



Photovoltaic Solar Energy and Electric Vehicles versus Internal-Combustion-Engine Vehicles

By: Randy Jackson
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1.0 How to Break our Addiction to Oil

1.1 Introduction

Why will the future be powered by photovoltaic (PV) solar energy and why will the electric motor replace the internal combustion engine (ICE) in the vehicles we drive? The next time you're outside on a sunny day or even a cloudy day, look around you and imagine how much energy it would take to light up everything that bright, a lot, right? ["In any given hour, more energy from the sun reaches the Earth than is used by the whole human population in any given year."](#)^[26] With so much energy all around us, just imagine if we could capture a small amount of this energy and put it to work in all kinds of ways including powering the vehicles we drive. As the oil embargo of the 1970s and the recent spike in oil prices have shown us, being addicted to oil is not good for families, the nation, or the world economy. Fossil fuels and uranium for nuclear reactors will eventually run out, and PV solar energy is the number one growing source of energy in the world. "World solar photovoltaic (PV) market installations reached a record high of [17 gigawatts \(GW\) in 2010, representing 65% annual growth rate over the past 5 years.](#)"^[27] Figure 1 shows how many hours of solar energy, reaching the surface of the earth, it takes to replace proven reserves of natural gas, oil, coal and uranium. As can be seen in Figure 1, the reserves of fossil fuels and uranium are small

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compared to the amount of annual solar energy, which reaches the surface of the Earth. The Sun is expected to be providing this amount of annual solar energy to the Earth for about the next 4.5 billion years.

As it will be shown, the electric motor is about five times more efficient than the internal combustion engine for powering a vehicle. This means that an electric vehicle can travel the same distance as an ICE vehicle on about five times less energy. So instead of going 20 miles on a gallon of gasoline, which costs about \$4.00, an electric car can go 20 miles on about \$0.80 of electricity!

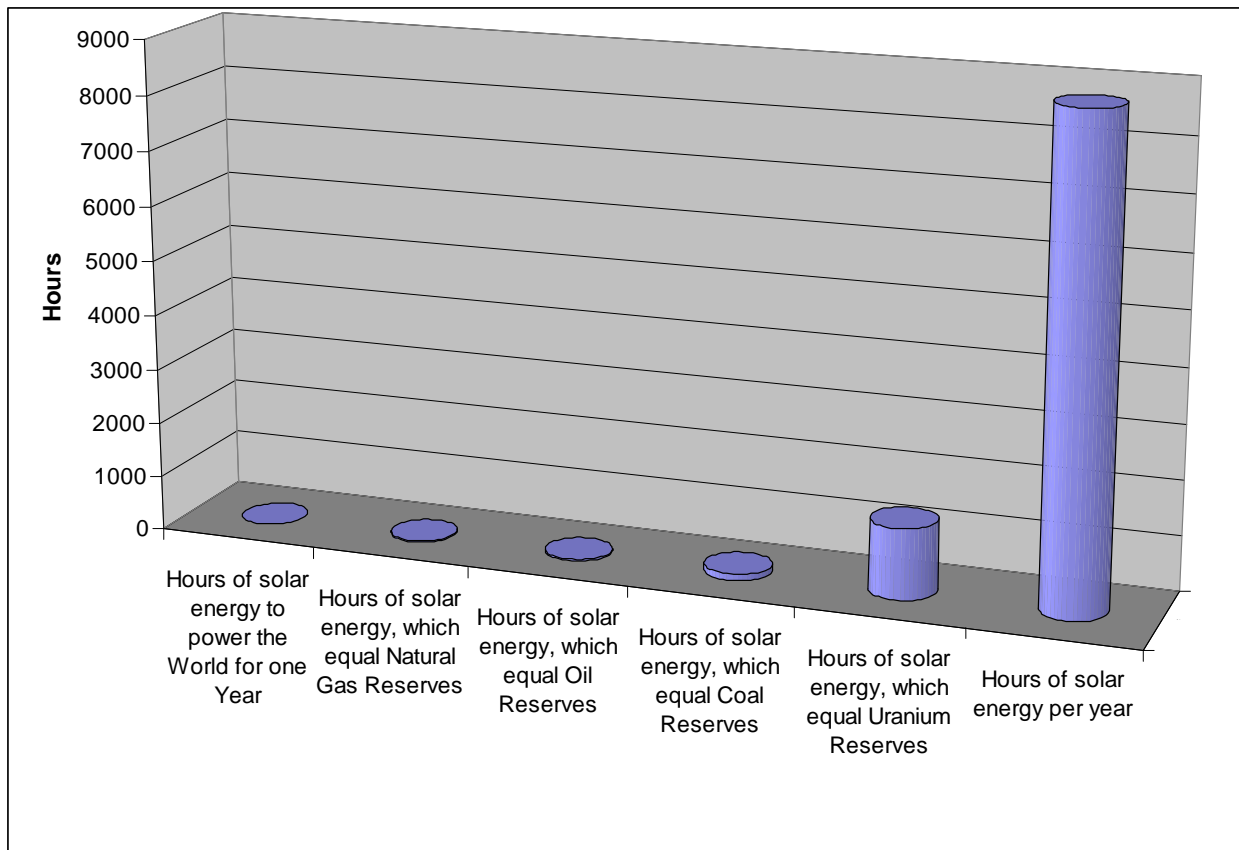


Figure 1. Hours of Solar Energy which Equals known Energy Reserves [\[29\]](#) [\[30\]](#)

1.2 Electric Vehicles versus Internal-Combustion-Engine Vehicles

The internal combustion engine is inefficient with about [80%](#)^[1] of the energy being wasted on heat and all the moving parts between the pistons and the wheels. The internal combustion engine is water cooled with the pistons and piston rods moving up and down, which turn the crankshaft, which is connected to the drive shaft and the transmission, which is connected to the differential, which finally converts the energy into the direction the wheels need to move. In contrast, the electric motor has only one moving part, which is moving in the same direction the wheels need to move, at a stop light, the motor is off (using no energy) and when going down hills or breaking, the motor is generating electricity to be used later. When was the last time your internal combustion engine gave back the gasoline it just burned up from accelerating or going up a hill?

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But, you may ask, how much more efficient is an electric vehicle (EV) than an ICE vehicle (ICE-V)? EVs can go 4.8 times more miles, on the same amount of energy, than ICE-Vs as shown in Figure 2. The ICE Mini Cooper hardtop gets a combined [32 MPG^{\[2\]}](#) city and highway and each gallon of gasoline has [33.7 kWh^{\[3\]}](#) of energy in it. The Mini E can go 152 miles on 33.7 kWh of energy because it gets [4.5 miles per kWh^{\[4\]}](#) (City driving kWh/mls 0.22). This means that EVs are 4.8 times more efficient than ICE-Vs.

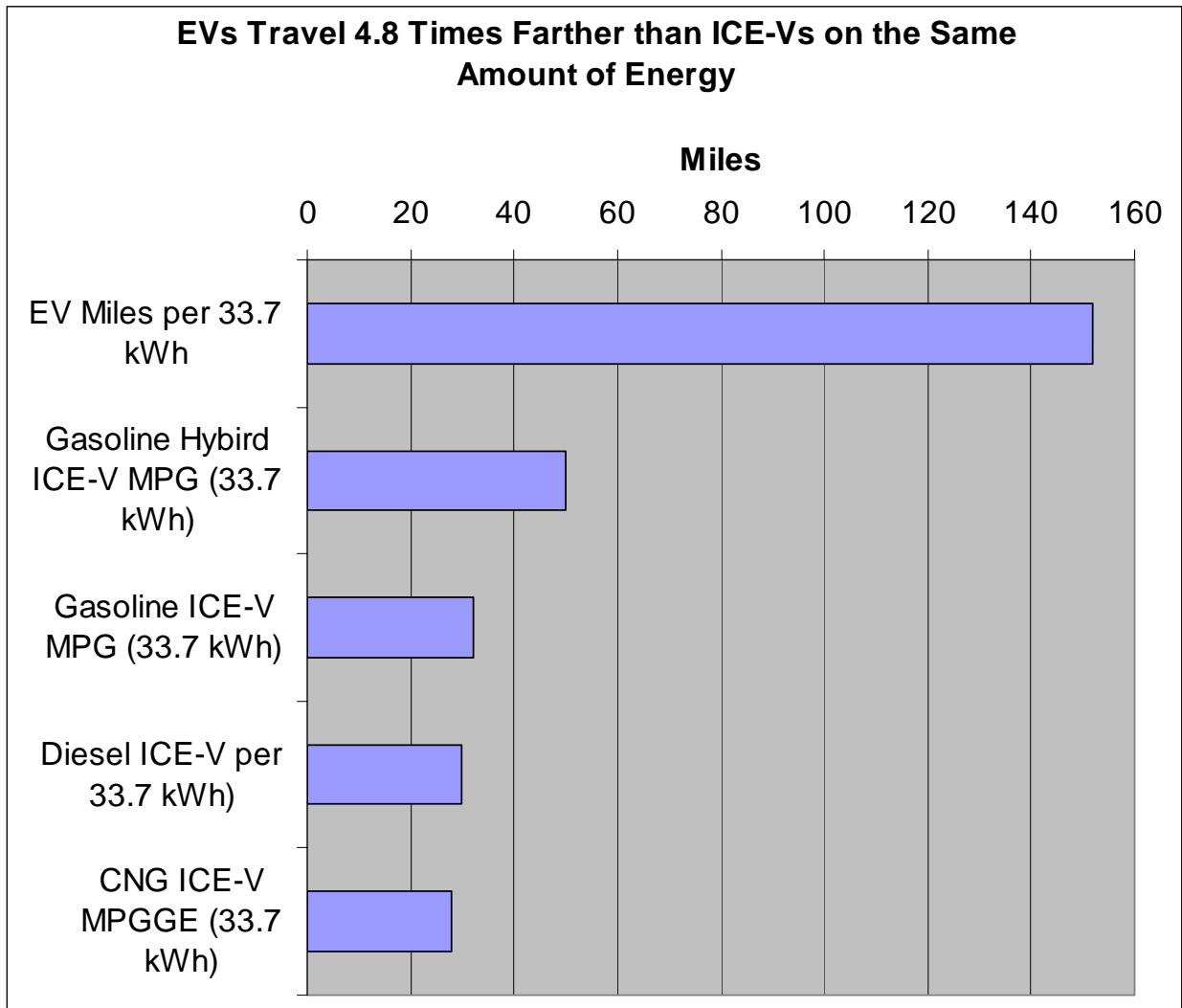


Figure 2. EV Miles versus ICE Miles

It is 80% less expensive to operate an EV versus an ICE-V. It costs \$19.00 for the ICE Mini Cooper to go 152 miles with gasoline at \$4.00 a gallon and it costs \$3.72 for the Mini E to go 152 miles with electricity at 11 cents a kWh. So, using expensive gasoline, diesel bio-diesel, ethanol, or even natural gas in inefficient ICE-Vs is far more expensive than using electricity in EVs. Also, once [peak oil^{\[5\]}](#) is reached and demand for oil outstrips supply, the price of gasoline will go much higher.

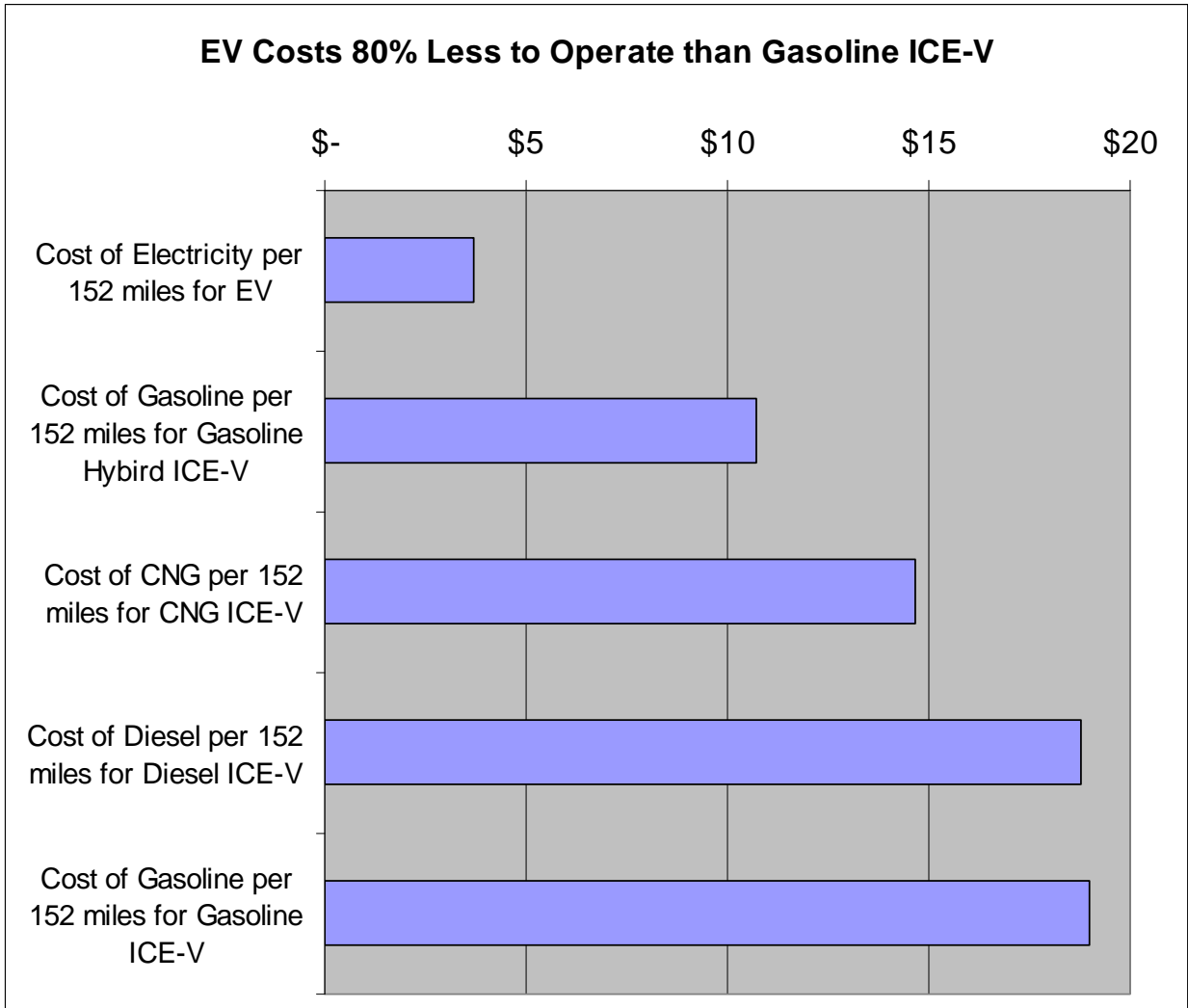


Figure 3. EV Operational Cost versus ICE-V Operational Cost

Why are 100% electric vehicles so much better than hybrids and hydrogen fuel-cell vehicles? Hybrid vehicles are only marginally better than ICE-Vs because they still use inefficient internal combustion engines for higher speed driving and they are dependent on gasoline. Hydrogen fuel cell vehicles require hydrogen to run and it takes electric energy to produce and compress the hydrogen. This electric energy could be used directly to power a 100% electric vehicle. Also, the distribution system for hydrogen is nonexistent and would be costly to implement. In contrast the 100% electric vehicle uses zero gasoline and the distribution system for electricity is in place directly to our homes and this would support most of the driving we do.

It actually takes less energy to drive an EV 32 miles (ICE Mini gets 32 MPG) than it takes to produce one gallon of gasoline. The energy required to produce oil and refine one gallon of gasoline is about 12 kWh. The Mini E takes 7.1 kWh to go 32 miles (Mini E gets 4.5 miles per kWh). This means we save 4.9 kWh for every 32 miles driven in an EV. So we will use less electricity, not more, if we all drive EVs because of all the energy we save by not having to produce gasoline.

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[The energy required to produce oil is 1440 MJ per barrel and each barrel contains 6164 MJ^{\[6\]}](#) (23.4% of the energy in 1 barrel of oil is required to produce one barrel of oil, note there are 42 gallons in one barrel of oil) and 6164 mega-joules (MJ) is 1712 kWh, so $1712 \times .234 / 42$ equals 7.9 kWh of energy per gallon to produce the oil. [The efficiency of the refining process is 87.7%^{\[7\]}](#) (therefore, 12.3% of the energy in 1 gallon of gasoline is required to produce one gallon of gasoline), which equates to 4.1 kWh of energy to refine one gallon of gasoline, which has 33.7 kWh of energy in it. So, it takes a total of 12 kWh (7.9 + 4.1) to produce one gallon of gasoline.

Another very important fact is that electric cars do not have to be small. Electric motors are used in locomotives, which pull trains very efficiently. Therefore, there are electric motors with more than enough power to drive SUVs and trucks. Why have electric motors been used for decades in trains and not in cars and trucks? The oil companies over the past century have worked hard to keep us addicted to oil by lobbying to law makers to pass laws such as a 54 cents a gallon import tax on ethanol, by buying battery patents from GM, and suing other auto manufacturers to prevent them from producing EVs. Also, by GM has bought mass transit systems and closed them. Much this and more is documented in the movie [Who Killed the Electric Car?^{\[8\]}](#).

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1.3 Photovoltaic Solar Energy

With the cost of oil, gasoline, diesel, natural gas and electricity all going up, over the long term, purchasing a PV solar energy system is a way to cap this expense. The approximate cost of the energy produced from non-tracking solar panels, assuming a 33 year life, mounted on the roof of a building or house is 11 cents a kWh. So, how many PV solar panels does it take to power an EV if you drive an average of 40 miles a day (14,600 miles a year)? This requires about 13.3 kWh per day and would take about 15 230 watt solar panels, which require about 190 square feet, about the same area as a living room. The cost of a solar power system, this size, is about \$15,000 or \$17,799 with a 10 year loan at 3.5%. This means in about 10 years the solar power system will be paid for by the amount saved on gasoline and after 10 years the PV solar panels will still have 15 years of warranted life. This means that you do not have to pay for gasoline or electricity to drive an EV for the remaining warranted life of 15 years!!!

How do the batteries in an EV charge at night when the solar energy is being produced during daylight? One way is to connect the solar power system to the electrical power grid so that during the day the power company is using the solar power and providing credits, which can be used at night to charge an EV. Another way is to charge other batteries during the day, which would then be used to charge the EV's batteries at night. This is not as cost effective as connecting the solar power system to the electrical power grid, however, it does eliminate dependence on the power grid.

Why is solar energy so much better than bio-energy, which is also a renewable source of energy? Because one square meter of a PV solar panel can produce 74 times more energy in one year than the energy produced from one square meter of land growing sugar cane, which can be used to produce ethanol. Plus, bio-fuels can only power

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inefficient ICE engines plus they require high quality land and water to be produced. Solar panels can be placed on less desirable land or even on the rooftop of buildings and houses. This means that the solar energy can be produced right where people are living and consuming the power.

There is far more energy produced in one square meter of a PV solar panel than in one square meter of land growing sugar cane or corn. In this example the ten 200 watts solar panels (134 sq feet) are located in Long Beach, CA facing West with a 15 degree tilt. (Note that none of this is optimal; the same size, but newer, solar panels can now produce 230 watts, Long Beach gets a lot of fog particularly in the summer months, and southerly facing panels with a 33 degree tilt would produce more power.) However, this solar power system will produce 224 kWh of power a year per square meter. Now, one acre of sugar can produce [560 gallons^{\[9\]}](#) of ethanol a year and one acre of corn can produce [420 gallons^{\[9\]}](#) of ethanol a year. Since ethanol has [22 kWh^{\[10\]}](#) of energy per gallon, this equates to 3.0 kWh of power from sugar cane and 2.3 kWh of power from corn a year per square meter. Therefore, one square meter of PV solar panels can produce 74 times more energy in one year than the energy produced from one square meter of land growing sugar cane and 98 times more than corn. Nearly two orders of magnitude more power from PV solar panels over power from bio-fuels, this is huge. This would require nearly a quarter to a third of acre of corn or sugar cane to produce the same energy as from 134 square feet of PV solar panels and most people neither have the land or the resources to farm and produce ethanol.

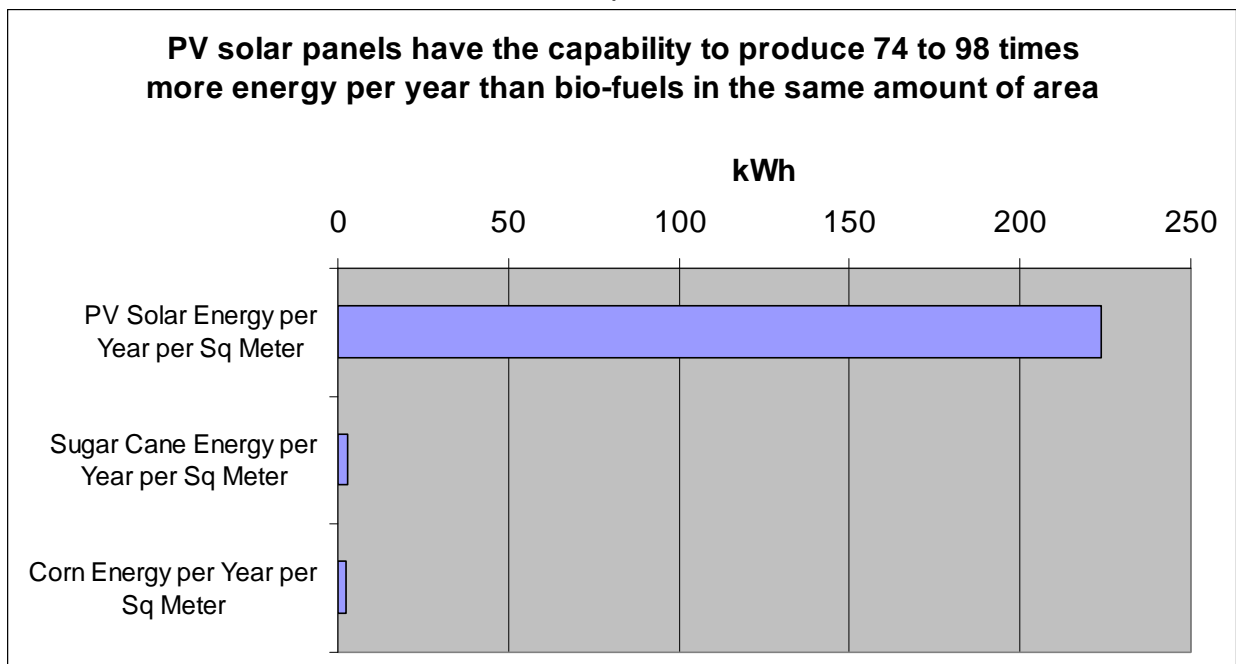


Figure 4. PV Solar, Sugar Cane, and Corn Energy per Year per Square Meter

Some people might argue about the energy it takes to manufacture the solar panels or the added cost of the EV over the ICE vehicle. Well, one solar panel will make enough energy in its lifetime to make [8 to 24 new solar panels^{\[11\]}](#) and the cost of the EVs will come down when they are in mass production. Others may even argue that the limit range and long charging time make the EV impractical. Most people drive on average of 40 miles a day or about 15,000 miles a year, so an EV, which has a range of 150

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miles and can be recharged over night should meet most people's needs most of the time. Just imagine if 10 minute charging stations were along most major highways, cross country driving in an EV would be possible. The company [Better Place](#)^[13] is already working to build electric car networks in the San Francisco bay area, Hawaii, Australia, Israel, and Denmark.

Another myth about solar power is that it can only be produced in the South-Western portion of the U.S. Well, the number one producer of solar power in the world is Germany, which makes 43.6% of the world's solar power in a country that gets less solar energy per square meter than Seattle, WA and is only about the size of the State on Montana. This means aside from Seattle and Alaska the rest of the U.S. receives more solar energy per square meter than Germany. This is sad that Germany out produces the U.S. in solar power. A solar map of Germany and the U.S. is shown in Figure 5 and existing 2010 photovoltaic solar production for the top 10 countries is shown in Figure 6.

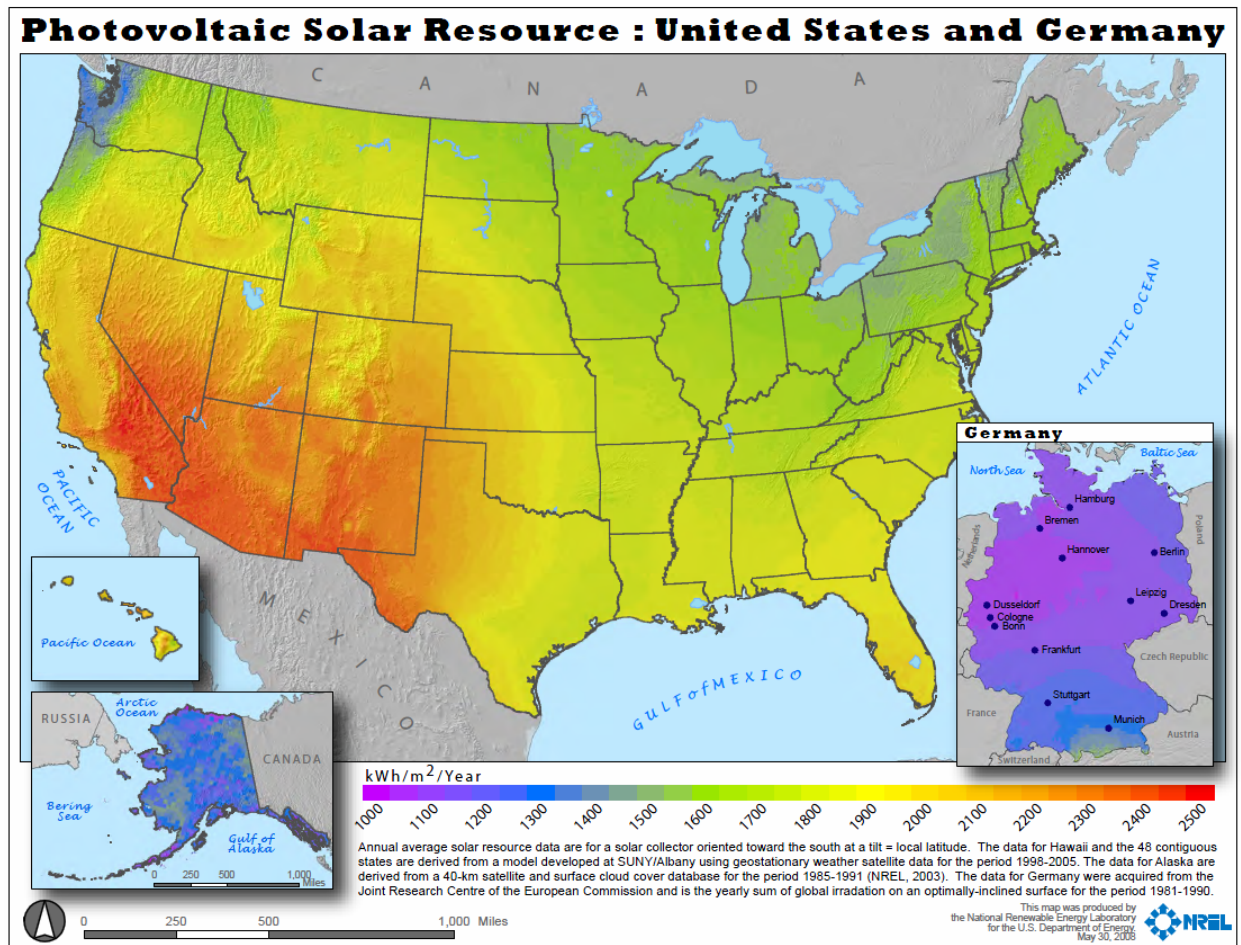


Figure 5. [Photovoltaic Solar Resource Map of United States and Germany](#)²⁸

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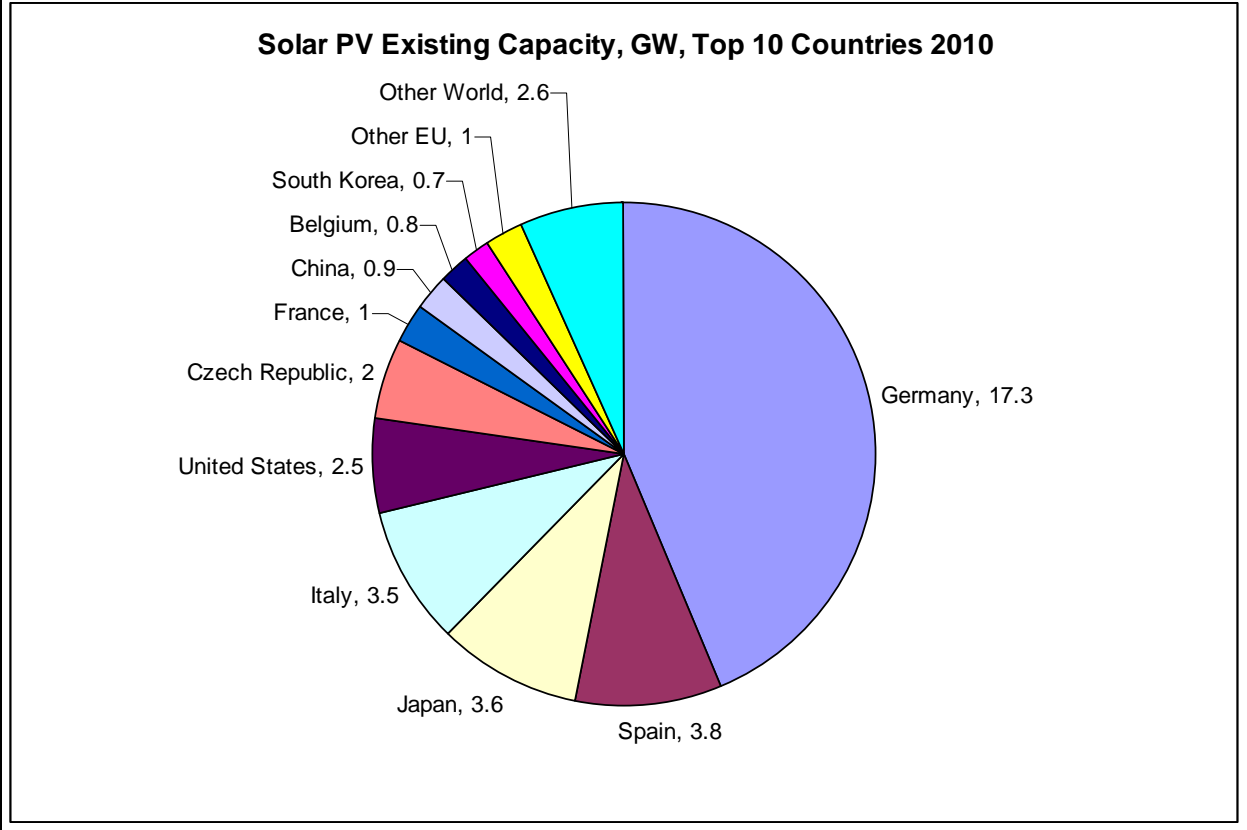
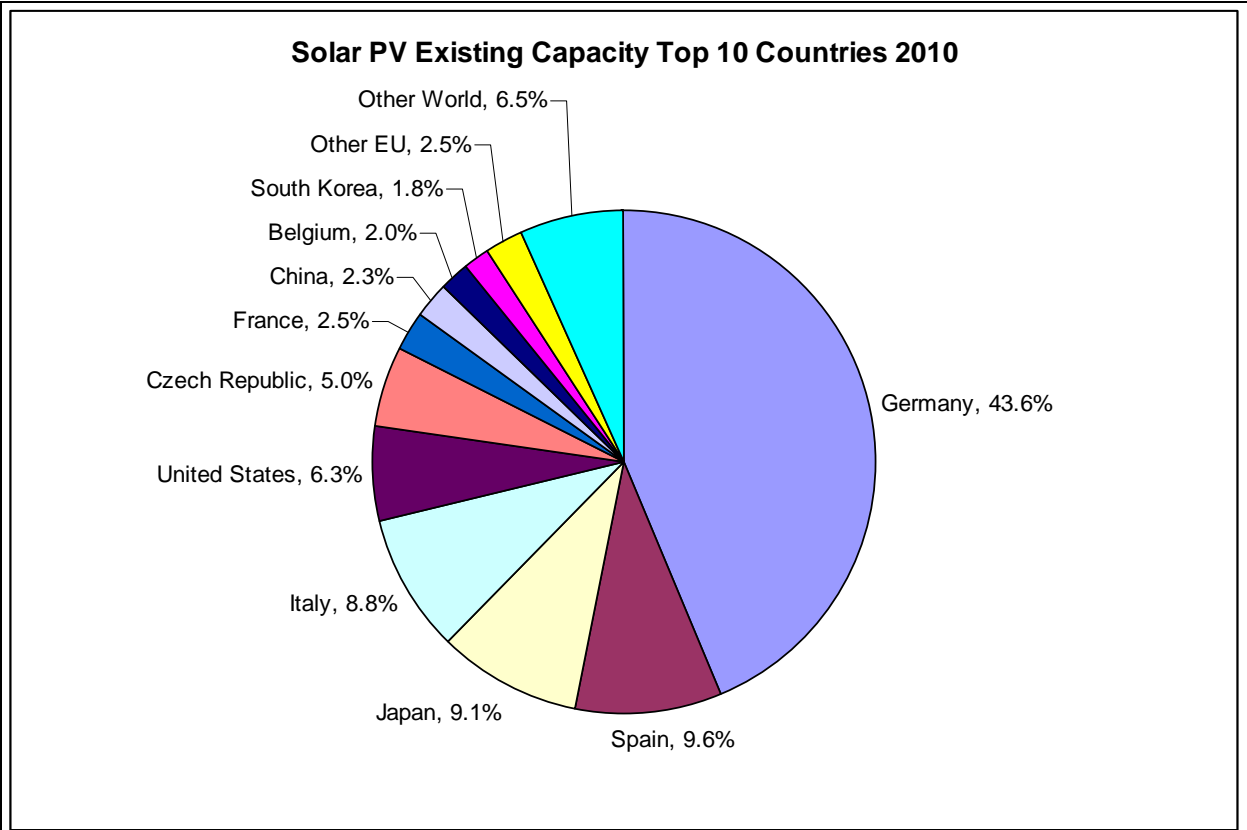


Figure 6. [Solar PV Existing Capacity, 39.7 GW, Top 10 Countries 2010³¹](#)
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2.0 Steps to Break our Addiction to Oil

So with electric vehicles 4.8 times more efficient than internal combustion vehicles and with photovoltaic solar panels having the capability to produce 74 to 98 times more energy than bio-fuels in the same amount of area, the future is clear and the technology is here today to break our addiction to oil. That technology is EVs using PV solar energy and it's easy to implement these into your life.

2.1 Install a Photovoltaic Solar System

The first step is to determine the PV system specifications for your location, which can be done by using the [PV Watts web site](#)^[14]. At this site, select the version 1 calculator, next select the state or country of interest and then select the city of interest. Next, enter in the DC power rating of the solar array, which is merely the rating of the panel (e.g., 230 watts) times the number of panels. Finally, enter in the tilt of your roof and the direction it is pointing (i.e., azimuth, East is 90 degrees, South is 180 degrees and West is 270 degrees) then click on the calculate button to determine the AC energy (kWh) per year the system will produce. To drive an average of 40 miles per day with 4.5 miles per kWh it will require an average of 8.8 kWh per day or about 3200 kWh per year. This is an iterative process until the PV solar system is sized correctly.

The next step is to get at least 3 estimates for the PV solar energy system from solar energy providers in your area. Each solar energy provider may be selling solar panels and inverters (converts DC from the PV panels to AC for your house) from many different manufacturers. Some of the most efficient PV solar panels are made by [Sun Power](#)^[15] and [Sanyo](#)^[16] and the most efficient inverters are Sunny Boy made by [SMA](#)^[17]. Most inverter manufacturers have a calculator on their web site, which allows for the design of a PV solar system with specific solar panels and inverter selection. These calculators are most likely what the solar energy providers use to design specific systems. Be sure to check out references from existing solar panel owners in your area from each of the solar energy providers.

Finally, select and have the PV solar energy system installed. The cost of the system should be significantly reduced by your energy company's rebate and the federal tax credit for solar systems. Starting in 2009, the federal tax credit is 30% of the cost the solar system and this credit is exempt from the alternative minimum tax reductions. You now have the capacity to generate the electricity for your EV and possibly your whole house depending on the size of the solar system installed.

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2.2 Stop Buying Internal-Combustion-Engine Vehicles

All you need now is a 100% electric vehicle, which will take a little bit more determination to acquire than the photovoltaic solar energy system. There are automobile manufacturers like [Tesla](#)^[20], and [Nissan](#)^[18], which are making EVs in the near term. However, the best way to make sure there will be a large supply and selection of EVs is let each auto manufacturer know that your next car will run on 100%

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electricity. This can best be done from the web site [Plug In America](#)^[21], which provides a link, email address, and phone numbers for each of the auto manufacturers. Also, let your politicians know that you would like them to pass laws to encourage auto manufacturers to start making and selling EVs.

Another way to start driving an EV is to have an ICE-V converted to an EV. There are companies, across the country, like [AMP](#)^[23], [Electric Blue Motors](#)^[24], and [Left Coast Electric](#)^[25], which provide this service. Be sure not to buy a new ICE-V and have it converted; this would only be a positive signal to the auto manufacturers that people still want to buy ICE-Vs.

Following these simple steps to install a PV solar system and switch to an EV will allow us to break our addiction to oil and create a healthier environment to live in. Please do your part to make this a reality. Here is a list of references to help get you started and if you have any questions or comments on this paper please forward them to Randy Jackson at RLJ327@gmail.com.

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