Revised Evaluation of Electric Cars

The article below titled **Why Electric Cars Are Not The Answer** was posted October 21, 2012. Today I am posting reconsideration of some salient issues. While these considerations make electric cars more acceptable serious reservations remain.

The key conversion formula for horsepower (HP) and watts (W) is still

$$1HP = 745.69987\ldots\ W$$

Thus, a 400 HP car is also a 300 kilowatt (kW) car to within 0.6 percent. While this conversion enables one to talk about engine power in two languages it does not reflect the differences in efficiency of function between a combustion-of-gasoline engine and an electric motor. A reliable source for quantitative comparisons is found at https://www.**fuel**economy.**gov**/. The important fact is that electric motors are about 3 times more efficient than gasoline motors in converting latent energy content into motive power. Electric motors are about 60% efficient whereas gasoline motors are about 20% efficient, plus or minus a percent or two in each case. Another conversion formula pertinent here is the electric energy equivalent of the combustion energy produced by a gallon of octane. Octane is the principal hydrocarbon in gasoline (87% - 91%) and its combustion can be represented by the chemical formula

$$2\ C_8H_{18} + 25\ O_2 \leftrightarrow 16\ CO_2 + 18\ H_2O$$

Going to the right this reaction releases 33.3 kWh (kilowatt-hour) of energy for each gallon of octane oxidized.

Cars do not normally operate at their HP ratings. For example a 400 HP car only approaches its 400 HP maximum when rapidly accelerating in a low gear.

When traveling at a constant speed of 60 mph it operates at a lower HP that is determined by wind drag and wheel/motor friction. If there were no wind drag or wheel/motor friction, the 60 mph speed could be maintained by almost no power expenditure at all (Newton's second law for no friction). However there is drag and friction so power must be expended to maintain a constant speed, even on a flat surface, but a 400 HP car may operate at only 200 HP, or less, to do so. The wind drag increases with the square of the speed and efficiency at 60 mph can be reduced by as much as 20% at 70 mph, and much more at 80 mph. A gallon of octane generates 33.3 kWh of energy but at 20% efficiency for a combustion engine, this is only 6.6 kWh of energy actually expended for motion of the car. At 60% efficiency for an electric motor, the same amount of energy needed electrically is 11 kWh.

Let us compare costs. A gallon of octane is needed to produce 6.6 kWh of energy in the motion of a combustion car whereas the same motion is achieved by 11 kWh of energy provided to an electric car. In recent times that gallon of octane costs somewhere around $2 to $4. At the national average for electrical energy that is 12 cents per kWh the cost is $1.32. That is quite a savings in fuel costs. Current all electric vehicles can take you 100 miles for 25 – 40 kWh of electricity. That's equivalent to 15 – 24 kWh of useful energy at 60% efficiency. At 20% efficiency a combustion engine needs 75 – 120 kWh of octane energy, or 2.4 – 3.8 gallons (about 41 mpg down to 26 mpg). Thus the 100 mile trip costs $3 - $4.8 electrically and $4.8 - $7.6 at $2 a gallon of octane, or $9.6 - $15.2 at $4 a gallon of octane. These numbers reflect current rates for electricity and gasoline. Increased use of electricity could force prices up although at present most power suppliers give lower prices for higher levels of usage. This could reverse if demand becomes very great. Gasoline engines pollute because they release carbon dioxide and water vapor, both of which are major greenhouse gases. Coal burning power plants also pollute but wind power and photocells produce electricity without releasing greenhouse gases. Hydroelectric power is non-polluting from the gases viewpoint but it causes ecological problems and dams have a finite lifetime. Nuclear power production raises a whole host of long term problems.

The bottom line is that my earlier estimate of power usage from 10 times to 20 times the present household usage rate if two car families convert from gasoline to electricity is too large by a factor of 3, that is electric power usage will increase 3.3 fold to 6.7 fold. A household using 35 kWh a day on average with two gasoline cars will use 120 kWh – 240 kWh, or more, a day if the cars become all electric. This assumes the equivalent of 200 HP - 400 HP cars used for commuting and all other transportation needs.

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June 30, 2016

Why Electric Cars Are Not The Answer

As the USA's dependence on foreign oil becomes increasingly problematic and as gasoline combustion byproducts continue to pollute the air there has been a surge in the promotion of personal, electric-powered transportation. Using some easily available numbers and a little common sense I will argue below why this approach is not the answer. To be clear, I am talking about cars that are purely electric and do not use any internal combustion. This excludes hybrid cars that can be made to use the energy of motion, while braking, to charge a battery and then use that stored electric energy for propulsion or other purposes. These types of hybrids simply do not waste all the energy that standard cars do not exploit while braking. They require no outside source of electricity and generate their own electric power. As is well understood, hybrids only work well as gasoline savers in stop and go city traffic and not so well on long distance trips.

The key to understanding my subsequent remarks is the basic conversion formula for converting mechanical power, "horsepower," into electric power, "watts." The conversion is

$$1HP = 745.69987\ldots\, W$$

where HP denotes horsepower and W denotes watts. There is also a term in usage called the "electrical horsepower" that is simply $746\ W$ and is sufficiently accurate for our purposes. We owe the unit of horsepower to the Scottish inventor James Watt (1736-1819), after whom the unit of a watt was named. Watt established the unit of HP by comparing steam engines with draft horses. From 1960 until 1993 I thought Watt's horses must have been sick or weak. However, in 1993 it was shown that for a few seconds a horse could achieve a peak power of $14.9\ HP$ but for sustained effort it could only achieve, fittingly enough, $1\ HP$, the power of seven or eight $100\ W$ light bulbs.

Several car companies have put purely electric cars on the market and a sampling of what is available indicates how much power they can generate:

Nissan LEAF:	$80\ kW$
Tesla Roadster 2.5 Sport:	$215\ kW$
Mitsubishi i-MiEV:	$47\ kW$
Ford Focus Electric:	$107\ kW$

in which kW denotes kilowatts, i.e. $1,000\ W$. To convert to horsepower, multiply the number of kW by 1.34

$$1\ kW = \tfrac{1}{.746}\ HP = 1.34\ HP$$

where I have used the electrical horsepower for simplicity and have dropped digits beyond the second decimal place in the second equality. Clearly all four cars have relatively low horsepower, indeed very low horsepower by contemporary SUV standards (the top ten SUV horsepowers go from $400\ HP$ to well over $500\ HP$).

For a purely electric car to work there must be a source of electricity to charge up its storage batteries. Presently storage batteries are expensive, heavy and take up space. They propel the car a rather short distance (less than 100 miles) before they need recharging and a typical commuter would need to recharge daily. Long road trips are not possible with present technology and the currently available electricity depots along our highways. Compared to refilling the gasoline tank, a complete recharging takes a long time as well.

Everyone should remember the times when there have been electric blackouts, especially during hot summers when too many air conditioners are used simultaneously. These events give a sense of how close to capacity our normal electric needs operate. Let us consider just the demands for a household and how they would change if all of us used electric cars. This leaves out the considerable drains on electricity caused by industries and city infrastructures. The average power use per home in the USA is estimated to be:

$$\frac{958\ kWhr}{month} = \frac{32\ kWhr}{day} = 1\tfrac{1}{3}\ kW$$

Remember that *energy is power multiplied by time*. So a household averaging

$$1\tfrac{1}{3} kW$$

of power over a whole day uses

$$24\ hr \times 1\tfrac{1}{3}\ kW = 32\ kWhr$$

of energy in a day (hr denotes hour and kWhr is the unit of energy *kilowatt-hour*). The census bureau estimates that there are 115,000,000 households in the USA (a third of which are apartments). It is also estimated that there are 220,000,000 light duty vehicles (cars) in the USA, or almost two per household. There are about 220,000,000 adults averaging 1.5 hours a day per person operating these cars. Let us now tally up the results. The daily total energy consumption by all households is

$$115,000,000 \times 32\ kWhr = 3,680,000,000\ kWhr$$

The daily total energy consumption by all electric cars, if everyone owned only electric cars (assume they are all Ford Focus Electrics for simplicity), is

$$220,000,000 \times 107 kW \times 1.5\ hr = 35,310,000,000\ kWhr$$

This is **ten times** the energy consumption per day per household for all other purposes. Switch to the higher kW generating Tesla Roadsters and it is **twenty times** as much.

Where is all of this electric energy going to originate? More hydroelectric dams, more coal burning generators, more windmills, more nuclear power plants, …? Note that electricity is always at least a secondary energy source, that is, some other energy source has to be converted into electricity: gravity in hydroelectric dams, coal oxidation in coal burning generators, wind energy for windmills and nuclear fission in nuclear power plants. This is less efficient than direct conversion. For example one could argue that each household could do its own conversion, say by running an electric generator. Imagine that you used a gasoline (kerosene, propane, natural gas, etc.) powered generator. It is more efficient to simply use a gasoline (kerosene, propane, natural gas, etc.) burning car instead of first making electricity and then using an electric car. Each conversion step is less than 100% efficient. Maybe a solar cell converter could be used by each household. At two cars per household, each at $107\ kW$ for 1.5 hour a day, $321\ kWhr$ of energy would be needed per day. Remember that this is **ten times** the energy per day consumption per household (see above). In October of 2012 roof top solar photovoltaic converters rated at $3.5\ kWhr$ per day were being highly touted in sunny California. Such solar photovoltaic cell converters are 11-13% efficient in converting sunlight into electricity. Even at 100% efficiency they would barely meet household needs, much less power the electric cars. More sophisticated versions of solar power using solar concentrators and sun trackers work better to meet household needs but it is clear that none of them would ever meet the needs for two electric cars.

Centrally located, large scale generation of power has advantages and disadvantages. You can generate electricity in a coal burning power plant but you cannot build a car that has a coal burning engine. The nature of the fuel and the nature of the vehicle are tightly connected. Size scale is critical. You can build a train locomotive that burns coal, and then many persons would have to share transportation rather than park their own little locomotive at home. Wind energy is ideal for powering a sailboat, even a small one. Coal burning can power a steamboat but not a canoe. Not everyone can build a hydroelectric dam on their own property. Few homes have a sufficient source of flowing water. We have saturated the reasonable sites for large scale dams in the USA already. Many are already silting up and otherwise becoming obsolescent. Private household windmills are also unfeasible. How would they help high rise apartment dwellers? Even roof top solar cell arrays require that you live where there are many sunny days per year. However, solar cell farms where there are many sunny days per year can distribute power to many homes where there are not. Nuclear power can be housed inside a nuclear submarine but it is out of the question for family cars. Only large scale plants can be adequately controlled for safety, and so far that hasn’t always worked out well. The eventual embrittlement of the containment vessels produces the need to dispose of them and that creates radioactive waste the disposition of which is not easy.

Biofuels are another approach to these problems, although not strictly an electric car solution. In this scenario, sunlight is used to grow crops such as corn. The corn is harvested and then fermented to produce alcohol, for example ethanol. The alcohol is burned by the car using an engine very much like a gasoline (or diesel) burning engine. Note that this is a three stage process each step of which is less than 100% efficient. Using these fuels to powered an electric generator instead introduces still another less than 100% efficient stage of conversion. So one would simply use the biofuel to burn it in a internal combustion car rather than generate electricity for an electric car. Biofuels require vast amounts of land to grow sufficient amounts of corn (or sugar cane etc.). This raises environmental questions regarding irrigation (droughts could be catastrophic to drivers), fertilizers (phosphate runoff creates algal blooms and then anoxia in streams, ponds and lakes that kills a level of the food chain including fish amphibians and insect larvae), pesticides (not such a big problem if the crop is used to make biofuel rather than food), ***etcetera*** and adversely affects worldwide starvation. Burning a molecule of ethanol produces three molecules of water and two molecules of carbon dioxide, a greenhouse gas. Thus, one pollution issue is not solved. Some efficiency is lost to the energy costs involved in powering planters, harvesters and fermenters etc. and the lower energy density of ethanol compared to gasoline. These debits are relatively large compared to the energy production.

Generally, using sunlight at the start of an energy conversion cascade is limiting because of the low power density that is not used at 100% efficiency (on a clear day at sea level the optimal *solar insolation* at the Earth's surface perpendicular to the Sun's rays is $1\ kW$ per square meter). This is partly the reason why it only directly powers plant growth, a slow process, and not directly animals that use muscles and nerves, tissues that require high levels of power to operate properly (an adult human male averages over one day roughly $100\ W$ of power consumption, $0.134\ HP$, that is provided by biochemical metabolism, not sunlight, and while running can exert a peak power of $1\ HP$).

Electric cars are not the solution to the gasoline powered car problems, neither the petro-political issues nor the environmental impacts. If a complete replacement of gas powered cars by purely electric cars were to be undertaken there would be insufficient electric generation to run them. Total household electricity utilization would increase at least ten-fold. Local, house by house electric generation scenarios are inadequate and unfeasible to provide the needed electricity for a typical household with two cars. Adequate large scale electric generation by solar photovoltaic farms, by windmills, by hydroelectricity or by nuclear energy has many problems as well.

Hopefully this essay convinces you that some simple arithmetic homework needs to be done before jumping on the bandwagon for any of various alternatives to energy conversion and utilization that would replace gasoline powered cars by purely electric cars. These small scale, high powered, long ranging and rapidly refueled personal vehicles were indeed a remarkable invention.

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October 21, 2012