Energy Storage for Alaskan Communities

Technology Summary

July, 2009

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Executive Summary

Energy storage is a pressing concern for the electric utility management and integration of renewable energy sources. Loads and resources vary on different timescales and with differing severity. This document considers available and emerging technologies for energy storage on a variety of time scales, with special attention paid to their applicability in Alaskan communities.

Utilities must meet a load that is constantly varying. Even in seconds and minutes, the amount of power required by a community can shift substantially. Additionally, the generating capacity of renewable resources such as wind or tidal will also change from minute to minute. For this time scale, it is important for utilities to have storage which can quickly charge and discharge to provide smooth power to the community. A flywheel is a mechanical solution to this problem which has been tested and installed in many facilities. However, not all sizes of flywheel are commercially available. Capacitors are another technology that has been tested for this scale of power management. While capacitors excel at quick discharge to meet a varying load, they are not a commercially available technology at the necessary scale, and require further development before Alaskan deployment. Some batteries, such as lead acid and zinc bromide batteries can meet short term capacity needs but cannot perform the rapid discharge of capacitors and flywheels.

For some wind, tidal, and solar resources the largest variation in generation capacity may occur over a single day. For instance, while the sun shines all day making solar energy available, nighttime loads cannot be met without storing the excess solar energy of the daytime. There are a number of batteries which can meet this diurnal load variation. The zinc bromide, lead acid, and VRB flow batteries have all been tested with power and energy capacity that are appropriate for rural villages that could rely of a varying renewable resource. Zinc bromide batteries are a commercially available technology that shows a great deal of promise for these applications, but are not yet fully commercial. Lead acid batteries are a commercial technology, but current Alaskan installations of lead acid batteries have encountered problems with battery failure and short lifecycles. When considering these technologies, verified lifecycle information should be obtained from the provider. The VRB flow battery is an emerging technology that is available in limited power selections. The lifetime of the VRB battery electrolyte is impressive, but testing to date has not demonstrated sufficient system reliability for field applications.

In addition to meeting electrical needs, most Alaskan communities have a significant thermal load that could also be met using diurnal excess electrical capacity from renewable sources. Installing a heated water tank at the utility site can immediately take advantage of a wind resource that periodically exceeds community load. As the tank gets larger, heat losses from the tank become almost negligible for as long as weeks. This is a simple technology that does not present significant technical installation problems. An added level of complexity comes when distributing this stored thermal energy to the community. There are commercially available units for distributing electrical heating throughout the community, which can reduce the need for residential boilers used for heating. Additionally, with a combined heat and power (CHP) infrastructure, centralized thermal storage can meet the thermal needs of the community using free excess renewable electricity on installed capacity.

Many of Alaska's renewable resources also vary seasonally. Communities that rely on hydropower might have excess capacity during spring melt periods while they cannot meet the community load during winter months as the hydro resource freezes. In most Alaskan instances, seasonal variability also applies to wind, solar, hydrokinetic, and tidal energy.

On a large utility scale, compressed air energy storage (CAES) has been implemented for the storage of enormous amounts of energy. However, this technology requires specific geological formations, salt caverns in most applications, which are not present in Alaska. Further development of CAES in natural gas reservoirs is occurring, and might show promise in the future. Pumped hydro is a long term storage option for communities with larger power capacities and the correct topographical features. Installing pumped hydro storage requires a natural or man-made reservoir at altitude of at least several hundred feet. Sodium sulfur battery technologies are also appropriate for long term storage, but are only commercially available in sizes 1 MW or larger. Cost for all long term storage options might be prohibitive as they require significant capital investment.

This report was produced as a first order assessment of the specific technology options available for short, mid, and long-term energy storage for Alaskan communities. The options considered as part of this report are summarized in Table 1, with Table 2 limited to the technologies considered technologically simple to implement. It is expected that this report will serve as a

guide for a more in-depth technical and economical feasibility assessment of specific options and storage configurations as part of efforts to stabilize the cost of energy in rural Alaska.

Energy Storage by Time Scale and Complexity

Table 1 - Energy Storage Options by Time Scale

Energy Storage Options by Time Scale		
Short (0-30 minutes)	**Medium (30 min - 12 hrs)**	**Long (12 hrs - 3 months)**
Flywheel	Ceramic Thermal Storage	Compressed Air
Zinc Bromide Battery	Thermal for Electrical Generation	Pumped Hydro
Lead Acid Battery	Thermal Fluid Storage	Borehole Community Thermal
Capacitors	VRB Battery	Sodium Sulfur Battery
	Zinc Bromide Battery	Hot Water Storage
	Lead Acid Battery	
	Electric Vehicles	
	Hot Water Storage	

Table 2 - Technologically Simple Energy Storage Options

Technologically Simple Energy Storage Options	
Type	**Time-Scale**
Ceramic Thermal	Medium
Borehole Thermal	Long
Lead Acid Battery	Short-Medium
Zinc Bromide Battery	Short-Medium
Hot Water Storage	Medium-Long

Reservoir Storage

Compressed Air Energy Storage (CAES)

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Large energy storage capacity (up to > 1 GWH) • Uses existing technologies and materials (standard air and compressors/turbines)	*Weaknesses* • Requires significant underground reservoirs • Current applications use natural gas heating for electrical regeneration
External origin (attributes of the environment)	*Opportunities* • Fits large and small scale seasonal storage needs • Develop alternative storage facilities, including synthetic reservoirs	*Threats* • Underground storage of surface air could negatively impact permafrost • Unacceptable leak rate in mine reservoirs (>1%)

Compressed Air Energy Storage Technologies					
Provider	**Type**	**Power**	**Energy**	**Website**	**Application**
Energy Storage Power Corp.	Salt Cavern	110 MW	2860 MWh	http://www.espcinc.com	McIntosh Power Plant, Alabama
KBB Underground Technologies	Salt/CH4	290 MW	870 MWh	http://www.kbbnet.de	Huntorf CAES, Huntorf, Germany
Iowa Stored Energy Park	CH4 Fired	200 - 300 MW		http://www.isepa.com	In Design

Compressed air can be used as a medium for storing excess energy using a process where air is compressed during times of excess energy, typically base load power at night, and running the air through a turbine when power is needed in addition to renewable capacity. One major hurdle is finding a storage container of suitable size to hold enough compressed air to store a useful amount of energy. Two plants are currently operational worldwide. In the Mackintosh, Alabama plant, large underground caverns in salt domes have been created by solution mining

which form large scale, gas tight volumes ideal for storing compressed air. In Phoenix, Arizona a compressed air storage system has been developed which uses solar energy to heat the air when it is being released, allowing more energy to be extracted from the stored air than the energy required to compress it.

Is This Technology Viable for Alaska?

The primary barrier to implementing CAES in Alaska is the lack of identified geological structures which would serve as storage reservoirs. Current CAES applications rely on underground salt caverns for storage. This resource is not available in Alaska. Significant additional research would be required to adapt current CAES technology to potential Alaskan reservoirs.

One possible course of research would be into using mines in Alaska for compressed air storage. However, compressed air storage works best at high pressures to maximize turbine performance and leak rates cannot exceed 1%[1]. In near surface mines, permeability in rocks and fissures would likely allow too much air to leak. Depleted natural gas wells may provide storage for compressed air in areas of the state where these occur, such as in the Cook Inlet basin.

Most current CAES applications rely on additional natural gas heating to raise released air to a higher temperature for more efficient turbine generator operation. One plant in development for Phoenix, Arizona by Brayton Energy relies on solar heating to replace this natural gas. Additionally, an adiabatic (no-heat) system is being developed by the Electric Power Research Institute[2], but is still in the design process. Because of the necessary air heating, communities lacking a source of natural gas or solar resources would not be well suited for CAES.

[1] Personal communication between Winston Burbank (ACEP) and Jim Kesslei (Brayton Energy)
[2] http://www.energystorageandpower.com/pdf/epri_paper.pdf, Page 5

Pumped Hydro (Water) Storage

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Large energy storage capacity (up to > 1 GWH) • Uses existing technologies and materials (pumps and existing water)	*Weaknesses* • Requires specific topography: reservoir needed at reasonable altitude (several hundred feet) • Current technologies use high power pumps (~50 MW) • Slow transition from charge to discharge
External origin (attributes of the environment)	*Opportunities* • Fits large and small scale seasonal storage needs • Adapt current release mechanism for smaller load (.5 – 5 MW) and longer discharge time	*Threats* • Pumping from ocean to reservoir at altitude introduces saline • Replace existing open land with industrial reservoir

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Pumped Hydro Energy Storage Technologies					
Provider	**Power**	**Energy**	**Head**	**Website**	**Application**
Pacific Gas and Electric	1,212 MW	<100 GWh	1,630 feet	www.pge.com	Helms Pumped Storage
Dominion/Allegheny Power System	2.1 GW		1,262 feet	www.dom.com	Bath County Pumped Storage
PSEG/First Energy	400 MW	2.8 GWh	700 feet	www.pseg.com	Yards Creek Generating Station

Pumped hydro uses excess electrical power to move water from a lower elevation to a higher elevation, and then runs the water back through the turbine to generate power during times of increased demand. Usually these cycles occur on the time scale of a day or week – when power demand is lowest, typically at night, water is pumped into the reservoir. Then, during the day when power needs are generally highest, water is released to generate power. In places where a

suitable location can be found to build a pumped storage system, this is the most cost effective form of storage available when large storage capacity is required. However it requires the right geographical location with adequate water, a moderate climate, and enough variation between times of low cost power and high cost power to make the project economical. Most pumped hydro facilities have been quite large and limited attempts have been made to integrate them into remote power systems. Capacity and rated power are generally determined by the geographical considerations and power response is quite good. However, due to momentum in the piped water column, most pumped hydro facilities cannot quickly go from consuming energy (pumping) to providing energy.

An additional opportunity is in controlling existing of hydroelectric generation to supplement additional renewable resources. When wind or solar resources are available, a hydro resource can be deferred in existing reservoirs. This storage capacity can increase overall renewable penetration and prevent the need for diesel generation using the stored hydro capacity.

Is This Technology Viable for Alaska?

Like CAES, pumped hydro storage relies on local geological attributes for energy storage. As the figure below indicates, a combination reservoir volume and height are required for significant energy storage. Alaska's plentiful lakes and varying topography suggest that finding appropriate reservoir locations should be possible for many communities. However, it is important to recognize the scale on which pumped hydro is possible. Because storage reservoirs require infrastructure investments (dams etc.), installing storage capacity for small utilities is unlikely to be economical.

Furthermore, the current applications of pumped hydro require 0.5-2 Gigawatts of generated power for pumping, which is much larger than most Alaskan communities. Pumped hydro storage is only a viable storage mechanism for utilities with relatively large load capability, making the proposed project in Kodiak an appropriate application of the technology. Finally, winter access to the pumped storage is only available if the reservoir is large enough or the climate is mild enough to maintain liquid water. This limits the applicability for seasonal storage in Alaska. An additional barrier to implementing pumped hydro storage is the current lack of

utility pricing structures in which the cost of power varies by time of day. This structure increases the economic viability of pumped hydro[3].

Kodiak Electric Association (KEA) is considering pumped hydro as a way to permit greater penetration of wind on their grid as part of the planned Pillar Mountain Wind Farm project. KEA is a grid-isolated utility with generation including a combination of diesel generators and hydropower from their Terror Lake project. KEA is planning to install 3 MW of wind (from two General Electric 1.5 MW SLE wind turbines) as the first phase of their Pillar Mountain project[4]. A second proposed phase would incorporate four additional GE turbines and push penetration in excess of 60%, but this would result in expected difficulty in maintaining grid stability and frequency regulation. KEA is currently assessing options for incorporating pumped hydro, as well as a small conventional battery storage system, to absorb power variations and ensure the power quality as a whole remains high.

Figure 1 below depicts the necessary volume for pumped hydro storage based on energy capacity and reservoir altitude.

[3] Email correspondence between Gwen Holdmann (ACEP) and Douglas Ott (AEA Hydro Program), 7/21/2009
[4] http://www.kodiakelectric.com/renewable.html

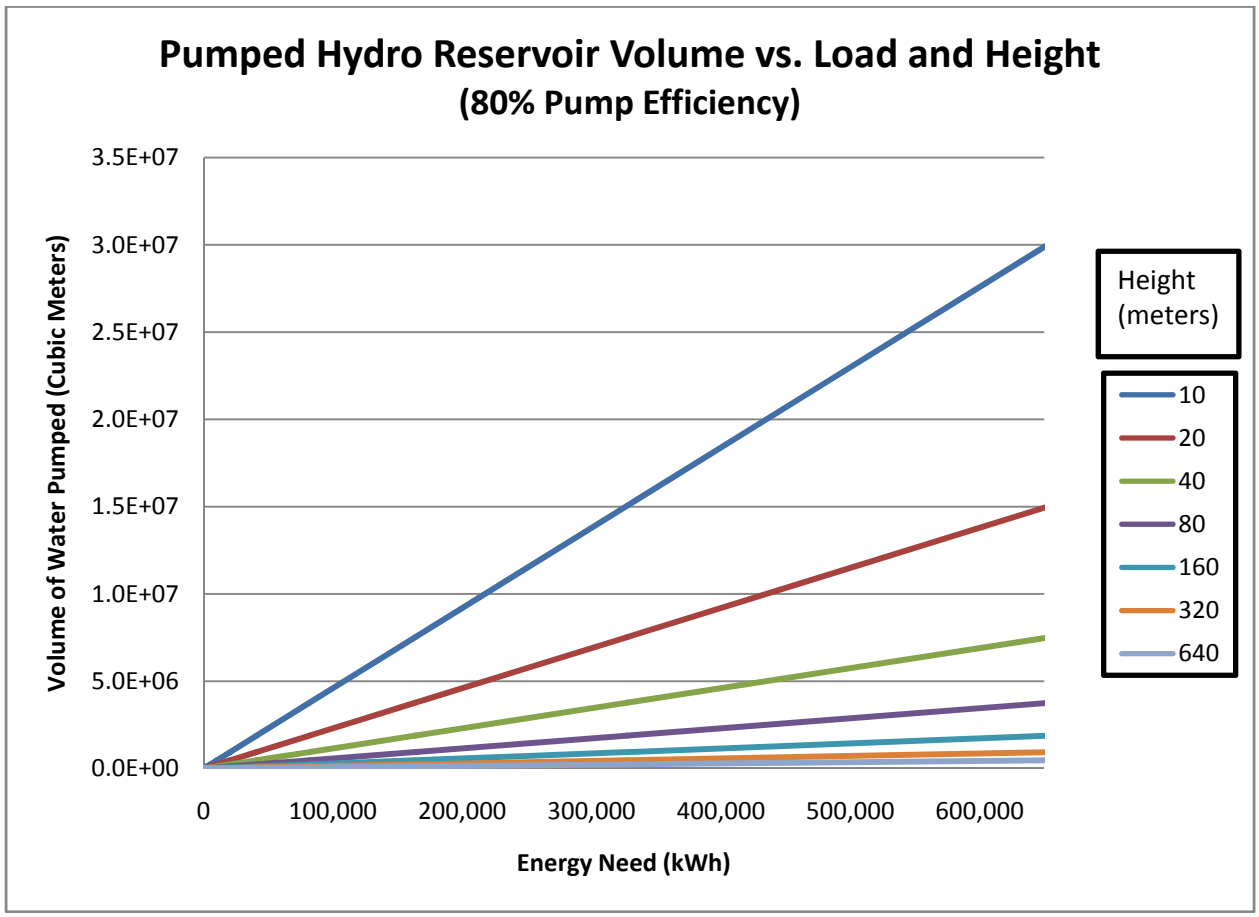


Figure 1 - Pumped Hydro Reservoir Volume Calculations

Mechanical Storage: Flywheel

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Load leveling technology • Mechanical solution could be well suited to Alaskan climate	*Weaknesses* • Not commercially available in a variety of sizes • Variability in many renewable resources too large for single flywheel
External origin (attributes of the environment)	*Opportunities* • Adapt high power systems to lower power/ • Maximize electrical generation efficiency to save expensive diesel fuel	*Threats* • Might not be the best use of limited funds when greater diesel reductions are possible elsewhere

Flywheel Energy Storage Technologies					
Provider	**Power**	**Energy**	**Discharge Time**	**Website**	**Application**
Beacon Power	20 MW	5 MWh	15 minutes	http://www.beaconpower.com	Prototype Facility - 100 kW units
Vycon	215 kW	.83 kWh	30 seconds	http://www.vyconenergy.com	Direct Connect VDC
PowerCorp	500-1000 kW	5 kWh	30-150 seconds	http://www.pcorp.com.au/	Wind-Diesel Integration

A flywheel is a device which stores kinetic energy in a rotating mass. Flywheels are not new technology, but modern materials and other innovations are spurring research into making flywheels systems that are smaller, lighter, cheaper, and have a greater capacity. Flywheels have been used in applications including energy storage such as uninterruptable power supplies, grid conditioners for high cost manufacturing, and even powering vehicles. For example, the gyrobuses used in Sweden in the 1950's were powered by flywheels. Flywheels have storage characteristics comparable to batteries in that their capacity is generally fixed but can be drawn down quickly or slowly depending on need. Typically flywheels are used in remote applications to smooth out power fluctuations and allow the starting of a dispatchable generator when needed.

As compared to batteries, typical storage times at rated power in the order of minutes are expected. As a mechanical system, flywheels have the advantage of very long lifecycles and require minimum maintenance. Additionally, flywheels have very fast response times. Although the limits of strength of the material used for the spinning rotor place upper limits on speed and thus capacity, most commercial flywheels are modular in that both capacity and rated power can be increased by using multiple units. There have been catastrophic failures from overloaded flywheels, but these are typically in research settings. Lastly, although recent developments such as magnetic bearings have reduced losses, flywheels have a parasitic loss to keep the unit spinning and relatively quick self discharge if additional energy is not provided.

Is This Technology Viable for Alaska?

Most current American flywheel installations use the energy storage mechanism for frequency control and power conditioning. Using the experience of other flywheel installations, this technology would be immediately appropriate for utilities where these concerns are important.

One barrier to applying this technology for storage of renewable energy is the fast discharge cycle[5]. Although flywheels can storage large amounts of energy, the high power dissipation would be inappropriate for a rural system with a relatively low load. Hence, storage of an hour-to-hour or diurnal resource is not a good application for flywheels. However, flywheels are appropriate for maximizing the benefit from a renewable resource when it is active ensuring stable power in a high penetration system.

With regards to renewable energy, the primary role of flywheels is to provide a quick-responding bridge between the times when the resource is available and unavailable. For instance, if a diesel generator must be ramped up to meet load when the wind stops blowing, a flywheel is an excellent quick discharge mechanism to meet this load gap. Using flywheels to meet load at this crucial time between sources requires sophisticated control systems and should be considered a "higher" technology.

One example of this application is PowerCorp. This Australian company has successfully integrated their flywheel system with wind systems and wind-diesel hybrid projects, typically in mining applications. The use of flywheels has allowed wind-diesel systems to operate at very

[5] Email correspondence, Louis Romo, Vycon Flywheel Energy, 7/2/2009

high penetrations of wind power, reportedly as high at times as 90%, to offset diesel generation[6]. In this scenario, the flywheel acts as spinning reserve and can provide frequency and voltage control. The PowerCorp flywheel ranges in size from 250 kW to 1 MW. The company has also developed control systems which alleviate the risk of blackouts despite the high penetration of a variable wind resource.

Thermal Storage

Thermal storage refers to the storing of energy in the form of heat in a reservoir that gains temperature and pressure as energy is added. Excess electricity can be used to produce this energy using resistive heaters, which dissipate heat as they draw current from an electrical source. Placed in a hot water tank, a resistive heater will raise the temperature of the water while current is applied, and the energy will remain in the water. Heating can also occur by utilizing the exhaust heat from a diesel generator. In such generators, a large amount of the energy in diesel fuel is not turned into electricity. Rather, it is released by heating the generator and the working fluids. Using this exhaust energy is called "waste heat recovery". Resources such as solar energy and geothermal energy occur naturally in the form of heat, which can be used directly or stored for later electrical generation.

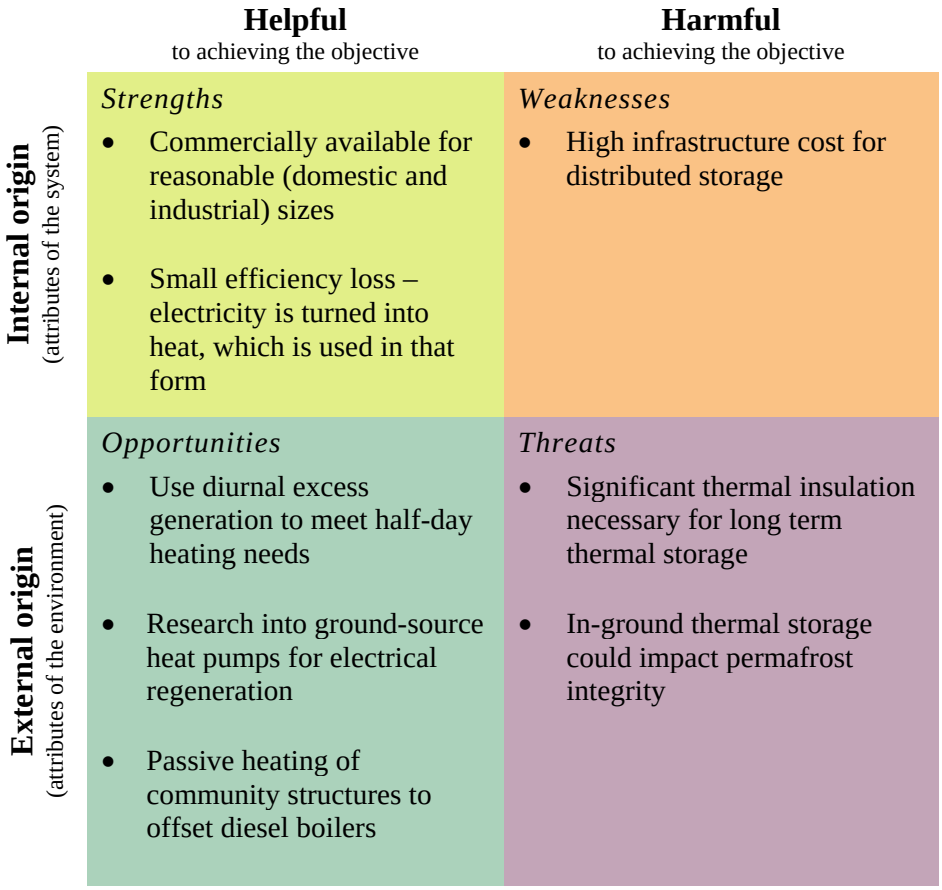
Stored thermal energy can be used to generate electricity using a variety of mechanisms. For low temperature heat, an Organic Rankine Cycle (ORC), operates similarly to a standard steam turbine, but replaces the steam with a refrigerant which vaporizes at low temperature. The ORC generator at the Chena Hot Springs power plant operates at a high temperature of around 165°F[7]. The lower operating temperatures make an ORC unit significantly less efficient than a standard steam turbine due to the Carnot limit, which is defined by the high and low temperatures in the fluid process. It is possible to achieve higher reservoir temperatures using different storage substances. In some solar-thermal applications, parabolic troughs focus solar waves onto a molten salt reservoir which can be kept at temperatures above 400-500°C[8]. These reservoirs are usually kept at high pressure to maintain the fluid. These high temperature reservoirs can be used to generate steam for a turbine or drive a reverse heat pump.

[6] http://www.pcorp.com.au/index.php?option=com_content&task=view&id=99&Itemid=157
[7] http://www.chenahotsprings.com/geothermal-power/
[8] http://www.nrel.gov/csp/troughnet/thermal_energy_storage.html

Although electricity generation is possible, the efficiency of the conversion process is quite low, as defined by the Carnot limit for heat engines. Because many communities in Alaska have a heating energy load that equals or exceeds their electrical energy load, a more appropriate use may be stored thermal energy directly for community heating. One option for this heating is to use excess electrical energy to heat thermal reservoirs in each home, or distributed within the community. Hot water tanks and ceramic blocks are useful for such storage. Although distributed storage eliminates the need for a heat distribution system, smaller storage units will have more significant losses and a higher reservoir capital cost, and increase the complexity of the control system needed. Another method for storage is centralized community storage, which can achieve an economy of scale in tank building. Larger water tanks will have less significant heat losses; as tank size increases, volume increases more quickly than surface area, meaning less heat is dissipated to the atmosphere from the tank surface, but the heat distribution system will add cost. A community in Canada has developed community storage in soil, using a heated borehole wherein the thermal energy can be used throughout the winter[9]. Centralized storage can be used to heat community buildings or installed distribution infrastructure can transport the heat to individual homes.

[9] http://www.dlsc.ca/borehole.htm

Thermal Storage for Heating Purposes



Thermal Storage and Heating Technologies					
Provider	**Type**	**Power**	**Energy**	**Website**	**Application**
Steffes Corporation	Ceramics	3.5 - 6.5 kW	13.5 - 40.5 kWh_t	http://www.steffes.com/offpeak	Household Units
Steffes Corporation	Ceramics	53 - 160 kW	300-1000 kWh_t	http://www.steffes.com/offpeak	Commercial/ Industrial
Drake Landing	Borehole		Meets Seasonal Need	http://www.dlsc.ca/borehole.htm	Community Heating

Is this technology viable for Alaska?

Storing excess electricity for heating is a good example of a low complexity storage technology that is immediately viable in Alaska. With equipment as simple as a heated water tank, currently

unused excess wind energy can be converted to heat in order to offset expensive diesel fuel used in conventional boilers. A case study of the Saint Paul Island load and wind resource indicates that a tank as small as 5,000 gallons, maintained at 90°C can achieve significant diesel savings over the lifetime of a 20 year project. See *Appendix I: Saint Paul Island Energy Storage Analysis* (page 34) for details. This tank is similar to one that has already been installed at the Saint Paul TDX power plant. Mixing glycol or a similar antifreeze with the water can achieve higher storage capacity per gallon by raising the boiling temperature and allowing a higher temperature (higher energy) reservoir.

Technologies such as distributed ceramic storage are commercially available, but would require in-home installation. A decision between centralized and distributed storage options would require an economic analysis of the storage equipment and necessary public infrastructure.

Figure 2 below depicts the necessary volume of a hot water tank at different reasonable storage temperatures.

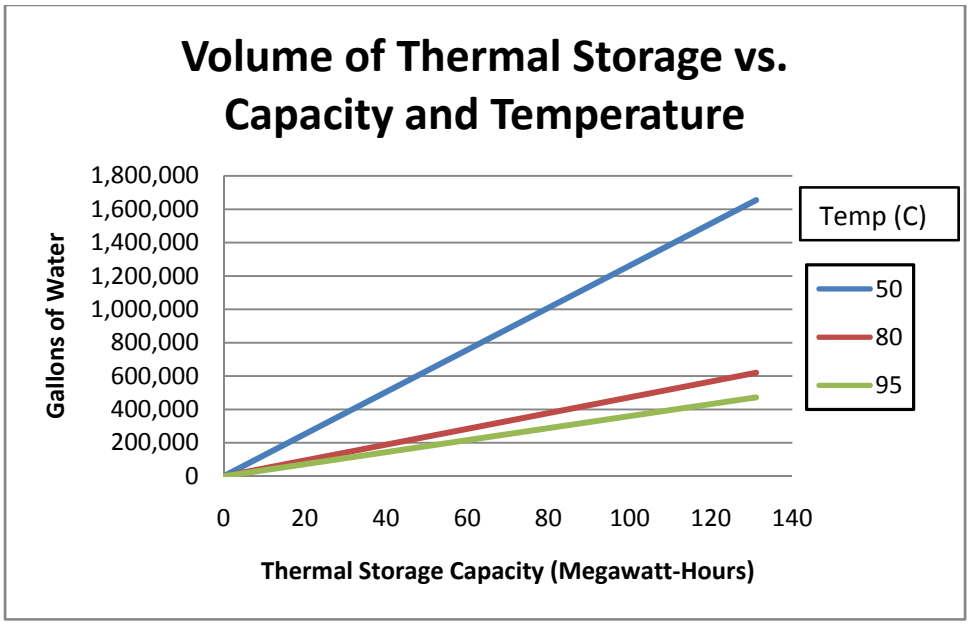


Figure 2 - Thermal Storage Volume

(assumes 100% electric to heat conversion and 32 ° C useful water temperature)

Thermal Storage for Electrical Purposes

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Useful for diurnal variability and peak shaving	*Weaknesses* • Strictly less efficient than thermal storage for heating purposes • Current viable systems require > 6 MW power input for 100 kW output
External origin (attributes of the environment)	*Opportunities* • Remote electrical generation from existing thermal sources	*Threats* • Significant thermal insulation necessary for long term thermal storage • In-ground thermal storage could impact permafrost rigidity

Thermal Energy Storage Technologies					
Provider	**Type**	**Power**	**Generating Efficiency**	**Website**	**Application**
Arizona Public Service	Xceltherm /ORC	1.16 MWe	20.7% Heat to Electric	http://www.nrel.gov/csp/troughnet/power_plant_data.html	Solar Trough Storage

Is this technology viable for Alaska?

When using stored thermal energy to regenerate electricity, most technologies encounter significant energy losses. For low temperature situations, such as a conventional water tank, an ORC turbine would result in heat-to-electric efficiencies well below 30%. Although ORC turbines are useful for converting existing low-temperature resources (i.e. hot springs) into electricity, a cycle which goes from electricity, to heat, and returns to electricity is an inefficient use of stored thermal energy. See *Appendix II: Thermal Storage Electrical Generation with ORC* for more information. In Alaska, the stored heat is better suited for direct heating systems.

Battery systems or reservoir storage are a more efficient way to store electricity for later electrical use.

Thermal Fluid Storage

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Stores energy in the form of hot fluids (oils, molten salts) • Large scale solar-thermal collection	*Weaknesses* • Requires high pressure storage • Relies on very high temperature (400° C) fluid • Current systems are large, > 6MW
External origin (attributes of the environment)	*Opportunities* • Offset fluid costs with filler in thermocline system • Explore lower cost concrete storage	*Threats* • Currently tested in hot desert climate – energy losses to atmosphere would be greater in Alaska • Fluids freeze at high summer temperatures – system threatened by power loss

Thermal Fluid Energy Storage Technologies					
Provider	**Type**	**Power**	**Energy**	**Website**	**Application**
Sandia National Lab	Molten Salt		2.44 MWh_t	www.nrel.gov/csp/troughnet/pdfs/jpacheco_thermocline.pdf	Thermocline
Solutia Inc.	Pressurized Therminol	50 MW		www.therminol.com	Iberese Thermosolar
Saipem/ Isentropic	Argon/ Insulated Gravel	6 MW	30 MWh	http://isentropic.co.uk	Ericsson Cycle

Is this technology viable for Alaska?

Most thermal fluid storage is currently adapted to large arrays of parabolic solar troughs. By focusing a significant solar resource, molten salts and similar fluids can be brought to very high temperatures suitable for electrical generation. Research has also been done into concrete arrays for high temperature thermal storage of solar energy. Alaska has an inconsistent solar resource, especially during the winter when energy demand is high. Hence, these storage technologies are not appropriate.

An additional barrier to use of thermal fluids in Alaska is the high freezing temperatures of the fluids. Most current applications exist in very hot, desert climates; even at mild Alaskan summer temperatures a thermal fluid system would be threatened by freezing.

Isentropic Ltd, a British energy company, is currently developing a system which stores heat in argon in an insulated gravel bed. While such system might reduce freezing concerns, the technology is reportedly two years away from demonstration, and is therefore not viable. Additionally, the prototype system will be large, ~ 6 MW, which makes storage feasible only in a limited number of larger Alaskan communities.

Chemical Storage

Batteries

For electrical systems, batteries are the most direct way to store electrical energy. Batteries are used for many conventional systems, such as uninterruptable power supplies, cell phones, and laptops. Although very large batteries are available for power supply, the amount of energy stored in typical batteries is much smaller than the amount of energy we use in residential and commercial buildings, which means that many batteries need to be combined to provide an appropriate amount of capacity. Current battery systems are also relatively expensive, have high maintenance costs, and have limited lifetimes -- typically five to six years in most remote power applications. This means that the cost of storage (the cost of the battery divided by the total number of kW-hours of storage possible) is often much higher than the cost of generating new energy from fuel, which means that batteries are not generally appropriate for long term energy storage. However, rising diesel fuel prices are making battery-renewable hybrid power systems

more economically attractive. Batteries are more appropriate to provide short term energy storage to allow a transition between a variable renewable energy source and a dispatchable generator, as is the case in the wind-diesel power system in Wales, or smaller applications, such as home or small community systems where the cost of dispatchable generators can be quite high. Since batteries operate on direct current (DC), a power converter is also required to allow them to supply (and be charged by) alternating current (AC). There are however many different types of batteries which have different operating characteristics. Development of sodium sulfur and flow batteries have potential for long term battery storage.

Flow Batteries

Several battery technologies have been developed during the past several decades that can be classified as flow batteries. These batteries store energy in liquids that contain materials capable of storing electrons as compared to the electrochemical reactions that drive more traditional battery systems. These batteries act very much like fuel cells, where electrons diverted to an external circuit while ions are exchanged through a membrane. The electrolyte is usually kept in very large tanks. Although the battery itself has no moving parts, pumps are required to move the electrolyte past the membrane. This fact allows the decoupling of power output and storage capacity that is found in most other batteries since a flow battery can be designed to provide a specific power output (by determining the membrane surface area and electrolyte flow rate) and specific capacity (the size of the electrolyte storage). The VRB (for Vanadium Red-ox Battery) is one of these battery types which was produced by VRB Storage Systems (Canada) and is currently marketed by Prudent Energy and Cellstrom . A small unit was being tested at UAF for the past two and a half years and several dozen installations exist around the globe. Several flow batteries have been implemented in remote applications, the most notably in a wind-diesel application on King Island, off the coast of Australia. Kotzebue Electric Company has also been interested in purchasing a battery of this kind to operate in conjunction with their wind farm. Unfortunately, VRB Storage Systems has recently undergone a change in ownership resulting in some uncertainty about the future of this product. Other flow batteries include sodium bromide and zinc bromide systems, but these share most of the same basic properties. Flow batteries usually have very low power density, meaning it takes a large volume of fluid to provide any significant capacity, but have very long theoretical system lives, with pumps and power

electronics being the typical weak links. Most flow batteries also have very fast response times and can be sized to meet a specific need. Depending on the electrolyte type, flow batteries must be kept at a relatively constant temperature. The low self discharge rate and ability to decouple power and capacity would allow flow batteries to be used for longer, multi-day or even seasonal storage.

Zinc Bromide Flow Battery

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Storage capacity up to 2.8 MWh • Power output (< 500 kw) appropriate for rural scale • Cost appropriate if projected lifetimes succeed	*Weaknesses* • Reliability remains in question
External origin (attributes of the environment)	*Opportunities* • Modularity makes transportation reasonable for local storage	*Threats* • Interactions with cold environment unknown

Zinc Flow Battery Storage Technologies					
Provider	**Type**	**Power**	**Energy**	**Website**	**Application**
Premium Power	Powerblock 150	150 kW	150 kWh	http://www.premium power.com	
Premium Power	Transflow 2000	500 kW	2.8 MWh	http://www.premium power.com	Duke Energy Substation Deferral
ZBB Energy	Zess 50	25 kW	50 kWh	http://www.zbbenergy.com	500 kWh transportable modules

Is this technology viable for Alaska?

Zinc bromide flow batteries have a number of attributes that make them immediately appealing for deployment in Alaskan power systems. This is an appropriately sized commercial technology that appears to be applicable for increasing renewable penetration by smoothly hourly and daily fluctuations in renewable resources. However, if the flow batteries are used to increase reliance on renewable sources, it is crucial that the reliability of the battery technology be tested in an Alaskan climate. By confirming an accurate lifetime for these batteries in Alaskan deployment, an accurate economic model could be developed which may support widespread inclusion of the zinc bromide flow battery in Alaskan power production.

VRB Flow Battery

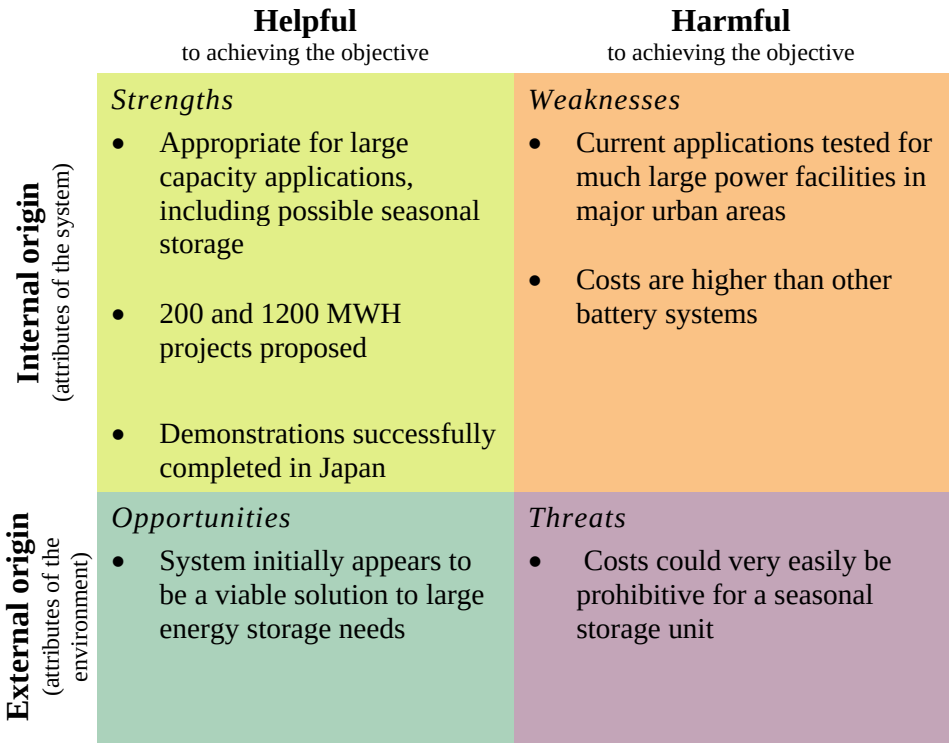
	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Technology tested in a university (UAF) environment • Electrochemical efficiency verified at +70% DC in/DC out basis	*Weaknesses* • Costs remain high • Reliability concerns remain • Business development issues
External origin (attributes of the environment)	*Opportunities* • Rural Deployment is a design priority	*Threats* • Some concerns about possible toxicity of some vanadium compounds

VRB Flow Battery Storage Technologies					
Provider	**Type**	**Power**	**Energy**	**Website**	**Application**
Prudent Energy	VRB-ESS	10 kW	10 kWh	http://www.uaf.edu/acep/projects/ energy-storage-devices/	ACEP Research Battery
Prudent Energy	VRB-ESS	250 kW	2 MWh	http://www.pdenergy.com	PacifiCorp Moab Utility
Cellstrom	FB10/100	15 kW	100 kWh	http://www.cellstrom.at/Products.39.0.html?&L=1	Solar/Remote/Mini

Is this technology viable for Alaska?

From a technological standpoint, the VRB batteries for sale from Prudent Energy are an appropriate technology for stabilizing power generation from variable renewable resources. VRB batteries can produce power and store energy on scales that are consistent with the needs of many Alaskan communities and the Moab Utility installation is a good example of the VRB applicability. However, there remain serious concerns about the life of this product which would seriously jeopardize the economic viability of installing VRB batteries. The test battery at UAF experienced a number of mechanical failures and the appropriate repairs would significantly increase the budget of a VRB battery installation beyond the capital costs. Any prospective VRB installations would require a detailed maintenance agreement with the provider in order to ensure a legitimate energy storage system. For more information on the VRB Battery please see the ACEP report at *http://www.uaf.edu/files/acep/VRB%20Vanadium%20Red-Ox%20Battery%20testing%20at%20UAF.pdf*.

Sodium Sulfur Battery



Sodium Sulfur Battery Storage Technologies					
Provider	**Type**	**Power**	**Energy**	**Website**	**Application**
NGK Insulators	NAS Battery	50 kW	360 kWh	http://www.ngk.co.jp	Utility/Transportation Research
NGK Insulators	NAS BESS	34 MW	245 MWh	http://www.rokkasho.jp/	Rokkasho Village Wind Farm

Is this technology viable for Alaska?

As a battery technology, sodium sulfur batteries are becomingly increasingly commercial. American distribution is beginning and third party verification through Sandia National Laboratory supports the viability of the storage mechanism[10].

Currently the only commercial supplier of sodium sulfur batteries is NGK Insulators. According to their sales division, the company is only prepared to manufacture and sell systems larger than

[10] Benjamin L. Norris, Jeff Newmiller, Georgianne Peek, Sandia National Laboratory, *NAS Battery Demonstration at American Electric Power*,< http://prod.sandia.gov/techlib/access-control.cgi/2006/066740.pdf>

1 MW with 6 MWhs of storage. The cost for such a system ranges from $3-4 million including the cost of DC to AC power conversion[11].

Because of the high energy storage capacity available in the NAS batteries, they are an attractive storage option for both diurnal and perhaps seasonal variations in renewable resources. With a relatively low-power system, wind blowing in the winter could fill a high capacity battery (1MWh) for use during the summer season of reduced wind velocity. However, such low-power systems are currently unavailable and therefore the battery is not a viable storage alternative for small-scale high penetration renewable systems. These batteries operate between temperatures of 290 and 390° C[10], so smaller batteries or long term storage may be difficult due to heat losses and will require additional heating to preserve battery life. Even larger systems are comprised of smaller storage units, and the possibility of future commercial NAS battery options for small scale applications make it an important technology to follow.

Lead Acid Battery

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • 1 MW/ 1.4 MWh size appropriate for diurnal storage • Tested in Alaskan environment (Metlakatla)	*Weaknesses* • Lifecycle is very short • Highly impacted by temperature
External origin (attributes of the environment)	*Opportunities* • Distributed storage capacity with household 100 kWh units	*Threats* • Large installation and capital cost for distributed storage • Critically shortened lifecycle changes economic analysis in cold climate

[11] Telephone conversation between John Murphy (ACEP) and Lorene Kelley (NGK Insulators), 7/10/2009

Lead Acid Battery Storage Technologies					
Provider	**Type**	**Power**	**Energy**	**Website**	**Application**
GNB Industrial Power	Absolyte IIp	1 MW	1.4 MWh	http://industrialenergy. exide.com	Metlakatla BESS (378 cells)

Is this technology viable for Alaska?

There have been some diesel battery hybrid power systems installed in the state, most notably at the new visitor center in Denali Park. This system allows the diesel generator to charge the system at night and permits visitors the experience of silence during the day. Other examples include a 2.25 MWhr system installed at Chena Hot Springs in conjunction with their geothermal power plant and a 1.4 MWhr system installed in Metlakatla[12]. Both were installed for load leveling to improve the quality of delivery, although the sawmill customer in Metlakatla which spurred installation of the system shut down 3 months after the battery bank was brought on-line. That battery now supports the total Metlakatla load and is charged almost exclusively by hydroelectric generation, displacing diesel generation. The original battery cells have reached the end of their expected life and are being replaced. In addition, a battery bank was installed in Lime Village to store energy from their solar array, but that system has experienced repeated failures which were not encouraging regarding the installation of batteries in rural Alaska.

[12] GNB Industrial Power/Exide Technologies, "The Metlakatla Battery Energy Storage System Twelve Years of Success." Presented at Electric Storage Association Annual Meeting, Washington DC, 5/20-22/2009

Hydrogen and Fuel Cells

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Working component (hydrogen) can be stored and produced using existing technologies • Long term storage, limited only by tank volume	*Weaknesses* • Electrical production adds inefficiency after electrolysis • Not a commercially available at utility scale • Expensive system components
External origin (attributes of the environment)	*Opportunities* • Generate hydrogen during excess generation periods for regeneration when load exceeds renewable generation • Explore CHP systems with fuel cell waste heat	*Threats* • Investing in test or demonstration technologies may fail to result in a successful energy storage system

Is this technology viable for Alaska?

Currently the use of hydrogen storage has been primarily focused on technology demonstration or experimental systems and due to its cost is not economically viable given the current state of the technology. However, if costs come down, component efficiency increases, and lower cost storage media is introduced, hydrogen may become a more viable storage media for remote power systems.

Within the last few years the use of hydrogen as a power system storage media has received a great deal of attention. To this end, several remote wind-PV-hydrogen systems have been installed where excess energy is converted into hydrogen using an electrolyzer, stored as a compressed gas, and then either burned in a modified internal combustion engine or run through a fuel cell when the renewable energy is not sufficient to cover the load. The cost of hydrogen systems is typically very high, partially driven by the need for very high quality hydrogen for most fuel cell applications but also by the costs for suitable storage tanks, and have very low round trip efficiencies, typically around 30%. As with flow batteries, the rated power and

storage capacity can be decoupled, with the fuel cell driving the rated power and the hydrogen tank size driving available capacity. When compressed gas is used, power density is typically quite good, but hydrogen systems do not typically have good response times and are sometimes installed with a small battery bank to smooth out power fluctuations. Due to the ability to store hydrogen in external tanks it is typically considered as a multi-day storage media, although the very high cost of current storage capacity limits its use for longer storage times. An excellent reference for fuel cell information is the Department of Energy website at *http://www1.eere.energy.gov/hydrogenandfuelcells.* Specifically see their fuel cell comparison chart available at *http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/pdfs /fc_comparison_chart.pdf,* which is partially summarized in Table 3 below.

Table 3 - DOE Fuel Cell Comparison

Fuel Cell Technologies					
Fuel Cell Type	**System Output**	**Electrical Efficiency**	**CHP Efficiency**	**Applications**	**Advantages**
Polymer Electrolyte Membrane (PEM)	<1 - 250 kW	53-58% for transportation, 25-35% stationary	70-90% (low grade waste heat)	Backup power, Portable Power, Small Distributed Generation, Transportation, Specialty Vehicles	solid electrolyte reduces corrosion and electrolye management problems, low temperature, quick startup
Alkaline (AFC)	10 -100 kW	60%	>80% (low grade waste heat)	Military, Space	cathode reaction faster in alkaline electrolyte - leads to higher performance, can use a variety of catalysts
Phosphoric Acid (PAFC)	50 - 1000 kW (250 kW module typically)	>40%	>85%	Distributed Generation	higher overall efficiency with CHP, increased tolerance to impurities in hydrogen
Molten Carbonate (MCFC)	<1 - 1000 kW (250 kW module typically)	45-47%	>80%	Electric Utility, Large Distributed Generation	high efficiency, fuel flexibility, can use a variety of catalysts, suitable for CHP
Solid Oxide (SOFC)	<1 - 3000 kW	35-43%	<90%	Auxiliary Power, Electric Utility, Large Distributed Generation	high efficiency, fuel flexibility, can use a variety of catalysts, solid electrolyte, suitable for CHP, Hybrid/GT cycle

Capacitors

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Capacitor technology is well understood • Power smoothing – assist control systems to meet a varying load and varying generation	*Weaknesses* • Usual energy density (J/m^3) lower than batteries • Not suited for extended generation losses[13] • Not available in large commercial scales
External origin (attributes of the environment)	*Opportunities* • Slow charging and quick dissipation: Vehicles and regenerative braking	*Threats* • Higher technology not a good investment for developing high penetration systems

A conventional capacitor is a passive electrical component that can store energy. Capacitors are commonly used in personal electronic devices for energy storage to maintain power supply while batteries are being changed. Capacitors have no moving parts and thus a very high cycle life, have very fast and consistent response, but also have very low power density. This means very large capacitor arrays are required to store meaningful amounts of energy. Conventional foil wrapped capacitors are used extensively on electric grids today to provide voltage support. Electrochemical capacitors also known as ultracapacitors and supercapacitors are able to store significantly more energy than conventional capacitors, but less than pure batteries, while maintaining a very high cycle life (>100,000 cycles). Capacitors have higher power capability than batteries, but store much less energy. Both capacitors and batteries are systems with multiple components and high capital costs. However, capacitors and batteries may be distributed throughout the system and do not require any specific geographical characteristics for implementation.

[13] http://eprint.iitd.ac.in:8080/dspace/bitstream/2074/252/3/tripathydyn96.pdf

Is this technology viable for Alaska?

Capacitors are also very costly and currently there are no commercial manufactures of large scale capacitor storage systems. They remain an emerging technology that has applications for large utility scale frequency/power leveling as well as developing electric vehicle technologies. With regards to Alaska's renewable energy resources, capacitors will likely play a role in controlling the balance between wind and diesel in future systems. However, capacitors do not provide significant storage capacity to meet load during periods of reduced generation.

Electric Vehicles

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Reduces high cost/demand diesel fuel usage in a currently non-electrified context • Adaptable to any utility capacity	*Weaknesses* • Demand side stimulus mechanism unclear • Charging and storage not centrally controlled • Costs remain high for larger vehicles
External origin (attributes of the environment)	*Opportunities* • Displace diesel fuel being used for ATVs and automobiles • Charge overnight for off-peak usage	*Threats* • Cultural resistance to electric vehicles • Danger of battery damage/losses in cold temperatures and remote vehicle use

Electric Vehicle Technologies				
Provider	**Type**	**Quote**	**Range**	**Website**
Ebus	Plug-In Fuel Cell Bus	$650,000		http://www.ebus.com
Ebus	Electric Bus	$295,000	45-100 Miles	http://www.ebus.com
Doran	e-ATV 36	$8,000	30 Miles	http://www.doranev.com
Electric Vehicle Systems	eForce	$8,000	8-12 Miles	http://www.evtworld.com/

A fleet of electric vehicles can essentially serve as a distributed set of storage batteries. With careful management and depending on economic viability, electric vehicles can put excess renewable energy to a good use. Additionally, by replacing gasoline or diesel vehicles, electric vehicles offset high cost and high emissions systems.

Electric vehicles are currently available in a variety of sizes. Electric ATVs and boats are commercial and the variety of manufacturers suggests that a competitive and cost-minimizing market exists. Batteries for electric automobiles have proven more difficult to manufacture successfully and only a few commercial options exist. Larger vehicles, such as electric buses, are also commercial, and costs appear to be falling as the technology becomes better honed.

Is this technology viable for Alaska?

From a technological standpoint, there are several ways in which an electric vehicle storage system could be immediately implemented in a variety of Alaskan communities. ATVs and boats are usually personal property, not under the domain of local governments or utilities. However, demand-side mechanisms could promote the purchase of electric vehicles in the forms of subsidies and loan systems. Coupled with an education program, it is possible that a growing electric vehicle fleet could take advantage of off-peak electricity and excess renewable.

Government owned vehicles are another option for electrical energy storage. Because larger electric vehicles are becoming commercially available, it is appropriate to consider the economic viability of purchasing such vehicles for government use.

Appendix I: Saint Paul Island Energy Storage Analysis

When considering energy storage technology options, it is useful to consider a realistic load profile and renewable resource schedule. The following case study relies on data supplied by the TDX utility on Saint Paul Island and AEA wind data. Using free modeling software provided by HOMER Energy, we were able to estimate the cost of installing and replacing different energy storage devices for a 20 year power generation project. The cost of installing and replacing the existing wind turbine and diesel generators that Saint Paul uses is also included. This attempts to create a full-project cost estimation. However, no operations or maintenance costs are included in the estimate. HOMER generates cost estimates based on the optimized use of installed equipment.

Diesel costs were estimated using $4/gallon, which is appropriate for including shipping costs. The HOMER software uses a 6% yearly discount rate for calculating the net present cost of the 20 year project. Equipment costs are based on supplier expectations or figures provided to independent researchers. Although these introduce significant uncertainty into the results, the case studies give useful guidance about how existing and emerging energy storage technologies might be incorporated into an Alaskan community relying on a variable renewable resource.

Energy Needs and Wind Resource

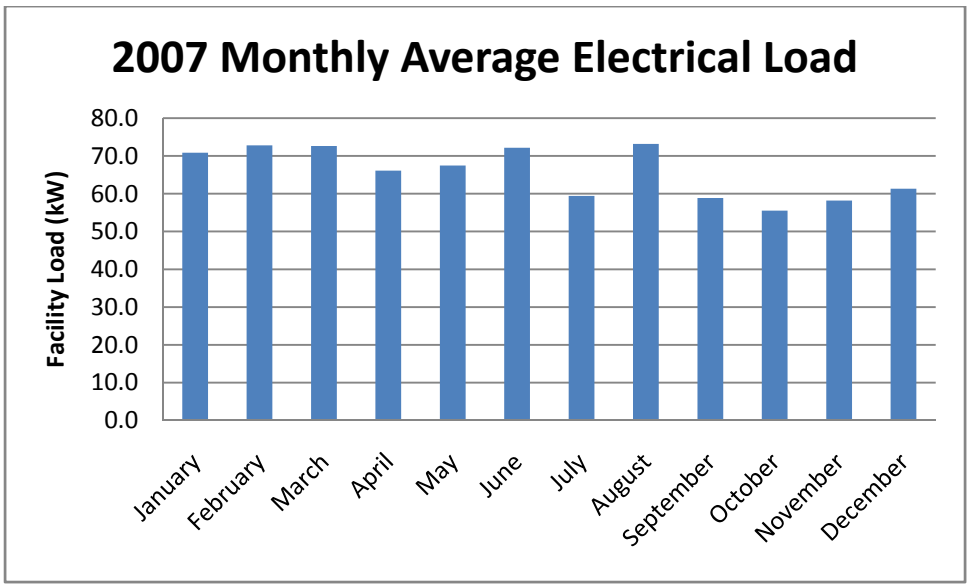


Figure 3 - Saint Paul Monthly Average Electrical Load - Source: TDX

Saint Paul load data was available in the form of monthly average loads, shown in Figure 3 above. For the sake of modeling a daily load profile, we used an educated guess as to the shape of the load over the day. Figure 4 below illustrates this approximation.

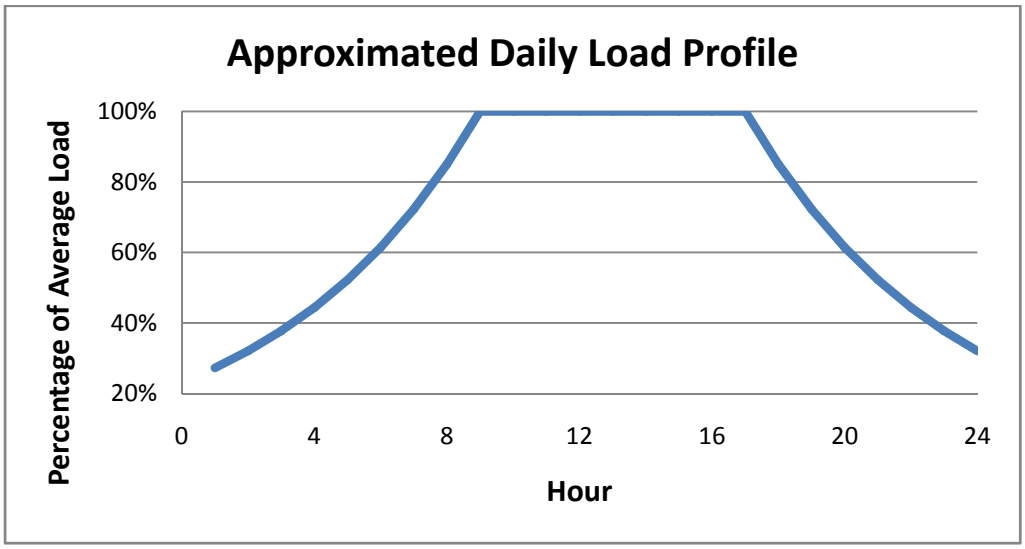


Figure 4 - Approximated Daily Load Profile

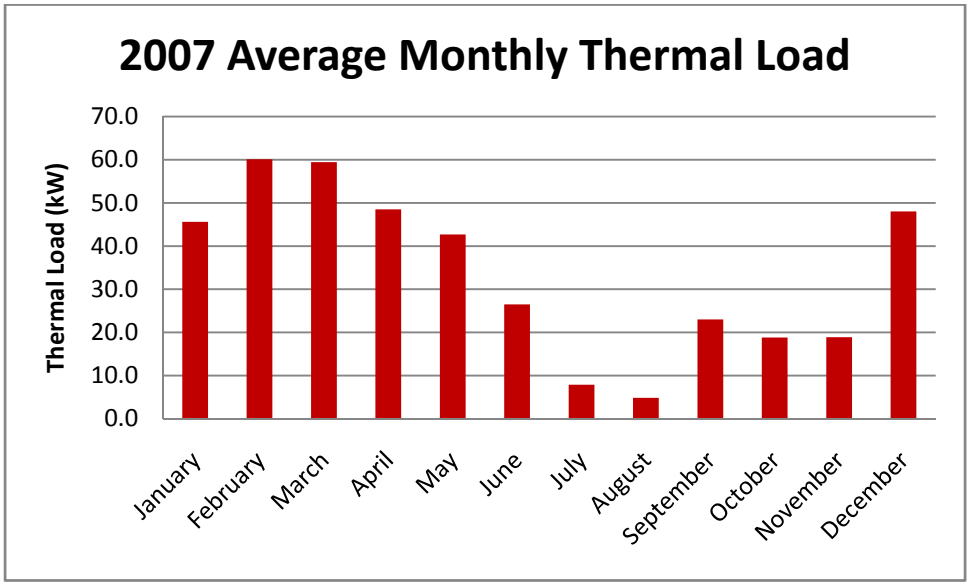


Figure 5 - Saint Paul Monthly Thermal Load (2007) – Source: TDX

TDX also provided information about the 2007 average thermal load at their utility, shown in Figure 5 above. For modeling simplicity, we treated this load as constant across each month and hour.

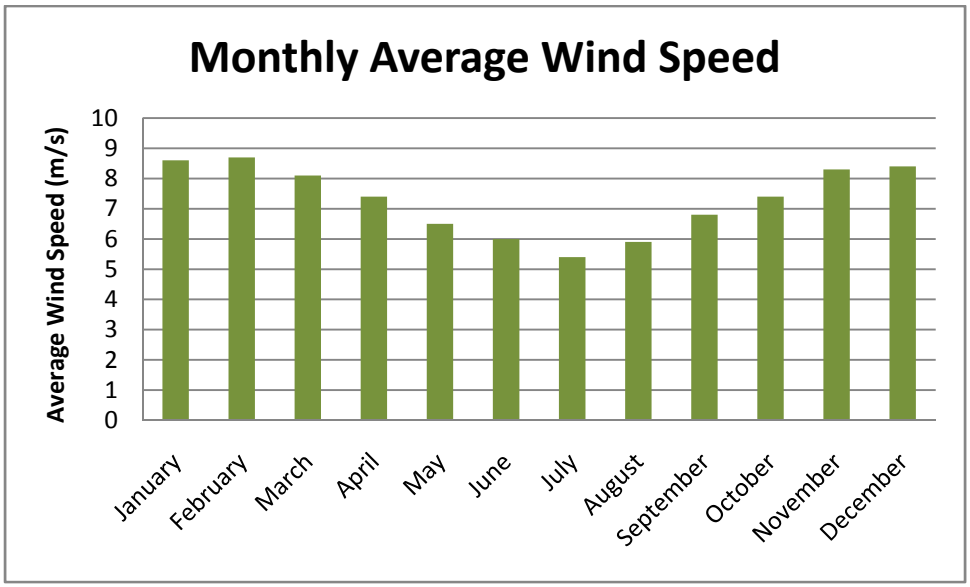


Figure 6 - Saint Paul Monthly Average Wind Speed - Source: AEA

The AEA Wind Program supplied an hourly wind profile based on data collected between 1995 and 2007. This data was collected at a height of 10 meters. As hourly data, the HOMER model accepts the AEA wind data verbatim. Monthly averages are shown in Figure 6 above.

Baseline Energy Cost Expectations

Current Equipment

Volvo 150 kW generator modeled with Volvo TAD722GE

The Saint Paul power plant currently has two 150 kW Volvo generators. According to the Power and Electric Volvo supplier, an appropriate contemporary generator is the Volvo TAD722GE.

Volvo Specifications:

Power: 197 kW

Cost: $32,000[14]

Lifetime: 20,000 hours[2]

Fuel Consumption Curve[15]: See Figure 7 below.

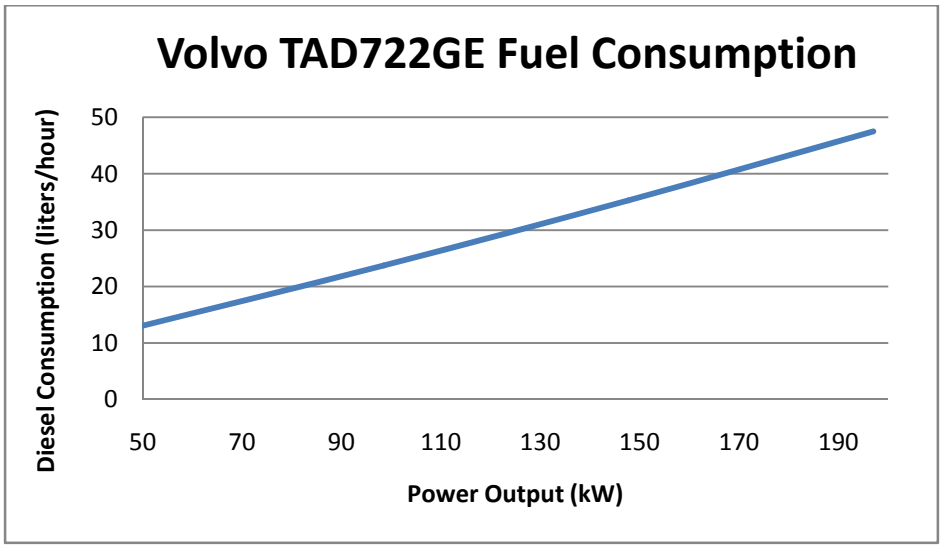


Figure 7 - Volvo TAD722GE Fuel Consumption Curve

Vestas V27 Wind Turbine

The Saint Paul facility also has one Vestas V27 wind turbine, rated at 225 kW installed on site.

Power: 225 kW

Cost: 468,500

[14] Power and Electric Company - http://www.powerandelectric.com/)
[15] http://www.volvopenta-mexico.com.mx/PDF/1800/t_tad722ge.pdf

Power Curve[16]: See Figure 8 below.

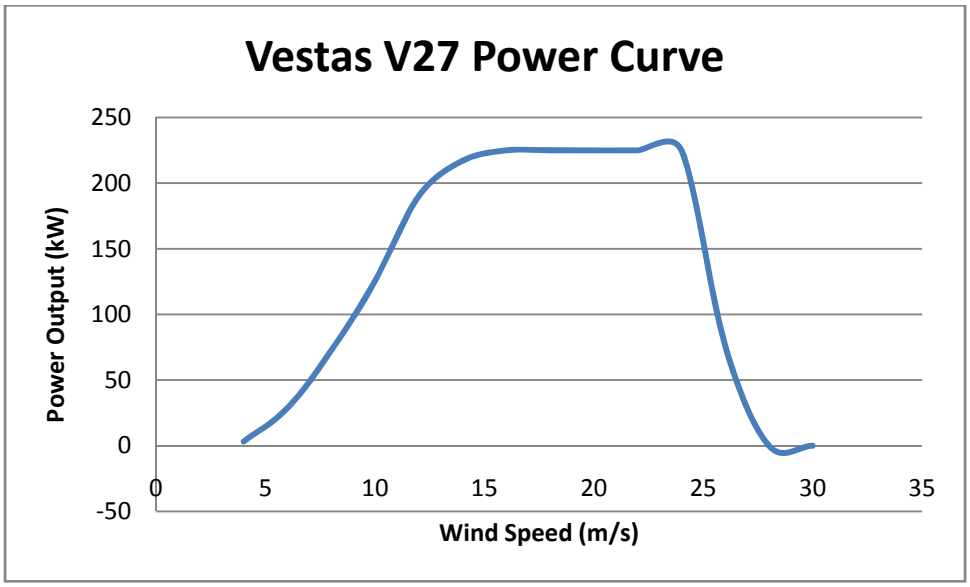


Figure 8 - Vestas V27 Power Curve

HOMER Results: **Net Present cost for 20 year project: $2,491,188**

The above value is based on the currently installed equipment and approximated load information. Figure 9 below illustrates the breakdown of optimized power generation for the Saint Paul system. It is clear that there is a great deal of excess electricity which occurs when the wind generation capacity exceeds the necessary load. Installing energy storage systems will take advantage of this excess electricity. Figure 10 depicts the project cash flows for the 20 year life of the project. "Volvo" and "Boiler" costs include diesel fuel and capital costs.

[16] http://www.windturbinewarehouse.com/pdfs/vestas/Vestas_V_27_SAC_DSM_7_8_05.pdf

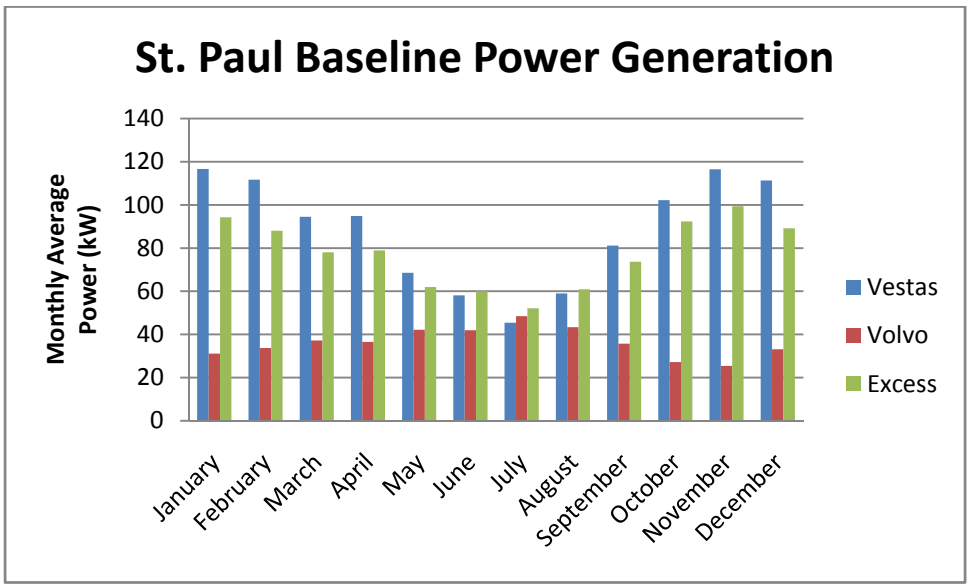


Figure 9 - Saint Paul Baseline Power Generation

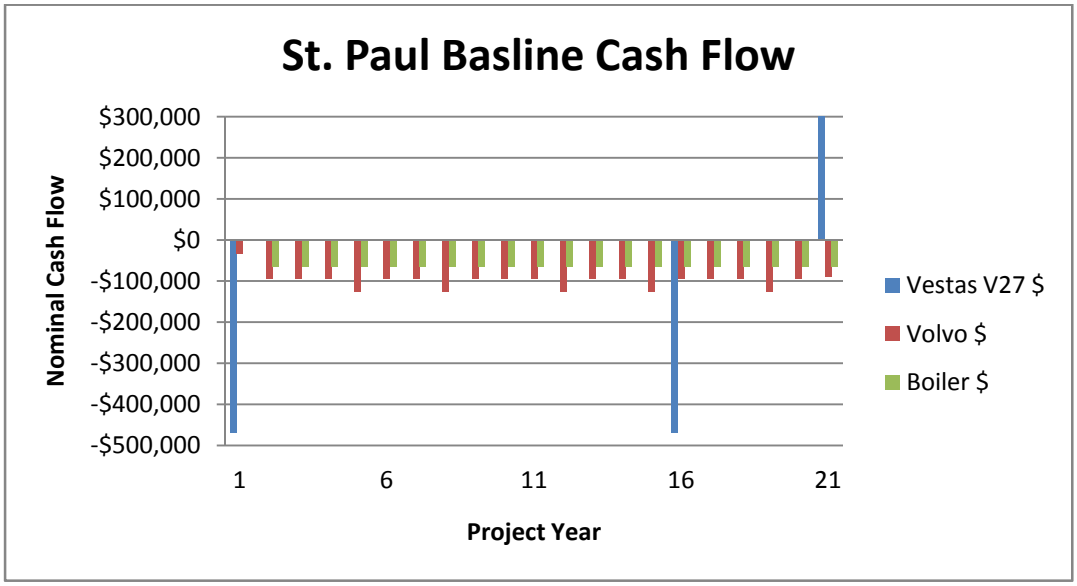


Figure 10 - Saint Paul Baseline Cash Flow

Note: Vestas salvage value is $312,333. Chart is formatted for clarity.

1 Megawatt-Hour Thermal Storage Tank

The first energy storage mechanism to consider is a 5000 gallon water tank with a maximum temperature of 80° C. This model operates on the assumption that all excess electricity can be converted into heat with 100% efficiency. Because the tank is large, our conservative

assumption is a heat loss rate of 0.1% per hour. Because HOMER does not model thermal batteries, we simply modified the original thermal load to reflect the ability to heat and circulate water using electricity and the water tank. Figure 11 below compares the original thermal load with the thermal load that remains after electric heating.

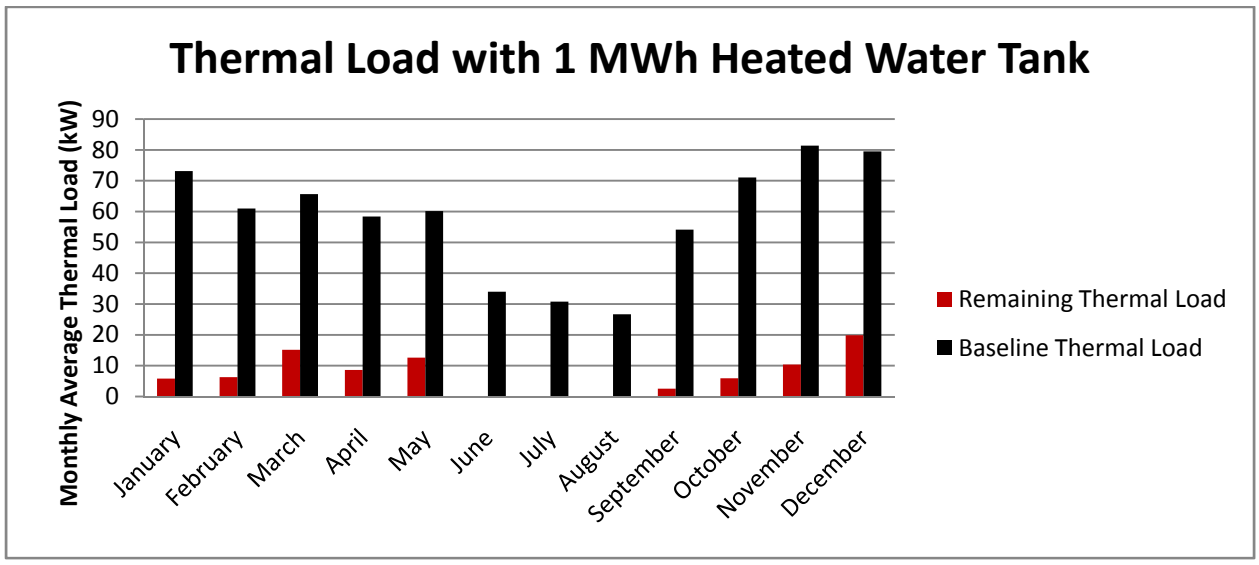


Figure 11 - Saint Paul Thermal Load Comparison

HOMER Results: **Net Present Cost for 20 year project:** $1,848,052 + $20,000 lifetime tank costs = **$1,868,052**

Because our HOMER model assumes that all thermal load must be met using a diesel boiler, reducing the thermal load using electrical heating and a water tank significantly reduces the diesel consumption by the boiler. Figure 12 below shows the annualized costs of diesel fuel in the boiler for both the baseline and thermal battery cases.

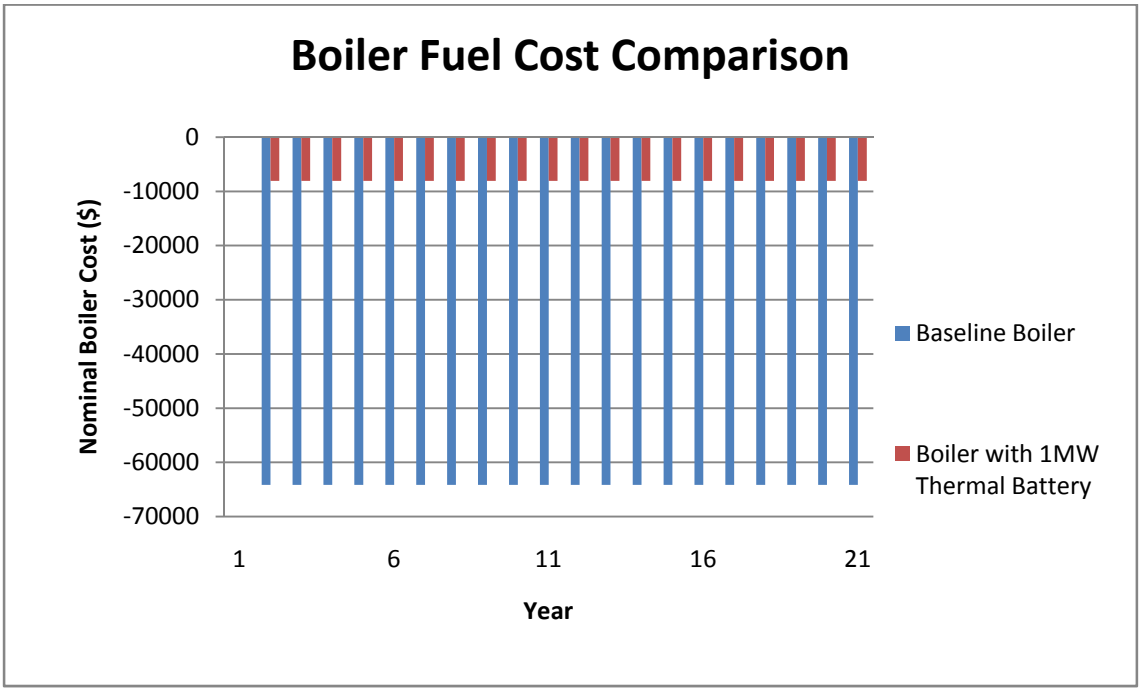


Figure 12 - Thermal Battery: Boiler Fuel Cost Comparison

50 kW_{ac}/360 kWh_{ac} Sodium Sulfur Battery

A second case study incorporates a sodium sulfur battery provided by NGK insulators. Cost and capacity information for this battery are based on a study by Sandia National Laboratory. Although the model provides useful information about a possible use for the technology, NGK currently only supplies battery systems larger than 1 MW for $3-4 million. As this system would be inappropriate for the relatively small Saint Paul load, the case study does not reflect an immediately implementable system. Still, it portrays an interesting possible future application of the sodium sulfur battery technology.

Costs for DC to AC converters were not available, and the $30,000 cost for 50 kW is approximate. Additionally, the battery was considered "off the shelf" and costs do not include transportation or installation.

Battery: NASG50 from NGK Insulators

Voltage: 64 Volts

Cost: $75,000[17]

Lifetime: 15 years

Converter: 50 kW @ $30,000

HOMER Results: **Net Present Cost for 20 year project: $1,945,503**

Baseline TAD722GE Fuel Consumption: 88,001 L/year

Annualized Fuel Operating Cost: $173,557 $/year

Generator Consumption with NASG50 Battery: 38,347 L/year

Annualized Fuel Operating Cost: $116,828 $/year

The figures below are the Volvo diesel generation results from the HOMER model using the NASG50 battery (Figure 13) and for the baseline case (Figure 14). The first figure depicts the battery case, where it is clear that the battery's ability to store excess wind energy eliminates most of the need for diesel generation in off peak hours. In some months the stored wind resource is great enough to almost completely supersede diesel generation. In contrast, the next figure depicts the baseline diesel generation. Without storage, a high level of diesel generation is almost always necessary. Hence, the possible fuel savings causes a significant reduction in net present cost in the NASG50 storage scenario.

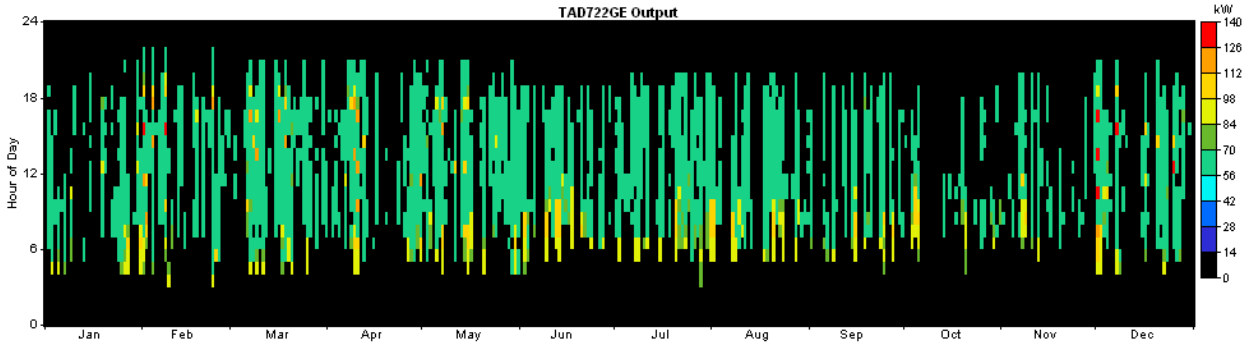


Figure 13 - Volvo Generation with NASG50 Battery

[17] Benjamin L. Norris, Jeff Newmiller, Georgianne Peek, Sandia National Laboratory, *NAS Battery Demonstration at American Electric Power*

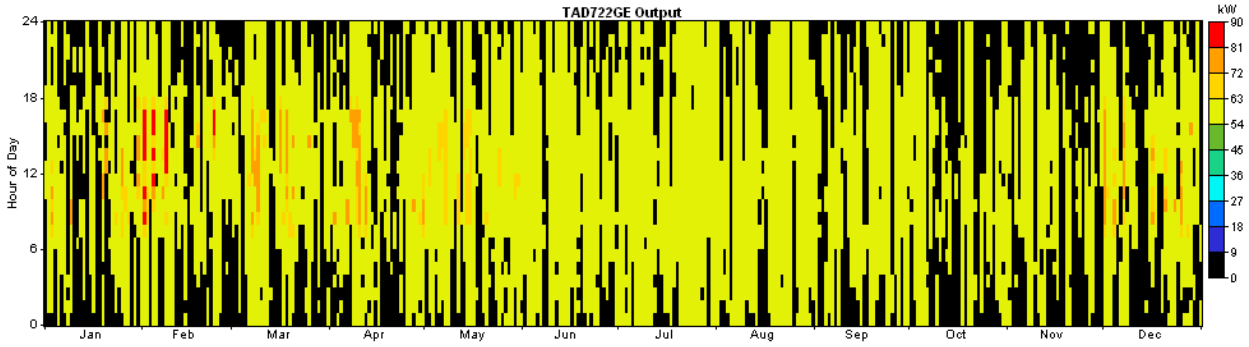


Figure 14 - Baseline Volvo Generation

5 kW/60 kWh VRB-ESS Flow Battery

Another battery storage option is the VRB-ESS flow battery. HOMER's optimization resulted in an optimum battery size of 5 kW and 60 kWh. Like the NASG50 scenario, transportation and installation costs are not included.

VRB-ESS Flow Battery

Cell Cost: $15,000

Electrolyte Cost: $90,000 ($1500/kWh)

Lifetime: 14,000 cycles[18]

Converter: 50 kW @ $30,000

HOMER Results: **Net Present Cost for 20 year project: $1,947,088**

Baseline TAD722GE Fuel Consumption: 88,001 L/year

Annualized Fuel Operating Cost: $173,557 $/year

Generator Consumption with NASG50 Battery: 38,273 L/year

Annualized Fuel Operating Cost: $114,350 $/year

Figure 15 below depicts optimum diesel generation using the VRB-ESS flow battery. The costs and generation are similar to the model outcomes for the NASG50 battery, indicating that the

[18] Dennis Witmer, Alaska Center for Energy and Power

smaller power and capacity of the VRB battery are a legitimate energy storage solution for the Saint Paul facility.

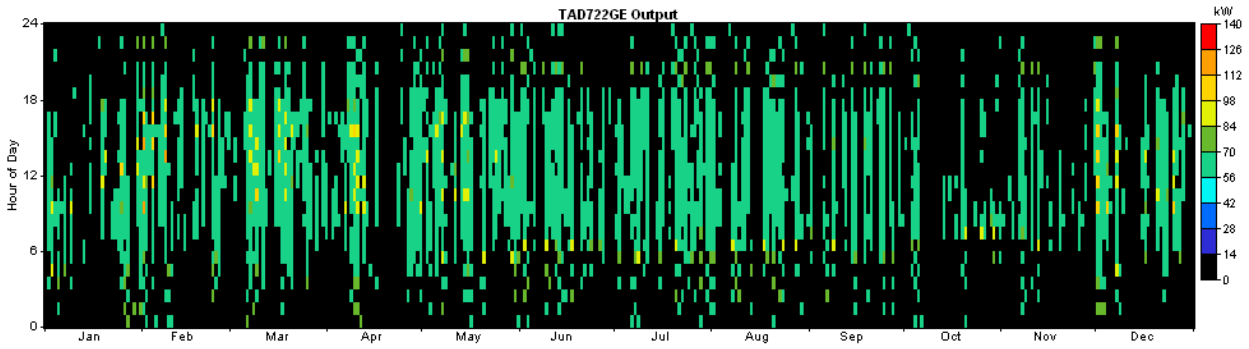


Figure 15 - Volvo Generation with VRB-ESS Battery

Saint Paul Island Case Study Cost Comparison

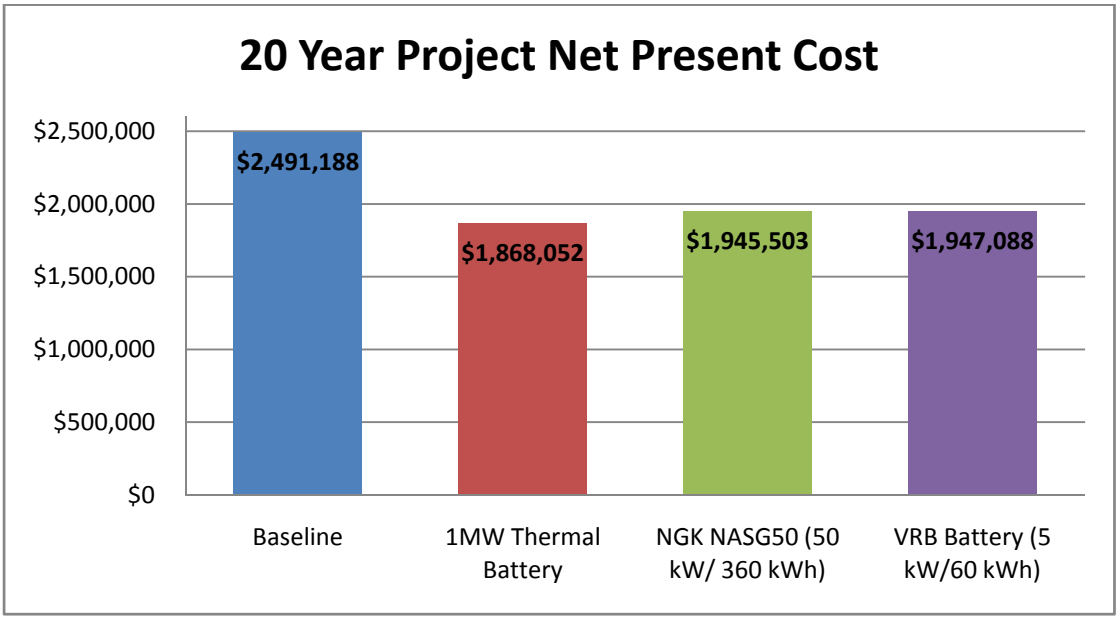


Figure 16 - Cost Comparisons for Saint Paul Energy Storage Options

Figure 16 above illustrates the comparative estimated costs for the four energy storage situations examined for the Saint Paul load conditions. Although the thermal tank appears to be the least expensive option, the model does not account for uncertainties in heat distribution and relies on rough cost estimates for the tank. Likewise, the battery costs do not account for transportation or installation costs and rely on cost estimates. Although no operations and maintenance costs are

included, the majority of these costs are likely caused by the installed wind turbine which is identical in all four storage scenarios. Despite the explicit uncertainty, the HOMER modeling process indicates that installing energy storage in the simulated Saint Paul system could result in cost savings using current commercial storage technologies.

Appendix II: Thermal Storage Electrical Generation with ORC

Utilities with installed wind turbines often encounter times when the wind turbines are generating, much more power than is demanded at that time. Later, when the wind supply is not available, diesel generation must be increased to meet the load. Hence, the ideal scenario is one in which all power generated by wind turbines is used, by storing the energy when it is in excess and using that energy when it is needed.

Possible Scenario: Use excess wind to heat water to then operate an Organic Rankine Cycle (ORC) unit to power a village.

One possible mechanism for storing excess wind energy is to heat up water when the power is not needed. If the water can be heated to around 135 ° Fahrenheit, the hot water could then be used to power a turbine operating on the ORC, which uses a refrigerant as a working fluid that changes phase at temperatures much lower than those needed for a steam-driven turbine.

Although the ORC is less efficient than most power generation, it is a viable way to recover some of the energy that is being lost when the excess wind power is not stored. It is interesting to consider the cost of such a system. The next page contains a comparison between the cost of an ORC unit is and a possible zinc-flow battery storage unit provided by Premium Power.

The economic analysis shows that storing wind energy using an ORC is relatively expensive, especially compared to diesel generated power. The real kicker is the size of the wind turbine system needed to provide the heat. It is important to note that these numbers are probably low because tanks, insulation, and pumps etc have not been included in capital costs.

(Continued)

ORC Energy Storage Economic Analysis	
Efficiency of ORC unit	0.08
Gross Power (kW)	285
Net to Gross Loss	0.8
Net Output (kW)	228
kW hour heat needed to operate ORC for 1 hour	4453.125
Capital cost of ORC	$350,000
Installation factor	2
Installed cost ORC	$700,000
Wind turbine size for heat side (kW)	4453.125
cost for Wind turbine ($/kW)	$1,500
Wind Turbine installed cost	$6,679,687.50
Total Capital (Present)	$7,029,687.50
Lifetime (Years)	20
RIO	6.00%
Total annual capital cost	$612,880.19
Charging time	25%
Discharging time	25%
Hours per year	8760
Hours ORC operates per year	2190
kW-hr/yr based on hours above and operating at max output	499320
Cost per kW-hr capital only	**$1.23**

Premium Power Battery Economic Analysis	
Battery Efficiency	0.8
DC Gross power (kW)	500
Net to Gross Loss	0.8
Net AC Output (kW)	400
kW hour needed to operate Battery for 1 hour	781.25
Capital cost of PP battery	$800,000
Installation factor	1.25
Installed cost PP system	$1,000,000
Wind turbine size for heat side (kW)	781.25
cost for Wind turbine ($/kW)	$1,500
Wind Turbine installed cost	$1,171,875.00
Total Capital (Present)	$1,971,875.00
Lifetime (Years)	20
RIO	6.00%
Total annual capital cost	$171,917.05
Charging time	25%
Discharging time	25%
Hours per year	8760
Battery Power Hours per Year	2190
kW-hr/yr based on hours above and operating at max output	876000
Cost per kW-hr capital only	$0.20

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