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Alternative Energy Sources for Fossil Fuel Independence

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Alternative Energy Sources for Fossil Fuel Independence

A Senior Honors Thesis

Submitted in Partial Fulfillment of the Requirements for Graduation in the Honors College

By
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The College at Brockport
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Abstract

Fossil fuel dependence has caused a massive increase in atmospheric greenhouse gas levels. These gases pollute the environment and warm the planet, resulting in climate change effects that will soon be irreversible. To prevent this, clean alternative energy sources need to be developed further and used to gain fossil fuel independence in the near future. Possible alternative energy sources to meet this goal are nuclear fission, fusion, solar, hydro, geothermal, and wind. In this paper, the results of an experiment performed to study on the relationship between a solar panel’s angle with the sun and its power production will be reported. It was found that angle of the sun on the solar panel is a significant factor in its power production ability. A change in the angle with the sun of 82° results in a 47% reduction in power production.
Introduction

Fossil fuel dependence is a big problem. The burning of fossil fuels is polluting our environment and warming our planet, and it is approaching the point in which the effects will be irreversible\(^1\). A new, clean source of energy needs to replace fossil fuels or the consequences will be dire for all that inhabit the Earth. The question is, which energy source has the most potential to fulfill this role? Many alternative energy sources are in development and have become more widely used and researched in recent years. Among the competitors, there’s nuclear fission and fusion, solar, hydro, geothermal, and wind. Each of these sources have their own intricacies and science behind them, so I will focus much on the introduction on solar and nuclear fission and fusion. It is important to find which of these will be able to produce enough energy in a short enough time frame to gain fossil fuel independence before it is too late.

Solar has seen a lot of progress lately, and it will likely be an important component of fossil fuel independence. Nuclear fission power plants have become widespread since the discovery of the reaction, accounting for almost 20% of the United States total electricity generation in 2018\(^2\). However, nuclear fission involves expensive reactants and produces long-lasting radioactive contaminants. Nuclear fusion has received an increased amount of attention in recent years, with an international experimental reactor due to be completed soon\(^3\), however it is often joked that nuclear fusion is and will always be 50 years away\(^4\). The time frame of this alternative source leaves its usefulness in gaining independence from fossil fuel small. Research is being conducted on all of these sources, and each has their own strengths and weaknesses.
Human-caused global warming induced climate change, from here on referred to as climate change, is arguably the biggest problem faced by people in the twenty-first century. Climate change has profound effects on ecosystems worldwide. It increases the severity of present environmental issues, causes more issues to develop and animal species to go extinct. Humans are causing the global temperature to rise through its emission of greenhouse gases, or GHGs. The major GHGs include carbon dioxide, methane, nitrous oxide, and fluorinated gases\(^1\). This can be seen by examining the Intergovernmental Panel on climate change’s Fifth Assessment Report from 2014\(^5\). This report shows that the globally averaged temperature anomaly has seen a net increase since the late 1900s. The study goes on to compare this to the human production of GHGs, and there is a direct correlation. As the global temperature rises, the ocean temperatures also rise. This results in thermal expansion causing a rise in sea levels and the melting of ice caps. To support this, the IPCC has observed sea levels to be rising across the globe, with a change of about 5 cm being observed in 2010, with an increasing rate of change being seen each year\(^5\). With the increase in ocean temperatures and the acidification of the ocean due to the formation of carbonic acid from increased ocean carbon dioxide levels, effects are already being seen. 90% of the Great Barrier Reef has died off, and more will follow as these conditions are projected to intensify\(^6\).

A major cause for concern with the problem of climate change is the irreversibility of it. Even if GHG emissions were to cease completely today, lasting effects from GHGs that have been emitted since the industrial age will continue to make themselves apparent. A study performed using advanced modeling techniques showed that the effects of GHGs, carbon dioxide in particular, remain 1000 years after the immediate cessation of emission\(^1\). The study
projected that, should Earth’s atmospheric carbon dioxide concentration exceed 450-600 parts per million by volume, irreversible effects will be seen across the planet. These could range from dry-season rainfall reductions, comparable to those seen in the “dust bowl” era, to a rise in the sea level on the order of meters. For some perspective, the current carbon dioxide concentration in parts per million by volume, as of March 5, 2019 at Mauna Loa Observatory in Hawaii, is 411.75 and in 2008 it was 385. The change in atmospheric carbon dioxide concentration over the years can be seen in the graph found in Figure 1 from co2.earth.

If GHG emissions continue at current rates, only about 20 years remain until atmospheric carbon dioxide concentrations reach 450 parts per million by volume. At that point, using a conservative modeling technique, there would be a global average warming of more than one degree Celsius, and a sea level rise of approximately a quarter of a meter, accounting only for thermal expansion. Should atmospheric carbon dioxide levels exceed 1000 parts per million by volume, a total rise in sea level of 2.5 meters is predicted. Even the conservative estimate of a quarter of a meter, accounting only for thermal expansion, would allow the sea to overtake many important coastal and island locations. Changes to rainfall were modeled by Solomon et al. It was found that should peak carbon dioxide levels reach 450 parts per million by volume, dry-season precipitation decreases of 8-10% would be observed in large areas of southern Europe, western Australia and North Africa. This would have a profound effect on these regions’ ability to produce food, and worsen existing food and water problems in these areas. Other possible results of continually rising atmospheric carbon dioxide levels include loss of arctic glaciers, increased hurricane intensity, increases in heavy rainfall and flooding in areas it is already prevalent, and loss of permafrost. As these phenomena are not
yet fully understood, quantitative predictions cannot yet be made, however they are extremely likely from what is currently understood\(^1\).

Because of the irreversibility of climate change and the limited time remaining before severe changes will be put into motion, it is vital to find alternative energy sources that will enable independence from fossil fuels in the near future. While there are many promising alternative energy sources, few have the potential to fully support Earth’s energy demands in a short enough time frame. The alternative energy sources that I will be introducing here are solar photovoltaic cells, nuclear fusion and nuclear fission. After looking at the science behind these energy sources and their present place in the world, I will examine a possible method of improving on current solar installations by having the panel track the sun. All of these sources are already useful energy resources, however it is vital to find which one, or which combination, has the most short-term potential to gain fossil fuel independence in a timely fashion.

The first alternative energy source I will be examining is nuclear fusion. Nuclear fusion has enormous potential as an energy source, so much so that it could meet all the energy wants of humanity for more than the lifetime of the milky way galaxy\(^8\). If utilized to its fullest extent, one gallon of seawater could produce the same energy as one hundred gallons of gasoline\(^8\). Nuclear fusion occurs when two atomic nuclei merge to form a single heavier nucleus, electromagnetic radiation, and sometimes small particles including neutrons, protons, neutrinos, and positrons\(^9\). As long as the resulting nucleus is less massive than that of iron, it will be more tightly bound by the strong force, be more stable, have a higher binding energy, and have a smaller total mass than the combination of the total masses of the initial lighter
nuclei. Binding energy, which is the difference between the rest mass of a nucleus and the rest mass of its constituent nucleons, is the source of the released energy in nuclear fusion reactions. The released energy is in the form of electromagnetic radiation or the kinetic energy of a released lighter particle, or a combination of the two. Nuclei more massive than iron have less binding energy per nucleon, and so will not release energy when they are produced by fusion, and instead release energy through fission. In order for a new nucleus to form, the two lighter nuclei must overcome the repulsive Coulomb force and come into a close enough range for the strong force to keep them together\(^9\). Classically, the only way for this to happen is for the two particles to collide with a combined kinetic energy greater than the Coulomb repulsion energy at the radius that the strong force becomes stronger than the Coulomb force. However, due to the uncertainty principle, nuclei are able to overcome potential energy barriers in a process called tunneling. In tunneling, if the uncertainty in the energy of the two particles combined with their kinetic energies is greater than the Coulomb repulsion energy, it is possible for them to undergo nuclear fusion, with a probability found from the particles wave functions. With tunneling, reactions can occur with only a tenth of the classically required energies\(^{10}\).

Nuclear fusion reactions that occur in nature in the stars were studied to form a basis for replicating it on Earth. These reactions include the proton-proton chain and the carbon-nitrogen-oxygen cycle. In the proton-proton chain four protons undergo a series of reactions to form an alpha particle and two positrons. In the carbon-nitrogen-oxygen cycle the same net reaction occurs, but carbon, nitrogen and oxygen act as catalysts. It was found that the most probable reaction for producing energy for use would be the deuterium-tritium reaction. This reaction does not occur naturally in stars, but it has one of the highest energy productions of all
hydrogen isotope fusion reactions. In this reaction an atom of deuterium fuses with an atom of tritium to produce an atom of helium-4, a neutron, and 17.6 MeV of energy, most of which is in the form of the neutron’s kinetic energy. For some perspective, a combustion reaction yields only a couple eV, more than a million times less energy\textsuperscript{10}. The two most promising methods of carrying out this reaction in a lab are inertial confinement fusion, ICF, and magnetically confined thermonuclear fusion. In the ICF of deuterium and tritium, a small pellet of fuel is compressed, often with laser beams, at a fast-enough rate so that it fuses before it is able to expand, due to its own inertia. In magnetic confinement, a toroidal magnetic chamber, called a tokomak, produces a magnetic field that contains a plasma of deuterium and tritium. The plasma is then heated until fusion occurs\textsuperscript{10}.

Magnetic confinement will be studied as part of the ITER project. ITER, the International Thermonuclear Experimental Reactor, “the way” in Latin, will build on the results of previous magnetic confinement projects such as JET and TFTR. Theoretically, it will pass the breakeven point, where the energy to start the reaction is equal to the energy received from the reaction, and even reach the point of a self-sustained plasma that would generate energy with no added energy after initialization. The Tokamak is being built in France, and is planned to be completed in 2025, when pure hydrogen plasma experiments will start. Then it will move on to deuterium plasma with a small amount of tritium, and then if everything is operational, full deuterium-tritium plasma experiments will begin in 2035. Following this, construction of a demonstration power plant, DEMO, is planned to begin in 2030s and begin operation in the 2040s, with its final design coming from innovations made in the ITER plasma experiments. While ITER will not
function to utilize produced energy, the DEMO will likely be able to use the energy it produces, and will produce 30 to 50 times as much energy as is put into it.\(^3\)

As a future power source that could be utilized to produce near limitless energy, nuclear fusion is great. Not only can it produce large amounts of energy, fusion’s main byproduct is helium which is becoming harder and harder to find on Earth. Thus, this energy source would not contribute any harmful pollutants to the environment, and would act as an important source of helium. However, with the most optimistic predictions setting power production not until the year 2040, by the time nuclear fusion comes into play the atmospheric carbon levels would already be at the point where drastic irreversible climate change effects would be set into motion. Research into this power production method is still important and nuclear fusion could still play an influential role in stopping climate change. Nuclear fusion’s role would not be in gaining fossil fuel independence. This alternative energy source would come into play much later, when the vast amount of potential energy it has the ability to produce could be used to begin to reduce atmospheric GHG levels and work towards setting the atmosphere back to a state similar to pre-industrial levels. Before working to reverse climate change, its progression must first be stopped by gaining fossil fuel independence.

Nuclear fission is common place in reactors today. The opposite of nuclear fusion and a form of radioactive decay, nuclear fission involves a large nucleus breaking apart to typically form two fragments, a number of free neutrons, and electromagnetic energy in the form of gamma rays. For this decay to occur, the Coulomb repulsive force must overcome the strong force and cause the nucleus to split. This is possible due to the shape of the nucleus. At equilibrium, most nuclei form a near perfect sphere and will often return to this shape after
being distorted from an outside energy. For larger nuclei that can experience fission decay, the nucleus at equilibrium is slightly distorted to a shape more akin to an ellipse. When this shape is distorted, it often returns to its original shape, but it can reach a point where it would be more energetically favorable for the nucleus to split into two fragments. The cause of this is the different ranges of the Coulomb repulsion force and the strong force. The strong force, having a much shorter range, is diminished far more than the Coulomb repulsion force, which is effectively unchanged, when the nucleus is distorted. Thus, the repulsion can overtake the attraction once a certain threshold, called the fission barrier, is passed. Like in nuclear fusion, the uncertainty principle allows this barrier to be tunneled through causing the probability of undergoing nuclear fusion to be higher than classical physics would predict.\(^\text{10}\)

The energy produced from this decay, similar to nuclear fusion, comes from the difference in binding energy between the product and the reactants. As long as the two produced fragments have masses greater than that of iron, the binding energy per nucleon will be greater than that of the original nucleus. For an example, Californium-254 is an artificial radioactive element that undergoes spontaneous nuclear fission. The Californium-254 nucleus has a binding energy per nucleon of approximately 7 MeV. After undergoing nuclear fission, two fragments with 127 nucleons each are the most probable products. These fragments have a binding energy per nucleon of approximately 8 MeV. Each nucleon in the products contains one more MeV of binding energy, so 1 MeV of energy must be released per nucleon for the energy of the reaction to be conserved. The law of conservation of energy, after accounting for conversion between mass and energy according to \(E = mc^2\), guarantees this. Thus, about 250 MeV of energy is generated from the fission of one Californium-254 nucleus, more than ten
times the energy produced from the deuterium-tritium fusion reaction. Most of this energy, about 80 percent, is in the form of the kinetic energy of the two fragments. The remaining energy is found in the beta decay and gamma decay products from the radioactive fragments, and the kinetic energy of produced neutrons. The fragment kinetic energy is then harvested by colliding with and heating water to generate steam, which can then turn a turbine. 

Most nuclear fission reactors in current operation utilize Uranium-235 as their source of energy. Uranium-235 does not have a high probability of naturally undergoing fission, so a neutron is collided with it. This generates Uranium-236, which then undergoes fission to form two fragments, often Rubidium-93 and Cesium-141, and two neutrons. The produced neutrons can then go on to activate more Uranium-235, allowing the reaction to sustain itself and generate a steady flow of energy. The fission of one Uranium-235 atom generates approximately 200 MeV of energy, making it an ideal material due to its high energy density. 

When neutrons are produced from fission, they have too much energy to immediately cause the fission of another nucleus of Uranium-235. The neutrons must be moderated by surrounding material, to reduce its energy so that it can be absorbed by the Uranium-235. Because of the large difference in mass, the neutrons are scattered by much heavier nuclei, and so nuclei of similar mass must be introduced. The hydrogen in water is a good candidate for this role, but the possibility of absorbing the neutron to form deuterium reduces it efficacy. To resolve this issue, water that is already deuterated, or heavy water, is sometimes used. The number of neutrons that can cause a fission reaction must also be controlled very accurately. If the average neutron production of each fission reaction is any higher than one, the reaction
could grow exponentially out of control. Thus a control rod of Cadmium, an element with a high probability to absorb neutrons, is used to control variations in the fission reaction rate.

While nuclear fission has great potential for producing large amounts of energy, it comes with a myriad of problems. The first problem is the safety of nuclear fission reactors. Due to the delicacy of the reaction control, any unforeseen problem could have catastrophic consequences. This makes nuclear fission reactors very prone to natural disasters, and several uncontrolled reactions have already been observed. This was seen in Fukushima in 2011, where a nuclear fission reactor was flooded from a tsunami. This caused the cooling pumps to fail, allowing the reactor core to overheat and partially meltdown. The flood water then carried the radioactivity to the surroundings, polluting a large area.

Fission reactors are not only unsafe, but also contribute their own form of pollutants to the environment. While no GHG’s are released, the heavy fragments produced are often highly radioactive with long half-lives and must be stored underground for an indefinite time. Three common products that are of the most concern are Cesium-137, Strontium-90, and Iodine-131. These fragments are all radioactive and highly toxic, Cesium-137 and Strontium-90 have half-lives of about 30 years, and Cesium-137 and Iodine-131 are volatile and likely to spread. These have a possibility of leaking into groundwater, which would be very dangerous to both people and surrounding ecosystems. Also, the heat generated from the reactor causes thermal pollution. As nuclear fission reactors have lower efficiencies and produce so much heat, they contribute about 50% more to thermal pollution.

Another problem with nuclear fission is the abundance of Uranium-235, and the other metals used in the reactor construction. Uranium as an element is about as common as tin, but
the useful isotope, Uranium-235, has only a 0.7 percent abundance. Thus, it must first undergo a costly enrichment procedure to reach a concentration of 3 to 5 percent\(^{10}\). Also, at current production rates, the availability of Uranium-235 will only last another 80 years, and if the world was powered solely from nuclear fission, it would last just 5 years. The core of a nuclear fission reactor must be able to last several years against a constant bombardment of neutrons, and so expensive rare metals such as Hafnium and Zirconium must be used in its construction. In his paper examining the viability of using nuclear fission on a global scale, Derek Abbott states, “Due to the cost, complexity, resource requirements, and tremendous problems that hang over nuclear power, our investment dollars would be more wisely placed elsewhere”\(^{11}\).

While nuclear fission currently plays an important role in the United States’ GHG emission reduction, as approximately 20 percent of the United States energy comes from nuclear fission, it is not a sustainable source of energy for the future.

Solar energy is a renewable energy source with great potential. The amount of energy that the sun radiates onto the earth is immense. When the sun is directly overhead on a clear day, 1000 W/m\(^2\) of power strikes the surface of the earth on average. The power from the sun that hits Earth, taking into account only a part of the world being illuminated by the sun at any given time, is 89,300 TW\(^{12}\). Assuming a 10% solar cell efficiency, where efficiency is defined as the amount of incoming energy from the sun that can be converted into usable electricity, only 0.17% of the Earth’s surface would have to be used to generate all the electricity used worldwide in 2001. With energy demands rising this percentage would be higher today, but solar panel efficiencies are also increasing so the change is negligible\(^{12}\).
Solar energy is produced in solar cells, which take advantage of the interaction between an electron acceptor and an electron donor to generate electricity. In organic solar cells, a common electron acceptor is a carbon mesh composed of fullerenes, and an electron dense polymer acts as the electron donor\textsuperscript{13}. Inorganic solar cells utilize doped semiconductors for their electron donors and acceptors. Doping is the process of introducing an impurity to the bulk of a semiconductor. If this impurity has more valence electrons than the semiconductor, this will create an N-type semiconductor. The additional valence electrons present in the impurity contribute free electrons to the material, creating an electron donor. If the impurity has fewer valence electrons than the semiconductor, a P-type semiconductor will be created. The lack of electrons in the impurity create holes, the absence of electrons, in the material, forming an electron acceptor\textsuperscript{14}. When a P and a N-type semiconductor are put together, the electrons of the N-type fill the holes of the P-type at the interface, and form what is called the ‘depletion region.’ When a photon strikes this layer, an electron-hole pair reform and can be harvested to produce electricity\textsuperscript{15}. In organic solar cells the electron acceptor acts as the P-type semiconductor and the electron donor acts as the N-type semiconductor and it follows the same process.

Solar cells have enormous potential as a renewable energy source. In a study by researchers at Stanford University, a roadmap to 100% renewable energy by the year 2050 was laid out. This study, performed in 2017, showed a way to convert to 100% renewable energy with the technology currently available. In the study, solar power was responsible for producing 57.6% of the world’s total energy. The land that would be required for this was calculated to be 347,910 km\textsuperscript{2}, only 0.3% of the available land on Earth. 87,410 km\textsuperscript{2} accounts for rooftop solar
panels, while 260,500 km² would be from large solar farms. In effect, only 0.2% of available land would need to be covered by solar panels to effectively provide 57.6% of the world’s energy demands. Assuming a power production of 150 watts per square meter, a km² of solar panels would produce 150 MW of power. The average cost of solar panels is about a dollar per watt, so one km² of solar panels would cost approximately 150 million dollars. Expanding this, 347,910 km² would cost approximately 50 trillion dollars. With a global net worth of over 300 trillion dollars. This estimate is also higher than the actual value, as solar panel efficiencies are constantly increasing as more research is being done, and as production becomes so large-scale manufacturing costs would undoubtedly decrease.

Solar energy has massive potential as a renewable energy source. The Stanford study showed that with technology currently available, solar can be the main source of the world’s energy if it is properly employed. Nuclear fusion has great potential for the future, but the technology to properly harness this technique simply is not currently available, and it will not be before climate change will have dramatic irreversible effects. Nuclear fission currently provides an important reduction to GHGs, but it is not without its own harmful byproducts, and its future is not bright. Thus, I believe that between these three alternative energy sources, research into solar should be the main priority.

Currently, solar energy is responsible for just 1.5% of the United States total energy demand. However, research into solar panels is progressing, and they are becoming more efficient and less expensive. Commercial crystal silicon solar cells currently have efficiencies that range from 14 – 19%. In the lab, efficiencies of up to 25% of been achieved for crystalline silicon cells. Efficiency values of up to 40% have been reported for gallium arsenide cells, a
more expensive material. Organic solar cells are not commercially available as of yet, but cells with up to 10% efficiency have been manufactured in laboratory settings. The appeal of organic cells is that they can be very thin and flexible allowing them to be installed on almost any surface.

While improvements to solar cell materials are important, there are engineering techniques that could be employed with current solar cells to improve energy production. The amount of power a solar cell is able to produce is dependent on the amount of sunlight that strikes its surface. The greater the angle between the cell and the sun, the less energy it will receive and the amount of power it can produce decreases. The amount of energy that could potentially be gained by tracking the sun (tilting a panel to directly face the sun) with a solar panel is an important question, and with this paper I set the groundwork for determining the potential payoff. While adjusting the angle may be difficult with rooftop mounted solar panels, large solar panel farms may be able to implement this improvement with little difficulty. Thus, the relationship between a solar panel’s peak power output and its angle with the sun is examined.

Experimental
For all experiments and measurements, a crystalline silicon solar panel from Sparkfun was used (part number PRT-13783). The motors used to move the solar panel stage were ServoCity HS-55 sub-micro servo motors. The moveable stage design was sourced from thingiverse.com user AtomKemp, the panel holder design was created using the Autodesk Fusion 360 software, and both were 3D-printed using a Dremel 3D printer. Automated measurements and programs were generated with LabView, a National Instruments
programming language and platform, to perform and automate experiments with electrical devices.

When measuring the solar cell parameters, the panel’s power and voltage are dependent on the load of the circuit. Thus, to characterize the panel a variable resistor was used to sweep the circuit load. The circuit current and solar panel voltage are measured and used to generate a Current-Voltage (IV) curve. The IV curve is used with Ohm’s Law to then generate a Power-Voltage (PV) curve, from which the panel’s peak power can be easily extracted. The peak power is the value of interest, as it is a measure of the panel’s ability to produce energy.

For a variable resistor in these experiments a metal-oxide-semiconductor field-effect transistor, or MOSFET, was used. A MOSFET consists of three pins, source, drain and gate, which are connected to a npn or pnp semiconductor junction. The source and drain pins are of the same semiconductor-doping type, while the gate is capacitively coupled to the opposite through a gate dielectric. Our MOSFET has a npn junction. When a voltage is applied to the gate, the holes in the P-type semiconductor are pushed away, and with a large enough voltage a layer of electrons forms, called the inversion layer. This layer is effectively n-type doped, and allows current to flow between the source and the drain, which are also n-doped. With this device we can connect our circuit across the source and drain, and apply a range of voltages to the gate pin in order to effectively sweep our circuit’s load.

To measure the current in our circuit, a small resistor and Ohm’s Law were used. We chose the smallest resistor available in the Brockport Physics Department so that it would not
have a significant effect on the circuit’s load. A resistor of 0.47 Ohms was used in the circuit. The voltage across this resistor was measured, and the current could then be calculated from the resistor’s resistance, voltage and Ohm’s Law.

Results and Discussion

Preliminary Results

A preliminary experiment was performed to confirm that the angle between a light source and a solar panel has a significant effect on its peak power. The methods to sweep the circuit’s load and measure the current previously described were utilized. The voltage across the solar panel and the resistor were measured by hand with a voltmeter and the MOSFET gate voltage was controlled with a DC power supply. A lamp was positioned directly above the solar panel, and the gate voltage was swept until the circuit current no longer showed a noticeable change. The light was then tilted at an angle of approximately 30° and the measurement was repeated. An IV and PV curve were generated. The circuit and light setup are shown in Figure 2.

Figure 3. shows the results of the preliminary experiment. Both the IV and PV curves have the expected shape, and the peak power is easily discernable in the PV curve. The PV curve shows a significant change in the peak power of the panel with the angle of the light. The perpendicular peak power is almost 40% larger than the tilted peak power value. This indicates that the angle of light on the solar panel has a significant effect, and that further experiments are warranted.

Solar Tracking Results
After confirming the experiment’s viability with a preliminary measurement, a LabView measurement program was created to automate the measurement process. This program applies a range of voltages to the MOSFET gate, measures the resistor and solar panel voltages at each applied voltage value, and calculates and saves the power to an excel file. The program has inputs for the resistance value for calculating the circuit’s power, and the minimum and maximum value of the voltage applied to the MOSFET gate. The measured power and solar panel voltage are displayed live on a graph to confirm the program is working correctly while being operated.

The LabView measurement program was tested to ensure it worked properly. The setup for this experiment is shown in Figure 4. The moveable stage, motors and panel holder were all assembled and are shown in Figure 5.

A second LabView program was created to move the solar panel stage through a range of angles, and generate a PV curve at each angle. This LabView program moved the panel through a range of duty cycles, previously determined with a motor calibration, in increments determined by the user. After moving the motor, the program generates a PV curve at each angle. The final result is a plot of peak power vs. angle plot.

Figure 6. shows a PV curve generated with the LabView measurement program. The maximum power values of this PV curve and of curves generated at other angles were then assembled to form Figure 7.

Figure 7. shows the results of the Power vs. Angle experiment using the final LabView program. The angle away from the sun was calculated by subtracting the angle of the sun above
the horizon from the angle of the solar panel with the ground. The angle of the sun above the horizon was calculated using the National Oceanic and Atmospheric Administration’s Solar Position Calculator using the time, date and location of the experiment, available at their website\(^\text{18}\). The LabView program tracked the angle of the solar panel with the ground. As expected, and supported by the results of the previous two experiments, as the solar panel’s angle away from the sun increases, the peak power of the solar panel decreases. There is an unexpected sudden dip in the panel’s peak power at approximately 30° away from the sun. The day this experiment was performed was a bright and mostly cloudless day, however a cloud did pass in front of the sun for a short time while the experiment was running. This dip is likely attributed to the cloud, but could also be from unsteadiness of the panel, as a slight wobble was observed as the motors moved near this angle. Comparing the initial power production of 12.57 W at a 9° angle with the sun to the power of 6.66 W at a 91° angle, it is shown that there is a 47% decrease in power production with a change of 82°.

**Future Experiments**

Based on these results, if a panel is positioned so that it can be angled less than 30° away from the sun during its peak power output time, a significant amount of power would not be lost. A possible future experiment setup up to maximize power with minimum motor movement would be to have three positions for the solar panel. Start at a 60° angle with the ground to the east at the start of the day as the sun rises, then move to a 90° angle when the sun is at its peak, and finally move to 60° above the ground to the west as the sun begins to set.
Further experiments to determine the net energy gain from using a motor to follow the sun all day compared to a stationary panel, and compared to the experiment as just described are necessary to fully determine the best method to make the most of the energy from the sun. Once the net energy from each of these methods are obtained, they can be compared while taking into account the energy required to move the solar panel. With this information the best method can be determined and the effectiveness of following the sun with a solar panel will can be found.

Conclusion

Upon examining nuclear fusion, fission and solar energy, it is clear where research efforts should be placed. Because of the harmful effects of climate change and their short time frame of preventability, solar is the best option of the three. Nuclear fusion will not be producing energy before GHG levels are already too far gone. Nuclear fission is useful for short term reduction in GHG production, but it has its own pollutants and it requires Uranium-235 to operate, a rare and dwindling resource. Solar panel efficiencies have been rising, and it has been shown that solar has the potential to provide more than half of the world’s energy demands. While research into new materials is important, there are engineering solutions that can increase the power production of current and future solar panels. By adjusting the angle the solar panel makes with the sun, more power can be produced.

This study has shown the direct effect of solar panel angle with the sun on the panel’s peak power output. It is clear that a noticeable effect is had from the sun’s angle, and that more power is produced when the panel is facing the sun. More research needs to be done to determine the net energy gain from following the sun with the panel throughout the day.
Figure 1 co2.earth's graph of atmospheric CO$_2$ concentrations since 1955. This data was gathered from the Mauna Loa Observatory in Hawaii. The rise in atmospheric CO$_2$ levels is made apparent in this graph.
Figure 2. Solar panel, lamp, circuit and generator set up used for the preliminary measurements. Here the lamp is positioned directly above the solar panel for a perpendicular measurement. The lamp is then tilted to generate the tilted curve data.

Figure 3. Results from the preliminary experiment to determine the project’s viability. The setup for this experiment is shown in Figure I. The perpendicular curve has a significantly higher peak power than the tilted curve, validating this project.
Figure 4. Setup to test the LabView measurement program. The laptop is connected to the DAQ assistant to interface with the circuit and the solar panel. This setup was then transported outside to perform measurements.
Figure 5. The solar panel assembled onto the 3D printed stage. The stage holds the solar panel and motors inside the base can move the panel to any direction. This is connected to the circuit and LabView to perform the power vs. angle experiment.

Figure 6. Results from the LabView measurement program testing experiment. The setup for this experiment is shown in Figure 2. The PV curve has the expected shape and follows the same trend as the results from the preliminary experiment.
Figure 7. Results from the Power vs. Angle experiment. The peak power from the PV curve generated at each angle was used to form this graph. As expected, the solar panel’s peak power decreases as the angle with the sun increases.

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