Ten Million Solar Roofs and Ten Million Gallons of Solar Water Heating Act of 2010

Final Report on the Scientific Analysis of S. 2993

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Summer Workshop in Applied Earth Systems Management

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EXECUTIVE SUMMARY

The following report is an analysis of the environmental science behind the issues addressed by the bill S.2993, *"10 Million Solar Roofs and 10 Million Gallons of Solar Water Heating Act of 2010"*, or *Solar Act of 2010.* This report examines the potential environmental benefits the Solar Act of 2010 could achieve through the implementation of a rebate program for solar photovoltaic and solar water heating systems.

Global climate change, which is directly correlated to the increases in carbon dioxide and other greenhouse gas emissions, presents a significant environmental problem. In the United States, 42 percent of carbon dioxide emissions come from electricity generation. Fossil fuels are used to generate 70 percent of the United States' electricity. The consumption of fossil fuels for electricity generation is also the cause of environmental quality issues such as smog and acid rain as well as the destruction of natural resources and habitats.

The Solar Act of 2010 presents policy makers with a potential solution for reducing the United States' reliance on fossil fuels as the primary fuel source for electricity generation and water heating. Analysis of the implementation of the Solar Act of 2010 determines an annual 3.04 percent potential carbon dioxide emissions reduction of the energy sector's total emissions. Additionally, implementation of the Solar Act of 2010 could increase solar power capacity to equal 18 percent of the coal based generating capacity of 2008. Thus, the implementation of increased solar capacity is a crucial first step toward curbing fossil fuel consumption for electricity generation.

The report identifies existing solar electricity and water heating technologies, as well as their strong points, shortcomings, and controversies. The concerns surrounding solar power's toxic components, questions on efficiency and reliance, and cradle to grave lifecycle are addressed in this report, and the findings show that the benefits far outweigh costs of continued fossil fuel reliance. Finally, the report sets guidelines for assessing the Solar Act of 2010's successful implementation.

The increased capacity of solar power will reduce carbon dioxide emissions, mitigating the effects of climate change as well as the environmental impacts that result from fossil fuel consumption for energy production. While it is concluded that increasing solar power's capacity in the United States has the potential to prevent further environmental problems, it remains undetermined whether the implementation of the Solar Act of 2010 is the effective economic mechanism to do so.

2. Introduction

Senator Bernard Sanders (I-VT) introduced the bill *"10 Million Solar Roofs and 10 Million Gallons of Solar Water Heating Act of 2010"*, or *S.2993,* to the 111th Congress on February 4, 2010. Herein referred to as the Solar Act of 2010, if passed, the Solar Act of 2010 would direct the Secretary of Energy to create a rebate program that would increase the use of solar photovoltaic and solar water heating systems in the United States by offering rebates on the purchase and installation costs of these systems. Specifically, the goal is to facilitate the purchase and installation of 10 million new solar photovoltaic systems with a total capacity of 30,000 megawatts, and 200,000 solar water-heating systems with a total capacity of 10 million gallons by 2019.

The major objective of the bill is to reduce the emission of greenhouse gases that arise from the combustion of fossil fuels for electricity and water heating in the United States. The bill addresses the main problems caused by the combustion of fossil fuels, namely climate change, smog and acid rain, and ecological destruction. This report assesses the proposed rebates for solar photovoltaic and solar water heating systems, the solar technologies involved and whether the Solar Act of 2010 has the potential to address the environmental problem.

The scientific issues within the application of the Solar Act of 2010 are the focus of this report. A scientific evaluation of the problem and the proposed solution is essential before political, economic, and administrative factors are taken into consideration in a subsequent analysis.

3. What is the Environmental Problem?

The Solar Act of 2010 seeks to reduce the United States emissions of anthropogenic greenhouse gases addressing the issue of global climate change. Global climate change refers long term changes in global climatic patterns that are directly attributed to human activities. Carbon dioxide, the most significant anthropogenic greenhouse gas, absorbs outgoing radiation in the Earth's atmosphere, raising global temperatures. Figure 1 below demonstrates the direct correlation between carbon dioxide concentrations in the atmosphere and temperature. Accordingly, increases in carbon dioxide emissions lead to increases in temperature.

Historic Change in Temperature and Atmospheric CO_2 Concentration

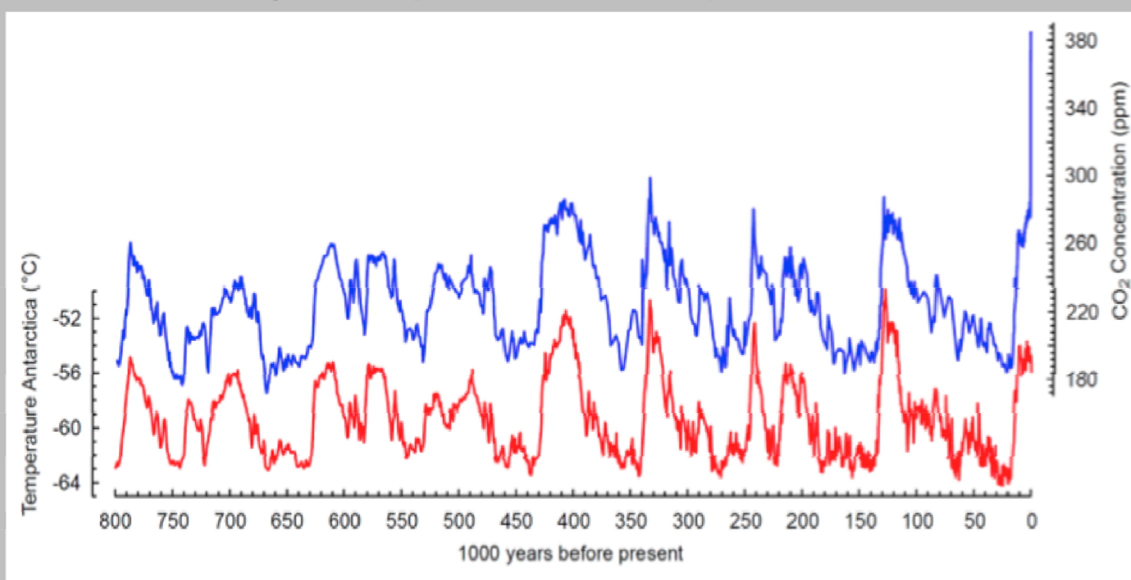

Figure 1: Carbon dioxide emissions and temperature changes from the Vostok Ice Core IPCC showing carbon dioxide and temperature changes in the last 800,000 years. Antarctica temperatures in degrees Celsius. Carbon dioxide atmospheric concentrations in parts per million. Source: IPCC Climate Change 4th Assessment Report. 2007

The long-term changes in climate due to increased carbon dioxide emissions are significant. From 1750 to 2005 anthropogenic emissions of carbon dioxide increased by 36 percent.[i] Within this time period the Earth has experienced increased global average temperatures, rising global average sea levels and reductions of snow and ice caps, as seen in Figure 2 below.

Effects of Greenhouse Gas Emissions

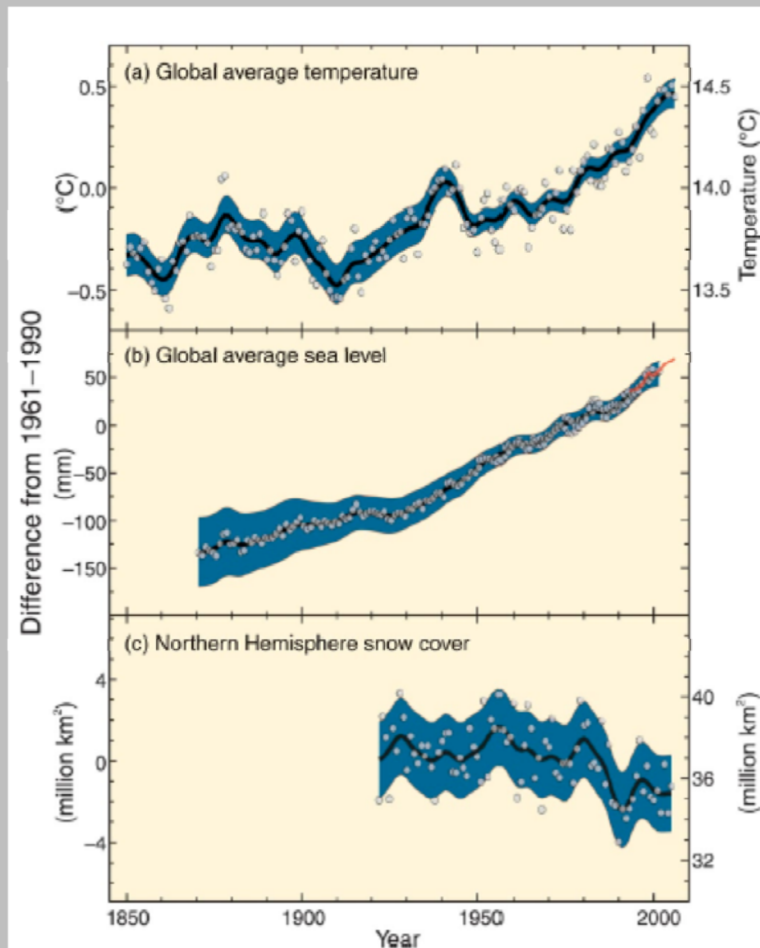

Figure 2: Global average temperature in degrees Celsius, global average sea level in millimeters, and snow cover in million square kilometers. Source: Source: IPCC Climate Change 4th Assessment Report. 2007

The United States is a leading emitter of greenhouse gases, accounting for 19 percent of the global greenhouse gas emissions from the combustion of fossil fuels in 2008.[ii] With continued consumption of fossil fuels at current rates, the Intergovernmental Panel on Climate Change projects that global temperature will increase by 2 to 11.5 degrees Fahrenheit by 2100.[iii] The Solar Act of 2010 addresses greenhouse gas emissions produced by the United States during the combustion of fuels for electricity generation.

3.1 Combustion of Fossil Fuels for Electricity Generation

Electricity generation from the combustion of fossil fuels is a primary source of greenhouse gas emissions. Fossil fuel combustion for electricity generation accounted for 42 percent, or 2,363.5 million metric tons of carbon dioxide emitted by the United States in 2008.[iv] Coal and natural gas the most widely used fossil fuels in the United States electricity sector, collectively comprising approximately 70 percent of the sources used for electricity generation (see Figure 3). While there are significant differences in the composition of their respective emissions, both coal and natural gas emit high volumes of carbon dioxide: 97 percent of coal emissions are comprised of carbon dioxide and although natural gas produces more energy per carbon atom, 99 percent of its emissions are carbon dioxide.[v]

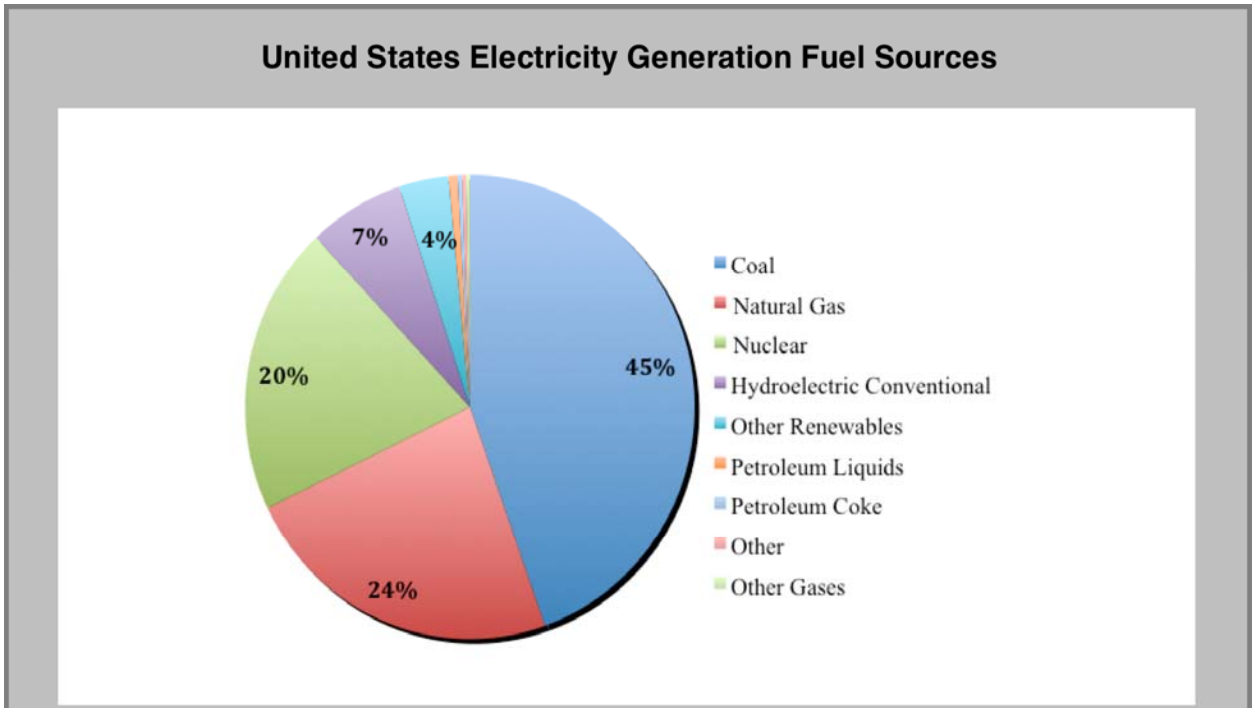

Figure 3: 2009 Electricity Generation by Fuel Type. Source: EIA

While combustion of fossil fuels contributes to climate change and other serious air quality problems, combustion is just the final, and most visible, link in the fossil fuel chain of environmental destruction, and omitting the other stages severely downplays fossil fuels' true environmental footprint. The following section acknowledges the environmental science behind all of coal and natural gas consumption's stages, which include extraction, transportation, combustion, and transmission.

Coal accounts for 45 percent of the United States electricity fuel sources (Figure 3). The process of generating electricity from burning coal is simple but inefficient; typically, coal is burned in a boiler to produce steam that is run through a turbine to produce electricity.[vi] The chemical process that occurs when coal is burned produces carbon dioxide as one of its by-products. Coal-fired power plants are inherently inefficient; only 40 percent of coal's potential energy is converted to electricity.[vii] Furthermore, an additional 10 percent of the electricity is lost in transmission over the 200,000 miles of power lines that stretching across the United States.[viii] In total, coal as fuel source for electricity generation has an efficiency rate of only 30 percent. A 70 percent inefficiency rate leads to unnecessary greenhouse gas emissions. This number does not account for the additional emissions of greenhouse gases generated in the mining, cleaning, and transporting of coal to power plants.

Natural gas, which is mostly methane, comprises 24 percent of the energy mix used for electricity generation. Natural gas production from hydrocarbon rich shale formations, known as "shale gas," is a rapidly expanding trend gas exploration and production today.[ix] Natural gas is promoted as a clean burning fuel that produces less greenhouse gas emissions than coal. It is true that burning natural gas emits less carbon dioxide than coal per unit of energy generated, as well emitting far less nitrous oxides and sulfur dioxides. However, combustion is only one stage of multiple production stages that release emissions, therefore the comparison is misleading.[x] Additional emissions of greenhouse gases occur during the extraction, processing, and transport of natural gas. The United States Environmental Protection Agency reports that in the transportation and storage of natural gas nearly 2.25 billion tons of methane are lost annually, 58 percent from escaped emissions along pipelines.[xi] When all carbon dioxide emissions from the life cycle of natural gas are considered, it is clear that it should not be considered an improvement over coal in mitigating the impacts of climate change.[xii]

3.2 Acid Rain & Smog

In addition to carbon dioxide, fossil fuel combustion emits other harmful pollutants such as nitrous oxides and sulfur dioxide. Increased anthropogenic nitrous oxides and sulfur dioxide emissions cause chemical reactions in the atmosphere creating air quality problems, the most significant being acid rain and photochemical smog.[xiii]

Sources and Transmission of Acid Rain

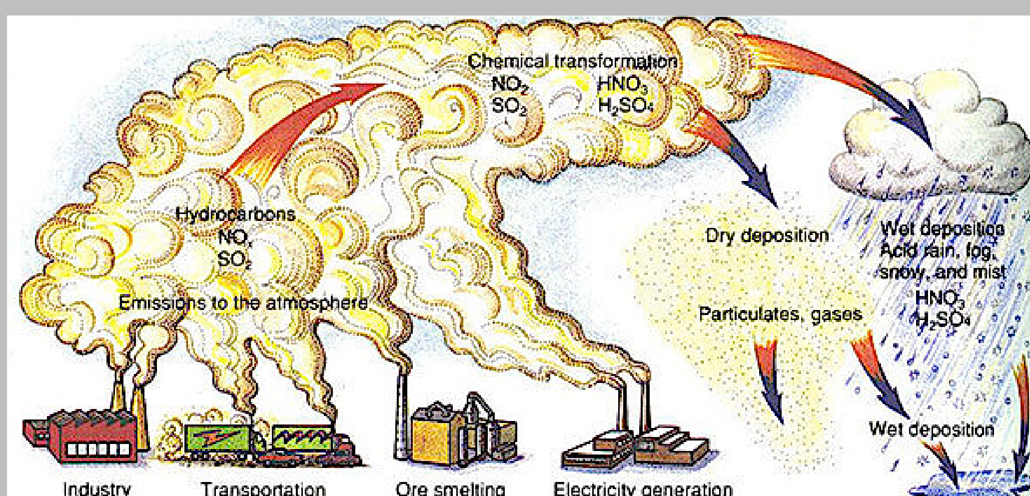

Figure 4: Sources of emissions that lead to the formation of acid rain and the transmission of acid rain from the atmosphere through wet and dry deposition.[xlv]

Acid rain is caused by excessive sulfur dioxide emissions in the atmosphere, which cause serious human health and environmental problems. Approximately 66 percent of all atmospheric sulfur dioxide gases in the United States are emitted from coal-fired power plants.[xv] Sulfur dioxide remains in and is transported through the atmosphere until it is cycled out via precipitation in a process called acid deposition, commonly known as acid rain (Figure 4). The dissolved sulfur in rainwater increases its acidity, harming land and aquatic ecosystems as well as degrading soil and surface water quality. Additionally, acid rain causes health problems to those exposed; if inhaled, acid rain damages the cardiac and nervous systems, as well as exasperating any existing respiratory disorders.

Formation of Photochemical Smog

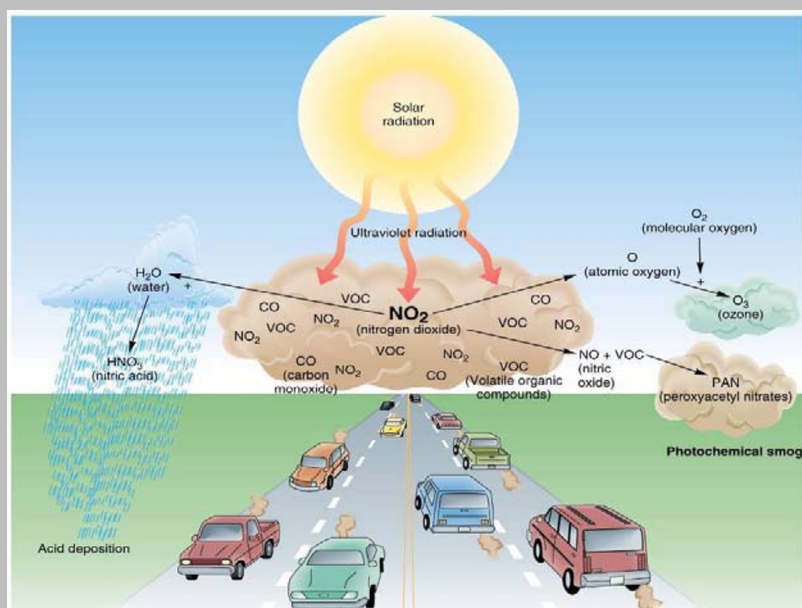

Figure 5: Photochemical smog sources and Atmospheric Chemical Reactions.[xvl]

Photochemical smog is the product of chemical reactions occurring between solar radiation and the nitrous oxides in the atmosphere emitted from coal combustion. Coal-fired power plants contribute 25 percent of atmospheric nitrous oxides emitted in the United States. Photochemical smog formation begins with the reactions between nitrous dioxide and the Sun's ultraviolet radiation; the term "photochemical" implies the reaction is driven by the Sun. This reaction results in the formation of tropospheric level ozone, the primary component of smog.

While smog is mostly known for its concentrations in highly populated urban areas such as Los Angeles, Houston, and New York City, it is important to note that smog is a chronic problem affecting the entire nation. Smog adversely affects human beings, increasing respiratory ailments such as asthma, bronchitis, and emphysema. Natural gas combustion is not a significant contributor to smog or acid rain problems, as it emits less than a third of the nitrous oxides, as well as 1 percent as much sulfur dioxide as coal-fired power plants.

3.3 Ecological Destruction – Extraction and Transportation of Fossil Fuels

Fossil fuels are extracted from the Earth through intensive and environmentally destructive processes. Surface mining, the primary method for extracting coal, completely alters the natural topography by removing vegetation and displacing wildlife. Approximately two-thirds of domestic coal production comes from surface mines, and the EPA estimates that by 2012 up to 1.4 million acres in Appalachia will have been deforested for mining purposes.[xvii] In addition, the mine tailings or materials leftover from coal mining processes are highly toxic, and can damage local aquatic ecosystems and seep into groundwater. The U.S. Forest service estimates that acid drainage from coalmines in the western United States affects up to 16 thousand kilometers of streams.[xviii]

Shale gas extraction has rapidly become the predominant method of natural gas extraction in the United States. It is projected that shale gas will comprise over 20 percent of the total U.S. gas supply by 2020.[xix] Shale gas is extracted via the process of hydraulic fracturing, commonly called "hydrofracking," which involves the pumping of a fracturing fluid under high pressure into a shale formation to generate fractures or cracks in the target rock formation. The amount of water needed to drill and fracture a horizontal shale gas well generally ranges from about 2 million to 4 million gallons per well, depending on the basin and formation characteristics. The water is often injected with chemicals with unknown effects on the environment.[xx] Despite the scale of natural gas extraction nationwide, the effects of hydraulic fracturing on the surrounding environment are not fully understood. In response, the United States Environmental Protection Agency ordered a study on hydraulic fracturing in March 2010 to better understand the short and long-term impacts of hydrofracking fluids on drinking water aquifers.

While natural gas remains the cleanest of the fossil fuels on the combustion end, when taking into account the hydrofracking extraction processes natural gas's cumulative carbon dioxide emissions levels are comparable with coal. While a comprehensive emissions assessment from natural gas extraction has yet to be determined, experts estimate natural gases' total carbon dioxide equivalent emissions increase up to a 2.4-fold greater level than combustion emissions alone.[xxi] This, coupled with natural gas' indirect emissions through the transportation process, suggest that while natural gas may be the cleanest fuel in terms of combustion, all the steps in the energy generation process must be considered and quantified in order to make accurate assessments on emissions and environmental impacts

3.4 Summary of the Environmental Problem

The Solar Act of 2010 aims to reduce the combustion of fossil fuels for the generation of electricity. As described above, the combustion of fossil fuels for electricity generation emits large amounts of greenhouse gases, which trap heat in the atmosphere and exacerbates the effects of climate change. These emissions are compounded by the additional environmental destruction and pollutants created from the extraction and transportation of fossil fuels. The environmental problems stem from the fact that the United States acquires 70 percent of its energy for electricity generation by burning fossil fuels. By increasing the capacity of clean renewable energy, such as solar, the United States can effectively reduce its dependency on these harmful fossil fuels, thus mitigating the environmental problems caused by their combustion.

4. What is the Solution Proposed in the Solar Act of 2010?

The Solar Act of 2010 addresses the aforementioned environmental problems by facilitating the increase of solar photovoltaic and solar water heating capacity in the United States. Solar water heating technologies use the thermal energy of the Sun to heat water, while photovoltaic technologies convert solar electromagnetic radiation into electricity. These technologies take advantage of the Sun's limitless resources, generating energy without producing greenhouse gases or other harmful emissions. The Solar Act of 2010 aims to facilitate the installation of 10 million solar photovoltaic systems with a minimum capacity of 30,000 megawatts, and 200,000 solar water-heating systems with a cumulative capacity of 10 million gallons by 2019.[xxii] Solar power's high capital costs are addressed through a rebate program subsidizing consumers' purchase and installation costs. The rebates outlined in the Solar Act of 2010 are intended to give Americans the financial incentive to take advantage of these technologies.

4.1 Solar Act of 2010 – Federal Rebates for Solar Technologies

The Solar Act of 2010 provides rebates to any homeowner, business, non-profit entity, state or local government that purchases and installs solar PV and/or solar water-heating system in the United States. The rebates outlined by the Solar Act of 2010 are as follows:

- *Photovoltaic Systems:* Rebates begin at a maximum of $1.75 per watt of installed capacity in 2010, decreasing to a maximum of $.50 dollars per watt of installed capacity by 2018. No rebates are scheduled after 2019. Rebates are not applicable to solar photovoltaic systems that exceed 2 megawatts.
- *Water Heating Systems:* Rebates begin at a maximum of $1.00 per watt thermal-equivalent of installed capacity; the rebates will then decrease on a schedule similar to the rebates provided for solar photovoltaic systems, but is unspecified by the bill.

Additionally, the act stipulates that the total amount of the rebate can cover up to 75 percent considering other federal, state and local incentives and tax credits.

4.2 Existing State Level Solar Rebate Programs

The Solar Act of 2010 resembles several existing state-level solar rebate initiatives. While California has implemented programs subsidizing the capital cost of solar photovoltaic systems, and Hawaii and Florida subsidize the cost of solar water heating, New Jersey subsidizes both. At the state level, these programs have led to increased installed solar capacity. New Jersey's Clean Energy Program has facilitated the installation of 5,952 solar panel systems with a total capacity of nearly 100 megawatts.[xxiii] The California Solar Initiative, a program that began in 2007, has facilitated the installation of 370 megawatts out of a goal of 1,940 megawatts.[xxiv]

4.3 The Proposed Solar Technologies: *Photovoltaic and Water Heating Systems*

Unlike the combustion of fossil fuels, solar photovoltaic systems and solar water heating systems do not produce any direct greenhouse gas emissions. These systems take advantage of the renewable solar radiation emitted from the Sun. Although both technologies utilize the same energy resource, the scientific processes involved in solar photovoltaic systems and solar water heating differ. The following section details the mechanics of how these two technologies work.

4.3.1 Solar Photovoltaic Systems

Solar photovoltaic systems convert the Sun's electromagnetic radiation into electricity. Using an average American home system as an example, the conversion process begins when the rooftop panels absorb solar electromagnetic radiation. A single photovoltaic panel contains multiple layers of cells containing the electricity generating material, usually silicon. When electromagnetic radiation hits the cells, it causes loose electrons within the silicon to create electric potential, which creates an electric current (see Figure 6 [xxv]).

Solar Photovoltaic Cell

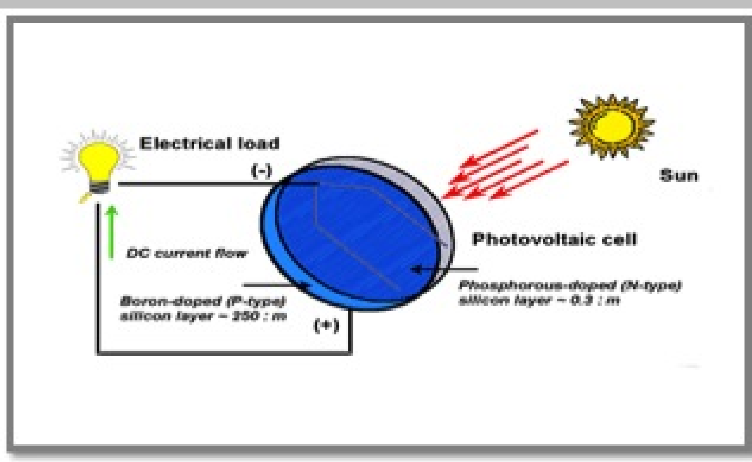

Figure 6: Conversion of solar radiation into electricity via a solar photovoltaic cell

This direct current cannot be used for most household appliances, so an electrical inverter converts the direct current into an alternating current that is ready for use in the home. A circuit breaker then distributes the electricity, and sends any unused power to the local electric grid. In some cases when electricity cannot be sent to the grid, the excess electricity can be stored in high capacity batteries for later consumption.[xxvi] As the home is still connected to the local grid, conventional grid power can still be used if at any time the electricity demands of the home are not met by the photovoltaic system.

Household Solar Photovoltaic System

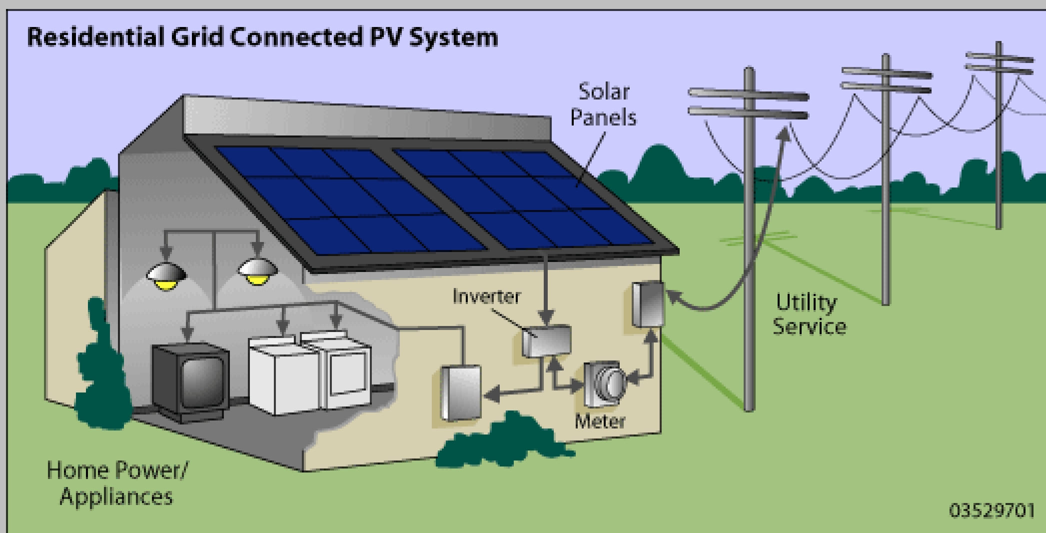

Figure 7: Solar photovoltaic system generating electricity in a common home. Source: U.S. Department of Energy

There are three primary types of photovoltaic panels, each unique with their own set of benefits. **Monocrystalline** cells are cut from a single piece of silicon. While these cells are the most efficient in turning sunlight into electricity, they are also the most expensive. **Multicrystalline** cells are made from slices of silicon, and although less expensive than monocrystalline cells, they are also less efficient than monocrystalline cells. The third variety of cell is the **amorphous cell**, which is made with thin films of silicon rather than crystals. While the cheapest and least efficient, the thin layers of these cells are flexible, and can be folded and used in applications other than rooftops.

The potential energy from the Sun is effectively limitless; in just one hour, the Earth receives more solar energy than what the entire world consumes in one year.[xxvii] While potential solar energy varies regionally, most of the United States receives enough solar energy to take advantage of photovoltaic technologies.[xxviii] This feature cannot be credited to other leading renewable technologies such as wind or tidal. Solar photovoltaic systems also feed electricity into the domestic grid ready to be used, as well the flexibility to be installed on any roof without modifications. Additionally, solar photovoltaic electricity production potential aligns with both daily and seasonal peak summer demand. On a daily basis, photovoltaic systems receive the most direct sunlight during the peak demand hours, in addition to receiving the most incoming solar radiation during the warmer, and higher demand, summer months.[xxix]

4.3.2 Solar Water Heaters

Like photovoltaic systems, solar water heaters use rooftop panels to absorb solar energy. Unlike photovoltaic systems, solar water heaters use the direct solar thermal energy of the Sun rather than electromagnetic radiation.

Household Solar Photovoltaic System

Figure 8: Solar water heated on the rooftop and distributed throughout the home. Source: US Department of Energy

The solar water heating panels, also known as solar collectors, heat water as it is pumped through the rooftop component of the system. Various types of these collectors exist. **Flat Plate Collectors** are the simplest type, heating water as it flows through tubes within the panel; these are the least expensive systems, and best suited for warmer climates. **Integrated Collector Systems** are more expensive while better suited for medium climates; these collectors are made up of one or several tanks, which heat and store the warm water until it is needed**. Evacuated Tube Collectors** are the most expensive and designed to address the technical hurdles of solar heating in colder climates.[xxx] These collectors are made up of tubes that create heat vacuums, efficiently heating the water.

Three Main Types of Solar Hot Water Heating Systems

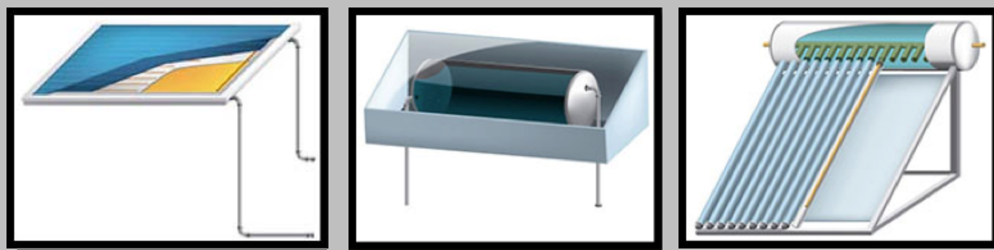

Figure 9: Three main types of solar water collectors: flat plate, integrated collector, and evacuated tube. Source: US Department of Energy

After it is heated the water is either distributed through the house for consumption, or stored for later use. There are two types of systems. **Direct systems** heat the water in the panels and distribute it throughout the house for consumption or storage. The storage tank is often a combination of a gas or electric heater for water use at night. This type of system is better for use in warm or mild climates where there is no risk of the water freezing. In colder climates, **indirect circulation** systems are used. This system heats a non-freezing fluid in the rooftop collector and circulates it through pipes in the water storage tank; a heat exchange then occurs between the heated fluid and the water in the tank.

Solar Water Heater Circulation Systems

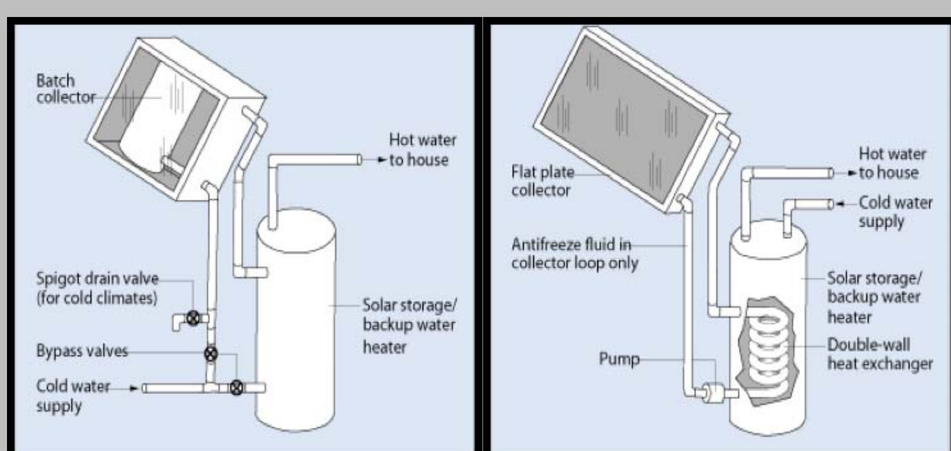

Figure 9: Two types of circulation systems: Direct and Indirect. Source: United States Department of Energy and United States Environmental Protection Agency

Solar water heating systems typically are not sufficient on their own, particularly as they stop heating water at night. However, when used in conjunction with conventional electric or gas heating methods they can meet a household's demand while reducing heating costs by 50 percent.[xxxi]

4.4 Quantifying Potential Environmental Outcomes: Kansas and New Jersey Study

The ultimate goal of the Solar Act of 2010 is the reduction of emissions associated with fossil fuel consumption, particularly carbon dioxide. Electricity fuel sources vary across the nation, so the emissions reductions will vary regionally. The following study is an extrapolation of the expected carbon dioxide emission reductions from the implementation of the Solar Act of 2010 taking into account regional differences. Assuming a consumption of 920 kWh (kilowatt-hours) per month, and an estimate of a 6.1kW photovoltaic system for the average American home, the potential carbon dioxide emissions reductions are determined in two states.[xxxii,xxxiii]

Kansas and New Jersey represent two extreme ends of the United States' energy spectrum, and thus were chosen for the study. In Kansas, 72 percent of electricity is derived from coal, with little renewable electricity capacity. On the other end of the spectrum, New Jersey is largely powered by nuclear and natural gas, at 51 percent and 30 percent respectively, emitting less direct carbon dioxide emissions than coal.[xxxiv] New Jersey is also a leader in solar photovoltaic installation, providing subsidies and tax refunds to consumers through the previously mentioned state rebate program.

4.4.1 Solar Photovoltaic Potential Extrapolated Emissions Reductions

Approximately 70 percent of the total electricity produced in the US is from fossil fuel sources; for the purposes of the study, it is assumed 7 million homes will reflect the energy profile of Kansas while 3 million homes will reflect the energy profile of New Jersey, equating the 10 million solar roofs goal as set by the Solar Act of 2010.[xxxv] A summary of the calculated emissions reductions can be seen in Table 1 below:

New Jersey/ Kansas Study: Impacts of Solar Photovoltaic Systems on CO_2 Emissions

	New Jersey	**Kansas**
Annual Carbon Dioxide Emissions Reduction by 10 Million 6.1kW Solar Panels (per state)	42,819,120 metric tons	83,254,992 metric tons
Approximate Annual Carbon Dioxide Emissions Reduction (national)	**71,112,075 metric tons**	

Table 1. Estimates of the total carbon dioxide reductions if 10 million solar photovoltaic 6.1kW systems installed in New Jersey or Kansas. To approximate a national average, it is assumed that 7 million homes with energy profiles similar to Kansas and 3 million homes with energy profiles similar to New Jersey installed 6.1kW systems.

The extrapolated estimates show the 10 million photovoltaic systems resulting from implementation of the Solar Act of 2010 have the potential to achieve a net emissions reduction of approximately 71.1 million metric tons of carbon dioxide per year. Putting this into context, this reduction in emissions is the equivalent to removing the annual carbon dioxide emissions of approximately 13.7 million passenger cars from American roads.

4.4.2 Emissions Reductions from Solar Water Heaters

The same extrapolations are made for the carbon dioxide emissions reductions by the 200,000 solar water heaters called for in the Solar Act of 2010. Assuming 70 percent of the nation reflects Kansas and 30 percent reflects New Jersey, 140,000 and 60,000 homes are assigned to each state's energy profile, respectively. The study assumes 9.2 percent of total electricity consumption used for water heating, with solar water heaters used in the household offsetting approximately 1,015 kWh per year.[xxxvi]

New Jersey/ Kansas Study: Impacts of Solar Water Heaters on CO_2 Emissions

	New Jersey	**Kansas**
Annual Carbon Dioxide Emissions Reduction by 200,000 Solar Water Heaters (per state)	1,258,616 metric tons	2,166,743 metric tons
Approximate Annual Carbon Dioxide Emissions Reductions (national)	**1,894,305 metric tons**	

Table 2. Estimates of the total carbon dioxide reductions if 200,000 solar water heaters, offsetting 1,015 kWh, were installed in New Jersey or Kansas. To approximate a national average, it is assumed that 140,000 homes with energy profiles similar to Kansas and 60,000 homes with energy profiles similar to New Jersey installed solar water heaters.

The implementation of the Solar Act of 2010 shows a potential to reduce approximately an additional 1.9 million metric tons of carbon dioxide emissions per year through 200,000 solar water heating systems. Put into context, this reduction in annual carbon dioxide emissions is the equivalent to removing the emissions of approximately 364,736 passenger cars from American roads for one year.

4.4.3 Implications of the Study

The above study shows how the Solar Act of 2010 could reduce carbon dioxide emissions in the United States, thereby mitigating the environmental problems caused by fossil fuel consumption. The combined effects of 10 million solar photovoltaic systems and 200,000 solar water heaters yield an estimated net emissions reduction of 73 million tons of carbon dioxide. However, it is necessary to contextualize these reductions both in terms of the United States total carbon dioxide emissions as well as in the context of the Solar Act of 2010 and its goals.

In 2005, the year on which the emissions values in the study are based, the United States emitted 5,753.30 million metric tons of carbon dioxide, 42 percent of which was emitted from electricity generation alone.[xxxvii] Thus, the calculated emissions reductions from the study estimate the emissions reductions achieved by 10 million 6.1 kW solar photovoltaic systems and 200,000 solar water heating systems throughout the United States will yield a reduction of 1.27 percent of the total 2005 carbon dioxide emission levels, which equates to a 3.04 percent emissions reduction from the electricity generating sector. Additionally, building a solar capacity of 10,000,000 solar roofs with an average 6.1 kW would create an additional 61,000 megawatts of installed solar power capacity. This capacity is equal to 18 percent of the coal based generating capacity of 2008.[xxxviii]

As the study shows, the expansion of the solar market into coal-dominated states, such as Kansas has the greatest potential for carbon dioxide reductions. These states are not only high carbon dioxide emitters, but also have little or no incentive programs exist to encourage consumers to transition to renewable energies. These states represent areas of opportunity for transitioning to cleaner renewable fuel sources.

4.4 Summary of the Proposed Solution

The Solar Act of 2010 presents a solution to the environmental problems related to fossil fuel consumption. By offering rebates to prospective customers, the Act will expand the solar market to those who would not have access otherwise. Solar photovoltaic and solar water heating technology is effective and reliable at delivering clean and renewable electricity and hot water, and provides flexible options to meet the needs of consumers. The emissions reductions achieved by the Solar Act of 2010's implementation will yield significant emission reductions.

5. Controversial Aspects of the Solution Proposed

Despite solar power's overall reputation as a clean energy source, it is not free from controversies. While these problems should be acknowledged and not ignored, an honest assessment of its shortcomings still demonstrate that it is less environmentally damaging than fossil fuels.

5.1 Hazards and Risks of Solar Photovoltaic Panel Production:

The conversion of sunlight into electricity incorporates many harmful chemicals. Different chemicals are used and produced in the production of photovoltaic panels, all with varying levels of hazards and relative risk. The majority of the photovoltaic market uses crystalline silicon cells, constituting nearly 90 percent of the market. The chemicals incorporated into the nanotechnology necessary to produce these photovoltaic panels are often either toxic themselves or create toxic by products as a result of the production process.

PV production begins with the mining of silicon, the primary electricity producing component in the panels. The mining process produces silica dust, which can cause the lung disease silicosis if inhaled.[xxxix] After the silicon has been extracted, it is made into polysilicon to be used in the photovoltaic cells; this process uses silane, an extremely explosive gas.[xl] The most prevalent toxic byproduct of the polysilicon production process is silicon tetrachloride, a liquid which when exposed to humid air produces the poisonous gas hydrogen chloride. Globally, 40,000 tons of silicon tetrachloride is produced and recycled back into polysilicon production. China alone, however, produces 40,000-60,000 tons, which is not currently recycled.

Finally, one of the most significant chemicals used in the production process is sulfur hexafluoride, which is used to clean silicon reactors. According to the International Panel on Climate Change, sulfur hexafluoride is the single most potent greenhouse gas with 25,000 times the heat absorbing capacity of carbon dioxide.[xli]

5.2 Operation, Recycling and Disposal Hazards of Solar Photovoltaic Systems

The only hazardous component of operating solar energy comes from Cadmium-tellurium (CdTe) cells, which, when burned, can produce a toxic fume. However, CdTe cells only make up 4.7% of the market and house fires typically do not burn hot enough to vaporize the cadmium.

In order to safeguard against burning panels, brominated flame retardants are incorporated into the plastic of all panels. Although these brominated flame retardants are carcinogenic, they are already prevalent in our environment, bioaccumulating in fatty tissues of humans and animals alike throughout United States.[xlii] While the United States does not regulate this substance, California has banned it in all photovoltaic cells in the state, requiring nontoxic and non-biocumulative substitutes.[xliii] Hexavalent chromium is another carcinogen of concern.[xliv] However, some, but not all, photovoltaic manufacturers have phased it out of their production. Finally, while rare in solar technology, arsenic has been incorporated into certain types of panels, potentially leaching into landfills if improperly decommissioned.[xlv]

Potentially the most serious health and environmental concern is lead used in photovoltaic wire coatings. If panels are not properly recycled, lead can leach into soils, potentially causing neurological damage and developmental problems in children. While lead is not required in solar photovoltaic systems it is legal and still used in the United States. Tin is an acceptable substitute.[xlvi] Likewise, the lead used in photovoltaic wiring is not specific to solar panels, and is used all types of electronics. The lead used in photovoltaic accounts for only 0.5 percent of the total lead used in the United States, making photovoltaic a very small contributor to national lead pollution.[xlvii] However, if photovoltaic capacity scales up, the use of lead would increase significantly. Use of tin could mitigate the use of this unnecessary heavy metal.

The Solar Act of 2010 lacks a plan for disposal of photovoltaic cells whose useful lifecycle averages approximately 30 years.[xlviii] As today's solar photovoltaic capacity in the United States is quite low, the current volume of waste is manageable; if solar photovoltaic capacity increases, an increased volume of waste will need to be addressed. However, all of these chemicals discussed can be recycled. In fact, photovoltaic cells use many of the same chemicals and components found in electronic waste, allowing e-waste facilities to recycle solar cells as well.[xlix]

Qualitative Assessment of Hazardous Substances

Substance	**Hazard/Concern**	**How/Where it's used**	**Regulations, Solutions or Mitigations**	**Risk Level Posed by Photovoltaics**
Silica Dust	Can cause silicosis	Produced from mining	Masks; running water through the drills reduces dust	Low
Silane Gas	Explosive	Used to produce polysilicon for the wafers	Standard Safety Procedures; incidents occur when the gas is accidentally released	Medium
Silicon Tetrachloride	If it reacts with humid air it creates hydrogen chloride, a poisonous gas	Byproduct of polysilicon production	Collected and recycled in the U.S. – Not recycled in China	U.S. – None China - High
Kerf	Particulate silica; can cause silicosis	Produced when cutting	Wearing of masks	Low
Sulfur hexafluoride	25,000 times more potent GHG than CO_2; Single most	Used to clean reactors	Scrubbers are required to limit emissions	Medium (No existing harm but accidental or

	potent GHG; can react with sulfur dioxide to form acid rain			fugitive emissions will undermine the environmental benefits of solar energy
Acids (hydrochloric acid, sulfuric acid, nitric acid)	Corrosive	Used to clean semiconductors and remove impurities	Standard safety procedures	Low
Lead	Can cause neurological damage and developmental problems in children	Electronic circuits for wiring	Currently legal under U.S. regulations.	Low
Brominated Flame Retardants	Carcinogenic and bioaccumulative	Added to the plastic to reduce flammability	Illegal in California, substitutes must be non-toxic and non-bioaccumulative	Low
Cadmium	Releases a toxic percentpercentfume when burned	Primary component of CdTe (cadmium-tellurium) solar panels	Does not burn hot enough to vaporize under typical house fire temperatures	Low
Hexavalent chromium (Cr(VI))	Carcinogenic	Coating to absorb solar radiation	Currently being phased out, many companies have stopped using it but some still do	Low
Arsenic	Carcinogenic	Component of GaAs (Galium Arsenide) panels	Only used in Ga-As panels, < .1% of panels	Very low

Table 3. Qualitative assessment of hazardous substances involved in solar panel production.

5.3 Reliability of Solar Photovoltaic Systems

A common concern over solar power is that sunlight availability may render the technology ineffective in some regions. However, this fear is unsubstantiated – according to the Natural Renewable Energy Laboratory, the average United States solar resource potential ranges from 4 kWh/m^2/day in northern regions, to 6.8 kWh/m^2/day in the southwest (figure 11).[l] Other renewable energy sources, such as hydropower and wind, are limited to very specific regions.

Available Solar Photovoltaic Resources in the United States

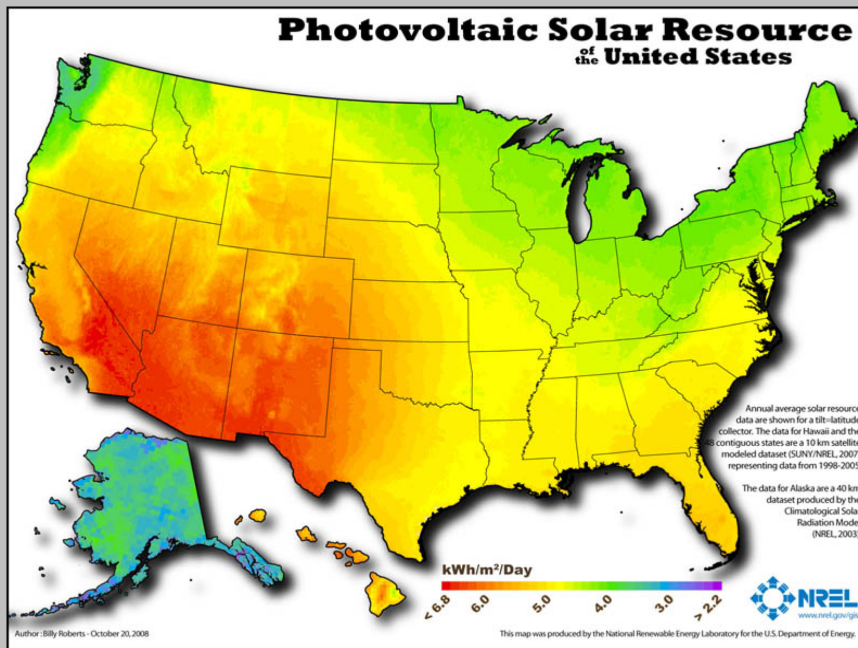

Figure 11: Solar resource availability in the United States. Source: National Renewable Energy Laboratory

5.4 Efficiency of Solar Photovoltaic Energy

Efficiency in solar photovoltaic systems is a measure of the potential solar energy that is actually converted into usable electricity. Marketable solar technology efficiency ranges from 7 to 17 percent. While efforts to improve efficiency are important for performance and value, the Sun is a limitless resource. In comparison, the efficiency of coal fueled electricity generation is only 28 percent and is achieved at an enormous environmental cost.[li]

Centralized solar PV technology is 89 to 98 percent more efficient in terms of volume of emissions/watt compared to the fossil fuel alternatives, even when accounting for the indirect emissions and harmful chemicals associated with fossil fuels used during the production process.[lii] This efficiency is even higher with rooftop panels due to reduced losses associated with transmission.[liii] Efficiency in photovoltaic electricity output is expected to increase in time; photovoltaic cells have reached up to 41 percent efficiency in laboratory tests, showing promise for future developments.[liv]

While the Solar Act of 2010 reduces greenhouse gases and other emissions emitted by increasing renewable power, it stops short of addressing grid improvements such as investments in "smart grid" technologies. A more comprehensive plan for increasing solar photovoltaic capacity would include support for the infrastructure needed to effectively integrate solar energy into the United States system.

5.5. Limitations and Concerns of Solar Hot Water Heating Systems

In contrast with solar photovoltaic technologies, solar water heater systems do not require the use of toxic processes or chemicals, as their simpler design uses the thermal energy of the Sun to directly heat water. These systems are more susceptible to losses in productivity during cloudy days, which means that they cannot fully replace gas or electric water heaters. However, they can be used to supplement conventional water heating needs by up to 80 percent, and pay for themselves by the end of their lifecycle, which ranges from 15 to 30 years.[lv]

5.6 Summary of Controversies of Solar Electricity Systems

Like all new technologies, solar power is not exempt from controversies. The technology incorporates toxic substances with concerns over toxicity, efficiency and reliability. These environmental and human health concerns can be addressed by the appropriate production, recycling, and disposal regulations. One would be prudent to ask whether solar is an improvement over conventional fossil fuel energy production. However, when all of the controversies and potential issues are accounted for, the solar power promoted by the Solar Act of 2010 holds up as an effective means to address the environmental problems associated with fossil fuel consumption.

6. Measuring the Success of the Solar Act of 2010

The specific goal of the Solar Act of 2010 is clearly stated within the legislation: to add an additional 10,000,000 solar roofs with a capacity of 30,000 megawatts and 200,000 solar water-heating systems with a cumulative capacity 10,000,000 gallons by 2019. Therefore, the success of the program will be measured by the percent of this goal achieved.

In order to implement this program, rebates will be issued based on the total installed capacity of qualified rooftop solar photovoltaic and solar hot water heating systems. To monitor the programs progress, it will be necessary for administrators to track the number of rebates issued, as well as the installed capacity of systems. This can be done through an application and rebate tracking system that will generate outcome measurements to inform whether the program has achieved its installed capacity goal. The value of rebates, or amount of capacity installed, can then be used to make extrapolations on the environmental outcomes of the program, such as the amount of greenhouse gases emissions that were curbed due to the installed capacity of the systems.

The reduction in greenhouse gas emissions is an important environmental benefit of the program, and therefore, developing a method of calculating these reductions will be important. As the analysis of the environmental science demonstrated, greenhouse gas emissions are emitted from the combustion of fossil fuels. Therefore, it can be assumed that the reduction of greenhouse gas emissions will be directly related to the amount of displaced fossil fuel combustion as a result of the installed of solar electricity capacity.

Along with greenhouse gas emissions, another important environmental indicator that can be used to measure the success of the program is the measurement of the kWh produced by the solar photovoltaic panels. A useful tool for measuring this is a net meter, which can be installed with an individual system in order to provide specific data about how much electricity is being produced and subsequently consumed by the home/business owner, or fed back into the electricity grid. However, due to inconsistencies in state net metering policies, not all participants may have the ability to track electricity production in this manner. A solution for the program would be to install net meters on a random sample of systems in order to collect data, which could be used as a representative sample of statewide system performance. By using this data in conjunction with the information of the total installed capacity, program administrators could determine average capacity factors for participating systems. Using this factor, the actual amount of energy that is being generated from the systems installed in the program could be extrapolated.

7. Conclusion

This report concludes that the Solar Act of 2010 sufficiently addresses the environmental problems of fossil fuel consumption through promotion of increased solar electricity and solar water heating capacity. Increased capacity of solar power will reduce carbon dioxide emissions, mitigating the effects of climate change as well as the aforementioned environmental issues caused by fossil fuel consumption for energy production. Implementation of the Solar Act of 2010 will provide rebates subsidizing the costs to American consumers, and will yield significant carbon-dioxide reductions.

The proposed solution cannot supply all of the electricity demand of the United States. However, building a solar capacity of 10,000,000 solar roofs with an average 6.1 kW capacity would create an additional 61,000 megawatts of installed solar power capacity as shown in the study in this report. This capacity is equal to 18 percent of the coal based generating capacity of 2008.[lvi] As shown in this report, the solar technologies proposed in the solution are by far cleaner and more efficient than the current source of electricity used in the United States, even after considering the shortcomings and externalities of the solar photovoltaic panel life cycle.

An increased solar power capacity in the United States is a significant step towards replacing fossil fuels with renewable energy sources that are not environmentally destructive. While it is concluded that increasing solar power's capacity in the United States has the ability to mitigate environmental problems, it remains undetermined whether the implementation of the Solar Act of 2010 is the effective economic mechanism to do so.

Glossary of Terms

acid rain: a chemical and atmospheric occurrence that happens when sulfur and nitrogen are released into the atmosphere from combustion of fossil fuels, and chemically converted into secondary pollutants like nitric and sulfuric acid, and deposited as acid rain, snow, or fog

alternating current: an electrical current that reverses direction in a circuit; within the United States, this is how power flows from a power plant, alternating 60 times every second

bioaccumulation: the process where chemical contaminants become more concentrated as they pass up a food chain; chemicals are stored in the fatty tissues of animals, with concentration levels increasing up the food chain

carbon dioxide: CO_2, a greenhouse gas formed by the combustion of fossil fuels

direct current: an electric current that does not reverse direction in a circuit; batteries, fuel cells, and solar cells all produce direct current

efficiency: this term has been used in several contexts throughout the report; in terms of combustion of fossil fuels, efficiency describes the amount of input energy required for the amount of output energy.; in terms of solar panels, efficiency is the amount of sunlight collected that is converted into usable energy in the form of electricity

electric grid: an interconnected network of power lines to deliver electricity from power suppliers (power plants) to consumers (homes and businesses)

electromagnetic radiation: waves of energy from electric or magnetic fields that travel at the speed of light at differing wavelengths from short-wave x-rays through ultraviolet, visible, and infrared to long wave lengths of radio waves

evacuated tube collectors: a solar water heating system which contains a set of parallel tubes which each contain another tube creating a heated vacuum, these are best in colder climates

flat plate collectors: a solar water heating system where cold water enters one side of the tubes, and warms up while it passes to the other side of the tubes; best used in warm climates

fossil fuel: a nonrenewable resource derived from the remains of organisms preserved within the Earth's crust (oil, coal, and natural gas)

greenhouse gas: a gas that absorbs out-going infrared radiation from the Earth's surface, trapping heat in the atmosphere; some of the main greenhouse gases are carbon dioxide, methane, nitrous oxide, and ozone

hydraulic fracturing: an operation where a mixture of water and chemicals is injected into the Earth's surface to break apart rocks to allow for the release of oil or natural gas *installed capacity*: the energy production capacity of a solar cell, usually expressed in kilowatt-hour

integrated collector systems: a solar water heating system using an unpressurized storage tank with painted absorber coatings, best for warm to medium climates

kWh (kilowatt-hours): a unit of energy that describes the amount of electricity needed to operate something over one hour

mine tailings: the refuse left over after the extraction coal

net meter: an electricity meter monitoring both the amount of electricity a solar PV system puts into the grid and how much electricity a home or business uses from the grid

nitrous oxide: a greenhouse gas caused by the combustion of fossil fuels, which reacts in the atmosphere to create photochemical smog

peak demand: a period of maximum demand on an electric system, usually defined by a specific time of day or year

photochemical smog: air pollution caused by nitrous oxides reacting with sunlight to produce tropospheric ozone

photovoltaic cell: a solar cell that converts energy from the sun into electrical energy

silicosis: an occupational lung disease caused by the inhalation of silica dust, mainly caused during silica mining

sulfur oxides: formed by the combustion of fossil fuels; react with the atmosphere to create acid rain

thermal energy: energy in the form of heat

troposphere: The lowest portion of the Earth's atmosphere where weather occurs

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