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The Environmental History of Solar Photovoltaic Cells

Samantha Hoang
shoang@wellesley.edu

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In the United States, solar energy technologies have been installed on the White House as a 'lead by example' action to promote green energy. President Carter began this trend in 1979, when he installed 32 solar thermal heaters as a symbol for his faith in renewable energies. As the solar industry advanced over time, we now see President Obama's solar photovoltaic (PV) cells lining the White House roofs in 2016. In the history of solar photovoltaic cells in the U.S., it is observed that as public and government interest increases, the amount of research in these solar technologies is heightened to create environmentally friendly and economically sound solar panels. The 1970's Energy Crisis and Global Warming concerns of the past 3 decades have shaped the attitudes of the federal government and public in more environmentally conscious ways that have led us to the state of solar photovoltaic cells that we live in today. However, solar PV technologies would not have been able to attain the success it experiences today without its long past of research and development, beginning in the 1800's.

The history of solar photovoltaic cells begins with Edmond Becquerel's discovery of the photovoltaic effect in 1839.[1] Becquerel found that when certain materials were exposed to light, an electric current was generated.[2] No one could provide an explanation of the photovoltaic effect until Albert Einstein published his Nobel Prize winning theory of the photoelectric effect in 1905. This theory explains that certain intensities of incident light, which are called photons, are able to interact and eject electrons from conductive metal.[3] Fifty years following Becquerel's theory, Charles Fritts invented the first solar cells from selenium wafers and gold transparent coverings. By the start of the 20th century, photovoltaics shifted from selenium to silicon. Silicon was a favored material because it was inexpensive, plentiful (found in quartz in sand), and contained many favorable chemical properties. These silicon photovoltaic cells were produced

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[1] Ken Butti and John Perlin, *A Golden Thread: 2500 Years of Solar Architecture and Technology* (New York, NY: Van Nostrand Reinhold, 1980), 222; U.S. Department of Energy, "The History of Solar," *Energy Efficiency and Renewable Energy*, n.d., https://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf.

[2] Robert K. Kaufmann and Cutler J. Cleveland, *Environmental Science* (McGraw-Hill Science Engineering, 2008), 468; Wikipedia, "Photovoltaic Effect," *Wikipedia: The Free Encyclopedia*, February 16, 2016, https://en.wikipedia.org/wiki/Photovoltaic_effect.

[3] Warren Davis, "What Is the Photoelectric Effect?," *Physics and Astronomy Online*, accessed March 8, 2016, http://www.physlink.com/Education/AskExperts/ae24.cfm.

using a method of thermal reducing silica with carbon. Their manufacturing, however, was expensive, contained many undesirable impurities, and wasted materials.[4] These initial models also converted less than 1% of the sun's incident energy, making the technology very inefficient and uneconomical. Due to the amount of wasted materials, low solar conversion rates, and high costs, silicon PV cells would not be seen as a viable commercial power source until the 1950's.[5]

The Birth of U.S. Photovoltaic Technology

In 1953, Bell Telephone Laboratories hired Daryl Chapin, Gerald Pearson, and Calvin Fuller to research a "dependable alternative power source for telephone systems in rural areas".[6] One year later, Fuller developed a solar photovoltaic cell of 4% efficiency, and later of 6% efficiency, by doping strips of silicon with boron and arsenic.[7] This initial solar PV system is known as a crystalline-silicon cell or 1st generation PV cell. These cells are created by producing large cylindrical crystals of silicon, doping them with boron and phosphorous, and slicing the cylinders to create wafers. Even though these panels have high efficiencies of 15-20%, they are unable to be sliced thin enough, generating more wasted materials. This model of the silicon PV cell converted enough of the sun's energy to be considered useful in common electric equipment, thus, giving birth to photovoltaic technology in the U.S. [8] Enthusiastic public attention of Fuller's solar PV cell was captured after *Business Week* magazine published a futuristic article of the possibilities of solar power, which included "solar-powered fans, lawnmowers, and even a solar convertible".[9] Due to its high production cost, however, the solar industry was unable to compete with traditional energy sources. A one-watt cell in 1956 costed around $300 per watt while fossil fuel based power plants were able to produce at 50 cents per watt. The only demand for the solar PV industry at this time came from consumer manufacturers, whose products

[4] M. Khalifa, M. Hajji, and H. Ezzaouia, "Impurity Removal Process for High-Purity Silica Production by Acid Leaching," 2012.
[5] Butti and Perlin, *A Golden Thread*, 227.
[6] Ibid., 228.
[7] Jeremy Shere, *Renewable: The World-Changing Power of Alternative Energy*, First edition (New York: St. Martin's Press, 2013), 120–121.
[8] U.S. Department of Energy, "The History of Solar."
[9] Butti and Perlin, *A Golden Thread*, 229.

required only small amounts of direct current. Radio and toy manufacturers used the silicon solar cells to power beach radios, toy ships, and the propellers of toy planes.[10]

In the three decades following World War II, solar cells did not gain any momentum in the energy market because of the emerging consumer culture and falling fossil fuel prices. In the 1950's and 1960's, U.S. electricity consumption increased 5-fold as consumer demands for home and electrical appliances grew.[11] Falling fossil fuel prices, caused by larger supply and high government support, led manufacturers and consumers to view gas as almost a renewable energy source. In 1954, one gas company executive stated, "The industry discovers more gas everyday than is consumed every day in the United States. I don't think in our lifetime we will see the depletion of our product".[12] Even when reports published by the President's Materials Commission predicted that fossil fuel supplies would be depleted by 1975 and urged for the support of renewable solar technologies, the federal government chose to ignore research and allowed for the uncontrolled production and consumption of fossil fuels. Because of the government's and public's wasteful views of fossil fuel based energy, solar technology and other renewable energy technologies were brushed aside for later decades.

Even though there was low demand for solar PV cells on Earth, this innovative technology was found to be highly useful in outer space. The Space Race that encapsulated the U.S. in the 1950's led to an increased surge in NASA research. One issue found in outer space research was how to supply these innovations with a power source. In the late 1950's, Dr. Hans Siegler, a power expert for the U.S. Army Signal Corps, advocated for the use of solar PV cells in NASA satellites rather than using batteries. He claimed that solar cells could power the radio power supplies for a much longer time than traditional batteries. The Vanguard I satellite resulted in containing a duel system of power, solar silicon cells and batteries, and was launched on March 17, 1958. The battery died a week later and the solar silicon cell maintained communication with Earth for several years, proving Siegler's prediction to be correct.[13] Within a few months of Vanguard I's launch, solar silicon cells were installed into other satellites, including Telstar, Explorer III, Vanguard II, and Sputnik-3. NASA has found thin silicon cells to

[10] "Passive Solar History," *California Solar Center*, 2015, http://californiasolarcenter.org/history-pv/; Kaufmann and Cleveland, *Environmental Science*, 470.
[11] Butti and Perlin, *A Golden Thread*, 221–222.
[12] Ibid., 221.
[13] "Passive Solar History."

be especially beneficial to satellite and vehicle power supplies due to their autonomous, compact, light, and cost effective features, making them the accepted form of power for outer space technology to today.[14]

About two decades later, solar PV applications finally came down from the remote outer space, to other remote locations on Earth. In the early 1970's, Dr. Elliot Berman created a poorer grade of silicon to be used in PV technology, which brought the cost of a silicon solar cell from $100 per watt to $20 per watt. This permitted for terrestrial demand to arise in remote, isolated areas where grid utilities were nonexistent or uneconomical. Solar PV cells were initially used for "small-scale electrical demands located away from utility lines", such as emergency call boxes, warning lights, off-shore oil rigs, lighthouses, and railroad crossings.[15] Even with solar technologies being applied on Earth, major interests in renewable energy did not arise until the 1970's Energy Crisis forced Americans to look for alternative energy.

The 1970's Energy Crisis

In the 1970's, the U.S. experienced a decade long energy crisis, where issues with domestic production, as well as imports from OAPEC (Organization of Arab Petroleum Exporting Countries), created unexpected price spikes and gas lines. While some may only attribute the decade long energy crisis to the 1973 OAPEC Embargo, Robert D. Lifset argues that problems with the fossil fuel industry and regulatory policies also are a large contributor, in his article, *A New Understanding of the American Energy Crisis of the 1970's*.[16] The unstable oil market, stemming from the unregulated production of oil in the 1930's, along with increased dependencies on foreign oil, caused the U.S. to be more vulnerable to the OAPEC Embargo. The country began to feel the effects of the energy crisis in 1973, when spikes in gas prices and notorious gas lines became common. The electricity utility sector also fell apart in the 1970's due to "technological stasis, the environmental movement and the oil and natural gas crisis".[17]

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[14] Butti and Perlin, *A Golden Thread*, 231–233.
[15] "Passive Solar History"; U.S. Department of Energy, "The History of Solar"; Kaufmann and Cleveland, *Environmental Science*, 470.
[16] Robert D. Lifset, "A New Understanding of the American Energy Crisis of the 1970's," *GESIS - Leibniz-Institute for the Social Sciences, Center for Historical Social Research*, n.d., 22–42.
[17] Ibid., 35.

Because the U.S. had enjoyed decades of stable energy consumption, the energy crisis came as an enormous shock. For Americans in the 1970's, Lifset says that "there was a good deal of anger and frustration at their inability to secure adequate supplies of a commodity that many had never expected to become scarce." [18] The energy crisis forced the general public and federal government to finally view fossil fuels as a non-renewable source. Scientists and homeowners began to look to other energy sources in hopes of maintaining their energy intensive lifestyles. A 1974 *New York Times* article, "As Energy Grows Scarcer, Science Again Looks to the Sun", remarks:

> "Today, as the prices of conventional fuels go up and supplies go down, it is not hard to see why the promise of power from the sun has aroused the interest of governments, and industries home owners and utilities, and has sent scientists scurrying into labs and deserts and onto roofs to see how this energy source can be captured and used efficiently on a broad scale." [19]

One year prior to the energy crisis, the federal government allocated less than 1 percent of the roughly $600 million budget for energy research to solar energy, which totaled to $4 million (See Table 1). They were mostly interested in new research in fossil fuels, nuclear fission, and fusion since they generate large amounts of energy in a small amount of space.[20] One year into the energy crisis, federal allocations to solar energy rose dramatically to $50 million as the US government began to turn their interests towards renewable energy sources.[21] In 1977, the US Department of Energy launched the Solar Energy Research Institute (which was later renamed as the National Renewable Energy Laboratory) in order to support solar technology research.[22] The federal government also placed energy tax credits towards solar technology when large losses of revenue from oil and gas occurred.[23]

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[18] Ibid., 23–24.
[19] Bayard Webster, "As Energy Grows Scarcer, Science Again Looks to the Sun," *The New York Times*, July 5, 1974.
[20] Allen L. Hammond, "Energy Options: Challenge for the Future," *American Association for the Advancement of Science*, September 8, 1972.
[21] Webster, "As Energy Grows Scarcer, Science Again Looks to the Sun."
[22] U.S. Department of Energy, "The History of Solar."
[23] Wikipedia, "Business Energy Investment Tax Credit," *Wikipedia: The Free Encyclopedia*, February 19, 2016, Business Energy Investment Tax Credit.

Table 1. Federal energy R&D funding proposed for fiscal year 1973, subject to approval by Congress

Item	Budget (10^6)
Fossil fuels	136
Nuclear fission	356
Nuclear fusion	65
Solar energy	4
Geothermal energy	3
Related technologies	55
Total	622

Even though more money and effort was put into solar energy research, there were higher interests in developing solar thermal systems (heating and cooling units) rather than solar PV cells.[24] Researchers at the time were certain that by the late 1970's, solar heating and cooling units would be out of R&D (research and development) and onto the consumer market. Many believed that solar thermal systems should first be integrated into the consumer market successfully before funding research for solar PV cells. A 1974 article in *Science Magazine*, reported:

> "Discussions for the uses of solar energy in the near future have tended to focus on the heating and cooling of buildings and not on the generation of electricity. The ultimate solar power device-photovoltaic cells that convert photons into electric energy-is often relegated, with nuclear fusion, to the next century." [25]

During this time, solar PV cells were still relatively expensive in comparison to traditional energy sources from fossil fuels. Even though they were rapidly decreasing in price and had some applications in remote areas, solar PV cells were seen to be viable for space technology, where this form of renewable energy was more cost effective than fossil fuel devised batteries.[26] Additionally, the federal government supported solar thermal systems with an aggressive energy conservation plan. They educated the public about renewable energy technologies and offered tax breaks to encourage consumers to purchase these devices. Because

[24] Webster, "As Energy Grows Scarcer, Science Again Looks to the Sun"; Allen L. Hammond, "Solar Power: Promising New Developments," *American Association for the Advancement of Science*, June 28, 1974; "Promise of the Sun," *The New York Times*, April 29, 1974; Richard Haitch, "The President's 'Solar Advocate,'" *The New York Times*, June 5, 1977; Hammond, "Energy Options: Challenge for the Future."
[25] Hammond, "Solar Power: Promising New Developments."
[26] Webster, "As Energy Grows Scarcer, Science Again Looks to the Sun"; Steve Lohr, "Technology: Solar Energy: New Procedure," *The New York Times*, August 14, 1980; Bayard Webster, "Solar Energy Found Practical for Homes in 2 Decades," *The New York Times*, July 6, 1977.

solar thermal systems were supported by the federal government and were readily available and cheaper on the consumer market, they were considered to be the more applicable form of renewable solar energy when compared to solar PV cells during the 1970's.

President Jimmy Carter, a strong advocate for solar energy, stated during a press conference on June 20, 1979 that he was interested in "harnessing the power of the sun [… in hopes of moving] away from our crippling dependence on foreign oil". In hopes of sparking a widespread use of solar technology, Carter had 32 thermal solar collectors installed in the West Wing of the White House. During the same press conference, Carter explained what the solar collectors symbolized:

> "A generation from now, this solar heater can either be a curiosity, a museum piece, an example of a road not taken, or it can be a small part of one of the greatest and most exciting adventures ever undertaken by the American people." [27]

This federal government 'lead-by-example' initiative was also followed by an optimistic Solar Energy Initiative. Carter wanted Congress to approve of a "$100 million 'solar energy bank' with the goal of generating 20 percent of U.S. power from alternative energy sources by 2000." The Solar Energy Initiative, however, was put aside 5 months later once the Iran Hostage Crisis was pushed to the top of the federal agenda. [28]

When President Ronald Reagan came into office two year later, one of his first requests was to remove Carter's solar heating and cooling units from the White house roofs. George Charles Szego, the engineer who persuaded Carter to install the panels, said that Reagan "felt that the equipment was just a joke".[29] As a politician who believed that corporate self-interest was best for the American economy, Reagan took a neutral stance on the energy tax policy that did not encourage fossil fuel development, energy conservation, or alternative fuels. This allowed energy utilities to match with market prices and encourage private investment. Because the solar industry relied heavily on federal aid, the elimination of solar tax credits ultimately marked solar energy to have high, uncompetitive prices.[30] Throughout the 1980's, the federal and

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[27] Tom Murse, "A Brief History of White House Solar Panels," *About News,* December 4, 2015, http://usgovinfo.about.com/od/thepresidentandcabinet/tp/History-of-White-House-Solar-Panels.htm.
[28] Shere, *Renewable*, 71; Catherine C. Robbins, "Where the Sun Shines, Solar Activity Is Still Brisk," *The New York Times,* May 22, 1988.
[29] Murse, "A Brief History of White House Solar Panels."
[30] Wikipedia, "Business Energy Investment Tax Credit"; Robbins, "Where the Sun Shines, Solar Activity Is Still Brisk."

public domains were losing interest in solar power as financial support waned and oil prices fell to support energy demands again. The oil markets stabilized in the early 1980's, marking the end of the 1970's Energy Crisis. Solar-power businesses consequently fell out of the market and the only demand for remaining businesses came from the occasional repair of a solar heating and cooling unit.[31] A 1989 *New York Times* article, "U.S. Companies Losing Interest In Solar Energy: Companies Abandon Solar Energy" observed that:

> "Some of the nation's biggest backers of solar energy are losing interest just as the technology to transform sunlight into electricity is getting closer to being economically competitive with some conventional power sources." [32]

Even though economic support and interest for solar technology in the 1980's fell, R&D supported by the PV industry and the U.S. Department of Energy allowed prices for solar PV systems to continue to drop closer towards fossil fuel energy prices. One attempt to reduce prices was through the development of thin film solar cells, which are also known as 2nd generation PV cells. Because these panels are much thinner (several mm thick) in comparison to 1st generation cells (200 mm thick), they reduce the amount of materials and money needed to construct a PV system. Thin film solar cells, however, contain rarer Earth metals, like indium and cadmium, which creates concerns for material sustainability. They also generate lower efficiencies of 7-12%, making thin film solar cells less marketable in comparison to the 1st generation silicon cells.[33] Overall, efforts to develop new models of solar panels, such as thin film solar cells, after the 1970's Energy Crisis were mostly in vain since 1st generation silicon cells continued to dominate 82% of the market (See Figure 2).[34]

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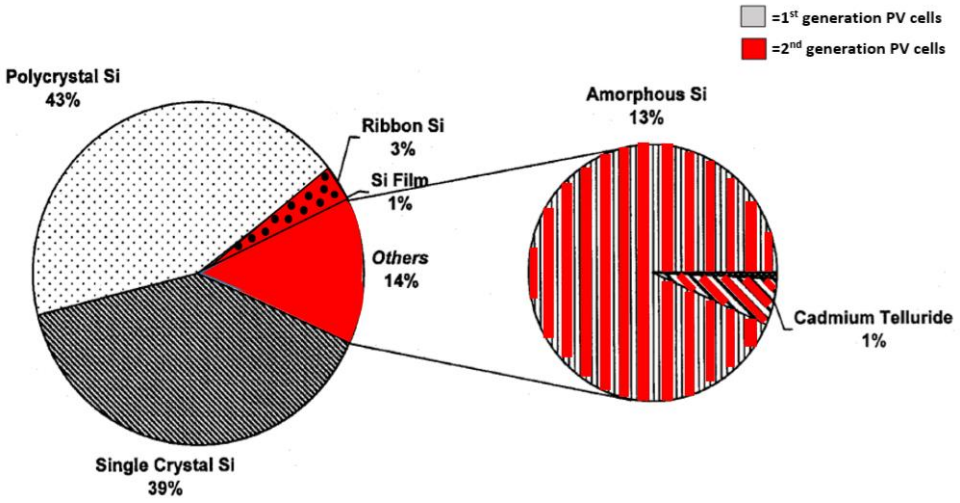
[31] Andi Rierden, "Homeowners Revive Interest In Solar Power: The Goal: 'To Get off the Grid.' Homeowners Reviving Interest in Solar Power An Energy-Conserving Home in New Canaan Is Built into a Hill.," *The New York Times*, August 25, 1991.
[32] Matthew L. Wald, "U.S. Companies Losing Interest In Solar Energy: Companies Abandon Solar Energy," *The New York Times*, March 7, 1989.
[33] Chris Woodford, "Solar Cells," *Explain That Stuff!*, March 27, 2016, http://www.explainthatstuff.com/solarcells.html; Hammond, "Solar Power: Promising New Developments."
[34] Tetra Tech, Inc., "Potential Health and Environmental Impacts Associated with the Manufacture and Use of Photovoltaic Cells" (Lafayette, California 94549, November 2003), secs. 2, p1.

Figure 2. Various solar photovoltaic cells by percentage of technologies in 1998. All percentages are rounded individually.



Global Warming

The solar PV industry woke up from its slumber of the 1980's when heat waves, droughts, and record high temperatures swept across the U.S. during the summer of 1988. The blame for the weather fell on the scientific theory of global warming, or global climate change. Global warming is the phenomena where increasing global climate is caused by greenhouse gases that trap the sun's heat to the Earth's surface. Greenhouse gases, which includes carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide, are thought to be released into the atmosphere from fossil fuel burning in industries, boilers furnaces, and car engines.[35] Even though the greenhouse theory had already been around for one century, the brutally hot summer of 1988 captured media attention and global warming began to be treated as a crisis by some. [36] The widespread attention pushed global warming to the top of the federal agenda, leading politicians and researches to look for solutions that would dwarf greenhouse gas emissions. A 1988 *New York Times* article, "Stemming the Global Warming Trend Would Mean an Upheaval for All", noted that "the magnitude of the changes could easily dwarf the conservation efforts of

[35] Matthew L. Wald, "Stemming the Global Warming Trend Would Mean an Upheaval for All," *The New York Times*, August 28, 1988; Kaufmann and Cleveland, *Environmental Science*.
[36] Mitchell Landsberg, "Global Warming Is Expected to Be the Hot Issue of 1990's," *Los Angeles Times*, October 29, 1989.

the early 1970's sparked by the oil embargo." [37] Similar to the 1970's Energy Crisis, some looked to nuclear power plants as a solution since they generate large amounts of energy and emit relatively low amounts of carbon dioxide in comparison to fossil fuel based plants. Scientists, such as Jan Beyea, believed that while "there certainly should be research into inherently safe nuclear power plants, [there should also be] an equal amount [..] put into photovoltaics." [38] The federal government generally followed this belief and focused on renewable energy sources in order to attend to the widespread media attention of global warming.

In the 1990's, the U.S. federal government began formulating national policies and incentives that encouraged widespread renewable energy usage in hopes of mitigating global climate change. The George H.W. Bush administration created the production tax credit (PTC) in 1992 as incentive for residential and commercial consumers of renewable energy to recoup a portion of the system cost. The PTC was extended under the George W. Bush administration, with the Energy Policy Act of 2005. This incentive allows residential and commercial consumers of solar energy systems to recoup 30% of the total cost of a system, with residents being limited to a cap of $2,000.[39] Originally, the ITC was set to expire at the end 2007, but concerns for the solar industry's independence led officials to reevaluate and add five separate extensions, ultimately pushing the program's expiration date to 2021.

In 1997, President Clinton announced the Million Solar Roofs Initiative at a United Nations conference on global warming. The goal of this initiative was to have 1 million solar technologies (includes photovoltaic and thermal technologies) installed on residential rooftops by 2010. This would take away carbon emissions equivalent to 850,000 automobiles and create 70,000 new jobs in the solar industry. The Department of Energy brought the influence of the federal government to businesses, organizations, and civic leaders to increase the demand and market share of solar technologies.[40]

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[37] Wald, "Stemming the Global Warming Trend Would Mean an Upheaval for All."
[38] Ibid.
[39] "The History an(d Future of the Solar ITC," *EnergySage*, May 18, 2015, http://news.energysage.com/the-history-and-future-of-the-solar-itc/.
[40] Matthew L. Wald, "For Now, an Industry Relishes Its Day in the Sun," *The New York Times*, August 16, 1997; Jeanette J. Fisher, "Solar Energy: The 'Million Solar Roofs' Initiative," *Environmental Psychology*, 2006, http://environmentpsychology.com/solar_energy_the_million_solar_roofs_initiative.htm.

Around the same time period as Clinton's Million Solar Roofs Initiative, many states also created policies to provide incentives for residents to go solar. Rules on net metering, which are requirements for electrical utilities to purchase surplus energy generated from residential and small businesses' solar panels, were established across eighteen states, with New York even working on implementing a net metering law. California, one of the leading states in solar, was planning to allocate $54 million in subsidies for solar and renewable energy users. Additionally, Arizona set a Renewable Portfolio Standard (RPS) that required utilities to generate at least 1% of their energy generation from solar power.[41] All of these state wide incentives encourages homeowners to go solar by lowering the total cost of owning a solar PV system.

During the 2000 elections, global warming was highly emphasized in national media under the democratic candidate, Al Gore. As a politician and environmentalist, he pushed for renewables as a solution to avert the consequences of global warming, such as glacial melting, flood, drought, natural disasters, and high temperatures.[42] The Republican opponent, George W. Bush, on the other hand, did not give much attention to the challenges of climate change and air pollution, and focused on Big Oil and coal companies instead. Even though Gore lost the elections, his voice was heard through his 2006 documentary on global warming, "An Inconvenient Truth". Many Americans who watched the film claimed that "it had made them more aware of the problem" of global climate change.[43] President Bush, however, did not want to watch the film and continued to ignore global warming as an issue caused from human activity. Because of President Bush's neglect, millions of Americans went to the 2008 polls hoping that the federal government would change to address the challenges of global warming.

In President Barack Obama's Inaugural Address, he stated that "we will respond to the threat of climate change, knowing that the failure to do so would betray our children and future generations." [44] In his first term as president, Obama pushed for a progressive environmental agenda that was designed to "protect public health from carbon and mercury air pollution, reduce

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[41] Wald, "For Now, an Industry Relishes Its Day in the Sun."
[42] Davis Guggenheim, *An Inconvenient Truth: A Global Warning* (Paramount, 2006).
[43] Wikipedia, "An Inconvenient Truth," *Wikipedia: The Free Encyclopedia*, April 25, 2016, https://en.wikipedia.org/wiki/An_Inconvenient_Truth#Public_opinion.
[44] Executive Office of the President, "The President's Climate Action Plan" (The White House, June 2013), 4, https://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

oil consumption, and simultaneously boost the economic recovery." [45] In addition to his first term environmental goals, President Obama announced his plan to install solar energy on the white house in 2010. Four years later, the installations were finally completed and a solar array the size of an average home began generating clean energy on the White House Roof.[46] 350.org leader, Bill Mckibben, commended the president's move to install solar panels, despite the dragged out installation time:

> "Better late than never – in truth, no one should ever have taken down the panels Jimmy Carter put on the roof way back in 1979. But it's very good to know that once again the country's most powerful address will be drawing some of that power from the sun." [47]

President Obama's 'lead by example' action of incorporating renewable energy on to the most famous house in the country is his way of encouraging Americans to make the conscious choice of going green. In addition to Obama's 'lead by example' tactic, other strong statewide policies, such as net metering, renewable energy standard, Property Assessed Clean Energy (PACE) financing, and tax credits, has led the United States to reach Clinton's goal of reaching one million solar panel installations. The goal was achieved sometime in February of 2016 and is attributed to solar PV technology's now competitive pricing. Installation costs have dropped more than 70% since 2005, driven down by competition and efficient engineering.[48] Now that the solar industry is on their feet and rapidly growing, it is optimistically projected that the next million solar panels will be installed in 2 years.

But even though the solar industry is accelerating in growth, solar energy still only accounts for 1% of the US' generated electricity.[49] It is vital for us to continue cultivating widespread solar energy use because unlike conventional power, solar does not produce any harmful emissions during its lifetime. However, it is important to note that while the idea of a

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[45] Climate Guest Contributor, "Obama's First Term: Assessing Progress On Top Energy And Climate Priorities," *Climate Progress*, January 9, 2013, http://thinkprogress.org/climate/2013/01/09/1420811/obamas-first-term-assessing-progress-on-top-energy-and-climate-priorities/.
[46] *Take a Behind-the-Scenes Look at the Solar Panels on the White House Roof*, 2014, https://www.whitehouse.gov/share/take-behind-scenes-look-solar-panels-white-house-roof.
[47] Katie Valentine, "Obama Administration Becomes The Third To Install Solar Panels On White House Grounds," *Climate Progress*, August 15, 2013, http://thinkprogress.org/climate/2013/08/15/2242481/solar-panels-white-house/.
[48] "The First Million Solar Roofs Is the Hardest," *BestTheNews*, May 10, 2016, http://bestthenews.com/article/first-million-solar-roofs-hardest-tue-05102016-1440.html.
[49] Shere, *Renewable*.

zero ‘carbon footprint’ is true for its lifetime, there are environmental and public health risks that arise from the manufacturing and disposal of solar PV cells.

Environmental Effects and Public Health

In his book *Renewable*, Jeremy Shere claims that “renewable energy is less a choice than an inevitability”.[50] Fossil fuels are a central part of modern civilization and it is difficult to imagine a society without them. There will come a time, unfortunately, when fossil fuel reserves become depleted and society will have no choice but to turn to other cleaner and sustainable energy sources. Even though society has not reached the point of exhausting traditional energy sources yet, the United States already has the necessary steps in creating a more sustainable environment with the development of solar photovoltaic (PV) cells.

The main environmental benefit of solar photovoltaic systems is that they do not release any greenhouse gases during its lifetime, other than carbon dioxide gases during the original manufacturing. Carbon dioxide emissions from solar PV cell manufacturing are found to be considerably less than the amount of emissions produced from traditional energy sources (coal, oil, natural gas, ect.). In a report made for the Public Interest Energy Research Program (PIER), it was found that “estimates of CO_2 emissions during PV cell manufacturing […] are 50-60 g/kWh, compared to the average emissions from conventional energy systems [… ,which are] 570 g/kWh.”[51] Solar PV cells are able to avoid environmental consequences that are normally created though traditional energy production, such as gasoline combustion, the release of crude oil in waterways, and the release of greenhouse gases into the atmosphere.[52]

Although solar photovoltaic systems are beneficial to the environment in creating a lower carbon footprint, they still contain many negative effects to the environment during their manufacturing and disposal stages. During the manufacturing stage, hazardous acids and corrosive liquids are used to remove impurities from raw semiconductor metals, such as

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[50] Ibid., 11.
[51] Tetra Tech, Inc., “Potential Health and Environmental Impacts Associated with the Manufacture and Use of Photovoltaic Cells,” secs. 2, p17–20.
[52] Andrew Hurley, *Environmental Inequalities: Class, Race, and Industrial Pollution in Gary, Indiana, 1945-1980* (Chapel Hill: University of North Carolina Press, 1995), 7.

hydrochloric acid, sulfuric acid, nitric acid, and hydrogen fluoride. The resulting wastes produced from manufacturing are sent to sewage treatment plants (35% of total waste), offsite treatment plants (37%), the atmosphere (27%), surface water (0.8%), and landfills (0.015%). If solar PV systems were to be disposed in normal landfills, their decomposition could release hazardous toxins. The materials and chemicals in the solar cells could negatively affect soil composition as well as run-off water composition. This can be avoided by recycling the units into other products or new solar panels. Recycling reduces the potential release of toxic materials, while also reducing the quantity of resources needed to be obtained for new products.[53]

The production of solar PV cells can also have a negative impact on human and animal health. According to the same report made for PIER, "the production of photovoltaic devices can involve the use of some toxic and explosive gases, corrosive liquids, and suspected carcinogenic compounds." [54] Specifically found in polycrystalline silicon cells, arsine, which is used as a doping gas, is known to be a toxic gas as well as a carcinogenic chemical. The greatest probability for human health risk would mostly be directed to manufacturing plant workers as well as human inhabitants and biota that are within the vicinity of the plant. In animals, the accidental release of toxic gases used in producing photovoltaic systems have led to health issues, such as impaired reproduction, decreased pulmonary activity, increased mortality, and reduced growth.[55]

Overall, the state of photovoltaics we live in today was achieved only through a long history of research, development, and policies that initially began in the 1800's. The 1970's Energy Crisis and Global Warming concerns, beginning in 1988, have marked major milestones for solar PV technology. And even though we have reached a great state of photovoltaics today, the United States still has a long way to go in developing solar panels that can be implemented for widespread use as well as manufacturing them to reduce public health risks.

[53] Tetra Tech, Inc., "Potential Health and Environmental Impacts Associated with the Manufacture and Use of Photovoltaic Cells," secs. 3, p3–19.
[54] Ibid., secs. 4, p9.
[55] Ibid., secs. 4, p12.

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