Alternative MetropolitanIPRO302PosterF09

Alternative Metropolitan Power Strategy 2.0

Wind Power for the
Windy City

IPRO 302
Illinois Institute of Technology

Final Paper
Fall 2010
Sponsored By: Sargent & Lundy

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2.0 Executive Summary

As a result of rising concern over the contribution of green house gas emissions to global warming, there has been a recent push to diversify the energy portfolio of many states across the U.S. by including renewable energy sources such as wind and solar technologies. In light of the government potentially mandating a nationwide 20% renewable portfolio standard (RPS), Sargent and Lundy, one of the power industry's leading consultation companies, asked IPRO 302-established as the Alternative Metropolitan Power Strategy (AMPS) - to create a hypothetical design that will account for 20% of the City of Chicago's power demand using renewable sources such as solar photovoltaic, solar thermal, and wind turbines. The final system presented by the team at the end of the Spring 2010 semester used wind turbines along with natural gas combustion turbines as a backup power source.

This semester, IPRO 302-named AMPS 2.0- sought to improve the design submitted last semester by creating a system that uses technologies that do not emit carbon dioxide (CO_2). The system was to use nuclear plants to supply 80% of Chicago's electricity needs, with wind turbines providing the remaining 20%. Because of the intermittent nature of wind, an electrical storage device needed to be selected to store the electricity generated during off-peak hours and dispatch it when needed.

The semester was divided into three basic phases: preliminary research, extensive research and final presentation. In the preliminary research phase, information on wind patterns as well as the power consumption and needs of the city was found. In addition, basic information was gathered on potential storage technologies. Based on factors such as capital cost, and technical maturity, several of the technologies were eliminated. During the extensive research phase, the team collected in-depth information on the remaining storage technologies. The economic and geographical viability of each option was assessed, and the levelized energy cost (LEC) for each storage technologies were calculated. Based on the aforementioned factors, an adiabatic compressed air energy storage system was found to be the most feasible storage technology. After finalizing the design of the system, the final presentation phase began and the final deliverables for Sargent and Lundy and the IPRO committee were assembled.

3.0 Purpose & Objectives

The purpose of the Alternative Metropolitan Power Strategy 2.0(AMPS2) will be to evaluate the economic and environmental costs and feasibility of supplying carbon-free electricity to the city of Chicago. This will be done with compliance to the federal government's Renewable Portfolio Standard (RPS) of 20% which means that by the year 2030, 20% of the total energy generated must be from renewable energy resources. The most favorable options for renewable energy supply come from wind and solar technologies. Preliminary research shows that wind turbines are more cost effective than solar technologies in the state of Illinois. Therefore, wind turbines will be the basis for our renewable energy supply. The power demand of the city of Chicago will be met by using wind power and nuclear power in conjunction with electrical storage technologies. A reliable storage technology will need to be implemented to cover the fluctuating demands in energy and non-dispatchable nature of wind production. Presently, the most reliable backup power supplies are based on fossil fuels (i.e. coal and natural gas) because of economical benefits and their ability to fluctuate with the energy demand. Proposed options for energy storage that are based on renewable energy sources include pumped hydro storage (PHS), compressed air energy storage (CAES), batteries, flow-batteries and thermal energy storage (TES).

Objectives

- Evaluate the electricity demanded in Chicago proper based on seasonal changes and time of day.
- Evaluate the electricity generated by nuclear plants for Chicago as the baseline for the demand of electricity.
- Estimate the amount of electricity generated (per unit system) by wind turbines, while considering the impact of the time of day and weather patterns.
- Rank current storage technologies based on operational and cost characteristics needed to support the fluctuating demand for electricity in Chicago.
- Determine locations of systems to maximize economic gain based on a balance where systems can yield the highest energy output (i.e. land with high wind and solar potentials) to areas where transmission costs would be least.
- Estimate the amount of systems needed to generate an adequate amount of electricity.
- Estimate costs over periods of time of the whole system by considering installation, maintenance, operation, land, transmission, and government grants and loans for renewable energy production.

4.0 Organization & Approach

4.1 Work Breakdown Structure

The three primary team stages are the Preliminary Research Team, The Extensive Research Team, and the Final Presentation Team. Due to its roles and responsibilities, the Integration/Communication sub-team is a continuous team throughout the majority of the semester.

4.1.1 The Integration/Communication

Time Keeper and Minute Taker- The role and responsibilities of this position is to track the time of each meeting to maintain the IPRO's adherence to the daily agenda's schedule; furthermore, this position records the minutes of the meetings and all major decisions.

Integration and Transition Manager - The role and responsibilities of this position is to determine the content and quality of the information gathered between the other sub-teams, compile information between the other sub-teams, be the primary agent of communication between the three sub-teams, and comprehend the data analysis for the final report.

Agenda Maker and Communication Manager- The role and responsibilities of this position is to function as the team leader of the Integration/Communication sub-team; to be the primary agent of communications between the IPRO group, the IPRO office, and the IPRO sponsor, Sargent & Lundy; and to develop meeting agendas to structure class periods and external meetings.

4.1.2 Preliminary Research

The Technology Research sub-team's role and responsibilities is to find preliminary information concerning a variety of technology relevant to storing energy along with a number of reputable sources of information that have detailed information concerning energy storage for further analysis.

Location/Environment sub-team's role and responsibilities is to analyze current trends of energy production by wind and nuclear means, locate protocol and restrictions on varying quantities of wind turbines and nuclear power plants, and determine geographical resources available for further wind turbines, nuclear power plants, and energy storage facilities.

4.1.3 Extensive Research

Technology Case Studies sub-team will actually be a series of sub-teams whose role and responsibilities will be to do depth based research on specific means of energy storage where each sub-team will cover a different form of energy storage. Thereafter, each sub-team will be responsible for completing cost analysis for their form of energy storage to be complied by the Integration and Transition Manager.

4.1.4 Final Presentation

Presentation sub-team is the group primarily responsible for the presentation to be made to the IPRO 302 sponsors, Sargent & Lundy, as well as the presentation to be made on IPRO day.

Report sub-team is the group primarily responsible for the collection of information gathered throughout the semester, compiling the data into a meaningful analysis, and detailing all the accomplishments, assumptions, and analysis within a final report.

Poster sub-team is the group primarily responsible for the poster and presentation to be made on IPRO day before the series of small judge groups.

Brochure sub-team is the group primarily responsible for the neat and organized production of the brochure or abstract as well as its presentation on IPRO day.

5.0 Background

5.1 Current Issues

Assisting clients' efforts to evaluate and implement emerging technologies has been a primary function of Sargent & Lundy as a leader in the power industry. Unsurprisingly, the company's current and recent work encompasses the full range of emerging renewable energy technologies such as wind, solar thermal and photovoltaic. In light of the federal government's consideration of mandating a 20% Renewable Portfolio Standard (RPS) nationwide, the company has sought to identify how Chicago can feasibly meet the 20 % RPS. IPRO 302 was established in the spring of 2010 to create a hypothetical design that will account for 20% of the City of Chicago's power demand using renewable sources such as solar photovoltaic, solar thermal, and wind turbines. To fulfill this assignment, the students took a number of steps to produce a prototype of a renewable energy system, including analyzing the electrical needs of the city of Chicago; examining the cost and performance of several renewable technologies, using coal as a benchmark to compare the costs; and researching back up sources to economically support the system. Based on the final financial calculations for each technology, the team concluded that 20% renewable energy for Chicago is feasible and that wind is the most economically viable renewable energy source. Since they are economical to install and can rapidly dispatch power to meet substantial load changes in the electrical grid, natural gas based systems were chosen to serve as back up sources.

This semester, IPRO 302 seeks to create a 100% carbon-free energy plan for the city of Chicago. This hypothetical system will be comprised of a base load of nuclear power and supplemental energy provided by wind turbines and their stored energy. In order to identify the economic and environmental cost and feasibility of supplying electricity to Chicago using a carbon-free energy plan, several key issues will be addressed, including the electricity demand of the city of Chicago, the electricity generation capabilities of wind turbines and nuclear plants, and the viability of potential storage technologies.

5.2 Technological Information

In looking at the potential technologies that could be used to solve the problem of integrating wind power into the Chicago power grid, it was found that existing technologies include chemical, biological, electrochemical, electrical, mechanical, and thermal types. Looking solely at chemical, electrochemical, electrical, and mechanical types, the list of available technologies[1] is as follows:

Chemical: hydrogen, biofuels, liquid nitrogen, oxyhydrogen, and hydrogen peroxide

Electrochemical: batteries, flow batteries, and fuel cells

Electrical: capacitors, supercapacitors, and superconducting magnetic energy storage (SMES)

Mechanical: compressed air energy storage (CAES), Flywheel energy storage, hydraulic accumulator, hydroelectric energy storage, spring, and gravitational potential energy (device)

With further investigation, it seems prudent to reject chemical forms of storage, as well as most forms of mechanical forms of storage, as impractical and cost ineffective. Therefore, it follows that focus

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[1] http://en.wikipedia.org/wiki/Energy_storage

should be maintained on electrochemical forms of storage as current technologies allow, and electrical and mechanical forms of storage should be considered as emerging technologies.

It should be noted that a study was conducted by Xcel Energy that finished in July of this year. This study utilized high capacity batteries and wind farms. Put simply, the study utilized 20 50 MW batteries that collectively, "are roughly the size of two semi trailers and weigh approximately 80 tons. They are able to store about 7.2 megawatt-hours of electricity, with a charge/discharge capacity of one megawatt. Fully charged, the battery could power 500 homes for more than 7 hours[2]."

5.3 Historic Attempts

Wind energy has been used for a long time for various purposes. It is one of the viable resources of renewable energy. According to the Energy Information Administration's (EIA) renewable energy trends, wind energy has been producing more electricity annually than the previous from 1989 (0.022 Quadrillion Btu) to 2006(most current year data is available) (0.240 Quadrillion Btu)[3] in the US. Thus, wind energy is a very promising source for a sustainable future. Innovations in engineering and technology are helping design and develop efficient and cost effective wind turbines. The IPRO 302 group of Spring 2010 semester attempted to find viable renewable energy resources for the city of Chicago and concluded that wind is the best option compared to solar.

Storage is our biggest concern. Various energy storage devices exist today. There are chemical, biological, electrochemical, electrical, mechanical and thermal storage devices. The most relevant storage devices for our project would be the electrochemical (batteries) and electrical (capacitors, super capacitors) storage devices. Currently, these devices have small energy storage density compared to the immense amount of energy we would need to store. So, for now we would have to use a large number of storage devices. In the future, we are expecting the technological breakthroughs to decrease the size, increase the efficiency and lower the costs of these storage devices.

5.4 Business or Societal Costs

In this project, we are mainly looking at establishing a viable source of renewable energy for the city of Chicago, which happens to be the wind energy[4]. We are also looking at storage devices in order to store energy during low peak hours and supply it to meet the demand during peak hours.

The business costs involved in this project are: cost of the wind turbines and storage devices, construction costs of the facilities for the storage devices, installation costs, labor costs, operation and maintenance costs.

Also, looking at the bigger picture, this project has a positive externality which means that the societal benefits are great. If we can completely depend on nuclear energy and wind energy for the generation of electricity then we can have 100% carbon-free electricity.

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[2] http://www.electricitystorage.org/images/uploads/docs/XcelReleaseWind_to_BatteryResults.pdf

[3] http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table1_5.pdf

[4] Conclusion of the research done by the previous IPRO 302 group during the Spring 2010 semester.

5.5 Proposed Implementation Outline

Given that the current amount of time devoted thus far to the formulation of solutions is exceedingly limited, the implementation outline at this point will be largely theoretical. The problem of how to transform the Chicago power grid into an entirely non-CO_2 producing system has already been considered. Since it has been decided to utilize nuclear power to comprise baseline power production, it follows that, as the current plants used for this purpose are retired, new nuclear plants must be constructed to offset the difference in production. This would continue until such time as the power produced by the aforementioned nuclear plants meets the predetermined baseline levels. Additionally, given the findings of last semester concerning both solar and wind power production, any plants used currently for the production of non-baseline power would be replaced, as needed, with a comparable number of wind turbine power plants. This would continue until the wind farms could produce sufficient power to meet historic peaks in power usage. Based on the specific aspects of the project scope, the replacement of all Chicago grid power plants with non-CO_2 producing alternatives would be accomplished within the next thirty (30) years.

6.0 Analysis & Findings

6.1 Energy Storage Technologies

Energy is the biggest requirement of the modern world. Today, energy is mainly generated from fossil fuels. The combustion of fossil fuels to generate energy also produces greenhouse gases like carbon dioxide which cause global warming. Another problem is that fossil fuel is a non-renewable resource and we will eventually run out of it. So, in order to reduce carbon emission and to reduce the dependence on fossil fuel for energy production, alternative energy resources are being explored. Some of them are solar energy, wind energy and geothermal energy. The main problem with these energy resources is that they are non-dispatchable which means that they won't be readily available whenever we need them. For example the sun doesn't always shine and the wind doesn't always blow. So, whenever the sun shines and the wind blows, we would like to store their energy in order to use that at times when they are unavailable. Thus, energy storage technologies are of high demand today. Some of the current and potential energy storage technologies are: pumped hydro storage (PHS), compressed air energy storage (CAES), batteries, flow batteries, fuel cell, superconducting magnetic energy storage (SMES), flywheel, capacitors, super-capacitors and thermal energy storage (TES).

This project is centered on a future goal to supply carbon free electrical energy to the city of Chicago by means of nuclear energy and wind energy. Nuclear energy will be used to meet the base demand (a certain amount of constant demand of electricity). Wind energy along with a potential storage technology will be used to meet the fluctuating demand above the nuclear base demand. So, we are dealing with a massive energy storage technology and we will be evaluating some of the storage technologies that are available today based on their application to this project.

6.1.1 Batteries

A battery produces electrical energy from chemical reactions. It can be a single electrochemical cell or a combination of them. There are two types of batteries depending on their recharging capability. They are:

Primary Battery (Non-rechargeable battery)

These batteries produce electrical energy by means of chemical reactions between the reactants stored in the battery. After the reactants are completely used electrical energy cannot be produced. Examples include alkaline batteries.

Secondary Battery (Rechargeable battery)

These batteries also produce electrical energy by chemical reactions. However, after the reactants are completely used, electrical energy is used to drive the reactions backwards to regenerate the reactants from the products. Once the reactants are regenerated, electrical energy can be produced again by the forward reaction. Examples: Lithium-ion battery, lead acid battery, Nickel cadmium battery, Nickel metal-hydride battery, sodium sulfur battery etc.

The rechargeable batteries are good energy storage devices. Electrical energy and chemical energy are directly inter-converted in a battery. And since electricity is directly generated, there is a fast response to the demand. However, various disadvantages also prevail depending on different kinds of batteries. Below is a short summary of each type of storage battery available today, how they work and what are the shortcomings of individual battery type relating to their application in our project. At the end, a graphical comparison is done for various parameters like the energy density, power density, and cost per unit of energy, etc. to show the overall feasibility of different battery types.

Lithium ion battery

The lithium ion battery consists of a carbon anode, a lithiated metal oxide cathode, and a lithium salt electrolyte.

The reactions are:

Positive Electrode $LiCoO_2 \xrightleftharpoons[\text{Discharge}]{\text{Charge}} Li_{1-x}\ CoO_2 + xLi^+ + xe^-$

Negative Electrode $C + xLi^+ + xe^- \xrightleftharpoons[\text{Discharge}]{\text{Charge}} CLix$

Battery as a Whole $LiCoO_2 + C \xrightleftharpoons[\text{Discharge}]{\text{Charge}} Li_{1-x}\ CoO_2 + CLix$

When the battery is charging, the lithium in the positive electrode changes into lithium ion which moves to the negative electrode and gets deposited as lithium upon receiving an electron. During discharge, opposite reactions take place which are spontaneous and produce electric current. Lithium ion batteries have very high current density, power density and number of cycles compared to other batteries. But, the main downside is high capital cost and high cost of energy per kWh per cycle.

Nickel Cadmium battery

In this battery, the positive electrode is nickel hydroxide and the negative electrode is cadmium hydroxide with some kind of alkaline electrolyte in between. The reaction is as follows:

$$2NiO(OH) + Cd + 2H_2O \leftrightarrow 2Ni(OH)_2 + Cd(OH)_2.$$

This battery has three cycles: charge cycle, discharge cycle and overcharge cycle. During the overcharge cycle heat is generated along with oxygen and water which vent out and less reactant will be available inside the battery. Nickel cadmium batteries have good energy density and power density. However, the main issue is the high installation costs and the cost per kWh per cycle. Also, cadmium is highly toxic and its application for a large scale application is not preferred due to its environmental unfriendliness. Nickel cadmium batteries also have memory effect which means that there is a loss in maximum energy capacity if the battery is partially discharged. The batteries should be completely discharged and should not be overcharged every time in order to maintain their life, which is not practical for large scale power application.

Nickel Metal hydride

Nickel metal hydride battery is an environmental friendly version of nickel cadmium battery because it does not contain toxic cadmium. It has better energy density than nickel cadmium battery and is less prone to memory effect. But, the downside is the high self discharge, limited life cycles, low performance at high temperatures and high maintenance. High self discharge makes it inefficient for large scale energy storage application which requires storing energy for a long time. The cost per unit of energy is lower than lithium ion and nickel cadmium batteries but is still high for it to be economic.

The batteries discussed above have really great features like high energy density and power density. They have been widely used in portable equipments like digital camera, laptops, and electric vehicles where size and weight matter more than the cost. But, because of their extremely high costs they are not suitable for a large scale energy storage application. The following batteries have been used in large scale power applications and are promising electrical energy storage technologies.

Lead Acid battery

Lead acid battery is one of the most mature battery technologies. The half cell chemical reactions involved in this battery are:

Anode: $Pb + SO_4^{2-} \leftrightarrow PbSO_4 + 2e^-$

Cathode: $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \leftrightarrow PbSO_4 + 2H_2O$

There are different types of lead acid batteries: flooded lead acid battery which requires distilled water, the sealed lead acid battery which contains a gel electrolyte, and the valve regulated lead acid battery. Some of the disadvantages of this battery include low energy density, low power density, limited cycle life, low performance at high and low temperatures, and toxic nature of the lead and acid used in the battery. However, the lucrative feature of this battery is the cost. It is probably the least expensive battery technology available today.

An inevitable need of modern, efficient and cost effective battery storage technology has led to a lot of research in large scale battery storage technologies and the development of the following batteries.

Sodium Nickel Chloride battery (ZEBRA)

This battery consists of nickel chloride as its positive electrode and molten sodium as its negative electrode. It is a high temperature battery which operates at around 300^{o}C because the sodium has to be kept in its molten form for the battery to operate. The reaction taking place in this battery is:

$$2NaCl + Ni \leftrightarrow NiCl_2 + Na$$

This battery has pretty good power density and energy density and high voltage. The downside is that this battery is in its research and development phase and the only company in the world, Beta R&D (UK), which manufactures this battery, is researching on its use for large scale operations. So, the technology hasn't been perfected yet and thus might not be cost efficient.

Sodium Sulfur Battery

This battery is a modern technology. It consists of liquid sodium that acts as the negative terminal and liquid sulfur that acts as the positive terminal. These liquid electrodes are separated by solid beta alumina ceramic electrolyte. The reaction occurring inside the cell is:

$$2Na + 4S \leftrightarrow Na_2S_4$$

While discharging, sodium ions pass through the electrolyte and reacts with sulfur to form sodium polysulfide. During this process, electrons flow around the closed circuit to generate electric current. While charging, sodium ions are obtained from sodium polysulfide and these ions pass through the electrolyte back to the sodium chamber.

Sodium sulfur battery has a large number of cycles, high energy density, power density and high efficiency. But, the battery has to be maintained at around 300^{o}C to keep the sodium and sulfur in their molten stage and some of the energy stored is used to maintain this temperature. The main challenge with this technology currently is that it is almost as costly as the lithium ion, nickel cadmium and nickel metal hydride batteries. Various utilities companies in Japan, U.S.A., Germany, France and U.A.E. are using this technology in small scale for demonstration purposes. According to the Tokyo Electric Power Company in Japan, which has performed multiple research and development (R&D) projects using sodium sulfur battery in large scale power application, the cost of the sodium sulfur battery is projected to decrease by a factor of 8 with mass production.

Below are the charts that compare various energy storage technologies according to different parameters.

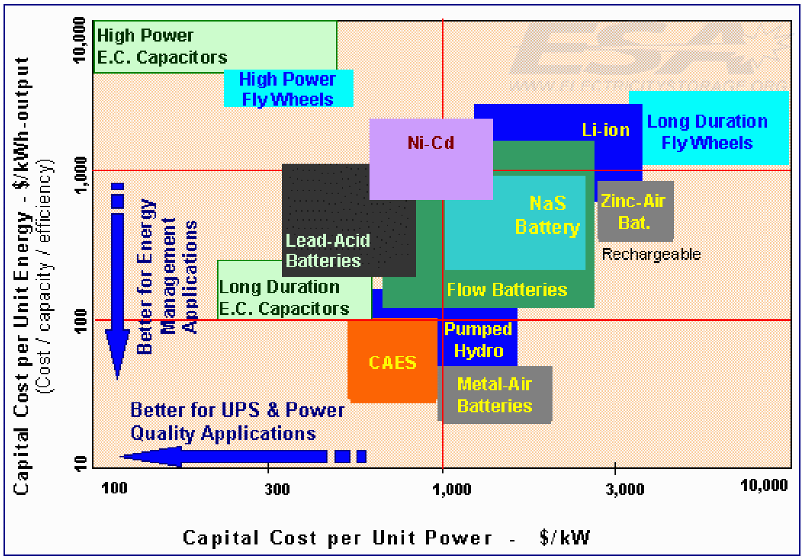


Figure 1.0

Figure 1.0 shows the various energy storage technologies based on the capital cost per unit energy and capital cost per unit power. We prefer the technologies which are towards the bottom left corner as directed by the blue arrows because we want the cost of supplying unit energy and the cost of supplying unit power to be the least. As we can see, among the batteries (excluding flow batteries, which were researched by a different team), lead acid batteries are the most cost efficient. Lithium ion batteries are very expensive from both angles (cost per unit energy and cost per unit power). In figure 1.0, we can notice that nickel cadmium battery and sodium sulfur batteries are competing among each other but sodium sulfur batteries are preferable because of the major disadvantages of nickel cadmium batteries like its toxicity and the memory effect. Another battery technology called the metal air battery also appear in figure 1.0 which seems to have the least cost per unit energy but we should also notice in the technical maturity chart (Figure 2.0) below that the metal air battery technology is immature. We can't rely on immature technologies to be considered for our project at this point because we don't know the fate of those technologies.

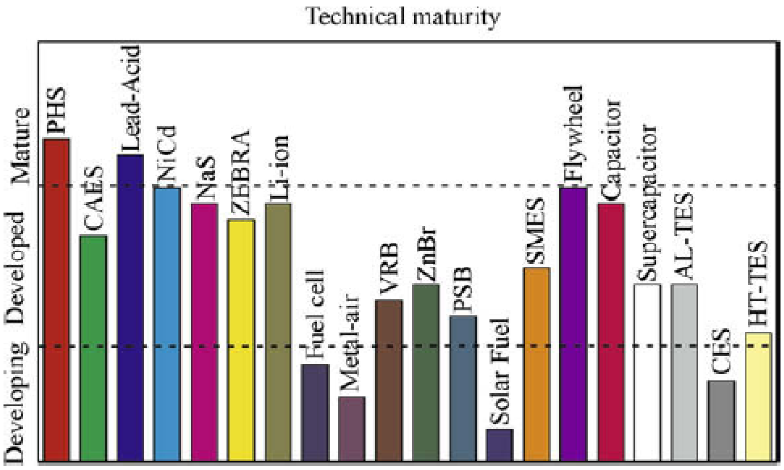


Figure 2.0

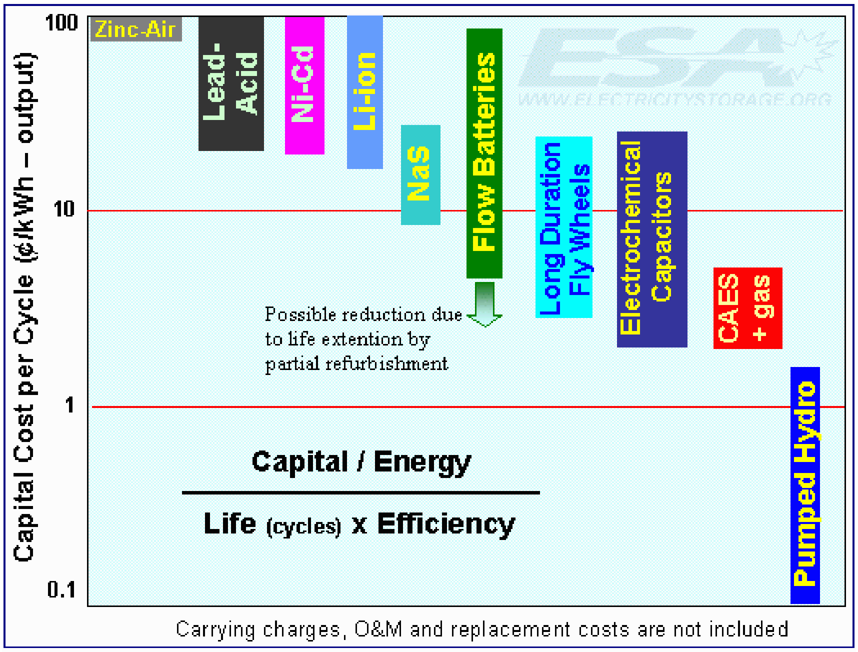


Figure 3.0

Figure 3.0 shows a better cost comparison between various technologies because it shows the capital cost of unit energy per cycle. As we can see that lead acid battery, nickel cadmium battery and lithium ion battery are in similar range. Nickel cadmium batteries and lead acid batteries are expensive but their efficiency and number of cycles is high. Lead acid battery is cheap but its efficiency and number of cycles is not as great as the previous two. This brings down these three batteries in the same range when it comes to cost of unit energy per cycle. Sodium sulfur on the other hand has high cost per energy but it also has high efficiency, high number of cycles due to which its overall cost of unit energy is less. The metal air (Zn-air) battery which seemed to be cheap in Figure 1.0, has the highest cost of unit energy per cycle because it has very low efficiency and low number of cycles. Figure 4.0 below shows the efficiency and the lifetime (number of cycles at 80% depth of discharge (DoD)) and figure 5.0 is the cycle efficiency for various battery technologies taken form a different source.

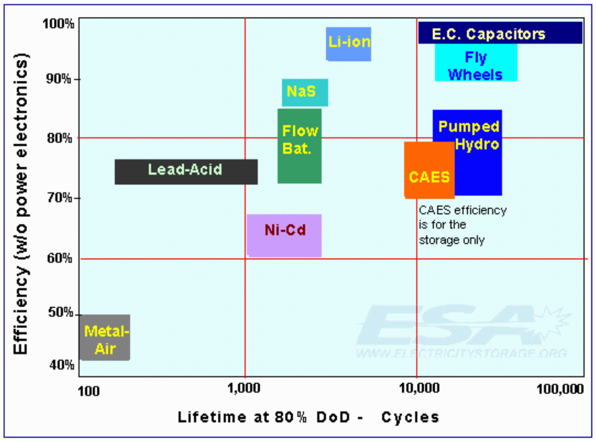


Figure 4.0

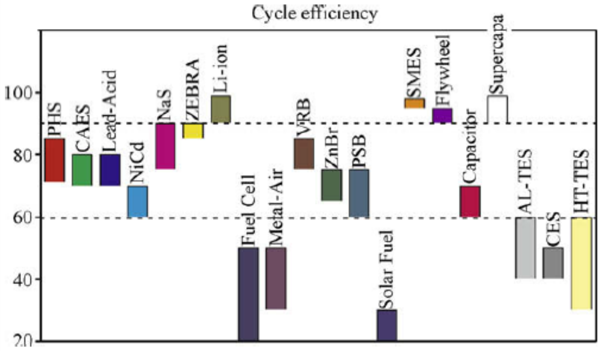


Figure 5.0

In figure 4.0 we would like the technologies to be towards the top right corner, which means that they would have high efficiency and high lifetime. Lithium ion battery has those characteristics followed by sodium sulfur battery. Lead acid comes next in the efficiency but has low lifetime. Nickel cadmium has higher life time but it is less efficient. Finally, metal air battery has the least efficiency and the least lifetime. The efficiencies shown in figure 5.0 are consistent with figure 4.0.

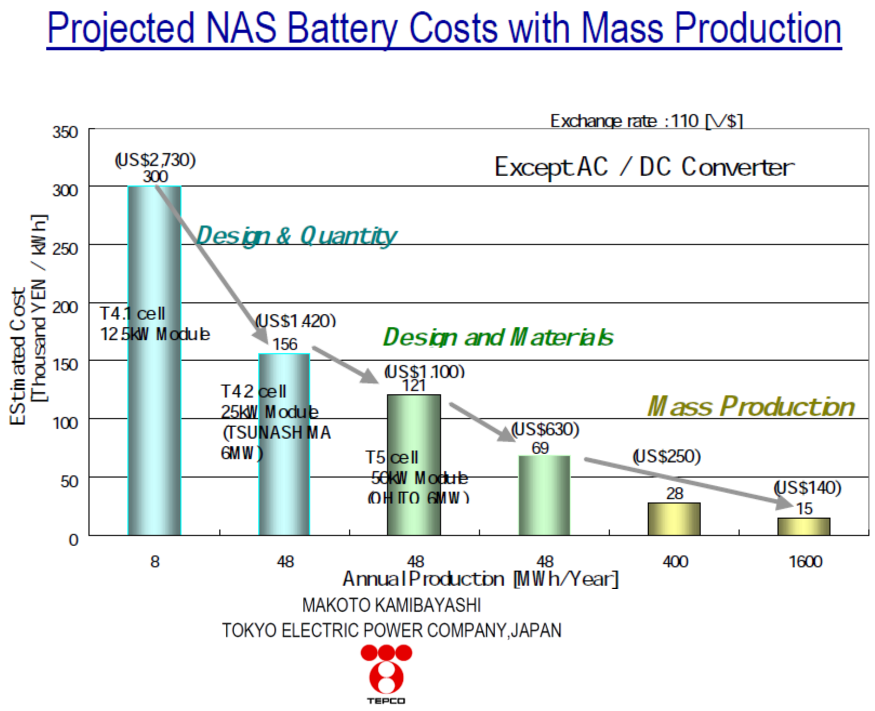


Figure 6.0

Figure 6.0 shows the projected cost of the sodium sulfur battery with mass production. Currently available largest system which is rated at 6MW and a production of 48MWh/year costs about US$1100/kWh. But, if we were to produce 1600MWh/year of electricity the cost could go down to about US$140/kWh. So, there is the potential for sodium sulfur battery technology to be a viable solution for our project.

6.1.2 Flow Batteries

Flow batteries are an energy storage technology that stores electricity as chemical energy in an electrolyte. They can respond in milliseconds and can provide energy for hours, making them useful for utility scale peak shaving applications. The energy is stored and released through a reversible chemical reaction. Flow batteries differ from conventional batteries, the electrochemical reaction occurs in the cell between two electrolytes rather than an electrolyte and an electrode. The electrolytes are stored externally in storage tanks and pumped through the cell during operation to delivery electricity, and the process is reversed during electricity storage.

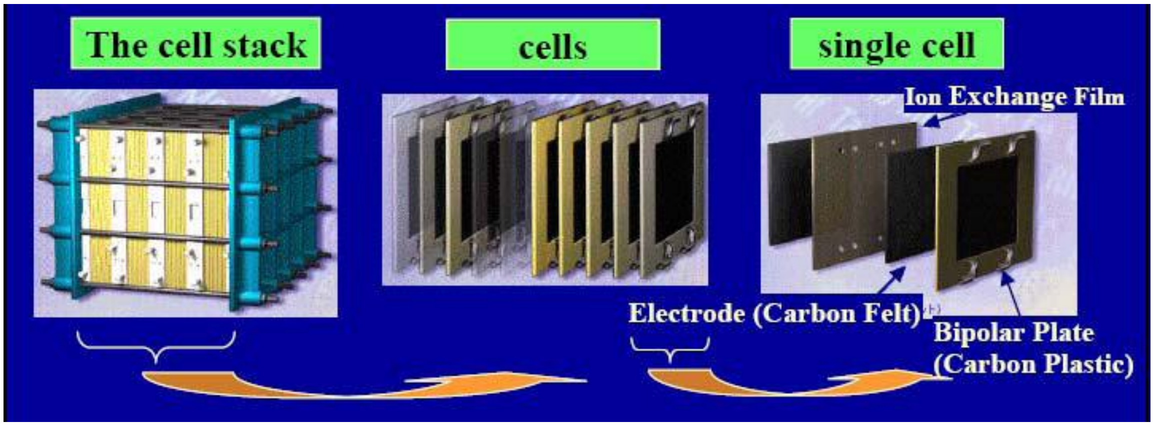


Figure 7.0

A flow battery is composed of two key components, the cell stack, and the storage tanks. The cell stack is where the electrical energy is converted to chemical energy when storing electricity, or the reverse when providing electricity. The cell stack consists of a stack of electrodes, which do not take part in the reaction, each separated by an electron exchange membrane like a sandwich to form a single cell. The cell stack's design determines the power rating of the system by changing the area of the membrane or the quantity of cells in the stack. The storage tanks are where the electrolytes are stored. The volume of electrolyte storage tanks determines the storage capacity. This makes the power rating and storage capacity of the system independently scalable for the particular application.

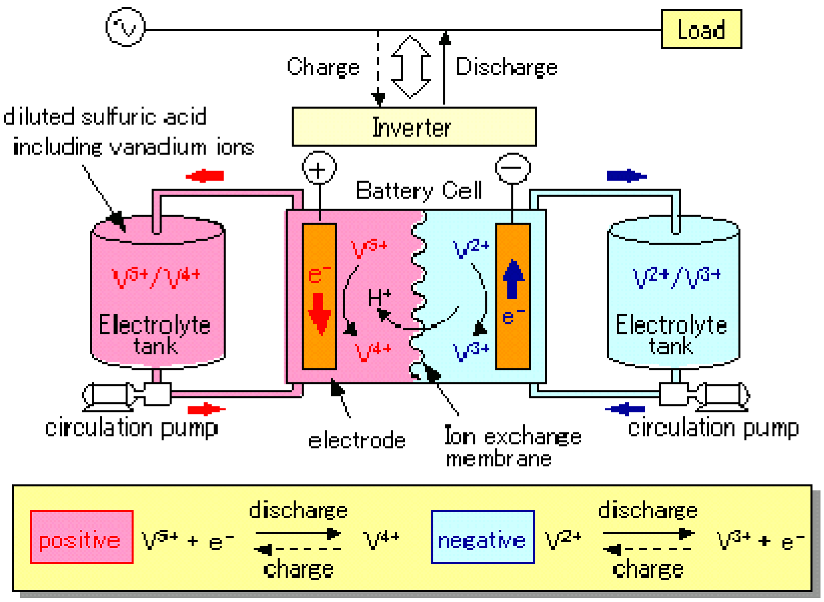


Figure 8.0

Vanadium Redox Flow Batteries

Vanadium Redox flow batteries (VRB) have the advantage that both electrolytes are identical in their discharged state. This is an advantage not only for manufacturing but during operation there is no possibility of contamination of one electrolyte by the other. This is possible because vanadium is stabile in +2, +3, +4, and +5 valence states, all of which are found in the VRB's electrochemical reaction. The electrolyte is composed of vanadium ions in an aqueous sulfuric acid solution. The temperature of the electrolyte should be regulated between 0ºC and 40ºC. The useable storage capacity of the electrolyte is about 20-30 Wh/L.

Typical DC-DC roundtrip efficiencies of actual operating VRB's have been 75%-80%, and the more important AC-AC roundtrip efficiencies of around 60%-70%, including parasitic loads from pumps, controls, and inverters. With proper maintenance a VRB should have a life over 20 years.

Response times vary depending on the application that the battery is being used for. If the system is left on hold (no electrolyte flow) after being fully charged the response time to full power will take a few minutes while the discharged electrolyte in the cell stack is replaced by charged electrolyte. However if the cell stack is kept active the response time can be as low as 350µs, at the cost of pump losses and looses through cell stack.

Cost Numbers for Vanadium Redox Flow Batteries

An estimate of the cost for the system *based on projections for future costs for components* can be made through the following equation:

Capital Cost = $1,250 x (kW rating) + $210 x (kWh rating) + $280,000 (2013 dollars)

This equation produces figures within about 5% of the cost figure estimated through the use of the more sophisticated cost model built for this analysis, for systems with power capacities ranging from 200 kW to 10 MW and with durations from 2 hours to 16 hours.

Assumptions

1. The installation was assumed to be in North America, approximately 1000 miles from the factory.

2. Costs were split between those incurred in the factory (those related in production of the cell stacks and the vanadium electrolyte) and those incurred at the site (those related to site preparation; tank purchase and installation; PCS purchase, shipping, and installation; and so on). To a large degree, costs associated with standard industrial products were incurred at the site, while special costs related specifically to the vanadium redox technology tend to be incurred in the factory.

3. Commercial and industrial costs were used in estimating costs for standard materials and services, such as tanks, PVC piping, and electrical cabling.

4. Labor cost was assumed to be $35/hour, before overhead and other costs are added.

5. Appropriate costs are assumed for a construction manager on site.

6. Overhead costs are applied as 10% of all material costs and 30% of all labor costs.

7. Profit is calculated as 10% over the overall costs after overhead is added.

6.1.3 Pumped Hydro Storage

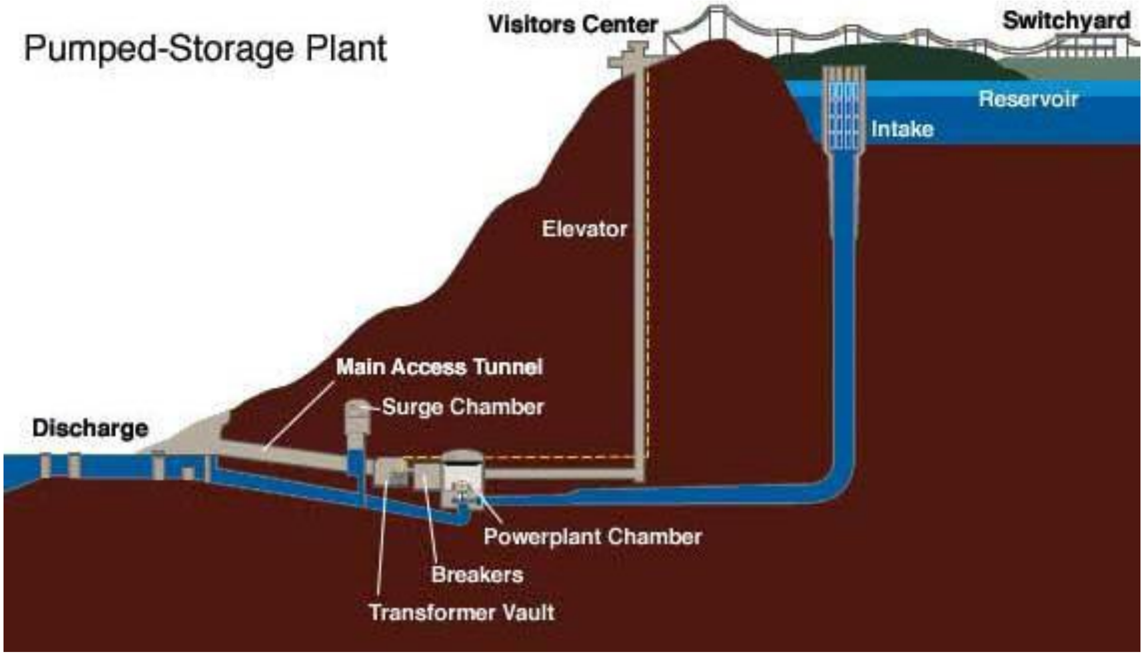


Figure 9.0

Favorable site characteristics of PHS:
· Water availability
. Accessible terrain
· High head potential

Initial cost
M= million $
Plant over 1000 MW built in the US would cost in 2009 from 0.442 M- 1.203M
With an average **u = 0.821M/MW**
(Cost include Access road, tunnels, surge shafts, piping, power station, generators, turbine pumps, transformers, and project management)

Maintenance cost
Maintenance cost**= 0.125M/MW**

Storage cycle efficiency
System efficiency is between **70 – 85%**

Power rating
Power rating goes from **100 - 5000 MW**

Energy Density
0.5 - 1.5x10$_{-6}$ MWh/kg

Self Discharge
1-24hours or more

Stage of Development
Most developed EES. It is 40 years old technology

This technology is not feasible in Illinois due to the lack of a high head potential.

6.1.4 Flywheel

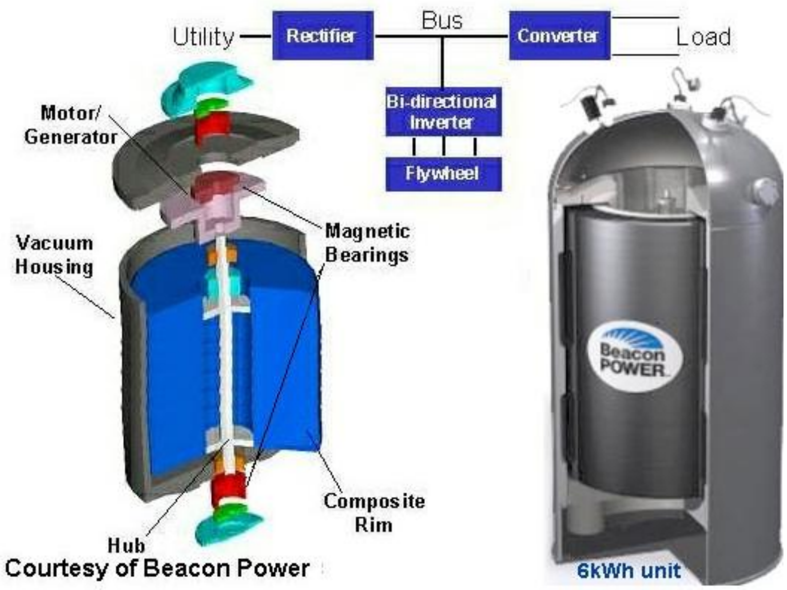


Figure 10.0

Flywheels store energy in the form of angular momentum of a spinning mass. This occurs when the flywheel is spun with the help of a motor and is charged, now during discharge, the same motor acts as a generator producing electricity from the rotationalenergy of the flywheel. The total energy of a flywheel system is dependent on the size and speed of the rotor, and the power rating is dependent on the motor-generator. Figure 10.0 shows a typical flywheel storage device.
Unfortunately the self-discharge rate of the flywheel is low and will not be considered for the scope of this project.

6.1.5 Thermal Energy Storage

Introduction

One of the objectives of the Alternative Metropolitan Power Strategy 2.0 (AMPS 2.0) is to evaluate the economic and environmental costs, and the feasibility of supplying electricity to Northern Illinois using nuclear power and wind turbines in conjunction will thermal energy storage. This report provides information on thermal energy storage (TES) technologies and evaluates the costs of implementing them into the model. It is important to note that these technologies are required to produce electricity, not simply store and use electricity in other forms.

Storage Strategies

There are two basic types of storage strategies, which are full storage and partial storage [2]. Full storage, also referred to as load shifting, provides the entire daily energy requirement from off-peak storage, providing the highest operating cost savings. The reason why this strategy provides the highest savings is because during off-peak hours, electricity is the cheapest. Partial storage meets on peak energy loads from both storage and operation of equipment. This means the system stores some of daily energy required from off-peak hours, but also pulls electricity during peak hours to provide daily energy required. This report assumes that the TES technologies will be using the full storage strategy in the model. Note that this strategy will affect the capacity requirement.

Types of Thermal Energy Storage

TES can take the form of sensible heat storage (SHS) or latent heat storage (LHS) [3]. SHS is where the temperature of the storage material varies with the amount of energy stored. The most common types of storage materials that SHS utilizes are water, molten salts, and oils. Typically, SHS materials are high in specific heat capacity, long term stability under thermal cycling, compatible with containment, and are low cost. LHS is where a phase change material (PCM) is utilized to store energy. That amount of energy required to change phases of a material is its latent heat. Though there are a lot of different PCMs, the most common are water-ice and salts. To store the same amount of energy, significantly large quantities of a storage medium are required for SHS in comparison to LHS. This is because in LHS the amount of energy required to convert a PCM to different phases is substantial compared to the amount of energy required to elevate or decrease the temperature of a material in a single phase. To give an example, it takes 80 times more energy to melt 1 kg of ice as to raise the temperature of 1 kg of water by 1 degree Celsius, which is due to phase change. This shows that LHS takes advantage of the volume of material to store energy and creates high energy densities.

Data on Thermal Energy Storage Systems

Table 1 illustrates the range of values for present day TES systems. These were given both local scale and utility scale systems. Due to specific requirements of TES systems for any given location, these values take on a large range. A feasibility evaluation is usually done before a TES system is designed or implemented. This allows engineers to provide a specific system for specific needs of an area or building. When more complex systems are required, as one can see, the values can vary substantially.

	Min	**Max**
Initial Costs ($/MW)	200,000	400,000
Operations & Maintenance ($/MW/year)	300000	800000
C-rate (Time) (Hours)	1	24+
Storage (cycle) Efficiency (%)	30	90
Power Rating (MW)	0.001	300
Total Capacity (MWh)	2560	16000
Energy Density (kWh/L)	0.0083	0.083
Power Density (W/ m^3)	3000	30000
Self Discharge (%/day)	0.05	1

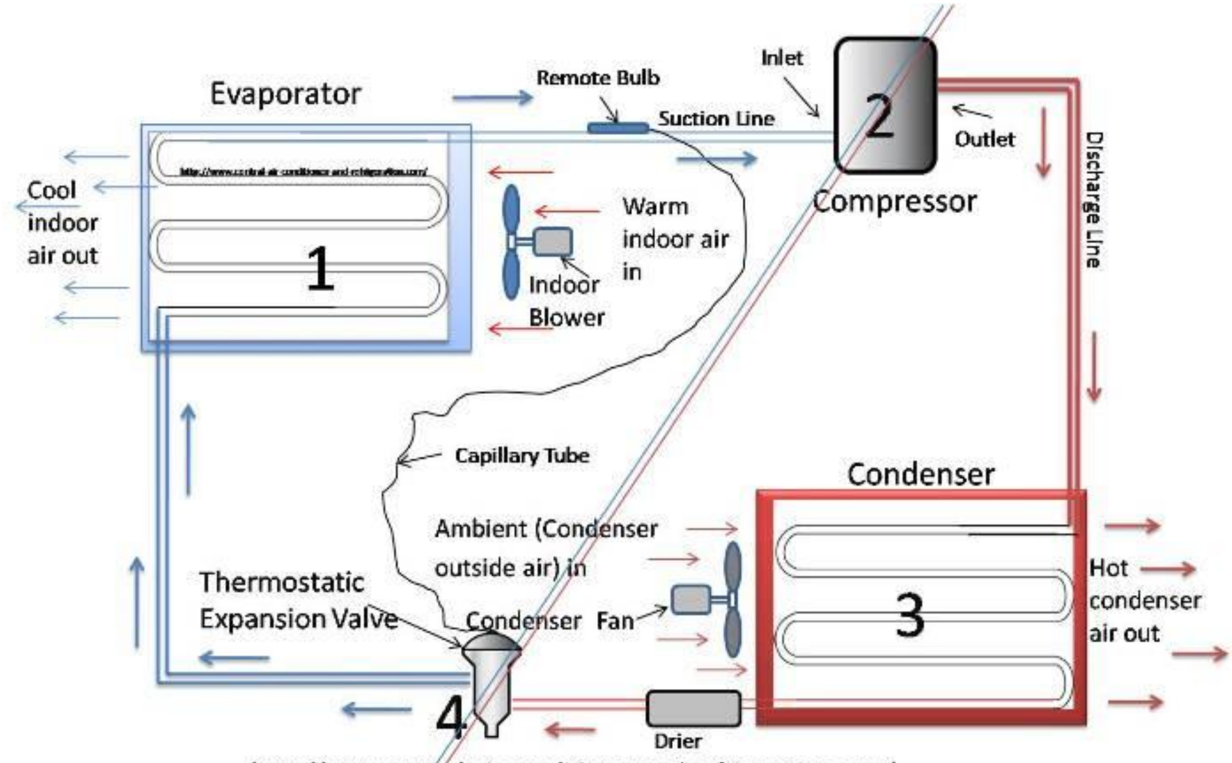
Table 1: Range of values for various TES systems

The initial costs include installation and capital costs. Operations and maintenance costs include costs for keeping the storage device running as well as fuel or electricity costs. C-rate is time it takes for a full stored system to charge or discharge. The storage efficiency is the percentage of charged energy used after discharge. The power rating is the amount of energy the system can provide at a certain rate. The total capacity is the amount of energy that the device can hold. It is important to note efficiency when referring to capacity because the capacity may need to be a lot larger due to low efficiencies. The energy density is the amount of energy that the storage materials can store for a certain volume. The power density is the amount of energy that the storage materials can exert at a certain rate. The self discharge is the percentage of energy lost per day. This is important to note because it may affect the efficiency and capacity required.

To be more specific, Table 2 illustrates different TES technologies in used or in development [1]. Aquiferous TES and Cyrogenic TES are examples of low temperature TES. Figure 11 gives a typical example of low temperature TES cycles, also referred to as refrigeration cycles. Aquiferous TES is where water is cooled during hours of off-peak hours, then that energy is used during times of high demand. Typically these systems are used in large commercial buildings to reduce energy and HVAC equipment costs. Cyrogenic TES is where a gas is turned into liquid by off-peak power and during peak demand the environment heats the cryogen to produce electricity. Typically, High temperature TES utilizes molten salts, oils, and PCMs. Molten salts and oils can be stored at very high temperatures without decomposing. Figure 12 illustrates a typical cycle that utilizes molten salts or oils. PCMs change from solid to liquid when heated and because of the latent heat of melting it has potential for higher energy densities.

	Aquiferous	**Cyrogenic**	**High Temperature TES**
Power Ratings (MW)	0 to 5	0.001 to 300	0 to 60
Discharge Time (hours)	1 to 8	1 to 8	1 to 8
Self-Discharge per day (%)	0.5	0.5 to 1	0.05 to 1
Capital Costs ($/kWh)	20 to 50	3 to 30	30 to 60
Energy Density (Wh-L)	80 to 120	120 to 200	120 to 500
Lifetime (years)	10 to 20	20 to 40	5 to 15

Table 2: Low Temperature (Aquiferous and Cyrogenic) and High Temperature TES [1]



http://www.central-air-conditioner-and-refrigeration.com/

Figure 11: Typical refrigeration cycle [4]

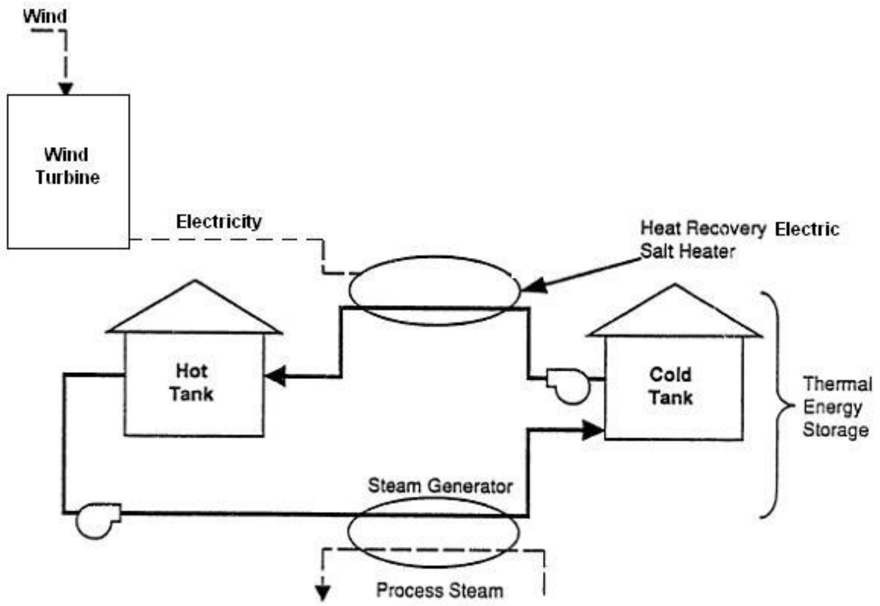


Figure 12: Modified high temperature TES cycle utilizing wind energy [5]

AMPS 2.0 Application

Given the objective that these thermal energy storage technologies are required to produce electricity and for electric utility purposes, the only type of TES that can be utilized for a centralized system is high temperature TES. In most of its applications, high temperature TES is used along with solar power plants or gas-fired power plants, which directly produce heat and thus the conversion heat-electricity-heat is avoided, increasing the overall efficiency of the system. In this model (figure 12), the energy is input in the system in the form of electricity generated by nuclear power plants and wind turbines, therefore it needs to be converted into heat before entering the storage. This is done with resistors. Some sources are citing the efficiency of electric heaters to be as high as 100% but for the purpose of this study we will conservatively take it as 90% for the calculation of the overall cycle efficiency of the storage. The storage energy is then converted back into electricity when necessary. Table 3 describes the specifications for a typical high temperature TES system. These values will be the basis for the cost evaluation of TES systems.

Initial Costs ($/MW)	400000
Operations & Maintenance ($/MW/year)	2500
C-rate (Hours)	2.5 to 24
Storage (cycle) Efficiency (%)	60 to 70
Energy Density (Wh/L)	25 to 30
Power Density (W/ m^3)	10000
Self Discharge (%/day)	0.05

Table 3: High Temperature Oils/Molten Salts [5]

6.1.6 Compressed Air Energy Storage (CAES)

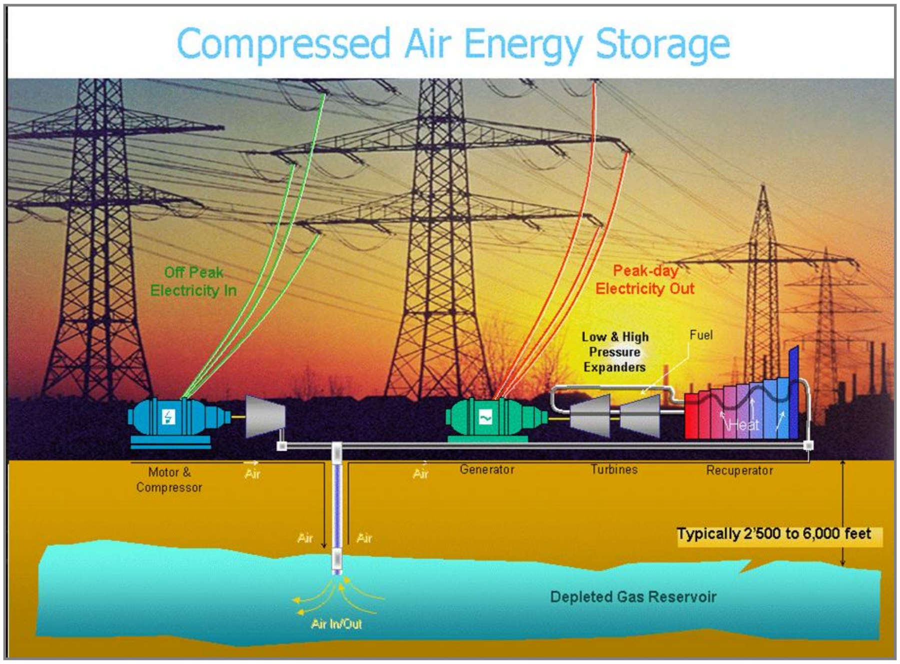


Figure 13: Schematic of a CAES plant

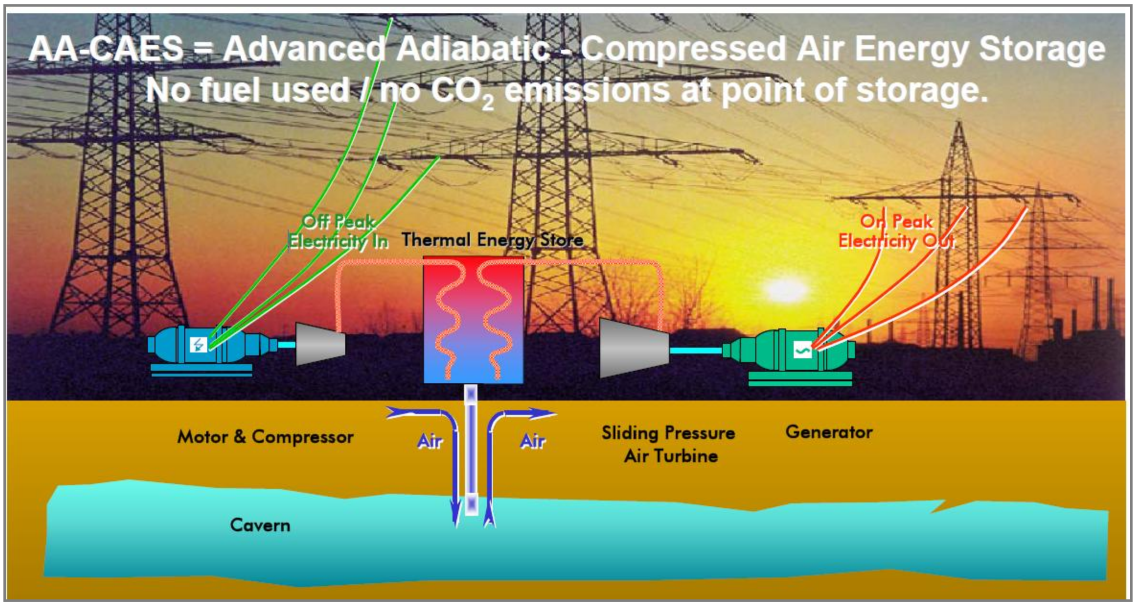


Figure 14: Schematic of an AA-CAES plant

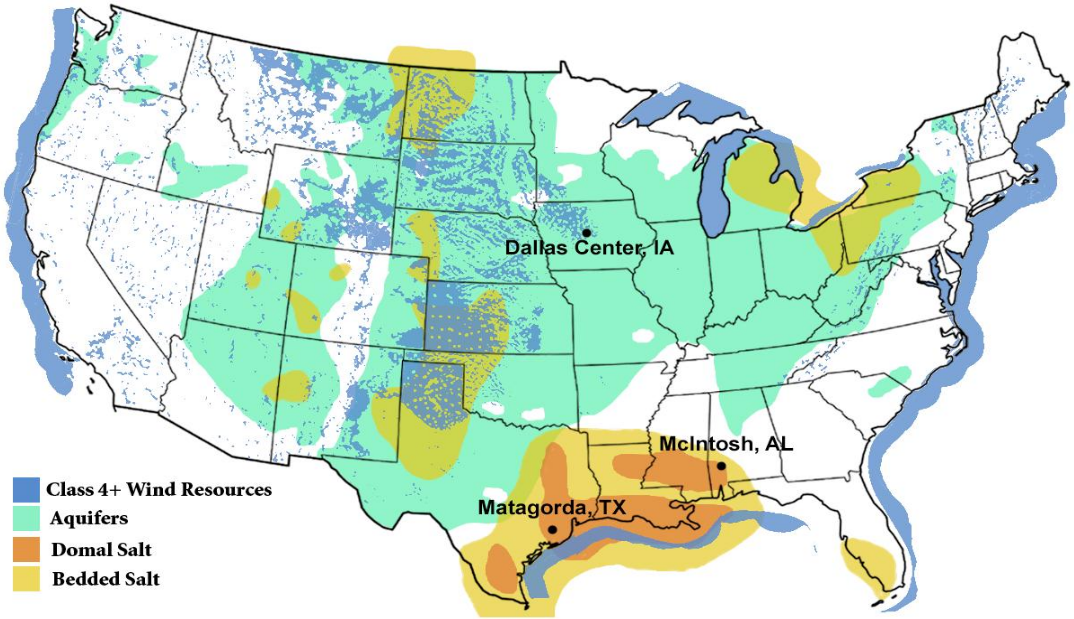
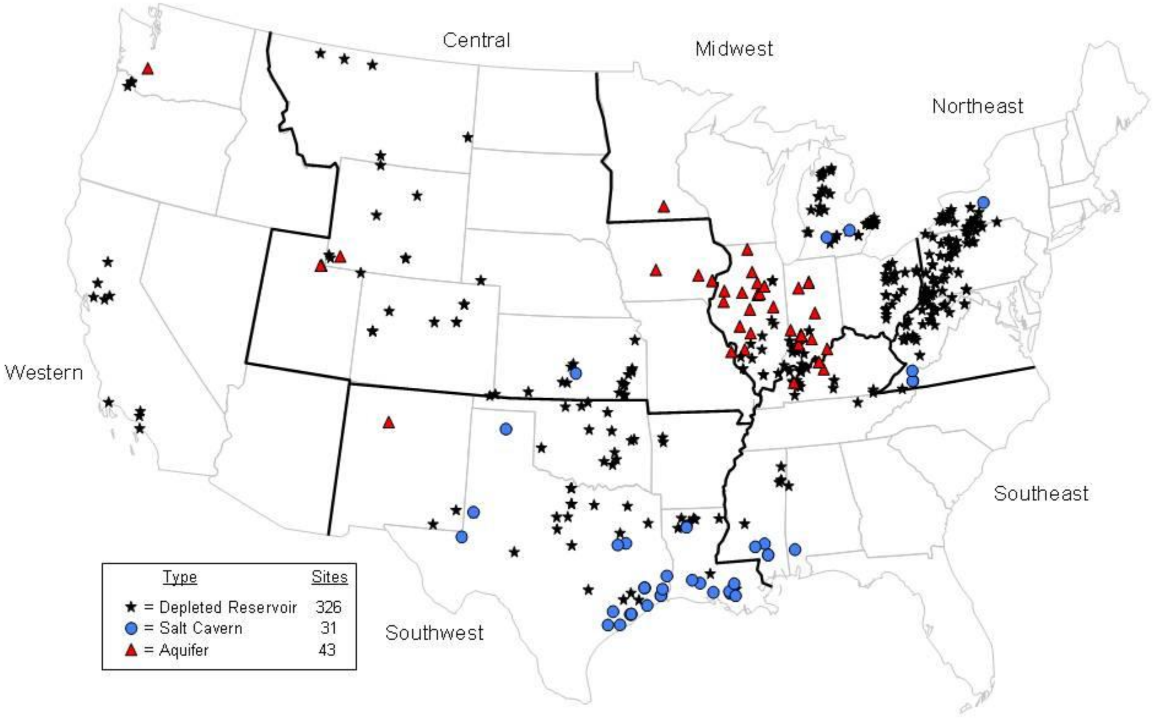


Figure 15: Areas with geologies favorable for CAES



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division Gas, Gas Transportation Information System, December 2008.

Figure 16: Aquifer Locations

Background

Compressed air energy storage (CAES) involves taking off-peak power from the electrical grid and using it to power a motor-driven compressor to pump air into a sealed underground reservoir to a high pressure. A schematic of a CAES system is shown in Figure 13.When needed at peak hours, air is extracted from the reservoir, preheated in a recuperator, mixed with small quantities of oil or gas and burnt in a combustor. The hot gas from the combustor is then expanded in the turbine to generate electricity. CAES has a number of advantages, including high storage capacity, fast start up times, and cost effectiveness. One of its greatest disadvantages is its low efficiency, which can be as low as 35%.

Currently, there are two CAES plants in operation. The 290 MW Huntorf CAES plant, the world's first CAES facility, is located in Bremen, Germany and has been in operation since 1978. The second CAES facility, The 110 MW McIntosh CAES plant located in McIntosh, Alabama, was completed in 1991.

Because IPRO 302 seeks to create a system that supplies electricity to the city of Chicago using non-$\mathrm{CO_2}$emitting technologies, a form of CAES know as advanced adiabatic CAES (AA-CAES), was considered. A schematic of an AA-CAES system is shown in Figure 14. With AA-CAES, the heat retained from the compression process is stored in a thermal energy store (TES) and reused to heat the air when it is expanded to generate electricity. The AA-CAES system is an improvement over the conventional CAES model in that the round trip efficiency of the system can reach 70%. An adiabatic CAES plant has yet to be implemented, and thus research is being performed to determine an optimum plant arrangement and design for the individual system components.

Geology and Storage Space Needs

According to a study conducted by the Princeton University's Environmental Institute, around 70% of the US has geology suitable for CAES storage. There are three different geological formations that can be used for storage: hard rock, salt domes and porous rock aquifers. Of the three, porous rock formations are best suited for the state of Illinois. When observing the maps in Figures 15 and 16, which detail the various locations of the different rock formations in the United States, it is seen that aquifers are widely available throughout the state of Illinois. In addition, at $0.11 / kWh, aquifers are the cheaper than hard rock and salt dome formations, which are $30/kWh and $2/kWh, respectively.

To calculate the cavern volume needed to store the needed amount of electricity, the needed storage capacity of 320,000 MWh was divided by the storage energy density of AA-CAES, which is 2.4 kWh/m^3, the needed storage volume was approximately 133 million m^3. When taking into account an estimated porosity of 30% for the aquifer, the storage volume calculated above was divided by 0.30, and the needed volume was found to be approximately 444 millionm^3.

Assumptions

Assumed uniform porosity for the entire aquifer volume

Assumed aquifer porosity of 30%

7.0 Conclusions and Recommendations

Based upon the evaluation of the initial technologies, the technologies analyzed financially included Pumped Hydro, Adiabatic CAES, Thermal, Vanadium Flow Batteries, and traditional batteries. Thereafter, the team was able to eliminate traditional batteries as a viable optional financially. Furthermore, pumped hydro was eliminated based upon the insufficient head height within Illinois topography. The team was able to conclude that in order to accomplish 20% renewable energy, supplanting carbon emission technologies with nuclear power production, and developing a functional storage system is a viable option through the use of Vanadium Flow Batteries or Adiabatic Compressed Air Energy Storage. With a levelized cost of energy at $0.149/kWh for a Vanadium Flow Battery system compared to the $0.089/kWh for an Adiabatic Compressed Air Energy Storage system, Adiabatic CAES is the most economically viable option for Illinois.

Although the cost of the Vanadium Flow Battery system is expensive, within our research, it was estimated that the cost of the system would significantly decrease as the technology is further developed and becomes better utilized. Whereas the financial figures calculated herein are based upon the current, more expensive system costs. In addition to this specific case of cost efficacy, the financial calculations do not include state or federal green energy incentives, which would serve to decrease the costs of this proposed storage system.

The final recommendation for an energy system that utilizes 20% renewable energy, carbon-free emissions, and a storage system to efficiently meet the power and energy demands of Chicago, as proposed by IPRO 302, is an Adiabatic Compressed Air Storage system that has sufficient thermal storage tanks and turbines to manage a 1500 MW power rating and a mined cavern space to manage a storage capacity of 320,000 MWh.

This design can be further refined and improved by any subsequent IPRO or group of interest. Steps for future investigation include researching the optimization of the system analysis with a realistic growth on the demands of power within the future as well as analyzing an optimal location for the storage facility within Illinois.

Appendix A- References

Batteries

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S.M. Hasnain. 1997. Review on sustainable thermal energy technologies part II: Cool thermal storage. *Energy Convers. Mgmt*. [2]

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Marc. A Rosen. 2002. Thermal energy storage systems and applications. *John Wiley & Sons, Inc*. [5]

Appendix B- Storage Evaluation Factors

- Capital Costs – The initial cost of the storage technology
- Operations & Maintenance Costs – The cost of the storage technology to operate and be maintained
- Storage Efficiency – The efficiency of the storage technology
- Self Discharge – How fast does this storage technology self discharge?
- Energy Capacity – The energy this storage technology is able to hold, is it within our parameters?
- Power Rating – What is the maximum power that is to be used with this storage technology?
- Stage of Development – How developed is this storage technology, is there sufficient data about it?
- Environmental Factors – Is this storage technology feasible in the environment we need it in?

Appendix C- Assumptions

Major Assumptions, assumptions that pertain to particular storage technology can be found under its respective technology.

- 5-Year System Analysis has identical consumer power and energy demand data each year.
- Base-Line is entirely Nuclear and Remainder Is Wind with a ration of .8 to .2 respectively.
- Wind is reliable and steady.
- At the beginning of the system analysis, the Storage System begins filled and must never have a negative internal energy value.
- The Worst Seven Days of the Year, Based upon Power Demand, Have No Wind Power Production, with these days being 6/28-7/04.
- 4% per Year Cost Inflation of $ (USD).
- CAES System Uses Porous Rock Mining Costs.
- Efficiency of Li-Ion and NiMH Batteries are 100% since specific data was not found or provided.

Appendix D- Similar Solutions

Cited below are scholarly articles regarding wind energy systems and energy storage methods. The discourses of the following articles range from analyses of the reliability of wind generators and energy storage to studies that examine and advocate the use of specific storage methods.

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Appendix E- Critical Documents

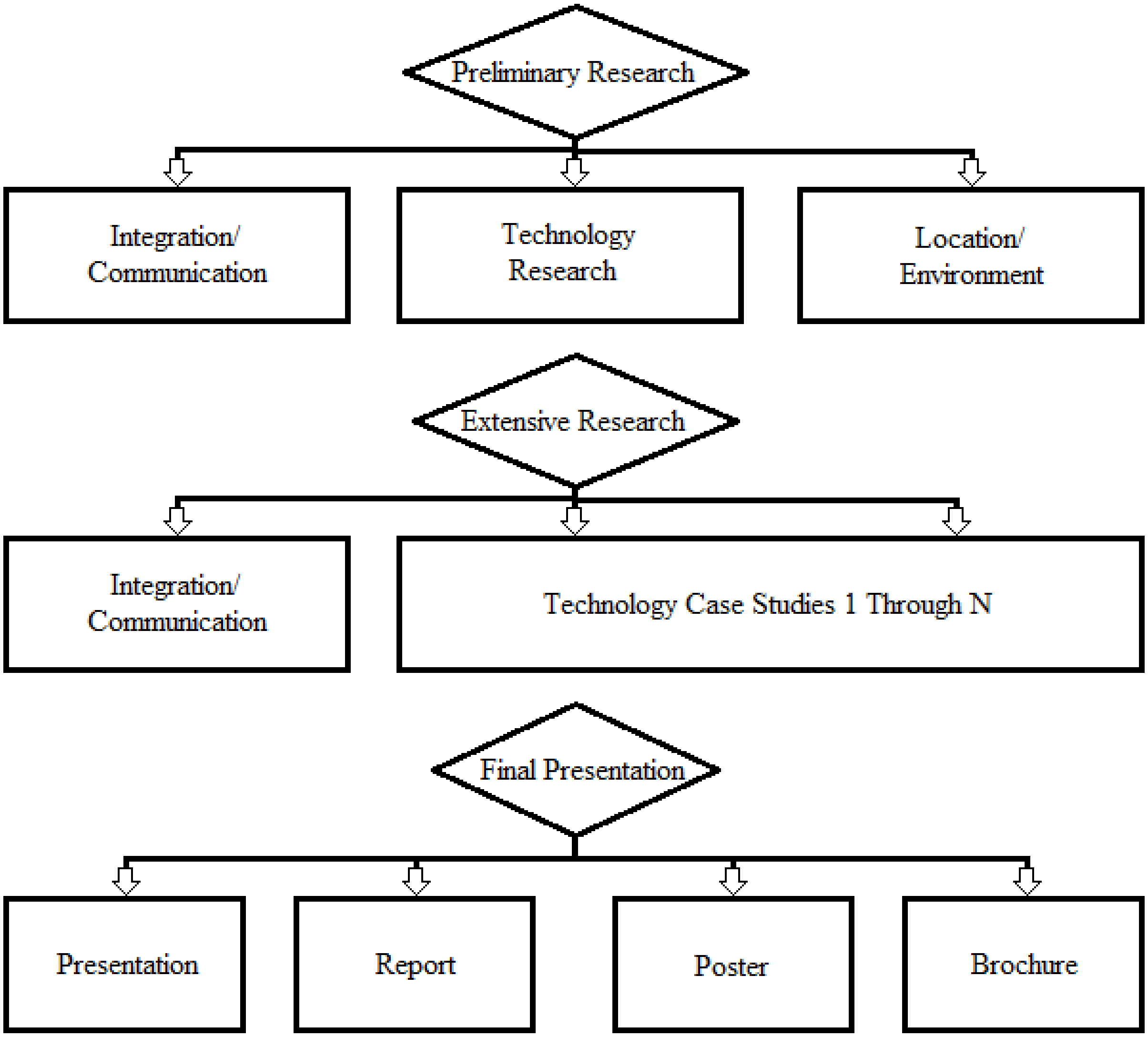
Thus far, the students of IPRO 302 have consulted the final report from spring 2010 to provide a context for efforts to find the most economically viable energy storage method and to base many of their early decisions on.

Appendix F- Sponsor Background

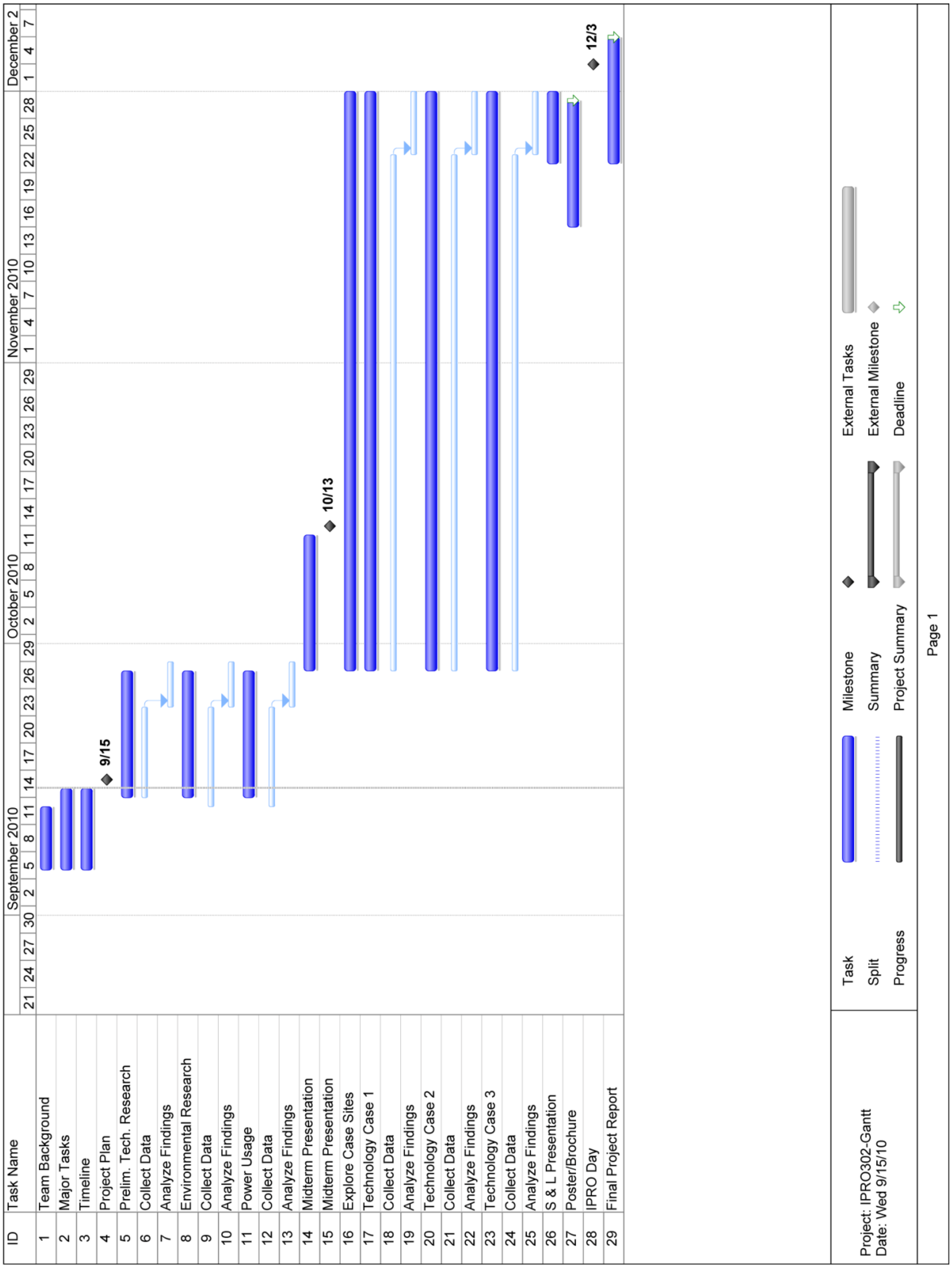
Sargent & Lundy LLC is a Chicago-based consultancy organization that has been a worldwide leader in providing professional services for the electric power industry and related clients for 119 years. Since its founding as an independent engineering and consulting company in 1891 by Frederick Sargent, a mechanical engineer, and Ayres Lundy, an electrical engineer, Sargent & Lundy has provided complete consulting, engineering, and project development services for various fossil-fuel, nuclear and renewable power generation and delivery projects, including feasibility advice, strategic project citing and project financial services. One of its first accomplishments was the design of the Harrison Street Station for Chicago Edison Co. in 1892, the first plant ever designed for condensing operation. Since then, Sargent & Lundy has produced a respectable record of achievements, including the design of 884 power plants totaling 122,149 MW for public and private sector clients as well as more than 5000 circuit miles of high voltage and extra high voltage transmission lines and 100 substations.

Appendix G- Team Structure & Timeline

Team Structure



Gantt chart


ID
Task Name
1 Team Background
2 Major Tasks
3 Timeline
4 Project Plan
5 Prelim. Tech. Research
6 Collect Data
7 Analyze Findings
8 Environmental Research
9 Collect Data
10 Analyze Findings
11 Power Usage
12 Collect Data
13 Analyze Findings
14 Midterm Presentation
15 Midterm Presentation
16 Explore Case Sites
17 Technology Case 1
18 Collect Data
19 Analyze Findings
20 Technology Case 2
21 Collect Data
22 Analyze Findings
23 Technology Case 3
24 Collect Data
25 Analyze Findings
26 S & L Presentation
27 Poster/Brochure
28 IPRO Day
29 Final Project Report
September 2010
October 2010
November 2010
December 2
21 24 27 30 2 5 8 11 14 17 20 23 26 29 2 5 8 11 14 17 20 23 26 29 1 4 7 10 13 16 19 22 25 28 1 4 7
9/15
10/13
12/3
Project: IPRO302-Gantt
Date: Wed 9/15/10
Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline
Page 1

Appendix H- Team Information

Team Roles

Agenda Maker: Aric Austermann- Creates agenda accordingly to the phase of the project, distributes copies to team and ensures everyone knows the purpose of the meeting.

Minute Taker: David Kronika- Records decisions made throughout the meeting and posts outlined notes in a timely manner to iGroups.

Time Keeper: David Kronika- Tracks the progress of the meeting as outlined in the assigned agenda for the day. Encourages everyone to stay on task and on time.

iGroups Moderator: Aric Austermann- Keeps track of timesheet status for members and ensure that all files, emails, photos, and other documents are properly organized.

Raquel Alvarez

Major: 4th Year Civil Engineering
Phone: [redacted]
Email: ralvare4@iit.edu
Individual Strengths to Contribute: As an individual, I have excellent leadership skills to contribute; I have been involved in various organizations as an executive board member and have worked with other people to reach a common goal. Also, this past summer I had the opportunity to intern with ComEd, the utility company here in Chicago that would ultimately be the ones to implement our renewable energy system. I have connections with engineers that can provide us with feedback on the feasibility of our project. I am also very organized and extremely motivated to complete this project.
New Knowledge/Skills to Develop: I would like to gain new knowledge about the renewable power technologies that are currently available. I cannot wait to share my knowledge of civil engineering with the rest of the group for the benefit of the project. I look forward to working with various people of different backgrounds and complete the large number of difficult tasks.
Overall Expectations about the Project: I expect all of the individual group members to work together and be conscientious of deadlines and the project purpose. I expect us to complete all of the required research on time and satisfy our sponsor, Sargent & Lundy.

Aric Austermann

Major: 5th Year Architecture
Phone: [redacted]
Email: aausterm@gmail.com
Individual Strengths to Contribute: Having already participated in an IPRO I feel I will be able to help with understanding and meeting the IPRO requirements. I have researched about many different green technologies but mostly on the smaller scale meant for individual buildings. My skills as an architect have

prepared me for presentations and the development of visual aids. I have had a decent amount of leadership experience that should help me in working with the team.

New Knowledge/Skills to Develop: I hope to learn more about larger power systems and how they differ from the smaller building oriented ones. I want to work on effectively being a member of a larger team.

Overall Expectations about the Project: This project is something that should actually be happening and hopefully we can find cheap enough resources and storage devices that this project could become real. Even if it doesn't I expect that we will work hard to get information for Sargent & Lundy so they can better provide services on green technologies to their customers while allowing us to better understand this complicated subject.

Yao Blagogee

Major: 3rd Year Electrical and Computer Engineering
Phone: [redacted]
Email: yblagoge@iit.edu

Individual Strengths to Contribute: I am skilled in circuit analysis, digital systems, and electrodynamics. I am able to work individually as well as in group. I also have skills in the Java programming language, Adobe Photoshop and Adobe Illustrator.

New Knowledge/Skills to Develop: This is my first IPRO and I am looking to improve my knowledge about renewable energy.

Lachezar Handzhiyski

Major: 4th Year Civil Engineering
Phone: [redacted]
Email: lhandzhi@iit.edu

Individual Strengths to Contribute: I have coursework experience in micro- and macro-economics, as well as in the analysis of capital investments. I could help by utilizing computer software in executing the various calculations associated with the project. I have been a physics tutor in IIT for two semesters and I understand the basic physics behind power systems. Since last year I have had personal interest in renewable energy sources, mainly photovoltaic systems and wind turbines and I have done a little research on the different options realized in a small scale.

New Knowledge/Skills to Develop: I am hoping to improve my communication skills as well as to gain knowledge about the renewable energy policy of the United States and the level of development and economic feasibility of the renewable energy sources available on the market.

Overall Expectations about the Project: The project will give everyone a chance to prove that they can take responsibilities, meet demanding deadlines, and work together with people from different academic backgrounds. It is an excellent opportunity for one to demonstrate analytical and technical, as well as leadership and teamwork skills.

Thomas Hotz

Major: 4th Year Mechanical Engineering
Phone: [redacted]
Email: thotz@iit.edu

Individual Strengths to Contribute: This being my second IPRO, I will be able to contribute to the process transitions over the course of the semester. I am very team oriented, always open to everyone's input and criticism. I am also very goal oriented, always need to set standards high. I am a positive person and try to keep that positive feel within the team. I display skills in leadership, reporting, communication, research, and the design process.

New Knowledge/Skills to Develop: I would like to develop more confidence and become more vocal, trying to be more persuasive with my thoughts, and voicing my opinion during class discussions.

Overall Expectations about the Project: I think that this project has a lot of promise and an already strong foundation among the classmates. My only expectation is that everyone works in a very cohesive manner, that everyone finds a lot of interest in all matters, that everyone puts in an equal amount of work, all of which builds us into becoming a strong contender on IPRO day.

David Kronika

Major: 4th Year History, Past Major: Aerospace Engineering, Minor in Business
Phone: [redacted]
Email: dkronika@iit.edu OR dkronika@gmail.com
Individual Strengths to Contribute: Ability to engage in historical research; interest in, and moderate understanding of, current and emerging technologies; moderate knowledge of economic and business principles.
New Knowledge/Skills to Develop: I hope to gain further insight into emerging renewable energy production technologies, and I hope to develop my understanding of business practices and public speaking.
Overall Expectations about the Project: As this will be my first IPRO, I expect the project to involve a fair amount of research and hard work.

Masnaga Masnaga

Major: 4th Year Civil Engineering
Phone: [redacted]
Email: mmasnaga@iit.edu
Individual Strengths to Contribute: As an individual, I have strong analytical skills; the ability to visualize, solve complex problems and concepts, and make decisions that make sense based on available information. I am open to new ideas and critics as long as they make sense. I also have time management skills. They include planning, setting goals, organizing, and scheduling. Finally, my greatest strengths that I can offer to the team are high motivation to finish this project and never giving up.
New Knowledge/Skills to Develop: I would like to have better understanding of the challenges that need to be faced when it comes to applying renewable energy resource. I also want to improve my ability to work with people from different backgrounds.
Overall Expectations about the Project: I expect all of the individual group members to contribute all their unique strengths and be meticulous of deadlines and project purpose. I also expect our team members to be active, initiative, and helpful to each others. So, we can complete all of the required research on time and satisfy our sponsor Sargent & Lundy.

Brian Olson

Major: 3rd Year Chemical Engineer
Phone: [redacted]
Email: bolson@iit.edu

Individual Strengths to Contribute: Strong ProE (CAD) skills, Microsoft Office, some C++, some GIS experience, organizational skills

New Knowledge/Skills to Develop: Hope to improve my people/group skills.

Overall Expectations about the Project: Be a productive part of the project and contribute to a high functioning team.

Meaghan Rollins

Major: 3rd Year Electrical/Computer Engineering Student
Phone:
Email: mrollin1@iit.edu or meaghanrollins@yahoo.com

Individual Strengths to Contribute: Knowledgeable of ECE related subjects, such as power systems. Good research and writing skills. Proficient in Microsoft Office Suite.

New Knowledge/Skills to Develop: Improve public speaking, organizational and project management skills. Increase knowledge of the business aspect of engineering.

Overall Expectations about the Project: Exceed the expectations of Sargent & Lundy. Increase knowledge of the potential of wind power and the obstacles that wind technologies face.

Jonathan Roraff

Major: 3rd Year Applied Math
Phone: [redacted]
Email: JRoraff@iit.edu

Individual Strengths to Contribute: Have previous IPRO experience. Leadership Skills. Effective Organizational Skills.

New Knowledge/Skills to Develop: Hone Presentation and Public Speaking Skills. Develop a greater capacity to function in a group.

Overall Expectations about the Project: My expectations for this project are to optimize upon my leadership and organizational skills to assist in bringing our IPRO group into a functional unit to best meet the goals set out by us, the students, as well as to best meet the expectations of our sponsor.

Jaya Singh

Major: 4th Year Chemical Engineering
Phone: [redacted]
Email: jbsingh86@gmail.com, jsingh23@iit.edu

Individual Strengths to Contribute: Have good literature research experience from previous projects in order to find valuable information for this project. Have enough coursework in Physics, Chemistry, Mathematics and Chemical Engineering which can be used to do mathematical calculations and engineering analysis involved in this project. Good knowledge of MATLAB programming which is a very powerful engineering and mathematical analysis tool. Some graphic designing experience which might come in handy for this project.

New Knowledge/Skills to Develop: Gain knowledge on various types of renewable energy resources and storage mechanisms. Work efficiently in a large group.

Overall Expectations about the Project: I am very excited about this project. I would like to contribute the best of my abilities to make this project a success and provide valuable results to our sponsor Sargent & Lundy.

Jake Wilson

Major: 4th Year Political Science, Minor in Naval Science

Phone: [redacted]

Email: jwilso9@iit.edu

Individual Strengths to Contribute: I am a Midshipmen First Class in the Naval ROTC, and also a public speaker. I can bring my sociological approach to the table and hopefully show my prowess in public speaking to better the group.

New Knowledge/Skills to Develop: I really look forward to getting a more non-military leadership experience and learn how to work with civilians. This will also be a good researching opportunity.

Overall Expectations about the Project: I think we have very good, smart people working on this project, and I believe we will succeed in accomplishing our mission.

Appendix I- Ethics & Team Values

Ethical Issues

Various internal ethical issues can arise during a project which should be properly addressed. All the team members should maintain honesty and integrity during the project. They should treat each other in the team with respect. In order to produce quality work, team members should show competence and complete their assigned tasks properly on time. Communication is very important for a team to perform efficiently. Therefore, proper communication should be maintained so that there is no discord between the team members on the assigned tasks. Any form of misconduct or hurtful comments intended towards other team members or teams should be avoided. Any form of plagiarism is intolerable. Therefore, all the research works used in the project should be properly cited in order to give credit to the original authors.

There are external ethical issues as well. Our project includes nuclear reactors for the generation of electricity. So, the biggest issue is about the nuclear waste. Nuclear waste should be properly and safely disposed. Wind farms must be built at proper locations away from public places so that they don't pose any safety risks to people. Safety issues must be given priority rather than monetary benefits gained by undermining the safety of the project.

Desired Behavior

- Group members shall be proactive and goal-oriented
- Group members are responsible for their own commitments and be conscientious of all deadlines
- Group members shall be open to others ideas and respect one another
- Every group member will have the opportunity to voice their opinions and ideas for the advancement of the project
- All group members will have a positive attitude and be motivated as difficult tasks arise
- Group members will be willing to ask others for help and provide help when it is asked
- Team members will effectively communicate with each other if they have any time and obligation conflicts, so that another group member provides their help. Personal interaction as well iGroups and email will be used as primary means of communication
- Group Members will be punctual to all meetings and classes

Conflict Resolution

- A discussion about the conflict will take place and group members will be conscientious about giving each other an opportunity to achieve their own goals without undermining those of other people and/or of the project.

- The discussion shall be courteous and non-confrontational, and the focus will be on the issues and not on individuals.
- Both parties will listen carefully to each other and explore all facts, issues as well as all possible solutions.
- If the conflict cannot be solved by both parties the issue shall then be handled by the team leader and if it still is not resolved it will then be handled by the IPRO instructors**.**

Appendix J- Budget

• Printing and Office supplies	$0
• Transportation ($0.55 x 300 miles x 4 cars) (cancelled)	$0
• Data Access	$0
TOTAL:	$0

Appendix K- Acknowledgments

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Sargent & Lundy

Jennifer Keplinger

IPRO Office

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