Solar Electricity Production

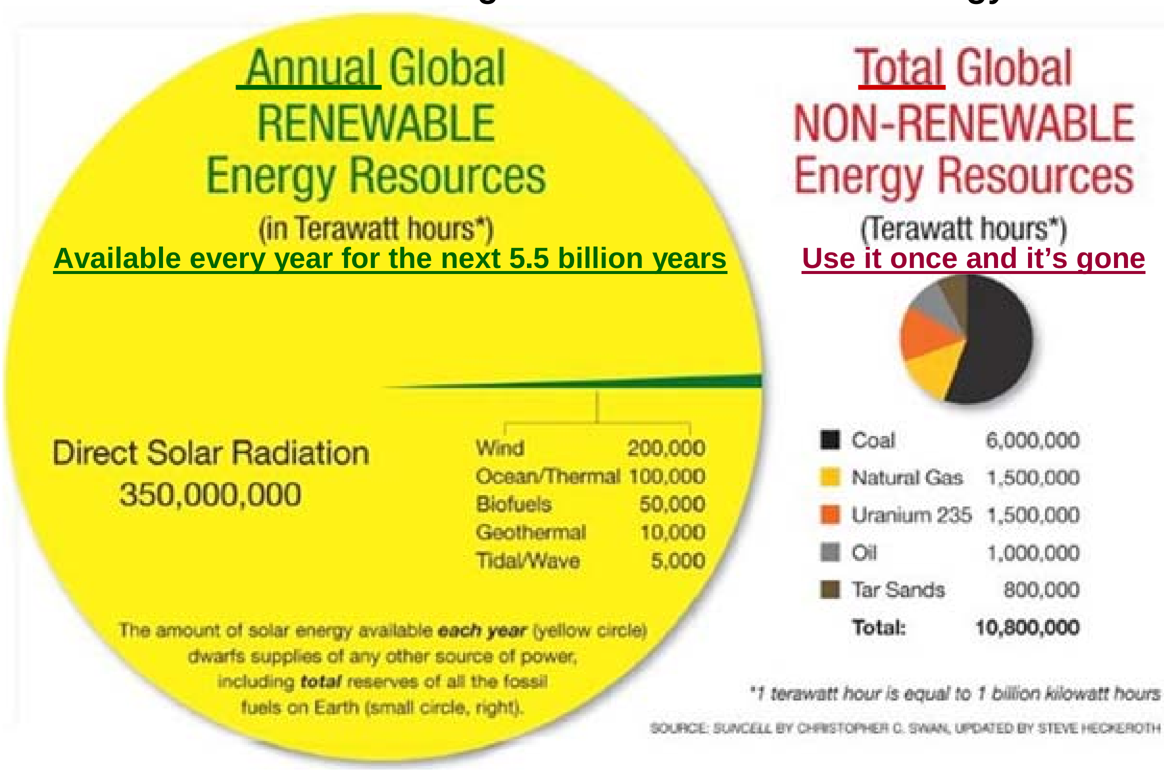
By Stephen Heckeroth

We know that relying on coal, oil and natural gas threatens our future with toxic pollution, global climate change and social unrest caused by diminishing fuel supplies. Instead of relying on unsustainable fossil fuels, we must transform our economy and learn to thrive on the planet's abundant supply of renewable energy.

I have been studying our energy options for more than 30 years, and I am absolutely convinced that our best and easiest option is solar energy, which is virtually inexhaustible. Most importantly, if we choose solar we don't have to wait for a new technology to save us. We *already have* the technology and energy resources we need to build a sustainable, solar-electric economy that can cure our addiction to oil, stabilize the climate and maintain our standard of living, all at the same time. It is well past time to start seriously harnessing solar energy.

The Good News:

There is more than enough sunshine for all our energy needs



Fossil-fueled Problems

Before you read on, take a moment to, study the two corresponding pie charts above which compare the Earth's estimated *total* reserves of *non-renewable* energy resources with the *annual renewable* energy options. You'll see that the potential of solar energy dwarfs all other options, renewable or otherwise. To understand why a solar-electric economy is our best option, let's look at the energy resources we currently depend on and compare them with the solar energy available to us.

Coal is burned mainly to produce electricity, and coal-fired power plants produce more than half the electricity used in the United States. But burning coal has serious drawbacks. One is that it releases carbon dioxide, which contributes to global warming. It also releases toxins, such as mercury and sulfur. These toxins that were locked in the Earth's crust over billions of years are suddenly spewed into the atmosphere and thus degrade our air, water and soil. The exhaust from burning coal contains more pollutants and global warming emissions per unit of energy produced than *any other fossil fuel*. In addition, the methods used to mine coal are destructive to the land and dangerous for the miners.

Now consider that coal is enormously inefficient from a total energy perspective. It took billions of years of solar energy to form the coal we have today. And while coal is the most abundant fossil resource, the total amount of energy produced by burning all the coal on the planet would only be equivalent to the solar energy that strikes the Earth every *six days*.

Natural gas supplies more than half the fuel used to heat buildings and about 15 percent of the electricity in the United States. Natural-gas-fired power plants only emit about half the pollutants produced by coal plants, as long as the fuel is extracted close to where it is burned. However, U.S. natural gas extraction can no longer keep up with demand, so expensive and hazardous methods to liquefy and ship foreign natural gas are being devised. In the future, natural gas for the United States would have to be imported from countries such as Russia, Kazakhstan, Qatar and Iran, which together have 60 percent of the world's reserves. When all the externalities, such as the cost and pollution caused by liquefying and transporting this fuel, are included, liquefied natural gas (LNG) is much more expensive than coal, and almost as dirty. Natural gas is the second most abundant fossil fuel, but its total potential energy is equivalent to only about *1 1/2 days* of sunshine striking the Earth

Nuclear power plants fueled by radioactive isotopes of uranium produce 20 percent of the electricity used in the United States. When radioactive materials were sequestered and dispersed deep under the Earth's surface, they presented very little threat to life. But we've made those materials far more dangerous by mining and concentrating them, and the byproducts left over after a nuclear reaction are even more dangerous than the original isotopes. Nuclear power plants create hundreds of thousands of tons of radioactive waste that will continue to be a threat to life for longer than humans will walk the Earth.

Even if the problem of radioactive waste could be solved, the recoverable world reserve of fissionable uranium is equivalent to less than *1 1/2 days* of the energy striking the Earth from the nuclear reaction of the sun.

Oil-fired power plants have all but disappeared in the United States, but oil (diesel fuel and gasoline) power nearly all our transportation. More than 60 % of the oil consumed in the United States is now imported. Demand for petroleum will soon exceed world production capacity and at that point the price of fuel will start to rise dramatically. We should be asking ourselves how we will cope with gas prices as they rise from $2.50 to $5 to $10 per gallon and keep rising. It's hard to imagine the hardship that will be faced by countries that remain addicted to oil, and even harder to imagine the suffering in countries that have oil, but do not have the strength to protect their resources or themselves.

Now consider that the entire recoverable world oil reserve is equivalent to the solar energy that strikes the Earth in *one* day.

Biofuels and Hydrogen

Before we explore the solar-electric future let's discuss biofuels and hydrogen as other possible alternatives. Although both have received a lot of good press, I believe neither is a viable solution for our future energy needs.

Waste oil and biomass can make good transition fuels but unless human population growth slows, we will need all existing agricultural land to grow food. There are already many examples of food crop land that is being used to create ethanol to power inefficient flex-fuel SUVs. The cost of tortillas quadrupled in Mexico in one year because of rising demand for corn to make ethanol. Why should the world's poor struggle to afford food so the rich can green-wash their gas guzzlers.

According to some studies, it takes 1,000 gallons of water and more than a gallon equivalent of fossil fuel to produce 1 gallon of corn ethanol. Finally, consider that biofuels just aren't very efficient. When you do the math, the overall efficiency of biomass used as transportation fuel, from sun to wheel, is about 0.01 percent to 0.05 percent. In contrast, the overall efficiency of using solar panels to charge electric vehicles from sun to wheel is 3 percent to 10 percent. This means that solar-charged electric vehicles are from 60 to 1,000 times more efficient than vehicles burning ethanol or biodiesel. Food should always trump fuel.

Hydrogen fuel cell vehicles are no more efficient than biofuels. Hydrogen is much lighter than air, and it must be contained in order to keep it from escaping the Earth's atmosphere, unless it is bound up in water or hydrocarbon molecules. The strong bonds that hold these molecules together take a significant amount of energy to break apart to extract the hydrogen. Once the hydrogen is extracted, more energy is needed to compress it into a container that is small enough to store on a vehicle. In order for a fuel cell vehicle to go 200 or 300 miles on a reasonably sized tank, the hydrogen must be stored in metal hydrates or at 10,000 psi in heavy containers.

Even after more than 20 years of development, fuel cell vehicles still cost more than a million dollars each and don't last very long or go very far. Finally, it takes about four times more renewable energy to drive a fuel cell vehicle than it does to charge the batteries in an electric vehicle to go the same distance. This is like the difference in fuel economy between a Hummer and a Prius. If you are wondering why hydrogen fuel cell vehicles continue to receive billions of dollars in funding given all these barriers, the fact that 97 percent of all hydrogen is currently extracted from fossil fuels may give you a clue. There are powerful vested interests controlling our energy policy. Only informed citizens acting together can steer the best course.

A Bright Solar-Electric Future

A solar-electric economy is well within our reach. We're already generating solar electricity at the utility scale using powerful concentrating solar power technology. We're also generating electricity through wind energy, which is really an indirect form of solar energy because it's driven by temperature differences created as the Earth rotates and is exposed to heat from the Sun.

Simply incorporating the energy efficiency, conservation and solar design strategies in this book can save up to 95 percent of the energy that is used in conventional buildings. With the addition of building-integrated photovoltaics, buildings can be turned into net energy producers.

SunPower Crystalline modules.

Flexible thin-film BIPV

The cost of conventional Crystalline PV modules dropped more than 25% in 2009 and new thin-film technologies are pushing the manufacturing cost even lower.

Crystalline PV modules are made by encapsulating wafers of highly refined silicon under rectangular sheets of glass framed with aluminum extrusions. Crystalline PV has dominated the industry since the discovery that sun light could be turned into electricity. For over 50 years, incremental improvements in conversion efficiency and manufacturing competence have resulted in glass covered aluminum framed modules capable of converting 12% - 18% of the solar radiation that strikes them into electricity. Crystalline modules still dominate in PV sales but in the last few years most of the new development work has been focused on thin-film PV technologies.

Large area thin-film PV modules and laminates have been commercially available since the '90s and the products now on the market have conversion efficiencies of between 6% - 11%. The higher the efficiency the less area and support structure is required to produce the same amount of electricity. But the cost of manufacturing some thin-film PV technologies is much lower and some thin-films have much better high heat and low light performance than crystalline PV cells.

There are four semi-conductor materials that dominate the thin film PV industry:

1. Amorphous silicon *(a-Si); first developed in the '70s by Stan Ovshinsky the founder of Energy Conversion Devices (ECD) became the material of choice for charging consumer products like watches and pocket calculators. ECD's solar division, Uni-Solar MI, produces a-Si, flexible thin-film (see 'Easy Solar Power' MEN Oct '06) with a real life conversion efficiency of 8.5% and a maximum lab efficiency of 13%. They offer a 25 year warrantee on their laminates when they are bonded to specified roofing products like standing seam metal or flexible membrane roofing. In spite of relatively low efficiency and high manufactured cost (around $2/W) the unique ability of their laminates to be adhered to roofing products has made Uni-Solar the undisputed leader in flexible thin-film for more than a decade. This dominance will probably soon be challenged by manufacturers who will use less expensive deposition and encapsulation techniques or develop products that do not require roofing as a substrate. There are many companies attempting to compete in the ridged PV module market with a-Si deposited on glass but none will likely survive unless they can challenge the low cost records set by First Solar with CdTe (see below).*

2. Copper indium gallium diselenide *(CIGS) was developed in the '80s as a high efficiency (11% real life, 20% lab) alternative to a-Si. The fact that CIGS degrade rapidly in the presence of moisture has led several well funded companies like Miasolé CA, Nanosolar CA and Solo Power CA to encapsulate their flexible cells under glass. This method of encapsulation squanders the light weight flexible advantage of thin-film and puts these companies in direct competition with every other PV module manufacturer in a race based only on cost. Global Solar AZ, Helio Volt TX, and, Ascent Solar CO are the leaders in flexible encapsulation but do not yet have commercially available products.*

Solyndra is the only CIGS manufacture that has a product ready for the building industry. To solve the moisture degradation problem Solyndra deposits CIGS on the inside of small glass cylinders and hermetically seals the ends. They have developed a method of fast installation of their finished modules on large flat roofs that does not require the roof penetrations or the heavy ballast needed for the installation of most glass PV modules. If the moisture degradation issue can be solved CIGS with the highest potential efficiency of any thin film will probably be the flexible thin-film material of choice.

3. Cadmium telluride *(CdTe) was developed in the '90s and has a real life efficiency of about 11% and a maximum lab efficiency of 16%. First Solar OH has recently overcome concerns about the toxicity of cadmium and is now the low cost leader for large scale ground mount installations. The Swiss Federal Laboratories for Materials Testing and Research in Dubendorf, Switzerland, announced in August '09 that it has improved the efficiency of flexible CdTe thin film solar cells to 12.4%. This development has the potential to make CdTe the low cost leader for flexible thin-film applications.*

4. Organic thin-films *currently are low efficiency (<6%) and have a short life expectancy (<6 years) so they are far from having a viable product for the building industry or to compete in the PV module market. G24i Innovations a manufacture of dye-sensitized solar cells made the first-ever commercial shipment of dye-sensitized PV modules in Oct '09 to Hong Kong for use on bags and backpacks. Konarka MA another organic thin-film manufacture has purchased a Polaroid printing facility capable of producing 1 GW of flexible plastic PV/year. This manufacturing output is predicated on the company's goal to raise efficiency to 10% and the life of its product to 20 years by 2011.*

In 2005 over 95% of the PV market was served by crystalline modules. Since then there has been a steady rise in thin-films share of the market and literally hundreds of thin-film PV companies have entered various stages of product development or production. For every thin-film company having some measure of success there are a dozen or more that are struggling with lack of adequate funding, development delays or cost overruns. The vast majority of these companies are encapsulating their thin-film cells under glass. The glass PV module market is almost entirely driven by installed cost so there will ultimately only be a few low cost survivors.

Utility Scale Ground Mount

In 2009 First Solar was the undisputed leader in PV module price reduction. They overcame concerns about the toxic cadmium used in there modules with a cradle to cradle recycling program and produced over 1GW (1 million kW) of cadmium telluride (CdTe) on glass modules with an average of 10.9% efficiency and excellent high heat performance in 2009. First Solar's revenues have grown from $14 million in 2004 to $2 billion in 2009 as they have lowered their manufactured cost from $3/W to $.93/W. This is close to half the manufactured cost of crystalline modules and most other thin-film PV products on the market. They also dramatically reduced the balance of system (BOS) costs to $1.20/W. The BOS includes wiring, inverters, and mounting structures, essentially everything but the PV modules.

Their winning cost cutting approach also includes reducing the permitting and installation time from years to months on utility scale projects. Initial side by side comparisons done by Fat Spaniel show a 10 -15% savings in installed cost with First Solar modules and about 10% greater output than crystalline modules with the same rated capacity. In August 2009 Southern California Edison signed a contract for 500 MW of First Solar modules for a desert installation capable of powering 170,000 Homes. Then in September, First Solar announced plans for a 2 GW installation in China. By 2014 First Solar is committed to increasing the efficiency of their modules to 15%, decreasing their manufactured cost to $.52/W and decreasing their BOS cost to $.95/W. If First Solar is successful in meeting these goals, some time early in the next decade utility scale thin-film PV will take a place alongside wind and concentrating solar power (CSP) to make the construction of new fossil or nuclear power plants a thing of the past.

A future with utility scale solar power plants is a step in the right direction but it still leaves control of power production in the hands of a relatively few large corporate and municipal utilities. In addition, getting the power from areas that have the best solar resource, like the Southwest, to the heavily populated areas of the country that have less sunshine would require a vast new network of transmission and distribution lines along with huge buffering infrastructure to store excess power when demand is low and release power when it is needed. The monetary and environmental cost of this scale of new infrastructure will be a significant obstacle to centralized power production.

Roof Mount DG

The alternative to centralized power production is distributed generation (DG). DG can make the existing grid operate more efficiently and limit the need for a huge expense on new transmission and buffering infrastructure by producing power were it is used. There is enough existing sun bathed roof and parking lot area, that could be covered with PV arrays, to provide all the electricity used in buildings and to charge a national fleet of plug-in vehicles. The same mass adoption that made room sized main frame computers give way to lap top PCs will make huge central power plants to give way to roof top PVs.

DG on the Google headquarters

DG on residential roofs in Japan

Net Metering

Net metering laws, that allow the energy produced by residential and commercial PV installations to be fed into the grid, are now in place in almost every state. Net-metering is a "win-win-win" for the utility, building owners and all life on the planet. The utility adds more clean power to its network from a power source located close to demand centers, reducing not only the need to build new plants to meet peak demands but also reducing the load on distribution lines. The process is a win for the building owner, who doesn't need a bank of batteries to store electricity to power the household at night or during overcast days. Instead the system uses the utility grid as a storage battery. And with every PV installation there are less CO2 emissions and we all breathe a little easier.

Here's how net metering works: When a solar-electric rooftop produces more electricity than the household needs (at midday when the family is away at work and school), electricity is sent to the utility grid and the home's meter runs backward. When the household needs more electricity than the system produces (at night), it is drawn from the utility grid and the electrical meter runs forward. The net difference between electricity exported to the grid and grid-electricity used forms the basis for the homeowner's electric bill. In many states, net metering is annualized. The utility credits solar electricity produced by the rooftop system during the summer against electricity needed from the grid during the winter. Some states like California have Time of Use (TOU) net metering which allow PV owners to be compensated at a much higher summer afternoon rate when their array is at peak performance. It is time to make the advantages of net metering available to everyone with a national standard that would incorporate the best from the individual state programs.

Incentive Programs

Many states also have incentive programs and there is a 30% federal tax credit to offset the cost of PV installations. There is a very helpful web site (www.dsireusa.org) that lists all the incentives, programs and laws that pertain to renewable energy in every part of the country. States like New Jersey and Pennsylvania have programs that can make PV installations cash positive from day one.

Not so long ago the US led the world in PV installations but now places like Japan, Germany and Spain are well ahead of the US in installed capacity. Many countries in Europe have encouraged solar installations by offering low or no interest loan programs that can be paid off with premiums paid for electricity from clean renewable sources like the sun. These payments for energy produced from renewables, called feed in tariffs (FITs), have been so successful that solar roofs are common place in some countries. As an example 1 out of every 5 roofs are covered with PV in the state of Bavaria, Germany, and 15% of their electricity comes from solar energy. By comparison, California with over 60% of the PV installations in the US gets less than 1% of its electricity from the sun.

To date most of the federal stimulus money, ear marked for renewables, is going to utility scale projects. It will take citizen action to convince Washington that these funds should be redirected to revolving low or no interest loans and FITs. These programs would cost the tax payers less money and promote true solar independence.

Many of the countries that have used FITs to stimulate renewable energy installations have acknowledged the benefits of DG by offering a higher payment for PV that is installed on buildings. Germany was the first to establish a FIT and started with a program that paid $.74/kWh for electricity for DG installed on buildings and $ .52/kWh for electricity from ground mount installations. Ontario, Canada now has one of North America's first FITs which pays up to $ .80/kWh for roof mount PV and only $ .44/kWh for PV mounted on the ground. France recently introduced a FIT that pays $ .38/kWh for ground mount and $ .57/kWh for PV mounted on commercial buildings. The higher payment for PV mounted on buildings is intended to aid businesses, factories and farmers to take profitable advantage of their large rooftops. France also has a new category that pays $ .70/kWh for building integrated photovoltaics (BIPV) to recognize and promote the synergies and cost savings available when PV materials are used to replace conventional building materials in parts of the building envelope such as the roofing, skylights, awnings or facades. Finally, the advantages of using the sun bathed portions of a buildings skin to generate energy are starting to be understood and supported.

Building Integrated Photovoltaics (BIPV)

The idea of BIPV is not new. Architects like Steven Strong and Richard Schoen have been using PV modules as roofing since the early ‘80s but using the glass modules that were available at that time was both challenging and expensive. Glass is transparent, weatherproof and long-lasting but it can shatter and it is not an ideal roofing material.

There are applications where glass PV modules can replace existing architectural elements like awnings and facades. There are also a few companies that produce thin-film modules that can be used as windows with various degrees of transparency. These modules like their crystalline cousins have fairly high cost but in urban areas at high latitudes the walls of multi-story buildings receive more solar radiation than their roofs, so glass modules will continue to have a niche for BIPV applications. Having products for niche BIPV applications is important but imagine the potential of being able to cover the solar exposed surface of any building with low cost roofing or siding that generates electricity.

Habitat for Humanity/Uni-Solar project in Sacramento CA Photo; Steve Heckeroth

Uni-Solar’s amorphous silicon (a-Si) thin-film laminates have been demonstrating the advantages of light weight flexible solar cells on roof top applications since 1997 with hundreds of MWs of installations bonded to roofing sub-straights. In the late ‘90s Uni-Solar started the transition from framed modules to BIPV with flexible laminates bonded to metal roofing and strips of thin-film cells that mimicked asphalt shingles. Uni-Solar’s shingles were difficult to install and the traditional adhesive used in PV industry were flammable so the product never got into mass production and was eventually discontinued. In 2001 Southern California Roofing spun off Solar Integrated Technologies (SIT) and developed a process for bonding Uni-Solar laminates to membrane roofing. SIT became the first of many roofing companies to work with PV manufactures to make products that serve the dual function of weather tight surface and power generation.

Solar Integrated Technologies (SIT) project in Los Angles CA Photo; Steve Heckeroth

In January of 2009 Carlisle Energy Services, a newly formed division of Carlisle Construction Materials, a leading manufacturer of energy-efficient single-ply commercial roofing systems announced a multi-year agreement to purchase Uni-Solar laminates. In July '09 Johns Manville a leading global manufacturer of single ply, built-up and modified bitumen roofing membrane systems announced the formation of a new business entity called E3 Co. and a multi-year agreement to purchase Uni-Solar laminates. In August '09 Uni-Solar announced a merger with SIT and in Oct '09 the merged company announced the sale of 4.8MW of PV laminates which will be installed on eight large commercial roof tops in Barcelona, Spain. Also in October CertainTeed a leading North American manufacturer of asphalt shingles announced a joint agreement with Uni-Solar to develop roof integrated PV products for the residential market. The New York Times ran an article in Oct '09 on SRS Energy's Solé Power Tile that incorporates Uni-Solar cells into a curved Spanish tile roof.

SRS Energy's Solé Power Tile that incorporates Uni-Solar cells

In addition to alliances between roofing companies and PV manufactures, major chemical companies like; BASF, DuPont, 3M and Dow have all formed solar divisions to improve the transparency, durability and fire resistance of the materials used to encapsulate PV cells. In Sept 2009 Dow Building Solutions announced that they are working with Global Solar a leading manufacture CIGS flexible thin-film cells to developing 15.5% efficient solar roofing shingles.

Electric Vehicles & Plug-in Hybrids

The other development that will bring solar energy to the main stream is the plug-in vehicles that will be available on show room floors in 2010. Given the choice between paying 10 cents or more a mile for fuel in a polluting combustion car and 1-3 cents to go the same distance in a clean EV, people should promptly start adopting Plug-ins. BIPV installations will follow as a popular way to achieve energy independence.

Most people don't realize how much energy they use in their cars. A gallon of gasoline is 30 kWh of concentrated solar energy that was hundreds of millions of years in the making. About 30 kWh is consumed each day in average US home. So if you burn more than a gallon of gasoline a day you could be using more energy in your car than you are in you home.

Fortunately electric vehicle drive trains are inherently five to ten times more efficient than internal combustion engines so switching to EVs will require far less energy than fossil fueled transportation. Even if the electricity to power EVs comes from fossil-fueled power plants, emissions are much lower per mile traveled than with internal combustion engines and they produce no greenhouse gases at the tailpipe. In addition, electric vehicles can be charged directly from renewable sources, thereby eliminating emissions altogether.

One of the main excuses the auto industry offers for the lack of electric vehicles is that “the batteries are not developed yet.” But consider how quickly cell phone batteries developed, transforming mobile phones from heavy, bulky, short-lived nuisances to amazingly light, small and long-lasting necessities. The oil companies are doing a good job of protecting the American consumer from “dangerous” batteries, but in parts of the world where oil companies have less control, large format battery development is progressing very rapidly. The collapse of the American auto companies is at least partially the result of the petroleum industries ability to stifle clean technology development. As affordable EVs come on the market, in spite of big oils best efforts, and word gets out that you can do your commute with the same comfort and convince for 2 cents a mile instead of $.10, even billions of dollars in advertising won’t stop the revolution. Don’t wait or you’ll be on a waiting list.

RAV4EV and solar charging shed on the Heckeroth Homestead Photo; Steve Heckeroth

Agriculture and Solar Charged Electric Tractors

Experts have estimated that it takes eight to 10 units of fossil energy to put one unit of food energy on American tables, and that it takes the equivalent of 10 barrels of oil to feed each person in the US. Hearing those figures, it's frightening to imagine what will happen as oil supplies dwindle and prices rise. Farm machinery like almost all modes of transportation is now totally dependent on oil.

The good news is that not only can tractors run on electricity, they make even more sense than other EVs because they can use battery weight for increased traction and they operate at slower speeds. A solar charged electric tractor can quietly accomplish all the tasks necessary to maintain productivity on a small farm.

Dealing with the rising cost of mobility and energy are huge challenges, but the biggest challenge facing humanity may be maintaining an affordable and nourishing food supply. We can have fresher and more nourishing food without fossil fuels. What it will take is public support for a switch to local food production on small organic farms using solar irrigation pumps and solar-charged electric tractors.

SolTrac and solar charging shed on the Heckeroth Homestead Photo; Steve Heckeroth

We Have the Power

It's easy to feel confused, cynical and even hopeless about the state of the planet these days. But I am excited and optimistic because I know we have the technology now that will allow us to wean ourselves from fossil fuels and move to a renewable solar-electric energy system.

Yes, I know — solar panels are still too expensive for many of us. But 10 years ago, nobody gave hybrid cars a chance of succeeding. Today, the Toyota Prius is the hottest thing going. Plug-in hybrids and all-electric options will be available by the time you read these words. For every new development that has been announced in the press there are dozens more in the works that will make future generations wonder why people ever burned fossil fuels to make energy.

If we work together and demand that our government set a wise energy policy and use taxes to support the right renewable energy options, I predict we can put the brakes on climate change and enjoy a clean and truly green energy source and planet.

Montara Elementary School lunch room with BIPV on the roof