Project Brief

Evaluating Renewable Energy Storage Options

Project Members:

Rebecca Hausheer

Kurt Heinze

Sheena Katai

Karly Kaufman

Gomati Madaiah

Jefferson Litten

Project Advisor:

Sangwon Suh

Introduction

In the last few decades, the drawbacks of fossil fuel dependency—global climate change, decreased energy security, and air pollution—have become increasingly prominent. One way to reduce fossil fuel dependency is to harness the earth's renewable energy resources. Renewable energy resources, such as solar and wind power, can help meet future electricity demand with negligible emissions. However, widespread adoption of renewable energy solutions has been limited by intermittency and variability of solar and wind resources—electrical generation can only occur when the wind blows or the sun shines.

Energy storage may have potential savings of avoided electricity purchase or avoided cost of carbon emissions. However, there are capital, operations and maintenance, replacement, and insurance costs. The complexity here lies in the fact that that all of these potential costs and savings depend on a variety of factors, from the price of electricity to the type of storage device used and the actual size of the device.

We need a tool to understand the cost implications of using energy storage.

Energy Storage: A Complex Solution

Energy storage offers a potential solution to these limitations by allowing electricity to be stored for use later when generation is unavailable. Energy storage may also improve the economics of renewable generation systems. Unfortunately, quantifying the economic benefits of energy storage technologies is difficult because of system complexities and limited information.

Figure 1 illustrates the complexity of the problem. If there is excess electricity, it can either be sold to the grid or stored. Giving power back to the grid incurs no additional cost, but there will only be savings if the generator can be paid for that electricity.
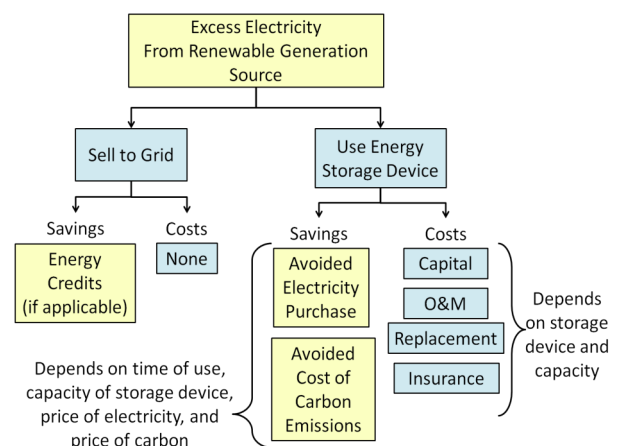

Figure 1: Options for handling excess electricity and the potential costs and savings implications.

Project Objective:
Create a tool to evaluate lifetime costs and benefits of energy storage. This tool can be used by electricity customers with on-side renewable energy generation to maximize the value of their generated electricity.

About Energy Storage

Energy storage involves the conversion of electrical energy into another form such as chemical, kinetic or potential energy. This energy can then be stored over a duration of time and converted back to electrical energy as the electricity is needed. At present, due to a number of economic and technical issues, energy storage technologies are not widely employed for large systems.

Despite technical and economic constraints, energy storage can provide a range of benefits. Storage can reduce the need for building power plants to meet peak demand, or enable a renewable energy generator to capture excess electricity and use it on site, negating the need to send it back to the grid.

Leading energy storage technologies include lead-acid batteries, flow batteries, flywheels, compressed air storage, pumped hydro and fuel cells. These technologies are all in different stages of development ranging from emerging to mature. The advantages, disadvantages and environmental impacts of some technologies are listed in the table below.[1,2,3]

Technology	Advantages	Disadvantages	Environmental & Health Risks
Flooded Cell Lead-Acid Batteries	•Mature and inexpensive technology •Readily available	•Short life cycle •Low energy density •High maintenance costs	•Potential lead pollution
Valve Regulated Lead-Acid Batteries (VRLA)	•Lower maintenance costs than traditional lead-acid •Mature technology	•Less reliable and higher costs than traditional flooded cell lead-acid batteries	•Potential lead pollution
Nickel Cadmium Batteries (NiCd)	•Mature technology •High density •Long cycle life	•Subject to price fluctuations of cadmium	•Cadmium is a highly toxic metal •Contains ground water and soil contaminants
Zinc Bromine Batteries (ZBB)	•Scalable •Low maintenance •Low temperature	•Early stage technology •Low energy density	•Contains corrosive and toxic materials
Sodium Sulfur Batteries (NaS)	•High density •Long cycle life	•High operating temperature •Relatively high cost	•Contains corrosive materials •High operating temperature can pose safety risk
Lithium Ion Batteries (Li-ion)	•High energy and power densities •High efficiency	•Relatively early stage technology •Special handling requirements •High production cost	•Contains toxic and flammable materials
Vanadium Redox Batteries (VRB)	•Scalable •Low maintenance •Long cycle life	•Relatively early stage •High cost •Low energy density	•Contains sulfuric acid at same concentration as lead-acid batteries
Nickel Metal Hydride Batteries (NiMH)	•Relatively mature technology •Long cycle life	•Material costs will likely keep cost of this technology high	•Contains ground water and soil contaminants •Less toxic than NiCd
Flywheels	•High power density •High cycle life •Quick recharge	•Not applicable for long duration storage applications •High Cost	•Failure of flywheel rotor during rotation can pose safety hazard
Compressed Air Energy Storage	•High capacity •Long lifetime	•Geographically limited •Requires fuel input •Low efficiency	•Some Nitrogen Oxide (NOx) emissions can occur
Pumped Hydro	•High capacity •Long lifetime	•Geographically limited •Expensive to site and build	•Special site required •Land impacts to create reservoir
Hydrogen Fuel Cells	•High energy density •Scalable	•Low efficiency •High operating temperatures	•Fire and explosion hazard

References:

1) U.S. Department of Energy, National Energy Technology Laboratory. 2008. *Market Analysis of Emerging Electric Energy Storage Systems.*

2) U.S. DOE, Pacific Northwest National Laboratory. 2008. *Wide Area Energy Storage and Management System to Balance Intermittent Resources in the Bonneville Power Administration and California ISO Control Areas.*

3) U.S. DOE , Sandia National Laboratories. 2008. *Solar Energy Grid Integration Systems-Energy Storage.*

A Tool To Evaluate Energy Storage: RESET

To address our objective, our team developed the Renewable Energy Storage Engagement Tool (RESET). RESET calculates the maximum economic value of excess renewable generation by optimally sizing energy storage systems. RESET allows any electricity customer to compare and evaluate the economic profitability of multiple energy storage technologies at their site.

Fourteen energy storage technologies are analyzed within the RESET framework. The costs and operational characteristics of the included energy storage technologies—both of which change according to the size of the required system—are used to determine the optimal size of the energy storage system required to meet the client's needs.

First, RESET calculates the excess electrical generation that would be available for energy storage. Next, RESET maximizes the net present value of each energy storage technology, determining the optimally sized system for storing the available excess. The results are displayed graphically and in tabular form, allowing the user to compare the optimal capacity and net present value for all fourteen technologies.

RESET
Renewable Energy Storage Engagement Tool

Renewable Energy Storage Engagement Tool

Renewable generation: Solar PV *Select from list*

Electric Utility Provider: Los Angeles Dept of Water & Power (LADWP) *Select from list -- This changes the terminology used by the tool*

Input monthly average electricity demand and generation BY HOUR here (in kWh):

	Midnight- 0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
Average Daily Weekday											
Demand - Jan	430.2	413	413	419	483	566	695	781	884	849	860
Feb	432.7	410									
Mar	449.6	419									
Apr	425.7	406									
May	421.8	401									
Jun	423.3	405									
Jul	445.4	426									
Aug	442.2	421									
Sep	469.8	451									
Oct	443.1	424									
Nov	444.7	425									
Dec	466.5	454									
Hourly Averages	441.25	421.7									
Average Daily Generation - Jan	0										
Feb	0										
Mar	0										
Apr	0										
May	0										
Jun	0										
Jul	0										
Aug	0										
Sep	0										
Oct	0										
Nov	0										
Dec	0										
Hourly Averages	0.00	0.0									

Electricity rates ($/kWh)
Current year average during each rate period:
High Season

| High-peak | 0.94 | Low-peak | 0.21 | Base | 0.11 |

Low Season

| High-peak | 0.23 | Low-peak | 0.12 | Base | 0.10 |

Energy credit rates (if applicable):

| High-peak | 0.00 | Low-peak | 0.00 | Base | 0.00 |

Stored Energy *Usage (%)* during each rate period:
High Season

| High-peak | 0% | Low-peak | 75% | Base | 25% | 100% |

Low Season

| High-peak | 0% | Low-peak | 100% | Base | 0% | 100% |

Storage Operation
Storage operating days: Weekdays only *Select from list*

Operating time per day: 4 *hrs*   Operating days per year: 261 *days*

Duration of storage: 4 – 8 hrs *Select from list*

Other relevant rates & factors
Discount rate: 10.0%

Annual electricity demand growth rate: 0.0%   Annual electricity price growth rate: 2.8%

Renewable generation factor: 1 *Multiplier for generation profile (for current generation use "1")*

Carbon Price ($/metric ton): $ - *Optional*

eGrid subregion CAMX – WECC California   0.31 *kg CO2e/kWh*

Geological conditions present for:
Pumped Hydro Unknown   Compressed Air (CAES) Unknown

Optimize

Users must input their annual hourly electricity demand profile

Users must input their annual renewable energy generation profile

Users must input electricity rate structures and energy credit rates

Users can input desired storage operation parameters and electricity time-of-use preferences

Users can input other factors such as their desired discount rate and expected demand growth rate

RESET can calculate potential greenhouse gas emissions reductions

RESET will maximize the net present value of an energy storage investment by determining the optimal capacity for each storage technology

Case Study: Los Angeles Harbor College

RESET was used to evaluate energy storage options for Los Angeles Harbor College, a 10,000 student community college with a 2.1 megawatt (MW) solar photovoltaic generation system. Harbor College presented to our group two main problems:

(1) Harbor College lacks the metering equipment to measure any excess electricity generation that may exist from their solar array

(2) Because Harbor College's solar generation capacity exceeds a threshold set by their utility, Harbor College is not eligible to receive compensation for excess electricity sent back to the grid.

Therefore, Harbor can either transfer excess electricity to the grid without compensation, or find a way to capture and use the electricity. Using RESET, we aimed to discover how Harbor College can maximize the economic value of its solar generation.

Recommendations to Harbor College

Based on Harbor College's existing generation and demand profiles, RESET calculated that sized storage capacity was 0 kilowatt-hours for all technologies (see Figure 2). In other words, the potential savings in avoided future energy bills do not exceed the costs any energy storage system. However, by increasing solar generation capacity or reducing demand through efficiency, energy storage may become a more cost-effective option at Harbor College.

Technology	Optimal Capacity	Optimal NPV	NPV, 500kWh
Flooded Cell Lead-Acid Batteries	0	$0	-$213,749
Valve Regulated Lead-Acid Batteries	0	$0	-$272,411
Nickel Cadmium Batteries	0	$0	-$900,965
Zinc Bromine Flow Batteries	0	$0	-$380,285
Sodium Sulfur Batteries	0	$0	-$896,305
Lithium-Ion Batteries	0	$0	-$1,163,320
Vanadium Redox Flow Batteries	0	$0	-$700,730

Figure 2: RESET Results for Harbor College. The optimal storage and net present value for all technologies were zero. Assuming a moderate size energy storage system of 500 kWh, net present values were all negative.

Conclusions

Though in the case study, storage was not profitable, our analysis demonstrates how energy storage can make emission-free, renewable generation available during all hours of the day. With further innovation and economies of scale, the costs of energy storage technologies will eventually fall, making energy storage coupled with renewable generation a more feasible for electricity customers across the nation. Renewable generation and energy storage in tandem can help replace fossil-fuel based electrical generation. It is our hope that RESET will allow all users to better understand the benefits of energy storage and aid in the path towards a clean energy future.