**Disclaimer—**This paper partially fulfills a writing requirement for first year (freshman) engineering students at the University of Pittsburgh Swanson School of Engineering. *This paper is a* ***student, not a professional***, paper. This paper is based on publicly available information and may not provide complete analyses of all relevant data. If this paper is used for any purpose other than these authors’ partial fulfillment of a writing requirement for first year (freshman) engineering students at the University of Pittsburgh Swanson School of Engineering, the user does so at his or her own risk.

SOLAR ENERGY AND ITS CHALLENGES

David Preiss ([dap152@pitt.edu](mailto:dap152@pitt.edu))

INTRODUCTION

As we begin the transition away from fossil fuels, we are noticing some of the things we took for granted. One of the greatest things about fossil fuels is that they served a dual purpose, as both a source of energy, but also a container for it. If you have extracted and refined some coal or oil, but you don’t want to use it right now? No problem, it will just sit there until it’s burned later. Unfortunately, the same cannot be said for sunlight, the most promising and rapidly growing source of energy. While ways of collecting energy from the sun has become sufficiently advanced and varied, methods for storing that energy is what is in demand. This unmet demand is holding sunlight, and the entire energy industry, back.

Or it was. An American company called SolarReserve have been making large facilities that collect and then immediately store the sun’s energy in the form of heat.

**HISTORY OF SOLAR**

The history of Solar energy began way back in the late 19th century when, in 1876, Selenium was discovered to produce electricity when exposed to light. This discovery, made by William Grylls Adams and his student, Richard Day, was instantly recognized as the beginning of something incredible. At least, it was touted as much by the scientific community. One expert in electricity at the time, Werner von Siemens, was especially praising, even claiming that it was “scientifically, of the most far-reaching importance”. Due to the inefficiency of selenium, most of the significance was in the mere confirmation of the idea that electricity could be derived from light alone, without any heat or moving parts.

It wouldn’t be until 1953, almost 80 years later, that Silicon would be used instead. Calvin Fuller, Gerald Pearson, and Daryl Chapin had achieved a similar effect, but at a magnitude that was practical, and could be used to provide power to small electrical devices. This discovery not only excited the scientific community, but the public as well. The New York Times chimed in, calling the discovery “the beginning of a new era, leading eventually to the realization of harnessing the almost limitless energy of the sun for the uses of civilization.”

However, that era was not the mid-1900’s as over the next couple of years, the prohibitive cost of solar power meant they found little use in commercial products. They did find a home in the USA and Soviet Space programs, where pockets were deep and demand for light, long-lasting power sources were in high demand. Solar cells very quickly became the standard for powering satellites, but little else.

However, the fact that solar cells had some sort of market meant that research was still being done to find a way to make them better and cheaper. In the 1970’s there was a breakthrough and the price rapidly dropped from around $100 dollars per watt hour to just $20 and continued to fall into the future.

From then on, solar panels have been able to be used by governments on projects with budgets smaller than that of the then huge USA space program. Soon, companies were using it to power large facilities or in small appliances like calculators in order to sell. Today solar panels can be seen powering cars, planes, and other large products. However, despite the clear success in its transition to commercial use, solar panels are still seen as too expensive for private power use.

**WHAT IS SOLAR ENERGY**

Solar energy is any energy that comes from the sun. A glass of water getting warmer is getting heated up by the sun, converting the energy of the sun’s rays into thermal energy by way of the hot surrounding air. And while this method is used for heating and can even be converted into power through thermoelectric generators, solar energy can also be converted directly into electricity via the Photovoltaic effect.

Solar cells are devices that use this effect to generate electricity. A basic description is as follows: photons from the sun excite the electrons in certain crystal atoms, ionizing them. These excited will jump from atom to atom, and, if all the atoms are ionized crystals, this flow of electrons forms an electric current. Solar panels are made using these special crystal atoms, usually silicon, arranged in a way to take full advantage of this phenomenon. Such measures must be taken as the amount of electricity is not very much, considering the cost and space of even a single solar cell. The best attained by most of today’s solar panels only captures 10-25% of the solar energy that they are exposed to. More expensive and experimental cells made of Gallium Arsenide have attained higher levels around 30%.

Even with all the advancements using Solar cells and the Photovoltaic effect, many scientists still question its superiority over plain old thermoelectric generators.[10]

**PROBLEMS**

A big question one might ask is “If the only drawbacks are poor short-term payoff and a cost that is unattractive to the private citizen, why can’t we just use them for giant power plants? What’s stopping solar panels from just simply replacing coal in the role of public power supplier?” The biggest problem is not actually the generation of electricity, but the management and storage of it. Ironically, the desire to draw power from the forces of nature contains the intrinsic issue that humans have little to no control over the forces of nature. Unlike the burning of oil, coal, or natural gas, the amount of sunshine cannot be throttled to meet demand.

The amount of electricity consumed follows a pattern throughout the day, depending on the city. As such, the rate of material burned can be adjusted to fit. There is also no point in time during which the plants are unable to provide any power, so any attempt to store excess energy would be merely to act as a reserve in case of an emergency.

While solar power plants would be expensive to build initially and can take up over 10 times the space[8] as coal powered ones, the simple fact that the sun only shines during the day is what creates a debilitating issue. Electricity doesn’t just wait around, and if the precious energy collected from the sun is more than is required, it needs to be stored in some way, or else it is lost. This is especially important because at nighttime the facility will generate absolutely no power and will have no other choice but to draw on stored energy.

For the what might be the first time ever, humans will have to find a way to store massive amounts of electricity for hours or even days as a time, over the course of the facility’s lifetime. Any inefficiency will be significantly magnified merely by the scale at which energy is going to be transferred. This means that a large amount of rechargeable AAA batteries won’t do the trick. Another thing to consider is that, according to the laws of thermodynamics, each and every time energy is transferred, some is lost. So, if the energy needs to be transferred into a different form for storage, it will pose a big problem.

**POSSIBLE SOLUTIONS**

In response to this problem, many storage methods have been proposed, all varying in what exactly they address and in how feasible they are. Possibilities include Hydrogen fuel cells, Pumped-storage hydroelectricity, and giant flywheels. However, I think the most promising and interesting is the method of thermal energy storage.

One method is to use the energy collected to facilitate the electrolysis of water into hydrogen and oxygen, where the hydrogen can be stored to be put into fuel cells later. Hydrogen fuel cells would be relatively efficient and eco-friendly. However, they are neither efficient nor cheap enough to justify using on a massive or small scale[2]. Hydrogen fuel cells are also very delicate and cannot be conveniently stored for long periods of time. Overall, while they may seem attractive for powering medium sized machines like large vehicles, their practicality in storing huge amounts of solar power merely to be used later is very limited. Hydrogen is also a very volatile gas, and storing large amounts of it for long periods of time may pose a hazard to safety. While research is still underway to reduce the price, increase the efficiency, and cut back on the complexity, Hydrogen Fuel cells have not yet reached a point where they are useful for anything, much less what is needed for this problem.

The most popular solution is to store excess solar power as gravitational potential energy by pumping water uphill. Since gravity is a conservative force, the amount of energy stored by the water would not decrease over time, meaning that it would be very good for long term storage. However, there are very few methods of energy harnessing that are so intermittent that the double inefficiency of water turbines both coming and going is made up for by the fact that no energy is lost while it’s sitting in storage. Larger installations also tend to have both reservoirs as giant, open-air ponds. In this instance, it is hoped that any evaporation is counterbalanced by rainfall, but this is rarely the case. Often, more water must be added. Size is also an issue, especially since solar installations have very large footprints to begin with.

Other solutions include the maintenance of a massive flywheel, where the large moment of inertia combined with a low-friction environment would work to maintain present rotational velocity and minimize any loss of stored energy. However, this would take up a lot of space and would have, by its very nature, a lot of massive components moving very fast. Also, the bigger the wheel, the more efficient it is, meaning there is no “sweet-spot” to maximize energy storage.

The most interesting solution is thermal energy storage, where the energy collected is stored as thermal energy using materials that have a very low tendency to lose heat. At first, this method seems to be a poor choice, as thermal energy tends to disperse over time. This means that even the most extensive insulation systems will not have the benefit of zero energy loss while in storage that other methods, such as pumped-storage hydroelectricity, enjoy. However, there are numerous benefits that I would argue far outweigh these flaws.

In most energy transfers, wasted energy is lost as heat. However, using thermal energy to store heat means that the insulation also performs a second function by protecting against the most common way systems lose energy. Thermal Energy storage also takes up far less space than other storage methods, with the facilities being relatively compact and often partially underground.

**EXAMPLES OF SOLAR THERMAL STORAGE IN THE WORLD**

One example is to store the electricity by using it to freeze ice. This ice can be used to provide cooling to buildings, but can also be melted later to be transferred back into electricity. This method uses a relatively cheap method of storage to make up for the larger cost of an array for photovoltaic solar cells.

An even smarter example of this type of storage is not just storing, but collecting the sun's energy in the form of heat. This method involves having mirrors focus the sun's rays to heat up a tube of liquid, bypassing the need for expensive photovoltaic solar panels entirely. Later on, this heat is used to turn water into steam, powering a turbine to produce electricity. Since all the energy transfer happens all at the end, right before it is used, this is in an incredibly efficient, and cost effective, process.

One American company, SolarReserve, has already started building facilities such as this using a special type of molten salt that is already widely used for heat transfer in the industry today[1]. They have already built multiple installations across the US and many companies in South America have followed suit. One company, Abengoa, even cited them directly as an inspiration[5]. The fact that the heat from the sun is immediately stored, without any energy transfer works to the strengths of both the method of collecting thermal energy and storing it. It makes two considerably efficient process seamlessly mesh together, cutting out major wasteful internal steps, enabling it to be pushed beyond its competitors.

**WHAT THIS MEANS FOR THE FUTURE**

While this solution is by no means perfect. It at least works well enough to serve as a long-term, but temporary, measure while the technologies behind Photovoltaic-powered solar panels and Hydrogen fuel cells get to the point where they can take over.

After seeing such success, it only goes to show that, in order to responsibly meet the growing energy needs of a new age through renewable, environmentally friendly means, we’re going to have to keep thinking outside of the box.

..k that.onsultant.u were writing, wouldation they have narrated.ppreciate their their own agency and how they learning about ..k that.onsultant.u were writing, wouldation they have narrated.ppreciate their their own agency and how they learning about

**SOURCES**

[1] P. Morales. “Molten Salt Energy Storage.” SolarReserve. 12.12.2014. Accessed 11.1.2016.

<http://www.solarreserve.com/en/technology/molten-salt-energy-storage>

[2] “26 Significant Pros and Cons of Hydrogen Fuel Cells” Green Garage. 6.26.2015. Accessed 11.1.2016

<http://greengarageblog.org/26-significant-pros-and-cons-of-hydrogen-fuel-cells>

[3] A. Nguyen. “Storing Solar Energy Underground for a Cloudy Day?” Poway, CA Patch. 11.23.2015. Accessed 11.1.2016

<http://patch.com/california/poway/storing-solar-energy-underground-cloudy-day-0?utm_source=dlvr.it&utm_medium=facebook&utm_term=community+corner&utm_campaign=recirc&utm_content=aol>

[4] J. A. Krisch. “3 Clever New Ways to Store Solar Energy.”

Popular Mechanics. 1.30.2015. Accessed 11.1.2016.

<http://www.popularmechanics.com/science/energy/a9961/3-clever-new-ways-to-store-solar-energy-16407404/>

[5] G. Parkinson. “Abengoa to Build 110 MW Solar Tower Storage Plant in Chile.” Green Technology. 1.16.2014. Accessed 11.1.2016.

<https://www.greentechmedia.com/articles/read/abengoa-to-build-110-mw-solar-tower-storage-plant-in-chile>

[6] W. Reece. “The History of Solar Power” Energy & Utilities. 1.1.2016. Accessed 11.1.2016.

<https://www.experience.com/alumnus/article?channel_id=energy_utilities&source_page=additional_articles&article_id=article_1130427780670>

[7] Z. Shahan. “13 Charts on Solar Panel Cost & Growth Trends.” CleanTechnica. 7.28.2016. Accessed 11.1.2016.

<https://cleantechnica.com/2014/09/04/solar-panel-cost-trends-10-charts/>

[8] Ted Nace. “Which has a bigger footprint, a coal or solar farm?” Grist. 11.17.2010. Accessed 11.1.2016.

<http://grist.org/article/2010-11-17-which-has-bigger-footprint-coal-plant-or-solar-farm/>

[9] C. Helman. “Solar Power Is Booming, But Will Never Replace Coal. Here’s Why.” Energy. 4.24.2014. Accessed 11.1.2016.

<http://www.forbes.com/sites/christopherhelman/2014/04/24/solar-is-booming-but-will-never-replace-coal/#6bed74622499>

[10] Jeff Klein. “Can Thermoelectric Generators Compete Against Solar Photovoltaics?” Energy and Natural Resources. 10.7.2014. Accessed 11.1.2016.

<http://insights.globalspec.com/article/98/can-thermoelectric-generators-compete-against-solar-photovoltaics>

[11] Karl W. Böer. “Solar Cells.” Chemistry Encyclopedia. Accessed 11.1.2016.

<http://www.chemistryexplained.com/Ru-Sp/Solar-Cells.html>

[12] W. Reece. “Solar Power History.” FuelFromTheSun. Accessed 11.1.2016.

<http://www.fuelfromthesun.com/history.htm>

[13] S. Tehrani, R. A. Taylor, P. Saberi, G. Diarce. “Design and feasibility of high temperature shell and tube latent heat thermal energy storage system for solar thermal power plants.”

Renewable Energy: An International Journal. 10.1.2016. Accessed 11.1.2016.

<http://web.a.ebscohost.com/ehost/detail/detail?vid=5&sid=f8186927-6097-4541-b566-57b34420aafd%40sessionmgr4007&hid=4106&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#AN=115920654&db=aph>

**ACKNOWLEDGMENTS**

I would like to give a special thanks to the library and librarians for helping me to find what I was interested in as well as learn more about the topic at hand. I would also like to thank my fellow engineering freshman for encouraging me and supporting me when I got stuck.