A Systems Analysis of Solar Power Potential in Coming Decades

by

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SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2007

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Abstract

Energy is a very important aspect of human life. In the past few centuries, energy consumption has increased dramatically to a point where humans are very much dependant of energy. Under the current nonrenewable energy extraction technique of burning fossil fuels there are many externalities that are negatively impacting the earth. Society is approaching a limit where these formerly cheap forms of energy will become increasingly more expensive due to the difficulty of their extraction. As such, it is apparent that new renewable forms of energy will develop out of necessity to fulfill the energy demand. The purpose of this paper is to examine the different aspects of the promising area of solar energy. The conclusions of the analysis show that a portfolio of alternative energies will be necessary in the future with solar energy, in particular photovoltaic cells, filling the bulk of the energy generation.

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Introduction

In a society that consumes a large amount of energy on an everyday basis, it is important to be able analyze the current energy situation by examining the true price and feasibility of the options. Since 1850, energy consumption has been growing rapidly. This is due to the seemingly cheap nature of the most prevalent forms of energy generation. Currently the world relies on the burning of fossil fuels for most of its energy.[1] Even though this form of energy is cheap now, there are very important factors to consider when looking towards the future. First, there are many externalities associated with the burning of fossil fuels. These externalities include health problems for humans and animals, as well as, general environmental degradation. Second, these energy resources took hundreds of millions of years to form and now they are being used at a rapid pace. When observing the disparity between the formation time and the consumption time, it is clear that the fossil fuels are being consumed in what is essentially an instant.[2] Even with the occasional discovery of new fossil fuel reserves, it is inevitable that the supplies will run out if consumption stays approximately the same. An estimate of the time to depletion is 300 to 500 years.[3] Economically speaking, the fossil fuels will likely never be depleted, but the price for extraction will become so high that it is no longer profitable to use the technology. Since this situation is inevitable, it is important to examine alternative and renewable sources of energy.

Given the facts that a large portion of the world is dependant on energy, consumption will continue to increase and inherently all non-renewable sources of energy have to run out eventually, renewable sources are going to be very important in the future.

Smil, Vaclav Energy at the Crossroads: 3-4

[2] Kraushaar, Jack J. and Ristinen, Robert A. Energy and Problems of a Technical Society:2

[3] Kraushaar and Ristinen: 3

Most of these renewable energy sources are either directly or indirectly related to the sun (with the exception being hydroelectric power). Even though direct solar energy (whether through photovoltaic cells or thermal solar cells) is not cost effective given the current technology, it shows a strong potential as an energy generation method that can work. In addition, the rate of improvement for the technology has been increasing.[4] In this analysis, an in depth view of all types of solar cells will be examined, along with comparisons to the other energy alternatives. This analysis will include an overview of the current technology, as well as, the future of the technology and the political, environmental, social, and economic implications.

Solar Energy

Solar energy can have a wide array of meanings. In its loosest definition, solar energy is just any phenomenon that is created by solar sources and harnessed in the form of energy, directly or indirectly.[5] This paper will examine the various types of direct solar energy, which is energy that is a direct result of the sun's rays. Indirect forms of solar energy would include wind power and biomass power, since they are indirectly linked to the sun.

There are many distinctions that separate the various forms of solar energy. The distinction between direct and indirect has already been made, so the next natural division is the distinction between active and passive forms of solar energy. Passive solar energy harnesses either the heat or the light from the sun, but never converts between the two forms. All passive solar energy simply collects the energy in its current form. The most

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[4] Bedford, Travis Solar Revolution: The Economic Transformation of the Global Energy Industry: 124-125
[5] Bedford: 87

prevalent form of passive solar energy is in the design of buildings. Certain features can be designed into structures in order to make them more efficient at gathering and keeping the energy. Passive solar energy can be very simple, such as creating more windows on the south facing side of the building or adding vents throughout the building to conserve heat.[6] It can also be more intensive, such as the creation of dark, heat absorbing walls on the south side of the building or the placement of other heat-storing slabs elsewhere on the building. Using certain material such as super insulation can also increase passive solar energy absorption. The most established form of passive solar energy is the greenhouse.[7] The greenhouse is designed to capture the light from the sun and then utilize it to create year round growing conditions. Passive solar energy is a clever way to increase energy efficiency, however, it is only effective if it is designed into buildings before they are built. Modifications to current structures are too expensive and the positive attributes would not be able to overcome the high cost.

Photovoltaic Cells

Active solar energy can be further subdivided based on the method used to generate electricity. Photovoltaic conversion is the newer and more complicated of the two options. The basis of photovoltaic cells relies on packets of energy, called photons, and the energy that is released upon the collision and freeing of electrons. The energy released from the collision of a single photon can be described as follows:[8]

$$E = h * f = h\frac{c}{\lambda} \qquad (1)$$

[6] Kraushaar and Ristinen: 166
[7] Kraushaar and Ristinen: 158-159
[8] Kraushaar and Ristinen: 176

where:

h is equal to plank's constant,

c is the speed of light and

λ is the wavelength of the photon.

The most frequently used materials for photovoltaic cells is silicon (Si). Silicon is used due to its atomic structure, namely it has four valance (outer shell) electrons. Since these are the electrons that will be freed with the photon collision, it is beneficial to have as many valance electrons as possible. Silicon is also the ideal choice because the valance electrons of one Silicon atom form a crystal bond with other Silicon atoms, leaving no free electrons.[9] Once the photon of light strikes, the electron can gather enough energy to transfer to the conduction band where it moves under the influence of an electric field and produces electric current itself.[10] However, the incoming photon must have a minimum frequency (maximum wavelength) in order to provide enough power for the electron to transfer bands.

The manufacturing of solar cells is an intricate and complicated process. Although silicon is very abundant, Silicon in its pure form is very rare. First, the purification of the Silicon is an expensive process. In addition, the Silicon ingot must then be grown from the molten Silicon. After the Silicon has cooled, it must be cut into wafers that are a fraction of a millimeter thick.[11] Using the most advanced cutting techniques, about half of the silicon is lost in the cutting process. A typical photovoltaic cell contains about forty to fifty solar cells in series. This leads to another issue of

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[9] Kraushaar and Ristinen: 176-177
[10] Krauter, Stefan C.W. Solar Electric Power Generation-Photovoltaic Energy System: 21-24
[11] Kraushaar and Ristinen: 178-179

efficiency. Since the cells are grouped in series, the least efficient cell in the series will dictate the maximum efficiency. This leads to the reduction in efficiency of the cells.

In order to decrease the cost of manufacturing the photovoltaic cells, there has been a lot of research to try to increase the efficiency of the process. Since the largest source of inefficiency lies in the ability to grow silicon crystals, this has been the crux of the research. A new method, known as the edge-defined film-fed growth (EFG), has been showing promise.[12] This method involves a ribbon of crystalline silicon being drawn up through a die from the molten silicon. The capillary action produces a thin ribbon that is approximately the correct thickness. The quality of this silicon is decent, leading to efficiencies of ten to twelve percent. Since this process is much cheaper, the slight decrease in efficiency appears to be a good tradeoff. Another way to increase the efficiency of these solar cells is to dope the silicon with an atom that has three valence electrons (aluminum, indium, boron). Since four electrons are needed to form the lattice, the electron vacancy can move around and contribute to electric conduction.[13]

There is also research into other materials that can be used instead of silicon. Compounds such as gallium arsenide, cadmium telluride and copper indium deselenide have all shown promise in this area. Although these compounds are slightly more difficult to fabricate, the increased efficiency of the process could compensate for it. In addition, some solar cells are being designed to have three layers of photovoltaic cells. Each layer would take in a different spectrum of light.[14] Since a larger array of wavelengths could generate electricity, this would help to increase the efficiency of the solar cells. Finally, another method for increasing efficiency is to combine photovoltaic

[12] Kraushaar and Ristinen: 179-180
[13] Smil: 288
[14] Kraushaar and Ristinen: 178-179

cells with concentrating solar collectors (which will be examined in greater detail in the subsequent section). When these two technologies are used in conjunction with each other, the solar collector can concentrate the energy onto a certain part of the photovoltaic cell. This could significantly raise the efficiency and lead to the manufacturing of smaller photovoltaic units. One must take into account the cost of the solar collector and its tracking system in order to get a complete picture of this alternative.[15] In addition, this would increase the temperature of the photovoltaic cell dramatically. This higher temperature would detract from the efficiency of the cell. A cooling fluid can be added to the system, but it would add to the cost of the solar cell.

Solar Collectors

Solar collectors form the other facet of active solar energy. Thermal applications of solar energy are older and simpler than photovoltaic energy. In most instances, the solar collector is used for the heating (or superheating) of water. In some cases this heated water creates electricity through a Stirling heat engine. Solar collectors vary widely in size and shape. In addition, solar collectors can be subdivided into two categories: concentrating and nonconcentrating. Concentrating solar collectors have a unique design that focuses the sun energy onto one area.

The most basic example of a solar collector is a flat-plate solar collector. Flat-plate solar collectors are nonconcentrating. The flat-plate solar collector is composed of a box of insulating material (fiberglass or polyester) that is isolated internally with phenolic glass wool and a blackbody that covers a largely copper exchanger.[16] In order

[15] Kraushaar and Ristinen: 181
[16] Kraushaar and Ristinen: 160-162

to increase thermal resistance and minimize losses, the system is isolated with silicon or glass wool. The absorbing surface of the collector is painted black in order to maximize absorption. The energy conversion process of these solar collectors can be divided into three phases: reception, transfer and accumulation.[17] The collector is connected to a heat exchanger in order to transfer the heat absorbed to the water through convection. For an efficient solar collector, the tubes must be well insulated and experience very little heat loss. The efficiency of a flat-plate solar collector hovers around fifty percent. The temperature of the water in a flat-plate collector can rise to the range of 150 to 200 degrees Celsius.[18]

While flat-plate collectors are ideal for small companies and consumer use, concentrating solar collectors can be much more profitable. One form of concentrating solar collectors is the parabolic trough. The parabolic trough incorporates a unique shape to concentrate all of the energy onto a certain area. These collectors are made of either silver or aluminum due to their reflective properties. Then, the heat is absorbed into clear oil that is carried through a pipeline to heat the water in a heat exchanger. When the water heats to an adequate temperature, it boils into steam and creates pressure to drive the turbine of an electrical generator.[19] In some of the more advanced parabolic troughs, there is a tracker that allows the troughs to follow the sun throughout the day. Temperatures of the water in these solar collectors can reach 400 degrees Celsius. Parabolic troughs can reach efficiencies of seventy and eighty percent, but the average efficiency is sixty percent. Solar troughs can lead to approximately seventy percent savings on hot water heating bills.

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[17] Farret, Felix A. and Simoes, M. Godoy Integration of Alternative Sources of Energy:119
[18] Kraushaar and Ristinen: 162
[19] Farret and Simoes:120-122

Similar to parabolic troughs are parabolic dish solar collectors. While similar in concept, a parabolic dish has the ability to concentrate the energy onto a certain point (the focus) instead of a wider area. Temperatures of these dishes can reach 800 degrees Celsius. At the focus of the parabola, there is a receiver that transmits the energy to an engine.[20] These engines typically run on a Stiling or Brayton cycle. Due to the negligible amount of losses, these systems are highly efficient. Parabolic dishes vary in size from domestic use to full-scale power plant use.

The final type of solar collectors is the solar power tower. This system is the most complicated and intricate of all the solar collectors. The solar power tower consists of a large solar tower in the middle of a field of heliostats (mirrors to reflect the energy to the tower). Each of these heliostats contains 25 highly reflective flat mirrors and is programmed to follow the suns movement for maximum efficiency.[21] In the center of the solar tower, there is a receiver containing a fluid with salt in it. The warm fluid then flows from the receiver to the tower block and finally to a heat turbine. The heated salt is pumped through a steam generator, where the steam drives the system to create electricity. [22] Although these systems are highly efficient, they are very expensive to build and maintain. As more of these power plants are built and as the technology gets better, the cost of these plants will decrease to an economically efficient level.

[20] Farret and Simoes:122-123
[21] Kraushaar and Ristinen: 170-171
[22] Farret and Simoes: 124

Alternate Forms of Energy Generation

Fossil Fuels

As discussed earlier, fossil fuels compose the majority of energy generation in the United States. The main classifications of these fossil fuels are petroleum and coal. While these fossil fuels currently supply a very cheap source of energy (4-5 cents per kWh)[23], there are many hidden costs that are not taken into account. These costs are mostly related to the environment and the pernicious effect the combustion reaction has on it. The resulting pollution can cause disease in humans and animals and decrease biodiversity. There is also a cost associate with disasters such as an oil spill. In addition, the current situation in the Middle East is exacerbated by the fact that the United States is completely dependant on their oil exports. The most pressing reason to decrease fossil fuel consumption is that the supplies are rapidly running low. If the supply gets too low, the price of energy will rise dramatically. Since the increase would happen in a relatively short amount of time, this would lead to costs of financial distress for the government and for individuals.[24] If alternative energies are adopted now, then the country will be prepared for the time when fossil fuel levels run low.

Nuclear Energy

Nuclear energy is another energy option for the future. While nuclear energy is not renewable, the projected time to depletion is far higher than that of fossil fuels.[25] In addition, the release of energy of nuclear energy is far higher than that of coal. This leads

[23] Bedford: 124
[24] Bedford: 32
[25] Kraushaar and Ristinen: 88-89

to higher energy yields per mass consumed.[26] In addition, since nuclear energy is a relatively new concept, constant improvements to the system are being made, which leaves room for growth in the future. Unfortunately there are some major drawbacks to nuclear energy. First, one must consider the disaster cost. If something goes wrong with a nuclear facility, there is the potential for catastrophic damage. Although these occurrences are very rare and have not happened in recent history (after certain safety developments), the potential for these disasters must be factored into the analysis. In addition, there is the issue of disposal of the nuclear waste. While some of these isotopes have a half-life of seconds, there are other isotopes that will not degrade for thousands of years. While the actual volume of the waste is not very large, it still poses a threat. Most important, however, is the fact that public opinion of nuclear energy is so low.[27] In order for a new system of energy to be developed, it must be accepted by the masses. Nuclear energy has the reputation of a very dangerous process. While many of these notions are inaccurate, this public perception will prohibit nuclear energy from becoming the main source of energy in the United States.

Wind Power

Energy created from the wind is another potential energy source of the future. Wind is a renewable source of energy. Since wind is an indirect result of the heat generated from the sun, some argue that wind power is a form of solar energy. There are two significant problems with wind-generated energy. First, wind is unreliable and

[26] Kraushaar and Ristinen: 88
[27] Kraushaar and Ristinen: 124-128

unpredictable.[28] This leads to a certain amount of volatility in energy production. Also, certain regions get more wind than others, so wind power would only be feasible in certain regions of the country. Another problem with wind power is the location of the tower and the footprint it leaves. Some see these wind towers as intrusive and a detraction from the natural beauty of the earth. There are also some arguments concerning the bird population that is killed as a result of the towers, but since car windshields kill far more birds each year, it should not be an issue. Finally, although wind power is the most rapidly growing alternative energy, there is not as much room for technological improvements as solar energy.[29]

Hydroelectric Power

Another renewable source of energy is hydroelectric power. Since this technology utilizes the water cycle, it is completely renewable. It is also a clean energy with little to no pollution in its everyday activities. However, there are some very distinct disadvantages and hidden costs to hydroelectric power. First, a hydroelectric plant requires a very large set up cost before it can start generating revenue. Also, a very large amount of land is need for the plant itself and the dammed river behind it. This can cause displacement of people from their homes or animals from their natural habitats.[30] In addition, it also affects the ecosystem that was present in the river before the dam was built. For example, the salmon population relies on being able to swim all the way upstream to procreate.

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[28] Smil: 274-275
[29] Simon, Christopher A. Alternative Energy:103
[30] Kraushaar and Ristinen: 188-189

Economic Implications of Solar Energy

Economic principals will almost certainly be the driving force in the implementation of solar energy. Government incentives may help encourage faster implementation, but if solar energy becomes cheaper than the alternatives, the free market will dramatically accelerate the switch to solar power.[31] It is important to note that environmental effects are not a significant influence on consumers when deciding which form of energy to use. The raw cost/kWh is the most important factor that consumers take into account.

For a centralized PV system, the cost can be calculated as follows:[32]

$$C = C_{var} + \frac{C_{fix}}{q_{el}} = (C_{fuel} + \frac{\tilde{C}_{O\&M}}{H_{el}} * 1000 - R_{heat}) + \frac{1000 * I(CRF)}{H_{el}} \quad (2)$$

where: C = generation costs per kilowatt-hour ($/MWh), C_{var} = running costs per energy unit ($/MWh), $\frac{C_{fix}}{q_{el}}$ = fixed costs per energy unit ($/MWh),

C_{fuel} = fuel costs per energy unit ($/MWh),

$\tilde{C}_{O\&M}$ = operation and maintenance costs per energy unit ($/MWh). ,

H_{el} = full-load hours (h/yr), R_{heat} =revenues gained from purchase of heat ($/MWh).

I = investment costs per kilowatt ($/kW),

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[31] Bedford: 30

[32] Farret and Simoes: 13

PT = payback time of the plant (yr), and

z = interest rate.[33]

The capital recovery factor is defined as:

$$CRF = \frac{z(1+z)^{PT}}{(1+z)^{PT} - 1} \qquad (3)$$

The price of photovoltaic cells today is approximately between 15 and 27 cents per kWh, while centralized solar thermal energy is between 10 and 18 cents per kWh. Currently the price of coal is just under 5 cents per kWh.[34]

Table 137

These electricity values vary widely for different regions. This is largely based on the amount of direct sunlight received in that region. Although specific regions may vary, the amount of direct sunlight is a function of latitude, climactic conditions and time of the year.[35] In Los Angeles, for example the local price of electricity is on average 12 cents per kWh. At the current cost of $6 per watt to install a solar system, it is economically beneficial to switch to photovoltaic cells. However, in Boston, the installation cost would have to fall to $4 per watt in order to be economically beneficial. This difference is solely due to the latitude and climate conditions. Current estimates predict that prices will not fall to this level until 2011. Below is a table indicating the breakeven isocost curves for major cities in the United States. As the cost drops, photovoltaic cells become more feasible for implementation. By 2045, photovoltaic cells should drop to a cost of

[33] Farret and Simoes: 13
[34] Bedford: 124
[35] Farret and Simoes:113-114

$1.50 per watt, making it economically beneficial for nearly all of the major cities in the United States.[36]

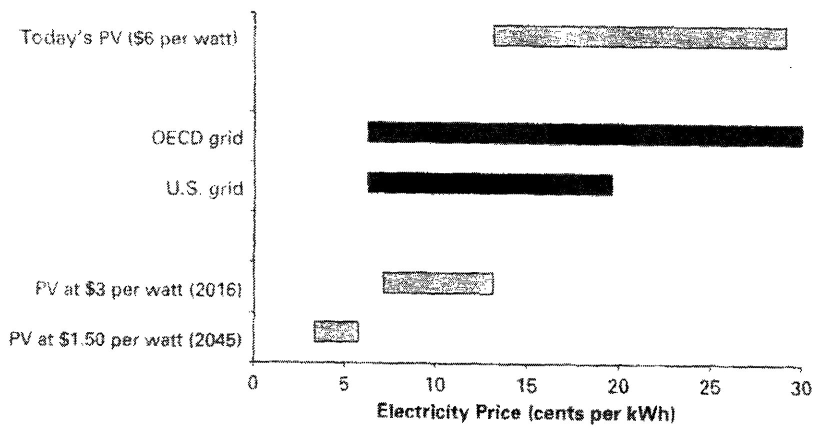

Figure 1: This figure depicts the predicted prices of photovoltaic cells in upcoming years[37]

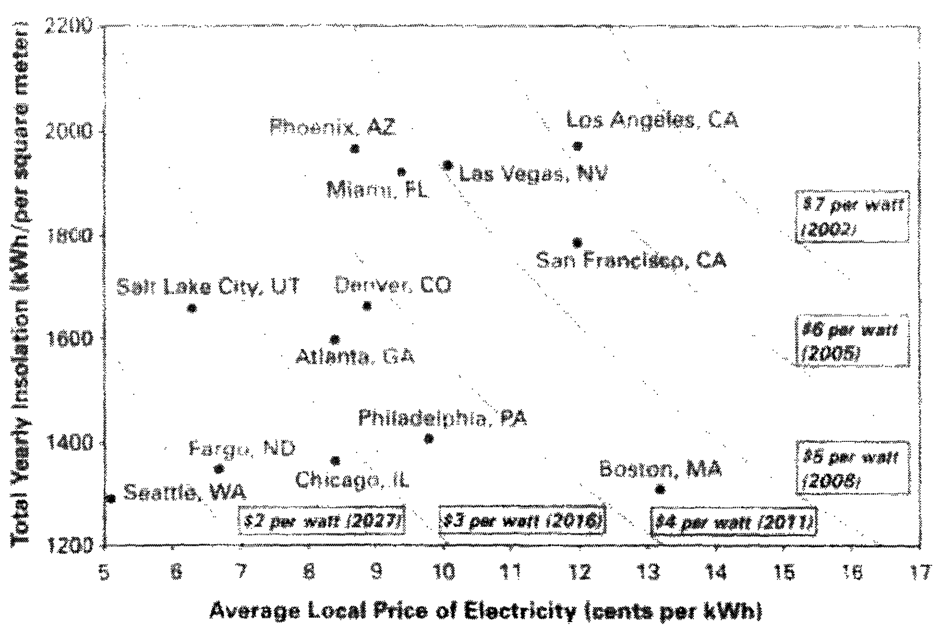

Figure 2: This chart depicts the isocost curves where it will be profitable to utilize PV cells[38]

[36] Bedford:146-147
[37] Bedford: 144
[38] Bedford: 146

Another important factor to consider is the cost of time in electricity generation. When the timing of electricity generation is considered, solar energy becomes even more appealing. By its very nature, solar electricity generation increases and decreases with varying amounts of sunlight. The electricity demand patterns are highly correlated to the solar availability. When there is high demand, the cost is effectively higher for generating electricity. With solar energy, this is perfect because it is the time of the day when the most electricity is being generated.[39] This makes solar cells comparatively more cost effective at certain times in the day and certain times of the year. Although this is not factored into the cost comparison of photovoltaic cells, it should be considered an added benefit. The graph below shows this phenomenon in greater detail.

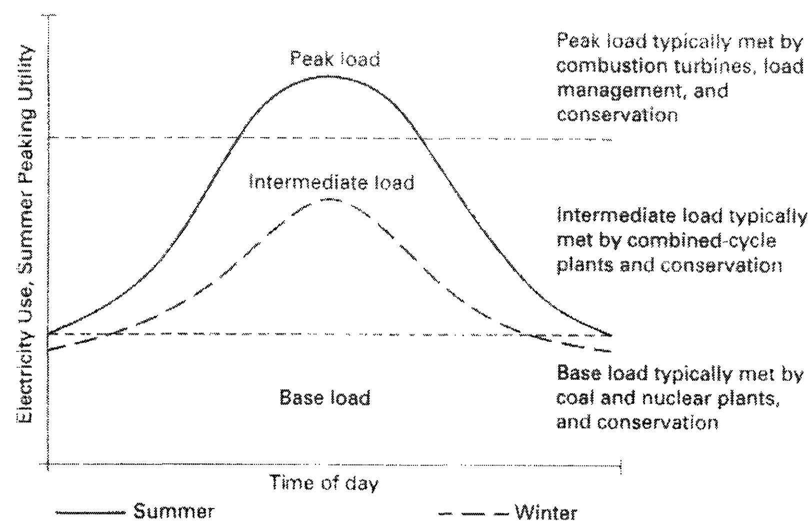

Figure 3: This figure demonstrates the complimentary cycles of sunlight and peak energy usage[40]

Another economic factor that should be considered is the hidden cost of current energy methods. Many of these methods contain externalities that have negative

[39] Bedford: 129
[40] Bedford: 129

consequences. These consequences include environmental concerns such as pollution and the loss of biodiversity. There are also political concerns such as the dependency on foreign oil. Finally, there is the cost of financial distress. In this situation it applies to occasional shortage on current energy methods (Oil Crisis of 1973 and California Energy Crisis of 2000). These shortage situations cause economic turmoil or economic shock and which effects are felt long after the supplies have been replenished.

Political Implication of Solar Energy

Public Policy and government initiatives have the potential to shape the future of alternative energies. There are many tiers of the government that can have an effect on the implementation of solar energy. As far as the Presidency is concerned, there are some minor effects that the President can have on the course of alternative energy.[41] Since the time of the Great Depression, the powers of the President have been increasing from the literal power to the inherent and implied power of the Presidency. As such the President and the President's policies concerning energy have been increasingly more important. President Clinton's policy was a mild form of green politics, however, opposing forces in Congress hindered his effectiveness. President Bush took the stance of a more free market driven system where the leading energy source would present itself through necessity in an efficient market. President Bush also proposed increasing the oil supply by opening the Arctic National Wildlife Area to petroleum and natural gas exploration. Since the Senate and the House of Representatives are frequently changing bodies, it is difficult to make energy policy reforms in a meaningful way. Without

[41] Simon: 190-193

aligned motives between Congress and the President, there is very little opportunity for large scale or long-term changes. Unfortunately achieving a broad based aligning of political will between the President and Congress is generally only accomplished as a result of a significant disaster or crisis.[42]

Local governments (city and state governments) also have the opportunity to shape the energy field of the future. Although local governments are implicitly under certain constraints by the federal government, there is still room for local public policy change. During the upcoming stages of solar energy, local governments have the power to grant subsidies to users of solar energy.[43] Without these subsidies, solar energy could still expand, but subsidies will expedite the implementation of solar systems. In addition, local laws can be passed for certain energy requirements of new buildings and structures. Since the value of solar cells increase when it is designed into the building, this could have a very significant effect. Local governments have more freedom than the federal government because they are working with a much smaller subset of the population. It is more likely that values will be aligned within a small community than with a much larger entity. Once the ideals and desires of the subset are aligned, it is easier to pass new laws and implement formal policies. Activist groups and interest groups will also have a strong effect on the implementation of solar energy. These groups can have a large effect on not only spreading the knowledge of alternative energies, but also they help to shape public opinion.[44] Since these groups tend to be very vocal, it will appear to the local governments that the views of their constituents are all aligned, again making it easier for a change in policy.

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[42] Simon: 194-196
[43] Simon: 202-203
[44] Simon: 203-205

Throughout history wars have been fought over natural resources, especially energy resources. In recent years, these wars have been focused mainly on the control of oil. The emergence of solar power has the potential to change the politics on a global level. If solar power (possibly combined with other alternative energies) can start to diminish oil exports from the Middle East, the face of international politics could change dramatically. The power and economic influence of the OPEC cartel would decline in significance and free market forces would regain prominence. Since a very large portion of the Middle East economy relies on exporting oil, a reduction in this market would severely impact the economies and the economic power of these countries.[45]

Environmental Benefits of Solar Power

The environmental benefits of solar power are some of the more noticeable benefits of solar power. Since the public is growing increasingly concerned with the environment and the impact humans have on it, the clean methods of solar power are becoming increasingly more appealing. Fossil fuels present "an enormous range of undesirable changes" to the environment.[46] In addition, these changes are even more detrimental because they are not visible on an every day basis. Disasters such as oil spills or nuclear meltdowns are events that garner rapid public attention and reaction. The burning of fossil fuels, however, is much more pernicious due to the fact that the effects cannot be seen until they have done a lot of damage.

One very attractive aspect of solar energy is that it is renewable. As such, one does not have to worry about a shortage or horizon effects when supplies are running low.

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[45] Smil: 116-120
[46] Smil: 105

There are also far fewer negative environmental impacts of this energy source. Although oil spills are fairly rare, when they do occur, they are very damaging to the ecosystem. Even after the cleanup occurs, there are negative consequences that cannot be reversed. Similar problems exist with nuclear energy, where problems do not occur often, but when they do occur, the results can be catastrophic. Solar energy is a clean energy, meaning there is very little nontoxic waste and no toxic waste as a result of the solar process.

One of the most compelling environmental benefits to consider is the elimination of burning fossil fuels to achieve energy. While the ideas of global climate change and global warming are still being debated, there is no question that air pollution is harmful to humans and the ecosystems in which they live in. One byproduct of the burning of fossil fuels is SO_2. This gas is colorless, but can be recognized by smell at low concentrations. At high concentrations, however, it is irritating and pungent.[47] Nitrogen oxide concentrations have also been on the rise in recent years. Nitrogen oxides are the largest source of volatile hydrocarbons in densely populated regions. Carbon Monoxide (CO) is a colorless and odorless gas that comes from the incomplete combustion of carbon fuels. Carbon Monoxide is deadly in high concentrations to humans. Although laws have been passed to cut down emissions (US Clean Air Act of 1963 and the Air Quality Act 1967) these pollutants are still growing in parts per million and are the leading contribution to smog. Concentrations of CO_2 are also increasing at a rapid rate. These CO_2 particles have the potential to cause a greenhouse effect that could trap excess heat inside the inner levels of the atmosphere. The extent of this effect is still yet to be proven, but a

[47] smil 106

significant portion of the scientific community has identified greenhouse gases as the primary cause of global warming.[48]

There are many negative consequences to the pollutants that are released from burning fossil fuels. The first, and most visible effect is the noticeable amount of smog in certain metropolitan areas of the United States. These pollutants can cause major reparatory damage to humans. These pollutants can also be linked to diseases such as asthma. According to the Centers for Disease Control, the prevalence of asthma increased 75% from 1980 to 1994.[49] In addition to the aforementioned problems, there are also more subtle issues associated with this pollution. When the pollutants settle, they have an effect on both water quality and the soil. This leads to an increase in cost for purifying the water or in other cases it leads to the ingestion of these particles by animals. As these organisms are effectively poisoned, the level of biodiversity decreases. In addition, when the pollutants tamper with the soil chemistry, biodiversity in plants decreases also. This leads to the loss of animal habitats and can also lead to a lower crop yield for farmers. If left unattended, these seemingly silent effects of pollutions can lead to a decrease in plant, animal and microorganism diversity, health issues in humans, and potentially a decline in the food supply.[50]

There are also some concerns with solar energy and the effects it could have on the environment. The largest of these concerns is the effect that solar collection towers or solar troughs could have on the ecosystems. There is sufficient evidence that habitats will adapt to the apparent intrusion in their area. As an example, the Aquarium of the Americas located in New Orleans, Louisiana, embarked on a program called the "Rigs to

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[48] Smil:106-108
[49] Centers for Disease Control. Surveillance for Asthma – United States, 1960-1995, MMWR. 1998; 47
[50] "Solar Cell Breaks the 40% Efficiency Barrier"

Reef" program.[51] This program, which has been in effect for more than six years, involves investors such as Shell, Chevron, and ExxonMobil. These companies invested in an experiment where after the life of an oilrig was complete, they would simply cut off the top and leave the bottom on the ocean floor as an artificial reef. Not only have the reefs not hindered the ecosystem, the marine life have actually flourished. Marine biologists such as Dr. Milton Love of the University of California, Santa Barbara Marine Science Institute have confirmed this phenomenon.[52] These reefs show far more biodiversity and marine life flourishes. This shows that if planned correctly, ecosystems have the ability to adapt and flourish in new conditions. Also, the shade from a solar collection trough or tower could be beneficial to microclimate. Another concern is that solar towers could affect bird migratory patterns or present dangers to insect populations. The amount of insects lost per year due to solar cells is statistically insignificant and should not be considered as a factor. Also, birds inherently avoid air zones that could potential be dangerous. This is likely due to the air turbulence from the tower that serves as a warning to the bird. [53]

Social Benefits of Solar Power

Social Benefits in the United States

The numerous social benefits of solar power are often overlooked due to their subtle nature. The largest benefit is to establish national and regional energy

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[51] <http://www.audubonistitute.org>
[52] Frantzeskaki, Gekas and Tsoutsos, Therocharis "Environmental impacts from the Solar Energy Technologies" Energy Policy Vol 33
[53] Frantzeskaki

independence. The inception of a distributed solar cell system would alleviate the dependency on imported forms of energy such as oil. As such, the volatility of price would go down and energy costs would remain relatively constant. On a smaller scale, establishing regional independence is also a benefit of solar energy. Energy costs vary widely across the country due to local government regulations and the infrastructure of the area. This would help to ensure a low cost energy for everyone and not just the people who happen to live in a privileged area. Another important social benefit of solar energy is that it will further diversify the choices for energy. When there is a well-diversified array of options, there is a smaller chance of an energy crisis such as the Oil Crisis of 1973 or the California Electricity Crisis of 2000. Energy crises such as these significantly impede social welfare in a variety of ways. For example, the economic shock disproportionately falls on low income and fixed income households. In addition, unavailability of energy for heating or air conditioning can negatively impact the health of infants, children and the elderly or exasperate existing health problems. These issues are mitigated with the rise of solar energy because it helps to provide a more diversified energy portfolio that would be less susceptible to interruption.[54]

Developing Worldwide Social Benefits

There are also numerous social benefits on a global level. There are many developing nations that do not have the funds or the infrastructure to provide adequate energy to their citizens. Many of these countries do not have natural resources that can be utilized. Solar energy would help bridge the gap in the disparity between resource rich and poor countries. (Note: photovoltaic cells in their current state are too expensive for

[54] Simon: 21-24

third world implementation. It would take major government intervention to implement solar cells due to their price and installation logistics. This section outlines the social benefits that will be realized with improved photovoltaic cells. This should be feasible within the next fifty years assuming adequate research and development. See future of solar cell section of the report.)

There are many problems that developing nations are plagued with on an everyday basis due to the lack of affordable energy. Everyday life is much more tedious without electricity. For instance, many households (here the term house is the typical house) are forced to burn wood or charcoal inside the house. This leads to many respiratory problems. In addition, the process of cutting down trees to be charcoalized or burned is very taxing on the environment. This often leads to soil erosion, floods and other detrimental factors that are dangerous to the inhabitants. Also, healthcare is very hard to come by due to the large energy requirement of hospitals. Some hospitals are forced to choose between lights and power for the refrigerator that keeps the vaccines at the required temperature. This leads to high infant morality rates and low life expectancy rates. These are two factors that are important in determining the quality of life.[55] The graphs below depict the infant mortality and female life expectancy at birth as a function of per capita energy consumption.

[55] Smil: 98-100

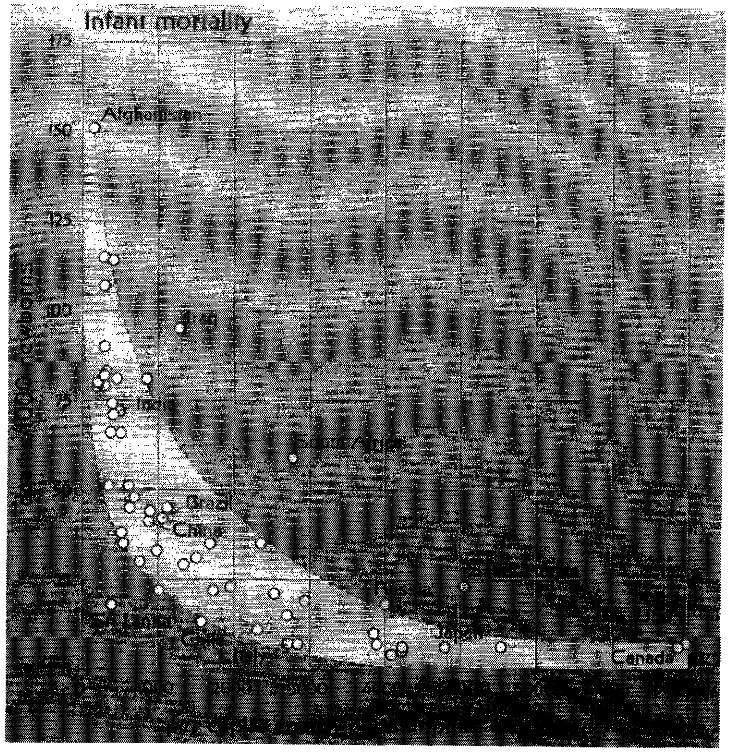

Figure 4: Infant mortality rates as a function of energy consumption in various countries[56]

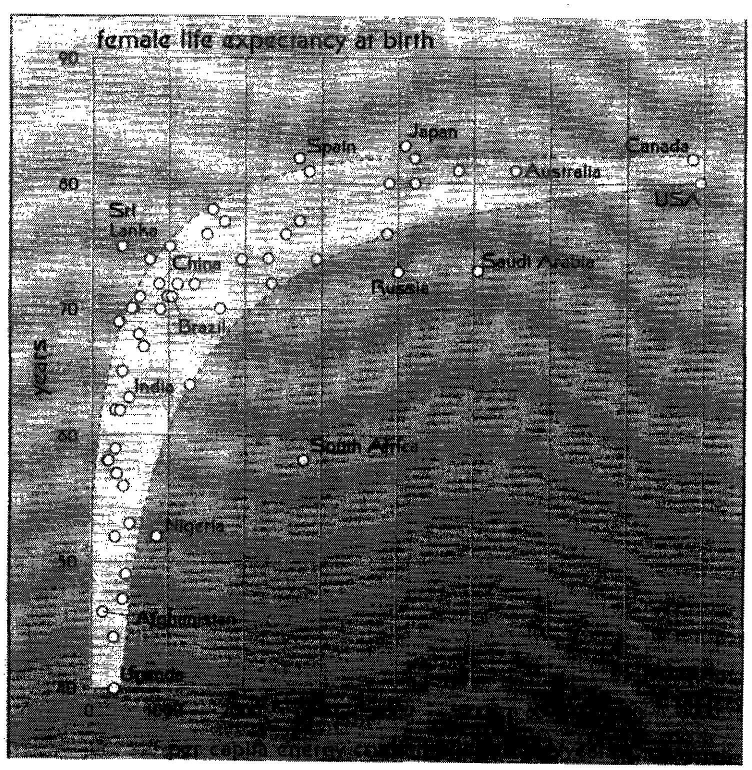

Figure 5: Life expectancy of females as a function of energy consumption in various countries[57]

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[56] Smil:100

There is a clear correlation between having enough energy and being able to sustain life. In addition, education suffers from the lack of energy. This lack of energy inhibits the teachers from many meaningful learning exercises. In some situations a classroom will not even have lights due to the cost of electricity. This puts the children of these developing nations at a severe disadvantage for education. An effective system of solar cells could help alleviate this situation.[58]

Conclusions

Among the subsets of solar energy, the recommendation for the future should be photovoltaic cells. Although thermal solar cells are better for the environment that fossil fuel burning, there are still some negative impacts. Many of these problems are similar to the issues of the wind tower such as the intrusion into nature. In addition, for thermal collectors to be efficient, they must be built on fairly large scale. This requires a lot of land for the plant. Photovoltaic cells are implemented on a much smaller level and have a smaller footprint on the environment. They are also more aesthetically pleasing than solar collectors. Although the prices of the two forms of energy are comparable right now, photovoltaic cells are being improved at a much faster rate. Ironically, there is so much room for improvement because of all of the current inefficiencies in the manufacturing process. With new research and possibly different materials (doped materials) photovoltaic cells can increase dramatically in efficiency. In fact, a new type

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[57] Smil: 101
[58] Smil: 100-101

of photovoltaic cell has recently been manufactured that has the potential to reach forty percent efficiency. These photovoltaic cells utilize a new class of metamorphic semiconductor materials. This yields to an installed cost of $3 per watt, which is comparable to current electricity cost.[59] Since photovoltaic cells started at a cost of $50 per watt in 1970, and decreased to $10 per watt in 1990 and $6 per watt is 2005, there is still a lot of room for improvement of manufacturing techniques and corresponding decrease in cost.[60]

Another major factor in choosing the energy of the future is public opinion.People are much more likely to switch to a new form of energy if it is similar to the old form of energy. Evolutionary change is easier to absorb than revolutionary change. Photovoltaic cells are implemented on an individual level and are very unobtrusive. Many people will be scared of change, so the less that appears to be different the more support it will achieve.

While the main form of energy generation in the future should be photovoltaic cells, it is important to have a portfolio of different energy generation techniques available. There is the opportunity to use certain types of energy generation where it matter most. For instance, in the windy areas of the Midwest, wind power should be utilized, while in the barren deserts of Mojave, solar collectors might be utilized. Having different types of generation techniques offers a comparative advantage where the optimum technology would prevail as the primary generator of electricity for an area or region. Also, by having well diversified portfolio of options, there is a certain amount of protection in case something goes wrong. In conclusion, although many types of energy

[59] Smil: 101-102
[60] "40% efficiency"

generation techniques should be considered and utilized, the main contributor to energy generation should be photovoltaic cells.

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