Solar District Cup

Project Sponsor:

U.S. Department of Energy

National Renewable Energy Laboratory

Faculty Advisor:

David Trevas

Mechanical Team:

Corey Burke, Grant Hale, Elizabeth Griffith, &
Daniel McConnell

Project Description: Review

What:

Design a photovoltaic solar energy and storage system for New Mexico State University that maximizes energy offset and financial savings over a 20 year time period [1].

How:

Assume the role of solar energy and storage developer to produce a proposal and analyze electric distribution grid interactions for district use [1].

Importance:

The U.S. is moving more towards renewable energy sources and solar is the most cost effective resource.

Designs Selected

Four designs were selected for use in the project

1. Dirt lots sized appropriately to consumption
2. Parking structure
3. Solar Awning in quad
4. Science Hall building

Designs Selected: Dirt Lot

Annual Production:
28,537MWh

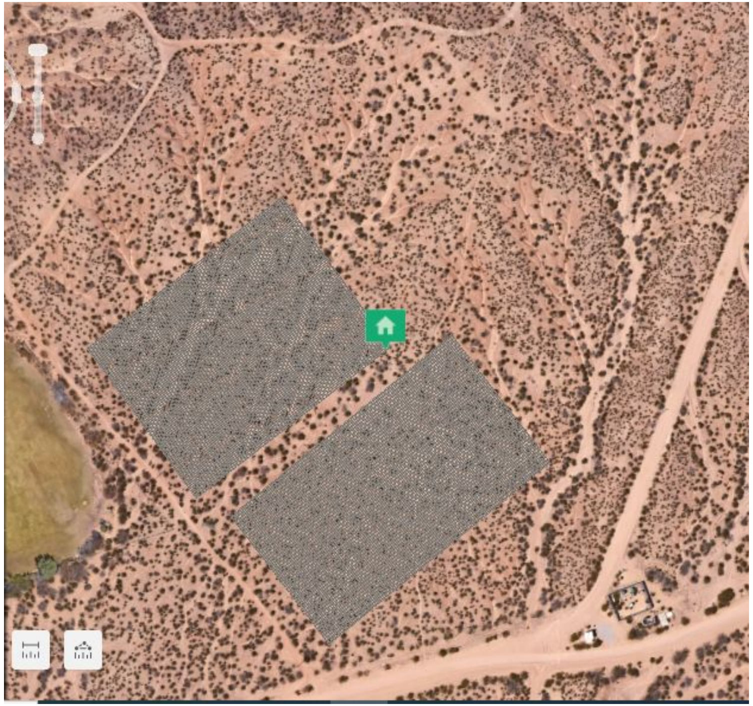


Figure 1: Dirt Lot Design

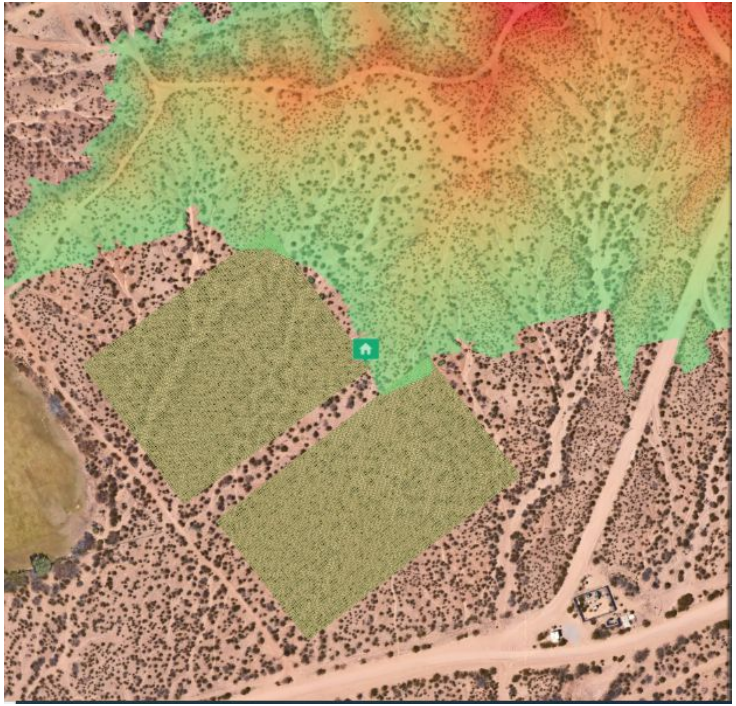


Figure 2: Dirt Lot Design with Lidar

Designs Selected: Parking Structure

Annual Production:
1,000,506KW

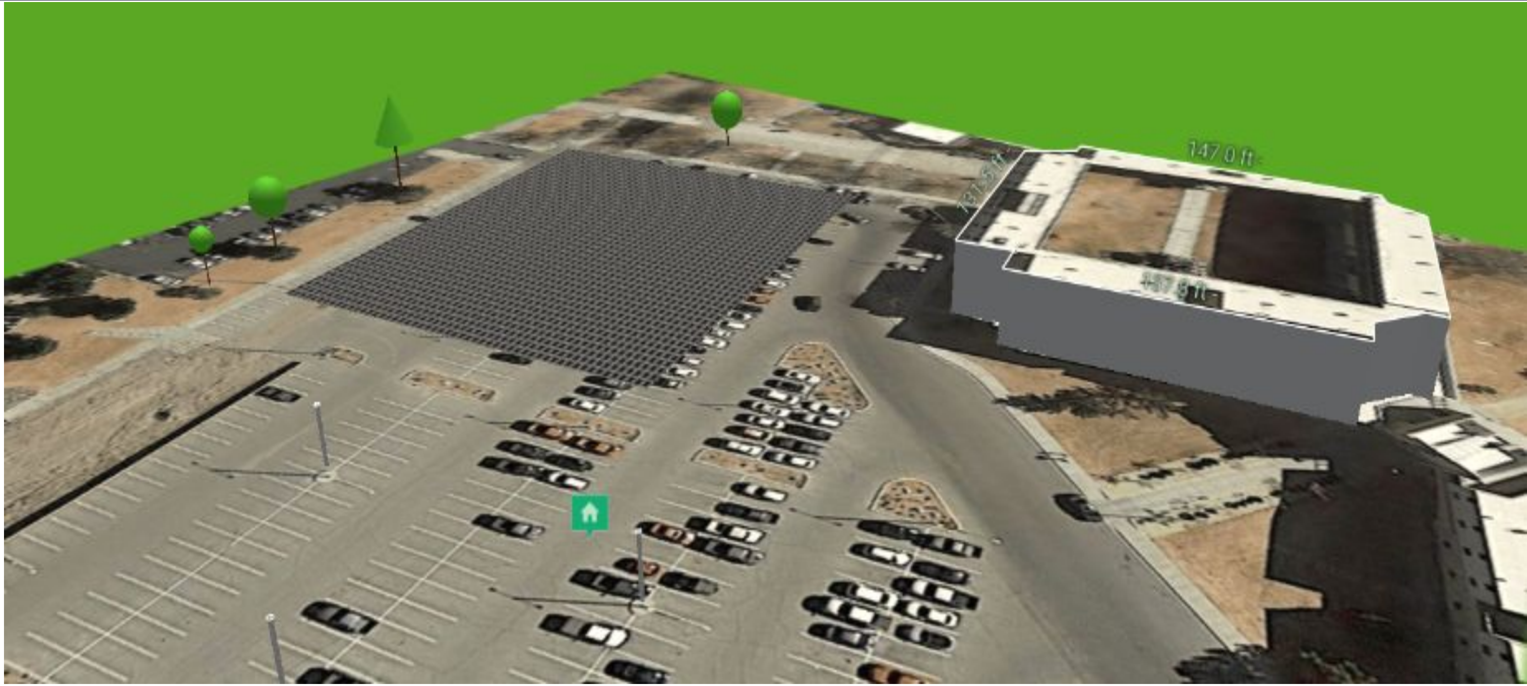


Figure 3: Student Union Parking Structure Design

Designs Selected: Science Hall

Annual Production:
709,565 KW

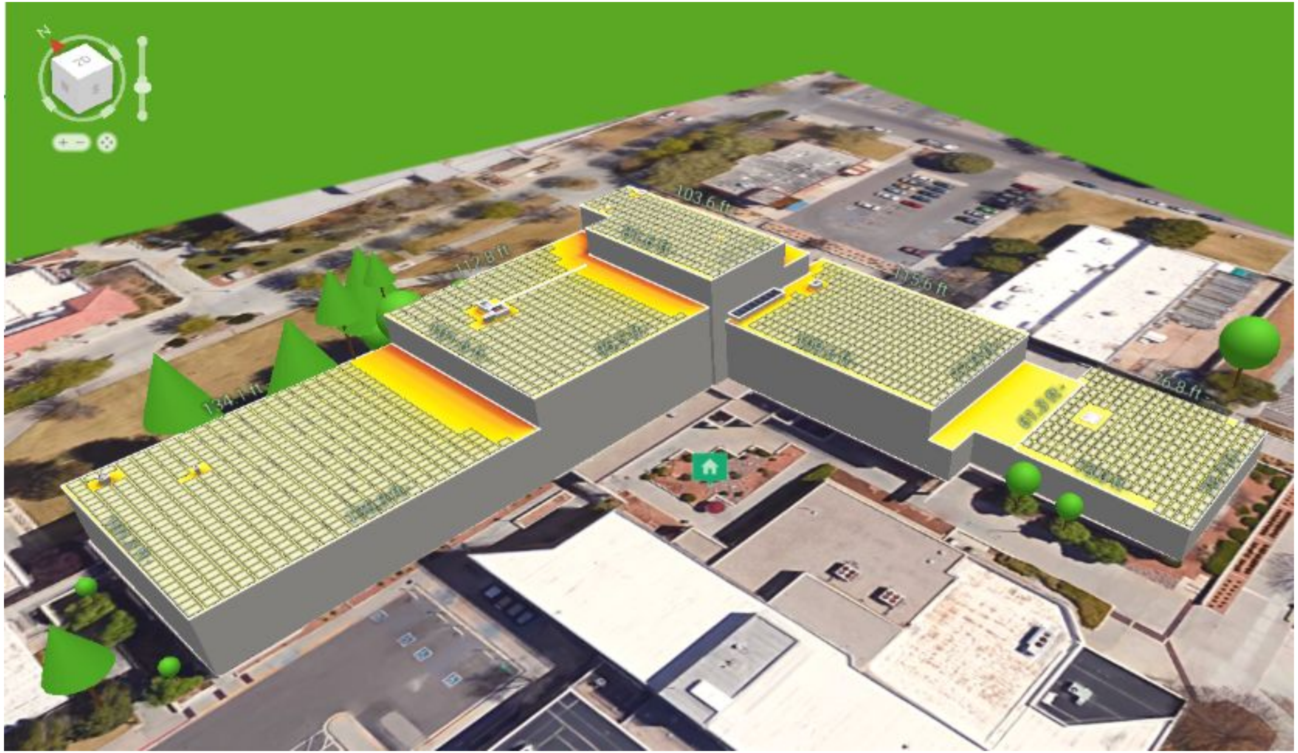


Figure 4: Science Hall Design

Designs Selected: Solar Awning

Annual Production:
250,878 KW

Figure 5: Solar Awning Design

Design Descriptions

- The dirt lot is a very large flat open area with enough space to power much of the campus
- The solar awning in the quad is not very practical, but one of the goals of the competition holders is to show their solar efforts
- The science building solar array provides power with minimal losses
- The parking structure both provides power with minimal losses and provides covered parking

Design Requirements

Requirements:

1. Implementing solar electric PV systems with average hourly energy production
   a. Dirt lot next to the Geothermal Substation [Figure 1]
   b. Student Union parking structure [Figure 3]
   c. Science Hall [Figure 4]
   d. Solar awning in the Horseshoe Quad [Figure 5]

2. Providing a power flow model (PDF) that includes
   a. Irradiance profiles [Figure 4]
   b. Electrical load profiles

Table 1: Progress Deliverable Package Content and Evaluation Sheet

Content	Evaluation Statement
1. Conceptual System Design	
A. Layout and specifications for the solar electric PV systems proposed within the district on one or more rooftops, parking lots, or ground areas [PDF].	A. Conceptual system design is complete and reasonable for PV system location and specifications.
B. Average hourly energy production output for each system over annual period [Excel spreadsheet].	B. Energy output is complete, based on a reasonable yield factor, and accounts for climatic variables.
2. Distribution System Impact Analysis	
A. Descriptive approach to power flow model [PDF], including: i. Irradiance profiles for the proposed PV systems ii. Load profiles for the connected buildings iii. Size of PV systems to comply with utility code iii. Control settings for the PV systems, capacitor banks, and voltage regulators.	A. Approach document provides clear explanation of input choices.
B. Power flow model [OpenDSS[1] input and output]: i. Demonstrating all network elements satisfy loading and voltage constraints ii. Demonstrating active elements have realistic settings, responses, and dead times.	B. Power flow model voltage analysis shows operation within expected bandwidth and with reasonable inputs.

Design Requirements

Requirements:

1. Creating a power purchase agreement (PPA) using local, state, and federal financial incentives to offset financial costs over a 20 year time period.

2. Applying all state and federal ordinances to ensure we comply with local codes and acquire the necessary permits for this project

Table 2: Progress Deliverable Package Content and Evaluation Sheet cont.

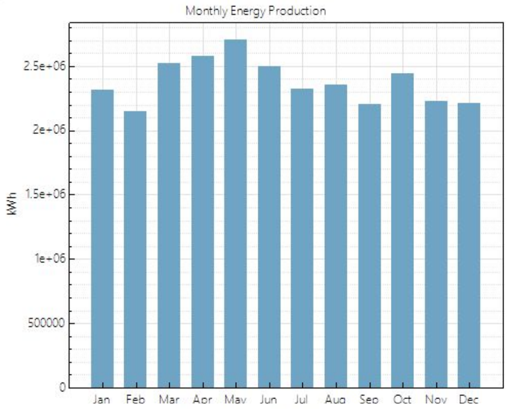
3. Financial Analysis	
A. A project financial model that uses the production data and other inputs to generate a PPA price for a 20-year term and that achieves a net present value of $0 [Excel spreadsheet].	A. Financial model has a complete set of reasonable inputs, models cash flows competently, and has a PPA price output that conforms to market benchmarks.
4. Development Plan	
A. Building and site plan for conceptual system design, including applicable local ordinances [PDF]. B. Construction plan to procure necessary permits and comply with local codes [PDF].	A. Building and site plan demonstrates compliance with district master plan, zoning, and other land use building restrictions. B. Development plan demonstrates compliance with permitting and relevant codes.

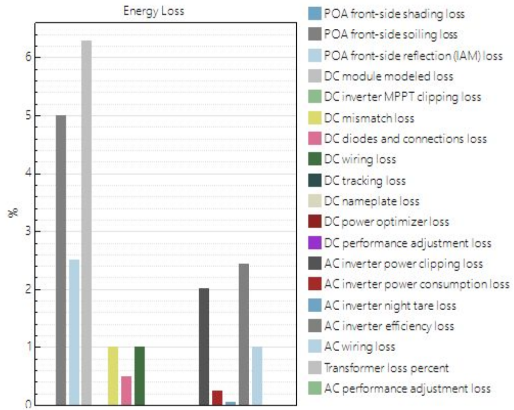
Design Validation: Dirt Lot

Seasonal Tilt Analysis

- Peak 2,540 MWh
- Annual 28,537MWh
- Energy losses minimized for system

Metric	Value
Annual energy (year 1)	28,537,544 kWh
Capacity factor (year 1)	23.3%
Energy yield (year 1)	2,038 kWh/kW
Performance ratio (year 1)	0.80
PPA price (year 1)	8.02 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	8.51 ¢/kWh
Levelized PPA price (real)	5.91 ¢/kWh
Levelized COE (nominal)	8.59 ¢/kWh
Levelized COE (real)	5.96 ¢/kWh
Net present value	$-165,894
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	20
IRR at end of project	11.00 %
Net capital cost	$26,100,462
Equity	$11,181,033
Size of debt	$14,919,429





Solar Tracking Analysis

- Peak 3,900 MWh
- Annual 38,416 MWh

Metric	Value
Annual energy (year 1)	38,416,496 kWh
Capacity factor (year 1)	31.3%
Energy yield (year 1)	2,744 kWh/kW
Performance ratio (year 1)	0.79
PPA price (year 1)	5.96 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	6.32 ¢/kWh
Levelized PPA price (real)	4.39 ¢/kWh
Levelized COE (nominal)	6.38 ¢/kWh
Levelized COE (real)	4.43 ¢/kWh
Net present value	$-165,894
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	20
IRR at end of project	11.00 %
Net capital cost	$26,100,462
Equity	$11,181,033
Size of debt	$14,919,429

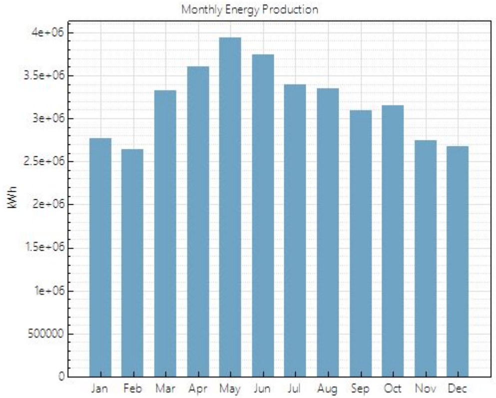


Figure 6: Energy Loss and Production

Design Validation: Analytical Budget

Dirt Lot

- No construction cost
- No solar tracking cost
- $/Wdc for Utility rate [6]

Direct Capital Costs

Module	45,144	units	0.3	kWdc/unit	14,001.4	kWdc	1.11	$/Wdc	$ 15,541,518.00
Inverter	15	units	770.0	kWac/unit	11,550.0	kWac	0.06	$/Wdc	$ 840,082.00
				Battery pack	0.0	kWh	0.00	$/kWh dc	
				Battery power	0.0	kW	0.00	$/kW dc	$ 0.00

	$		$/Wdc		$/m²		
Balance of system equipment	0.00		0.20		0.00		$ 2,800,273.50
Installation labor	0.00	+	0.13	+	0.00	=	$ 1,820,177.63
Installer margin and overhead	0.00		0.06		0.00		$ 840,082.00
						Subtotal	$ 21,842,134.00

Contingency

Contingency	3	% of subtotal	$ 655,264.00
		Total direct cost	$ 22,497,398.00

Figure 7: Total Direct Cost and Bill of Materials

Design Validation: Financial Savings

- Average yearly electricity bill $1,704,253
- 20 year electricity cost $34,085,060
- Dirt Lot Cost $22,497,398
- Total savings over 20 years $11,587,662

Table 3: Financial Analysis of Dirt Lot

20 Year Cost without Solar	$34,085,060
Cost to Construct Dirt Lot Solar Field	$22,497,398
Net Savings	$11,587,662

Physical Budget

Available Dollars: $0

Anticipated Expenses: $4095 + taxes

- Travel
  - **Driving**
    - Flagstaff, Az to Phoenix, Az $50
    - Phoenix, Az to Flagstaff, Az $50
  - **Flights**
    - Phoenix, Az to Atlanta, Ga
      - 8 Tickets @ $365 each + taxes
  - **Hotel**
    - Atlanta, GA
      - 2 Nights, 4 Rooms @ $1000 total

Expenses to Date: $0

Resulting Balance: $0

Schedule: Remainder of Fall Semester

- Implement net metering and state/Federal benefits
- Complete competition deliverables Nov 21st
- More accurate utility bill of campus
- Accurate construction cost
- Cost of leveling dirt lot
- Cost Analysis for solar tracking dirt lot
- Optimize system using cents/kWh

Failure Modes and Effects Analysis

Table 4 : FMEA

Item/Function	Requirements	Potential Failure Mode	Potential Effects of Failure	Potential Causes	Current Design Preventions	Current Design Detections	Recommended Action
Solar Panel	Convert solar radiation to usable energy	Over-heating	Degridation of panel efficiency	High heat from building and sun	Using monocrystalline panels and avoiding locations with AC vents	NONE	Add a heat sensor on the panels to monitor the heat of the panel and potentially send someone out to reduce the heat of the panel
Inverter	Convert energy from DC to AC	Over-heating	Degridation of inverter efficiency	Long run time and heat from other sources	Scheduled down times	NONE	Add a heat sensor on the inverters to monitor the heat of the inverters and potentially increase down time to reduce heat
Roof	Support solar panels	Breaking of beams	Destruction of building and potential harm to people in building	Too much load on the roof from solar panels	Avoid old buildings	NA	Use custom lightweight materials on roofs and put inverters inside, not on the roof.

Schedule: Spring Semester

Work is broken down based on each team members individual skills

- Corey - SAM
- Daniel - Aurora Solar
- Elizabeth - Website
- Grant - Finances

Key Tasks:

1. Hardware Review
2. Final Deliverable Package
3. UGRADS

Current Status: On Schedule

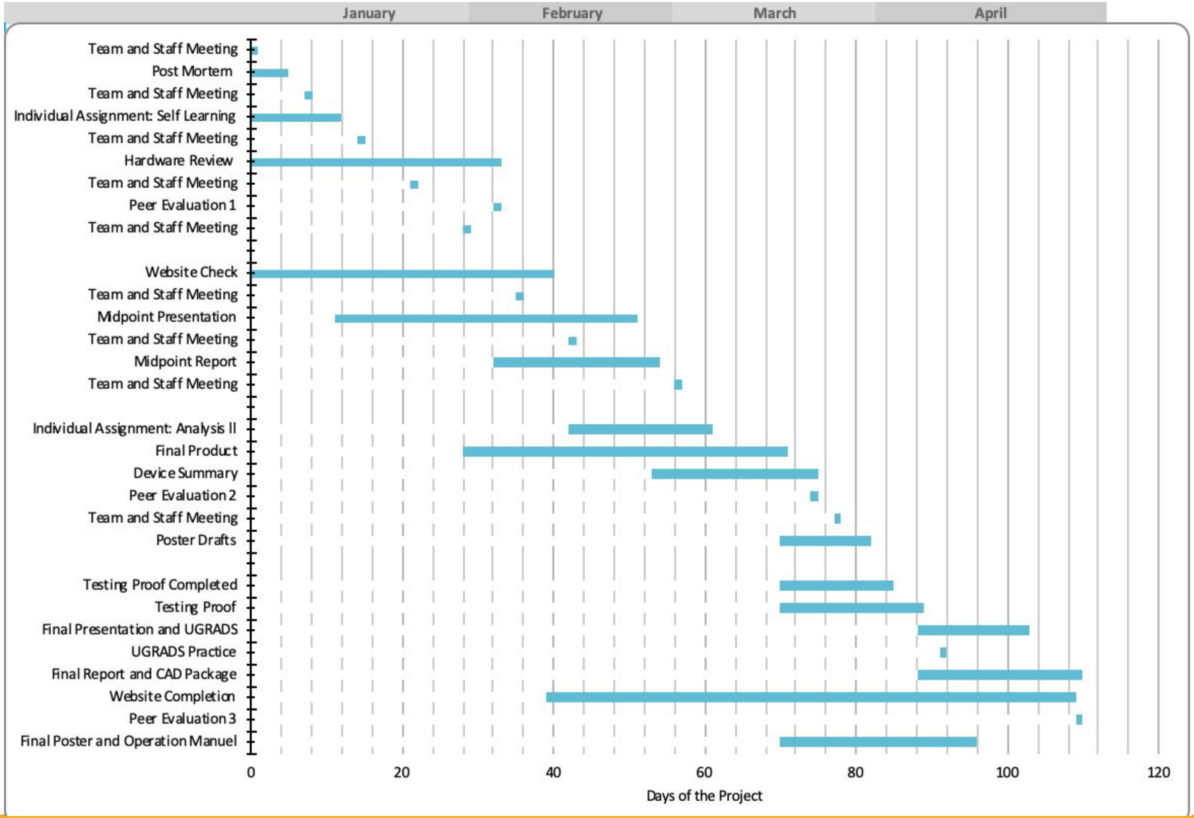


Figure 8: Spring 2020 Gantt Chart

Works Cited

[1] Herox, “Solar District Cup,” HeroX, 2019. [Online]. Available: httpss://www.herox.com/SolarDistrictCup. [Accessed 13 09 2019].
[2] GroupNIRE, “DOE-LOGO,” GroupNire, 2017. [Online]. Available: https;//groupnire.com/home/doe-logo-white/.[Accessed 17 September 19].
[3] NREL, “About NREL,” NREL, 2018. [Online]. Available:https://www.nrel.gov/about/. [Accessed 17 September 2019].
[4] National Renewable Energy Laboratory, “System Advisor Model,” National Renewable Energy Laboratory, 2019. [Online]. Available: https://sam.nrel.gov/. [Accessed 16 September 2019].
[5] C. Morris, “Tesla Energy:Here’s Why Grid Storage Will Be Huge - On Both Sides of the Meter,” Evannex, 29 August 2017. [Online]. Available: https://evannex.com/blog/news/why-grid-storage-will-be-huge-on-both-sides-of-the-meter. [Accessed 10 October 2019].
[6] National Renewable Energy Laboratory, “U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018” 2018.[Online] Available: https://www.nrel.gov/docs/fy19osti/72133.pdf

Questions?