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CONCENTRATED SOLAR POWER, AND ITS ADVANTAGES

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Abstract— *Evidence suggests that global temperatures are rising partially due to the fossil fuels that are used to generate electricity. Therefore, it is logical for the energy industry to utilize renewable energy sources, like solar energy. Concentrated Solar Power (CSP) facilities, specifically Heliostat Power Plants (HPPs), are not only safer for the environment, but more efficient than other solar energy technologies.*

HPPs work by heating a material (such as salt) to extreme temperatures using the sun's energy, and then immediately storing it in double-walled tanks filled with ceramic insulation, which prevent any significant heat loss. To create energy, water is pumped through metal veins with molten salt inside, which causes the water to evaporate, thus creating steam that powers a turbine connected to a generator. This storage and power generation method is why HPPs can function even at night.

CSP facilities as a whole produce less greenhouse gases than any other form of energy, and consequently, are far better for the environment. The salt can be used for over 30 years before needing replacement. It can be used as a fertilizer after its lifespan is up, as well. HPPs not only do minimal damage to the environment, but also features technologies, such as molten salt, that can be beneficial to the environment.

This paper will explore the impacts, the technologies needed for, and the companies that are currently investing in and creating HPPs. The paper will also look into the effectiveness of HPPs when compared to other ways of creating energy. Finally, this paper will evaluate the ethical issues faced by the installation and research of HPPs. This paper will cite sources from both industry, as well as third parties.

Key Words—Alternative Energy, Climate Change, Concentrated Solar Power, Heliostat Power Plant, Molten Salt, Solar Energy

INTRODUCTION

Global climate change has been an issue for quite some time now, and as time goes on, it only becomes more of a problem. Data collected and analyzed by the National Aeronautics and Space Administration (NASA) details the global temperature trends over the past 133 years. Through this data, NASA found that the warmest year on record was 2016, and 17 of the 18 warmest years in history occurred after 2001, and this trend is illustrated in figure 1. Overall, this evidence shows that there has been a major upward trend in global surface temperatures, and this trend is consistent with research done by the Climatic Research Unit and the National and Atmospheric Administration [1]. As of January 2018, temperatures have, on average, increased .71 degrees Celsius, demonstrating that there has been a notable change in the wellbeing of the environment [2].

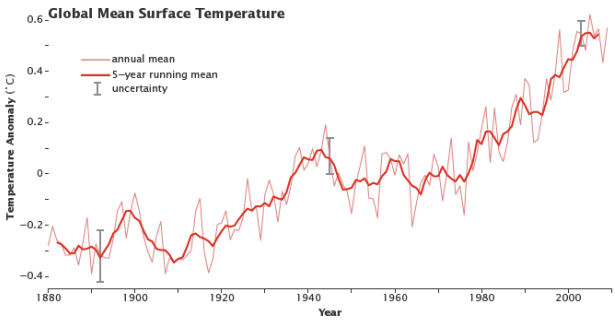

Figure 1 [3]
Rising Global Temperatures From 1880-Present

However, there are more aspects to climate change than rising global temperatures. The Fourth National Climate Assessment, (NCA4) compiled in 2017, outlined the myriad of adverse effects of climate change in the United States. Evidence from the NCA4 suggests that the consequences include changes in precipitation, droughts, floods, wildfire, extreme storms, arctic changes, rising sea levels, and ocean acidification [4]. One of the major consequences which has had a major impact was the increased number of extreme storms. The NCA4 determined that, based on collected global temperature data as well as weather patterns correlated with tropical storms, climate change has led to an increase in both North American hurricanes and North American tropical storms [4]. The year 2017 was an extremely active hurricane season, which is demonstrated by the fact that hurricanes Harvey, Irma, Nate, and Maria all did significant damage to the Atlantic southeast. Kerry Emanuel, an MIT atmospheric scientist who studies hurricane patterns, said that this active

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hurricane season is due to the deteriorating condition of the atmosphere, and that the warm temperatures this year made the atmosphere ideal hurricane forming conditions [5]. The increase in intensity and frequency of extreme storms and their consequences are just one of the adverse effects of climate change. In order to prevent another hurricane season like 2017, as well as prevent other consequences of climate change, it is necessary to make efforts to reduce humans' impact on the environment.

THE REALITY OF CLIMATE CHANGE

Due to the surplus of scientific evidence that there has been a clear change in not only global temperatures but overall climate, the concept of climate change is generally accepted by most of the population. Although this is daunting, humans and modern technologies have the ability to prevent the worsening of climate change. This is a possibility because humans are believed to be the cause of climate change. The majority of the scientific community agrees in the belief that there is substantial evidence that indicates humans are the main cause of global warming. Figure 1 is a graph of the rising global temperatures, and the steady rise illustrated demonstrates this point further.

According to NCA4, it can be said with high confidence that human contribution has led to "...93%-123% of the observed 1951-2010 change." The NCA4 continues on to say that "It [can be reported with 95% confidence] that more than half of the global mean temperature increase since 1951 was caused by human influence on climate." This same study concluded with high confidence that, although there are other factors that lead to climate change they have had little to no impact when compared to the impact of humans. The NCA4 standard for high confidence consists of moderate evidence, several sources, some consistency, medium consensus, but some varying methods of data collection [4]. This means that the NCA4 cannot necessarily prove that climate change is completely human caused but there is enough scholarly evidence to relate the two. Since climate change has such a negative impact and it is primarily caused by humans, vital efforts must made to reduce the impact humans have on climate change.

THE EFFECTS OF FOSSIL FUELS

One of the findings of the NCA4 is that there is a correlation between Carbon Dioxide (CO_2) in the atmosphere and rising global temperatures. The research consulted in the NCA4 made strong connections between the two and concluded that as the CO_2 in the atmosphere continues to increase the global temperatures will continue to increase as well.

Since the correlation between fossil fuels, greenhouse gases, and climate change is so strong, it would be logical to reduce the amount of fossil fuels used worldwide. However, some countries are heavily reliant on fossil fuels. For example, in the United States, a majority of fossil fuels are used in energy production. In 2015, the leading contributor to excess greenhouse gas production in the United States was electricity production. According to the Environmental Protection Agency (EPA), out of the 6,587 metric tons of CO_2 emissions produced in 2015, 29% of said emissions were due to electricity production [6]. The amount of greenhouse gases produced by electricity generation is high because energy production in the United States relies heavily on fossil fuels. The United States Energy Information Administration (EIA), a branch of the United States Department of Energy, states that "most of [the United States'] electricity is generated using fossil fuels." The main contributors to the United States' electricity production are natural gas and coal. Combined, the two energy production materials made up 64% of all electricity production in the United States [7]. Due to this relationship between fossil fuels and climate change, it is clear that the current electricity production system in the United States must be changed, or it will continue to negatively impact the environment and contribute to climate change.

There are other issues with fossil fuels besides the impact they have on climate change. Although fossil fuels have been found to be harmful to the environment, they are naturally found in the earth. This means that there is a limited supply of coal, oil, and natural gas available in the earth. This implies that at some point there will be no more fossil fuels available to be used to generate energy.

Because of this fact, there is controversy in the scientific community over how many years remain before fossil fuels run out. One prediction states that natural gas will run out in 2060, coal will run out in 2088, and crude oil will run our it in 2052 [8]. Although these are approximate predictions, and it is likely that more fossil fuels will be found before then, at some point fossil fuels will run out. It is therefore absolutely necessary to utilize other forms of energy production.

ALTERNATIVES TO FOSSIL FUELS

Due to the finite amount of fossil fuels in existence as well as the impact fossil fuels have on the environment other forms of energy are necessary, and more specifically, energy that is sustainable. Sustainable energy is energy that come from a unlimited source. Forms of energy such as solar energy, wind energy, hydrothermal power, and geothermal energy all fall into this category. The main aspect of suitable energy and sustainable technology in general is that they come from unlimited resources and can continue to be used well into the future. However, there is more to sustainability than just the availability of resources. Maurice Strong the founding executive director of the UN Environment Programme said in regards to sustainable development that "Sustainable development - development that does not

destroy or undermine the ecological, economic, or social basis on which continued development depends - is the only viable pathway to a more secure and hopeful future for rich and poor alike." [9]. In other words, sustainable development, sustainable technologies, and sustainable energy are more than just innovations that use renewable resources but a means to stop the destruction of the environment. While fossil fuels do not fit into the definition of sustainability in any manner, most alternative forms of energy are sustainable.

Although the United States is very reliant on fossil fuels for electricity production, there are alternative, cleaner forms of energy that can be utilized. Other countries have ambitious goals and plans for cutting back on fossil fuels using said alternatives. Sweden is a prime example of a country making a serious effort to cut back on its fossil fuel usage. As part of the 2015 Fossil-Free Sweden initiative, Sweden is currently aiming to completely eradicate fossil fuels from their country. When the amount of fossil fuels used in the United States. is considered, it seems nearly impossible for Sweden to achieve this goal. The difference between the United States and countries like Sweden, however, is that many others rely far less heavily on fossil fuels. According to the CIA World Factbook as of 2015, there were 112 countries that used a smaller percent of fossil fuels in energy production that the United States [10]. This evidence, as well as the United States' technological standing, demonstrate that it is very possible for the United States to use far less fossil fuels.

While there are numerous forms of alternative energy that make it possible to use less fossil fuels, there are a few that stand out significantly as feasible forms of alternative energy. These energy sources include nuclear power, solar photovoltaic energy, and concentrated solar power (CSP). They have pollution rates of 14, 57-109, and 11-90 grams of carbon dioxide per kilowatt hour, respectively [11]. All of these alternative forms of energy have incredibly low levels of greenhouse gas emissions when compared to coal/ignition's levels of 690 to 820 grams of carbon dioxide per kilowatt hour. This implies that there are better, more environmentally friendly ways to generate power for everyday use.

However, these technologies have drawbacks. Photovoltaic (PV) panels are the most commonly used alternative technology when it comes to residential power generation, and for this reason they are the most easily recognized form of solar energy. PV panels convert sunlight into electricity in a 100% emission free process. While this aspect makes the technology environmentally safe, PV panels do have a number of drawbacks. First of all, PV panels are substantially less efficient than other forms of energy. According to research done at Northwestern University, the average PV panel only converts 14% of energy into electricity [11].

Additionally, PV panels on their own have no way of storing energy for later use. Without additional batteries, PV panels cannot produce energy at night, in snow, or on cloudy days when there is no sunlight. This is because typical PV panels do not have any means for storing solar energy collected during the day. [12] There are some PV panels that use batteries to store energy collected when there is sun, to be used when there is no direct sunlight. While this may seem like a breakthrough, there is a severe lack of storage ability. Lithium batteries take up a large amount of space and do not store very much energy when compared to their size. These batteries are also very expensive. For a 5.6-kilowatt solar energy system, a homeowner can expect to pay an average of $15,581, after tax credits. This is without a battery. With a 3-kilowatt battery, however, the average user can expect to pay around $27,703 [12]. Given this information, it can be concluded that while PV panels are emission free and should not be completely overlooked as a viable source of alternative energy, they have some major drawbacks. These drawbacks make it clear that there must be more efficient and innovative forms of alternative energy.

Nuclear energy, on the other hand, excels in some of the areas where PV panels are lacking while also not releasing any greenhouse gases. Nuclear fuels, such as uranium or plutonium, undergo a nuclear reaction to produce electricity. This process is more efficient than all other current ways of producing energy, seeing as it produces a million times more energy per kilogram of fuel when compared to coal, the most commonly used fossil fuel in electricity production [13]. According to the Nuclear Energy Institute, nuclear energy is the leading form of alternative energy that is meeting the United States' energy needs without producing emissions.

However, while nuclear power is free of greenhouse gases it has potential to negatively impact the environment. While nuclear power, as a general rule is very stable and only fails in very certain situations, there is certainly at least a minimal level of risk associated with it due to the radioactivity of the fuels. For example, even if there was no possibility of a failure causing a meltdown, there is still a certain amount of nuclear waste produced. According to Greenpeace UK, the nuclear waste produced by nuclear energy would remain radioactive for "...hundreds of thousands of years..." after it is produced [14]. If an accident caused this nuclear waste to be released into the environment it would could be detrimental to both the environment and public health. Therefore, even though nuclear power is better for the environment than fossil fuels in terms of greenhouse gases, it is still not ideal in the sense that it poses a certain level of risk.

CONCENTRATED SOLAR POWER: AN EFFICIENT SOLUTION

One of the reasons Sweden decided to set the goal of becoming 100% fossil fuel free is simply because the country wants to prove that it is possible to do [15]. However, if you consider just solar photovoltaic energy and nuclear power, it seems that there are not numerous options for alternative energy and phasing out fossil fuels would be completely impossible. Due to the inefficiency of solar photovoltaic energy and the risks associated with nuclear energy, it seems

that alternative energy sources would not be a good replacement for fossil fuels in energy production. These forms of energy are usable, but they are also not ideal. However, concentrated solar power (CSP) is a form of alternative energy that is more efficient than solar photovoltaic energy, safer than nuclear energy, and has no greenhouse gas emissions. CSP facilities have similar basic functions to PV panels. Both CSP facilities and PV panels rely on solar energy to produce electricity, however CSP facilities, rather than using panels to directly collect the energy, use mirrors to focus the solar energy into one location. The most prominent difference between CSP facilities and PV panels is that CSP facilities have the ability to store the energy that they create. While there are different types of CSP facilities that vary structurally, they all have this capability.

While CSP facilities are more efficient than PV panels, they too are safe for the environment. Additionally, they do not use any fuels that could pose a risk to humanity. These factors set CSPs apart from other alternative forms of energy. However, the production of energy by CSP facilities, like PV panels and nuclear power plants, creates no greenhouse gases and does not contribute to climate change. Considering both efficiency and environmental safety, CSP is a superior method for producing electricity for the public [16].

HELIOSTAT POWER PLANTS

As previously mentioned, there are structurally different versions of CSP facilities. It is due to these differences that not all facilities are equally as efficient. The most common versions of CPS facilities include the parabolic trough, the compact linear fresnel reflector, the power tower and the disk-engine [17]. All of these types of CSP facilities are very similar because they all direct heat and sunlight to a focal point. That being said, research has proven that the "power tower" design configuration is the most efficient [17]. Within the realm of power towers, there are even more specific types of facilities which consist of technology that makes energy production even more efficient and safer for the environment. These facilities are known as heliostat power plants (HPPs). However, there are even specific versions of HPPs that have more advantages when compared to regular HPPs. Heliostat power plants that utilize molten salt as a heat transfer fluid, as opposed to HPPs that use water as a heat transfer fluid, are a ground breaking and innovative technology. While there are some notable drawbacks, heliostat power plants are a technology that addresses the environmental and efficiency aspects of electricity production and have strong potential to significantly alter the energy sector.

Figure 2 [18]
Crescent Dunes Power Plant

HPPs are a relatively new technology, but that being said, there are a number of them in existence today. One molten salt HPP that is currently in use is the Crescent Dunes facility, located near Tonopah, Nevada, about 190 miles from Las Vegas, which can be seen in figure 2. This facility is run by SolarReserve, a limited liability company that specializes in renewable energy. After five years of construction, the facility began functioning in 2016. Thus far, the facility has been relatively successful and it is a very good example of a typical, high tech molten salt HPP facility [19]. For these reasons, the rest of this paper will continually refer to the Crescent Dunes facility when discussing the technological and structural details of HPPs.

THE BASIC SETUP OF HELIOSTAT POWER PLANTS

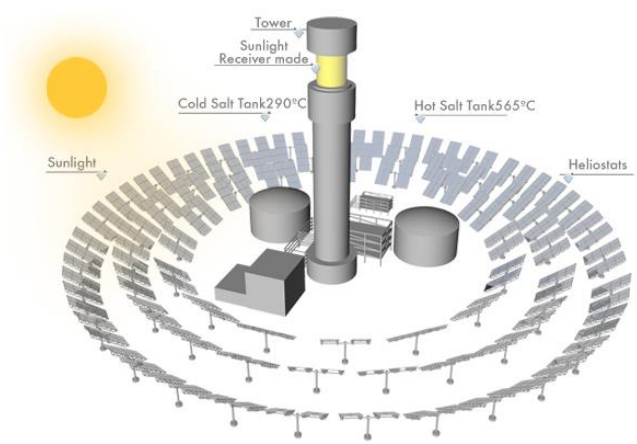

Figure 3 [20]
The Basic Setup of a Heliostat Power Plant

HPPs share the majority of their structural qualities with generic power towers. Both HPPs and power towers are composed of an immense field of mirrors all focused onto a central point at the top of a tower, which is also known as the

"receiver." Liquid, which can be salt but is not necessarily so in all cases, is then pumped through the aforementioned receiver. The salt is then heated up to more than double its original "cold" temperature of 500 degrees Fahrenheit to, in Crescent Dunes' case, about 1,050 degrees Fahrenheit. These temperatures are kept precise by the usage of double-walled storage tanks, separated by a ceramic insulating material, and these tanks can be seen in figure 3. To go more into depth on the heating, the field of mirrors are all specifically made to track the sun in order to reflect the maximum possible amount of sunlight onto the receiver. This is accomplished, once again in case of Crescent Dunes, through the usage of a tracking system which is "...derived from the control system deployed on the International Space Station … to capture energy from the sun…" [19]. From there, the receiver is heated due to the sun's energy, which heats the liquid that is then stored in a tank for later usage. This storage method is the reason HPPs differ from other methods of alternative energy, most notably other forms of solar energy. While most solar energy plants are only operational during the day, HPPs can be operational at night. The liquid stays at its high temperature until it needs to be used, and when it does get used up, it is pumped through a series of pipes running through a tank full of water in order to turn it into steam. This steam powers a turbine that is connected to a generator in order to actually create the energy that will be later distributed to homes. By the time all of the salt that has been heated up on the previous day is used up, the next day's energy production has already begun, which simply goes to show the innovative design of the heliostat power plant, which goes above and beyond the similar structure of other concentrated solar power plants.

HPPs are used for mostly residential purposes, due to their solar nature. The future for major industrial applications, however, is bright. As mentioned earlier, HPPs do not directly convert sunlight into energy and then fail to produce energy at night, like their photovoltaic cousins. HPPs instead store the energy as heat which allows them to be utilized around the clock [19]. This also means that they are dependable in situations where other forms of solar power are not. For example, in a case where traditional photovoltaic panels are unable to generate power, like when it is cloudy outside, HPPs are able to waste minimal amounts of power stored, while simultaneously distributing the remaining amount of energy.

Also, as mentioned previously, the heat transfer liquid is stored in tanks that allow the liquid to lose a negligible amount of heat while stored. The ceramic in between the two walls acts as insulation, which prevents the salt from losing any significant amount of heat. On average, this storage system only allows the salt to lose about one degree per day, which implies that the liquid can be stored for virtually as long as needed. Once again, unlike PV panels, HPPs can use this stored liquid at any time, which solves the issue of not being able to store the solar energy that is generated.

MOLTEN SALT: A CRUCIAL COMPONENT

Seeing as it has been mentioned so many times, it can be inferred that molten salt is an incredibly important part to the whole process of power generation in heliostat power plants. Traditional PV panels do not have any way to store energy as mentioned earlier and can neither create nor store energy for later use. The usage of molten salt circumvents this limitation. Molten salt can, in the case of HPPs, store energy. The molten salt that is heated is stored in a tank, which essentially functions like a battery. When the tank in the Crescent Dunes facility is full, it can keep the facility running for 10 hours, or 1100 megawatt hours of storage. Lithium-ion batteries have been used as a method for storing renewable energy, but the storage capabilities of the molten salt tanks used in the Crescent Dunes Facility are 10 times greater than the storage capabilities of Lithium-ion batteries [21].

However, there are some of the other HPPs run by SolarReserve which have even better storage. The HPP in the city of Copiapo in the Atacama Region of Chile powers 560,000 homes 24/7. Additionally, the Likana and Tamarugal facilities which are also both Chile provide 24/7 power to 870,000 and 800,000 homes respectively [19]. This 24-hour energy capability is a big step forward for the solar energy field and truly sets molten salt HPPs apart from other alternative energy methods.

ENVIRONMENTAL IMPACT OF HELIOSTAT POWER PLANTS

Since HPPs function through the use of solar energy rather than burning fossil fuels, these facilities are not contributing to climate change. As previously mentioned in detail, fossil fuels, which are the primary means of energy production in the United States, create greenhouse gases which, as research has shown, are the leading cause of climate change. HPPs do not use fossil fuels for their primary energy production and therefore release no emissions. Some HPP facilities rely on fossil fuels for backup energy because molten salt storage tanks work like batteries do, molten salt HPPs do not need fossil fuels as a backup [21]. Crescent Dunes, though, is an example of a HPP that does not use fossil fuels. This is not unique to the Crescent Dunes facility. According to SolarReserve, all ten of their HPP facilities are 100% fossil fuel free [19].

Emissions created by fossil fuels are shown to have negative effects on the environment and are one of the main reasons that alternative forms of energy are needed. However, while it is vital to create alternative forms of energy that are emission free, there are other factors that impact the environment that need to be considered. Nuclear power is a good example of a form of alternative energy that is free from fossil fuels but not necessarily safe for the environment in the long run. The risks posed by nuclear energy, in some views, have the potential to outweigh the advantages. For example,

although it was due to the 15-meter tsunami combined with the 9.0 magnitude earthquake, the Fukushima nuclear power plant disaster caused the loss of "well over 1000 deaths," which is a loss of life unequaled by all solar power plant malfunctions combined [22].

These other factors are the reason why nuclear power, although it is free from fossil fuels and CO_2, has the potential to harm the environment. This point raises the question of whether HPPs have similar risks. Because of this, it is necessary to consider the other factors before determining if they are actually safe. One thing that should be considered is the consequences of a leak in the molten salt tank. The only real issue with salt leaks is the dangerous amount of heat, since as one of the main qualities of molten salt is that it has an incredibly high heat tolerance, because the mixture of sodium nitrate and potassium nitrate is so densely packed together from a microscopic standpoint [23]. There is also the possibility of oxidation if the salt is not cleaned up in a timely manner [16]. However, the molten salt mixture itself is very environmentally friendly. The salt mixture commonly used for heat transfer has a chemical formula of sodium and potassium nitrate. This mixture is not only safe for the environment, but it can also be used as fertilizer when it is decommissioned [21].

While there have been few major events that make it possible to fully assess if a molten salt leak is truly harmless, there was a minor leak at the Crescent Dunes facility. This problem arose because there was a miscommunication between the engineers and the builders that led to two metal parts that were supposed to be independent being welded together and becoming rigid [16]. Essentially, part of the storage tank was supposed to be able to expand, due to the heat of the salt, but it was not able to. It is possible an engineer along the way failed to compensate for thermal expansion, which caused a critical failure to the tank. The main consequence of this leak was that the plant had to close for maintenance, although it was already scheduled to close the next month for maintenance that was scheduled. The leak did not cause any lasting damage to the surrounding community, the workers, or the plant [16].

In the early years of HPP technology, there seemed to be one very serious environmental issue caused by the facilities: bird deaths. The extreme heat generated by the heliostats, seared the wings of birds flying by causing them to not be able to fly, and in some extreme cases, the heat immediately killed the birds. Many media outlets highly publicized this issue, claiming that hundreds of birds were being killed. However, while it is true that some birds have died as a result of the heat of the HPPs, the amount of bird deaths is far too small to have an ecological impact. With that being said, both the SolarReserve and NGR, an energy company that runs the Ivanpah facility, the other major HPP facility in the US, have made effort to lower the amount of bird deaths even further to guarantee that these facilities will not negatively impact the population of birds [24].

Finally, one other environmental aspect that should be mentioned, especially when comparing alternative energy sources to fossil fuels, is if there will ever be a shortage. Besides the fact that fossil fuels are hurting the environment, another issue with them is that there is a limited supply in the Earth [8]. This is far less of an issue with HPPs. There is an unlimited amount of energy from the sun so that is not an issue when considering if there will ever be a shortage of the resources used by HPP. However, the salts used in the molten salt mixture should be considered as well. According to SolarReserve, there is a surplus of sodium nitrate, as well as potassium nitrate, which, as mentioned earlier, make up the mixture that is used as molten salt, found naturally in the earth [21]. However, even if there was not a large amount of these salts, the lifespan of the molten salt is long. SolarReserve has stated that molten salt can be used in heat transfer for over 30 years before needing replacement. [21] Therefore, the expendability of the resources used by HPPs is not an issue, and HPPs, although they are utilizing some natural resources, will not drain the earth of natural resources due to the relatively low usage.

Although HPPs are relatively new, there is no research thus far proving, or even suggesting, that HPPs are bad for the environment. Therefore, HPPs are good for the environment in multiple ways. The most important fact, though, is that they do not produce emissions that contribute to climate change. This is positive because they are not producing harmful emissions and can be used to replace fossil fuels, which are contributing to climate change. Additionally, HPPs, and even molten salt HPPs, are not impacting the environment in any other negative ways. Therefore, based on all of this data, we can conclude that HPPs are environmentally safe.

ASSESSING THE EFFICIENCY

As was previously mentioned, HPPs, although they have the similar environmental consequences (or lack thereof) to PV panels, they are much more efficient. CSP facilities in general have be found to be more efficient. Within the family of CSP facilities, power towers are the most efficient. The central receiver set up maximizes the efficiency. All of the mirrors are focused at one point, the central receiver, which maximizes the temperature within the receiver and thus maximizes the efficiency. Additionally, since the heliostat mirrors adjust throughout the day to focus the most amount of sunlight at receiver as the sun moves, they are more efficient than if the mirrors did not move as is the case with PV panels.

SUSTAINABILITY

Another aspect of HPPs that should be evaluated is the overall sustainability of these technologies. As was previously mentioned sustainability is a multifaceted topic. Sustainability deals with issues such as limited resources, but

overall is focused on maintaining the wellbeing of the environment and quality of life for future generations. As climate change continues to occur it is of utmost importance that new technologies are sustainable. HPPs can be considered sustainable for a number of reasons. One sustainable aspect of HPPs that has been outlined already in this paper is that HPPs, specifically the Crescent Dunes facility, are able to function without any fossil fuels [19]. The HPP facilities that do use fossil fuels use a very minimal amount. This is extremely relevant to sustainability because fossil fuels are not only a limited resource but also have a strong link to climate change.

The resources used in HPPs also make it sustainable. The energy source of HPPs is the sun which is completely unlimited. What's more, the molten salt used not only is an abundant resource, but also has as lifespan of upward of 30 years [21]. Therefor HPPs are sustainable because they not only do not use a harmful and limited resources, but also because the main resources that they do utilize are abundant. Additionally, HPPs have over all been found to have very minimal negative impacts on the environment. Although there was some concern about the bird population, HPPs although they do harm a small portion of birds have little to no impact on the overall bird population [24].

In the context of limited resources and overall environmental safety and protection HPPs can be considered to be sustainable, however according to Maurice Strong and his views of sustainable development there are a few other aspects that should be considered.

COST

Solar power plants in general account for .5% of the United States' energy, and this begs the question: if all of the aforementioned facts are true, why isn't solar energy implemented more? While HPPs have numerous environmental benefits, another aspect that should be considered is the cost. One of the main arguments against alternative energy is that fossil fuels are cheaper. Although the two topics do not seem directly related, one of the important aspects of sustainable development is the question of economic feasibility. If sustainable energy is not affordable for the majority of people then it will never be implemented. This logic is apparent in solar energy as a whole because although it is beneficial to the environment it is considered to be very costly. Many companies and homeowners are unwilling to spend the money to switch over to a more sustainable method of energy production [25].

As previously mentioned, PV panels are very expensive, however purchasing power from a CSP plant is not. According to the Solar Technology Office, the cost of electricity produced by CSP facilities has been lowered from 21 cents to 12 cents per kilowatt hour [25]. Additionally, HPPs are not extremely expensive for consumers. While HPPs are still expensive, there has been a significant decrease in the power price in the past eight years. In 2009 when this technology was still relatively new the cost of electricity generated from the Crescent Dunes power plant was 13.5 cents per kilowatt hour (kWh). In 2017, the cost of electricity generated from the Copiapo power plant in Copiapo, Chile was less than 5 cents per kWh. For context, both of these power plants were developed by SolarReserve, therefore the chance of a confounding variables impacting the drop-in cost is reduced.

Since the power price is becoming less expensive it is becoming more accessible to those with less expendable income [25]. What's more the cost of energy produced by HPPs is not much more expensive than the cost of energy produced by fossil fuels. According to data collected by the EIA in 2016 the average cost of electricity in the United States was 12.55 cents per kWh [26]. Although this is less than the cost of electricity produced by the Crescent Dunes facility in 2009 it is not substantially less. what's more the overall cost of power generated by HPPs has lowered since 2009. Therefore the cost consumers pay for HPP generated energy, specifically the cost of energy generated by the Crescent Dunes, is not necessarily a major drawback as it is just slightly above the average national cost of energy.

The cost of HPPs from the point of view of investors and manufacturers should be considered as well. SolarReserve took out a title 17 clean energy loan for 737 million dollars, but the overall cost of the facility is closer to $1 billion [27]. Although HPPs are more expensive upfront there are long term financial incentives to building and forming HPPs. One of the three primary reasons that Sweden started its Fossil-Free is because it "makes good economic sense". Sweden's logic is that because climate change is becoming more of a crucial issue it is necessary to develop more sustainable technology. The Swedish government believes that fossil fuels and fossil fuel related technologies will become outdated and financially burdensome [15]. Therefore, in the long term, it could financially benefit those who invest in HPPs because they are an innovative and sustainable technology. However, because there is no data to back Sweden's assumption, the definitive return on investment is unclear.

DRAWBACKS

While HPPs are efficient, environmentally safe, and have storage capabilities there are other outlying factors of HPPs that are imperfect. The heliostat mirrors take up 296 acres of land and some cities simply don't have enough space for this massive field of mirrors that are required to reflect the sun's light onto the receiver in order to heat up the heat transfer material [19]. Additionally, the receiving towers are extremely tall. The central receiving tower of the Crescent Dunes facility is 640 feet tall. To put this in perspective, the Cathedral of Learning in the University of Pittsburgh is 535 feet tall, which means that the receiving tower is over 100

feet taller [27]. The overwhelming size of these facilities are an obstacle if these facilities were to be implemented in more populated areas. Although HPPs are an innovative and sustainable it is unrealistic to assume that these towers will be able to be implemented outside of deserts.

CONCLUSION

Heliostat power plants, on the whole, are an environmentally friendly and potentially round the clock energy producer, albeit with a few drawbacks. HPPs have enough potential to become the future of clean and sustainable energy in certain regions. The lowered energy price, along with the lack of negative consequences on the environment, propel HPPs to the forefront of clean energy production. Especially in vast spaces of open land, such as the Southwest, HPPs appear to be the best option for producing energy for the surrounding communities. HPPs benefit the environment, especially in comparison to other forms of energy that are not sustainable and help to reduce humanity's carbon footprint in the long run. Despite the fact that HPPs take up so much space, and are expensive to implement, the return investment for both the environment, as well as financial investors, is bright.

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