Appendix 5.19
Evaluation of Energy Storage Technologies
(Transgrid Solutions 2016)

Engineering Support Services for:

Energy Storage Technologies

Yukon Energy Corporation

Attention:

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Evaluation of Energy Storage Technologies

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Executive Summary

Energy storage technology for power system application has recently attracted significant interest and attention as an enabling technology for energy management and integrating the growing capacity of variable renewable energy resources into the electric grid. Energy storage systems are likely to become an essential contributor to grid modernization investments to meet the future constraints under low carbon emissions limits.

The report will provide the Yukon Energy Corporation better understanding of what types of energy storage technologies are available to support their power system requirements. The selection of an appropriate energy storage technology combined with a responsive power conversion system will have to accommodate their present and future energy demands in terms of power quality, grid support and load shifting and possible integration of other renewables in to their power grid.

Based on the requirements for a reduction of their diesel generation utilization during peak load conditions and addressing power quality aspects, two energy storage options have been selected to address this. Electrochemical battery technology using lead acid batteries or lithium ion batteries are capable to supply the power and energy demands during the peak load conditions and as well as mitigating power quality concerns on the electrical grid.

Based on the financial model provided by Yukon Energy, the power and energy requirements determined from the 2015 load data and the total cost of a completely installed Battery Energy Storage System (BESS) under study, the net present value was calculated for 4 storage options. There were 3 lead acid based systems rated at 4 MW, 40 MWh (power/energy), 6 MW, 60 MWh, and 8MW, 80 MWh capacities and a lithium ion with an 8 MW, 40 MWh capacity. Over the 30 year lifetime of the project, all options studied had significantly higher costs as compared with their respective benefits and hence a negative NPV.

The lead acid 4 MW, 40 MWh Battery Energy Storage System (BESS) had the best Net Present Value followed by the lithium ion 8 MW/40 MWh BESS. The timeline for bringing this system online is approximately 18 months. This includes engineering and drawing, preparatory civil works, purchase and delivery of the system components, construction, and testing.

1. Introduction

The Yukon Energy Corporation is entering a new planning cycle scheduled to be completed at the end of 2016 with the issuance of its Integrated Resource Plan. An early component of the planning process is to look at potential resource options to meet the long term load forecast (2016-2035). With the higher penetration of intermittent energy sources, Yukon Energy would like a better understanding of the various energy storage technologies to offset the use of diesel generation and to support integration of renewables. The energy storage system would increase capacity during period of shortage in terms of power quality, T&D grid support, and load shifting and bulk power management. Hence, Yukon Energy is looking for technical support for a review of current energy storage technologies and to recommend viable technologies could assist the Corporation in the future.

Energy storage mediates between variable sources and variable loads. Without storage, the present energy generation must equal energy consumption. Energy storage works by moving energy through a time period, energy generated at one time can be used at another time through storage when needed. Electricity storage is one form of energy storage.

The objective of this project is to identify and evaluate energy storage technologies that would help the system meet its present and future long term energy demand by increasing capacity during times of power shortage, and that would support the integration of renewables (intermittent energy sources). Currently, the Yukon power system's main source of energy is supplied via three hydroelectric plants.

2. Scope of Work

The scope of work is to review the current energy storage technologies available for Yukon Energy Corporation's power/energy requirements for power management, grid support & load shifting and power quality. The work will include the following topics.

2.1 Literature Review

The literature review includes a high level evaluation of the mature and emerging energy storage technologies including the pros and cons of each of these technologies as they apply specifically to the Yukon power system. The evaluation will also take into consideration the sizing of the power and energy requirements of the storage system to offset some of the existing diesel generation and provide an energy storage system capable of suppling optimal power and energy requirements during peak load conditions. Included will be a review of the maturity and current trends in cost of each of these technologies and identify sites if possible where these technologies have already been implemented.

The literature review will also consider storage options based on the following specific usages for the Yukon power grid:

- Power quality
- T&D grid support and load shifting
- Bulk power management (excluding pumped storage)

2.2 Cost Estimation/Project Schedules/Footprints

Develop cost estimates and high level project schedules from early planning to commissioning of any viable options of these technologies and the potential life of these various assets will be assessed. Additionally, the minimum footprint required to implement the storage technologies will be evaluated.

2.3 Risks and Show stoppers

The report will also assess each potential energy storage technology in terms of the risks, located within or near Whitehorse and potential barriers based on:

- Pros and cons of each technology
- Maturity of each technology
- Current trends
- Sites where the energy storage technology has been implemented
- Financial attributes
- Technical attributes
    - Installed capacity in terms of power(MW) and energy (MWh)

The evaluation of energy storage options against environmental and socio-economic attributes will be completed as a separate project by Yukon Energy.

The current scope of work does not include an evaluation of pumped storage as an energy storage technology or obtaining any environmental, geotechnical or physical data collection.

3. Yukon Energy Load Profile

The Yukon Territory is located in the northwestern part of Canada, bordered by the State of Alaska to the West, the Province of British Columbia which is to the South and the Northwest Territories to the East. As of March 2015, the population of the Territory was approximately 37,178. The Territory's capital is Whitehorse, having a population of 28,700 people and is the largest load center.

Current and committed generation capacity owned and operated by Yukon Energy Corporation (YEC or the Corporation) includes approximately 130 MW of installed generation on the Yukon Power System (approximately 92 MW hydroelectric, 0.8 MW wind, 37.8 MW thermal (diesel and natural gas)). The remaining generating assets connected to the Yukon Power System are owned by ATCO Electric Yukon and consist of about 1.3 MW of hydroelectricity and 6.8 MW of diesel.

As shown in Figure 1, there are three hydroelectric plants supplying more than 99% of the energy within the Territory. The plants are Aishihik Generating Station (37 MW, ~150 km west of Whitehorse), the Mayo Generating Station (15 MW located 450 km north of Whitehorse) and the Whitehorse Generating Station (40 MW). Transmission is at a voltage of 138 kV with the exception of the Mayo-Dawson line that operates at 69 kV.

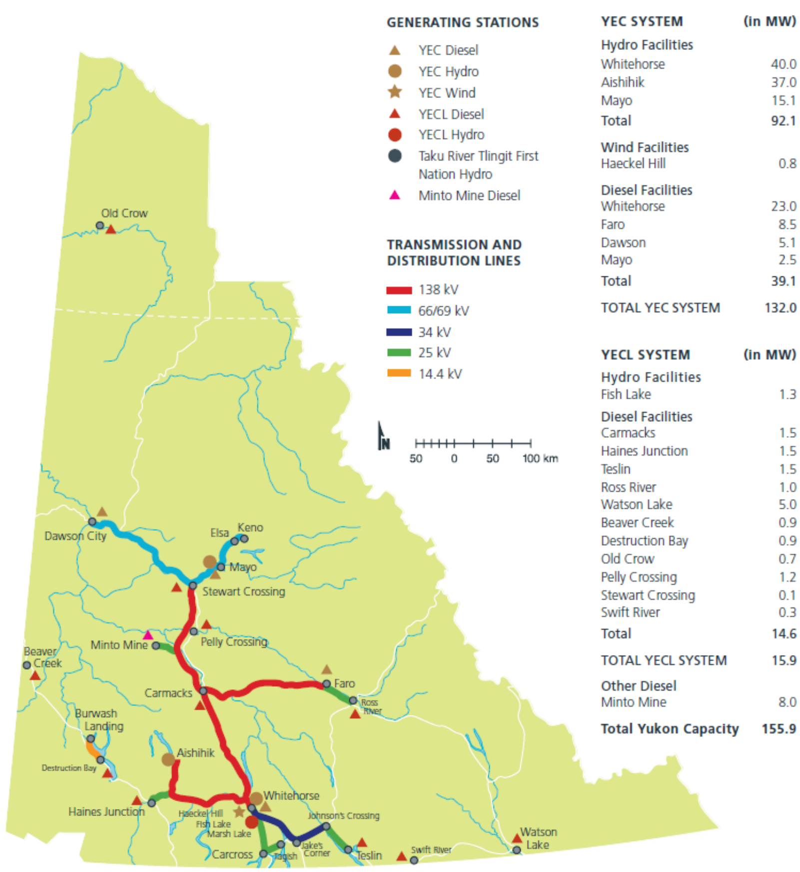


Figure 1 Yukon Energy Power Generation and Transmission System

Yukon Energy is entering a new planning cycle scheduled to be completed at the end of 2016 with the development of its Integrated Resource Plan. An early phase of the planning process is to explore potential resource options to meet the long term non-industrial load forecast under base case (2016-2035) as shown in Figure 2.

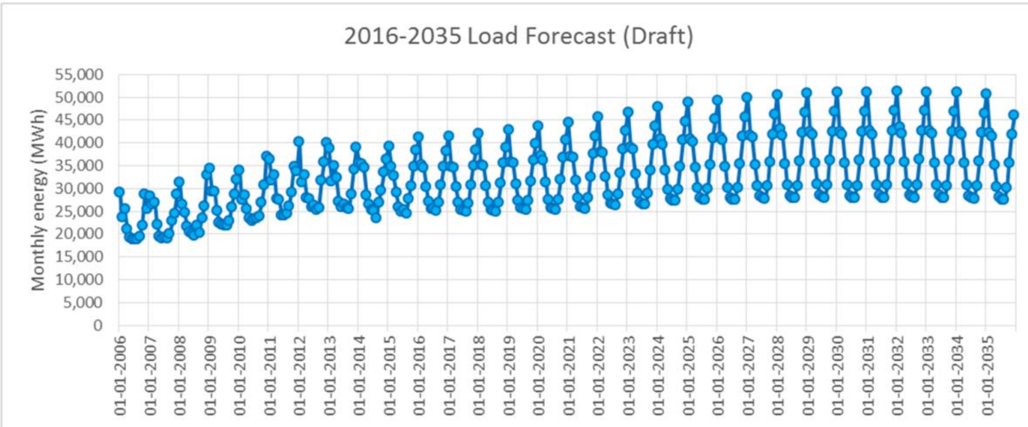


Figure 2 Yukon Energy Load Forecast

With the higher penetration of intermittent energy sources, Yukon Energy would like to better comprehend energy storage technologies to support integration of renewables and increase capacity during periods of shortage (i.e., power quality, T&D grid support, load shifting and bulk power management).

In terms of the verbal information provided during the conference calls, Yukon Energy is looking at basically two categories of an energy storage/delivery system to resolve:

1. Daily load variations
2. Intermittent generation , overvoltage problems and frequency variations

Yukon Energy has provided recent load profiles showing the electrical generation supplied from both hydro and diesel installations over the 2015 period as shown in Figure 3.

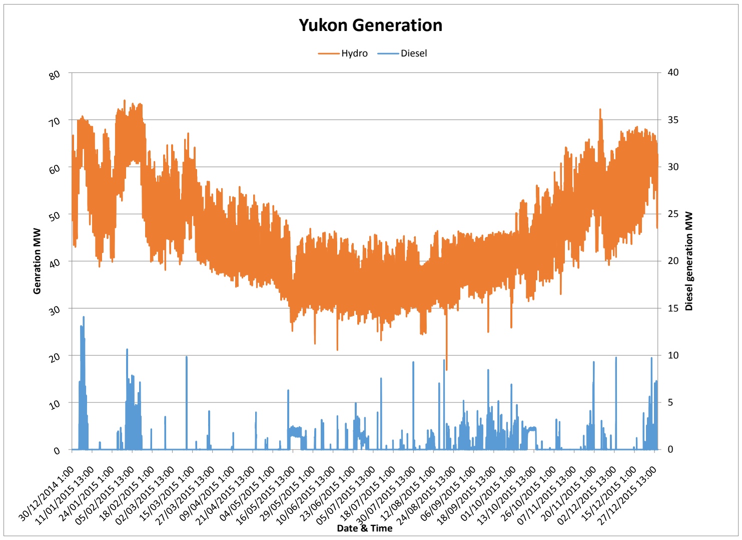


Figure 3 Hydro and Diesel Generation for 2015

Upon closer examination of the diesel generation output, the most active diesel generation time periods in terms of magnitude, frequency and duration were during the months of January and February of 2015. During these periods, the diesel generation reached a peak of 14 MW and the diesel activity was on a regular basis depending on weather conditions and customer energy demands.

As well, Yukon Energy has indicated that their electrical grid does experience overvoltage problems and some frequency deviations from time to time. Actual data was not provided regarding the severity of the frequency shifts (approximately 3 Hz), nevertheless the type of energy storage system must be capable of responding quickly to mitigate these power quality concerns.

Therefore the selection of an appropriate energy storage technology combined with an advanced power conversion system will eventually have to accommodate the present and future energy demands by Yukon Energy in terms of power quality, grid support and load shifting and possible integration of other renewables in to the power grid.

4. Energy Storage Technologies

Information regarding the literature review originates from various research and technical papers as listed in the References section of this report.

An important characteristic of electricity is that electrical energy cannot be stored directly. Consequently, the supply of electricity must be balanced continuously with the demand for it. The constant balancing of supply and demand has significant operational and cost implications. For example, sufficient generating capacity needs to exist to supply the highest level of demand.

The following section outlines a description of various groups of popular energy storage technologies that were chosen according to the form of stored energy that is employed. Figure 4 illustrates these broad categories in terms of: mechanical energy storage, electrochemical (and chemical) energy storage, electrical and magnetic field energy storage and thermal energy storage.

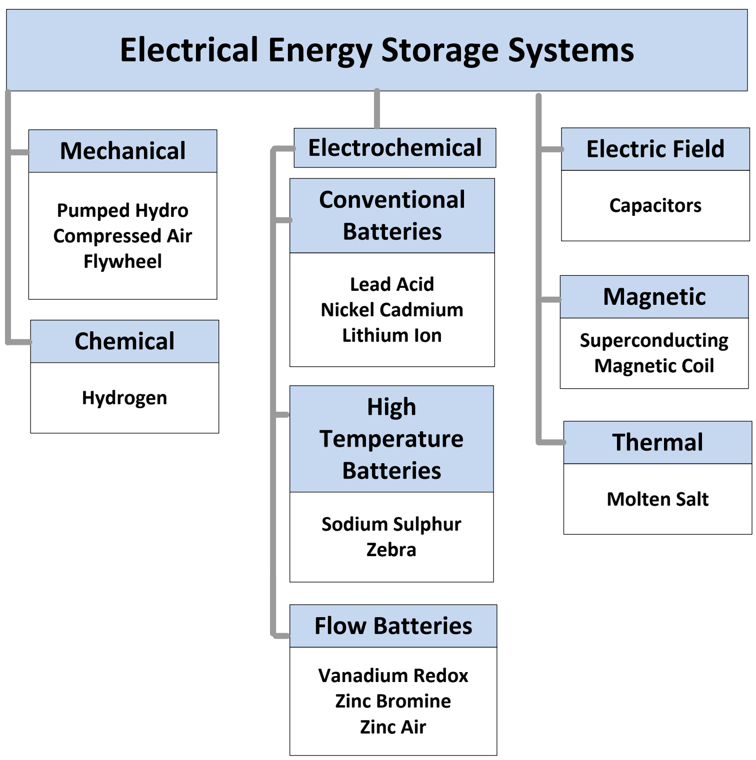


Figure 4 Classifications of Energy Storage Systems

4.1 Mechanical

4.1.1 Pumped Hydro Storage

4.1.1.1 Technology

Many locations in the United States and around the world use pumped hydro electric energy storage as a large, mature, and commercial utility-scale technology for an energy storage option. Off peak electricity is used to pump water from a lower level reservoir up to another high level reservoir at a higher elevation. When electricity is required, water is released from the upper reservoir through a hydroelectric turbine into the lower reservoir to generate electricity as shown in Figure 5.

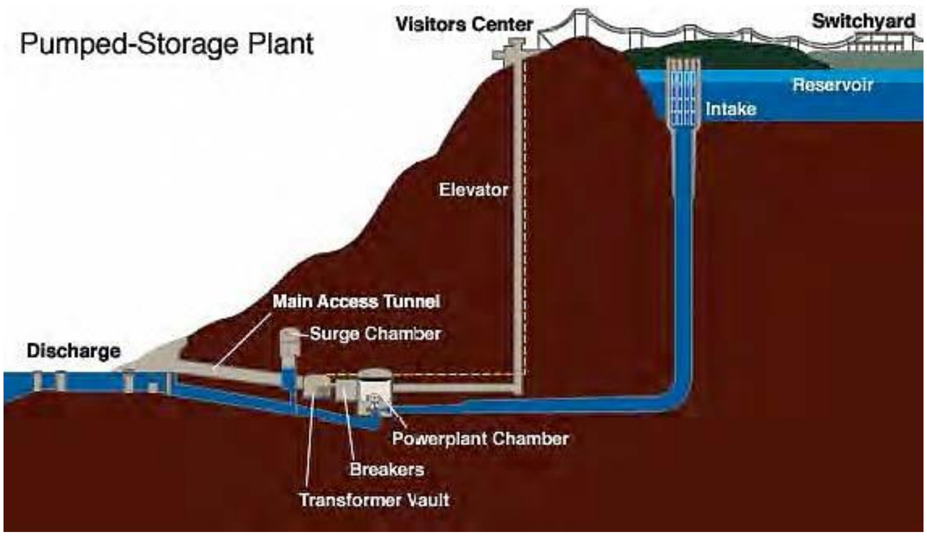


Figure 5 Cutaway of a Typical Pumped Storage System
DOE/EPRI 2013 Electricity Storage Handbook [1]

4.1.1.2 Performance

Depending on design, some projects may be practically sized up to 400 MW and operate at about 76%–85% efficiency. Pumped hydro plants have lifetimes on the order of 50-60 years. Typically a reservoir one kilometer in diameter, 25 meters deep and having an average head of 200 meters would hold enough water to generate around 10,000 MWh. [1]

4.1.1.3 Maturity and Commercial Availability

Pumped hydro storage is a mature form of energy storage. There is growing interest in opportunities for pumped hydro in the United States, however the siting, permitting, and associated environmental impact processes can take many years.

4.1.1.4 Pros and Cons as Applicable to Yukon Energy

For the scope of this work, Yukon Energy has excluded the subject of pumped hydro storage and will not be considered in this report.

4.1.2 *Compressed Energy Storage*

4.1.2.1 *Technology*

Compressed Air Energy Storage (CAES) systems use off-peak electricity to compress air and store it in a reservoir, either an underground cavity or aboveground pipes or containers. When electricity is required on the grid, the compressed air is heated, expanded, and directed through an expander or conventional turbine-generator to generate electricity. [1] Figure 6 shows a typical diagram for an underground compressed air storage system.

There are two general types of CAES: bulk and small. Bulk CAES is practical for storage needs greater than 5 hours and hundreds of megawatts. Typical storage capacity ranges from 300 to 400 MW over the course of 10 to 30 hours. Aboveground systems typically are smaller and have capacities on the order of 10 to 20 MW and shorter discharge times (less than 6 hours). Small CAES systems use pipes, bladders, or other man-made vessels to store compressed air. [2]

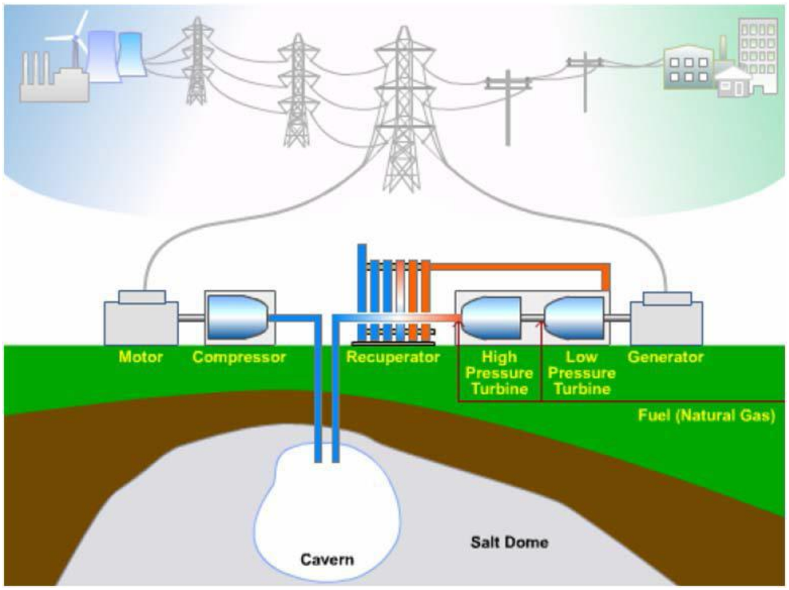


Figure 6 Diagram of a Compressed Air Storage System

Utility Scale Energy Storage Systems Benefits, Applications, and Technologies [2]

4.1.2.2 *Performance*

Aboveground CAES storage would typically be smaller than plants with underground storage, with capacities on the order of 10 to 20 MW. The discharge times would be 2 to 6 hours. Aboveground CAES plants are easier to locate but more expensive to build (on a $/kW basis) than using underground CAES systems. The reason is primarily due to the incremental additional cost associated with aboveground storage medium. [1]

4.1.2.3 Maturity and Commercial Availability

CAES is a relatively mature energy storage technology and is the only commercial bulk energy storage plant available today other than pumped hydro. There are two operating first-generation systems: in Germany and Alabama. In the past few years, improved second-generation CAES system cycles have been defined and are being designed. Second-generation CAES hold the potential for lower installed costs, higher efficiency, and faster construction time than the first-generation systems

4.1.2.4 Site Implementation

Aboveground CAES plants are easier to site but more expensive to build (on a $/kW basis) than CAES plants using underground air storage systems, primarily due to the additional cost associated with aboveground storage medium.

Underground CAES storage systems are most cost-effective with storage capacities up to 400 MW and discharge times of 10 to 30 hours. Placement of such plants involves finding and verifying the air storage integrity of a geologic formation appropriate for CAES in a given utility's service area. [1]

4.1.2.5 Pros and Cons as Applicable to Yukon Energy

Yukon has advised that due to the local ground conditions, underground storage could not be considered and aboveground storage would have to be assessed on risk, ease of site implementation and environment considerations.

Recently Toronto Hydro has installed the first ever underwater compressed air storage system in 55 metres of water using balloon like structures. As a pilot project, this is a unique energy storage system as it uses compressed air and water pressure to run its system.

4.1.3 Flywheel

4.1.3.1 Technology

Flywheel Energy Storage (FES) stores energy in the form of the momentum in a rotating mass called the rotor. The work done to spin the rotor is stored in the form of kinetic energy. A flywheel energy system then changes the kinetic energy into AC power through the use of its controls and power conversion systems.

Most modern flywheel technology has some type of sealed housing for safety, reducing friction and performance enhancement purposes. The housing is usually a thick steel vessel surrounding the rotor, motor-generator, and other rotational components of the flywheel. See Figure 7 for a breakdown of the FES components. If there is a failure while spinning, the containment vessel would stop or impede flying parts and fragments, preventing injury and damage to the surrounding equipment or human contact. Containment systems are used also to enhance the performance of the flywheel by means of a vacuum or filled with a low-friction gas to reduce the effect of friction on the rotor. [1]

The rotor is the most important element of flywheel assembly. The rotor mass (diameter and material) influences its energy capacity. The bearings and casing are designed primarily to decrease the friction (which reduces efficiency and shortens life time). The motor-generator and power electronics characteristics determine the maximum power output of flywheel storage systems. An important aspect of flywheel systems is that power and energy capacities are relatively independent from each other. This permits the flywheel technology energy and power capacity to be optimized for specific applications. [2]

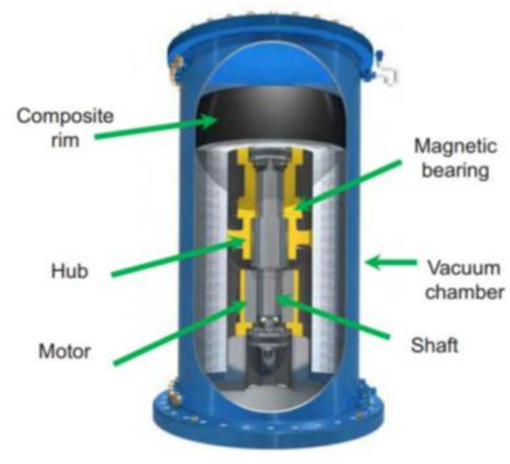


Figure 7 Flywheel Cross Section.

Utility Scale Energy Storage Systems Benefits, Applications, and Technologies [2]

4.1.4 Performance

The overall efficiency and standby power loss are critical design factors in energy flywheel design since the losses represent a degradation of the primary purpose provided by the storage system (energy). Losses are immaterial in a power flywheel design, although standby losses are a factor in operating cost in comparison with other storage technologies that have significantly lower losses. For these reasons, flywheels for energy usage usually require more advanced technologies than power flywheels applications.

The energy flywheels usually have composite rotors enclosed in vacuum containment systems, with magnetic bearings. Such systems typically store between 0.5 kWh and 10 kWh. The largest commercially available systems of this type are in the 2- to 6-kWh range, with plans for up to 25 kWh. Energy flywheels available currently are DC output systems. Overall efficiencies for energy flywheels are usually between 70% and 80%. The standby losses are very small, typically less than 25 W DC per kWh of storage and in the range of one to two percent of the rated output power.

Flywheels can be charged relatively quickly with recharge times comparable to discharge times for both power and energy flywheels designs. High-power flywheel systems can often deliver their energy and recharge in seconds, if adequate recharging power is available.

FES in general exhibit excellent cycle life in comparison with other energy storage systems. Most developers approximate the cycle life in excess of 100,000 full charge-discharge cycles. The rotor is subject to fatigue effects arising from the stresses applied during charge and discharge cycles. The most common failure mode for the rotor is the formation of cracks through the rotor over a period of time. The rotor parts may become loose and propelled by momentum into the surrounding environment, posing danger to personnel or equipment. There is also operating noise that may pose a constraint on the siting of flywheel systems. [2]

4.1.4.1 Maturity and Commercial Availability

FES is currently being marketed as environmentally safe, reliable, modular, and high-cycle life alternatives to lead-acid batteries for UPS and other power-conditioning equipment designed to improve the quality of power delivered to critical or protected loads. Okinawa Power has installed a demo 23 MW flywheel system for frequency regulation. Fuji Electric has demonstrated the use of flywheel technology to stabilize wind power generation. [1]

They have a very fast response time of four milliseconds or less and can be sized typically between 100 kW and 1650 kW. FES is commonly used for short durations of up to one hour for power quality type applications. They are approaching very high efficiencies ranging from 80 to 90%, with lifetimes estimated at 20 years.

4.1.4.2 Pros and Cons as Applicable to Yukon Energy

Flywheel storage is currently employed for shorter energy duration systems, typically for durations of less than half an hour suitable for power quality type applications or for emergency back up and not generally suitable for Yukon Energy's energy storage requirements. Since FES are generally applicable to short term duration, the cost per kWh is very high ranging from $7800 to $ 8800 US (2010).

4.2 Chemical

Chemical energy storage relies on electric energy to create fuels that may be burned in conventional power plants. An advantage of synthetic methane (and hydrogen to some degree) is that it can be injected into the existing natural gas storage infrastructure. The benefit of chemical storage over some of the other technologies is the high energy density (kWh/liter) of chemical storage compared to most of the other technologies. [3]

4.2.1 Hydrogen

4.2.1.1 Technology

Hydrogen can be used in the combustion process with the compressed air storage technology. [2] In using hydrogen as a fuel, an above ground storage vessel would be advisable due to safety or environmental concerns in Whitehorse.

4.2.1.2 Performance

A typical hydrogen storage system consists of an electrolyzer, a hydrogen storage tank and a fuel cell. An electrolyzer is an electrochemical converter which splits water with the help of electricity into hydrogen and oxygen. It is an endothermal process, i.e. heat is required during the reaction. Hydrogen is stored under pressure in gas bottles or tanks, and this can be done practically for an unlimited time. To generate electricity, both gases flow into the fuel cell where an electrochemical reaction which is the reverse of water splitting takes place: hydrogen and oxygen react and produce water, heat is released and electricity is generated. For economic and practical reasons oxygen is not stored but vented to the atmosphere on electrolysis, and oxygen from the air is taken for the power generation. [5]

4.2.1.3 Pros and Cons as Applicable to Yukon Energy

Yukon Energy advised that due to the ground conditions, underground gas storage could not be considered and deployment of above ground storage vessels would be a significantly risky option especially when dealing with hydrogen gas with safety and environmental concerns.

4.3 Electrochemical

The Electrochemical classification involves storage technologies that convert electricity to chemical potential for storage and then back again. There are three main categories of electrochemical batteries**:** conventional, high temperature, and flow batteries. This section reviews the basic components, functions, and common examples of each category of battery storage. [3]

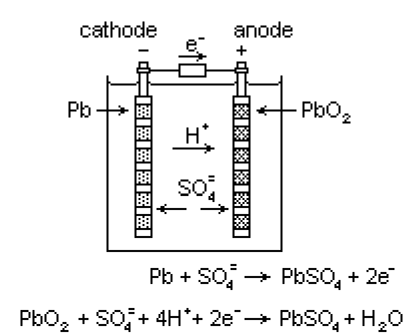
4.3.1 Conventional Battery

Conventional batteries are composed of cells which contain 2 electrodes (a cathode and an anode) and electrolyte in a sealed container. During discharge, a reduction-oxidation reaction occurs in the cell in which electrons migrate from the anode (oxidation) to the cathode (reduction). During recharge, the electrochemical reaction is reversed through the ionization of the electrolyte that links the anode and cathode. Numerous combinations of electrodes and electrolytes exist for conventional batteries. Common chemistries for conventional battery energy storage projects include: lead-acid, nickel-cadmium, and lithium-ion. [2]

4.3.2 Lead Acid

4.3.2.1 Technology

Lead-acid batteries are the most established form of rechargeable battery technology. The positive electrode is composed of lead-dioxide, PbO2, while the negative electrode is composed of metallic lead, Pb as shown in Figure 8. The active material in both electrodes is extremely porous to maximize surface area. The electrolyte is a sulfuric acid solution, usually around 37% sulfuric acid by weight when the battery is fully charged.



Lead-Acid Storage Cell

Figure 8 Lead Acid Storage Cell

Lead-acid energy storage technologies are divided into two types: lead-acid carbon technologies and advanced lead-acid technologies. Lead-acid carbon technology has a fundamentally different approach to lead-acid battery and is vented or flooded (VLA) through the inclusion of carbon to improve the power characteristics of the battery and to mitigate the effects of partial states of charge. [1]

Certain advanced lead-acid batteries are conventional valve-regulated lead-acid (VRLA) batteries with technologies that address the inadequacies of previous lead-acid products through incremental changes in the technology. [1]

Maintenance requirements for a lead acid battery involve a float charging, the equalization charging, water replacement and cell post maintenance. To prevent self-discharge, voltage is continuously applied to the already charged battery to generate a small current. Equalization charging corrects the inconsistency in state of charge between individual battery replacement is only necessary for flooded lead acid batteries (not for valve-regulated lead acid) to compensate for water lost through evaporation and electrolysis.

Furthermore, lead acid batteries contain toxic materials that pose environmental and safety hazards. In part due to regulation, lead acid batteries are one of the most recycled products. Regulations typically apply a fee when the battery is purchased which can be used to cover environmental consequences.

4.3.2.1.1 Lead-acid Carbon

Lead-acid carbon technology can exhibit a high-rate characteristic in both charge and discharge with no apparent detrimental effects as are typically experienced in traditional VLA and VRLA batteries. This characteristic allows the lead-acid carbon batteries to deliver and accept high current rates only available with higher-cost nickel metal-hydride (Ni-MH) and lithium ion (Li-ion) batteries. [1]

Presently there are three major lead-acid carbon technologies moving into the market with each having a different implementation of carbon integrated with the traditional lead-acid battery negative plate. The improvements include: significantly faster recharge rates, considerably longer cycle lives in deep discharge applications, and minimal maintenance requirements. The new cell configurations allow thousands of cells to be gathered in massive parallel and series matrices, suited for use in large-scale utility applications requiring many megawatts of power while still maintaining a manageable footprint. [1]

4.3.2.1.2 Advanced Lead-acid Technologies

Advanced lead acid technology has the properties that reduces maintenance requirements, extends life expectancy, and improves cell uniformity which increases both battery life expectancy and cost. These advanced lead-acid products focus on technology enhancements such as carbon-doped cathodes, granular silica electrolyte retention systems high-density positive active material, and silica-based electrolytes. [1]

Some advanced lead batteries even have supercapacitor-like features that give them fast response, similar to flywheels or Li-ion batteries. Advanced lead-acid systems from a number of companies are currently in early field trial demonstrations. [1]

One commercial example is the ultra-battery which is a hybrid advanced lead acid battery-capacitor that claims extended life expectancy. Thin metal film lead acid technology applies a new and fairly difficult construction technique to considerably increase power density at the expense of energy density. This research has dropped off due to manufacturing difficulty and short cycle life of these batteries.

4.3.2.2 Performance

Traditional VLA and VRLA batteries are typically designed for optimal performance in either a power application or an energy application, but not both. Which means that a battery specifically designed for power applications can indeed deliver significant amounts of energy but it is not designed to deliver substantial amounts of energy (e.g., 80-percent deep discharges) on a regular basis. [1]

Disposal of lead-acid batteries is an important part of the life cycle. The environmental and safety hazards associated with lead require a number of regulations concerning the handling and disposal of lead-acid batteries. Lead-acid batteries are among the most recycled product in the world.

Lead acid batteries have a 2 V nominal voltage and efficiency ranges between 75% and 85%. Some problems of lead batteries include: self-discharge, sensitivity to temperature, sulfation, hydration, and degradation. These batteries are inclined to self-discharge but can be resolved by injecting a float charge through the battery while it is not operational. Optimal operation for a lead acid battery is at room temperature, approximately 77°F (25°C). [2]

Some advanced lead batteries have supercapacitor-like features that give them fast response, similar to flywheels or Li-ion batteries. [1]

4.3.2.3 Maturity and Commercial Availability

Lead-acid batteries are the most commercially mature rechargeable battery technology in the world. VRLA batteries are used in a variety of applications, including automotive, marine, telecommunications, and uninterruptible power supply (UPS) systems. However, there have been few utility T&D applications for such batteries due to their relatively heavy weight, large bulk, cycle-life limitations, and perceived reliability issues (stemming from maintenance requirements).[1]

Lead acid is the most technologically mature of the battery technologies. It remains popular due to its low cost, despite toxicity, low specific energy and power, short life cycle and maintenance requirements. Lead acid is generally best suited to power quality applications. Overall efficiency is between 75 and 85% and expected life, depending on technology is between 3-10 years. A total of 35 MW of lead acid batteries are deployed for power applications worldwide. [3]

For example a 1-MW, 1.5-MWh lead-acid battery has been operating for 12 years in Metlakatla, AK. In this project, the battery system exhibited very little visible degradation upon post-test analysis and was replaced in 2008, after 12 years of continuous shallow discharge service. Other lead-acid carbon energy systems have been deployed in sizes of 10 to 20 MW. [1]

Hitachi is developing their advanced lead-acid product for renewable integration and smart grid projects in Japan, with the intent of competing with sodium-sulfur (NAS) and Li-ion batteries. In August 2009, Hitachi completed a 10.4-MWh battery, built to stabilize a 15-MW wind facility at Goshogawara in northern Japan. A similar plant was installed in late 2010 at another wind-generation site at Yuasa. This battery is now available to companies for integration into the United States, although costing for the United States is uncertain at this time. [1]

4.3.2.4 Pros and Cons as Applicable to Yukon Energy

Based on the power/energy requirements by Yukon Energy during the cold and winter months, lead acid battery storage should be able to meet both the required power and energy prerequisites. Power quality attributes for frequency control is available with response times within milliseconds and is dependent on performance characteristics of the front end power conversion/inverter system.

4.3.3 Nickel Electrode

4.3.3.1 Technology

Nickel electrode batteries are known as dry cell batteries. Each dry cell contains a pair of electrodes, a positive nickel electrode and a negative electrode of cadmium, zinc, hydrogen, iron, or a metal halide. Depending on the chemistry of the negative electrode material, a divider is chosen to separate the two electrodes. After cell construction and packaging, liquid electrolyte is circulated into the porous electrodes. Only nickel-cadmium and nickel-iron have utility scale energy storage demonstrations or commercial installations. Of these two, nickel-cadmium remains the most popular for utility energy storage applications. [2] See Figure 9 which shows a typical Nickel Cadmium cell.

Figure 9 Nickel Cadmium Battery

4.3.3.2 Performance

Nickel electrode batteries experience both reversible and irreversible degradation. Reversible forms of degradation are reversed by completely discharging the cell and then recharging. Irreversible degradation varies across electrode types and application but is related to temperature and the depth and number of charge/discharge cycles. Some common irreversible degradation sources include: nickel-electrode corrosion, organic material decomposition into the electrolyte, formation of dendrites on the negative electrode, gas barrier failure, and electrode poisoning. [2]

Nickel electrode batteries have a nominal voltage of approximately 1.2 V and have an overall efficiency ranging from 65 to 85 %. Nickel cadmium batteries typically have much lower efficiency, around 60 and 70 percent (not including losses from ancillary equipment). Unfortunately cadmium is a highly toxic substance.

This range in efficiency is caused from differences in electrolyte concentration, charging procedures, stand-by time, and operation temperature. Nickel electrode batteries tend to have relatively higher charge losses resulting from a variety of chemical interactions within the battery cells and deviances from ideal operating temperatures. Like many batteries nickel electrode cells are susceptible to “thermal runaway,” a vicious cycle of heating and increased discharge and voltage. [2]

4.3.3.3 Maturity and Commercial Availability

Nickel cadmium batteries are the most common nickel electrode battery technology in the utility energy storage industry. Although more costly than lead acid batteries, the relative low cost, high energy density, high power delivery capabilities, hardiness, reliability, and life expectancy of nickel cadmium batteries makes them a popular choice for substation batteries and bulk storage. They are technologically mature and offer a longer life span than lead-acid of around 10-15 years. [3]

Several other nickel electrode battery chemistries are under development, but not yet in commercial use for utility scale storage. Nickel hydrogen batteries have attractive operational features, such as long cycle life, low maintenance requirements, and high reliability, but very high costs. The nickel metal hydride, an offshoot of the nickel hydrogen battery, has many of the same advantages of the nickel hydrogen battery and lower costs. However, it tends to be less hardy to electrical abuses such as overcharge and high rate discharge than nickel cadmium batteries. [2]

There has been one application of 27 MW of installed capacity for 15 minutes and commissioned in 2003 that is being used for electric power systems applications. Ni-Cd has also been used for stabilizing wind-energy systems, with a 3 MW system on the island of Bonaire commissioned in 2010 as part of a project for the island to become the first community with 100% of its power derived from sustainable sources. [ESA website]

4.3.3.3.1 Pros and Cons as Applicable to Yukon Energy

Nickel cadmium batteries are generally suited for grid angularity stability, grid frequency excursion suppression, short duration power quality, which suits some of the small scale applications. However for Yukon Energy, the amount of energy storage requirements for the grid support could not be met.

4.3.4 Lithium Ion

4.3.4.1 Technology

When compared to the long history of lead-acid batteries, Lithium Ion (Li-ion) technology is relatively new to the bulk power/energy storage field. In saying this, the technology is mature and well used in consumer applications and plug in hybrid electric vehicles.

In a Li-ion battery cell there are two reactive materials capable of undergoing an electron transfer chemical reaction. To experience this reaction, the materials must contact each other electrically, either directly or through a wire, and must be capable of exchanging charged ions to keep the overall charge neutrality as electrons are transferred. The battery cell is designed to keep the materials from directly contacting each other and to connect each material to an electrical terminal isolated from the other. These terminals are the cell’s external contacts. [1]

As shown in Figure 10, Lithium ion battery's components include: a carbon (graphite) negative electrode, a metal-oxide positive electrode, an organic electrolyte (ether) with dissolved lithium ions, and a micro-porous polymer separator. When the battery is charging, lithium ions flow from the positive metal oxide electrode to the negative graphite electrode. When the battery is discharging the reverse flow of ions takes place. [2]

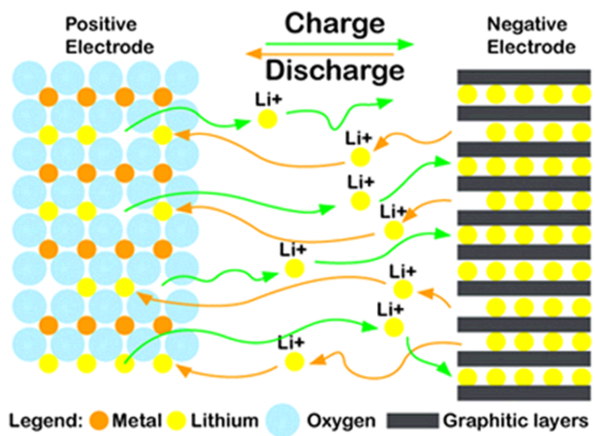


Figure 10 Lithium Ion Function and Components

Utility Scale Energy Storage Systems Benefits, Applications, and Technologies [2]

4.3.4.2 Maturity and Commercial Availability

Since 2000, Li-Ion batteries have become a popular choice for electric vehicle and aerospace applications. This resurgence in research and development of Li-Ion technology for electric vehicle purposes has also led to interest in demonstrating the battery's potential to perform utility functions. [2]

The large scale manufacturing of Li-ion batteries (estimated to be approximately 30 GWh by 2015) may result in possibly lower-cost battery packs which could also be used and integrated into systems for grid-support services that require about 4 hours of storage. Many stationary systems have been deployed in early field trials to gain experience in siting, grid integration, and operation. Li-ion systems now dominate the landscape for grid-scale storage systems in the United States. [1]

Recently, a large investor owned utility in California wanted to evaluate the performance of a battery energy storage system combined with new smart inverter technology. In 2013, the utility installed an 8 MW – 4 hour (32 MWh) lithium-ion battery combined with two 4.5 MVA EssPro PCS units from ABB. The installation was in one of California's largest wind resource areas. The many project benefits of installing this battery energy storage system include added voltage support and grid stabilization, decreases in transmission losses and congestion, frequency regulation support and optimization of the wind energy output through capacity firming and smoothing. [4]

One of the largest Li-Ion installations in the United States is in Elkins, West Virginia. This facility connects 98 MW of wind generation with 32 MW of storage for reserve capacity and renewables integration. [2]

The technical characteristics of Li-Ion batteries are dependent on the electrodes and electrolyte materials but some observations can be made.

1. Due to their high energy density, Li-Ion cells have nominal voltage of 3.7 V. This is much higher than many other battery cell chemistries, which means fewer Li-Ion cells are needed to produce the same power output.
2. Like some other batteries, the response times are on the order of 20 milliseconds.
3. Li-Ion batteries have relatively high overall efficiency, usually ranging between 87 to 92 %
4. Li-Ion batteries have expected lifetimes of 2,000 to 3,000 cycles or 10 to 15 years.[2]

Li-Ion batteries have several disadvantages [2] as well such as:

1. The expected lifetime is related to the cycling depth of discharge. Li-Ion batteries should not be used for applications that require full discharge.
2. The metal oxide electrode can become thermally unstable due to over discharge or charge and be subject to thermal runaway if left unchecked.
3. Li-Ion batteries still face significant cost barriers.

4.3.4.3 Pros and Cons as Applicable to Yukon Energy

Lithium Ion battery system would be a good fit for the power and energy requirements as well as power quality (frequency regulation) for Yukon Energy needs. In 2013, an 8 MW (32MWhr) lithium-ion battery combined with two 4.5 MW power conversion units by ABB were install and California for grid support and frequency stabilization.

4.4 High Temperature Batteries

4.4.1 Sodium Sulphur Battery Energy Storage

4.4.1.1 Technology

Sodium-sulfur (NAS) batteries are a commercial energy storage technology which is finding applications in electric utility distribution for grid support, wind power integration, and high-value grid services. NAS battery technology has the potential for use in grid services because of its long discharge period (about 6 to 8 hours). Using a suitable inverter, it is capable of prompt and precise response to such grid requirements such as mitigation of power quality events. [1]

NAS battery cells contain a molten sodium (Na) anode as the negative electrode, a solid ceramic electrolyte, with a molten sulfur (S) cathode as the positive electrode. Positively charged sodium ions flow through the solid ceramic electrolyte into molten sulfur where an electrochemical reaction generates a current as shown in Figure 11. To enable ion transfer, the sodium and sulfur are kept molten at temperatures between 300° and 360°C (572° and 680°F). [2]

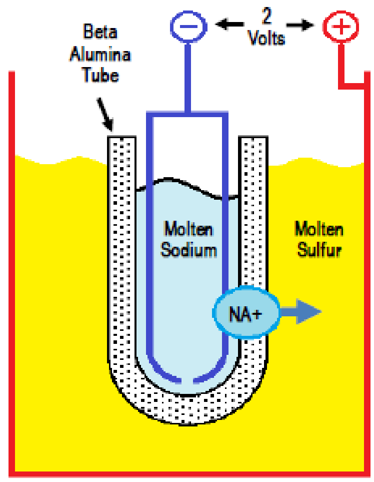


Figure 11 Sodium Sulfur Cell Diagram

Utility Scale Energy Storage Systems Benefits, Applications, and Technologies [2]

4.4.1.2 Performance

Energy density by volume for NAS batteries is 170kWh/m3 and by weight is 117kWh/ton. NGK projects its NAS to have a cycle life of 4500 cycles for rated discharge capacity of 6 MWh per installation MW. Rated at 4500 cycles, NAS batteries are projected to have a calendar life of 15 years. [1]

NAS batteries are suitable for energy, power, or both energy and power applications. Typically, NAS batteries primary function is long duration energy storage, used for load leveling, arbitrage, “islanding,” and renewables output smoothing. However, quick response time (1 millisecond) and the ability to provide pulse power make them suitable for many power quality applications [2].

4.4.1.3 Maturity and Commercial Availability

NAS installations providing the functional equivalent of about 160 MW of pumped hydro storage are currently deployed within Tokyo. NAS batteries are only available in multiples of 1-MW, 6-MWh units with installations typically in the range of 2 to 10 MW. The largest single installation is the 34-MW Rokkasho wind-stabilization project in Northern Japan that has been operational since August 1, 2008. At this time, about 316 MW of NAS installations have been deployed globally at 221 sites, representing 1896 MWh. Customers in the United States include American Electric Power (AEP) (11 MW deployed at five locations), PG&E (6 MW, in progress), and Xcel Energy (1 MW, deployed). [1]

NAS batteries are suitable for energy and/or power applications, generally long duration energy storage. This includes load leveling, arbitrage, “islanding,” and renewables output smoothing, although their fast response time (1 ms) and the ability to provide pulse power make them suitable for a very wide range of applications. [2]

NAS batteries are still in the early stages of commercialization, especially on the grid scale. Thus far, most of the grid applications are in Japan. The overall efficiency is generally high (70 to 90%), although the energy required to maintain the electrodes in a molten state may reduce this efficiency figure.

Due to their early stage of commercialization, costs remain high and as with many other battery technologies, there are toxicity concerns. There are also safety concerns due to the high operating temperatures and explosive nature of sodium when exposed to water. [3]

In summary, NAS batteries are located in over 190 sites in Japan. More than 270 MW of stored energy suitable for 6 hours of daily peak shaving have been installed. The largest installation is a 34 MW 245 MWh unit for wind stabilization in northern Japan. US utilities have deployed 9 MW for peak shaving.

4.4.1.4 Pros and Cons as Applicable to Yukon Energy

Sodium-Sulfur batteries must operate at extremely high temperatures and can explode if they come into contact with water, making them a safety hazard if not handled properly. Like any battery, toxicity concerns, especially related to decommissioning and disposal, are still major obstacles to widespread installation. Consumers and environmentalists may protest the prospect of batteries located close to residential or highly populated areas.

Since this is still emerging as a commercial grid-scale energy storage technology, cost estimates still remain high. The NAS battery technology does provide the power and energy requirements for Yukon Energy as well as the power quality support available on demand. A drawback is there is currently one major off shore supplier of this technology and competitive pricing would be difficult.

4.4.2 Zebra (Sodium Nickel Chloride)

4.4.2.1 Technology

Sodium nickel chloride batteries are also referred to as Zero Emission Battery Research or (Zebra). Like the NAS battery, it is a molten sodium based battery. It contains a molten sodium negative electrode and a nickel chloride positive electrode as illustrated in Figure 12. To support in ion transfer, the battery operates around 270°C (518°F). [2]

When charging a Sodium-nickel-chloride battery at normal operating temperatures, salt (NaCl) and nickel (Ni) are transformed into nickel-chloride (NiCl2) and molten sodium (Na). The chemical reactions are reversed during discharge and there are no chemical side reactions. The electrodes are divided by a ceramic wall (electrolyte) that is conductive for sodium ions but an isolator for electrons. The cell reaction can only occur if an external circuit allows electron flow match to the sodium ion current. The porous solid NiCl2 cathode is impregnated with a sodium ion conductive salt (NaAlCl4) that offers a conductive path between the inside wall of the separator and the reaction zone. Cells are hermetically sealed and bundled into modules of about 20 kWh each. [1]

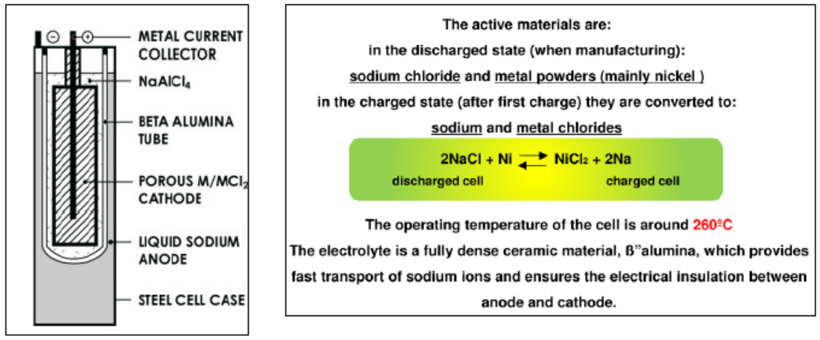


Figure 12 Deign and Features of a Zebra Battery

DOE/EPRI 2013 Electricity Storage Handbook [1]

This technology has been commercially available since 1995. So far, much of the recent research has been with electric vehicles however, there is development of Zebra systems for renewables integration and load leveling applications. [2]

4.4.2.2 Performance

Technically Zebra batteries are so far rated power between 5 and 500 kW with up to 100 kWh of energy. Zebra units have 85-90% overall efficiency, 20 millisecond response times, and expected cycle lives of up to 3,000 cycles at 80 percent depth of discharge.[2]

4.4.2.3 Maturity and Advantages

Advantages of Zebra over NAS technology includes:

- tolerance of overcharge and discharge
- higher cell voltage
- potentially better safety characteristics

Due to its high tolerance to short circuits, the failure of one cell does not cause complete failure of the Zebra battery. [2]

4.4.2.4 Pros and Cons as Applicable to Yukon Energy

Sodium nickel chloride technology does not have the energy capacity requirements of Yukon Energy.

4.4.3 Flow Batteries

Flow batteries are unlike conventional batteries and high temperature batteries because of cell construction. The electrolyte material is stored in tanks external to the electrodes. During discharge and charge, electrolyte is pumped from its container into the cell stack to interact with the electrodes, see Figure 13. Flow batteries are now considered a practical choice for energy applications requiring discharge durations greater than 5 hours due to cost efficiencies with large volumes of relatively low-cost electrolyte material. [2]

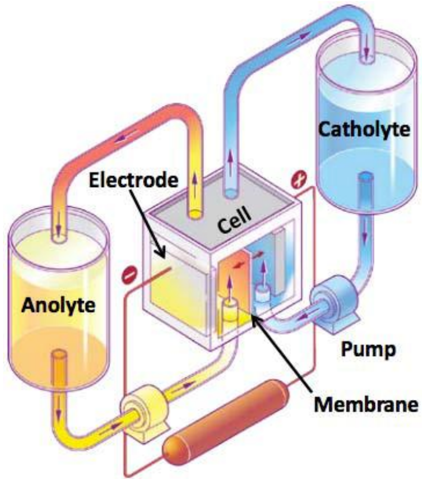


Figure 13 Flow Battery Construction

Utility Scale Energy Storage Systems Benefits, Applications, and Technologies [2]

Unique to flow batteries is the ability to independently control and vary energy and power capacity. The discharge duration (energy) is determined by the volume of electrolyte, while the power ratings are determined by the number of cells. The ease with which electrolyte can be chemically managed and replaced as well as tolerance for overcharge/discharge and partial state of charge makes them robust to processes that degrade conventional and high temperature batteries' lives.[2]

Disadvantages of flow batteries relate to cost and construction complexity. The addition of pipes, plumbing, tanks, and other non-electrochemical components increase probability and cost of repair and electrolyte leakage. Flow batteries have relatively low power and energy density compared to their conventional and high temperature counterparts. Additionally, there are efficiency losses accrued by auxiliary equipment used to pump electrolytes from tanks to cells. [2]

There are two types of flow batteries: hybrid flow batteries and redox flow batteries.

<u>Hybrid Flow</u>

Hybrid flow batteries have one or more electro-active components deposited as a solid layer and the battery cell contains one battery electrode and one fuel cell electrode. A hybrid flow battery's energy is limited by the size of the battery electrode. [2]

<u>Redox Flow</u>

Redox flow batteries are a reversible fuel cell in which electro-active components are dissolved in the electrolyte. A redox flow battery's energy is related to electrolyte volume and power is related to electrode area in the cells. Common redox flow battery chemistries include zinc bromine and vanadium. [2]

4.4.4 Vanadium Redox

4.4.4.1 Technology

Vanadium redox flow batteries (VRB) contain vanadium ions that are dissolved in an acid aqueous solution. The main components of a VRB are the electrolyte, a carbon felt electrode, an ion exchange membrane that separates the electrolytes, a bipolar plate that separates cells, and the electrolyte tanks, pumps, and piping as shown in Figure 14. [2]

Both the negative and positive electrolytes (sometimes called the anolyte and catholyte, respectively) are made of vanadium and sulfuric acid mixture at approximately the same acidity as that found in a lead-acid battery. The electrolytes are stored in external chambers and pumped as needed to the cells. [1]

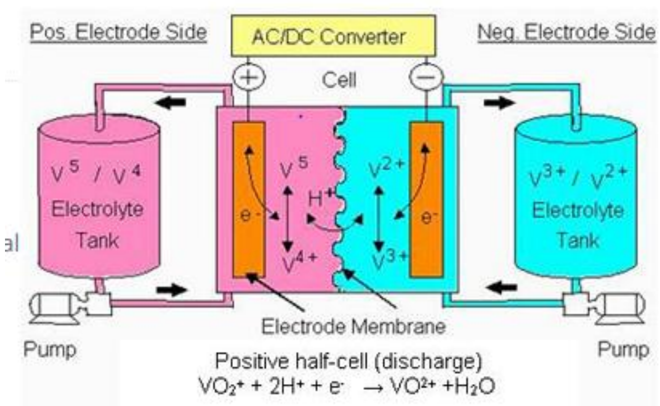


Figure 14 Vanadium Redox Battery System

4.4.4.2 Performance

VRB flow battery is suited for energy applications such as peak shaving and spinning reserve. Their full power discharge ranges from four to ten hours. Life expectancy is 10 to 15 years, with the internal membrane the limiting factor, although refurbishment can extend the lifetime to 20 years. Efficiencies are in the 60 to 70% range with nearly instantaneous response times for the battery itself (0.35 ms), although the pumps and power electronics have a slower response time, overall one can expect a response of several milliseconds. [3]

Vanadium redox batteries have recently demonstrated their compatibility with PV and wind generation, load leveling, and power quality and reliability, as well as spinning reserve. Like all flow batteries, rated energy and rated power are independently determined. Both the concentration of vanadium ions in the electrolytes and the tank volumes determine the energy storage capacity in a VRB. There are about 20 to 30 watt-hours per liter of electrolyte when the battery is fully charged. [3]

The electrode surface area determines the power of a VRB system. In contrast to conventional batteries, VRBs are generally useful for energy applications because the volume of electrolyte determines energy capacity. Full power discharge ranges between four and ten hours for systems as of 2006. Each cell has a nominal voltage of 1.4 V and supplies about 26 watts.

4.4.4.3 Maturity and Advantages

Flow batteries, including the VRB have a much larger space requirement than other electrochemical storage technologies, for example a VRB system rated at 2.5 MW and 10 MWh requires between 12,000 and 17,000 square feet. This is about twice as large as the estimated space requirements for other electrochemical storage technologies.

Current commercial units are around 5 kW in size, although some demonstration units are around 250 kW and expected rated power is between 100 kW and in the future up to 10 MW. Each liter of electrolyte provides 20 to 30 Whr at full charge. [2] Presently there are 50-kW, 100-kW, 500-kW, 600-kW, and 1000-kW systems in operation. The largest in the U.S. is a 600-kW/3600-kWh system in a customer energy-management application. A 1-MW, 5-MWh system is in operation in Japan.

Advantages

Vanadium redox batteries have two main advantages over other flow battery chemistries:

1. The positive and negative electrolytes are the same when the battery is in a discharged state. This has several implications for cost, manufacture, and efficiency. Costs to ship, store, and manage electrolyte are low and the electrolytes will not contaminate each other should they be mixed (the battery will only self-discharge).

2. The sulfuric-based electrolyte does not release poisonous or corrosive vapors like other flow batteries using halide-based electrolytes.

The Vanadium redox battery could be suitable for power systems with future demonstration projects ranging in size with ratings of 100kW to 10 MW and storage durations in the 2 to 8 hour range.

4.4.4.4 Pros and Cons as Applicable to Yukon Energy

Size is a concern, as a flow battery generally has twice the footprint of a similar electrochemical storage device. Figure 15 shows system consists of 200-kW modules providing a total of 6 hours of electrochemical energy storage.

This type of technology could be suitable for the requirements of Yukon Energy depending on the rating and size requirements and as long as there are no physical constraints on site. The socio- economics still would have to be evaluated for this technology.

Figure 15 Prudent Energy 600kW/3 600 kWh VRB

DOE/EPRI 2013 Electricity Storage Handbook [1]

4.4.5 Zinc Bromine

4.4.5.1 Technology

Another type of flow battery is the Zinc-bromine battery in which the zinc is solid when charged and dissolved when discharged. The bromine is always dissolved in the aqueous electrolyte. The cell is made of two electrode surfaces and two electrolyte flow streams separated by a micro-porous film. The positive electrolyte is called a catholyte; the negative is the anolyte. Both electrolytes are aqueous solutions of zinc bromine (ZnBr2). [1]

During the charging, elemental zinc is plated onto the negative electrode. Elemental bromine is formed at the positive electrode. Ideally, this elemental bromine remains only in the positive electrolyte. The micro-porous separator allows zinc ions and bromine ions to migrate to the opposite electrolyte flow stream for charge equalization as shown in Figure 16. At the same time, it inhibits elemental bromine from crossing over from the positive to the negative electrolyte, reducing self-discharge because of direct reaction of bromine with zinc. [1]

Zinc bromide batteries are still in the initial stages of development, but have the potential for low cost and high energy density. Sometimes the zinc builds up unevenly on the electrodes and as a result the battery must be fully discharged every 5 to 10 cycles.[3]

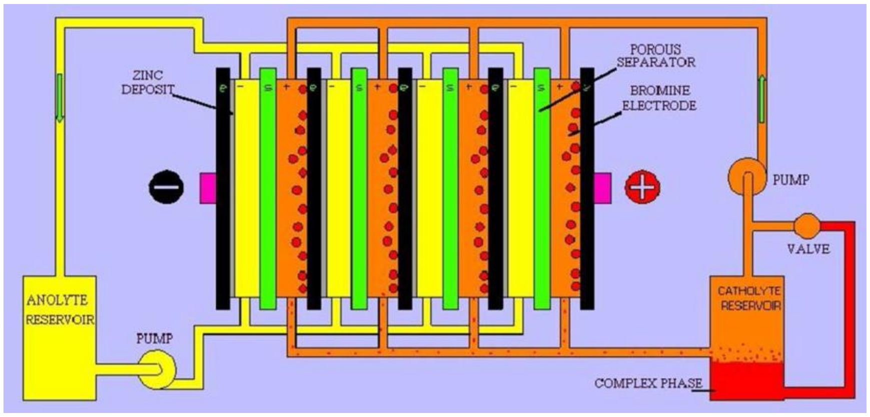


Figure 16 Zinc Bromine Cell Configuration

DOE/EPRI 2013 Electricity Storage Handbook [1]

4.4.5.2 Performance

The most common factor in degradation and potential failure of Zinc-bromine batteries arises from the extremely corrosive nature of the elemental bromine electrolyte. This substance tends to attack all the components of the Zinc-bromine system that are exposed to it. Past failure modes have included damaged seals, corrosion of current collectors, and warped electrodes. The active materials themselves do not degrade. The significance of this fact is that the lifetime is not strongly dependent on the number of cycles or the depth of discharge, but on the number of hours that the system has been operational. During normal operation, Zinc-bromine batteries do not present unusual environmental hazards. They do contain materials however that can become environmental contaminants. Bromine is a toxic material and should be recovered in the event of a spill or when the unit is decommissioned. Zinc-bromine is a corrosive and should be handled appropriately. Zinc is considered a transition-metal contaminant in some locales and thus should be properly recovered when the unit is decommissioned [1].

Zinc bromide flow batteries have relatively high total efficiencies ranging between 70 and 80 percent depending on system design. A typical ZnBr cell has a nominal voltage of 1.8 V and operates at or slightly above room temperature, between 20ºC and 50ºC. Although system temperature does impact efficiency, it is to a lesser degree than some other storage technologies. [2]

As bromine is extremely corrosive the limiting factor in lifetime of the units is not charge cycles but simply hours the storage system has been in operation, with estimates of around 6,000 hrs. The corrosive property is potentially a human and environmental hazard as well.[3]

4.4.5.3 Maturity and Applicability & Availability

Zinc-bromine batteries are in an early stage of field deployment and demonstration trials. While field experience is currently limited, vendors claim estimated lifetimes of 20 years, long cycle lives, and operational AC-to-AC efficiencies of approximately 65%. Module sizes vary by manufacturer but can range from 5 kW to 1000 kW, with variable energy storage duration from two to six hours. In the United States, electric utilities plan to conduct early trials of 0.5 – 1.0 MW systems for grid support and reliability by 2014. [1]

Zinc bromine flow batteries are best suited for load shifting and applications requiring high energy density as opposed to high power density. Example applications currently in use include load shifting (peak shaving) (Japan and Australia), regulation control (load following) (Detroit, Michigan), and renewables time shifting (50 kW, 100 kWh New York). The Imajuku plant in Fukuoka, Japan is rated at 1 MW and 4 MWh and is directly connected to the grid to perform peak shaving purpose. [2]

4.4.5.4 Pros and Cons as Applicable to Yukon Energy

As a consequence of corrosive liquid bromine in the electrolyte there is the possibility of hazardous environmental event or personnel exposure. Although not expected to leak, should some electrolyte contaminate the surrounding area, it could prove hazardous to proximate personnel.

The corrosiveness of the liquid bromine is a significant environmental concern when making decommissioning and disposal preparations. Due to energy limitations this technology would not be applicable to Yukon Energy requirements.

4.4.6 Zinc Air

4.4.6.1 Technology

Zinc-air batteries are a type of metal-air electrochemical cell technology. Metal-air batteries use an electropositive metal, such as zinc, aluminum, magnesium, or lithium, in an electrochemical couple with oxygen from the air to produce electricity. Since these batteries only require one electrode, they can potentially have very high energy densities. In addition, the metals used in most metal-air designs are relatively low cost. The oxygen serves as an electrode, while the battery construction includes an electrolyte and a zinc electrode that channels air inside the battery as shown in Figure 17.[1]

A current is created when the air electrode is discharged with the help of catalysts that produce hydroxyl ions in the liquid electrolyte. The zinc electrode is then oxidized to releases electrons to form an electric current. During recharging, the process is reversed, and oxygen is released into the air electrode.

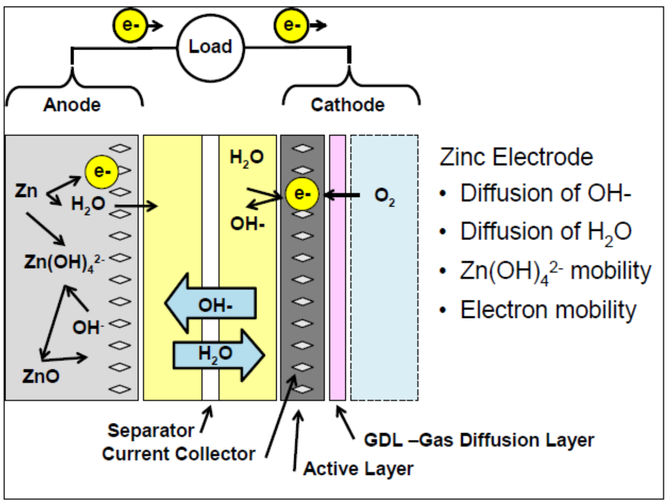


Figure 17 Zinc Air Battery Diagram

DOE/EPRI 2013 Electricity Storage Handbook [1]

4.4.6.2 Performance

Electric recharge has been challenging and inefficient with metal-air batteries, with typical overall efficiencies between 50 and 75% percent. Various manufacturers have tried to overcome low efficiencies with mechanically rechargeable systems in which the discharged metal anode is replaced with a fresh metal anode and the system continues to operate. [1]

Zinc-air batteries have up to three times the energy density of Li-ion, but unlike Li-ion, Zinc-air batteries neither produce potentially toxic or explosive gases, nor contain toxic or environmentally dangerous components., The main material in a zinc-air battery is Zinc-oxide which is 100-percent recyclable.[1]

4.4.6.3 Maturity and Commercial Availability

Zinc-air technology is still in early R&D phase for stationary storage systems for grid services markets although technology holds a great deal of potential due to its low capital cost for grid support and potentially for electric transportation applications.

Research and Development is underway by several manufactures to bring this energy-dense, high-operating-efficiency, better depth-of-discharge stationary technology into the market for utility T&D grid support, with some research still in the university laboratory stage.

4.4.6.4 Pros and Cons as Applicable to Yukon Energy

Zinc air energy storage is a relatively new technology and would not be suitable for the requirements of Yukon Energy.

4.5 Electrical Field

4.5.1 Electrochemical Capacitors

In general capacitors consist of two electrical conductors separated by a non-conducting material (a dielectric), is used to store energy in the form of an electric field. When a charge is applied across the conductors, opposite electrical charges build up on the conductors, creating an electric field. Energy is stored in the electric field. The capability of the capacitor to store energy is determined by the surface area of the conductors and the distance between. Most capacitors consist of two plates separated by a thin dielectric.

There are three types of capacitors: electrostatic, electrolytic, and electrochemical. An electrolytic capacitor is distinguished from an electrostatic capacitor because it uses a liquid electrolyte as one of the plates. [2]

In electrochemical capacitors (also called double layer, super-capacitors or ultra-capacitors) have a higher energy density than other capacitors. Some double layer capacitors have a voltage rating at or above 600V. This makes them suitable for power quality and intermittent renewables fluctuation suppression applications. [2]

4.5.1.1 Technology

Electrochemical capacitors are usually called double layer capacitors (DLC) or commonly known as super-capacitors or ultra-capacitors. They are distinct from other capacitors because of their high energy density. Electrochemical capacitors consist of two electrodes, a separator, an electrolyte, two current collectors and a container as shown in Figure 18. Capacitors store energy statically as opposed to batteries which store energy chemically. Electrochemical technology is similar to battery technology in that they use aqueous electrolyte and are configured into cells. [2]

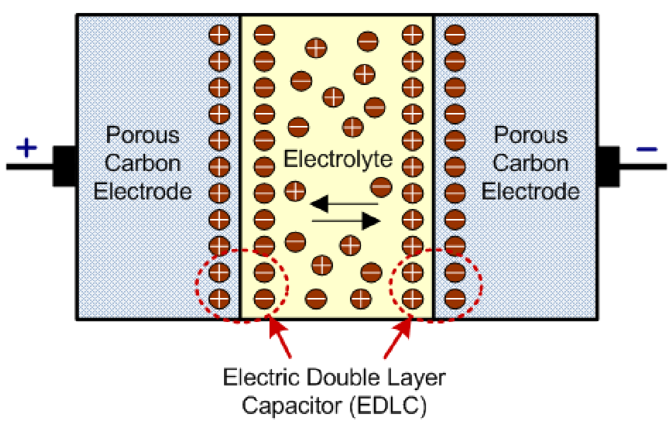


Figure 18 Capacitor Construction Diagram

Utility Scale Energy Storage Systems Benefits, Applications, and Technologies

General Electric introduced a two-terminal charge storage device in the late 1950's and by 1979, capacitor storage was used for computer memory backup applications. They have since evolved and are able to store much more electricity, with some series of electrochemical capacitors having voltages at or above 600 V. These high power levels make it suitable for power quality and intermittent renewables fluctuation suppression applications. [2]

There are two basic double-layer capacitor (DLC) electrode configurations, symmetric and asymmetric. Symmetric configurations have identical electrodes, while asymmetric designs have different electrodes. [2]

The two main features of capacitor technology are the extremely high capacitance values, of the order of many thousand farads, and the possibility of very fast charges and discharges due to extraordinarily low inner resistance which are features not available with conventional batteries. [5]

4.5.1.2 Performance

The disadvantages of DLCs are firstly the interdependence of the cells, sensitivity to voltage imbalances between cells and maximum voltage thresholds, and the safety issues. If just one cell in the string fails, it may lead to the breakdown of the entire string, or it may lead to a voltage and stress increase across the other cells. This then follows into the second disadvantage that the cells life expectancies are directly tied to stringent maximum voltages. [2]

Due to their chemical properties, DLCs are suited especially to applications with a large number of short charge/discharge cycles, where their high performance characteristics can be used. However DLCs are not suitable for the storage application requiring energy over longer periods of time because of their high self-discharge rate, their low energy density and high investment costs. [5]

4.5.1.3 Safety

There are several safety issues associated with electrochemical capacitors including electrical, chemical, fire, and explosion hazards. Electrical and chemical hazards are similar to those common to batteries. The voltages of double layer capacitors are often lethal and should be treated with the same precautions as other high voltage devices. Type I and III capacitors have aqueous electrolyte which eliminates the possibility of hazardous fires, but allows for the possibility to chemical burns similar to those from other electrochemical storage devices. Type II poses a potential fire threat and health threats if inhaled, ingested, or contacts skin. [2]

There are also environmental implications due to the lack of recycling programs for electrochemical capacitors. This may contribute to siting, permitting, and disposal costs.

4.5.1.4 Applicability to Yukon Energy

Due to their low energy storage capacity, short duration of discharge and safety issues with capacitor technology, the use of DLC technology is not considered a viable option for Yukon's application.

4.6 Magnetic Field

4.6.1 Superconducting Magnetic Energy Storage

4.6.1.1 Technology

Superconducting Magnetic Energy Storage (SMES) uses the flow of direct current through a cryogenically-cooled, superconducting coil to produce a magnetic field that stores energy. Once the superconducting coil is charged, the current does not decay and the magnetic energy can be stored for an indefinite amount of time. The stored energy can be released whenever needed by discharging the coil. To keep the magnetic coil cool enough to have superconducting properties, cryogenic refrigeration must be an essential part of the storage system. See Figure 19 which shows a simplified diagram of the system. [2]

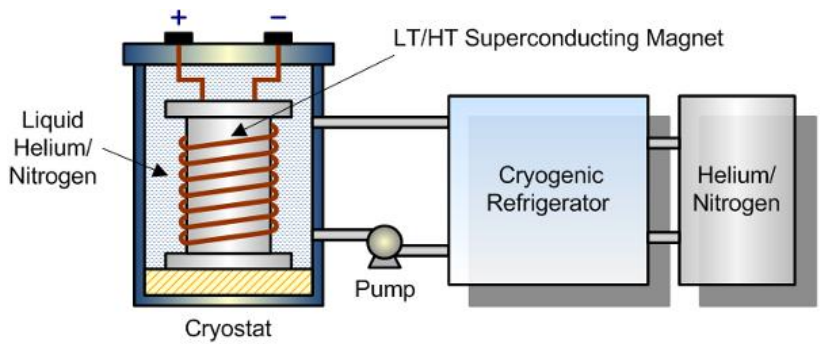


Figure 19 Diagram of a SMES System

4.6.1.2 Performance

SMES systems have several advantages including permanent storage, immediate response, life expectancy that is independent of duty cycle, high efficiency, and high reliability. The implied permanent storage relates to the stored energy may be held indefinitely, meaning that there are no standby losses. This is due to the sources of efficiency loss such as heat dissipation, and evaporation do not exist for SMES technology. Also a SMES system is capable of almost instantaneous response and is limited only by solid state materials ability to react in a charge/discharge cycle. [2]

The charging and discharging characteristics of the magnetic field has a much faster process than the mechanical and chemical energy conversion processes. This quality makes a SMES an excellent choice for UPS and power quality applications. The life expectancy of SMES a does not rely on the number of cycles or the depth of discharge as other storage technologies. The SMES overall efficiency is above 95 percent and there are very few mechanical moving parts. This means that there are less chances of failure and makes the SMES highly reliable technology. Some major disadvantages of SMES technology are the refrigeration energy requirements, the use of huge magnetic fields, and system costs.

The only commercial large scale SMES systems available around the 2000 to 2002 time frame were the D-SMES systems manufactured by American Superconductor (AMSC). The D-SMES unit is trailer-mounted system with a capacity to deliver 3 MW for about 1 second and 8 MVAR continuously at 480 Volts (AC). Their primary use was for grid stabilization.Table 1 below shows the locations and applications of these three D-SMES systems. [2]

Table 1 Commercial D-SMES in the United States

In Service Date	Utility	Location	Application
June 2000	Wisconsin Public Service	Northern Wisconsin	Transmission loop stability
July 2000	Alliant Energy	Reedsburg, Wisconsin	Transmission voltage stability
May 2002	Entergy	North Texas	Voltage stability

4.6.1.3 Maturity and Commercial Availability

Prior to making the D-SMES units, American Superconductor had manufactured several smaller SMES units designed for power quality applications where fast response times are needed. These units were used mostly in industrial settings to deal with voltage sag issues.

4.6.1.4 Pros and Cons as Applicable to Yukon Energy

SMES technology does not have the energy and discharge capability to supply the Yukon power grid's energy requirements.

4.7 Thermal

There are several thermal storage technologies that are used to provide support to the electric power grid. Only molten salt energy storage will be considered since most of the other thermal storage technologies are on the consumer's side of the meter.

4.7.1 Technology

In a basic system, molten salt is pumped to a receiver which absorbs reflected sunlight from a heating chamber. The molten salt then is circulated through highly specialized piping in the receiver (heat exchanger) during the day, and held in storage tanks at night. The tanks store the salt at atmospheric pressure. Use of molten salt for both heat transfer and thermal energy storage minimizes number of storage tanks and salt volumes needed. Molten salt is stored at 1050^{o}F (566^{o}C) until electricity is needed, whether or not the sun is shining. As electricity is required, molten salt is pumped from the hot tank through a heat exchanger to create super-heated steam which then powers a conventional steam turbine. The molten salt never needs replacing or topping up for the entire 30+ year life of the plant. Heat loss is usually only 1^{o}F per day. The molten salt, an environmentally friendly mixture of sodium nitrate and potassium nitrate, is able to be utilized as high grade fertilizer when the plant is eventually decommissioned. [3]

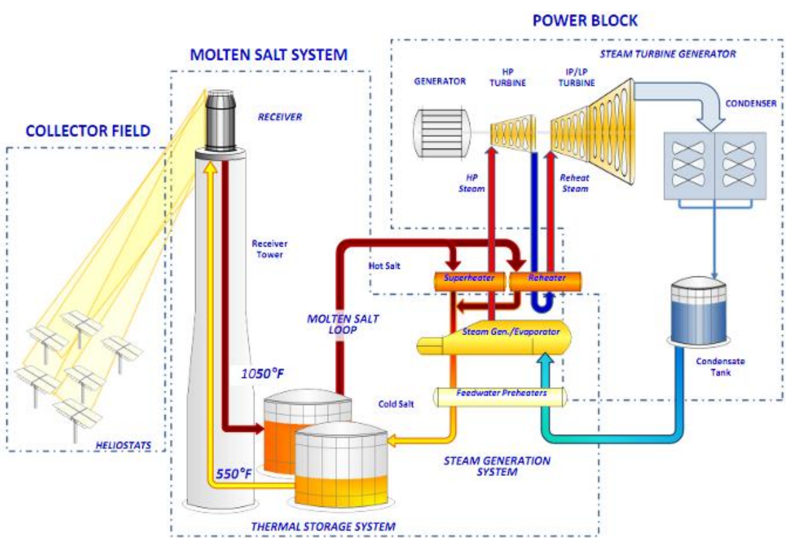


Figure 20 Molten Salt Energy Storage System

4.7.2 Performance

There a two solar heat facilities in the United States. One is the Abengoa's Solana 280 MW solar power station in Arizona which began operating in October 2013 with six hours of thermal energy storage.

Another project is Solar Reserve's 110 MW Crescent Dunes power tower solar thermal plant near Tonopah, Nevada that will have 10 hours of storage and is scheduled for completion in 2014. [3] In late September, 2011, the project received a $737 million loan guarantee from the US Department of Energy. ACS Cobra was the EPC contractor which carried out the engineering design, procured the equipment and materials necessary, and then constructed and delivered the facility to Tonopah Solar Energy. The project entered commissioning phase in

February 2014 following completion of construction. See Figure 21 which shows an overview of this solar collector site.

Figure 21 Crescent Dunes Solar Collector Site

All power generated by the Crescent Dunes project in the next 25 years will be sold to Nevada Power Company for $0.135 per kW hour. It has been in operation since September 2015.

The relatively low efficiency (25-35%) may be offset by relatively low capital costs if the resistance heating capability is added to an existing solar thermal plant.

4.7.3 Maturity and Applicable to Yukon Energy

Molten salt energy storage is widely used with solar power energy applications. This type of technology would not be compatible with the energy storage requirements for Yukon Energy as there are no solar energy installations at present.

5. Comparison of Energy Storage Technologies

There is a wide range of different energy storage technologies that are available as documented in the previous section. The selection of the most applicable technology(s) depends on the particular application which is based on the rated power, rated energy, and discharge duration demands of the electrical grid. The selected technology must also address any power quality requirements such as frequency regulation with a front end inverter and storage that can quickly respond to these variations.

Table 2 summarizes the various energy storage systems that were looked at for this project. From this table, there are four promising storage technologies that have been identified based on an estimated power rating requirement ranging from 1 to 10 MW and with an energy component ranging from 30 to 60 MWh with discharge duration between 2 to 5 hours. The power, energy and discharge requirements are an approximation derived from the Yukon Energy's diesel power generation over the 2015 time period. The selection of the four technologies was also verified by Figure 22 which confirms that the technologies that were selected were appropriate for the energy capabilities. Figure 23 shows how quickly these technologies can discharge and is useful when considering which technologies are best for providing power quality and grid support aspects.

There are also requirements that that promising technologies be mature and proven with minimal risks and be a cost effective solution to offset the present diesel generation of their grid.

The four promising energy storage technologies that were identified were all electrochemical based and are as follows:

1. Lead Acid Battery
2. Lithium Ion Battery
3. Sodium Sulphur Battery
4. Vanadium Redox Battery

Of these four energy storage technologies, only two were selected based on safety, overall cost and proven technology, and those were the lead acid battery and lithium ion battery.

The determination of the power, energy and discharge characteristics will be determined which will provide further information into the costing and footprint of the system. The next section of the report explains the cost estimates and physical size of these two technologies and options for the integration into the electrical grid. A comparison then can be made of which energy storage system would be most economical and best fit.

As reported previously, there is only one off shore supplier of the Sodium Sulphur battery, therefore competitive pricing would be an issue and there are safety concerns due to high operating temperatures. The Vanadium Redox battery would have a large footprint and is still in the development stage with the largest commercial system in service system at 600 kW

Table 2 Comparison of Energy Storage Systems

Storage Type	Power	Capacity (MWh)	Discharge Duration hrs	% Efficiency or Total Cycles	Lifetime years	Total Capital Cost (USD/kW) Note 1
Pumped Hydro	250 MW -400 MW	1600 – 14,000	2 to 24	76%-85% >13,000	50 to 60	1500 – 4300 Size dependant
CAES (Above Ground)	3 to 50 MW	250	2 to 6	>13,000	35	390 - 430
Flywheel	100 kw to 1650 Max:20 MW	0.5 to 10 kWh Plans to 25	5 sec to 15 min	70 to 80% >100,000	20	1950 to 2200
Hydrogen	Demo NA	Demo NA	Demo NA	30 to 45%	demo	1370 to 2740
Lead acid Batteries (advanced)	3 to 50 MW	250	10 sec to several hrs	75-80 (DC) 70-75 (AC) 4500 cycles	3 to 10	1740 to 2580
Nickel Cadmium Batteries	3	Total installed capacity 27 MW	15 min	60 to 70%	10 to 15	NA
Lithium Ion Batteries	8 MW	32 MWh	15 min to several hours	87 to 92% 2000 to 3000	10 to 15	4300 to 6200
Sodium Sulfur High Temp	34 MW	245 MWh	8 hr	80 to 85%	15	3100 to 3300
Sodium Nickel Chloride (Zebra)	50 kW to 2 MW	Up to 8hrs	80% depth of charge	85 to 90%	Up to 3000 cycles	4500 and 10,00
Vanadium Redox	4 MW	Demo up to 250 MWh	2 to 8 hrs	60 to 70%	10 to 15	3100 to 3700
Zinc Bromine	40 to 100kW Demo to 1 MW	4 MWh	2 to 6 hrs	60 to 80%	20	1450 to 2420
Zinc Air	1 MW	5.4 MWh	5.4	50 to 75%	4500	1900 to 3900
Electrochemical Capacitors (DLC)	1 MW	Very low	Up to 30 seconds	90%	>500,00 cycles	1500 to 2500
SMES	1 to 3 MW	low	milliseconds to 3 seconds	90%	>30,000 cycles	1000 to 10,000
Thermal Molten Salt	Demo 280 MW	Demo	6hrs	25 to 35%	NA	NA

Note 1 : Costs are estimations based on several sources between 2003 and 2013 and are representative of that time period and do not reflect the 2015 dollar values. [1], [2], [3], [7]

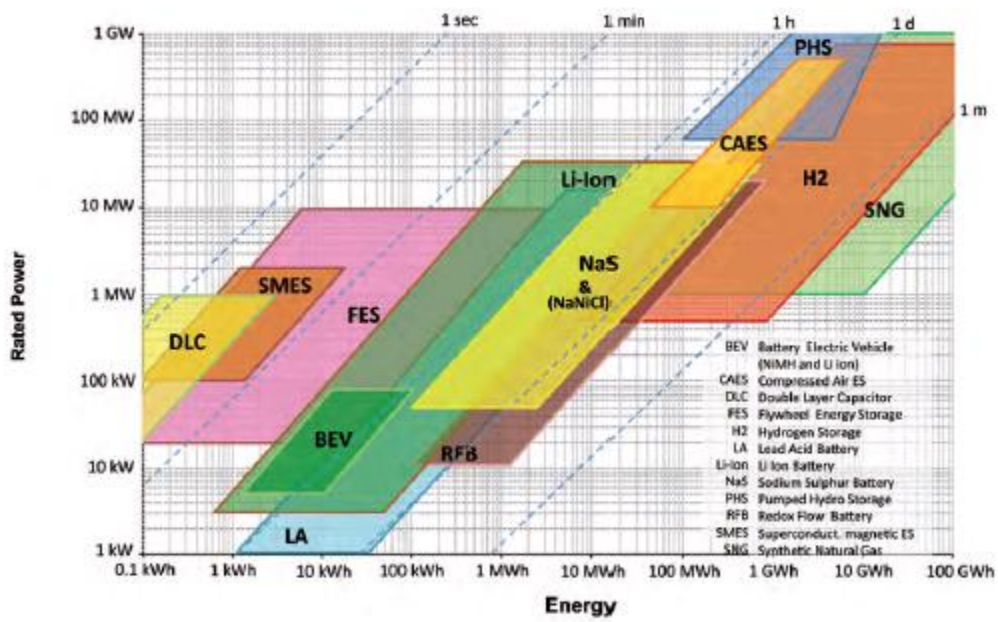


Figure 22 Rated Power Energy and Discharge Duration

Utility Scale Energy Storage Systems Benefits, Applications, and Technologies [2]

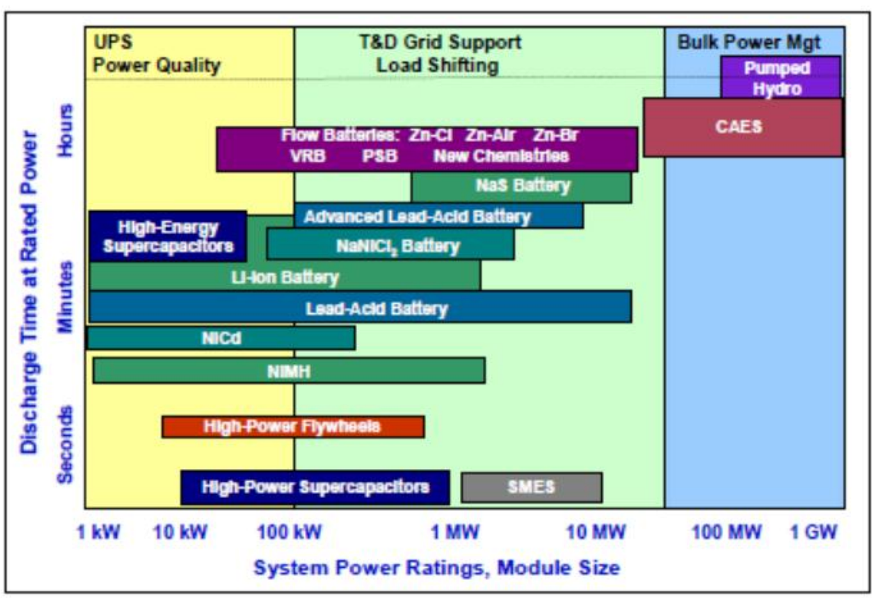


Figure 23 Comparison of Discharge Time Rating

Prospects for Large Scale Energy Storage in Decarbonized Power Grids [7]

5.1 Determining the Energy Storage System Power and Rating

The battery energy storage system power rating will be determined to reduce the use of the diesel generation while utilizing the two natural gas reciprocating engines (8.8 MW in total) during peak demand. Yukon Energy provided information that the two gas units are rated at 4.4 MW each and can be base loaded for at least 4 hours. The use of the gas generation will decrease the rating of the storage system to an optimal size based on the Yukon's Energy's requirements for a safe and mature technology.

In order to understand how often the peak power demand in 2015 reaches distinct values, a chart was developed which shows the frequency of the peak diesel power demand (see Figure 24).

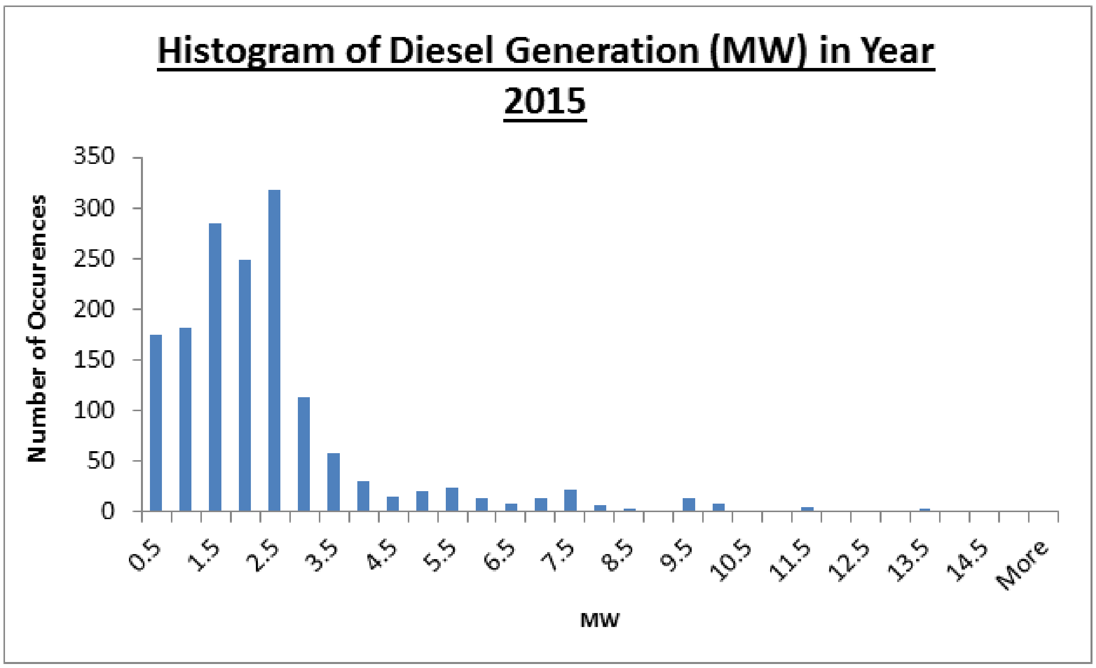


Figure 24 Frequency Plot for Different Power Levels

The general shape of the histogram is that of a Weibull distribution rather than a normal distribution, so that the median and mean values are not equal. Figure 25 shows the cumulative probability distribution for the peak power demand.

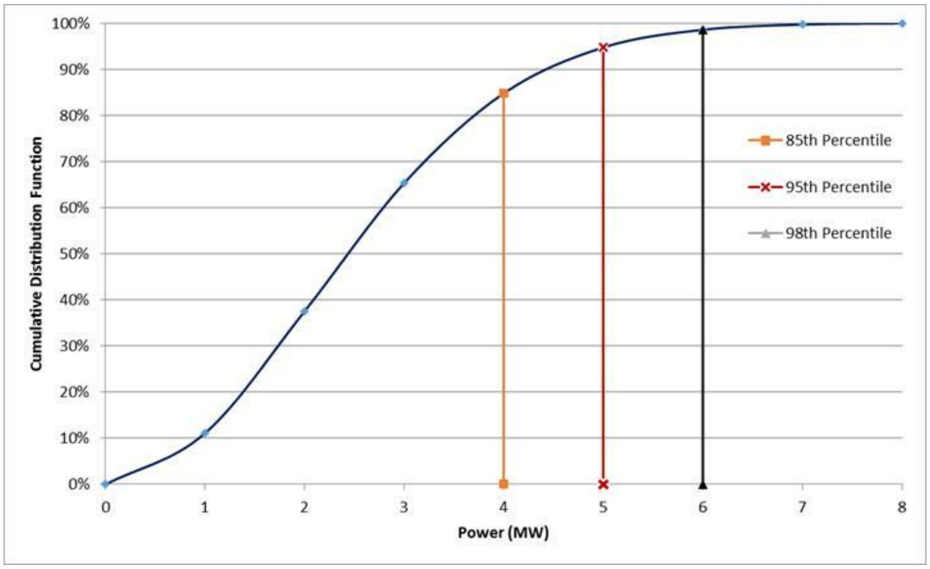


Figure 25 Cumulative Distribution Function of Optimum Power Levels

The mean value was calculated as the average of the power values, which was 2.58 MW. More importantly, from this curve, the 85th percentile value for peak power demand was approximately 4.0 MW. This means that 85% of the time (during the year 2015) the power demand was equal to or less than 4.0 MW. Only for 15% of the time did the power demand have very brief excursions above that value. Similarly, the 98th percentile value for peak power demand was approximately 6.0 MW. Therefore, 4.0 MW value was chosen as the minimum desired power output rating of the system.

With a 4.0 MW energy storage system added to the available natural gas reciprocating engine power of about 8.0 MW, the total production would be 12.0 MW to offset the diesel generation used for peaking purposes. The diesel generation is still expected to operate should the peaking demand grow greater than the combined generation of the energy storage system and natural gas units. In the data provided, this higher demand was found during the winter months.

Similar to determining the desired power rating of the energy storage, its energy rating was determined by analyzing the cumulative probability distribution of diesel energy requirements for the entire year of 2015 (see Figure 26). The median for the distribution is approximately 22.81 MWh. Using the 90th percentile point, an energy rating of approximately 40 MWh would cover greater than 90 percent of the energy demand. Similarly, the 96th percentile value for the energy demand was approximately 50 MWh. Therefore, 40 MWh value was chosen as the minimum desired energy output rating of the system.

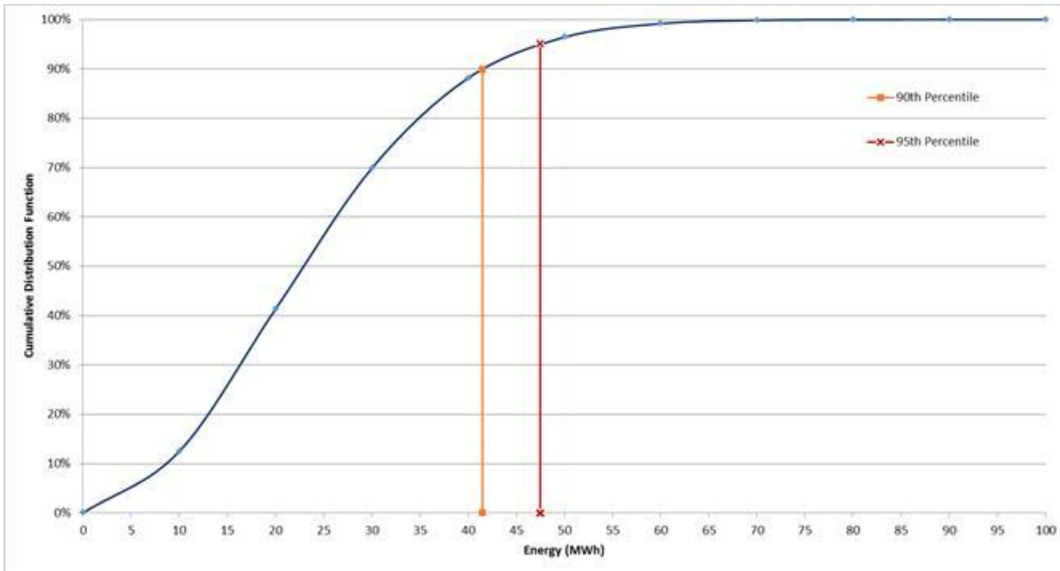


Figure 26 Cumulative Distribution Function for Energy Levels

Therefore the minimum recommended ratings for power and energy of the storage system are 4 MW and 40 MWh.

One of the mature energy storage technologies capable of providing the recommended ratings is the lead acid storage technology. Other technologies, due to having a significantly shorter discharge time, would have to have a significantly higher power output to have the same energy rating. Another mature battery energy storage technology capable of meeting the recommended energy and discharge ratings is the lithium ion battery system.

For this study, a 4 MW, 40 MWh lead acid battery energy storage system (ESS) was first selected. Due to the high MW and MWh usage in the months of January and February, this ESS will need to be complemented by the use of both 8 MW natural gas generation units. To reduce the use of the natural gas generation units, a 6 MW/60 MWh and an 8 MW/80 MWh lead acid battery energy storage systems were also studied as options. For price comparison purposes, an 8 MW/40 MWh lithium ion battery energy storage system was also considered.

6. Cost Estimates, Schedule, and Footprints

The 2015 load data for hydro-electric and diesel generation provided by Yukon Energy Corporation (see Figure 3) was used to assess the power capacity need of an energy storage system. The data showed diesel and natural gas generation was used mainly for peak demand. Diesel generation is a mature and well developed technology and has a low capital cost but a very high operation and maintenance cost. The diesel generators, as well as the trucks transporting the fuel, produce environmentally damaging SOx and NOx gas emissions. Other known problems associated with diesel generation include fuel storage leaks, leakage of generator lubricants, and variations in fuel price. Hence there is a focus to curtail diesel generation with an energy storage system together with the natural gas generation.

As discussed in Section 5, the type of energy storage chosen was a battery energy storage system (BESS), specifically either the lead acid or lithium ion batteries. Going forward in this report, all references to an ESS will imply battery energy storage. Battery Energy Storage Systems possess many advantages for the improvement of power reliability over diesel generation. One advantage is that these systems (both the power conversion systems and energy storage technologies) are modular so that they can be installed in a reasonable time frame and power capacity can be added in small increments as the demand grows. The modular concept is also beneficial for equipment transportation. Most energy storage technologies should be built in a modular arrangement and not install the energy storage system with full capacity at the beginning. This could be wasteful in terms of the utilization of the energy storage technology due to their relatively short lifespan and high costs. Also, by adding to the BESS in increments, one can take advantage of future improvements in battery technology and efficiency.

These systems are considered multifunctional, aside from assisting in continuing the supply of power during peak demand, the energy storage systems may contribute for improvements in transient stability, voltage stability, frequency regulation, transmission and distribution grid support, load shifting, bulk power management and power quality.

6.1 Battery Energy Storage System Components and Footprint

To evaluate the minimum footprint of each energy storage system one needs to examine the major components of a battery energy storage system. The BESS can be broken down into the following three categories.

1. The Energy Storage Technology (EST) consist of all equipment necessary to store and supply energy to the Power Conversion System (PCS), duties, shipping and installation at site, and engineering support for installation and commissioning. For this study, the lead acid and lithium ion battery manufacturer's recommended battery connections to the PCS are shown in Table 3.

Table 3 Battery Configuration to the PCS

Energy Storage System Model	Battery Connections to the PCS
4 MW 40 MWh Lead Acid	Four (4) 1 MW connections
6 MW 60 MWh Lead Acid	Eight (8) 750 kW connections
8 MW 80 MWh Lead Acid	Eight (8) 1 MW connections
8 MW 40 MWh Lithium Ion	Four (4) 2 MW connections

2. The PCS consist of all necessary power electronic equipment that will control the supply of electrical energy from the utility grid to the ESS and that will later discharge the stored energy in the ESS, returning it to the grid. The PCS converts the DC power of the energy storage device to AC power used by the utility grid and vice versa when the grid power is used to re-charge the storage device. Table 4 lists the major PCS equipment required for the four options of battery energy storage systems being studied.

Table 4 Power Conversion System Major Equipment List

Energy Storage System Model	**PCS Equipment**
4 MW, 40 MWh Lead Acid	One (1) PCS Module packaged in one 40’ trailer. The one module includes the following: • Four (4) 1 MW inverters with AC and DC circuit breakers; thermal management; control and protection • Four (4) 1000 kVA padmount transformers : 35 kV : 267 VAC • One (1) MUC (Multiple Unit Control)
6 MW, 60 MWh Lead Acid	Two (2) PCS Modules packaged in two 40’ trailers. Each module includes the following: • Four (4) 750 kW inverters with AC and DC circuit breakers; thermal management; control and protection • Four (4) 750 kVA padmount transformers : 35 kV : 267 VAC • One (1) MUC (Multiple Unit Control)
8 MW, 80 MWh Lead Acid	Two (2) PCS Modules packaged in two 40’ trailers. Each module includes the following: • Four (4) 1 MW inverters with AC and DC circuit breakers; thermal management; control and protection • Four (4) 1000 kVA padmount transformers : 35 kV : 267 VAC • One (1) MUC (Multiple Unit Control)
8 MW, 40 MWh Lithium Ion	Two (2) PCS Modules packaged in two 40’ trailers. Each module includes the following: • Two (2) 2 MW inverters with AC and DC circuit breakers; thermal management; control and protection • Two (2) 2000 kVA padmount transformers : 35 kV : 454 VAC • One (1) MUC (Multiple Unit Control)

3. The Balance of Plant (BoP) consists of the utility’s costs for the project engineering, construction management and grid connection to build an energy storage system substation.

   For the study the major equipment and requirements included:

- All required site preparation, foundations, grounding, support structures, cabling, bus work, protection, controls, and SCADA at the substation.
- The building for housing the batteries
- The slabs on grade for the PCSs,
- 3 three-phase 34.5 kV circuit breakers
- 3 three-phase motor operated disconnects
- 3 three-phase manual disconnects
- Cabling between the substation and PCS
- Cabling between the PCS and EST

The proposed development single line diagrams of the battery energy storage systems are shown in Figure 27 for the 4 MW, 40 MWh BESS and Figure 28 for the 6 MW, 60 MWh, the 8 MW, 80 MWh and the 8MW, 40 MWh (lithium ion)BESS.

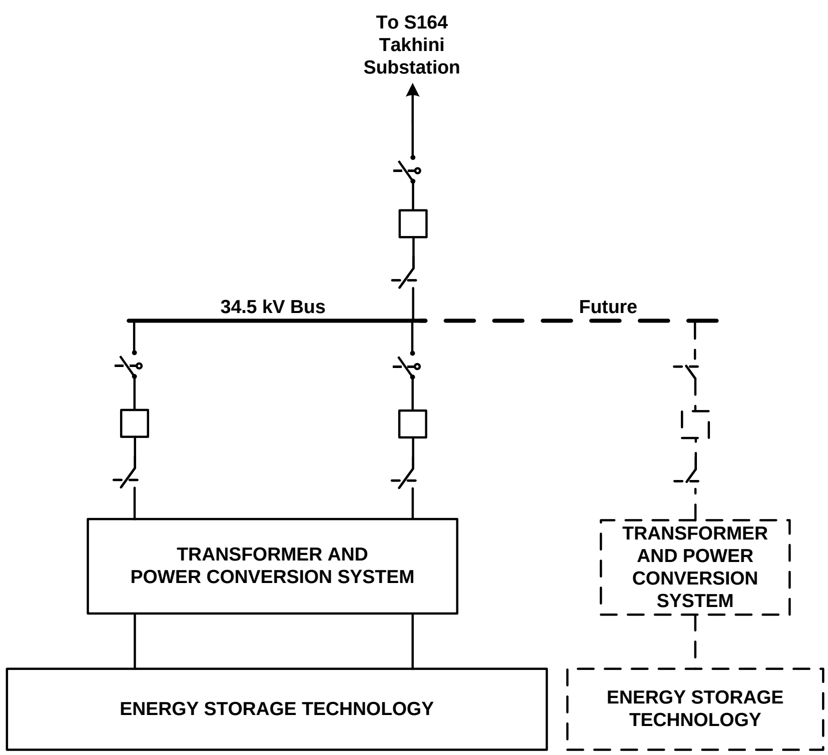


Figure 27: 4 MW, 40 MWh Battery Energy Storage System Configuration

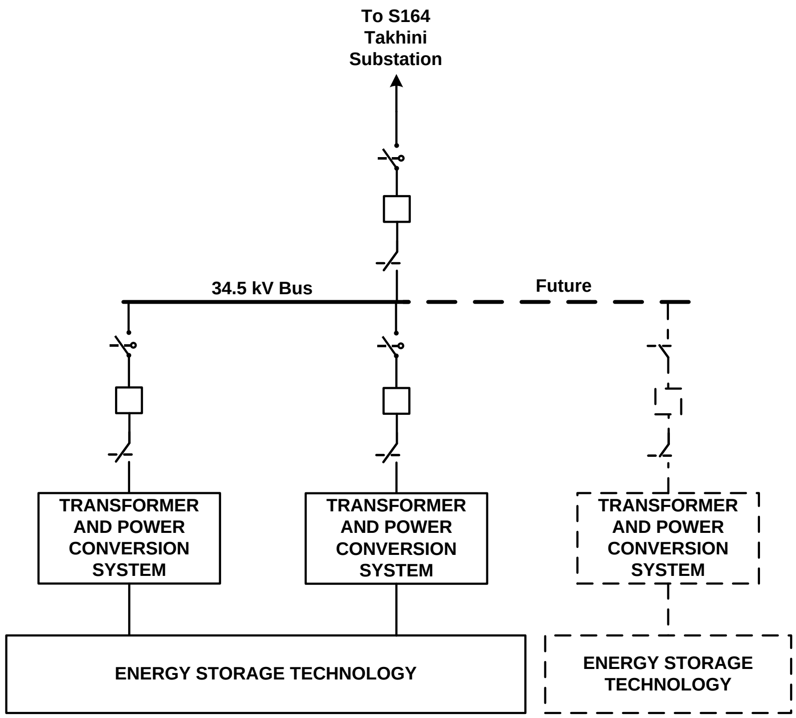


Figure 28: 6 MW, 60 MWh; 8 MW 80 MWh and 8 MW, 40 MWh Battery Energy Storage Sytems Configuration

The energy storage system was treated as a separate substation and the anticipated location is near the S164 Takhini 138 kV / 34.5 kV substation. The energy storage system will connect to the 34.5 kV system as shown in Figure 27 and Figure 28. By connecting to the relatively low transmission line voltage of 34.5 kV, the need for a second step-up transformer was avoided. A detailed engineering study of the electrical system at the S164 Takhini substation was not studied in regards to the effects on and the interaction with the energy storage system and should be considered if the project proceeds. Modular design was considered when designing the energy storage system. The proposed footprints for the different energy storage systems are shown below in the following figures.

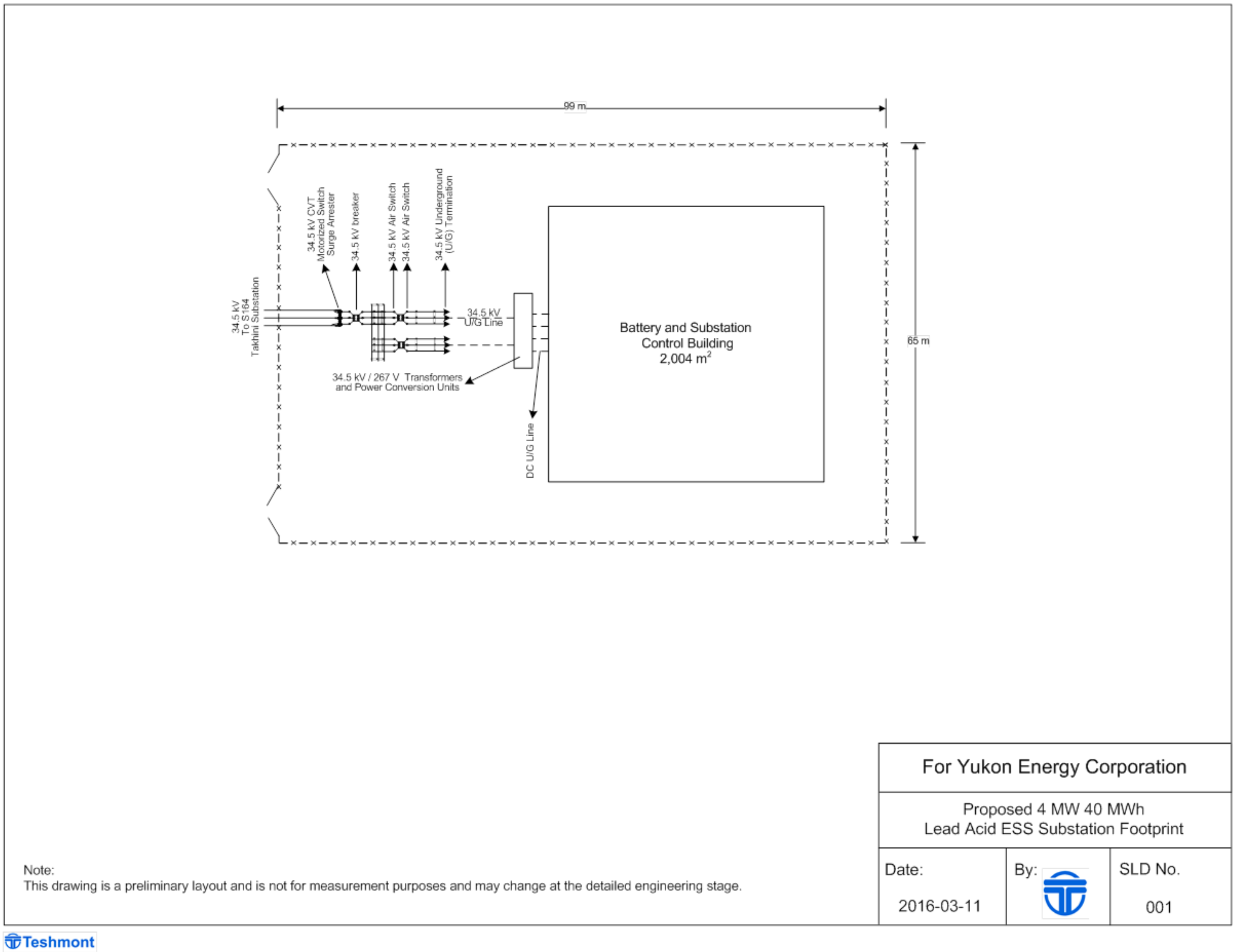


Figure 29 4 MW, 40 MWh Proposed Arrangement

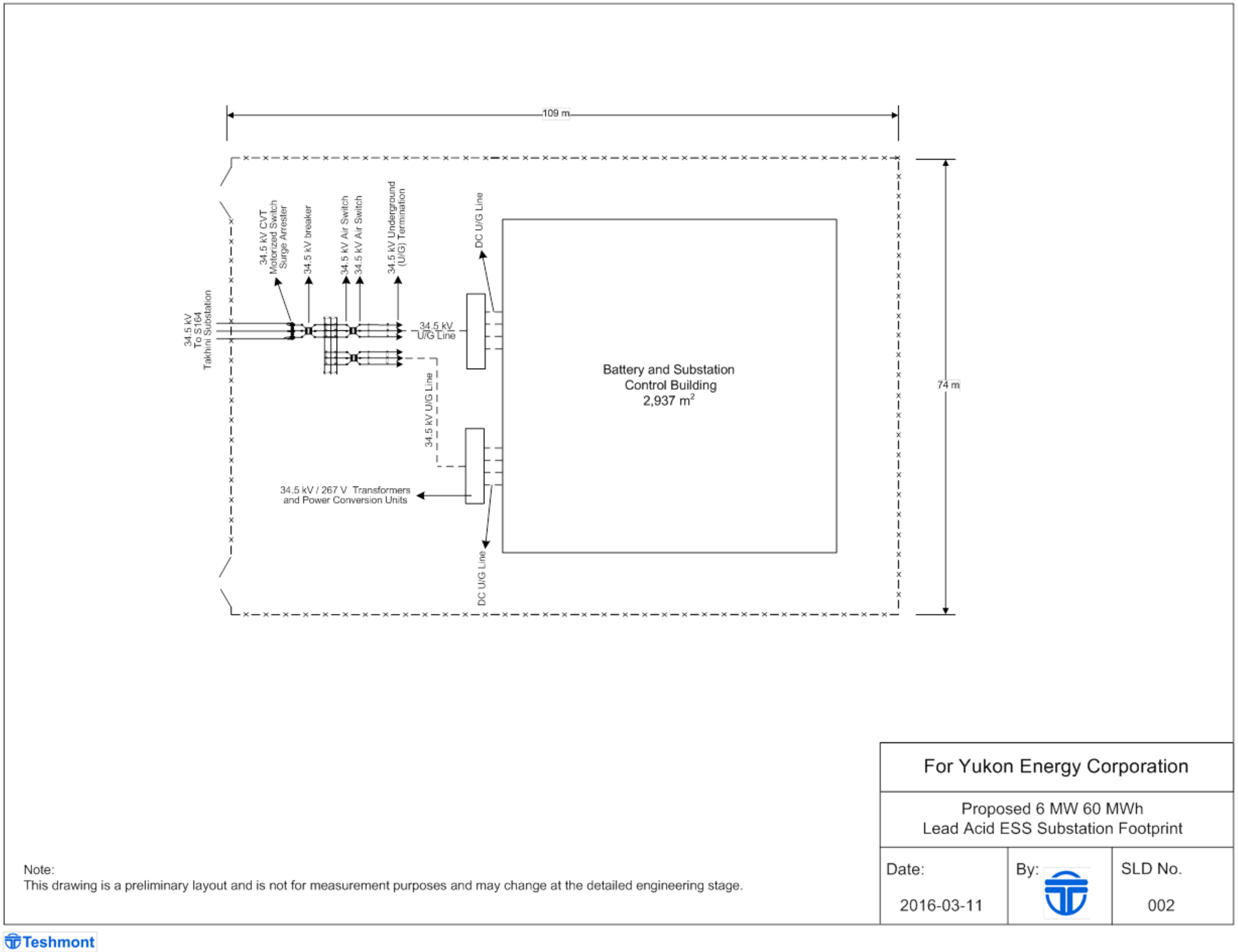
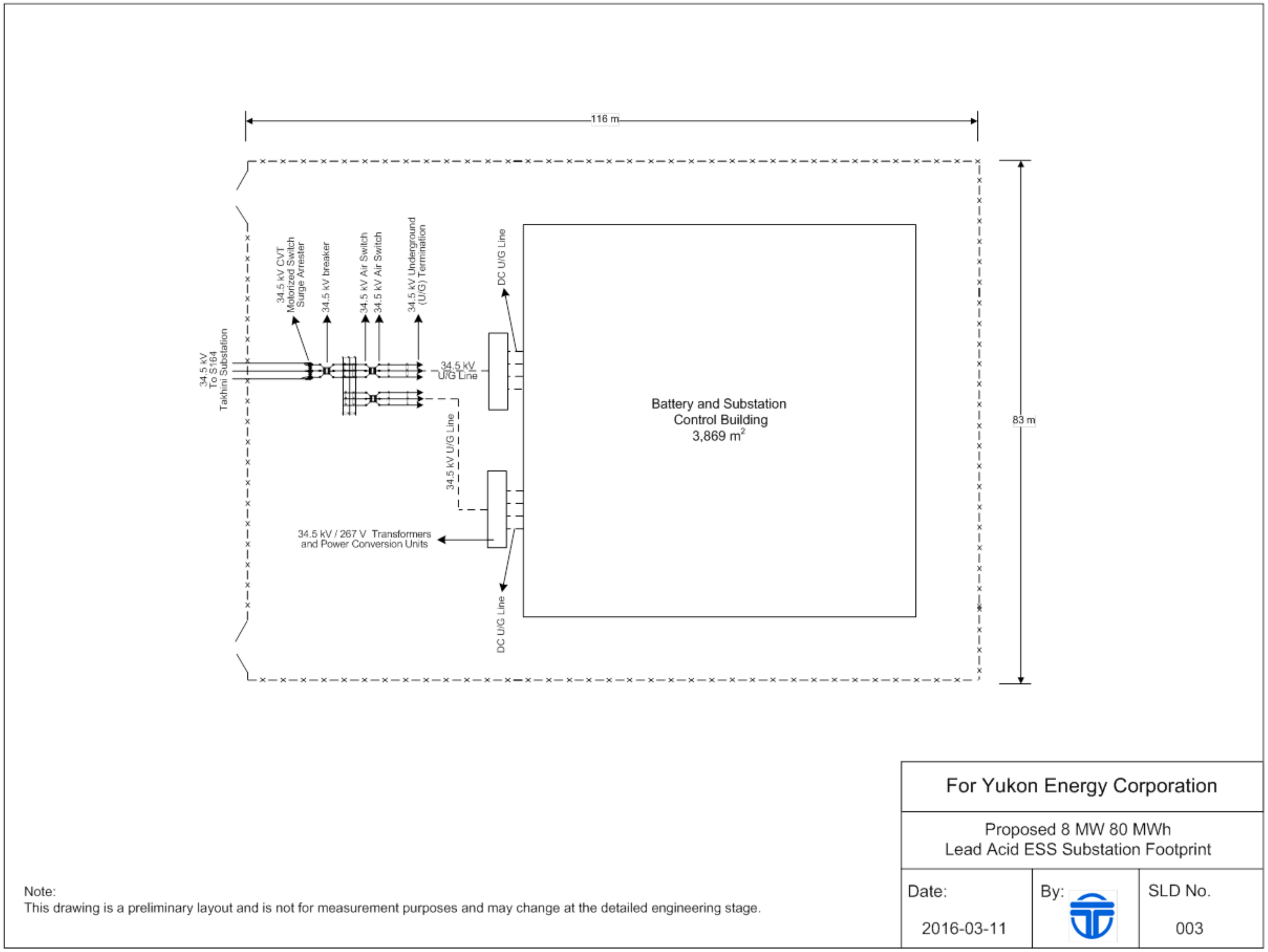
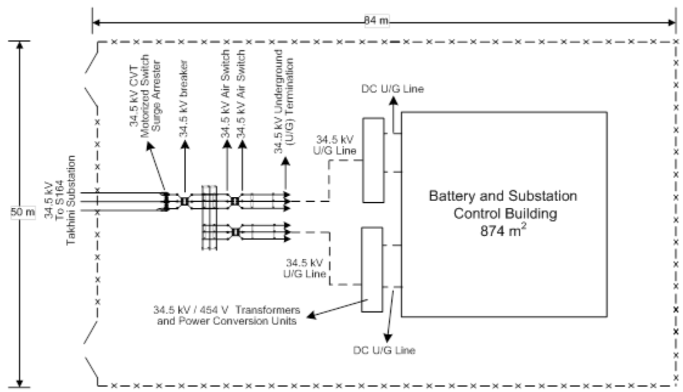


Figure 30 6 MW, 60 MWh Proposed Arrangement



Teshmont

Figure 31 8 MW, 80 MWh Proposed Arrangement



For Yukon Energy Corporation		
Proposed 8 MW 40 MWh Li-Ion ESS Substation Footprint		
Date: 2016-02-25	By:	SLD No. 004

Note:
This drawing is a preliminary layout and is not for measurement purposes and may change at the detailed engineering stage.

Teshmont

Figure 32 8 MW, 40 MWh Proposed Arrangement

6.2 Development of Cost Schedule

The economic viability of implementing either of the BESS applications (lead acid or lithium ion) was explored by performing a 30 year life cycle cost-benefit analysis. The analysis was performed using an economic model developed especially for this purpose that detailed the estimated costs and expected benefits over the projected total life of the energy storage system. Future costs and benefits are converted to present value using a user defined discount rate. The total of all present value costs are then subtracted from the total of all present value benefits to provide a total Net Present Value (NPV) for the project. When the NPV value is negative, the project represents an overall economic burden to the system owner while a positive NPV provides an overall benefit to the owner.

The financial model takes into account the following costs and benefits:

- Capital cost of energy storage system equipment
- Capital cost of the building and auxiliary systems
- Capital cost of the civil works
- Operating and maintenance cost of the energy storage system and building
- Replacement cost of energy storage system components (primarily the batteries) after 15 years for lead acid batteries and after 20 years for lithium ion batteries
- Cost of power losses
- Cost of energy production differential benefit for using hydro power in place of diesel power

To evaluate different alternatives and scenarios, the model allows for certain economic parameters to be changed to assess the impact on the overall NPV. A base case was established based on current conditions and information obtained from Yukon Energy Corporation, summarized in Table 5.

Table 5 Economic Parameters

Financial Parameters	
Year for NPV and Currency Exchange Rates	2016
Study Period (years)	30
Nominal Discount Rate - annual	5.45%
Cost for Electric Power Losses (cents/kWh)	6.0
Electricity Cost Escalation rate - annual	2.0%
Owner’s Portion of the Total Capital Cost	100%
Cost of Electricity Production from Hydro(cents/kWh)	6.00
Cost of Electricity Production from Diesel(cents/kWh)	30.80

The NPV was calculated to 2016 Canadian dollar values. The expected useful life for the energy storage system was set at 30 years, which required replacement of all batteries after 15 years for lead acid batteries and after 20 years for lithium ion batteries. No salvage value for the batteries was considered, nor was any anticipated decrease in future battery prices. The nominal discount rate used to calculate the Net Present Value of future costs was 5.45

percent, provided by Yukon Energy Corp. YEC was assumed to provide 100 % of all costs, with no outside incentive funding. A 2.0 percent per year electricity escalation rate was assumed. The cost differential between utilizing diesel generation and hydro generation represented a savings of 24.80 cents/kWh.

The energy storage system parameters, shown in Table 6 , were obtained through consultation with Exide Technologies for lead acid batteries [9], LG Chem [10] for lithium ion batteries, ABB for the PCS [11], and Tru-Steel [12] for buildings that will house the batteries. Information provided included the efficiency of the system, the replacement period for the EST and cost parameters such as capital cost, operation and maintenance (O&M) costs and replacement costs. All other costs which are not included in the EST and PCS portion of the energy storage system costs are found in the Balance of Plant cost.

Table 6 Energy Storage System Parameters

BESS Parameters	**Lead Acid**			**Lithium Ion**
Energy Storage System Model	**4000 kW, 10h**	**6000 kW, 10h**	**8000 kW, 10h**	**8000 kW, 5h**
Power (kW)	4000	6000	8000	8000
Duration (h)	10	10	10	5
Power Discharge Efficiency (%)	80	80	80	90
Replacement period (years)	15	15	15	20
Capital Cost (PCS +EST)	$19,597,000	$30,086,000	$39,057,000	$25,670,000
Replacement Cost	$17,389,000	$26,084,000	$34,779,000	$22,082,000

Based on discussions with Exide Technologies and LG Chem., replacement of the energy storage technology (batteries) is expected to take place in the fifteenth year and twentieth year respectively, and have been estimated at the respective battery cost. The battery power discharge efficiency was quoted by Exide Technologies as 80 percent for lead acid and by LG Chem as 90 percent for lithium ion. The batteries costs included the engineering, installation and commissioning of the battery racks and enclosures. The PCS costs included the engineering, installation and commissioning of the units described in Table 4.

Table 7 shows the balance of plants parameters consisted of the building for the batteries and substation controls and the 34.5 kV substations.

Table 7 Balance of Plant Parameters

BESS Parameters	**Lead Acid**			**Lithium Ion**
Energy Storage System Model	**4000 kW, 10h**	**6000 kW, 10h**	**8000 kW, 10h**	**8000 kW, 5h**
EST Building Type /Size (m)	45 x 45 x 6.6	54 x 54 x 6.6	62 x 62 x 6.6	30 x 30 x 6.6
Building Costs	$820,000	$1,201,000	$1,583,000	$423,000
Substation Costs	$1,300,000			

Based on the discussion with Tru-steel the cost included the installation and supply of a Pre-engineered building. The cost did not include soil conditions, site access, winter work, travel expenses and accommodations. The substation estimates were validated using in-house cost-estimating tools. The major equipment and requirements include all required site preparation, foundations, grounding, support structures, cabling, bus work, protection, controls, and SCADA at the substation, 3 three-phase 34.5 kV circuit breakers, 3 three-phase motor operated disconnects, 3 three-phase manual disconnects, Cabling between the substation and PCS and Cabling between the PCS and EST. Since the substation costs were negligible in the overall cost calculations, the 8000kW 10h was selected to represent all the different substation configurations costs.

Table 8 shows the operation and maintenance parameters as well as the annual energy savings.

Table 8 Operation and Maintenance Parameters

BESS Parameters	**Lead Acid**			**Lithium Ion**
Energy Storage System Model	**4000 kW, 10h**	**6000 kW, 10h**	**8000 kW, 10h**	**8000 kW, 5h**
Annual Energy production (MWh)	2443	2667	2780	2780
O&M Costs Escalation Rate (%)	2.00	2.00	2.00	2.00
Estimated Annual O&M Cost	$210,200	$321,300	$416,800	$260,900

The annual energy production for the different energy storage systems were calculated as the amount of energy required to replace the diesel energy production in 2015. For an example, the 40 MWh lead acid BESS is used to replace 2443 MWh of diesel energy production per year. Annual O&M assumed the facility heating and air conditioning, janitorial, storage system maintenance and general building upkeep. The cost for maintaining the different battery systems were also include in the annual O&M costs. The annual O&M cost for was subject to a 2.0 percent escalation rate.

The present value costs for the different energy storage systems included the capital costs of the battery technologies, the power conversion systems, and the balance of plant, the sum of the annual operation and maintenance cost, the sum of the annual costs of energy use to recharge the batteries and the replacement cost of the batteries. The equation used was as follows

$$PV_{Cost} = Cap_{Total} + \sum_{i=1}^{30} OM_{F\,i} * (1+d)^{-yr\,i} + \sum_{i=1}^{30} EL_{i} * (1+d)^{-yr(i)} + \mathrm{Rc} * (1+\mathrm{d})^{-Rp}$$

Where

Cap_{Total} = Capital Cost + BoP
OM_F = $Annual\ O\&M\ cost * (1 + O\&M\ Escalation\ rate)^{yr}$
EL = $Energy\ production * Electricity\ cost\ for\ losses * 0.01 * (1 + electricity\ Escalation\ rate)^{yr}$
Rc = Replacement cost
Rp = Replacement year
d = nominal discount rate

The expenditure savings realized by utilizing the energy stored in the batteries was the net difference in energy production cost from replacing diesel energy with stored hydro energy. The net income from peak demand power was considered to be zero, as the power supplied by diesel was being directly replaced by the hydro power.

Based on all parameters in Table 5, Table 6, Table 7 and Table 8 the base case NPV value for the two energy storage systems being considered are shown in Table 9.

Table 9 Base Case NPV for Energy Storage Systems

	Lead Acid			**Lithium Ion**
Energy Storage System Model	**4000kW, 10h**	**6000kW, 10h**	**8000kW, 10h**	**8000kW, 5h**
Present Value – Benefits ($)	$11,085,000	$12,102,000	$12,615,000	$12,615,000
Present Value – Costs ($)	$35,981,000	$53,008,000	$68,119,000	$42,860,000
NPV ($)	-$24,896,000	-$40,906,000	-$55,504,000	-$30,245,000

Table 9 shows that over the lifetime of the four projects, all would have significantly higher costs compared with their respective benefits and hence a negative NPV. This evaluation considers only presently available technology. For the lead acid energy storage systems, the change in cost was directly related to the ratio of power. For example, the 6 MW and 8 MW lead acid energy storage systems costs 1.5 times and twice that of the 4 MW lead acid energy storage system.

Another way to evaluate and compare different energy technologies is to divide the total costs to construct, finance, operate and maintain a plant by its useful output. The costs are levelized using the cost of capital or discount rate to calculate a flat dost for energy in $/kWh and the capacity $/kW-yr over the life of the plant.

The primary basis for comparison of generation assets is the levelized cost of energy (LCOE) in $/MWh. The cost or value of capacity is levelized on an annual basis (LCOC) is expressed as $/kW-yr. The capital cost represents the cost of the plant being available to provide electrical generation whether or not it actually operates and is analogous to an insurance policy. The equations that were used for LCOE and LCOC were calculated as follows:

$$LCOE = \frac{PV_{Cost} * CRF}{\text{Annual Energy production}}$$

$$LCOC = \frac{PV_{Cost} * CRF}{\text{ESS Power (kW} - \text{yr)}}$$

Where

$$CRF = \frac{d * \; 1 + d \;^{30}}{[\; 1 + d \;^{30}] - 1}$$

Nominal discount rate is d = 5.45%

In Table 10 the LCOE and LCOC were determined for the different energy storage systems under evaluation.

Table 10 LCOE and LCOC

	Lead Acid			Lithium Ion
Energy Storage System Model	**4000kW, 10h**	**6000kW, 10h**	**8000kW, 10h**	**8000kW, 5h**
LCOE ($/MWh)	$1,010	$1,360	$1,680	$1,060
LCOC ($/kW-yr)	$620	$600	$580	$710

Since the operation of the Lithium ion is expected to operate at half its rated value the ESS power is 4000 kW in the LCOC calculation.

6.3 System Cost vs Utilization Sensitivity Study

To realize a positive NPV from any of the BESS, the system must be utilized more than it would be for only intermittently replacing up to 4 MW of diesel power production. As an example, the 40 MWh lead acid BESS is used to replace 2443 MWh (approximately 60 days of operation per year) of diesel energy production per year (based on the year 2015). Table 11shows the approximately number of days in operation per year based on the year 2015 for the different BESS.

Table 11 Operation Parameters

BESS Parameters	Lead Acid			Lithium Ion
Energy Storage System Model	**4000 kW, 10h**	**6000 kW, 10h**	**8000 kW, 10h**	**8000 kW, 5h**
Annual Energy production (MWh)	2443	2667	2780	2780
Approximate Days of operation	60	45	35	70

It was assumed the efficiency losses as the energy consumed during the charging cycle but not delivered to the loads during the discharge cycle. If the BESS can be used for providing more of a base load, either by load shifting or by load growth, then this unused capacity can generate more revenue or hence increase the NPV. Figure 33 shows the resulting increase in NPV for all 4 BESS with increased utilization.

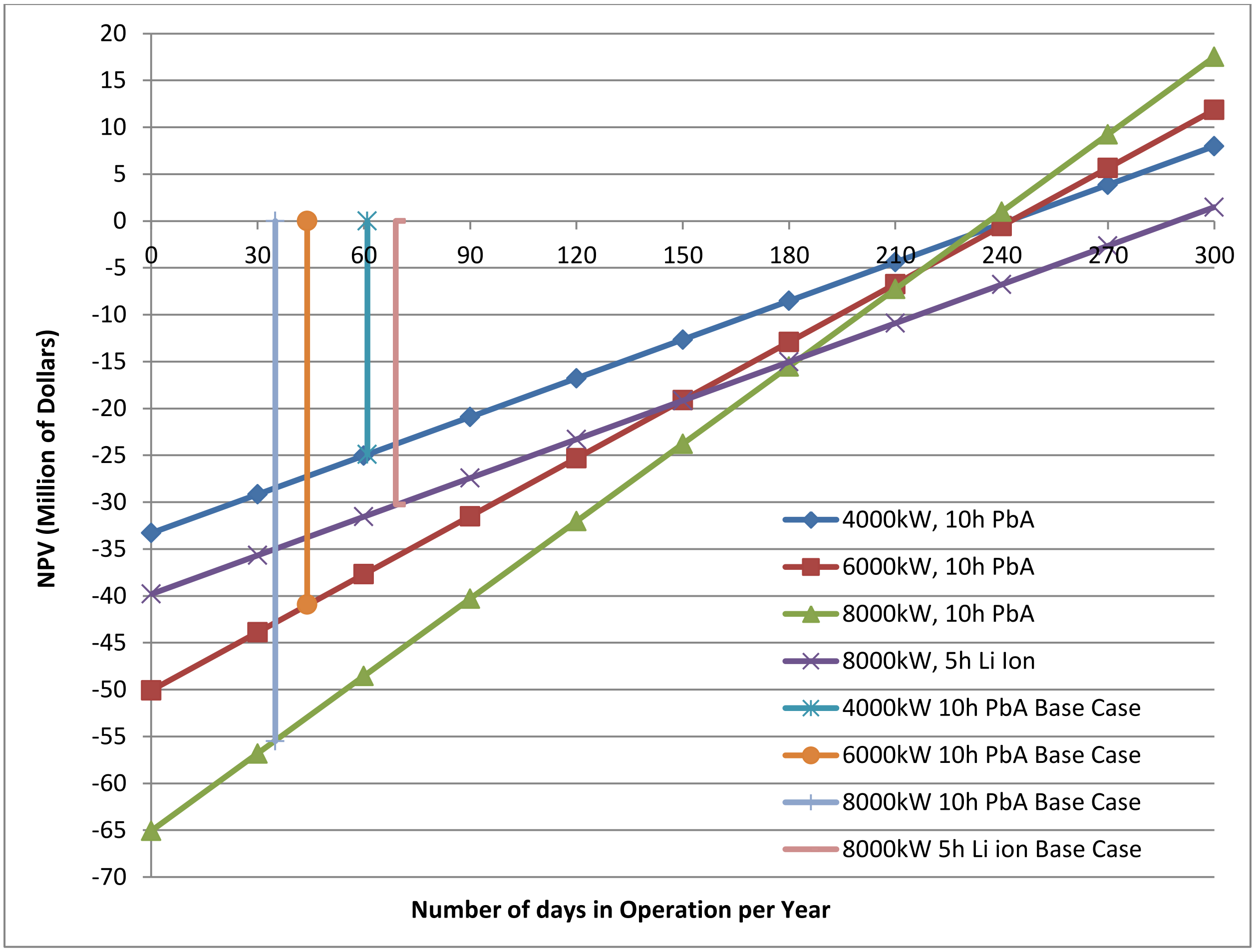


Figure 33 Battery Energy Storage System vs NPV Utilization

A day in operation, shown in Figure 33 , was represented by 10 hours of discharge and approximately 12 to 14 hours of recharge. As the number of days increased the NPV values improved. For the Lead Acid BESS would need approximately 240 days (approximately 8 months, 7 days a week) to the break-even. The Lithium Ion BESS would need approximately 290 days (approximately 9.5 months, 7 days a week) to the break-even.

6.4 Generation of high level project schedule

The high level project timeline was based on contributions from the manufactures of the different components for the energy storage systems. Figure 34 shows the time in weeks for each energy storage component; project planning and engineering, construction and site improvement and testing and commissioning. The duration of the total project is also shown.

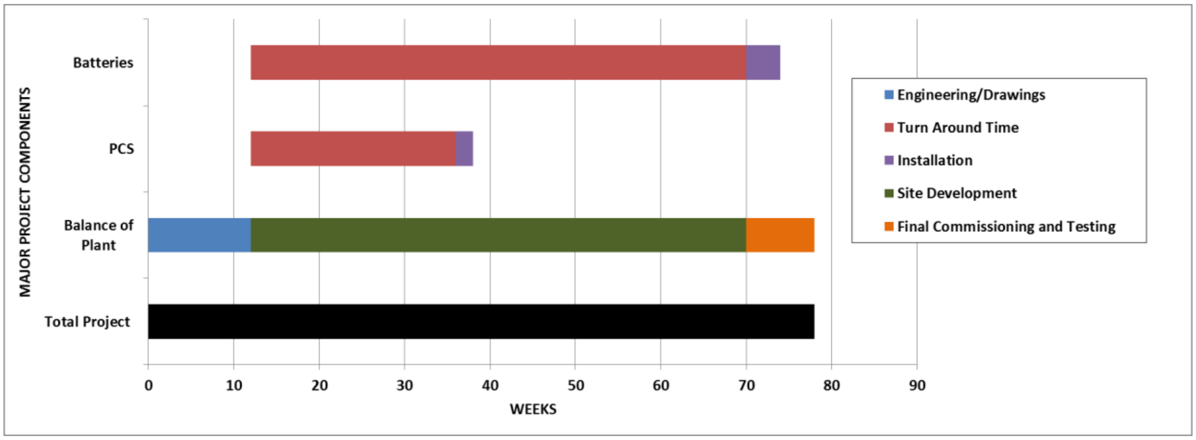


Figure 34 Battery Energy Storage System Timeline

Turnaround time includes procurement, manufacturing, and delivery. The estimated time to build the battery energy storage system from start to finish is 78 weeks (approximately 1.5 years).

6.5 Environmental and Societal Considerations

Although the life cycle costs are a major part of selecting any energy storage system, one must also consider the impact these energy storage systems will have on the environment and society.

Most of the chemicals used for creating the selected battery technologies are mined. The process from mining to manufacturing the batteries is energy intensive. Lead, when mined in large quantities produces a large amount of pollution within its mining areas. Lead, by itself, is also hazardous to human health. The chemical Lithium, on the other hand, is minor component when building lithium ion cells. The major chemicals required for these cells are copper and aluminum and the environmental impacts are more significant [8].

Furthermore, disposal of both battery technologies are an important part of the life cycle. There a number of regulations and safety concerns when handling and disposing of lead-acid batteries. Lead-acid batteries are among the most recycled products in the world [1]. Many lead acid manufactures accept old batteries and recycle the batteries. Recycling lithium ion batteries is still a challenge due to cells not having the ability to recharge. However, the newer lithium ion batteries are showing signs of recovering [8]. Therefore the recyclability of lithium ion batteries should rise.

In addition, battery layouts of this size are not common in utility systems. Both batteries have been known to have incidents of "thermal runaway" where the batteries rapidly increase in temperature causing fire and dangerous gases. During the design, construction and operation of the energy storage system, the utility and local authorities should familiarize themselves with the handling, operation and the chemical contents of the batteries. Since the battery facilities are large buildings, they should also be aware the location of emergency and critical components in the building and around the project site. Manufacturers should provide Material Safety Data Sheets to utility and local authorities.

6.6 Spinning Reserve

The definition of spinning reserve is the online capacity that is synchronized to the grid and ready to supply the electrical demand within 10 minutes of a dispatch instruction by the independent system operator. Spinning reserve is required to maintain system frequency stability during emergency type operating conditions and random load swings.

Earlier research indicated that large energy storage systems could be designed to accommodate a utilities' spinning reserve by installing extra power capacity into its dc to ac advanced power converter system. The rating of the converter could be sized about 20% greater than the normal output rating. With the recent technology advancements involving a BESS with an advanced PCS, some power markets may assign a value to this function and allow the BESS facility with this characteristic to acquire monetary benefits.

However for the type of BESS being considered in this report, the cost of the converter is a very small portion of the overall cost. With oversizing the inverter, it would be difficult to find enough benefits to evaluate and justify the advantage of having the increased spinning reserve.

7. Conclusions

Several Energy Storage System (ESS) options were considered to:

a. provide additional power to the YEC transmission system for "load levelling" purposes, and

b. avoid additional environmentally unfriendly diesel generation

From the extensive list of ESS options, the most technically viable were chosen based on the calculated power, energy, and discharge time characteristics required. Maturity of the ESS was also considered; as this is not an academic R&D project, using a proven, mature technology was important. This brought battery energy storage systems (BESS) to the forefront, and in particular lead acid and lithium ion batteries.

These two types of BESS, besides meeting the technical operational requirements, have other advantages. As they are a modular system, BESS power capacity can be added in small incremental steps to meet future power demand. This allows for easier financial planning, as well as taking advantage of future improvements in battery technology.

Using the known diesel power generation profile for the year 2015, the operational requirements of the BESS were determined to be:

a. Power rating = 4 MW

b. Energy rating = 40 MWh

c. Discharge time = 10 hours

The above BESS power rating of 4 MW, plus an anticipated 8 MW of natural gas reciprocating engines generation in the near future, provides a total of 12 MW of available power. 95% of the diesel power generation for 2015 was equal to or less than 12 MW, so the BESS plus NG solution can fully replace the present demand for diesel power 95% of the time. Future load growth can be met incrementally by adding modules of the BESS.

For cost comparison, four options of a BESS were considered:

a. 4 MW, 40 MWh, 10 hour discharge time, lead acid battery system

b. 6 MW, 60 MWh, 10 hour discharge time, lead acid battery system

c. 8 MW, 80 MWh, 10 hour discharge time, lead acid battery system

d. 8 MW, 40 MWh, 5 hour discharge time, lithium ion battery system

Budgetary prices of all major components of each BESS were provided directly by vendors. The financial model and approximate cost of civil works was provided by Yukon Electric Corp. A thorough consideration of costs and income was made over the next 30 years to arrive at the lowest total cost option for a BESS.

Based on the information provided from Yukon Energy, the power and energy determined from the load data and the total cost of a completely installed BESS system under study, the net present value was calculated for each option. Over the lifetime of the projects, all 4 options would have significantly higher costs compared with their respective benefits and hence a negative NPV. The lead acid 4 MW, 40 MWh BESS had the best NPV followed by the lithium ion 8 MW, 40 MWh BESS.

The timeline for bringing this system online is approximately 18 months. This includes engineering and drawing, preparatory civil works, purchase and delivery of the system components, construction, and testing.

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