EMI Energy Source Analysis

Professional Development Course

designing a world of hope

Presenter:

Hannah Peterson, P.E.

2019 **EMI Conference**

October 2019

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Course Description:
EMI Energy Source Analysis

Client's are increasingly interested in EMI's guidance regarding alternatives to grid-supplied electrical power.

This course will equip the designer with a basic knowledge of energy options and provide the knowledge and resources to select the appropriate solution for a given application.

Learning Objectives

At the completion of this course, participants should be able to:

L.O. 1: identify the components and function of commonly used energy systems.

L.O. 2: compare the advantages and limitations of each energy system for a given scenario.

L.O. 3: analyze available energy solutions using the EMI energy alternatives cost analysis tool.

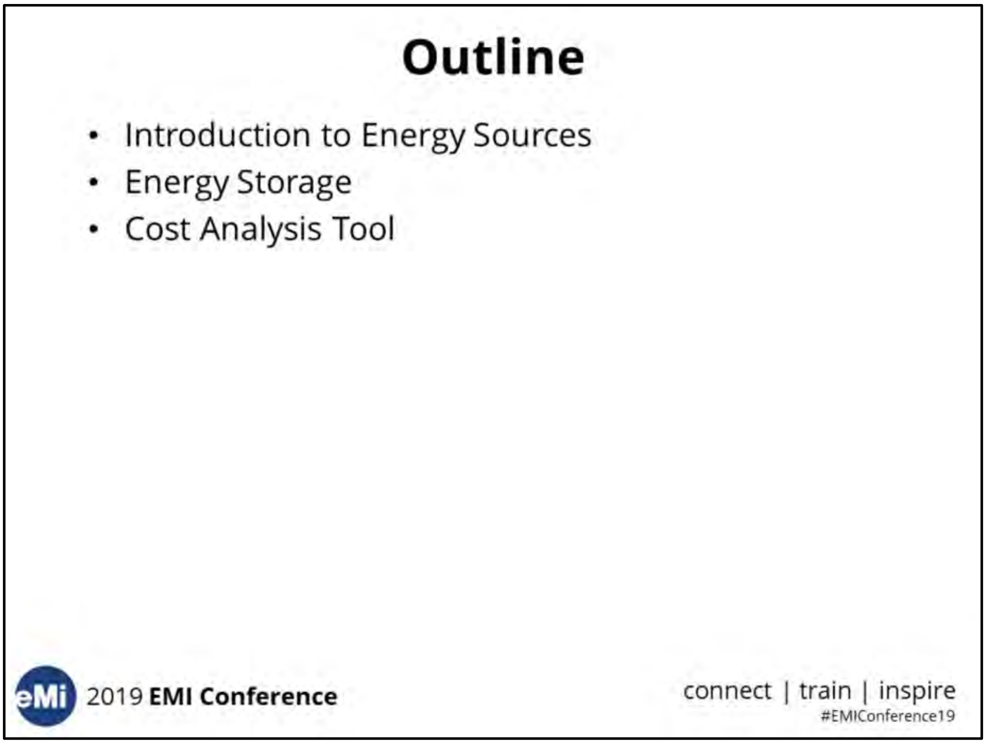
L.O. 4: make design recommendations on which components should be included and their sizing.

Introductions

Presenter: Hannah Peterson, PE

Before EMI:
- Solar Power [Fronius, Nusun]
- Diesel Generators [Cummins]
- Data Acquisitions [US Air Force]

EMI
- 5 years
- Associate Staff, Electrical Engineer



Other options include:

Solar (thermal)

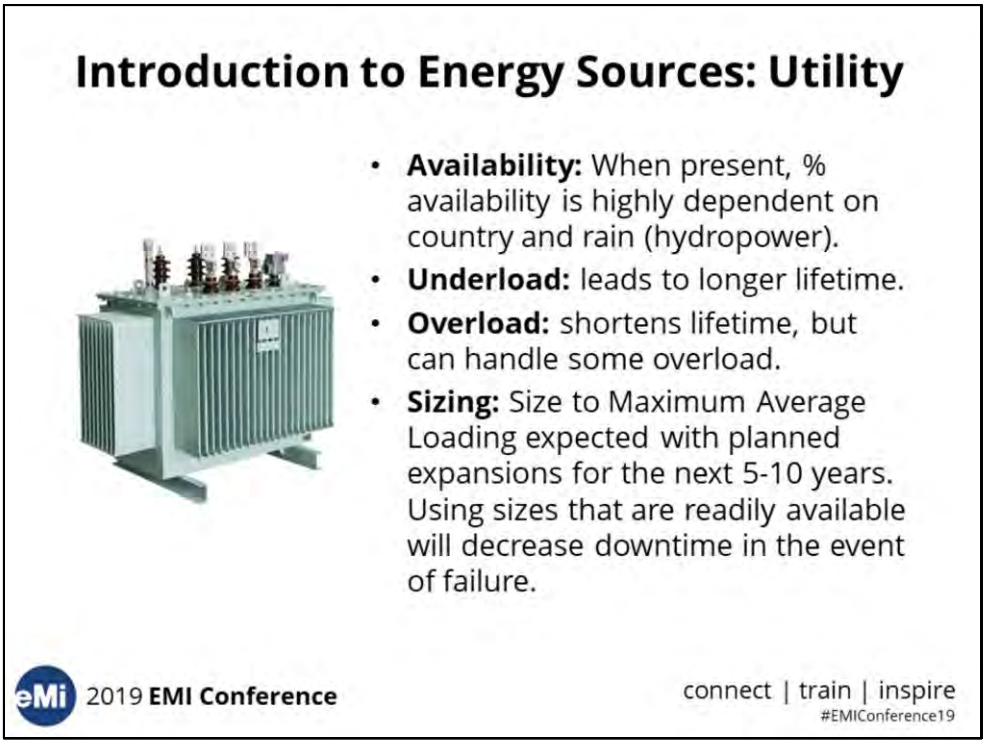
Geothermal

…

These are beyond the scope of this course.

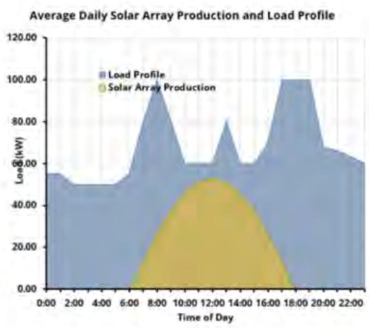
Introduction to Energy Sources: Utility

- **Price:** Highly dependent on the country based on sources and subsidies.
  - $0.03/kWh (Zambia)
  - $0.35/kWh (Haiti)
- **Voltage:**
  - In our context almost 100% Wye output on low voltage side and often in the 400/230V range.
  - should be +-5% nominal at transformer, but have seen +-10%.



Using sizes that are readily available may mean putting in two transformers in the place of where one used to be and perhaps locating the second one in a differnet region to decrease wire size required to keep voltage drop down.

Introduction to Energy Sources: Utility



- **Paralleling:**
  - The utility will always be the grid-former
  - Other sources can be paralleled without feeding power back to the grid.
  - What sources do we parallel to the utility in our context?
    - Diesel Generator- No
    - Solar- Yes
    - Batteries - Yes

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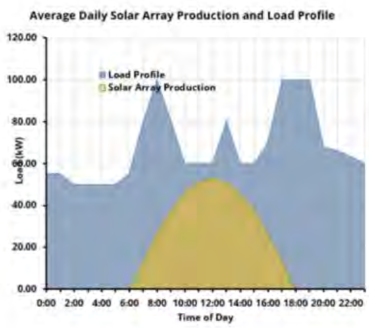
Diesel power is very expensive so it never makes sense to parallel it with the grid in our context. This is only done in on demand peak shaving where the utility can call you at any time and tell you how much power to push to grid and they pay a much higher rate to you for that power. It could be done, but we have not found any customers interested in being on-demand peak shaving plants thus far… doesn't mean it couldn't' happen in the future.

Introduction to Energy Sources: Utility



- Feeding power back to the utility:
  - Net-Metering (usually best $)
  - Feed-in Tariff
  - $0, no payment OR No export allowed – configure to zero export

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Explain differences between net-metering, feed-in tarrif, and $0.

Net-metering means they keep track of your net usage, usually zeroing out each year. So if you produce more than you are using during day hours they subtract that # of kWh from your bill. This is best financial situation in most cases, because you effectively get paid for power you feed into grid the same amount as the $ you pay for power you take from the grid.

Feed-In tariffs are often worse as they pay you some lower rate for all the power you feed back into the grid and charge you more for power you take from the grid.

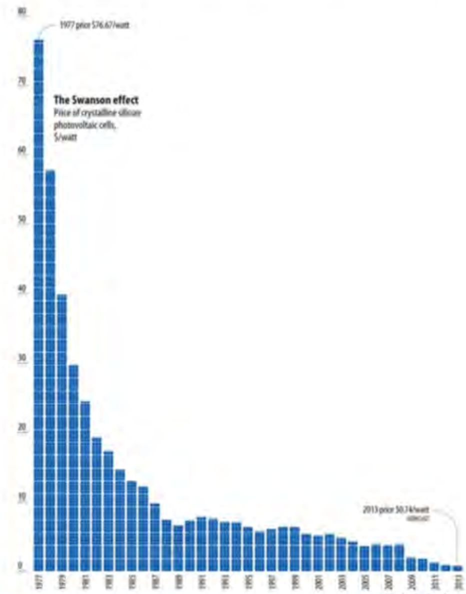
$0 means they pay you nothing for the extra power you send to them, but they allow you to feed power back onto the grid.

Introduction to Energy Sources: Solar

- **Price:** Price/kW module and inverters is similar around the world. $/kWh will change by insolation at location. $0.02-$0.06/kWh at 10 years common.
- **Voltage:**
  - DC module operating voltage: 30-38V
  - DC voltage of strings: 600V or 1000V max.
  - Inverter AC voltage, excellent power quality.

Introduction to Energy Sources: Solar

Price of PV
$/Watt vs Year
From 1977
to 2013



Introduction to Energy Sources: Solar

- **Availability:** When sun is present. When source it is paralleling to is present.
- **Underload:** In general no negative impact of under loading in modern systems other than financial waste. Solar can be curtailed by controller.
- **Overload:** Solar inverters and battery inverters will have a maximum rating. This can curtail the solar module output OR if the only source lead to a power outage.
- **Sizing:** Many options: zero export, net-zero utility usage, 100% solar/battery... use cost analysis tool.

Introduction to Energy Sources: Solar

- **Paralleling:** Solar will always be the grid follower. In nearly all our applications solar is paralleling with some other source.
  - Utility
  - Battery System (AC Coupled)
  - Diesel Generator

Introduction to Energy Sources: Solar

- Solar power modules

Photovoltaic = PV = Solar Power ≠ Solar Thermal

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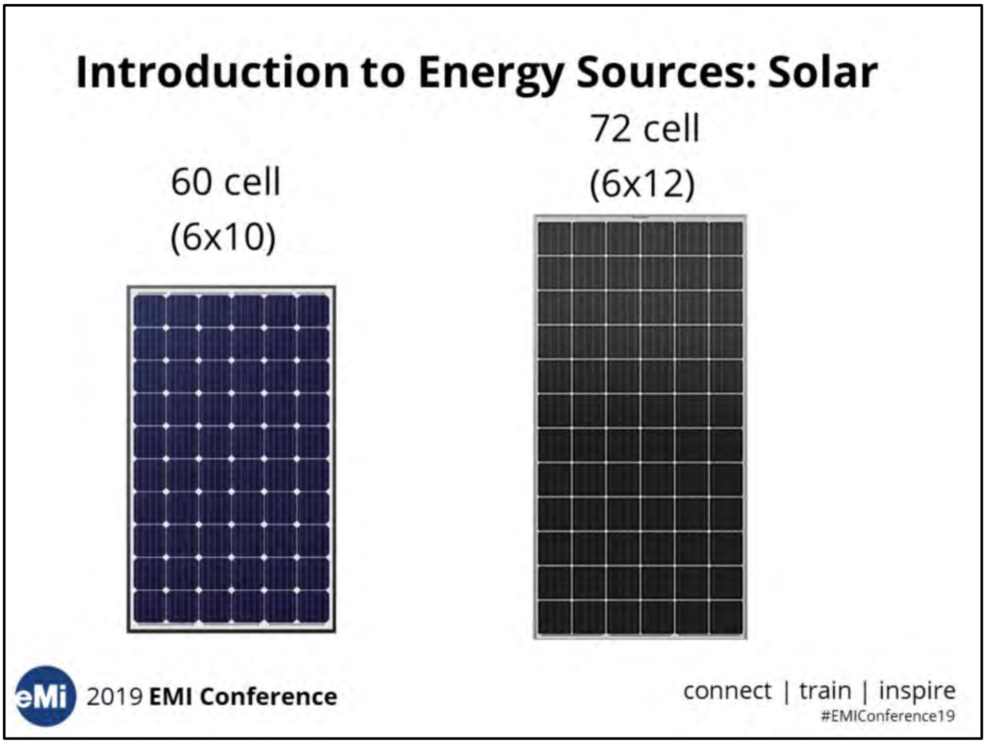
A lot of different shapes, sizes, and colors.

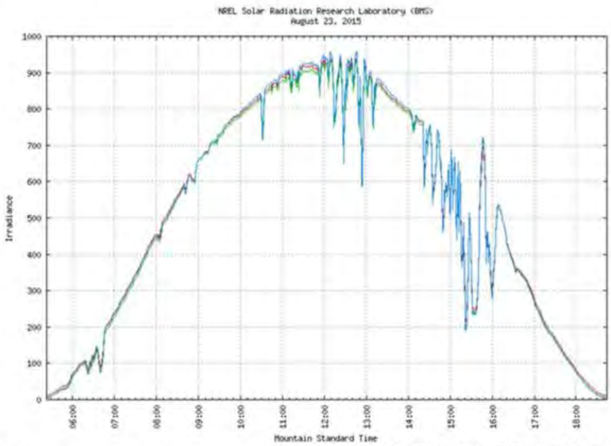


Standard sizes are 60 cell and 72 cell modules.

Introduction to Energy Sources: Solar

- How do we measure solar energy?

- Solar irradiance W/m²
- Irradiation (insolation) Wh/m^2, integral or area under the curve



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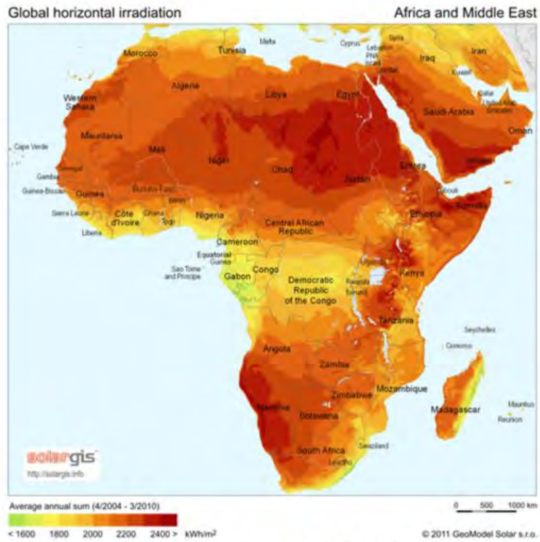
Jagged sections are times with some cloud or other partial shading. Notice the shape of the curve. This is the same shape the output of the solar power will be. Notice the time range: about 6am to 6pm. The majority of the solar power occurs between 8am and 4pm. So it is particularly important to avoid any shading during these hours.

Introduction to Energy Sources: Solar

- Peak sun hours or sun hours:

$$\frac{Insolation}{1000}$$

$$\text{units} = \text{hours} = \frac{Wh/m\text{^}2}{W/m\text{^}2}$$



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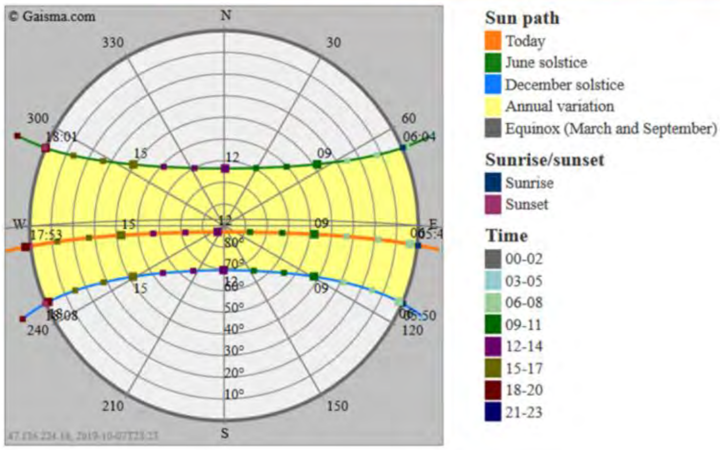
Map of average annual insolation

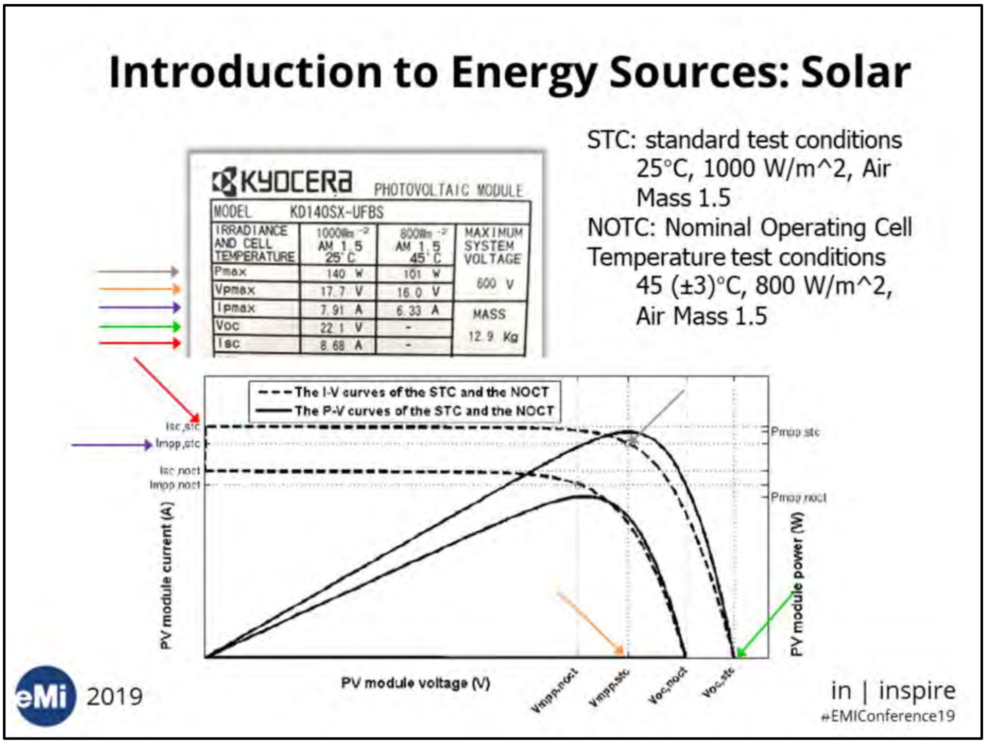
Introduction to Energy Sources: Solar

GAISMA

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m²/day	4.68	4.98	4.78	4.56	4.42	4.76	5.25	5.26	5.16	4.66	4.36	4.50



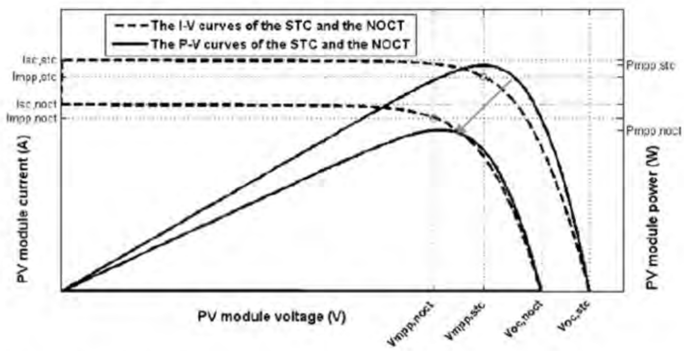
Use worst case month if 100% solar with battery system. Average if utility interactive. Sun path is used for shading analysis, determining interrow spacing required, space from nearby building etc to avoid shade between 8am and 4pm at least.



Part of a typical solar module label and a graph showing where these values come from. By changing the load applied the voltage is controlled and swept across the range: 0V to open circuit voltage. (Use slide animation as explain the following) Notice where Isc: short circuit current, at V= 0 and Voc : open circuit voltage, at I=0 fall on the curve. Also notice where the power output is maximum. This is called the “maximum power point”. Inverters used to convert the DC power from a solar array into AC power constantly operate the total array at this point using “MPPT” or maximum power point tracking software. The power output shifts based on temperature and irradiance. Irradiance impacts current. Temperature impacts voltage.

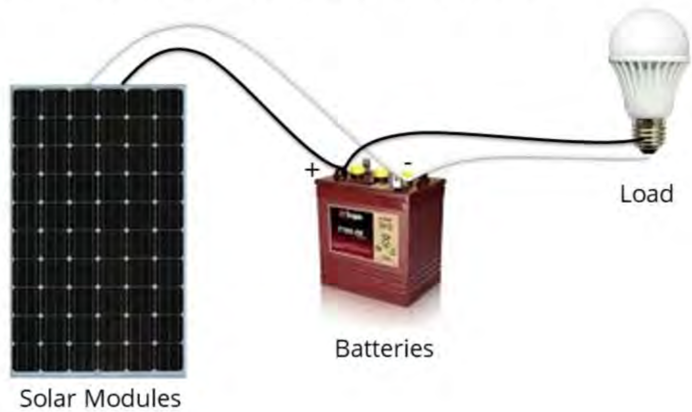
Introduction to Energy Sources: Solar

- Site load ≠ Solar array rating [It isn't that simple.]



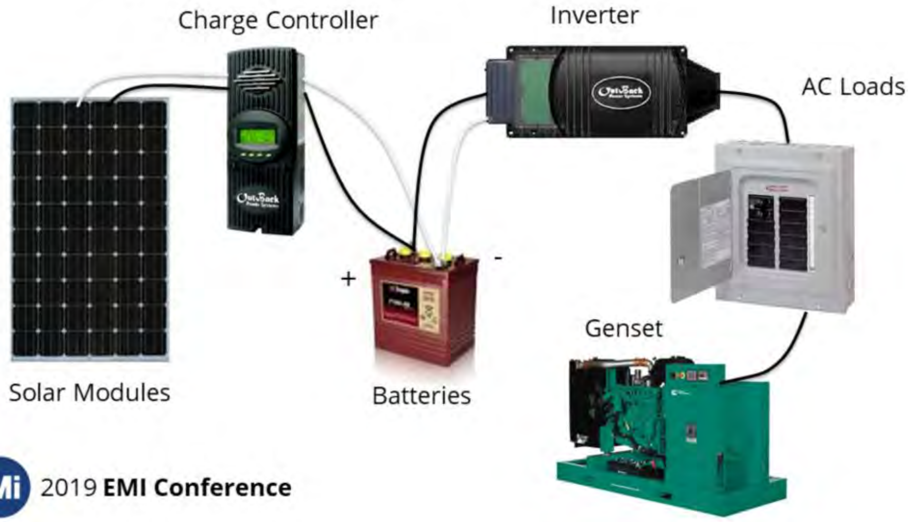
Introduction to Energy Sources: Solar
Types of Solar Systems

- Off-Grid, Self Regulating Systems



Introduction to Energy Sources: Solar
Types of Solar Systems

- Off-Grid, Stand-Alone



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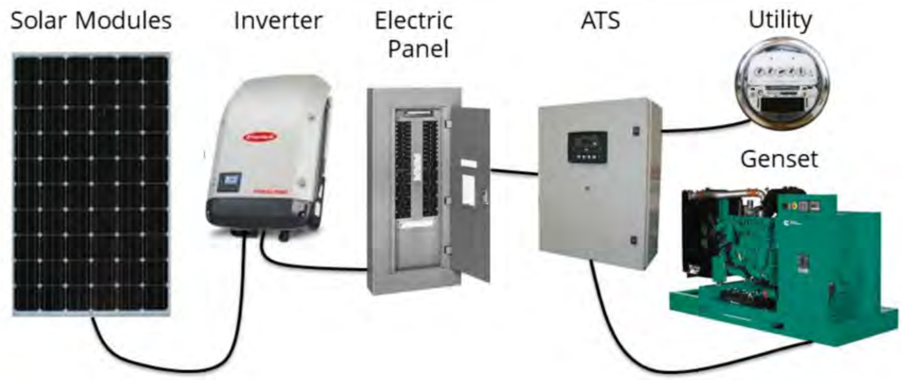
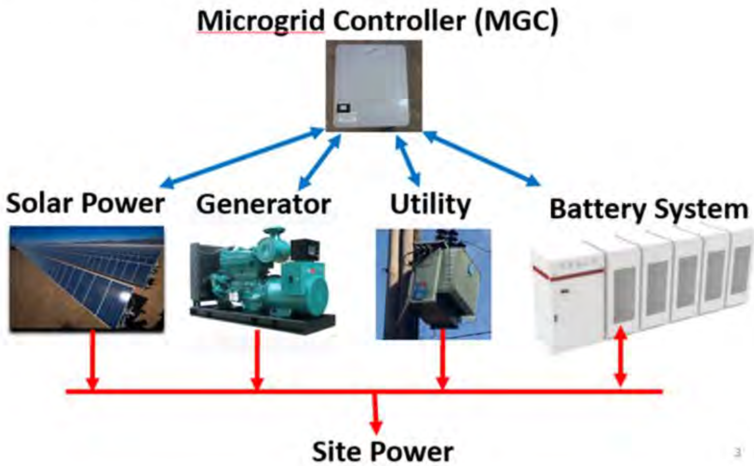
Introduction to Energy Sources: Solar
Types of Solar Systems

- Utility-Interactive and/or Genset Interactive



Introduction to Energy Sources: Solar
Types of Solar Systems



Introduction to Energy Sources: Diesel Generators

- **Price:** Global Average is $3.82/gallon which is $0.28/kWh
- **Voltage:** Will suffer if large load steps as % of rating. Keep load steps below 50% of the total rating if possible. Recommend G3 ISO 8528 for best voltage: steady state of +-1% and +-15% during large load step.

GlobalPetrolPrices.com

Introduction to Energy Sources: Diesel Generators

- **Availability:** 100% availability as long as there is diesel fuel
- **Underload:** If below 30% of rating will cause damage to the generator called wet stacking.
- **Overload:** If using prime rating there will be a buffer of 10% extra, but if you exceed that the generator will trip off or stop running. Note that generator may not be able to accept full 100% in single step from start up. In cases where run near its rating apply in two steps.

Introduction to Energy Sources: Diesel Generators

- Genset Wet Stacking
  - If caught before this stage may be reversible

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This was a genset that had to be run at low loads due to necessity from a main electrical buss failure.

Introduction to Energy Sources: Diesel Generators

- Genset Wet Stacking
  - Unburned fuel comes out of the combustion chamber
  - Results:
    - Fouled injectors
    - Buildup on exhaust valves, turbo charger, and exhaust
    - Loss of engine performance
    - Premature engine wear due to degraded oil seals

Introduction to Energy Sources: Diesel Generators

- **Sizing:** kVA rating should not be larger than (Current Average Load)/(0.30) to avoid wet stacking. If the above rule allows, the generator should be sized to maximum expected load after growth or (calculated max average) *1.25.
  - Use Prime rating if operating for over 500 hours a year (If using prime rating there is a 10% buffer for short duration loads)
  - Use Standby rating if operating less than 500 hours a year
  - Emergency Standby rating only if less than 200 hours a year

Introduction to Energy Sources: Diesel Generators

- **Paralleling:**
  - **To each other:** Preference is to split the system instead of paralleling generators to minimize controls complexity, but can be done.
  - **To solar:** Generator is the grid-former. Must have controller to ensure generator maintains 30% load to avoid wet stacking.
  - **To utility:** Diesel is most expensive source of power so only makes financial sense for on demand peak shaving plants contracted by utility. Has never applied to an EMI project.
  - **To battery system:** Diesel is most expensive source of power so only done in rare cases.

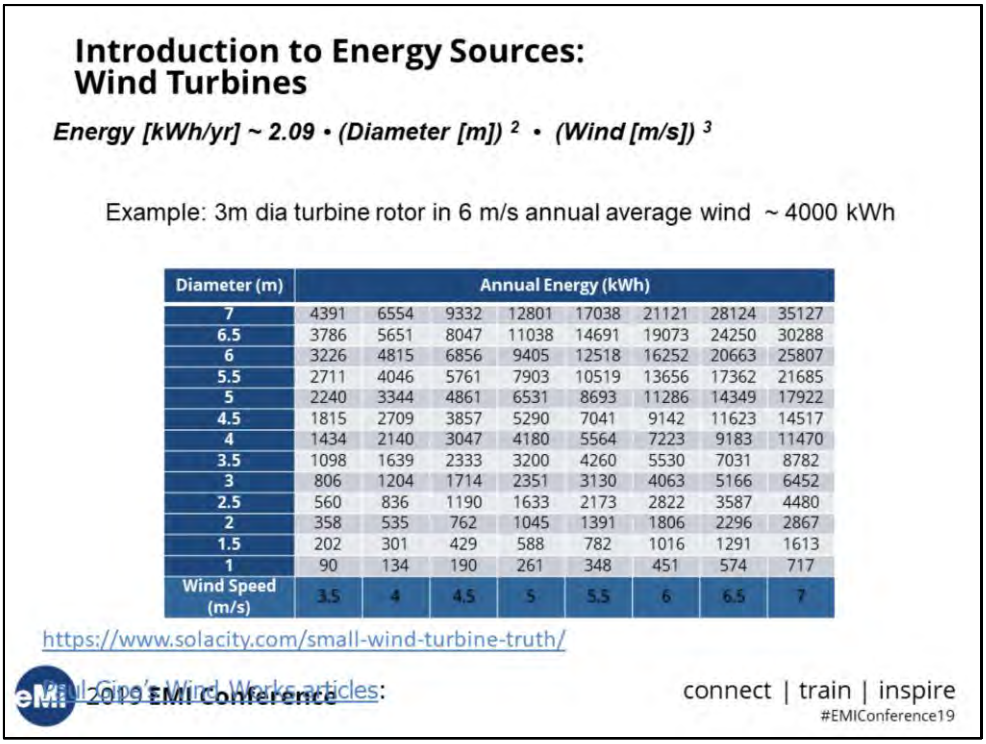
Introduction to Energy Sources: Other types of Generators

- In our context diesel generators are often the only feasible and affordable option.
- If you find yourself in a country or site where natural gas is readily available and inexpensive feel free to consider it.

- In our context diesel generators are often the only feasible and affordable option.
- If you find yourself in a country or site where natural gas is readily available and inexpensive feel free to consider it.

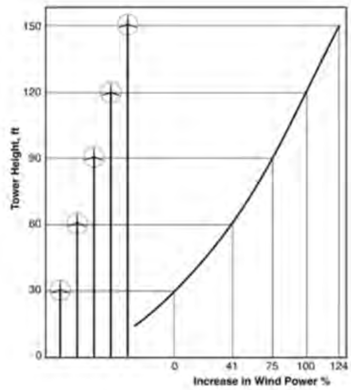
Introduction to Energy Sources: Wind Turbines

Small wind doesn't make sense financially. Large wind is at $0.03-0.06/kWh so is an inexpensive source of power, but is typically outside of the scope of feasibility in our context.



The equation uses a Weibull wind distribution with a factor of K=2, which is about right for inland sites. An overall efficiency of the turbine, from wind to electrical grid, of 30% is used. That is a reasonable, real-world efficiency number. Here is a table that shows how average annual wind speed, turbine size, and annual energy production relate:

Introduction to Energy Sources: Wind Turbines



Class 3 winds (average annual speed of ~15 mph at 50m) **minimum** to make *economic* sense on large wind commercial projects. (Ref: U.S. DOE, NREL 2011 "Wind Data Details.")

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For off-grid battery charging wind turbines you should deduct 20 – 30% of the predicted numbers, due to the lower efficiency of a turbine tied to batteries, and the losses involved in charging batteries.

Introduction to Energy Sources: Hydro Power

Large hydro averages $0.05/kWh so it is an inexpensive source, but it is outside of our scope and feasability. Mini Hydro can be in the $0.10-0.25 range. It is rare that we come across a site where small hydropower makes sense from a financial and maintenance perspective.

Energy Storage

- Must be Deep Cycle Batteries
- Most common deep cycle battery types:
  - Lithium Ion
  - AGMs (default) a type of valve regulated lead acid (VRLA)
  - Fluid filled lead acid
- We do not recommend fluid filled lead acid due to higher maintenance requirements.

Energy Storage

- Default is Lithium Ion as their total cost/kWh for their lifetime is generally lower than other options. (Price is based on Tesla Powerpack System that includes battery charger and inverter)
- Prices will vary based on manufacturer. Get a quote if possible for the system type you are considering

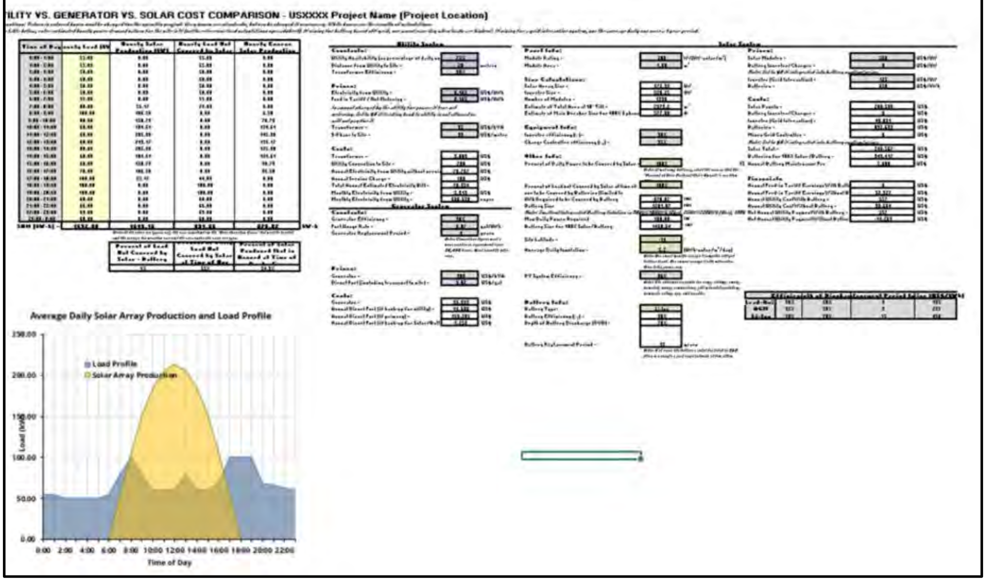
Battery Type	$/kWh Rating	DOD	Lifetime	$/kWh over lifetime
Lithium Ion	650	70%	15 yrs	$0.17
AGM	225	50%	3 yrs	$0.43
Lead Acid	135	50%	3 yrs	$0.27

ENERGY SOURCE COST ANALYSIS TOOL

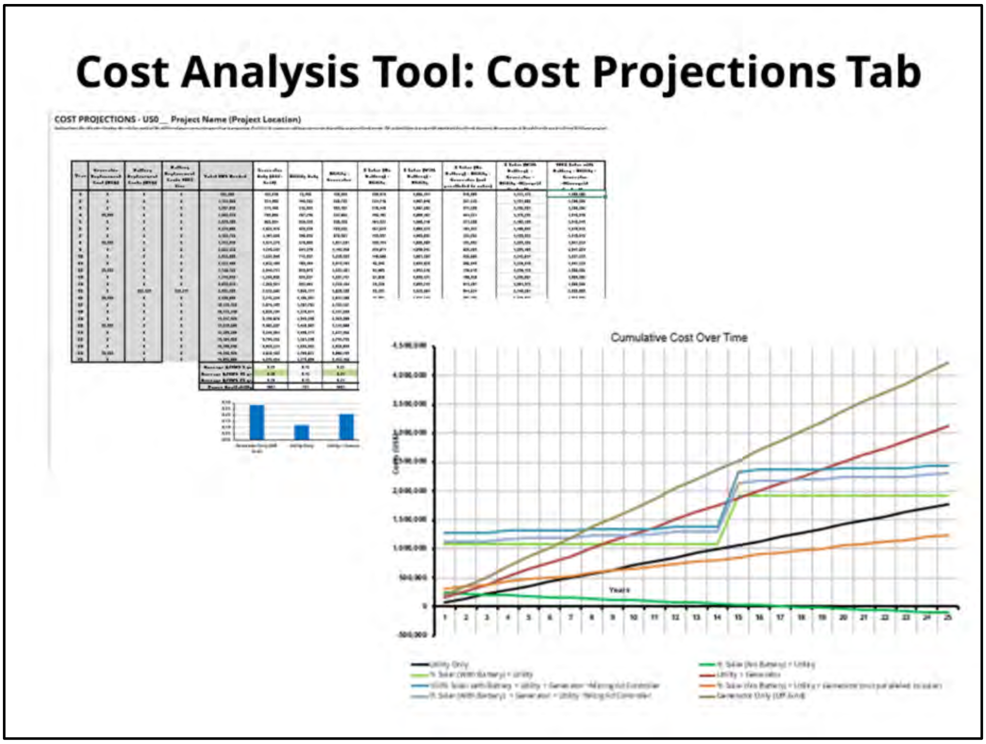
Energy Source Cost Analysis Tool

- 4 Tabs/Worksheets
  - Instructions
  - Input
  - Cost Projections
  - Solar Insolation Curves

Cost Analysis Tool: Input Tab

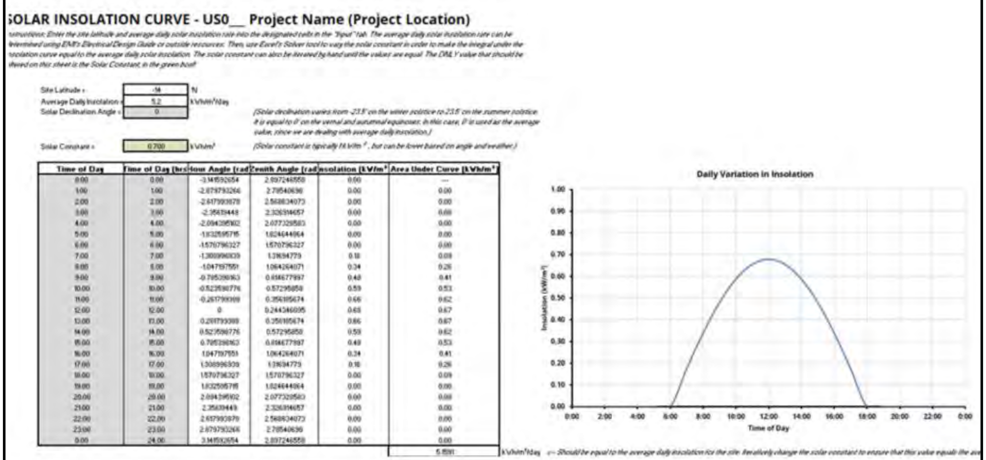


Where we input known information, adjust % solar and % battery, and have a graphical view of solar output versus load.

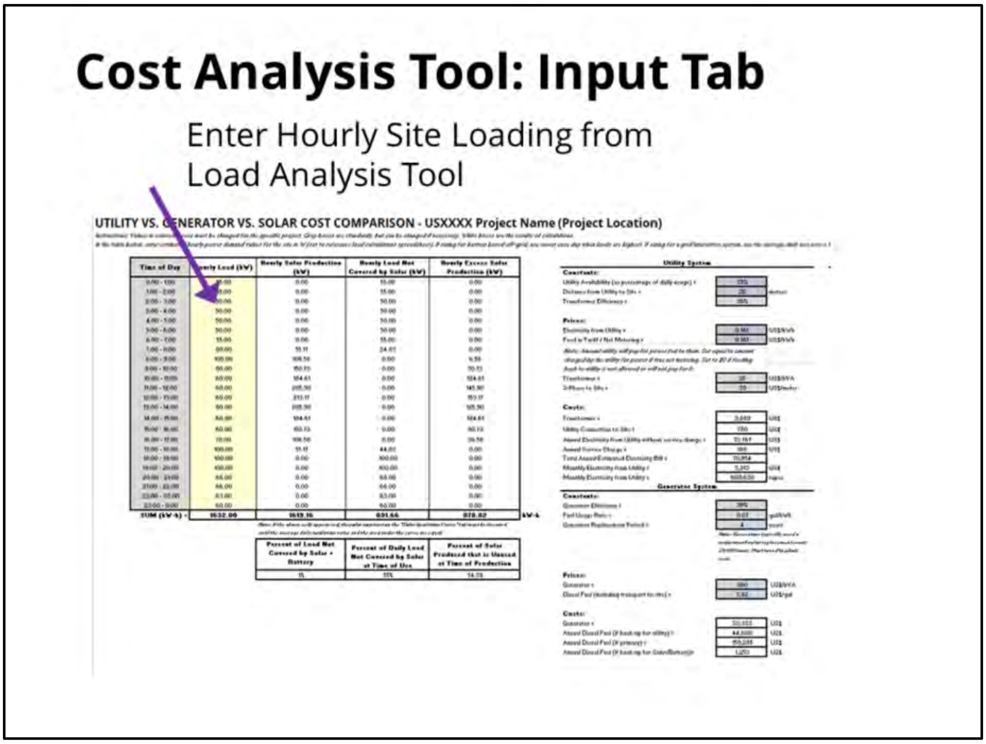


Shows us cost projections for various common combinations of utility, generator, solar, and battery

Cost Analysis Tool: Solar Insolation Curve Tab



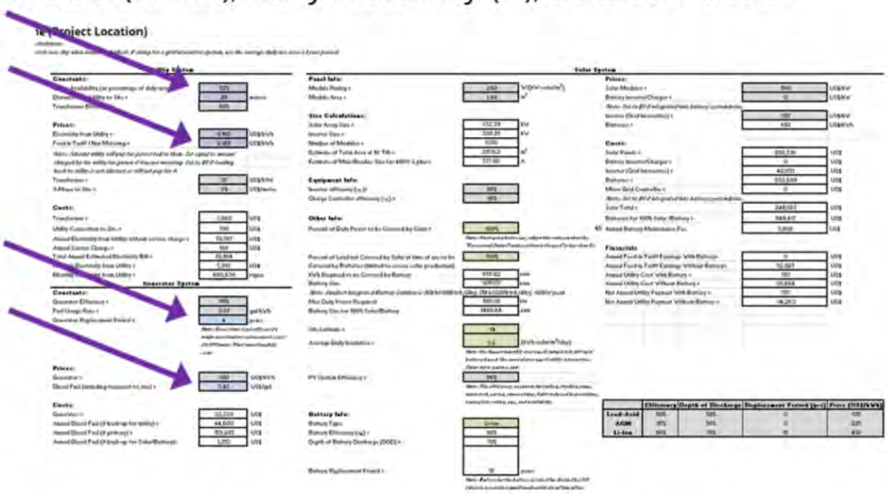
Generates the average daily solar energy (kW/m^2) versus time based on latitude and average daily insolation entered on input sheet as well as solar constant on this sheet. Used for estimating solar power output (W)



For existing sites these will be based on (max average real load data)*1.25 plus expected expansion and new loads.

Cost Analysis Tool: Input Tab

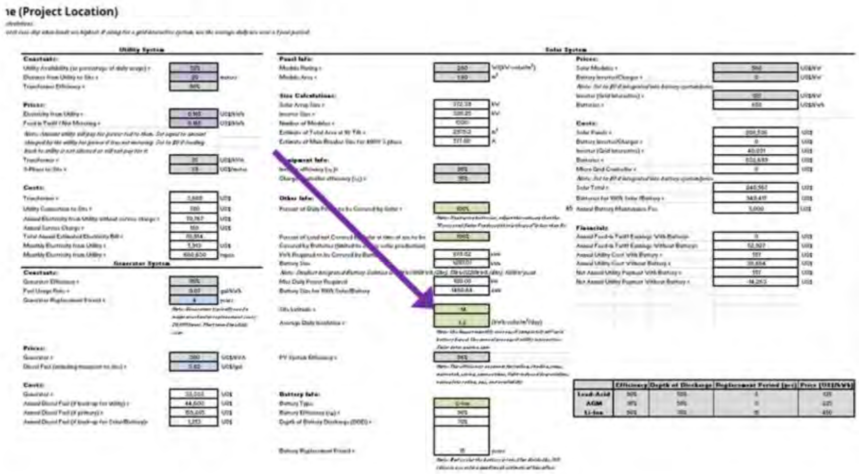
Enter the knowns (colored cells):
costs for diesel fuel ($USD/Gallon), utility power ($/kWh), feed-in tariff ($/kWh), Utility Availability (%), Generator lifetime



Generator lifetime = 20,000/ (hours run per year). Round to nearest whole year.

Cost Analysis Tool: Input Tab

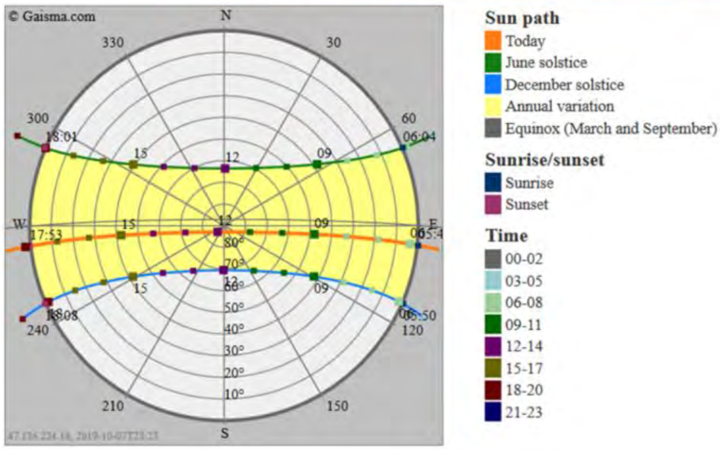
Enter solar insolation (average daily) and latitude for location [gaisma.com]



Introduction to Energy Sources: Solar

GAISMA

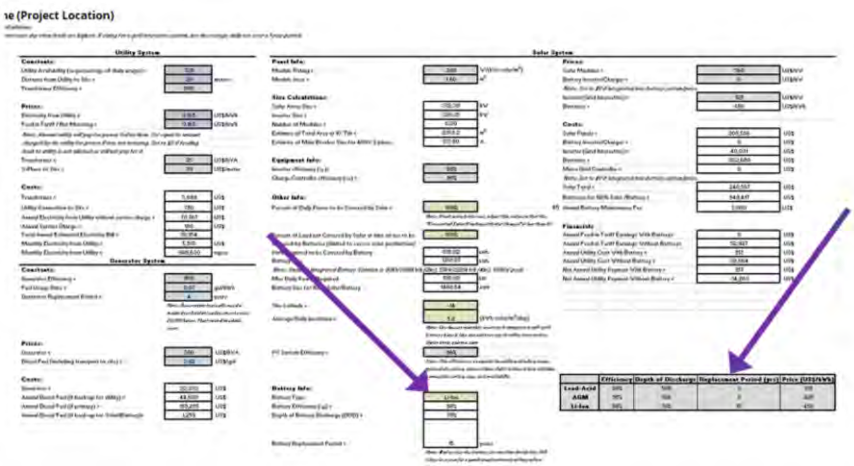
Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m²/day	4.68	4.98	4.78	4.56	4.42	4.76	5.25	5.26	5.16	4.66	4.36	4.50



Use worst case month if 100% solar with battery system. Average if utility interactive. Sun path is used for shading analysis, determining inter-row spacing required, space from nearby building etc to avoid shade between 8am and 4pm at least. Use trigonometry using worst case altitude angle for entire year between 8am and 4pm to determine spacing.

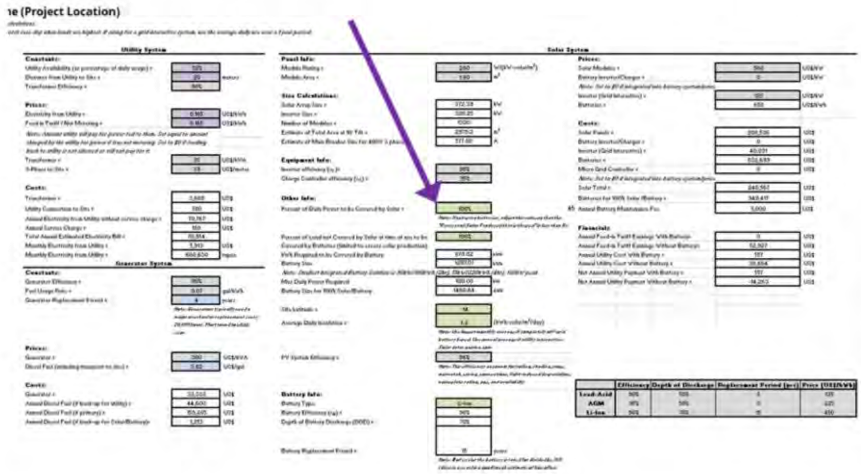
Cost Analysis Tool: Input Tab

Can change battery type from dropdown. Can change Depth of Discharge, Lifetime, or prices for each type in the table.



Cost Analysis Tool: Input Tab

Cells for % solar and % battery will be adjusted up and down to optimize.



Cost Analysis Tool: Solar Insolation Curve Tab

Adjust Solar Constant until the total kWh/m^2/day equals the average daily insolation entered on the input tab.

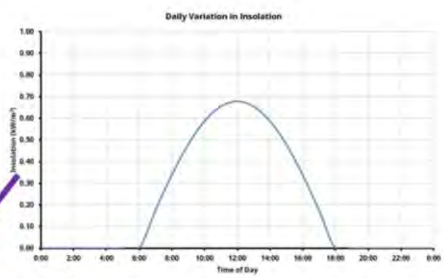
Site Latitude =	-14	N
Average Daily Insolation =	5.2	kWh/m²/day
Solar Declination Angle =	0	
Solar Constant =	0.700	kW/m²

(Solar declination varies from -23.5° on the winter solstice to 23.5° on the summer solstice. It is equal to 0° on the vernal and autumnal equinoxes. In this case, 0° is used as the average value, since we are dealing with average daily insolation.)

(Solar constant is typically 1.4 kW/m², but can be lower based on angle and weather.)

Time of Day	Time of Day (hrs)	Hour Angle (rad)	Zenith Angle (rad)	Insolation (kW/m²)	Area Under Curve (kWh/m²)
0:00	0.00	-3.141592654	2.897246558	0.00	---
1:00	1.00	-2.879793266	2.79540838	0.00	0.00
2:00	2.00	-2.617993878	2.568634073	0.00	0.00
3:00	3.00	-2.35619449	2.326894657	0.00	0.00
4:00	4.00	-2.094395102	2.077320583	0.00	0.00
5:00	5.00	-1.832595715	1.824644864	0.00	0.00
6:00	6.00	-1.570796327	1.570796327	0.00	0.00
7:00	7.00	-1.308996939	1.31694779	0.18	0.09
8:00	8.00	-1.047197551	1.064264071	0.34	0.26
9:00	9.00	-0.785398163	0.814677997	0.49	0.41
10:00	10.00	-0.523598776	0.57295958	0.59	0.53
11:00	11.00	-0.261799388	0.356185674	0.66	0.62
12:00	12.00	0	0.244346095	0.69	0.67
13:00	13.00	0.261799388	0.356185674	0.66	0.67
14:00	14.00	0.523598776	0.57295959	0.59	0.62
15:00	15.00	0.785398163	0.814677997	0.49	0.53
16:00	16.00	1.047197551	1.064264071	0.34	0.41
17:00	17.00	1.308996939	1.31694779	0.18	0.26
18:00	18.00	1.570796327	1.570796327	0.00	0.09
19:00	19.00	1.832595715	1.824644864	0.00	0.00
20:00	20.00	2.094395102	2.077320583	0.00	0.00
21:00	21.00	2.35619449	2.326894657	0.00	0.00
22:00	22.00	2.617993878	2.568634073	0.00	0.00
23:00	23.00	2.879793266	2.79540838	0.00	0.00
0:00	24.00	3.141592654	2.897246558	0.00	0.00
					5.1591

kWh/m²/day <-- *Should be equal to the average daily insolation for the site. Iteratively change the solar constant to ensure that this value equals the avera*



Cost Analysis Tool: Cost Projections

- System Types Included by default
  [Feel free to add more columns]
  - Generator only
  - Utility only
  - Utility + Generator
  - X% Solar (No Battery) + Utility
  - X% Solar (With Y% Battery) + Utility
  - X% Solar (No Battery) + Utility + Generator (not paralleled to solar)
  - X% Solar (With Y% Battery) + Utility + Generator + Microgrid Controller
  - 100% Solar, 100% Battery

First three are self-explanatory.

X% Solar is (average daily kWh of solar production)/(daily kWh load estimated)

X% Battery is the % of unused solar (at time of use) that will be store in the batteries for use when (site load)>(solar output). If not store in battery that % is wasted or sold to the utility.

X% Solar (No Battery) + Utility: This is grid-tied solar. If utility is on and sun is out power is fed from the solar to the site and any excess can be fed to the grid. If utility is off solar is off even if sun is out.

X% Solar (With battery) + Utility: Generally only makes sense in cases where net-metering is not available and difference in what they pay utility versus what the utility pays them for power is high. When solar production greater than load excess is stored in batteries. When load>solar the battery power is used to minimize utility power usage. If utility is down battery system may carry load for some period, but is not necessarily designed for full backup power.

X% Solar (No Battery)+Utility+Generator (not paralleled to solar): Same as the previous only when the utility is down and battery depleted the generator runs and solar does not produce power.

X% Solar Y% Battery, Utility, Generator, MGC: 100% power availability. Solar and Battery will be used whenever possible, utlity will be the next in priority, and generator will only be used when neither is available. Solar will still produce when generator running, but will be limited to only what is above 30% load of the generator.

100% Solar, 100% Battery: Self explanatory

Cost Analysis Tool:
Cost Projections

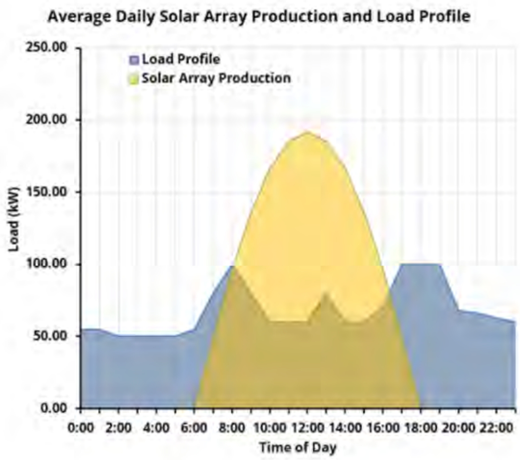
- Important Questions before completing the cost analysis:
  - Do they need 100% power availability?
  - How many years forward is the ministry interested in looking? "Payback period"

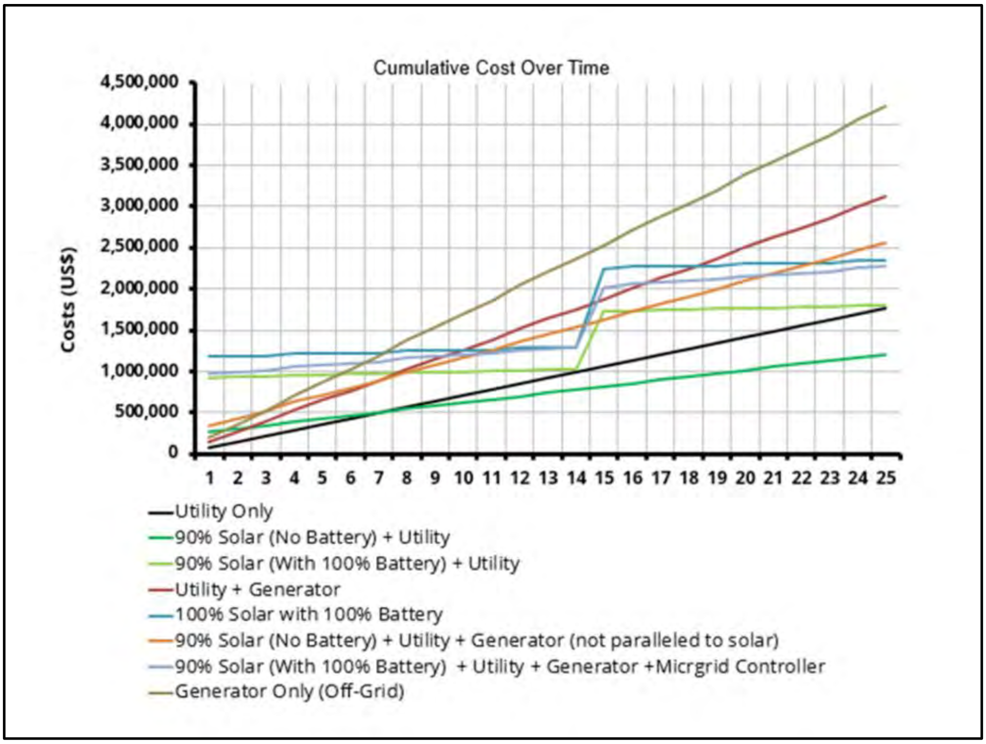
For this example:
- Yes
- 10 years

First question: hospital = yes, school in general = no, but anywhere can be yes if the ministry decides they need it.

Sometimes the second question is a judgement call on the part of the engineer.

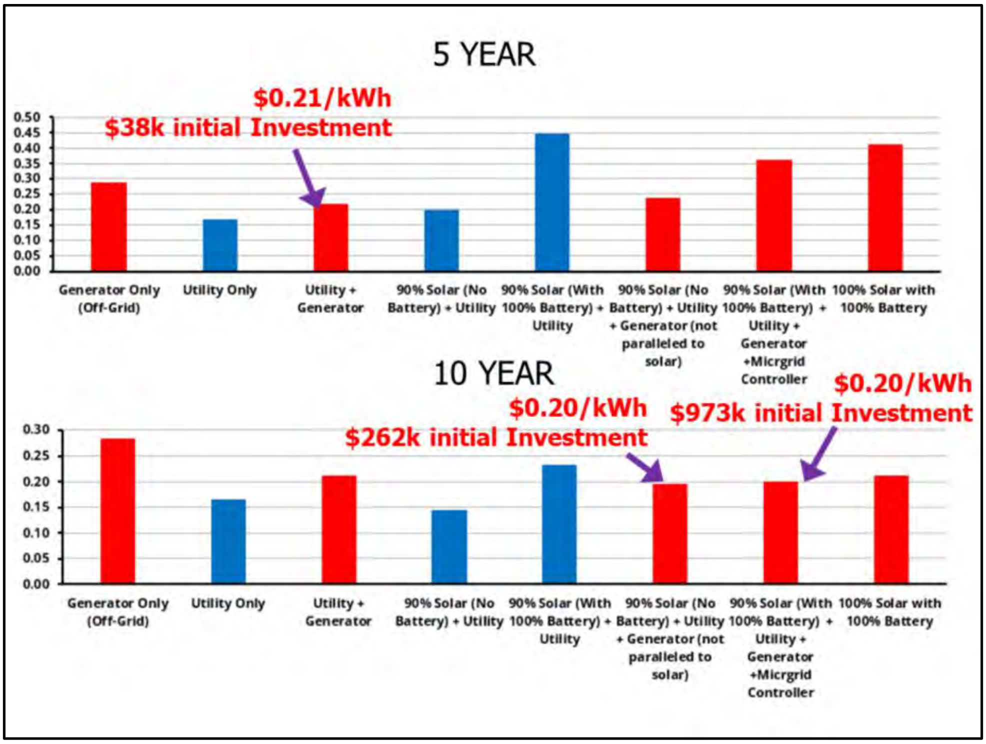
We're going to start with 90% solar and 100% battery for this example, but the starting point for iteration is not critical.





End points and cross over points are key.

What is the payback period for Solar with utility versus utility alone for this site at 90% solar? (7 years, crossover point)



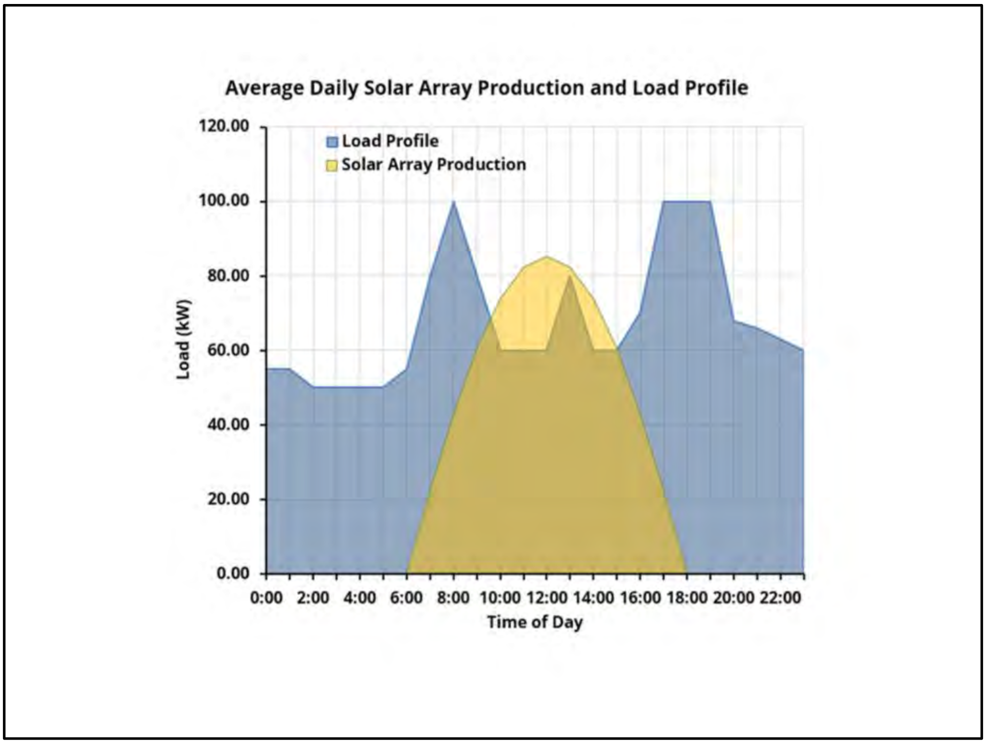
Another better way is to look at it is the $/kWh average at year 5 and year 10. Red represent 100% available power. Note that even a small difference in $/kWh can be BIG $ savings for the site. For this site at 595680kWh/year, a $0.01 difference is about $6000/year in savings.

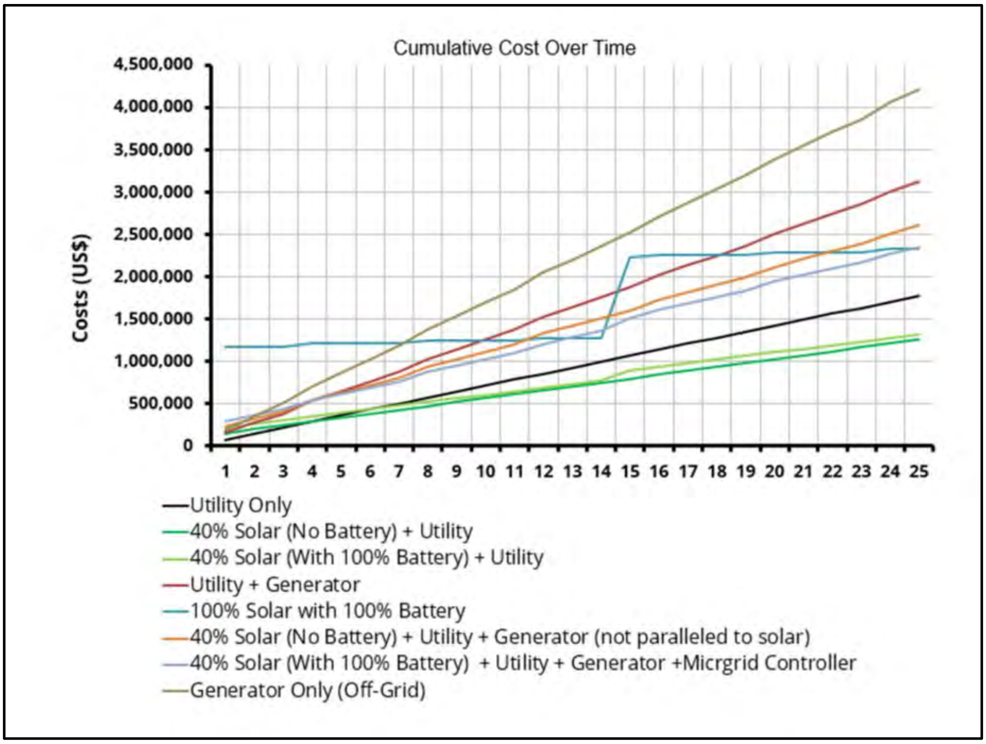
Cost Analysis Tool: Cost Projections

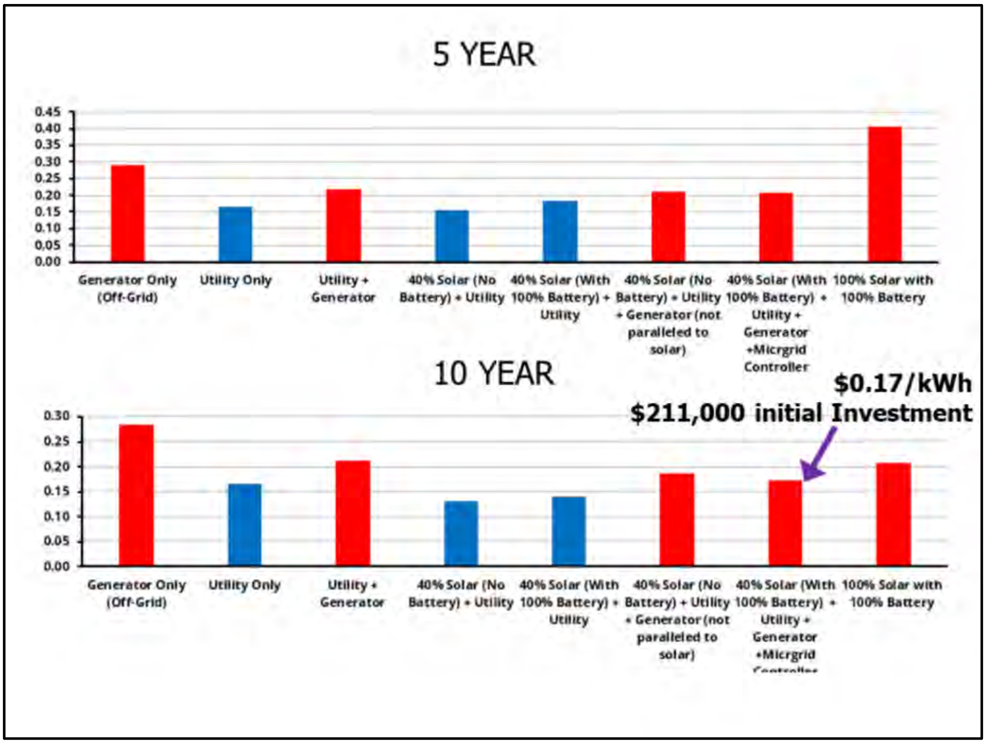
Iteration Process Question 1:
Can we beat $0.20/kWh for the timeframe desired?

Cost Analysis Tool: Cost Projections

Answer: Yes. $0.17/kWh
40% Solar, 180kWh Battery (min. system size), with Micro Grid Controller allowing parallelling with generator


Average Daily Solar Array Production and Load Profile
Load Profile
Solar Array Production
Load (kW)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00
Time of Day


Cumulative Cost Over Time
Costs (US$)
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Utility Only
40% Solar (No Battery) + Utility
40% Solar (With 100% Battery) + Utility
Utility + Generator
100% Solar with 100% Battery
40% Solar (No Battery) + Utility + Generator (not paralleled to solar)
40% Solar (With 100% Battery) + Utility + Generator +Micrgrid Controller
Generator Only (Off-Grid)


5 YEAR
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Generator Only (Off-Grid)
Utility Only
Utility + Generator
40% Solar (No Battery) + Utility
40% Solar (With 100% Battery) + Utility
40% Solar (No Battery) + Utility + Generator (not paralleled to solar)
40% Solar (With 100% Battery) + Utility + Generator +Micrgrid Controller
100% Solar with 100% Battery
10 YEAR
$0.17/kWh
$211,000 initial Investment
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Generator Only (Off-Grid)
Utility Only
Utility + Generator
40% Solar (No Battery) + Utility
40% Solar (With 100% Battery) + Utility
40% Solar (No Battery) + Utility + Generator (not paralleled to solar)
40% Solar (With 100% Battery) + Utility + Generator +Micrgrid
100% Solar with 100% Battery

Cost Analysis Tool: Cost Projections

Iteration Process Question 2:

Can we beat \$211k initial investment and still achieve \$0.17/kWh for the timeframe desired?

Answer: 35% Solar,180kWh battery appears to achieve $0.17/kWh with $159k initial investment.
(I wouldn’t go finer than 5% intervals as these are rough estimates)

Cost Analysis Tool: Cost Projections

- Warning
  - The cost analysis tool will let you design systems that are not feasible in real life so always check for feasibility
    For example, roof size may limit the size of your solar array.
  - The tool does not represent every system type so check the calculations to make sure the system type you are considering matches.
  - Feel free to add columns with additional scenarios

designing a world of hope

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2019 **EMI Conference**

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