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ESSENTIALS OF ENERGY STORAGE

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Essentials of Energy Storage

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Synopsis

Hawaii is the most fossil fuel dependent state in the United States. But HI has set 2045 deadline for 100% renewable electricity sourcing. Unfortunately, two of the principal renewable energy sources, wind and solar are intermittent, producing energy only when the wind blows or the sun shines. Even with substantial increases in renewable electricity production, there will be periods without enough available power. Some sort of bulk energy storage will be required. For various reasons, only the Sisyphus system of energy storage will be suitable for Hawaii's use. Fortunately, the cost of the Sisyphus system in terms of levelized cost of energy is lower than all other renewable options.

Introduction

Hawaii is the most fossil fuel dependent state in the United States. It produces 859,000 MWH per month of electricity, divided as shown in Table 1. However, HI has set 2045 deadline for 100% renewable electricity sourcing.

Table 1. HI Electricity Sources

Petroleum-fired	562,000 MWH
Coal-fired	128,000 MWH
Hydroelectric	12,000 MWH
Non-hydro renewables	134,000 MWH
Distributed renewables	23,000 MWH

Hawaii currently has two types of energy sources, firm and intermittent. The firm sources can be expected to produce constant amounts of power throughout the day. These sources are the following:

- Petroleum-fired,
- Coal-fired,
- Geothermal, and
- Waste-to-energy (H-Power).

The intermittent sources produce variable amounts of power during the day, dependent on the environment. These sources are the following:

- Wind and
- Solar.

The load profile shows the typical power demands over a day's time. Figure 1 shows the typical load profile for the continental USA. The load is lowest around 4 AM and highest around 4PM each day. In this figure, the horizontal line shows the base power supply, that is, the amount that is generated regardless of load. The portion of the load above this line must be supplied by "peaking" sources, sources such as natural gas-fired generators that can be easily turned on and off. The area below the base supply line and above the demand (load) curve is wasted power, power that is produced but not used.

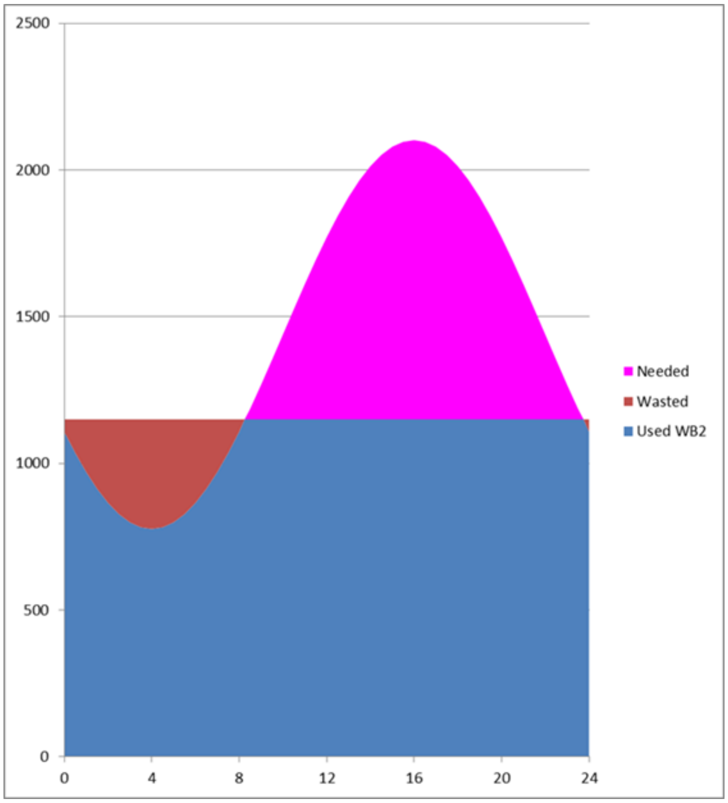

Figure 1. Continental US Load Profile

The typical Hawaii load profile is similar, but has differences based on the details of the Hawaiian economy, as shown in Figure 2.

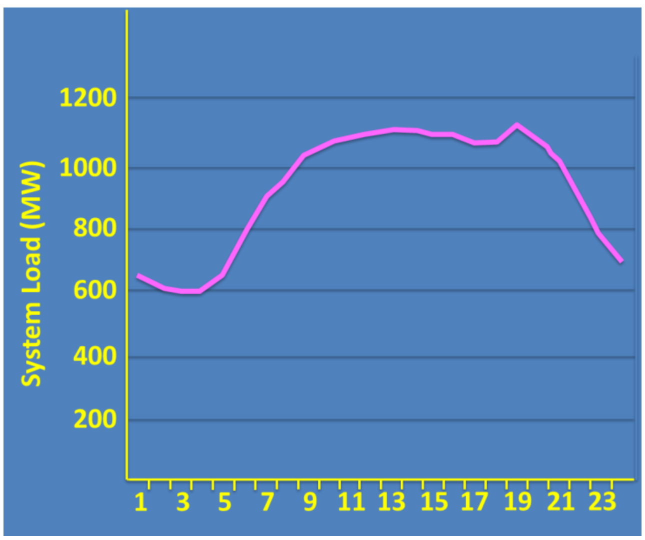

Figure 2. Hawaii Load Profile

Meeting the 2045 goal for Hawaii will require energy storage to match availability to demand, as will be discussed next.

Energy Storage Requirement

First we create some electricity sources profiles for 2045. The actual values will undoubtedly be wrong; however, the general picture will be correct. Figure 3 shows the results. We have increased the firm green sources, geothermal and waste-to-energy, showing the total as a constant value across the hours of the day. Then we add a source profile for solar production, using the Hawaii solar insolation curve, increasing its total value from the current total. Finally, we invent a set of curves for wind power. In this case we assume higher winds in the morning and afternoons, but with variable strengths (three different curves). This is the best case alternative, in that it supplements the solar power, when insolation is low. The worst case alternative is that the wind peaks nearly coincidentally with the solar peak. We will use the middle curve in the next figure.

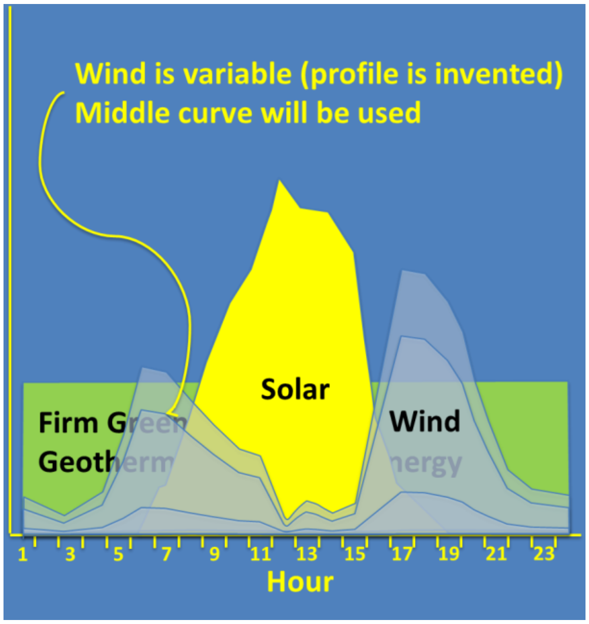

Figure 3. 2045 Electricity Sources Profile

In Figure 4, we stack these sources and plot them against the load curve. In the middle of the day, the production exceeds the demand, resulting in wasted production. At the beginning and ending of the day, there is not enough power, resulting in un-met needs.

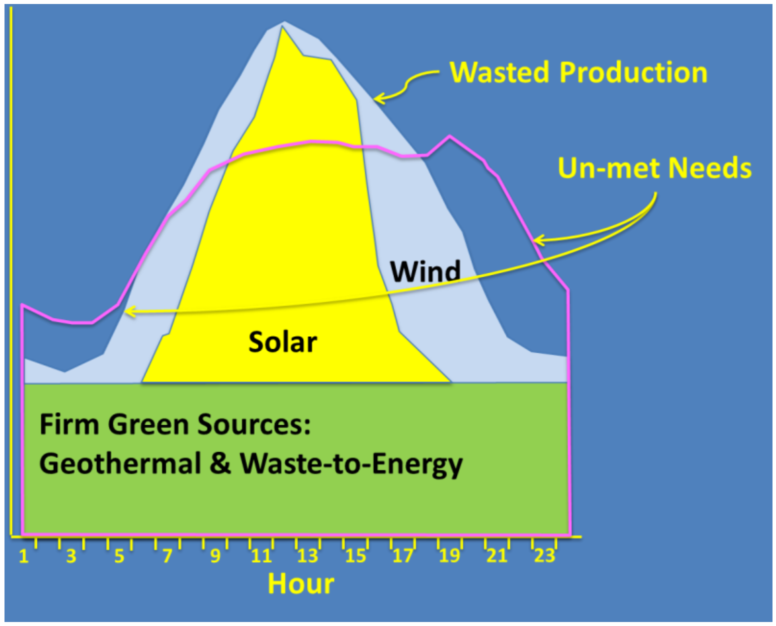

Figure 4. Un-met Needs and Wasted Production

For simplicity, we scaled the production so that the wasted production area equals the un-met needs area. (Actually, the planned production capacity would have to be larger to account for the natural variations from day to day.) Also, from this figure, you can see that in order to always meet all needs with no storage, the total production capacity would probably need to be about twice the average load. This would also result in tremendous amounts of wasted production on an annual basis. The cost would be enormous.

Figure 5 shows the only reasonable alternative. The excess energy is captured and stored when it is produced, rather than being wasted. During the times when there are un-met needs the stored energy is recovered and used.

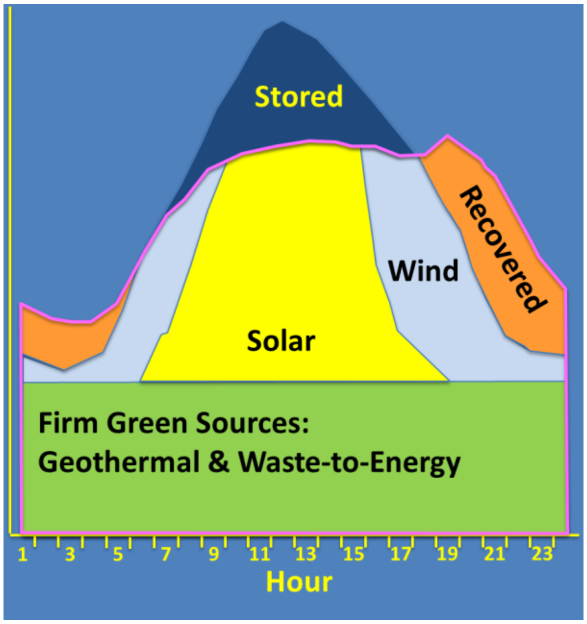

Figure 5. Storing and Recovering Energy

Energy Storage Options

Figure 6 shows a version of an Electric Power Research Institute (EPRI) chart on energy storage options. Some energy storage needs require rapid discharge times; however, this is not one of those needs. Here discharge times of minutes to hours are appropriate. Some uses, such as uninterruptible power supplies and power quality issues can make do with smaller power ratings; however, bulk power management requires power ratings in the 100 MW to 1000 MW range. The only candidate systems in the upper right portion of the figure are compressed air energy storage (CAES), pumped hydro energy storage, and Sisyphus.

CAES works by using energy to compress air and recover the energy by using the compressed air to drive a turbine. For effective bulk power management, the container for the compressed air has to be a natural or artificial cavern. The cavern has to be air-tight, which would require sealants in Hawaiian geology. It also has some technical issues that lower its efficiency considerably, i.e., the amount of energy that can be recovered compared to the amount that was stored.

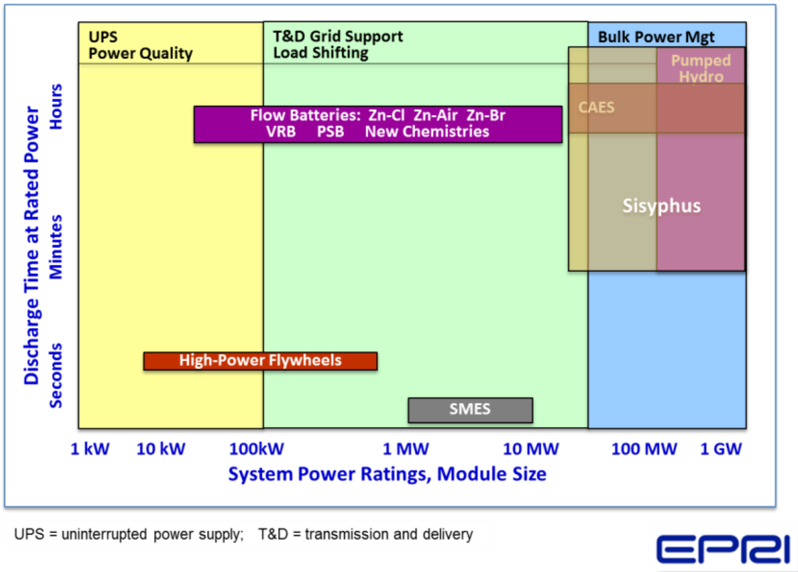

Figure 6. Energy Storage Options

Pumped hydro is a popular option, accounting for more than 99% of the world's energy storage. Figure 7 diagrams the working of pumped hydro energy storage. Water from some source (typically a river) is pumped uphill into a dammed lake. This takes energy. When the energy is needed, it flows back through the pumps, which now act as turbines, generating electricity. The efficiency for pumped hydro is less than 80%. That is, for every 1000 MWH of energy stored, less than 800 MWH can be recovered. The major constraint is finding a place where a dam can be sited, with a corresponding large area lake behind it.

Figure 7. Pumped Hydro Energy Storage

The Sisyphus system is diagrammed in Figure 8. Energy is used to move a large number of 100 metric ton blocks up a mountain (or actually from any low point to any high point). When the energy is needed, the blocks are brought back down the mountain, generating energy. The efficiency is more than 90%, meaning that for every 1000 MWH of energy stored; more than 900 MWH can be recovered.

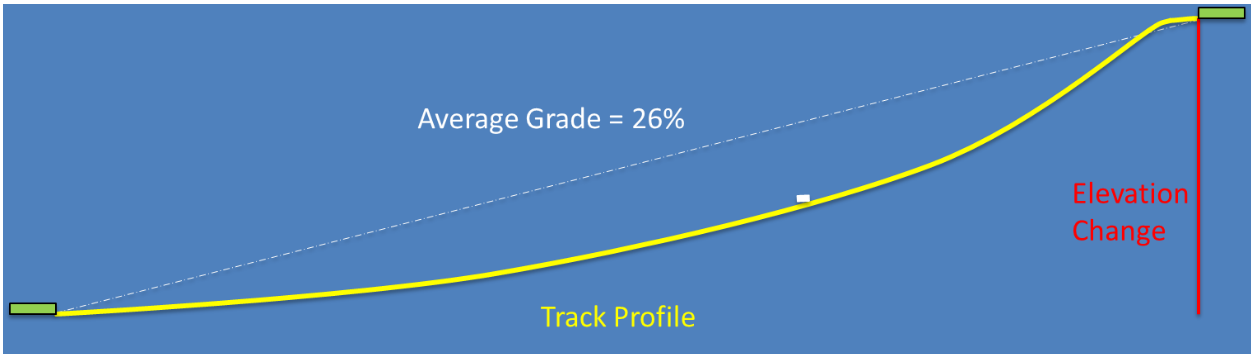

Figure 8. Sisyphus Energy Storage

The reason for the high efficiency is the use of superconducting magnetic levitation. Superconducting magnets are lossless and the levitation means that there is no friction to cause energy losses. The primary reason for energy losses is wind resistance, as the vehicles carrying the blocks move at 60+ miles per hour.

Sisyphus System Details

Figure 9 illustrates the parts of the vehicle and block. The vehicle weighs 10 tons and the block weighs 100 metric tons (220,000 pounds). Together, they are about the same size and weight as a loaded coal hopper car on a conventional railroad. The superconducting magnets are mounted on the vehicle and react against non-superconducting aluminum coils on the sides of a guideway beam (monorail).

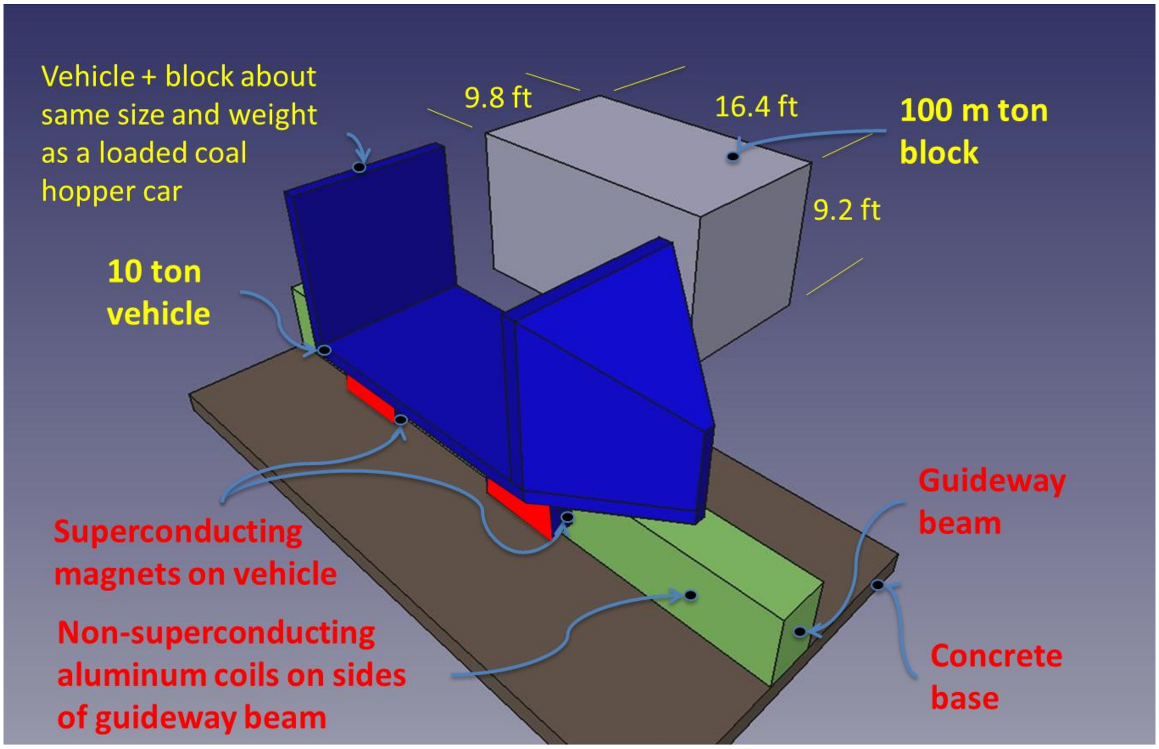

Figure 9. Sisyphus Vehicle and Block

The magnet/guideway coil systems provide four functions:

- They react against each other, levitating the vehicle.
- They provide automatic level maintenance (anti-tilt) and horizontal centering.
- In motor mode (going uphill), locally energized coils provide vehicle acceleration (a linear induction motor).
- In generator mode (going downhill), local coils recover energy by decelerating the vehicle (a linear induction generator).

Figure 10 illustrates the other major component of the Sisyphus system, one of the two storage yards. In the energy storage mode, the vehicles pick up blocks from the lower storage yard and carry them up to the upper storage yard. In the energy recovery mode, the vehicles pick up blocks from the upper storage yard and carry them down to the lower storage yard.

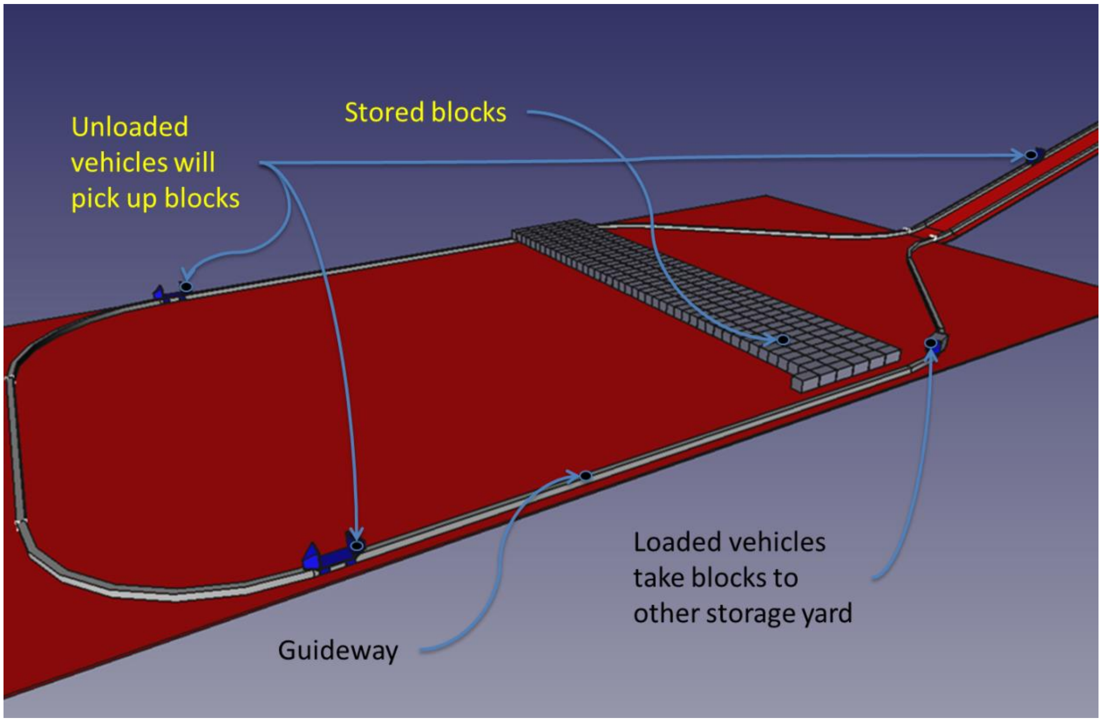

Figure 10. Sisyphus Storage Yard

Computing Storage System Needs for Hawaii

The amount of energy that a Sisyphus system can store depends on the height difference between the lower storage yard and the upper storage yard and the number of 100 m ton blocks that are moved – simple physics. We will define the canonical system to be one with a 640 meter height differential that moves 5750 blocks. This system will store 1000 MWH (1 GWH) of energy.

For this exercise, we will assume that Hawaii's electricity needs do not grow. Thus the need shown in Table 2 for 2045 is 859 GWH/month, the same as for 2017. We will assume that the hydroelectric capacity will not change, because of problems finding places to dam rivers (the same reason that pumped hydro storage will not be used in Hawaii). We will assume a small growth in the "distributed" energy sources and that the bulk of the increase in energy production will be in geothermal, wind, commercial solar, and possibly some ocean sources, with no fossil fuel electricity generation. The total is assumed to be the same as the need, as required by law. For computational purposes, we will assume that 10% of this amount will need to be stored and recovered to cover the timing mismatch caused by the intermittent power sources (see Figure 5). Under these assumptions, 86 GWH/month of energy storage will be required, which can be supplied by less than 4 canonical 1 GWH/day Sisyphus systems, one per major island. (4 systems x 1 GWH/day x 30 days = 120 GWH/month > 86 GWH/month).

Table 2. 2045 Energy Storage Requirements

	2017	2045
Need	859 GWH	859 GWH
Hydroelectric	12 GWH	12 GWH
Distributed	23 GWH	25 GWH
Non-hydro renewables	134 GWH	822 GWH
10% Storage		86 GWH
Sisyphus Systems		4

Energy Costs

We have said that CAES is unsuitable for Hawaii (and possibly for any commercial large-scale use). We have also said that the use of pumped hydro in Hawaii is unlikely for siting reasons. That leaves Sisyphus as the only option, if the 2045 goal is to be met. What will it cost?

We can divide energy cost considerations into two components as follows:

- Indirect
    - Air pollution from burning fossil fuel,
    - Greenhouse gas production from burning fossil fuel, and
    - Environmental pollution from mining or drilling.
    - These are parts of the reason for Hawaii going totally renewable by 2045.
- Direct
    - Plant capital costs,
    - Plant operating and maintenance (O&M) costs, and
    - Fuel costs.
    - Comparing among alternatives is difficult.

The energy experts have devised a way for comparing the direct costs of energy, called Levelized Cost of Energy (LCOE). Figure 11 presents the formula and a simplified explanation. The first term calculates the contribution of plant capital cost, based on its operating lifetime (discounted), stated in cost per kilowatt hour (kWh). The next two terms calculate the O&M cost contribution per kWh. The final term calculates the fuel cost per kWh. These are added together to produce the LCOE.

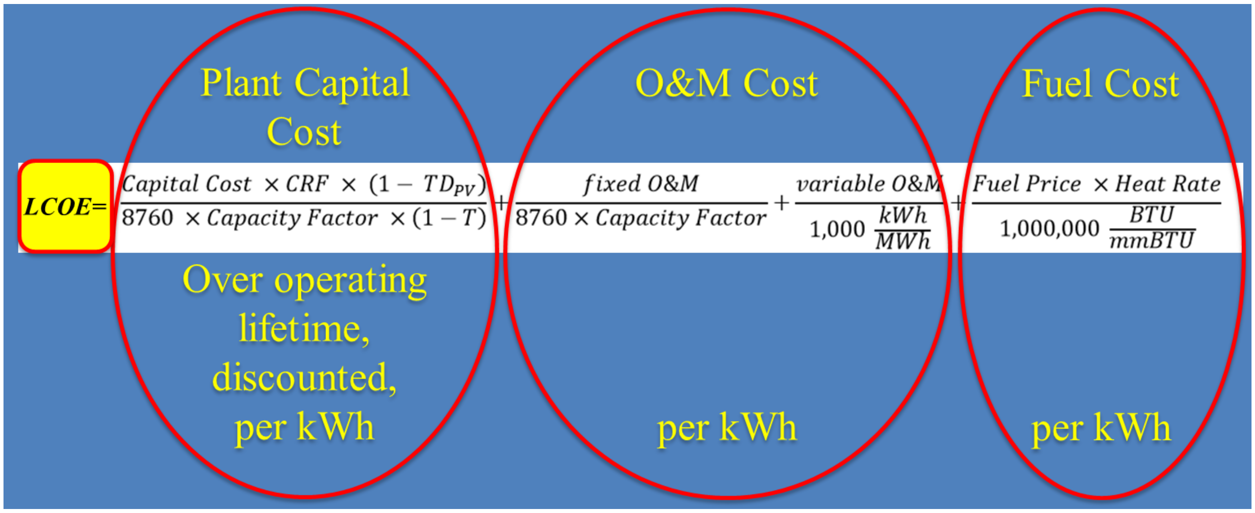

Figure 11. LCOE Formula

Figure 12 presents the LCOE values for a number of technologies that might be used to generate electricity (or store energy) in Hawaii. These costs may be read as fractional dollars per kWh or fractions of millions of dollars per GWH. The latter yields the levelized cost of a 1 GWH/day system. Because the costs of actual power plants vary, several cost points are given, a minimum, a maximum, an average, one standard deviation below the average, and one standard deviation above the average. The take-away point is that the average cost for a Sisyphus system is lower than the average cost of any other system, except for a natural gas combined cycle plant, which is a fossil fuel plant. And even that system's cost and the Sisyphus cost are probably within the margin of error of being the same. This says that Sisyphus will cost Hawaii less than the cost of adding generating capacity.

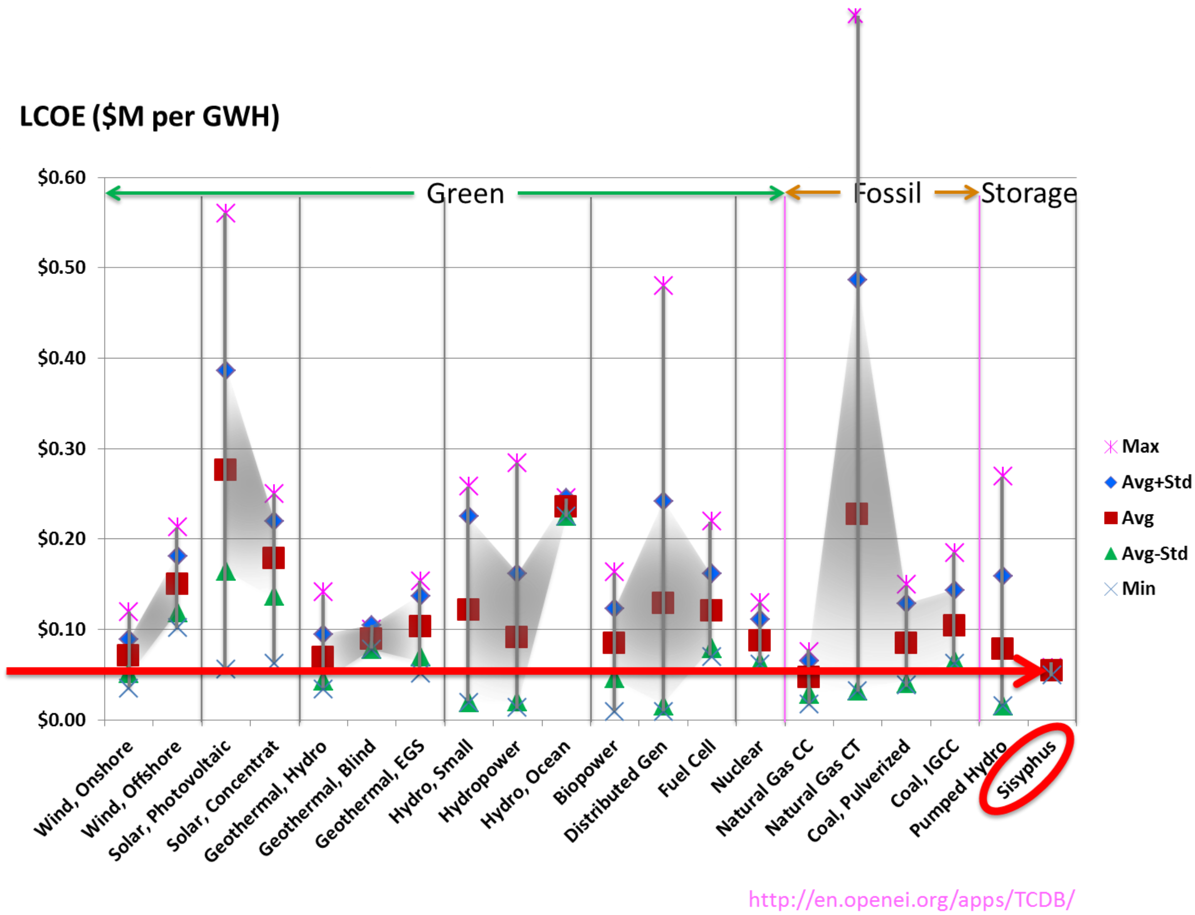

Figure 12. LCOE Comparisons for Various Energy Technologies

Conclusion

Except for geothermal and waste-to-energy, renewable electricity production is intermittent. Going green by 2045 will require bulk energy storage to store energy when it is available and supply it when it is needed. Sisyphus is the only viable storage system for Hawaii and it is cost effective.

For more information, visit http://SisyphusEnergy.com.