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: 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.

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 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.

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.
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.\(^1,2,3\)

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

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.

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