California State University Long Beach

Mechanical and Aerospace Engineering Department

MAE 336: Power Plant Design

PROJECT

SOLAR PHOTOVOLTAIC POWER PLANT

Submitted by:

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John Paolo Sucro

Date of Submitting Project: 12/01/2022

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TEAM MEMBERS

Mark Leonardo Gliane

I am the project manager, and I am a Mechanical Engineering major expected to graduate in Spring 2024. My main interests in the engineering field are along the lines of the automotive industry and manufacturing.

Ricardo Jimenez

I am a third year mechanical engineering student, expected to graduate in the spring of 2024. I am in charge of the cost analysis for the project. My interests mainly lie along the lines of the aerospace industry.

Alexander Ramirez

I was the head designer for our Solar PV power plant. I am currently a fourth year mechanical engineer with an expected graduation date of Spring 2024. I have been involved with engineering since high school and have been a part of many projects that have relied on the engineering process. I hope to continue to expand my skills and acquire a job in the automotive space in the near future.

Johnny Rosas

I am a mechanical engineering student in my fourth year and I expect to graduate in the fall of 2023. I have internship experience in both aerospace manufacturing and automotive industries, but I hope to continue my career in automotive after I graduate.

John Paolo Sucro

I am a Mechanical Engineering major expected to graduate in the spring of 2024. In the engineering field, I take interest in the manufacturing, automotive, and aerospace industry.

BRIEF PROJECT DESCRIPTION

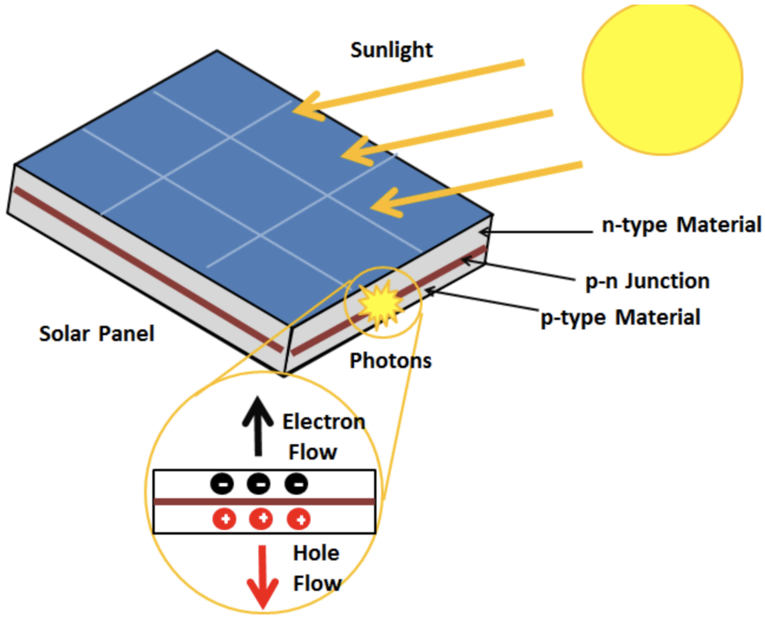
There are several different types of power plants that generate energy around the world, but the focus of this project is to research, discuss, and design a Solar Photovoltaic Power Plant. Solar energy from solar photovoltaic power plants has become one of the fastest growing sources of renewable energy. Photovoltaics, or PV for short, gets its name from the process of converting light (photons) to electricity (voltage), which in turn is referred to as the photovoltaic effect. It has helped cut down pollution from fossil fuels, which is a growing threat to our climate due to the Carbon Dioxide that is being released.

As the objective is to ultimately design a solar photovoltaic power plant, there are certain guidelines to be followed to achieve the target at hand. A solar photovoltaic power plant consists of various different components including the types of solar panels which can also vary depending on the certain material used, inverters and transformers, and an ample amount of land in a strategic location with a sufficient amount of daylight hours to construct the power generation system. The primary goal for this project is to design a 12 MW solar photovoltaic power plant to serve as a clean, renewable energy source.

RESEARCH RESULTS

There are many alternatives to renewable energy sources. The main ones are solar, wind, and hydro energy. They are all different in many ways, but they all fight the same battle of replacing fossil fuels that is harming our climate. With wind energy, it is hard to predict how much power it will produce since wind is unpredictable. Wind is necessary for the motor to turn on unlike solar that only needs a little bit of sunlight to produce energy. Since droughts are occurring more often in the US, it can be a problem because water is the main source. Both wind and hydro energy also have moving parts, which is a risk for the system to fail. Solar energy is reliable because even on cloudy days, power can still be produced. It can still produce 10 to 15% of its power capacity. Solar energy is in a fixed position and doesn’t have any moving parts, which makes it more reliable than the two. This is why solar energy is one of the top alternatives in creating renewable energy. The energy produced can be used to power our electronic devices that we use in our daily lives.

Solar energy produces energy from the sun and the solar energy is converted to electrical energy. This is called a Photovoltaic effect. The solar cells are made of two different semiconductors, which are P-type and N-type. When they are joined together, they are called a P-N junction, which then forms an electric field in the region of the junction. Sunlight is composed of photons and this energy can be absorbed by a photovoltaic cell. Energy is transferred to an atom of the semiconducting material in the junction, which means that energy is transferred to the material’s electrons. The electrons then jump to a higher state known as the conjunction band, leaving a “hole” in the valence band where the electron jumps up from. In this state, the electrons are free to move though the material. The movement of the electrons creates an electric current in the cell.

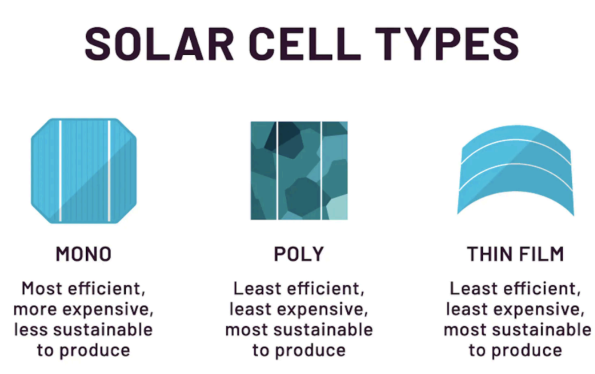


Since the sun is always out, clean energy is always created. Even on cloudy days, some power is still produced. In the rain, solar panels can still operate, but the power output will depend on the cloud coverage. On the bright side, rain can clean the panels in a safe and easy way. Solar energy can be used anywhere as long as the sun is shining, which makes every country a producer of solar energy. This makes it a reliable source of energy and beneficial to our climate. The best location in the US for solar panel installations are Texas, California, Arizona, and Florida. These states are considered the sunniest places in the US. Solar energy systems don't require a lot of maintenance and it can be cleaned at a low cost. Solar panels typically need maintenance annually and it costs $15 to $25 to clean per panel. This is the average cost with a solar company, but it would cost less if you clean it yourself. However, it is best to contact a solar company first. It is necessary to maintain the solar panels for longevity and efficiency. The lifespan of a reliable solar energy system is up to 30 years.

DESIGN PARAMETERS

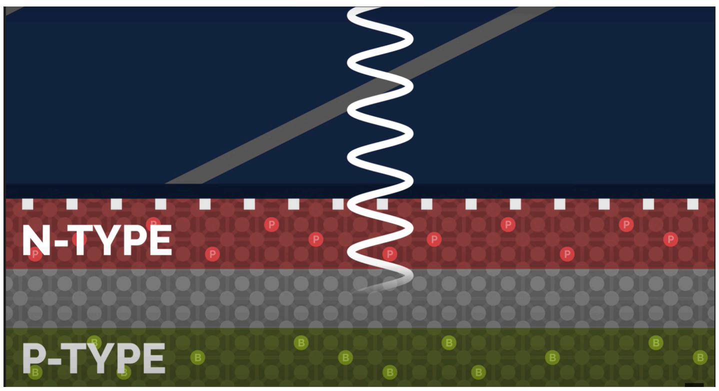
The most efficient type of solar panel is made from monocrystalline solar cells due to it being cut from a single source of silicon unlike the polycrystalline, which is cut from multiple sources of silicon. This makes the polycrystalline slightly less efficient than the monocrystalline. There is also a Thin-film technology that costs less than the monocrystalline and polycrystalline. However, it is less efficient than the two. To be efficient, it would be best to use a 72-cell solar panel made from monocrystalline. They perform well in high heat and lower light environments. The solar panels are grouped together to create an array. A 300 watt solar panel can produce 2100 watts a day, assuming that there's 6 hours of sunlight per day.

To have the best results in production of energy, it is best for the solar panel to tilt between 30 and 45 degrees. It will produce the most electricity when it's placed perpendicular to the sun. The distance between each panel also matters. Since the angle of the sunlight changes, it affects the amount of sunlight they can absorb. Increasing the distance between the panels decreases the level of shading. This allows the panel to convert more energy from sunlight. For a 12 MW solar photovoltaic power plant, we would need approximately 40,000 solar panels. The PV charge creates an electric current DC, which is captured by the solar panel wirings. DC electricity is then converted into AC, which is an alternating current. This conversion occurs through an inverter. 40 strings of inverters produces a power of 1 MW.

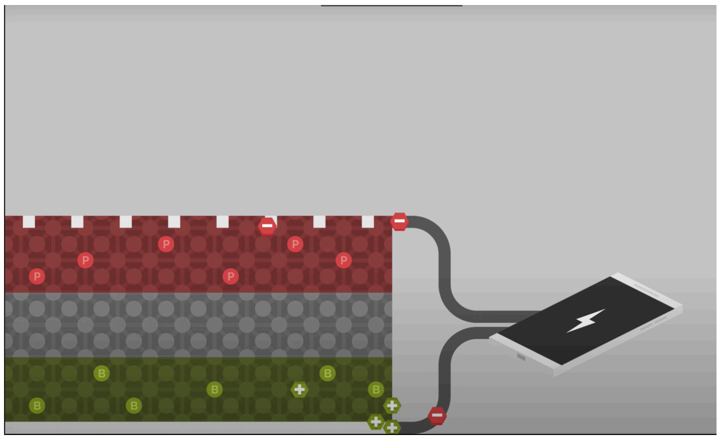


DISCUSSION

In order to convert sunlight into electricity, it's important to understand how a solar cell works. Solar cells are made up of a semiconductive material, which tends to be silicon. The wafer, or thin layer, of silicon is made up of 3 sublayers. The top layer is called the negative type, or "N-Type" layer and is often composed of a mixture of silicon and elements that have more electrons than silicon. Phosphorus is often used for the top layer and this abundance of electrons makes the top layer more conductive. The bottom layer is called the positive type layer or "P-Type" layer. This layer usually consists of silicon and elements that have less electrons than silicon such as Boron resulting in the bottom layer being less conductive. This imbalance in electrons creates a difference in electric potential also known as voltage.



When photons from sun rays hit a solar cell, they knock electrons off of silicon atoms in the middle layer. Each atom that loses electrons becomes more positively charged. The loose electrons move into the top layer. The loose positively charged atoms, sometimes referred to as "holes", move into the bottom layer. Wiring up both the top and bottom layers allow the electrons to flow towards the holes and the flow of electrons is how electrical current is generated. Lining up multiple cells in a square creates a module, and arranging multiple modules in a larger panel creates the solar panels most people see on rooftops of houses or across large fields off of highways all across the U.S. PV cells generate direct current which can be used to charge batteries that power electrical appliances. However, most electricity is supplied as alternating current so PV systems pass current through inverters which turn direct current into alternating current if necessary.



CALCULATIONS

The goal is to design a 12 MW Solar PV Power Plant. Best case scenario, our solar panel can produce 350 watts per hour but if we calculate using a scenario of 300 watts per day we get:

$$\frac{12{,}000{,}000\ watts}{300\ watts} = 40,000\ solar\ panels$$

The project's site location will see an average of 6 hours of sunlight per day throughout the year. Which means in one day a single solar panel will produce:

$$0.300\ kW\ *\ 6\ hours\ =\ 1.8\ kWh$$

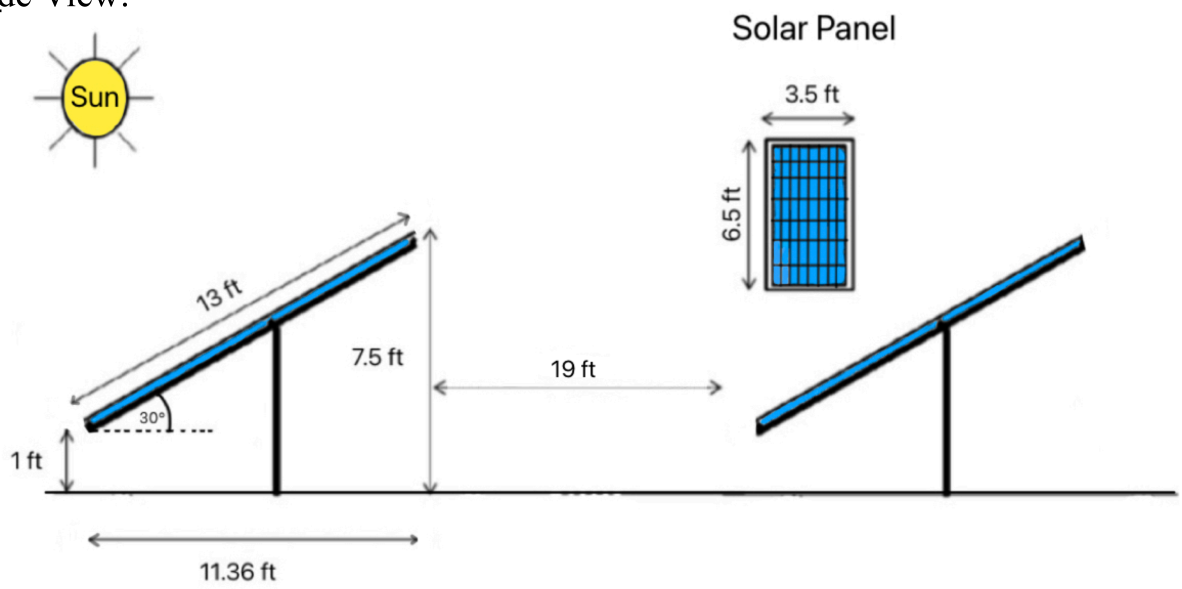
Therefore, the entire power plant, with its 40,000 solar panels will produce:

$$1.8\ kWh\ per\ panel\ *\ 40,000\ panels\ =\ 72,000\ kWh\ per\ day\ =\ 72\ MWh\ per\ day$$

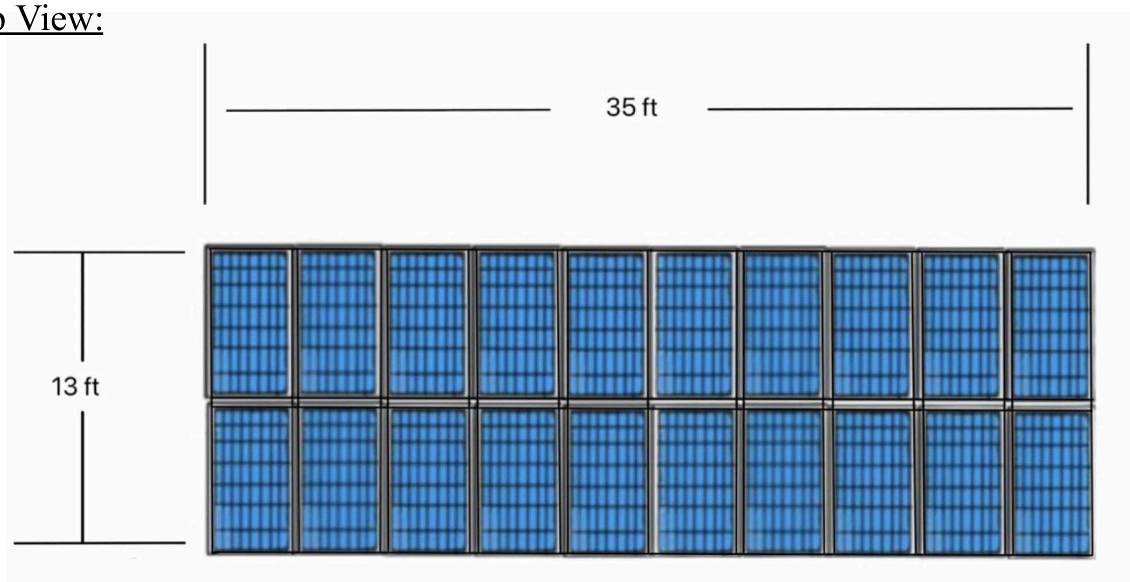
$$72\ MWh\ per\ day\ *\ 300\ days\ =\ 21,600\ MWh\ per\ year$$

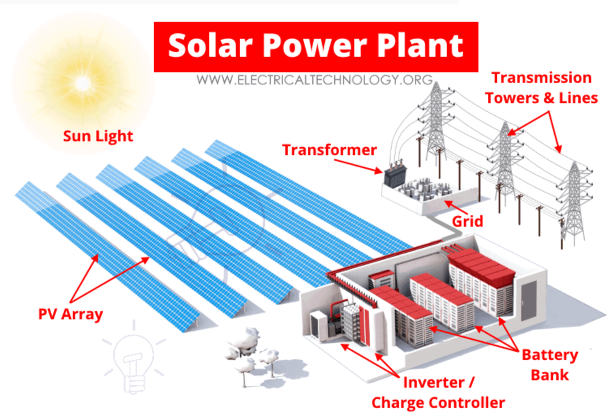
CONCEPTUAL DESIGN LAYOUT

Side View:



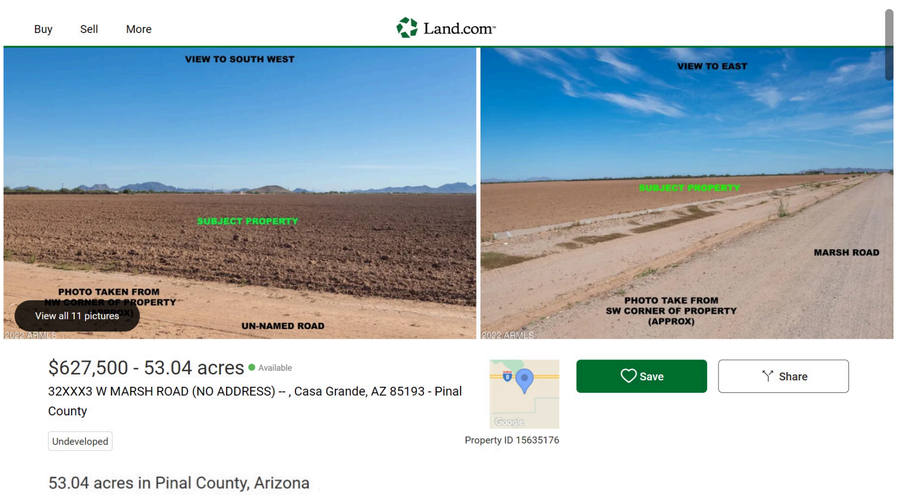
Top View:

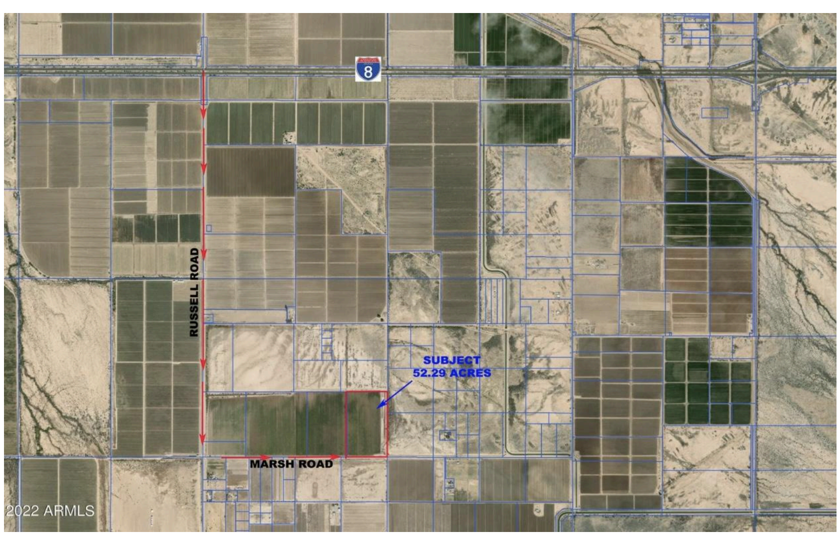




PROJECT SITE LOCATION

The site location we have selected is in Pinal County, Arizona. Although solar panels efficiency is reduced with higher temperatures, Arizona is known to have one of the highest daylight hours. The land we've acquired is 52.29 acres (roughly 2,177,752 ft^2). We are using the average commercial grade solar panels which are 72-cell – 3.25ft (39 inches) X 6.5ft (77 inches). The land asking price was set at $627,500 USD, which is our biggest upfront cost. With roughly 53 acres of land we will have 41,380 total commercial grade 3.35 ft X 6.5 ft panels. We only have 2,250,172 ft^2 to work with because there is a 20 ft X 1074.50 ft to allow for vehicles and maintenance and a 30 ft x 30 for the battery bank, transformer and Inverter charge controller.





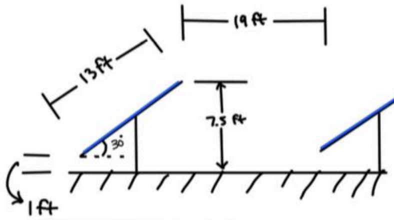
52.29 Acres = 2,277,752 ft^2

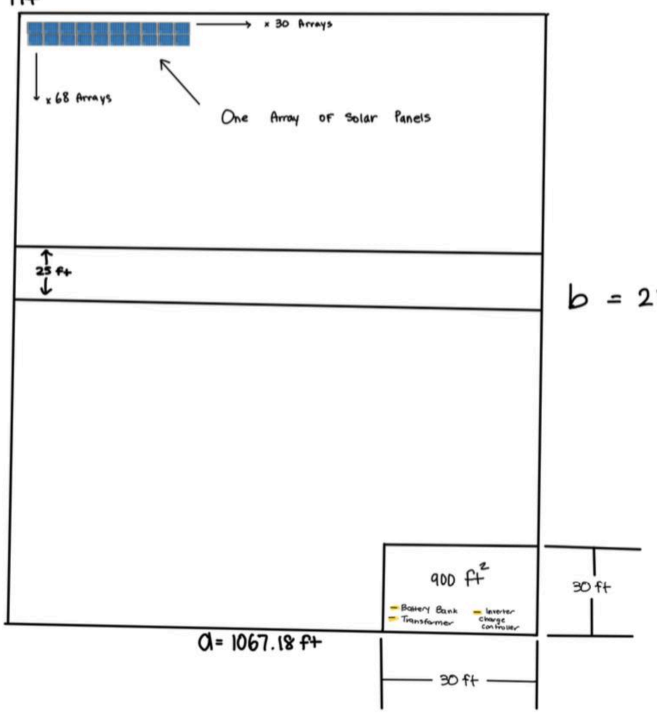
$a \times b = 2,277,752\ ft^3$

$a \times 2a = 2,277,752\ ft^3$

$a = 1067.181$ ft

$b = 2a \rightarrow b = 2135.62$ ft





(2135.6 − 30 − 25) ft

2080.6 ft

(1067.18 − 30) ft

1037.18 ft

$\frac{1067.18\ ft}{35\ ft}$ → 30 panel Arrays ⟷

$\frac{1037.18\ ft}{35\ ft}$ → 29 panel Arrays ⟷ (On Transformer)

$\frac{2080.6\ ft}{30.36\ ft}$

68 panel Arrays ↕

1 panel Arrays ↕

Total Panels

30 × 68 = 2040

29 × 1 = 29

2040 + 29 = 2069

2069 Panel Arrays :

(2069 × 20) →

20 panels

41,380 Total Panels

COST ANALYSIS

Our 12.4 MW PV power plant is projected to cost around $10.6 million. This is assuming that the trend of price remains constant since this is based on the 857 USD/kWh average cost of a utility-scale project commissioned in 2021. This cost includes; module and inverter hardware and non-module hardware. There is no resource cost for power generation since the power plant's fuel source is the PV rays from the sun along with the by-products.

Our proposed 12.4 MW PV power plant produces ~74,000 kWh / day, resulting in a power output of ~22 GWh / year. Assuming this is true, we are able to sell electricity at a rate of $0.18/kWh. This puts our yearly revenue at ~ $4,000,000 if we are to assume the plant is not under maintenance for 300 days out of the year.

Our target location has a set cost of $627,500 for ~ 53 acres of land. Therefore, assuming property and equipment cost is 50% of the total cost, this yields ~$11 million. Then, 15% of our total cost, ~$3.3 million, will be for engineering and project management. Finally, 35% of our total cost, ~$7.7 million, will be for construction. This puts the total cost of the PV power plant at approximately $22 million. While this cost does not include the interest rates on loans to build the power plant, there is still a sizable profit for the power plant. Our projected revenue allows the PV power plant to pay for itself in around 5.5 years, which is quite modest seeing as its economic life should be around 25 years.

	Total installed costs (2021 USD/kW)			Capacity factor (%)			Levelised cost of electricity (2021 USD/kWh)		
	2010	2021	Percent change	2010	2021	Percent change	2010	2021	Percent change
Bioenergy	2 714	2 353	-13%	72	68	-6%	0.078	0.067	-14%
Geothermal	2 714	3 991	47%	87	77	-11%	0.050	0.068	34%
Hydropower	1 315	2 135	62%	44	45	2%	0.039	0.048	24%
Solar PV	4 808	857	-82%	14	17	25%	0.417	0.048	-88%
CSP	9 422	9 091	-4%	30	80	167%	0.358	0.114	-68%
Onshore wind	2 042	1 325	-35%	27	39	44%	0.102	0.033	-68%
Offshore wind	4 876	2 858	-41%	38	39	3%	0.188	0.075	-60%

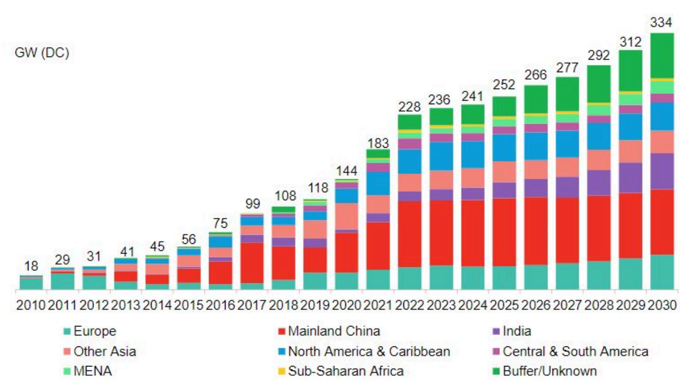
	Engineering & Project Management	Property & Equipment	Construction	Total Cost	Yearly revenue	Revenue for 25 Years
USD	$3.3 million	$11 million	7.7 million	$22 million	$4 million	$100 million

CONCLUSIONS AND RECOMMENDATIONS

As a result of the research conducted, discussions made, and calculations performed for this project pertaining to the design of a solar photovoltaic power plant, various observations can be made. The solar photovoltaic power plant designed by our team was able to achieve its goal of producing a 12 MW solar photovoltaic power plant as our design constraints enabled us to formulate a 12.4 MW power plant at our location in Pinal County, Arizona. The most common estimate of the average payback period for solar panels is six to ten years, and with the cost analysis conducted, the payback period for our proposed power plant design is about 5.5 years, making our design worth the investment. Over the course of the average lifespan of a solar photovoltaic power plant, our proposed design is expected to generate about $100 million in revenue over 25 years.

As solar becomes an even more efficient source of energy, the goal in mind is that it will continue to help offset the cost of electricity and make our planet a better place for all of its inhabitants. Reducing carbon dioxide emissions from our atmosphere is critical to the contribution of transitioning from climate-damaging fossil fuels towards clean, renewable forms of energy. The consistent growth of solar photovoltaic power generation encapsulates a crucial part of the global energy transformation. Power generation through the means of solar photovoltaic power plants is likely to continue to grow rapidly. According to the National Energy Laboratory, solar energy can provide 45% of the electricity in the United States by 2050 if the energy system is fully decarbonized.

Figure 1: Global PV installation estimate and forecast, as of January 2022



Source: BloombergNEF

The steady growing industry of solar photovoltaic power plants is not a perfect one, and there are several ways in which this form of power generation can be improved upon. While solar photovoltaic power plants serve its purpose in reducing carbon emissions, there are still ways in which it actually contributes to the issue as well. While solar panels have become almost synonymous with the likeliness of clean, renewable energy, there are aspects regarding the overall mode of power generation that isn't always clean. For example, the production of solar panels themselves requires a significant amount of energy as mining, manufacturing, and transportation all require a plethora of energy and can cause pollution. In addition, solar panels can create toxic waste as some of the materials in compounds that can be found inside of solar panels include cadmium, lead, and gallium arsenide among many others. With these toxic and hazardous materials used in the production of solar panels in mind, it can have a detrimental effect on the environment when these materials are being disposed of irresponsibly.

Although solar panels are responsible for some greenhouse gas emissions, they don’t have anywhere near the impact on the atmosphere as burning fossil fuels, but it is still significant to understand that this form of renewable energy isn’t perfect and can still be improved upon. The proper recycling of solar materials can help to reduce the carbon footprint that exists currently in the construction of solar photovoltaic power plants. Also, further research towards eliminating the toxic ingredients in solar components and finding more eco-friendly materials can help to make solar energy usage more beneficial for the environment.

Overall, as a means to move towards a cleaner and greener world, the steady incorporation of solar photovoltaic power plants around the globe will surely contribute to the cause.

MEETING MINUTES

Meeting #1
Date: 09/15/2022
Location: In-Person
Attendees:
- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Absences:
- N/A

Agenda:
1. Open discussion for roles of the project.
2. Discuss availability for future meetings.

Summary of Discussion
1. Roles will be chosen or assigned by the next meeting.
2. In-person meetings will be limited due to scheduling conflicts. Zoom has been decided to be the primary mode of meetings.

Next Meeting: 09/29/2022

Meeting #2
Date: 09/29/2022
Location: Zoom
Attendees:
- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Absences:
- N/A

Agenda:
1. Finalize roles for the group project.
2. Set due dates for each section as far as rough drafting.

Summary of Discussion
1. John: Research, Design Parameters
   Alex: Project Site Location, Conceptual Design Layout
   Johnny: Discussion, Calculations
   Ricardo: Cost Analysis
   Mark: Brief Project Description, Conclusion, Editing
2. Preliminary stages of each role to be submitted and discussed by the next meeting.

Next Meeting: 10/11/2022

Meeting #3
Date: 10/11/2022
Location: In-Person
Attendees:
- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas

Absences:
- John Paolo Sucro

Agenda:
1. Review progress of each role thus far.
2. Discuss any needed information from each role to continue with the progression of each assignment.

Summary of Discussion
1. All roles are on track as far as progress.
2. John and Alex have decided to collaborate more in their roles in order to more efficiently complete each given assignment. Johnny and Ricardo proceed with their assignments as far as they can until information from John and Alex is needed.

Next Meeting: 10/27/2022

Meeting #4
Date: 10/27/2022
Location: In-Person
Attendees:
- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Absences:
- N/A

Agenda:
1. Assign peer editing tasks for each assignment.
2. Discuss any comments or concerns.

Summary of Discussion
1. Peer edits were assigned and are due by next meeting
2. Concerns regarding the design layout were clarified.

Next Meeting: 11/01/2022

Meeting #5
Date: 11/01/2022
Location: In-Person
Attendees:
- Mark Leonardo Gliane
- Ricardo Jimenez

- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Absences:
- N/A

Agenda:
1. Return peer edits made for each role.
2. Discuss the edits that were made and adjust accordingly.

Summary of Discussion
1. Effective use of peer editing as errors were found in certain areas of given assignments.
2. Continue to work on each assigned portion of the project.

Next Meeting: 11/17/2022

Meeting #6
Date: 11/17/2022
Location: In-Person
Attendees:
- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Absences:
- N/A

Agenda:
1. Check progress of each member's assignment
2. Discuss availability for meetings during fall break in order to practice presentation.

Summary of Discussion
1. Team is almost completely done with the overall first draft of the entire report.
2. We will be able to meet during the break and want to meet at least one time in-person.

Next Meeting: 11/21/2022

Meeting #7
Date: 11/21/2022
Location: Zoom
Attendees:
- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Absences:
- N/A

Agenda:
1. Fine tune report and presentation slides.
2. Review calculations and cost analysis.

Summary of Discussion

1. Met through zoom and saw some mistakes we needed to fix first before practicing presentation.
2. All other sections of the report are finished, so our group will turn our focus towards the calculations and cost analysis.

Next Meeting: 11/22/2022

Meeting #8

Date: 11/22/2022

Location: Zoom

Attendees:

- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- John Paolo Sucro

Absences:

- Johnny Rosas

Agenda:

1. Check to see if we are satisfied with the changes made from the previous meeting.
2. Review presentation slides and script.

Summary of Discussion

1. Overall satisfied with the completion of the report.
2. Work to make the slides have less words and make sure everything matches the report. We will practice presenting our slides at the next meeting.

Next Meeting: 11/23/2022

Meeting #9

Date: 11/23/2022

Location: In-Person

Attendees:

- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Agenda:

1. Practice presenting our slides with scripts available for us to read.
2. Check our timing to see if we are at the required length.

Summary of Discussion

1. Our script was detailed and covers the main points of our report.
2. We are between the 7-8 minute range, so we are deciding if we should add more info to speak about during our presentation.

Next Meeting: 11/27/2022

Meeting #10
Date: 11/27/2022
Location: In-Person
Attendees:

- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Agenda:

1. Discuss added information to our presentation.
2. Practice presenting our slides without our scripts available to us.

Summary of Discussion

1. The added information was beneficial and still kept at the required time range at a little bit over 8 minutes.
2. We were somewhat having a hard time presenting without our scripts in front of us, so we will make it a goal to have it fully memorized by the next meeting.

Next Meeting: 11/30/2022

Meeting #11
Date: 11/30/2022
Location: In-Person
Attendees:

- Mark Leonardo Gliane
- Ricardo Jimenez
- Alexander Ramirez
- Johnny Rosas
- John Paolo Sucro

Agenda:

1. Practice our presentation slides with no script.
2. Discuss final edits for both report and presentation

Summary of Discussion

1. We were able to successfully complete sessions with a fully memorized script within the required length of time.
2. Mark will complete the report and presentation slide edits.
3. Team will continue to practice presentation individually until presentation time.

Next Meeting: 12/01/2022 (Due Date)

WORKS CITED

"51.04 Acres in Pinal County, Arizona." Land.com, https://www.land.com/property/51.04-acres-in-Pinal-County-Arizona/15635176/.

"The Cities of the World with the Most and Fewest Daylight Hours." Endesa, https://www.endesa.com/en/the-e-face/energy-efficiency/cities-hours-sunlight#:~:text=According%20to%20the%20World%20Meteorological,hours%20of%20sunshine%20per%20year.

Farhat, Hassan. "What Is the Pitch Distance and Why Is It Important?" *RatedPower*, RatedPower, 4 May 2022, https://ratedpower.com/blog/pitch-distance/.

"Hello Sunshine: The Future of Solar Power." *National Grid Group*, https://www.nationalgrid.com/stories/energy-explained/how-does-solar-power-work.

HomeAdvisor. "Learn How Much It Costs to Clean and Maintain Solar Panels." How Much Does Solar Panel Maintenance Cost?, HomeAdvisor, Inc., 23 Aug. 2022, https://www.homeadvisor.com/cost/cleaning-services/solar-panel-maintenance/.

Marsh, Jacob, et al. "Solar Panel Direction and Angle: Does It Matter?: Energysage." *EnergySage Blog*, 4 Oct. 2022, https://news.energysage.com/solar-panel-performance-orientation-angle/.

Marsh, Jacob. "How Do Solar Cells Work? Photovoltaic Cells Explained: Energysage." *EnergySage Blog*, EnergySage, 8 Nov. 2022, https://news.energysage.com/how-solar-photovoltaic-cells-work/.

"Monocrystalline vs. Polycrystalline Solar Panels." *Unbound Solar*, 4 Dec. 2020, https://unboundsolar.com/blog/monocrystalline-vs-polycrystalline-solar-panels.

"Photovoltaic Effect." *Photovoltaic Effect - Energy Education*, https://energyeducation.ca/encyclopedia/Photovoltaic_effect.

PortableSolarExpert. “How Much Power Does a 350 Watt Solar Panel Produce?” *Portablesolarexpert.com*, 27 Aug. 2021, https://www.portablesolarexpert.com/how-much-power-does-a-350-watt-solar-panel-produce/.

“Q4 2021 PPA Price Index.” *LevelTen Energy*, https://www.leveltenenergy.com/post/q4-2021.

“Renewable Power Generation Costs in 2021.” *IRENA*, 1 July 2022, https://www.irena.org/Publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021.

SciToons. “How Do Solar Cells Work?” *YouTube*, YouTube, 30 Apr. 2018, https://www.youtube.com/watch?v=UJ8XW9AgUrw.

Solaralliance. “How Do Clouds, Rain & Snow Affect Solar Panel Output?” Solar Alliance, 13 Apr. 2022, https://www.solaralliance.com/how-do-clouds-affect-solar-panels/.

SunPower. “The Best Location for Solar Energy: Sunpower Solar Blog.” SunPower, SunPower, 26 May 2022, https://us.sunpower.com/blog/2022/05/26/best-location-solar-energy.

Sunrun. “Solar Array.” *Sunrun*, Sunrun, 28 Aug. 2019, https://www.sunrun.com/go-solar-center/solar-terms/definition/solar-array.

TEDEducation. “How Do Solar Panels Work? - Richard Komp.” YouTube, YouTube, 5 Jan. 2016, https://www.youtube.com/watch?v=xKxrkht7CpY&t=139s.

“Top 5 Solar Farm Land Requirements.” YSG Solar, 10 June 2021, https://www.ysgsolar.com/blog/top-5-solar-farm-land-requirements-ysg-solar.

“U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.”

Photovoltaics and Electricity - U.S. Energy Information Administration (EIA), https://www.eia.gov/energyexplained/solar/photovoltaics-and-electricity.php.

Williams, Gennareno. “Solar, Wind, or Hydro Energy - Which Renewable Is Right for You?” Purelight Power, 12 May 2022, https://purelightpower.com/blog/national/solar-wind-hydro-renewable-energy/.

Wilson, Kyle. “Solar Panel Size & Weight Guide.” Those Solar Guys, 5 July 2021, https://thosesolarguys.com/solar-panel-size/.