2021 HiMCM
Problem A: Storing the Sun

Your team is helping to plan the use of solar power to provide electricity to a 1600 square-foot home being built in a remote area. You need to plan for enough energy to support the energy requirements of the home at night and on a cloudy day. You have done some research and found that you can either pull energy from the grid (i.e. a power company) when your solar panels aren't producing enough, or use an ***energy storage system***. As the house is in a remote area, the cost of connecting to the grid is very expensive, so you decide to go ***off-the-grid*** and invest in energy storage.

Background. An energy storage system allows you to capture electricity, store it as another form of energy (battery, thermal, mechanical) and then have it available to use when needed. The purpose of these storage units is to store energy produced during sunny daylight hours for use when the solar panels do not produce enough energy for the demand (night or cloud covered), or for storage and transfer of excess energy. Of the solar-powered homes that use an energy storage system, most use some sort of battery. Some homeowners have only one large battery, while others may use a "bank of batteries" (two or more batteries connected). Energy storage can be expensive and so homeowners should choose a system that is appropriate for their situation. **Figure 1** shows the general concept of off-the-grid energy.

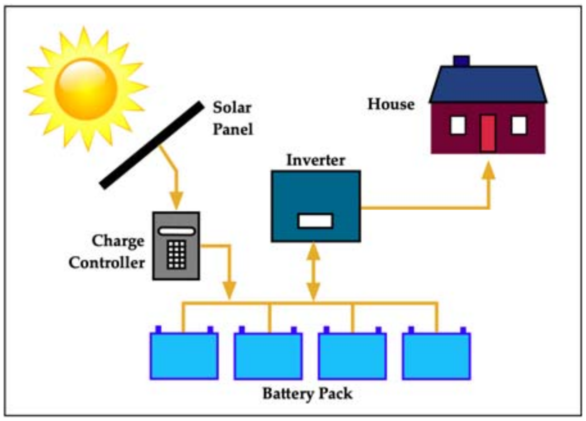

Figure 1: Off-the-Grid Energy System

In choosing an energy storage system there are many criteria to consider. Here are a few of the most common decision criteria, as well as which battery specifications matter most for each criterion.

- To power more of your home at once, you will want a battery with a high ***continuous power rating.***
- To power a more energy-intensive appliance (requiring more power in short bursts), your battery should have a high ***instantaneous power rating***.
- To run your home for a longer amount of time, look for a battery with a higher ***usable capacity***.
- If you want to get the most out of every kilowatt-hour of electricity you put into your battery, look for a battery with a higher ***round-trip efficiency.***

Additional considerations apply for the type of battery.

- Lead-acid (flooded or sealed) and lithium-ion batteries are ideal for a full-time, off-grid supply of different levels of use.
- Lead-acid batteries have been around for a long time and are known for their low prices and reliability.
- Lithium-ion batteries are more expensive, but require no maintenance. Other options are nickel cadmium and flow batteries.
- Look for lithium iron phosphate (LFP) batteries (a type of lithium-ion battery) to get the longest ***lifetime*** that you can cycle the most times.
- For the absolute highest safety rating possible (although they are all safe), look to LFP batteries.

Requirements

1. Consider the 1600 square-foot off-the-grid home you are planning.

a. Analyze your solar-power storage requirements by first making a list of questions to determine your energy needs. Discuss the range of possible answers to your questions. To get you started, here are a few questions:

- How many people will be using energy in this home?
- What items in the home will need energy and how much energy will they need?
- When will people in the home use energy?

b. Use your analysis from part 1.a., along with the criteria and considerations from the problem background and any other factors you consider important, to develop a mathematical model or algorithm for choosing the "best" battery storage system for your off-the-grid home.

c. Consider available battery storage options and use your model to choose the best option for your off-the-grid home. The chart at the end of the problem statement provides several, but not all, battery options. Discuss your choice.

2. Adjust and generalize your model from Requirement 1 so that it is adaptable to individual needs and preferences to choose the best battery storage for any home. Discuss the changes you make to your model. Evaluate your model.

3. Recently, researchers in Sweden discovered that cement could be used to store energy[1]. Concrete, which is made with cement, is used to build buildings, sidewalks, bridges, and countless other structures.

a. Identify some of the advantages and disadvantages of using cement batteries to store solar power. Describe how might you incorporate cement as a battery for your off-the-grid home or for any home?

b. Determine and discuss the additional information you would need in order for you to model and compare the use of cement batteries to currently available batteries for solar-power storage. Note: You are NOT required to create the model.

4. Write a one-page non-technical news article describing your solar power battery storage decision model. Include in your article any recommendations for the future possibilities of a cement battery.

Your PDF solution of no more than 25 total pages should include:

- One-page Summary Sheet.
- Table of Contents.
- Your complete solution.
- One-page Article.
- References list.

Note: The HiMCM Contest now has a 25-page limit. All aspects of your submission count toward the 25-page limit (Summary Sheet, Table of Contents, Reference List and any Appendices).

Glossary

Continuous Power Rating: the kilowatts (kW) or Amps (A) of power that the battery can provide continuously (until the battery runs out of power).

Energy Storage System: a system that captures electricity, stores it in another form, and then retrieves it for use at a later time.

Instantaneous Power Rating: the kilowatts (kW) or Amps (A) of power that the battery can provide in short bursts (but not sustain over a long period).

Lifetime (of battery): the length of time your battery will continue working which is measured by expected years of operation, expected throughput (kWh of use), and expected number of cycles (charging and discharging).

Off-The-Grid: not using or depending upon public supply of electricity (or other utilities).

Round-Trip Efficiency: the number of units of electricity you'll get out of a battery for every unit you put into it measured in a percentage.

Usable Capacity: the amount of electricity, in kilowatt-hours (kWh) or Amp-hours (Ah) that a battery is able to store and supply to your home.

Reference

[1] Zhang, Emma Q., and Luping Tang. 2021. "Rechargeable Concrete Battery" *Buildings* 11, no. 3: 103. https://doi.org/10.3390/buildings11030103

Sample of Batteries Used for Solar Storage[1]

Battery	Cost (USD)	Battery Type	Weight (lbs.)	Dimension (L×W×D in inches)	Continuous Power Rating (kW)	Instantaneous Power Rating (kW)	Round-Trip Efficiency (%)	Usable Capacity (kWh)
Deka Solar 8GCC2 6V 198	$368	SGLA	68	10.25 × 7.1 × 10.9	0.049 kW (for 20 hrs.) - 0.017 kW (for 100 hrs.)[2]	Not Available	80-85%[3]	1.18 kWh
Trojan L-16 -SPRE 6V 415	$492	FLA	118	11.7 × 6.9 × 17.6	0.19 kW (for 10 hrs.) - 0.023 kW (for 100 hrs.)[2]	Not Available	80-85%[3]	2.5 kWh
Discover AES 7.4 kWh	$6,478	LFP	192	18.5 × 13.3 × 14.7	6.65 kW	14.4 kW (for 3 sec)	>95%	7.4 kWh
Electriq PowerPod 2	$13,000	LFP	346	27.5 × 50 × 9	7.6 kW	9 kW (for 60 sec)	96.60%	10 kWh
Tesla Powerwall+	$8,500	NMC	343.9	62.8 × 29.7 × 6.3	7 kW	10 kW (10 sec)	90.00%	13.5 kWh

[1] This is just a small sample of available batteries for solar storage systems.

[2] Estimate to include 10% battery imperfection and converter loss.

[3] Losses from lead-acid batteries are 15-20%

Battery Types
SGLA - Sealed Gel Lead Acid
FLA - Flooded Lead Acid
LFP - Lithium Iron Phosphate
NMC - Lithium Nickel Manganese Cobalt Oxide
Abbreviations in Table
USD - United States Dollars
lbs. - Pounds
L×W×D - Length × Width × Depth
kW - Kilowatt
kWh - Kilowatt Hours