Chapter 2
The Solar PV Market Today and the Need for Non-polluting Solar Energy

In Chap. 1, it was noted that installed solar PV systems prices have now dropped to approximately $4 per W in the US. What does that mean in terms of cents per kWh and how does that compare with the costs of other ways of generating electricity? The US Department of Energy (DOE) Energy Information Agency (EIA) published a projection for 2017, for the costs of the various forms of generating electricity as shown in Table 2.1 [1].

It is interesting that there is a row for carbon capture and sequestration, which already suggests a bias in favor of hydrocarbon fuels since this technology does not yet exist. Nevertheless, let us explore the solar PV predictions. The range is from 12.2 cents per kWh ($122 per MWh) to 24.6 cents per kWh. How does one relate installed system price in $ per W to Levelized Cost of Electricity (LCOE) in cents per kWh? The following is a simple intuitive way of connecting these numbers. One needs the number of annual hours of solar energy in kWh/m2/year and as well as the PV technology efficiency. The following is a simple example calculation. If the PV module efficiency is 20 %, then for a solar intensity of 1 kW/m^2, 1 kW of solar PV will require 5 m^2 of module area. That 1 kW will cost $4,000 at $4 per W installed. Next one needs a map of solar intensity as for example in Fig. 2.1 for the US.

Notice from this map that most of California has a solar resource of over 2,000 kWh/m^2 per year. This means that at 10 cents per kWh, 1 kW of installed PV will produce revenue of $200 per year and it will require 20 years for an investment payback. However, at 20 cents per kWh, the payback time will be 10 years. In either case, the PV modules are warranted to last for 25 years.

The Age of Hydrocarbon Fuels

We now live in the age of energy from hydrocarbon fuels. Oil has certainly changed our lives to the extent that the energy in one barrel of oil equates to approximately 25,000 h of human labor or 12.5 years at 40 h per week [3].

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Table 2.1 Projected costs for electricity from various fuel sources for 2017 [1]

Plant type	Range for total system levelized costs (2010 USD/MWh)		
	Minimum	Average	Maximum
Conventional coal	90.1	99.6	116.3
Advanced coal	103.9	112.2	126.1
Advanced coal with CCS	129.6	140.7	162.4
Natural gas fired			
Conventional combined cycle	61.8	68.6	88.1
Advanced combined cycle	58.9	65.5	83.3
Advanced CC with CCS	82.8	92.8	110.9
Conventional combustion turbine	94.6	132.0	164.1
Advanced combustion turbine	80.4	105.3	133.0
Advanced nuclear	108.4	112.7	120.1
Geothermal	85.0	99.6	113.9
Biomass	101.5	120.2	142.8
Wind	78.2	96.8	114.1
Solar PV	122.2	156.9	245.6
Solar thermal	182.7	251.0	400.7
Hydro [16]	57.8	88.9	147.6

O&M = operation and maintenance. *CC* = combined cycle. *CCS* = carbon capture and sequestration. *PV* = photovoltaics. *GHG* = greenhouse gas

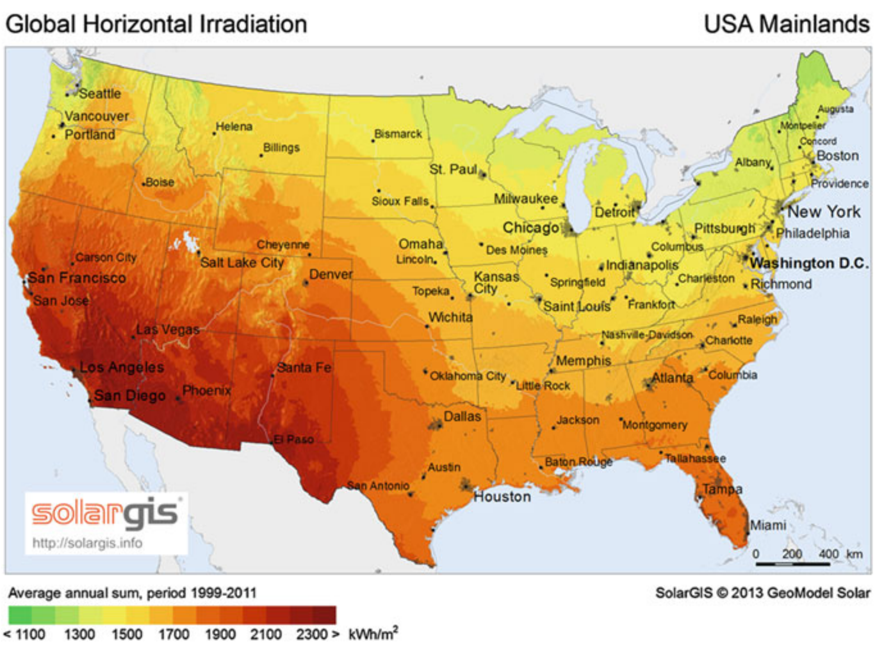

Fig. 2.1 Solar radiation map for US [2]

Hydrocarbon fuels include oil, natural gas, and coal. Of these, oil is the most apparent in our lives in that we depend on gasoline for transportation and we are very aware of gasoline prices at the pump.

Peak Oil

Oil has revolutionized our means of transportation. However, economically recoverable oil reserves are finite. In 1956, the geologist M. King Hubbert predicted that U. S. oil production would peak in the early 1970s. Almost everyone, inside and outside the oil industry rejected Hubbert's analysis. The controversy raged until 1970, when the U. S. production of crude oil started to fall. Hubbert was right. Around 1995, several analysts began applying Hubbert's method to world oil production, and most of them estimated that the peak year for world oil would be between 2004 and 2008. These analyses were reported in some of the most widely circulated sources [4]: Nature, Science, and Scientific American. The oil price hit $147 per barrel in July 2008. However, this price fell with the beginning of the great recession. While the great recession was attributed to subprime mortgage defaults, higher gasoline prices may have contributed to some of the stress on mortgage payments. Nevertheless, the oil industry denied that peak oil might be approaching.

Figure 2.2 presents data and a projection for the US DOE EIA for World's Liquid Fuel Supply. It shows that the World's Liquid Fuel Supply has been level at around 83 million barrels per day since 2008. It also shows a developing decline in known production sources starting in about 2015 [5]. One can be optimistic that unidentified sources might fill the developing gap between supply and demand.

However, many doubt that new liquid fuel sources will be found to fill this gap. For example, Olivier Rech, at one time responsible for petroleum issues at the International Energy Agency has said "The production of oil has already been on a plateau since 2005 at around 82 mb/d (NB: with biofuels and coal-to-liquid, it is approximate 88 mb/d for all liquid fuels). It appears to me impossible to go much higher. Since demand is still on an increasing trajectory (unless, possibly, the economic crisis engulfs the emerging economies), I expect to see the first tensions arising between 2013 and 2015. Afterwards, in my view, we will have to face a decline of the production of all forms of liquid fuels somewhere between 2015 and 2020" [6].

Why is peak oil relevant to a discussion of Solar PV? Solar PV is not going to replace oil for transportation in the near term. However, Solar PV could in the longer term provide electricity for electric car batteries. This will be discussed further in Chap. 9.

Jeremy Leggett has written a recent book entitled, *Energy of Nations*, where he talks about an ongoing energy debate between an Incumbency and an Insurgency [3]. The Incumbency comes from the Oil, Natural Gas, Coal, Nuclear, and Financial sectors and the Insurgency is the Solar and Renewable Energy sector. He

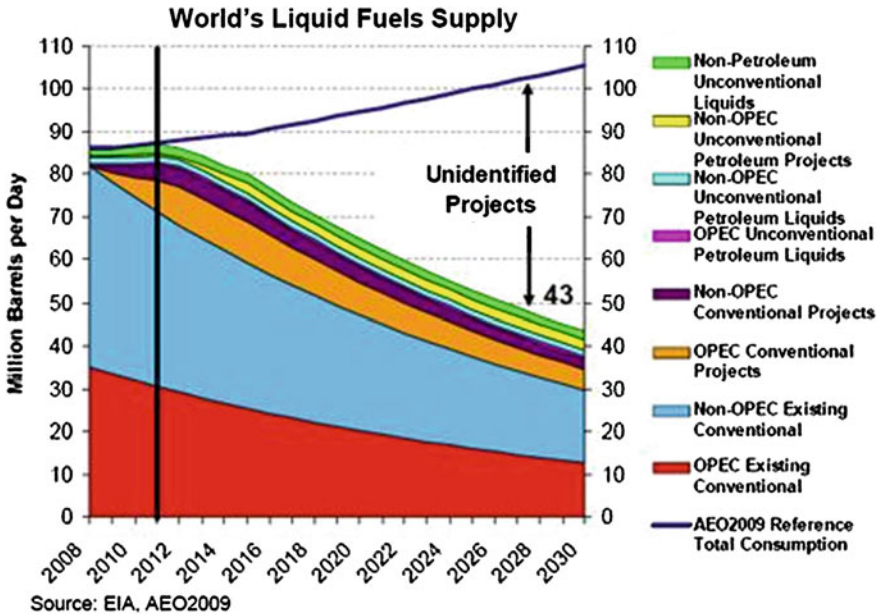

Fig. 2.2 EIA projection for liquid fuels supply [5]

argues that the money is now flowing to the Incumbency, but when there is an obvious decline in Liquid Fuel supply, there will be a shift in Context or mindset and money will then start to flow to Solar and the renewable energy sector.

Global Warming

Meanwhile, there is another driving force in favor of renewable energy and that is global warming or climate change. This is happening more slowly and again denied by the Incumbency. However, the evidence for climate change is abundant. The burning of hydrocarbon fuels is generating CO_2 in the atmosphere and that is producing a greenhouse effect trapping radiant heat by the atmosphere, thereby slowly increasing the earth's average temperature. Figure 2.3 shows the evidence for increasing CO_2 over time [7].

The dominant fuel burned in both the US and China for generating electricity is coal. It generates both particulates and lots of CO_2. In December of 2013, smog from burning coal in China severely limited visibility in both Beijing and Shanghai. Figure 2.4 shows a photograph of Shanghai on a typical smoggy day.

In spite of the denials from the Incumbency, there is ample evidence of global warming. For example, Fig. 2.5 shows that the Arctic Sea Ice is melting.

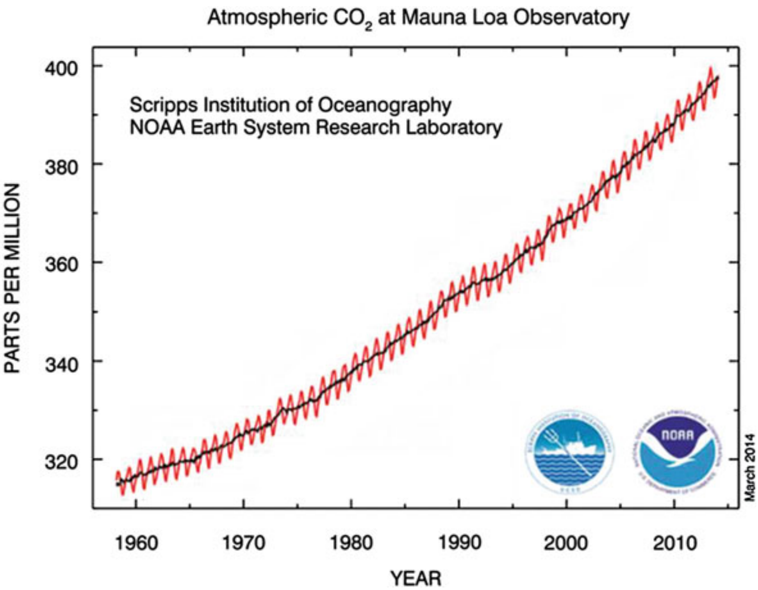

Fig. 2.3 Measured CO_2 levels in the atmosphere [7]

Fig. 2.4 Shanghai Dec 3, 2013

There are also recent weather events that should serve as warnings. For example, Superstorm Sandy at the end of 2012, caused $62 billion in damages and led to the flooding of the New York subway system. Then in 2013, Typhoon Haiyan pictured in Fig. 2.6 killed 6,000 people with more than 12 million people

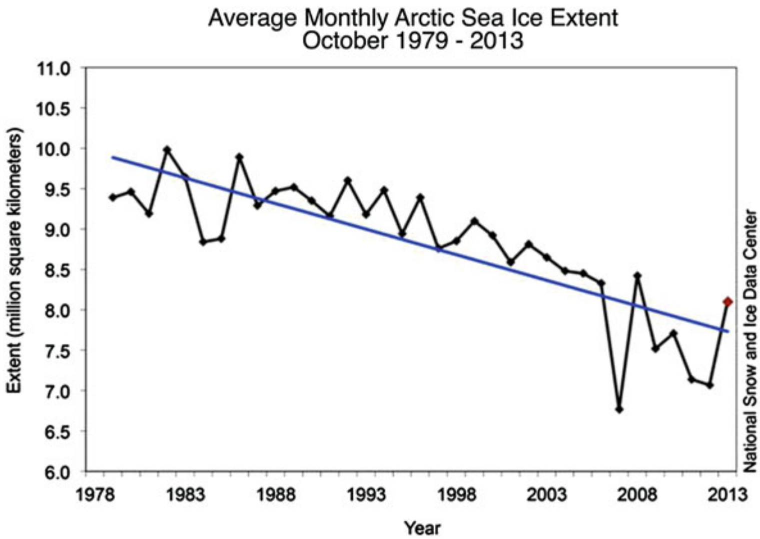

Fig. 2.5 Satellite photos show that the arctic sea ice is melting [8]

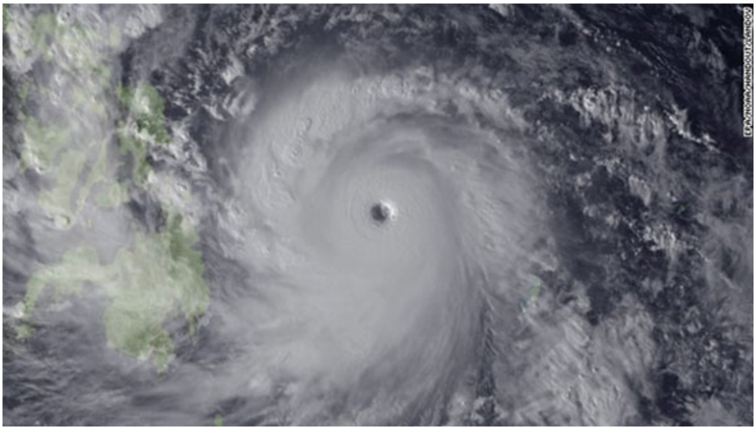

Fig. 2.6 Photograph of Typhoon Haiyan taken from the international space station [9]

affected by the monster typhoon. It left behind catastrophic scenes of destruction and despair when it made landfall in the Philippines.

So, the relevant question here is: What can be done to survive a decrease in oil supply and global warming? The obvious answer is a shift to renewable energy. Unfortunately, the Incumbency is still dominant. Figures 2.7 and 2.8 show what may well happen by continuing to burn hydrocarbons with business as usual [10]. Representative Carbon Pathways (RCP) have been modeled based on the amount of hydrocarbon burning in the future and the effect of thermal energy trapped by

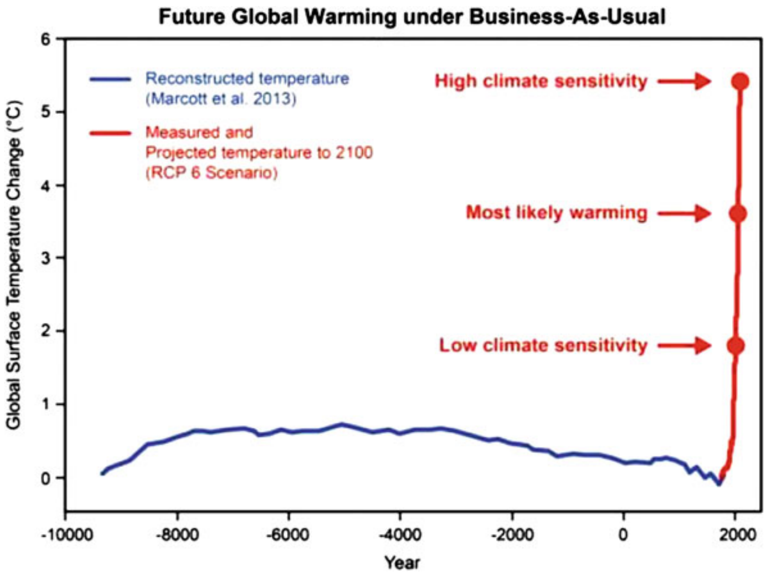

Fig. 2.7 Predicted global surface temperature change by 2,100 for the RCP-6 scenario. Representative concentration pathways (RCPs). Specify radiation forcings at this interval—3, 4.5, 6 W/m^2 plus the big one at 8.5 W/m^2 (*the* 3 W/m^2 *scenario actually peaks earlier at* 3 W/m^2 *and declines to* 2.6 W/m^2 by 2100)

the accumulated CO_2. For example, RCP-6 implies that the earth warming from CO_2 will be increased by 6 W/cm^2.

Most recently, there has been a news media promotion for shale oil and natural gas. The incumbency is now claiming that the Shale Gas boom will last for 100 years. However, there are critics. Bill Powers in his book entitled *Cold, Hungry and in the Dark: Exploding the Natural Gas Supply Myth* argues that the Shale gas supply will peak in 2015 or soon thereafter [11]. In any case, it is true that Natural Gas is the least polluting of the hydrocarbon fuels and will be complementary with solar PV in the next decade.

The Arguments for Solar Energy

My group at Boeing first demonstrated the 35 % solar cell 24 years ago in 1989. It then took another 17 years before there was funding to incorporate this cell with optics into a 33 % efficient concentrating PV module. Why did it take so long? When I wrote my first book, *Path to Affordable Solar Electric Power and The 35 % Efficient Solar Cell*, in 2004 [12], I made a plea for a US Apollo program to launch solar energy.

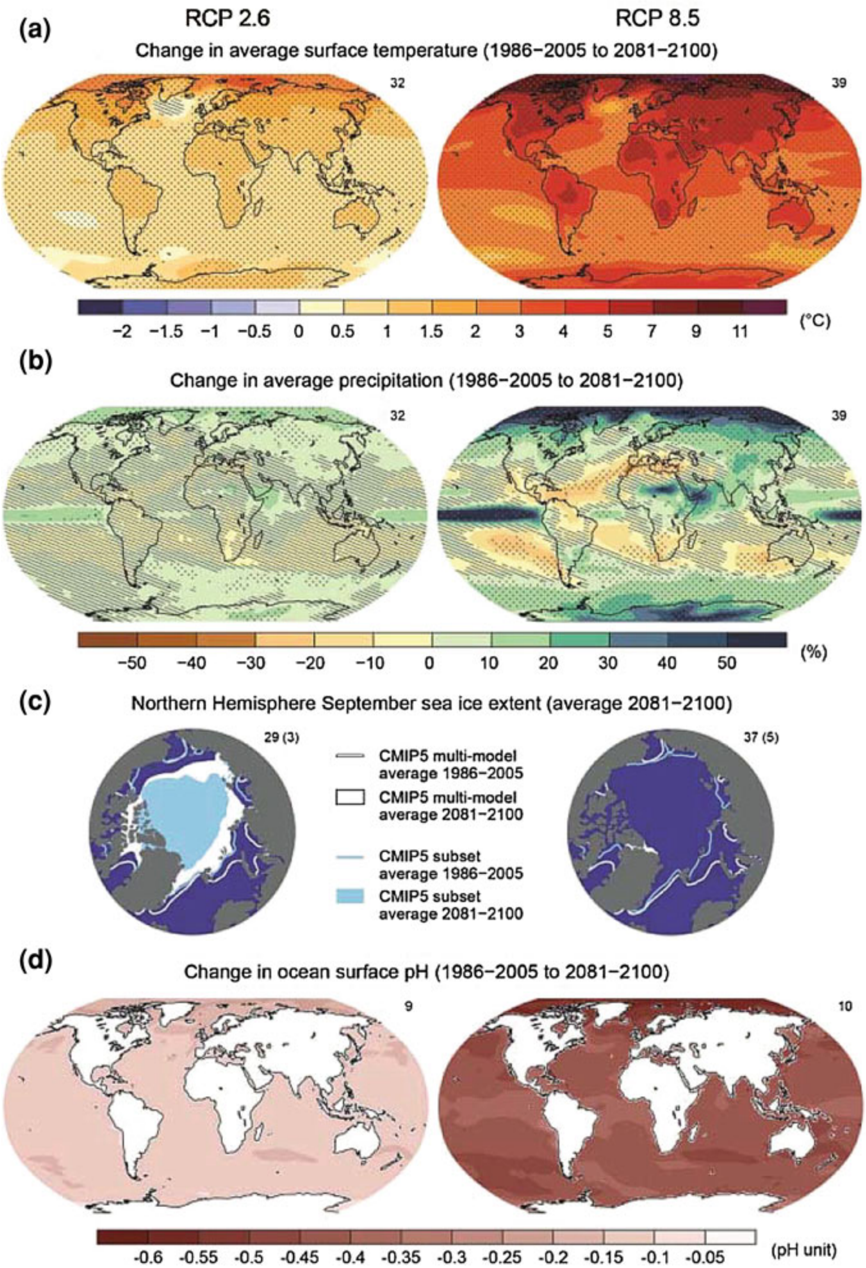

Fig. 2.8 Predicted global changes [10] between approximately 2000 and 2100 for the RCP 2.5 and RCP 8.5 cases. **a** Change in average surface temperature (1986–2005 to 2081–2100), **b** change in average precipitation (1986–2005 to 2081–2100), **c** Northern Hemisphere september sea ice extent (average 2081–2100), **d** change in ocean surface pH (1986–2005 to 2081–2100)

At that time, I asked: "Who is going to commercialize solar energy?" I noted: "It is not the American oil companies given that they can obtain low-cost oil from the Middle East secured by the American military. It is probably not the defense industry given that their charter is to develop weapon systems. It is probably not the electric utilities as they are very conservative and it may not be in their interest for the homeowner to generate his own power." I noted that while I had hoped that it could be small business, I had discovered that small business do not have access to the financial resources to play in the energy game. This game requires hundreds of millions to billions of dollars in order to play.

My plea in 2004 was not answered by the US government and as I noted in Table 6 in Chap. 1, the focus for solar PV shifted away from the US to Europe and China after 2001. China actually provided the billions of dollars required for manufacturing to launch silicon PV modules.

I am writing this book to make two strong statements: First, solar energy can become a mainstream source of energy over the next 10 years. And second, I would like to see the US re-establish a serious national program to develop alternative energy. There are still opportunities in PV for innovations leading to still lower costs as I will describe in Chaps. 7–12 in this book.

Why do I make these statements? I have three sets of reasons. My thinking has evolved through my career and so, I have to tell you a little about myself. I am a US scientist and I have been working on solar cells as well as other semiconductor devices for the last 40 years. I have worked with major defense contractors on space solar cells (Hughes from 1973 to 1978 and Boeing from 1986 to 1992) and at a major oil company on terrestrial solar cells (Chevron from 1978 to 1986). For the last 20 years, I have been president of JX Crystals Inc., a small solar cell research company.

In the following, I enumerate my reasons for advocating a larger national solar energy program now.

Reason #1: Lower-Cost Solar Electricity

Since I have spent my career in industry, I have learned that my first argument should be that solar cells can generate electricity at cost competitive rates with respect to other sources of electricity. This is because today's commercial solar cells produce electricity in sunny locations at rates of around 15 cents per kWh. However, advanced solar cells have been demonstrated that are twice as efficient as today's commercial cells. My group at Boeing demonstrated a solar cell in 1989, with 32 % efficiency as measured by NASA. This is the efficiency for space. Subsequently, it was shown that these cells can be operated here on earth with an efficiency of 35 % [13]. Higher cell efficiencies will bring down costs. Besides efficiency improvements, still other cost reductions are possible. Glass or plastic lenses or aluminum mirrors can be used to concentrate sunlight onto efficient solar cells. These collector materials are cheaper than single crystal semiconductor material. Cost reductions can also come by tracking the sun, thereby producing more kilowatt-hours (kWh) per kW installed. Implementing these cost reductions in high volume production can bring solar electric costs down below 10 cents per kWh. However, very large investments are required to integrate these cells into CPV systems and manufacture these cells and systems in quantities sufficient to bring down prices. The issue of the cost of solar electricity is a complex subject that will be treated in detail in the chapters throughout this book.

Reason #2: Rising Oil and Natural Gas Prices

My second reason relates to the fact that our oil and natural gas resources are being depleted. The consequence of this "Impending World Oil Shortage" is that electricity prices are going to be rising probably abruptly within the next 5–10 years. Add to this the possibility that global warming may lead to a carbon tax when the costs of weather disasters and increased insurance costs are finally added to the costs of burning hydrocarbon fuels. This affects the economics of solar electricity as solar modules based on semiconductor devices will last for 25 years or longer. Today's cost competition assumptions for solar usually assume a short-term payback and nonescalating energy prices.

Reason #3: War, Weapons of Mass Destruction, and the Moral Argument for Solar

When one thinks about conventional electric power production, one thinks about oil, natural gas, nuclear, and coal as fuel sources. The incumbency does not include Solar on this list. However, these conventional fuel sources have hidden unintended costs.

For example, nuclear fuels are coupled with nuclear waste management and nuclear weapons. Then nuclear waste and nuclear weapons are coupled with the cost of homeland security and our fear of weapons of mass destruction. There are hidden costs involved in attempting to guarantee that nuclear materials do not find their way into the hands of terrorists.

As another example of hidden costs, our dependence on oil from the Middle East has linked us unavoidably with terrorists from the Middle East. We have now fought two wars in the Middle East to secure our oil supply.

In contrast to the unintended costs just enumerated, let us look at solar energy. Solar is inevitable on the larger scale of time. Solar energy is really already a primary energy source through wind and hydroelectricity. Solar energy generated our coal, oil, and natural gas via photosynthesis a hundred million years ago. Solar cells are very much more efficient than plants at converting sunlight to useful energy. Finally, solar energy is benign and will benefit the whole world.

My problem is that I have watched our US energy policy over the last 30 years and independent of political party, our national energy policy de facto has simply been to guarantee the oil supply from the Middle East with our military as necessary. It is now time for a shift in policy.

This then brings me to my moral argument for solar energy. It is clear that oil and natural gas are resources being depleted. If we do nothing and allow these resources to become more and more scarce, we will be fighting future wars over these scarce resources. If on the other hand, we decide to invest in solar energy, we can decrease or eliminate our dependence on foreign oil.

We can make solar electric power generating arrays for the western US economically using automation. Automation is ideal for solar arrays and automation is what has allowed high American productivity. Then, we could even export solar power arrays to the Middle East and developing world in exchange for cash to buy oil. The present problem with this scenario is that automating solar array production will require very large investments.

So where are we now? Over the last 35 years since 1989, I have seen massive government funding to make 30 % efficient solar cells, the primary power source for spy satellites and I have seen the same semiconductor materials used in large numbers of weapon systems. As president of a small company, I have looked for funding to bring the 35 % solar cell to the terrestrial market place. However, there has been little interest in peaceful applications.

At the same time, I have learned that the amount of investment required to make an impact in the energy field is massive. The energy business is a multi-billion-dollar business. This book outlines a path to cost competitive solar electric power, but argues that major government commitment and cooperation with industry is needed to bring solar electricity into the mainstream in the US. While the investment support required is larger than small entrepreneurs can handle, it is small compared to the cost of war and terrorism.

Let us pause for a moment to put the current US government support for photovoltaic (PV) or solar cell development into perspective. The US DOE budget for solar energy in 2014 is $350 million to be divided between universities and government labs and the whole US solar industry. Most of this funding is going to universities and government labs. Meanwhile, the Chinese government is spending $2.1 billion in 2013 in subsidies to Chinese Solar Companies. The Chinese solar companies are using Si module technology initially developed in the US. Let me put these costs into a larger context. The cost of a new 1 GW electric power plant is roughly $1 billion. The cost of the Iraq & Afghanistan wars is estimated to be between $4 and $6 trillion. The cost of the Manhattan Atomic Bomb Project was $20 billion for the effort between 1940 and 1945[12]. Finally, the five-decade-plus bill for the U.S. nuclear weapons enterprise up to 2004 was $5.5 trillion, in 1996 dollars.

Over the next 20 years, solar electricity is inevitable. Building on U.S. discoveries, solar electric industries are now being expanded outside the U.S. through foreign government support. It is hoped that this book will awaken informed interest in the US.

I would like to see the US government set us on a path for a peaceful future. We will need the knowledge to make intelligent choices. I want the US to be remembered 100 years from now as the country that put a man on the moon and did constructive things and not as the strong military power that built the atomic bomb and took whatever it needed through wars.

At this point, some readers will object to my plea for government support and, in fact, this is a difficult issue that will require intelligent and careful implementation. My point here is that the Iraqi war has told us that time is running out. My message in this book is that there are already proven technical paths to affordable solar electric power. The problem is moving these innovations into commercially viable systems, qualification testing these systems, and then moving from small-scale production into automated high volume production. The magnitude of funding required for these early tasks is too large for private investors to handle without government commitment and cooperation. In this regard, government needs to actually help small businesses and investors and not just feed government labs and universities with long-term searches for miraculous future breakthroughs.

Solar PV Cells and Markets

There are a large number of PV cell types and a large variety of PV cell markets. Let us begin with the markets for the terrestrial Silicon solar cell planar module. The silicon solar cell planar module represents 80 % of the terrestrial market. All the terrestrial solar cell types will be discussed in Chaps. 3 and 5 will discuss the c-Si cell and module technology in more detail. This market began with off-grid cabins in the 1970s, but then spread to grid connected residential with PURPA in the 1980s. Grid-connected commercial installations with hundreds of kWs then began in the 1990s. Finally, after 2005, the utilities began to install systems with 10–100 MW sizes.

Today's terrestrial solar market is divided into three sectors with residential PV systems being generally less than 10 kW in size, commercial systems being in the 100 kW to 2 MW range, and utility systems being in the over 2–500 MW size today. In the future, a solar market segment with systems of 1 GW and larger should be expected.

Figure 2.9 summarizes the terrestrial solar PV market as of the end of 2013. Accumulated solar PV installed power hit 134 GW. However, the US fraction of this accumulated total was only 13 GW or 10 % of this total [14]. The message here in Leggett's terminology is that the US is the home of the incumbency. However, there is a small indication that a shift may be underway. In 2013, the total new PV capacity hit 35 GW worldwide with 5 GW of new capacity for solar in the US. The US share is then increasing to 14 %. However, China installed 12 GW in 2013 [15].

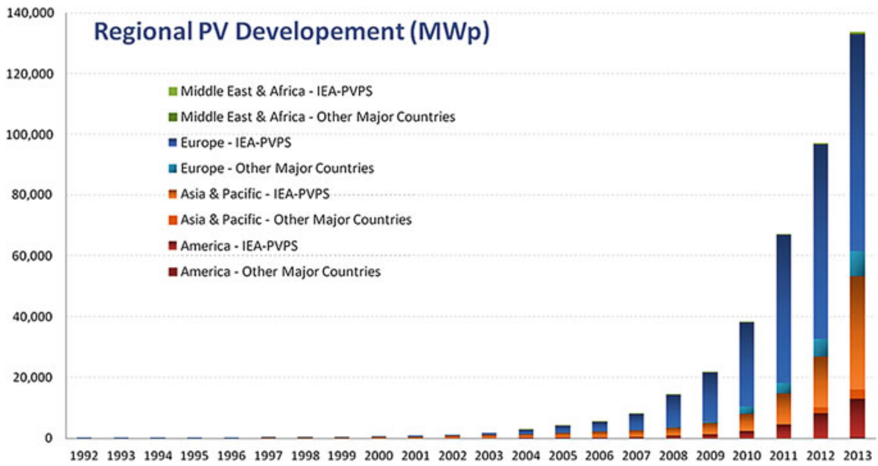

Fig. 2.9 PV development by region [14]

Solar PV Economics

The solar community often talks about module costs in $ per W. A Watt is a unit of power. However, it is now more relevant to talk about installed system power costs in $ per W instead of just module cost. It is even more important to talk about the LCOE in cents per kWh. A kWh is a measure of energy. The Electric Power Research Institute (EPRI) presented an important equation for calculating the LCOE for solar cell electricity systems [16]. This equation is repeated in Fig. 2.10 below along with nine important input variables required in order to calculate a numerical value for the LCOE. This equation is more precise than the simple qualitative intuitive example presented at the beginning of this chapter. The nine variable in Fig. 2.10 are important because they highlight the fact that vertical integration and cooperation is required amongst a large number of diverse groups in order to bring down the price of solar electricity in terms of cents per kWh.

For example, emphasizing low-cost modules is just the C_m term in the LCOE equation. The module supports, field wiring, and installation costs can be higher when the module efficiency is low because more modules need to be installed. This is the C_b term in this equation. The sunlight, S, available at the location is certainly important. Following the sun by tracking the modules will increase the number of hours per year of operation, which is the h_a term. Increasing the annual hours of operation will reduce the impact of the inverter cost, C_i. Note also that the cost of the hardware and installation are not the only costs. The projects have to be financed by the banks and this is the finance, F, term. Government permitting is also required and this can cause delays increasing costs and this is part of the project specific overhead, r, term. Finally, the system will need some maintenance over time.

Fig. 2.10 EPRI equation for calculating the levelized cost of electricity [16]

Leveled Cost Of Electricity

$$L = (1+r)(C_m + C_b)F_s / \eta_s S h_a + (1+r)C_i F_i / h_a + O\&M$$

The 9 key variables are:

1. η_s = PV system conversion efficiency
2. C_m = PV module cost ($/m ^{2})
3. C_b = area related BOS including installation ($/m ^{2})
4. S = Site specific solar intensity (kW/m ^{2})
5. h_a = Annual solar hours for PV system (tracking)
6. C_i = Inverter cost in $/kW
7. F = Fixed charge rate (converts initial investment into annualized charge)
8. r = Indirect cost rate (permitting, NRE)
9. O&M

Figure 2.11 provides information on solar power system costs in $ per W from a DOE study [17]. Referring to the equation in Fig. 2.10, this study presents results for

$$(1 + \mathbf{r})(\mathbf{C_m} + \mathbf{C_b} + \mathbf{C_i})\mathbf{F}.$$

Notice from this figure that the system cost is being doubled relative to the hardware cost by the permitting and financing terms, r & F. One might describe these as soft costs or, perhaps as some penalties associated with Leggett's Context imposed by the Incumbency.

The penalty associated with soft costs is significantly lower in Germany.

Installed PV system costs have been steadily falling. Starting in 2008, supply exploded as new manufacturing capacity was built. From 2008 to 2012, 80 % of the decline in total system cost was a result of falling module prices. The costs of nonmodule hardware also declined slightly, including "soft costs" like marketing, customer acquisition, design, installation, permitting, and inspection. But they did not fall as rapidly as module costs.

Whereas module prices declined as a result of global market factors—particularly the rapid buildup of supply in China, and strong feed-in tariff (FIT) incentives ensuring demand in Europe—reducing soft costs will require public policy changes aimed at removing market barriers and accelerating deployment.

Soft costs are the main reason why small residential PV systems installed in 2012, cost far less in Germany, Italy, and Australia than they did in the United States. Excluding sales or VAT taxes, Germany's median installed system price ($2.60/watt) was half the U.S. price ($5.20/watt). Unsurprisingly, residential system size has increased as prices fell. The median system size in 1998 was 2.4 kW; by 2012, it had grown to 5.2 kW.

The cost difference is even more pronounced with larger systems. Utility-scale systems in Germany were quoted at $1.90/watt in 2012, while they were installed for $4.50/watt in the U.S.

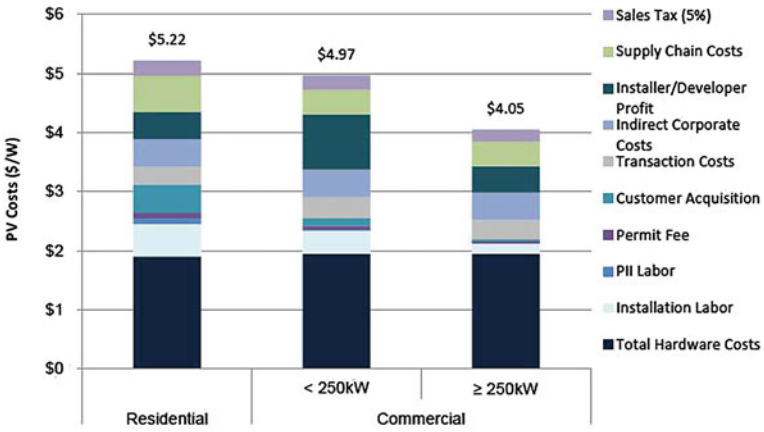

Fig. 2.11 Total US PV system price, by sector and system size (*first half of* 2012). Opportunities for PV improvements [17]

Maintaining the growth of the U.S. PV industry depends on continuing cost reductions, and that depends on significantly reducing soft costs. How can that be done? A LBNL report [18] found that soft costs for residential PV in Germany are just 19 % of those in the U.S. Why?

First, it costs about one-tenth as much to acquire a customer in Germany. That is primarily because Germany has a national FIT and the U.S. does not.

Second, costs for permitting, interconnection, and inspection in Germany are also nearly one-tenth of those in the U.S. Part of that is because it takes much less time: about 5.2 h per system in Germany, versus 22.6 h in the U.S. It takes an extraordinary amount of labor to create extremely burdensome, redundant, and oftentimes totally unnecessary permit packages to satisfy the requirements of building and planning authorities, which are different in every little town and county. The best way to reduce those costs is to standardize building and planning requirements for PV systems nationwide, and make it as easy and as cheap as possible to pull a permit. Local authorities should follow the example of Lancaster California where mayor Rex Parris directed city staff to clear away obstacles in the building and planning approval process to encourage the growth of PV. Contractors can now pull a simple permit for a residential solar system in Lancaster in 15 min, over the counter, for just $61.

Third, it's vital to cut the cost of installation labor. It takes almost twice as long to install a system in the U.S. as it does in Germany, partly because German installers rarely use the roof-penetrating mounting systems that are usually required in U.S. building codes. U.S. wiring practices should also be harmonized and standardized to reduce the amount of time installers have to spend trying to satisfy nitpicky and unnecessary requirements in certain jurisdictions.

Fourth, we should exempt solar PV systems from state sales taxes. Those taxes accounted for a median \$0.21/watt in the U.S. in 2011, whereas in Germany, residential solar systems are exempt from revenue, sales, or value-added taxes.

Finally, U.S. markets could be more open to competition in installation labor. Too many customers (particularly tax-exempt entities) are subject to restrictions requiring them to use union labor, or to allow only electrical contractors with certain licenses to install solar systems. Liberalizing installation rules could cut prices further.

The U.S. solar industry needs policymakers, regulators, code jockeys (electrical, building, and planning), and elected officials to step up and keep its growth momentum going.

Future Opportunities for PV Technology Improvements

Referring to Fig. 2.9, worldwide solar PV is growing dramatically. Solar PV in the US is finally growing even more dramatically up by 35 % in 2013 relative to 2012. To date, solar PV consists principally of planar silicon PV modules. However, there are some exciting PV developments on the horizon as will be described in this book.

Chapter 7 herein will describe a very exciting development involving highly-efficient solar cells with lens technology, or so-called concentrator photovoltaics (CPV). This new technology is just getting established in the market, and has a growth rate exceeding several hundred percent per year. It is already competitive, but still has great potential to become even cheaper. In the San Diego area, where there is a factory producing these types of cells, a 300 MW solar plant is being planned.

However, a problem for solar PV is that it just functions when the sun is shining during the day. However, Chap. 11 herein describes a nonsolar PV option where man-made heat sources can be used to generate infrared radiation where infrared sensitive PV cells can be used to generate electricity day and night. ThermoPhotoVoltaics or TPV can be used for generating heat and electricity in residential furnaces for small distributed systems. In other words, solar PV cells can be placed on the home's roof for electricity during the day and IR PV cells in the home furnace can be used for heat and electricity at night and on cold winter days. TPV can also be used to convert waste heat in industrial systems into electricity as, for example, in steel mills.

Finally, there is the dream of using solar cells to generate electricity 24 h per day with Space Power Satellites. This idea is explored in Chap. 12 of this book. A more economic variation on this idea is to deploy mirror in space in a low earth–sun synchronous orbit to deflect sunbeams down to GW sized solar farms distribute in sunny locations around the world. While this option does not provide solar energy 24 h per day, it can extend the sunlight hours at the GW sites into the early morning and evening hours reducing the cost of solar electricity to below 6 cents per kWh.

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