SUMMARY OF OPTIONS FOR THE GROWTH OF SOLAR ELECTRICITY AND CONCLUSIONS OF THE 3.003 TASK FORCE ON ENGINEERING THE FUTURE OF SOLAR ELECTRICITY

The plan presented in previous sections allows for the slow but steady transition towards solar energy as a key energy source in the next fifty years. Solar energy is optimal for various reasons, but presents multiple challenges, the main being cost. Photovoltaics avoid the carbon dioxide and greenhouse gas emission issues which arise from traditional oil and coal energy production. The use of photovoltaics in the United States would also reduce its dependance on foreign oil sources, strengthening the country's ability to produce its own energy and self-sustain.

Some key considerations to analyze with regards to the implementation of a solar energy system are cost, materials, peak load, and policy. In terms of cost, solar power is more expensive than oil and gas. According to the United States Department of Energy, by 2015, the retail electricity range will be $0.06 to $0.15/kWh, and the wholesale electricity range will be $0.04 to $0.08 kWh—solar must reach around this range to be competitive. Due to government subsidies in this plan (which can be granted because of the benefits solar energy has to the nation and world), the price of solar energy does not in the near future (a fifty year timespan) have to drop to this level.

Using the United States Department of Energy's Solar Advisor Model (SAM), for a SunPower Model 315 Solar Cell plating in Tuscon Arizona over a fifty year span, the LCOE (Levelised Cost of Energy) is about $0.14/kWh. The LCOE is a way of measuring the cost per kilowatt-hour over a system's *entire lifetime*. This value, $0.14/kWh, is comparable to the range seen above. One point to note is that this is over a fifty year span (a focus in this analysis). However, the same calculation was computed for 15 years and the difference was only about $0.005 greater, so the solar cells will pay off even in fifteen years. The payoff in five years will be slightly less but not negligible.

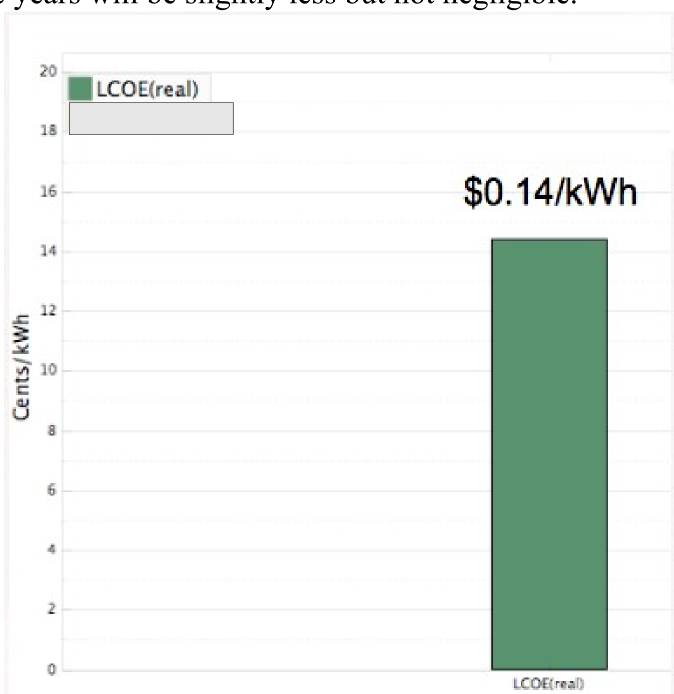

Figure VI.1 The LCOE of a Sunpower 315 cell over fifty years

Figure 4.1 above shows the overall cost per kWh over a fifty year timespan for a Sunpower Model 315 cell, including a 1%/year solar panel degradation scheme.

The next overarching consideration is materials optimization. The choice of materials in an energy system is of utmost importance, and simulations and calculations performed to determine an optimal choice of materials are detailed above in previous sections. The decision calculus behind the choice of silicon for local power and cadmium telluride for grid scale power will be reevaluated below, considering various factors including toxicity, availability, cost, and performance.

Considering aspects beyond the micro-material level reveals a negative consequence of solar power as it stands today—it is only available during the day and there is no efficient way to save it for use when needed. According to a study of New York City (see section I for graph and source), the peak energy needed was at 9 PM—when the sun is no longer shining. This requires a backup use of natural gas and oil. There are various ways of alleviating this issue, including using solar concentrators in some areas in order to heat water and generate electricity—this will keep warm for a while after the concentrators stop collecting energy. However, even without excellent energy storage, replacing a specific percent of the daily load will be beneficial to the environment and will save money in the long term since oil and coal will not have to be replenished periodically.

Transitioning away from a materials or technical perspective leads to a discussion of the political aspects of the move to solar. Government support is of utmost importance to a fledgling industry—in the form of subsidies, policy enactment, and general support for action. In terms of subsidies, it is important for the government to fund the beginning stages of solar technology and its commercial ventures because the market is currently too small, especially compared to the main competition—fossil fuels. Currently, fossil fuels are much cheaper than photovoltaics; government funding has been key in getting many European solar ventures off the ground and functioning. In addition, the government's ability to enact policy mandating various solar-friendly policies is extremely vital to helping society accept a transition to increased solar use. For example, the government could help ensure that new property would be built using solar panels and perhaps help subsidize the cost for low-income households. Another example of governmental help is the choice to invest in research and development for a successful infrastructure and logistical setup for aspects like more efficient direct current to alternating current technology, the push to run more household appliances on direct current, and so on.

The government and eventually industry have many reasons to invest in photovoltaics as a solution for the future. Solar electricity has some very appealing attributes. The first is the availability of solar power: though the sun does not shine at night, causing a discrepancy between peak load and peak production, solar energy during the day is readily available to cut down the use of oil and gas when solar is available. To ease the transition for traditional power plants between when solar becomes unavailable (at night), since they will have to make a jump to cover peak electricity use, we suggest solar concentrators as a possible solution. Because solar can drop the fossil fuel use during the day *only*, the use of oil and gas will drop during the day but return with an even higher jump for nighttime use—but solar concentrators can store some energy in the form of heated water to turn turbines.

Second, solar power has various positive security and safety attributes to consider. In terms of national security, it was mentioned above that replacing foreign oil imports with solar power will help the United States become more energy dependent. In terms of the safety of the actual photovoltaic cells, safety evaluation is worth being discussed. Silicon solar cells are safe to install anywhere—silicon has been proven nontoxic. It is true that some dangerous chemicals are used in the manufacturing of silicon cells, but they are contained in a factory setting and with standard manufacturing and processing FDA regulations, are managed safely and securely, just as they are in a silicon wafer fabrication plant in the microprocessor industry. Cadmium and tellurium (for cadmium telluride cells) do pose safety threats to humans and ecosystems. However, when in combination, the two elements as a compound are not as dangerous. In addition, the use of CdTe cells in large fields away from homes (where fires could start releasing toxic gases, etc), and in securely monitored grounds can prevent harmful effects.

Reduced transmission losses are a third aspect of the *local* portion of our solar future plan. The ease of localized production lowers transmission losses (of over fifty percent, see Section II) which occurs from transmitting power over long distances. A home that can produce power on its rooftop and then use it less than twenty feet away presents less resistance to dissipate energy than a pipe running for miles. Fourth, local photovoltaics run independently of grid power generation. This is related to the reduced transmission losses in that local photovoltaics avoid the losses associated with grid energy transportation. These aspects of solar energy, particular *local* solar energy serve to present the local photovoltaic power industry as a solution to a portion of the energy crisis.

Fifth, grid load leveling can ease surges in the grid and stabilize overall production by making up for losses. Using solar to ease changes in grid load—having people pump power into the grid from homes, etc., can prove very effective to stabilize the grid load. Sixth, solar cell implementation would drastically reduce carbon dioxide emissions and other greenhouse gas emissions that normally result from traditional energy sources. This is incredibly beneficial for the environment and will work towards easing issues like climate change. Finally, one last (seventh) attribute is the creation of new jobs to the market—solar factories can create many jobs when opened. Though as solar starts supplementing and eventually starts replacing the fossil fuel industry, many people will have to switch to working in a solar industry workplace, transferring some of the workforce.

Ideally, these attributes would stand alone without a set of assumptions or limitations, but this is not the case. New energy technologies have absolutely no *guarantee* of success. For a market to be successful and self-sustaining, it must be valued at around two hundred billion dollars (Kimerling). This is clearly difficult to reach from a small industry and will take government subsidies and policy to help reach that point. However, as mentioned above, there are many attributes that make solar electricity an appealing option, more so than fossil fuels. Taking into account solar power's current twenty to thirty percent exponential growth rate, it is projected to reach power demand in fewer than twenty years.

The graph in section I displaying capacity growth shows the integrated growth rate of solar as plotted against the megawatt capacity of total usage. With a growth rate of 35%, solar can catch up in about fifteen years (see Section I) This is an optimistic assumption, as it depends on a *constant* and *continued* growth rate of 35%. However, even with a smaller growth rate, solar could still take over part of the energy industry, easing the energy crisis and environmental concerns.

It is important to rectify the issues presented above, especially through cost minimization and efficiency maximization. The metric is to examine materials choice, grid versus local implementation, and direct current to alternating current transformations, and how they affect cost and efficiency. Choosing the right materials is of utmost importance to maximize productivity. As mentioned above, a summary of materials choice decisions will be given here. We chose to use a thickness of thirty microns for a silicon cell as an *optimum* (our PC1D simulator results helped confirm this suggestion). However, in practice and industry, this is not feasible—normally cells (thin film) are less than ten microns thick. Thus, for ease of implementation (at the current time) the following text will refer to the cells as thin film silicon, though *if* better manufacturing processes can yield a thirty micron thick cell we will have to change that plan for greater efficiency. Silicon is nontoxic as well. In addition, silicon is readily available and is the second most abundant element in the earth's crust—occurring at about 28% (Hyperphysics). A silicon system is not as efficient as a cadmium telluride system, since thin film silicon stays at around a constant efficiency, while cadmium telluride has reached at times (in the laboratory and in the PC1D simulation) above 20%. Cadmium telluride is toxic, though with proper maintenance, does not pose a threat to humans, as discussed above. In addition, cadmium and tellurium are fore more scarce than silicon, but the United States posesses reserves, which can cover current projections for electricity demands (See section III). Cadmium telluride cells are cheaper than silicon, and that helps add to their appeal.

The next form of rectification comes in the balance between grid and local power generation. It is extremely important to determine the structuring of this system for logistical issues.The metric used to determine if an entity will be powered by a local source or by the grid is power density.. This term here means that if the solar panels covering the roof of a building can cover the building's power needs, it will be fed by a local power system. However, if it cannot (for example, high energy use factories—on the factor of megawatts), will need to be fed by a grid.

The last efficiency consideration is the issue of the conversion of direct current to alternating current. Photovoltaic cells produce direct current, but many large home appliances run on alternating current—such as refrigerators and washing machines. However, many appliances do in fact run on DC power, such as toasters or other appliances that do not have a motor.

A metric to gauge the positive effects of the above points for the future of solar is the Total Annual Impact, suggested by the United States Department of Energy, and described in Figure 4.4.

Total Annual Impact =
(Baseline-Improved Costs)(Serviceable Addressable Market)

Increase Δcosts by decreasing improved costs
Cheaper materials (thin film silicon)
Government subsidy for photovoltaic R&D
Garner essential support
Lobby for political support
Community task forces to determine power needs and logistical issues

Figure VI.2 The Total Annual Impact of an improvement can be represented by (Δcost)*(Serviceable Market)

Namely, if you increase the difference between the baseline and improved costs and increase the serviceable market, then the product of the two (the total annual impact) will increase dramatically. The way to increase the delta cost is to drop the improved costs—and the previous section (on why materials choice, grid versus local implementation, and direct current versus alternating current improve efficiency and decrease costs), along with government subsidies, shows exactly how the plan does that.

To increase the serviceable addressable market, it is necessary to garner political support and have community task forces to spread the local photovoltaic systems across communities. Overall, this will increase the positive impact.

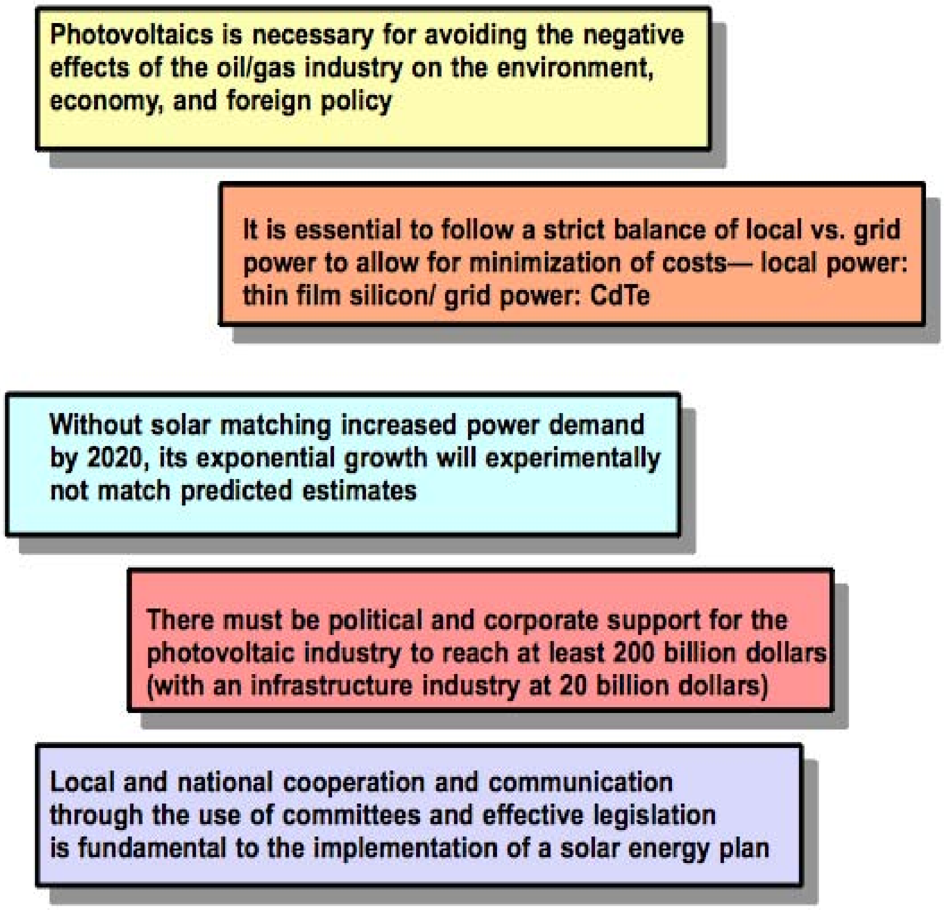

Figure VI.3 The five key points to consider when analyzing the implementation of solar power

Figure VI.3 summarizes the key points presented in the plan. In fifty years, if the photovoltaic industry maintains an exponential growth rate, large solar fields coupled with local and residential solar plates can replace most of the need for unappealing and environmentally, socially, and politically unfavorable gas/oil sources (perhaps all with the possibility of energy storage). The goal is to continue funding research and development of solar technology to provide a strong base of cadmium telluride cells to provide grid scale power, while using safer and consistent thin film silicon cells for local power.

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