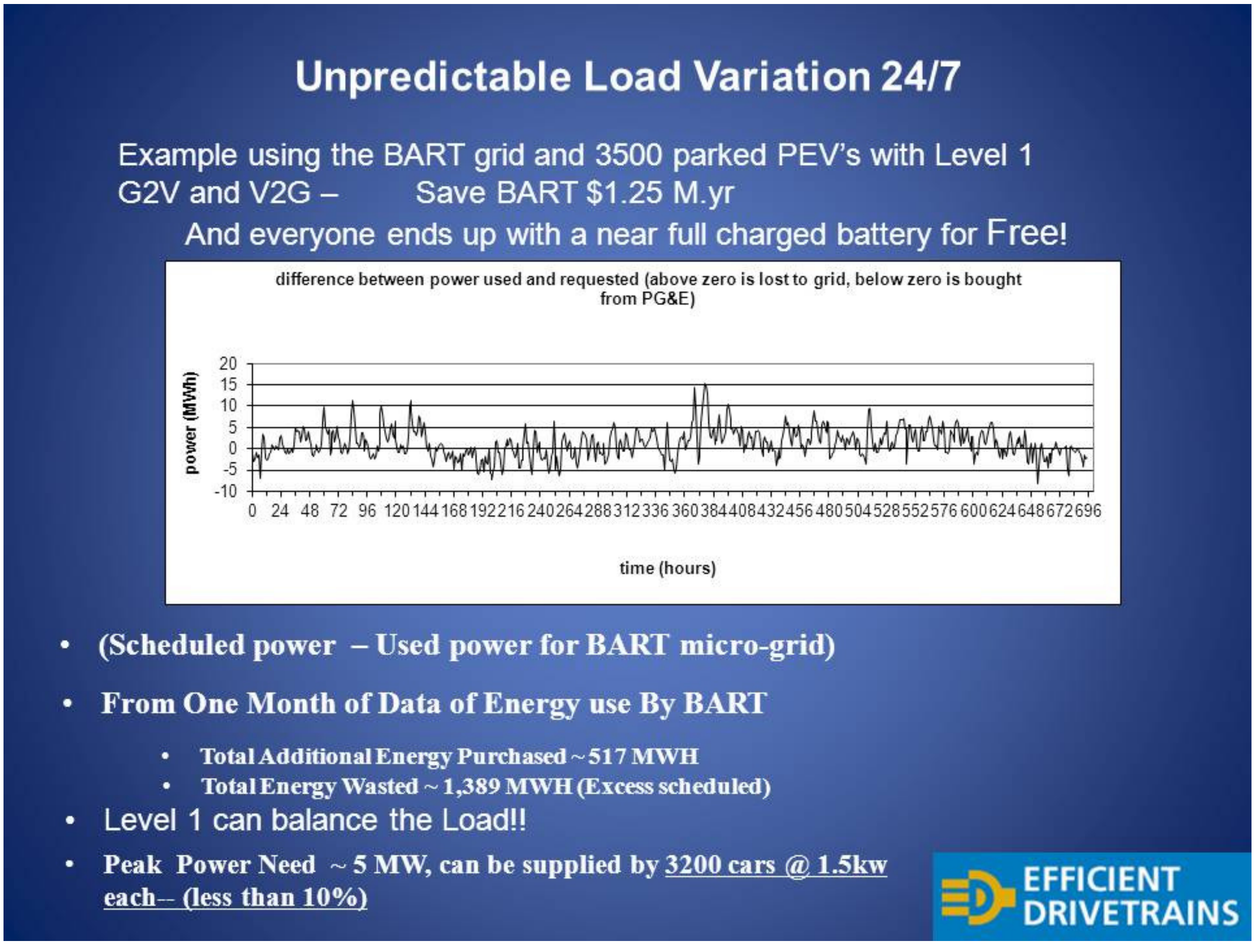
Islands of Hawaii – 90% of all energy consumed is from imported fossil fuel today

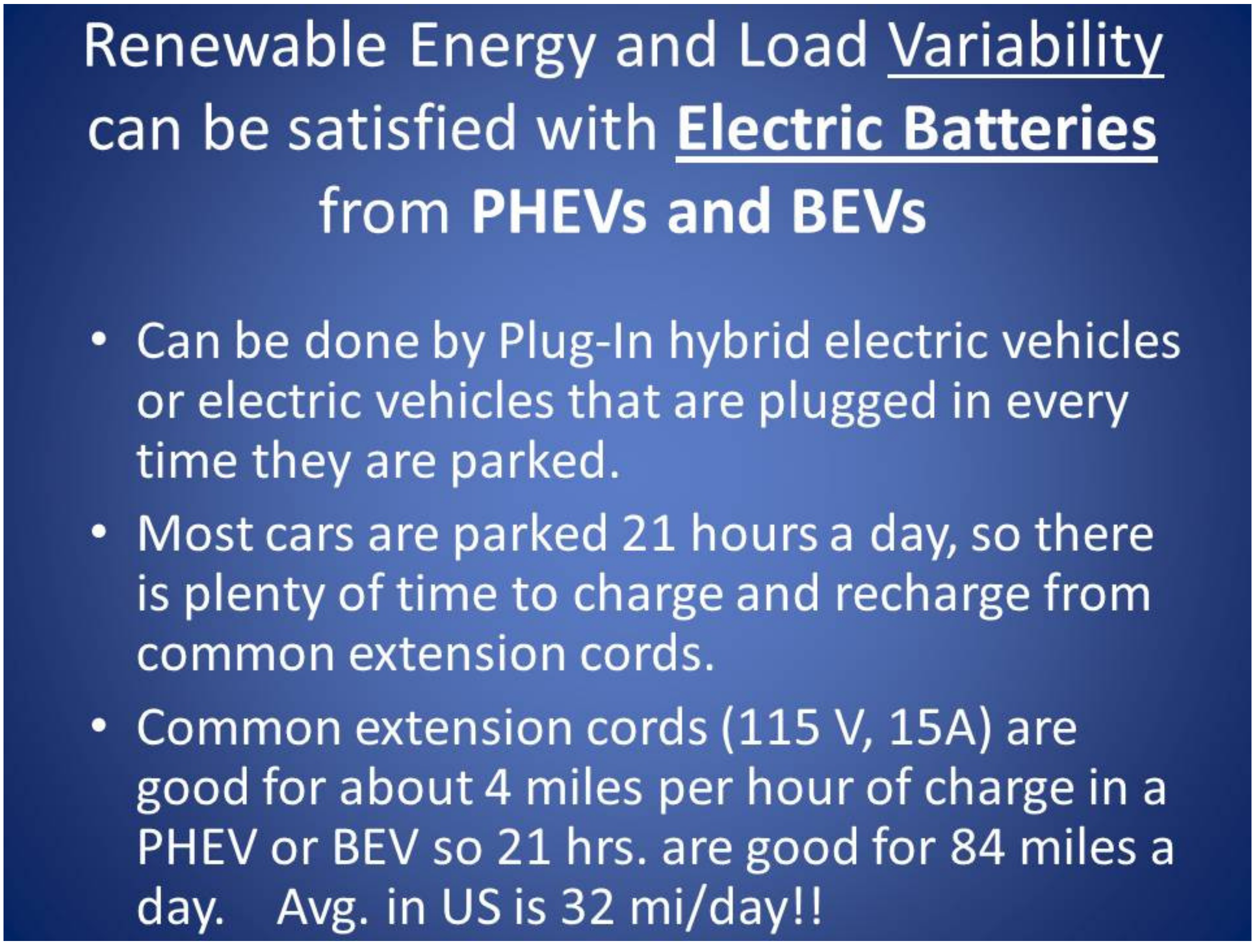


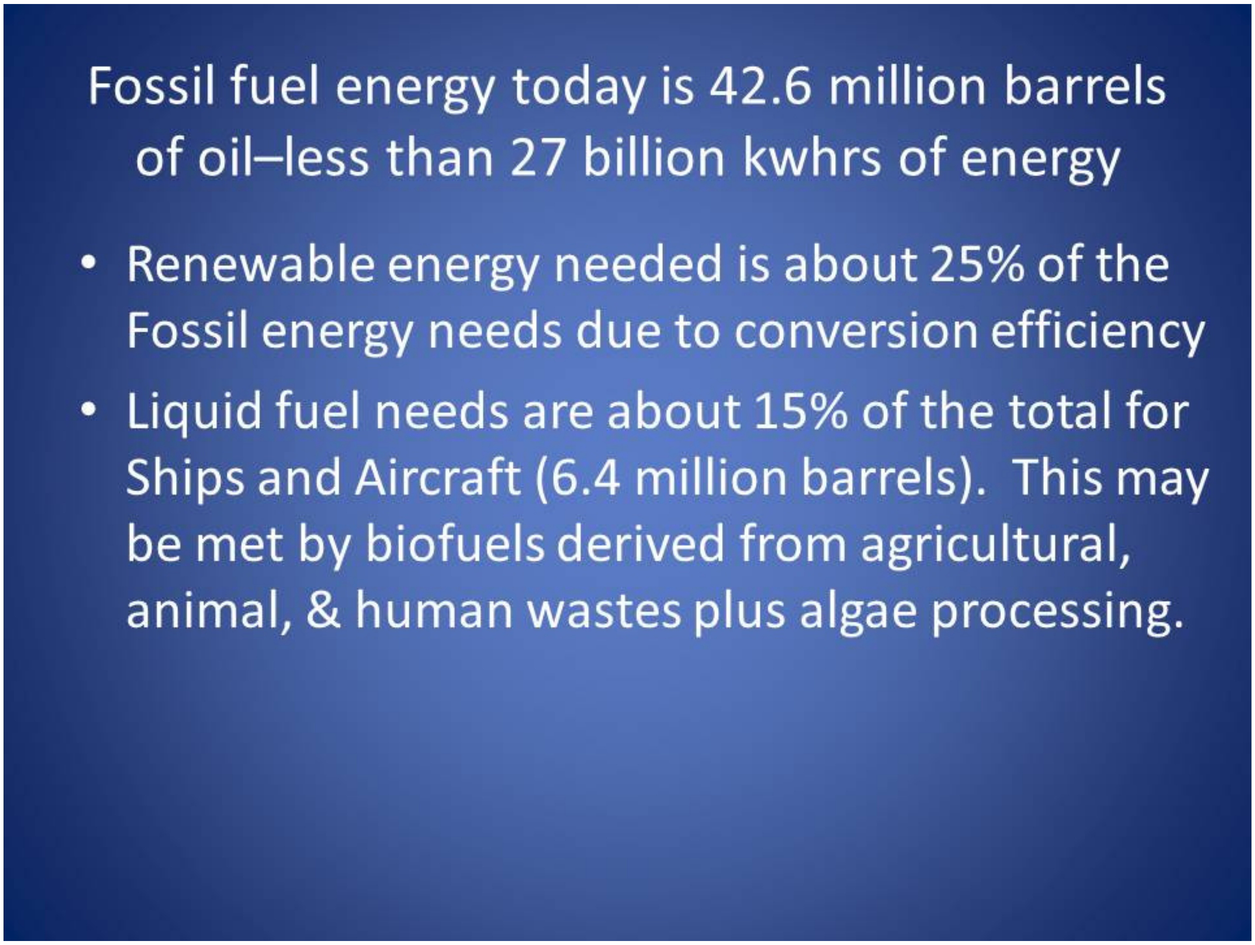
<u>We will show a roadmap to convert the islands to all wind energy in fifteen years!!</u>

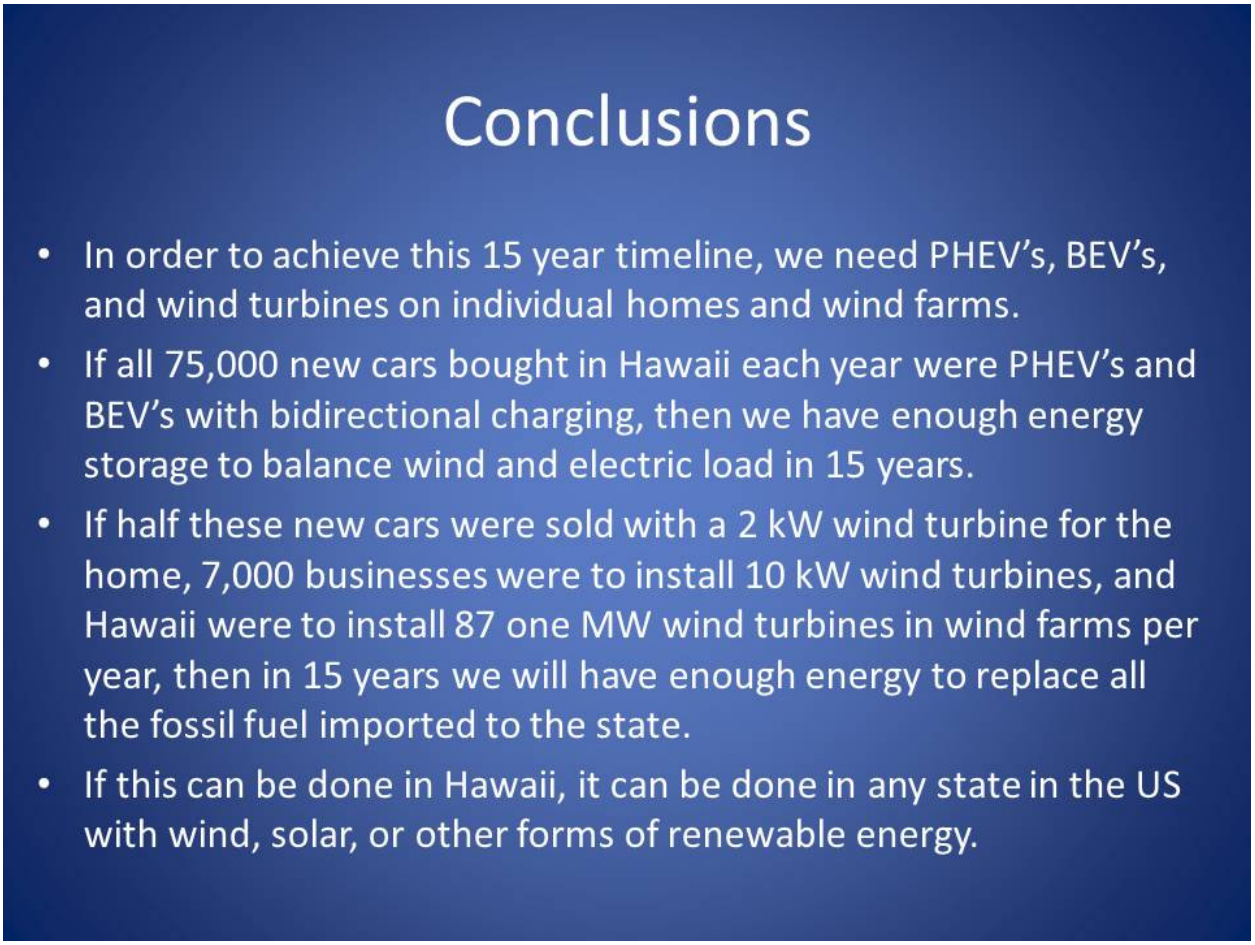

Roadmap to Energy Sustainability in Hawaii
90%
0%
Fossil fuel use
Large Wind Turbines
Home Wind Turbines
Fossil fuel use
Wind use
0%
90%
2010
2015
2020
2025


Renewable Energy Variability both Local and Central
The solar variability
Jay Apt and Aimee Curtright's Working Paper,
"The Spectrum of Power from Utility-Scale Wind Farms and Solar Photovoltaic Arrays."
The wind power flying spaghetti monster {from a 2007 CAISO (California Independent System Operator) }
Springerville AZ, One Day at 10 Second Resolution
Real Power Output (kW)
Seconds
Each Day is a different color.
Day 29
Day 9
Day 5
Day 26
Average
Megawatts
EFFICIENT DRIVETRAINS


Unpredictable Load Variation 24/7
Example using the BART grid and 3500 parked PEV's with Level 1 G2V and V2G – Save BART $1.25 M.yr
And everyone ends up with a near full charged battery for Free!
difference between power used and requested (above zero is lost to grid, below zero is bought from PG&E)
power (MWh)
20
15
10
5
0
-5
-10
0 24 48 72 96 120 144 168 192 216 240 264 288 312 336 360 384 408 432 456 480 504 528 552 576 600 624 648 672 696
time (hours)
• (Scheduled power – Used power for BART micro-grid)
• From One Month of Data of Energy use By BART
• Total Additional Energy Purchased ~ 517 MWH
• Total Energy Wasted ~ 1,389 MWH (Excess scheduled)
• Level 1 can balance the Load!!
• Peak Power Need ~ 5 MW, can be supplied by 3200 cars @ 1.5kw each-- (less than 10%)
EFFICIENT DRIVETRAINS


Renewable Energy and Load Variability can be satisfied with Electric Batteries from PHEVs and BEVs
• Can be done by Plug-In hybrid electric vehicles or electric vehicles that are plugged in every time they are parked.
• Most cars are parked 21 hours a day, so there is plenty of time to charge and recharge from common extension cords.
• Common extension cords (115 V, 15A) are good for about 4 miles per hour of charge in a PHEV or BEV so 21 hrs. are good for 84 miles a day. Avg. in US is 32 mi/day!!


Fossil fuel energy today is 42.6 million barrels of oil–less than 27 billion kwhrs of energy
• Renewable energy needed is about 25% of the Fossil energy needs due to conversion efficiency
• Liquid fuel needs are about 15% of the total for Ships and Aircraft (6.4 million barrels). This may be met by biofuels derived from agricultural, animal, & human wastes plus algae processing.


Conclusions
• In order to achieve this 15 year timeline, we need PHEV's, BEV's, and wind turbines on individual homes and wind farms.
• If all 75,000 new cars bought in Hawaii each year were PHEV's and BEV's with bidirectional charging, then we have enough energy storage to balance wind and electric load in 15 years.
• If half these new cars were sold with a 2 kW wind turbine for the home, 7,000 businesses were to install 10 kW wind turbines, and Hawaii were to install 87 one MW wind turbines in wind farms per year, then in 15 years we will have enough energy to replace all the fossil fuel imported to the state.
• If this can be done in Hawaii, it can be done in any state in the US with wind, solar, or other forms of renewable energy.

Solar area charge needs for PEV cars and trucks

1.5 kw solar 200 sqr. ft enough for 40 miles in a small SUV

30 kw charge station enough for 5 trucks or 20 cars.

In Hawaii the Wind may be more consistent and a 6 kw Wind charge station is about 20 feet in diameter for each house and good enough for a truck.