Evaluation of Permanent Load Shift Technologies and Development of Pre-Feasibility Tool

DR12.20

Prepared by:

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Customer Service
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Acknowledgements

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The Electric Power Research Institute (EPRI) was contracted to conduct this work on behalf of SCE. EPRI staff included Ram Narayanamurthy, Sudeshna Pabi, and Paul Sanford. Gabriel Meric from Global Vision, LLC, and Openergy conducted the EnergyPlus™ modeling work. Lumina Design Systems developed the front-end tool to provide usability and the building analysis that leveraged the EnergyPlus development work. The National Renewable Energy Laboratories (NREL) supported development of new EnergyPlus functions for thermal storage and supported correcting inconsistencies in modeling of chillers within EnergyPlus.

EXECUTIVE SUMMARY

This project was funded by the Emerging Products program at Southern California Edison (SCE) to investigate emerging technologies for energy storage, with particular relevance to Demand Response and Permanent Load Shift (PLS) programs. The state of the technology and policy has evolved significantly in the last four years, with emergence and significant advancement of battery storage technologies, as well as new thermal energy storage technologies. Many of these technologies are focused on the customer side of the meter, where they are being installed to provide customer services such as demand charge management, backup power and in some cases, self-sufficiency so as not to export excess generation at certain times of the day. This market is an evolving market that is closely being monitored.

With the new regulatory requirements in California supporting energy storage, Southern California Edison (SCE) along with other Investor Owned Utilities (IOUs) has set up procurement of megawatt-scale energy storage installations. Within SCE's related procurements, two of four awardees are focused on customer side storage; one supports customer storage with a thermal storage solution, and one supports storage with a demand response (DR) plus storage controls platform for commercial buildings. The statwewide Permanent Load Shift Program (PLS) has developed incentives for thermal storage technologies that focus on larger commercial and industrial buildings. In parallel, the Self Generation Incentive Program (SGIP) provides incentives for battery storage systems. These programs help to accelerate market transformation of battery storage technologies, especially tied to photovoltaic (PV) generation.

This project has three main objectives: (1) to provide a market characterization and technology review of energy storage and load shift technologies, (2) to review and advance existing EnergyPlus™ building simulation models used for predicting thermal energy storage savings, and (3) to develop a free, open-source, cloud-based tool based on EnergyPlys to estimate energy savings and implementation costs for thermal energy storage systems used in buildings. The second and third objectives peripherally support the building industry by advancing predictive energy tools, yet the primary intent of these two tasks are to support participation in the statewide PLS Program, by providing customers and program implementers with a quick yet accurate pre-feasibility tool for assessing thermal energy storage systems.

The report starts with a review of the PLS program followed by a review of multiple types of load shift technologies. The load shift technologies include traditional thermal energy storage systems, and battery storage systems, as well as newer technologies such as refrigeration storage, and controls enabled load shifting technologies that can be utilized for renewables balancing and fast response requirements. It then details the process of developing EnergyPlus models both for baseline and with incorporate TES systems. Research of EnergyPlus was conducted in collaboration with the National Renewable Energy Labs (NREL) and is one of the first implementations of the Thermal Energy Storage module incorporated by NREL into EnergyPlus in 2013. The research revealed bugs in the controls systems with chiller operations, some of which have been corrected and incorporated back into EnergyPlus.

Finally, a PLS predictive tool was developed called the Thermal Energy Storage Screener (TESS) tool. The TESS tool was created to support the existing statewide PLS Program by helping to quickly evaluate thermal energy storage (TES) systems at no cost. Evaluating

feasibility of TES systems can be costly to building owners, as large scale audits are typically required to determine if TES makes fiscal sense. At times, a building owner can be asked to spend money on an audit without any guarentee that TES will make sense at their site, or without any guarentte of receiving a financial incentive from the PLS program. This programmatic scenario has made incenting customers to install TES systems a difficult proposition. The TESS tool was created to help mitigate some of this issue by using a large presimulated calibrated dataset as the foundation for and quick and easy to use feasibilty tool. The tool is unique in its structure with an ability to scale models to match building characteristics with multiple levels of scaling; first for building size and then for annual energy use and finally for monthly peak demand. The tool is completely open-source and was calibrated using real data provided by SCE's PLS Program. The overall objective of this work is to increase participation in the statewide PLS Program by providing customers and program implementers with easy to use resources.

The Thermal Energy Storage Screener (TESS) tool is temporarily being hosted here: https://www.analyticacloud.com/acp/ClientAs3/AcpFlex.aspx?inviteId=123&inviteCode=942263&subName=Lumina

ABBREVIATIONS AND ACRONYMS

AHI	Aqueous Hybrid Ion
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMS	Battery management system
DESS	Distributed energy storage systems
DOD	Department of Defense
DR	Demand Response
EPRI	Electric Power Research Institute
ESP	Energy storage platform
ESS	Energy storage system
HVAC	Heating, Ventilation and Air Conditioning
ICAES	Isothermal compressed air energy storage
IEEE	Institute of Electrical and Electronics Engineers
KVA	Kilovolt-Amps
kWh	Kilowatt Hour
LCOE	Levelized cost of energy
LMB	Liquid Metal Battery
MSDS	Materials Safety Data Sheet
NDV	Negative Delta V
NEC	National Electric Code
NEMA	National Electric Manufacturers Association
NEPA	National Electric Protection Association
NiCd	Nickel Cadmium
PbC	Lead Carbon
PLS	Permanent Load Shift
PV	Photovoltaic

RESU	Residential energy storage unit
SCE	Southern California Edison
SESS	Smart energy storage system
SGIP	Self-Generation Incentive Program
SRS	safety-reinforced separators
TES	Thermal Energy Storage
TESS	Thermal Energy Storage Screener tool
TMS	Thermal management system
VDC	Volts DC (Direct Current)
Wh	Watt-Hour
ZBM	Zinc Bromine

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INTRODUCTION

Permanent Load Shifting refers to the shifting of energy usage from one period of time to another on a recurring basis, often by storing energy produced during off-peak hours and using the energy during peak hours to support loads. Permanent load management technologies have undergone significant evolution in the last decade, especially in the area of customer side systems. Previously, the only viable systems were cold thermal storage systems for large commercial and industrial buildings and lead acid batteries. However, recently the technology choices have significantly expanded and now include:

- Packaged ice storage systems;
- High efficiency electrical storage technologies such as Li-Ion and zinc oxide batteries;
- Flow batteries promising much lower cost of electrical energy storage; and
- Advances in building controls that can enable latent storage systems in buildings with minimal customer discomfort.

PLS technology is one that can accomplish routine shifting of energy-use from one time period to another during the course of a day to help meet peak loads during periods when energy-use is typically high and improve grid operations in doing so (economics, efficiency, and/or reliability).

PLS technologies, while sometimes grouped with demand response, have some significant differences. The defining characteristics of PLS technologies are:

- They are located on utility customers' premises, but may be controlled by either the utility or the customer.
- They move energy-use by the building (premise) away from a pre-defined time period.
- They do not require any comfort compromise for the customer.
- They do not need a signal from the utility (though that may be the case), and have a built-in capability to shift load.
- They have a medium in which energy is stored for future use.

One of the main goals of these technologies is to relieve congestion in the grid, whether in the generation, transmission or distribution segments at times of need. The net energy use of the building in most cases is not reduced, and may increase in some cases due to losses related to energy storage.

This project will review a large array of PLS technologies including but not limited to thermal energy storage (TES) technologies. The key considerations will be cost-effectiveness, ease of implementation and operation, and reliability for shifting building loads from one time period to another. Evolution in enabling technologies such as sensing, controls, and communications can enable a broader range of technologies to provide PLS benefits through performance verification.

TECHNOLOGY OVERVIEW

Three technology segments are considered in the analysis: active thermal storage, electrical storage, and building controls based storage. All three segments can provide varied levels of load management at varied cost level and operating characteristics. This section provides details on common operating characteristics of thermal and electrical storage.

THERMAL STORAGE

Thermal energy storage has historically been lower cost, but can only provide load shifting (e.g. it cannot send energy back into the grid). The charging and discharging profiles depend on the actual technology. From a heat transfer/thermodynamics standpoint, the charging rate will fall off as ice is built due to the heat transfer barrier created by the ice. However, by optimizing heat exchanger design and using water circulation and other mechanisms most of the manufacturers have overcome the problem of creating a more linear charging profile. During the discharge phase, internal melt systems can provide a flatter profile while external melt systems will provide higher discharge rates. Some manufacturers combine internal and external melt to reduce complexity in design and application.

The charging curve for thermal storage has a characteristic shape of a constant charge rate early with a rapidly decreasing charge rate. The charge cut-off signal is either a glycol temperature or refrigerant pressure signal that indicates sufficient ice formation. The actual cut-off temperature or pressure depends on the individual manufacturers' design, and the higher the cut-off condition, the greater is the efficiency of charging, given that the charging cycle is the primary energy user for thermal storage system. The graph in Figure 1 shows three different designs, with the more efficient design completing charging at a higher control setpoint (temperature or pressure), and in a shorter period of time. The total energy used for charging will be lower for the more efficient charging cycle.

During discharge, most manufacturers have designed their systems to ensure a constant discharge rate. Discharging is usually complete when the ice or chilled water has lost its capacity, or when the time limit (end of peak period) is reached. The thermal cut-off is detected by a rapidly increasing glycol or refrigerant temperature which indicates insufficient cooling capacity.

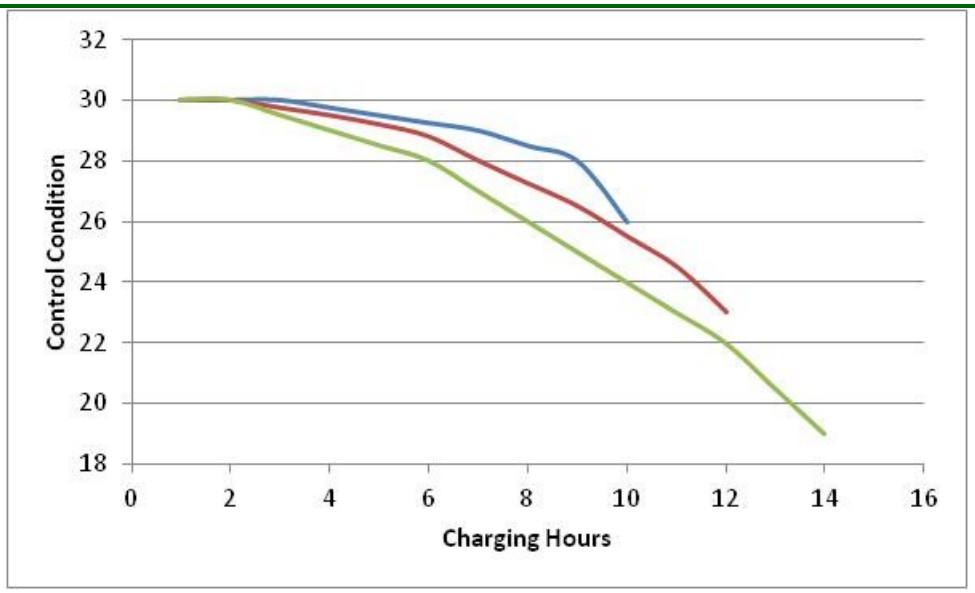

FIGURE 1. THERMAL ENERGY STORAGE 3-CASE COMPARISON

ELECTRICAL STORAGE

Electrical energy storage systems have charging and discharging characteristics that vary based on the technology. On the customer side of the meter, batteries and flywheels are considered the most likely possibilities for storing energy for load management. Ultracapacitors have high charging and discharging rates, but can only store a fraction of the energy. Therefore, while they are good for regulating transient events, ultracapacitors cannot perform well within a load management program such as PLS.

Batteries charging and discharge through chemical reactions that capture and release ions. The basic element is a cell with an anode, cathode, and electrolyte. Larger batteries are comprised of smaller cells combined in either series or parallel, that provides a broad range of charging and discharging characteristics. The rate limitations of chemical reactions serve as the limitation to charging and discharge rates of the cells and consequently the batteries. In this section, the charging profiles refer to the charging rates of individual cells. The battery charge rates will be a function of the battery construction. During discharge, the voltage produced by the battery slowly reduces from the peak value, with a sharp knee near the cut-off voltages at which point roughly 95% of the energy is used. But in many cases, such as lead acid batteries, the controls cuts the discharge earlier to avoid reliability concerns with deep discharged. The end-of-discharge voltage for lead acid is 1.75V/cell; nickel-based system is 1.00V/cell; and most Li-ion is 3.00V/cell. To protect the battery from over-discharging, most devices prevent operation beyond the specified end-of-discharge voltage. A high load current lowers the battery voltage, and the end-of-discharge voltage threshold should be set lower accordingly.

We consider five types of electrical storage systems in this study each with their own performance characteristics in greater detail: lead acid, lithium ion, nickel metal hydride, flow batteries, and flywheels.

End of discharge	Li-manganese	Li-phosphate	Lead Acid	NiCd/NiMH
Normal load	3.00V/Cell	2.70V/Cell	1.75V/Cell	1.00V/Cell
Heavy Load	2.70V/Cell	2.45V/Cell	1.40V/Cell	0.90V/Cell

Lead Acid Batteries

The advantage of lead acid batteries is their cost-effectiveness. However, they are not very reliable from the viewpoint of limited life especially with deep discharges. A lead acid battery can only take 200 – 300 cycles when deeply discharged. This can be further compromised at higher discharging rates, resulting in hysteresis losses.

Depth of Discharge	Starter Battery	Deep-cycle Battery
100%	12-15 cycles	150-200 cycles
50%	100-120 cycles	400-500 cycles
30%	130-150 cycles	1,000 and more cycles

For usage in utility applications, the lead acid batteries are usually set to discharge to only 40% or so of full capacity to retain their capacity for a longer period of time. The battery is also not conducive to fast charging and takes 12 – 16 hours to fully recharge. They must always be stored at full charge. These requirements are usually managed through the storage control system.

Lead acid batteries should be charged in three stages, constant current charge, constant voltage charge, and a float charge used to keep the battery topped up. The constant-current applies the bulk of the charge and takes up roughly half of the required charge time; the constant voltage charge continues at a lower charge current and provides saturation, and the float charge compensates charge compensates for the loss caused by self-discharge. Approximately 70% of the charge is acquired in the first few hours. From a modeling standpoint, we will assume that a lead acid battery is only discharged to a maximum of 60% of its capacity to preserve its long term effectiveness.

Lithium Based Batteries

Lithium ion batteries are quickly becoming a very cost-effective storage solution, especially at the customer level. Lithium ion batteries cannot be overcharged without causing undue stress and the charging has to be well-managed. The Li-ion charger is a voltage-limiting device similar to the lead acid system, but there is not a need for a float charge to keep the unit at full-charge. The Most cells charge to 4.20V/cell with a tolerance of +/–50mV/cell. Higher voltages can increase the capacity, but the resulting cell oxidation will reduce service life.

Lithium ion batteries charge in approximately 3 hours. Charge efficiency is 97 to 99 percent and the cell remains cool during charge. Full-charge occurs when the battery reaches the voltage threshold and the current drops to 3 percent of the rated current. A battery is also considered fully charged if the current levels off and cannot decrease further. Increasing the charge current does not hasten the full-charge state by much. Although the battery reaches the voltage peak quicker with a fast charge, the saturation charge will take longer accordingly. The amount of charge current applied simply alters the time required for each stage; Stage 1 will be shorter but the saturation Stage 2 will take longer. A high current charge will, however, quickly fill the battery to approximately 70 percent.

NICKEL BASED BATTERIES

Nickel Cadmium batteries have historically been used for applications requiring high robustness, but nickel metal hydride (NiMH) batteries have become more popular due to their higher energy densities and lower toxicity. They are safer than Li-Ion and their cost is about half of Li-Ion though recent advances is bridging the gap. The disadvantage of NiMH is that it self-discharges approximately 20% of its charge in the first 24 hours and then approximately 10% a month after that. The cells reach optimal performance after priming that involves several charge/discharge cycles, usually as part of normal use. A battery may require 50–100 charge/discharge cycles to reach the best formation. Quality cells are known to perform to full specifications after only 5–7 cycles. Peak capacity occurs between 100–300 cycles, after which the performance starts to drop gradually.

Full-charge detection of sealed nickel-based batteries is more complex than that of lead acid and lithium-ion. Manufacturers detect full-charge using one of three methods – a fixed cell temperature usually 50 C, rate of temperature increase over time (dT/dt) or using the voltage signature. The temperature of the cell rises rapidly when fully charged, and the usual threshold in the “delta temperature” method is 1 C/min. The Negative Delta V (NDV) method looks for the sudden drop in cell voltage characteristic of a fully-charged battery.

NDV works best with fast charging. A fast charge also improves charge efficiency. At a 1C charge rate, the charge efficiency of a standard NiCd is 91 percent, and the charge time is approximately an hour (66 minutes at an assumed charge efficiency of 91 percent). A battery that is partially charged or has reduced capacity due to age will have a shorter charge time because there is less to fill. In comparison, the efficiency on a slow charger drops to 71 percent. At a charge rate of 0.1C, the charge time is approximately 14 hours. During the first 70 percent of charge, the efficiency of a NiCd is close to 100 percent; the battery absorbs almost all energy and the pack remains cool.

FLOW BATTERIES

A flow battery is more similar to a fuel cell in that it has a membrane separating two electrolytes and ion exchange through the membrane produces storage. Each electrolyte is stored in its own tank making these units bulky. While it has technical advantages such as potentially separable liquid tanks and near unlimited longevity over most conventional rechargeables, current implementations are comparatively less powerful. Cell voltage is chemically determined by the Nernst equation and ranges, in practical applications, from 1.0 to 2.2 Volts.

A typical flow battery uses two solutions; one is a Vanadium oxide VO2+ with water and the other is a V2+/V3+ ions. During charging, the vanadium oxide breaks down the water to release hydrogen ions and electrons on one side, while the Vanadium V3+ acquires an electron to reduce to V2+ in the other solution. Because the two solutions are separate, flow batteries offer full flexibility in charge rates and the amount of energy storage. In addition, they can prolong their performance for well over 10,000 cycles more in line with thermal storage systems. They can also be deep cycled without loss of life or efficiency as with other batteries. Their disadvantage is that their energy and power densities are approximately one-fourth of Li-Ion technologies and overall energy efficiency is only 66 – 75%.

FLYWHEELS

Flywheels are purely mechanical devices that do not suffer from the degradations that batteries go through. Flywheels can either be high mass, low rpm or low mass, high

rpm. Usually, they are designed for fast response applications such as frequency regulation and voltage control. However, there are a few products that are designed for storing and discharging over 2 – 3 hours. These products operate at between 6,000 and 10,000 rpm and can be charged and discharged at varying rates. The advantage of flywheels is that they have very high energy efficiencies and do not degrade in performance over many deep discharge cycles.

From a modeling standpoint, flywheels will be modeling as charging and discharging at a constant rate as specified by the manufacturer. Only flywheels that can operate over at least 2 hours will be considered in the study. A detailed Technology Summary can be found in Appendix A.

MODEL OVERVIEW AND RESULTS

ENERGYPLUS MODELING OF BUILDING INTEGRATED TES

Sound deployment of energy storage systems located on the customer side of the meter requires assessing the value of these systems for utility purposes such as offsetting marginal generation, relieving distribution networks and for customer benefits such as resiliency and first cost benefits.

Given that each storage technology differs in terms of storage capacity, discharge characteristics, cost, and applicability to a building type based on construction and occupancy, there is a need for an integrated approach that can conduct cost-benefit analysis and provide an integrated storage strategy for various types of commercial buildings.

In order to develop this approach, a DOE-developed building simulation code called EnergyPlus was used to simulate building energy use. The simulations generated 8,760 hourly load curves with and without thermal energy storage in place. The load curve can then be used to carry out cost-benefit analysis based on the cost of electricity, demand response programs and incentives, etc.

The approach can be used for virtually any type of building, climate conditions, and storage systems. In the framework of this project, two types of thermal energy storage solutions were simulated: ice tank and chilled water tank; both solutions allow the offsetting of a building's electricity demand during period of cooling. Two types of buildings were considered; commercial buildings and educational buildings and both have surfaces from 100,000 to 2,000,000 square feet. Several climate zones located in Southern California Edison's territory were simulated. Actual load data from commercial buildings was then used to assess the validity of the established model, and to calibrate the models when relevant.

ENERGYPLUS OVERVIEW

EnergyPlus - Overview

- EnergyPlus is DOE's 3rd generation dynamic building energy simulation engine
- Can be used for energy use, load calculations, modeling of natural ventilation, photovoltaic systems, thermal comfort, water use, green roofs
- Captures the complexity of measures and their interactions
- Now in C++

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FIGURE 2. ENERGYPLUS OVERVIEW

EnergyPlus - Architecture

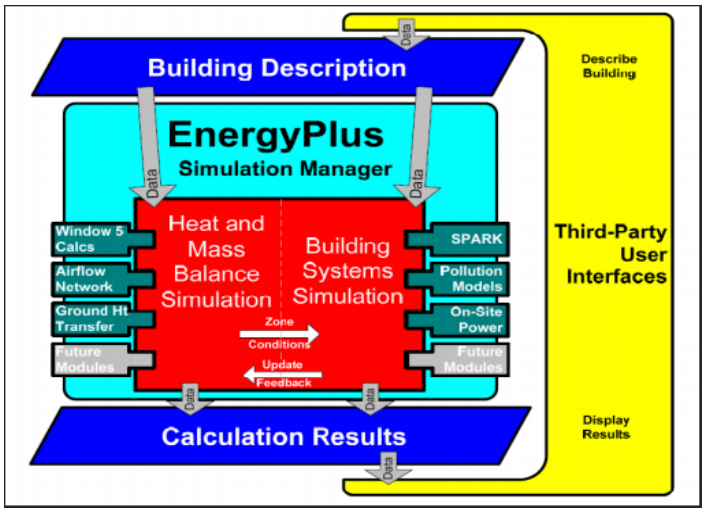

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FIGURE 3. ENERGYPLUS SOFTWARE ARCHITECTURE

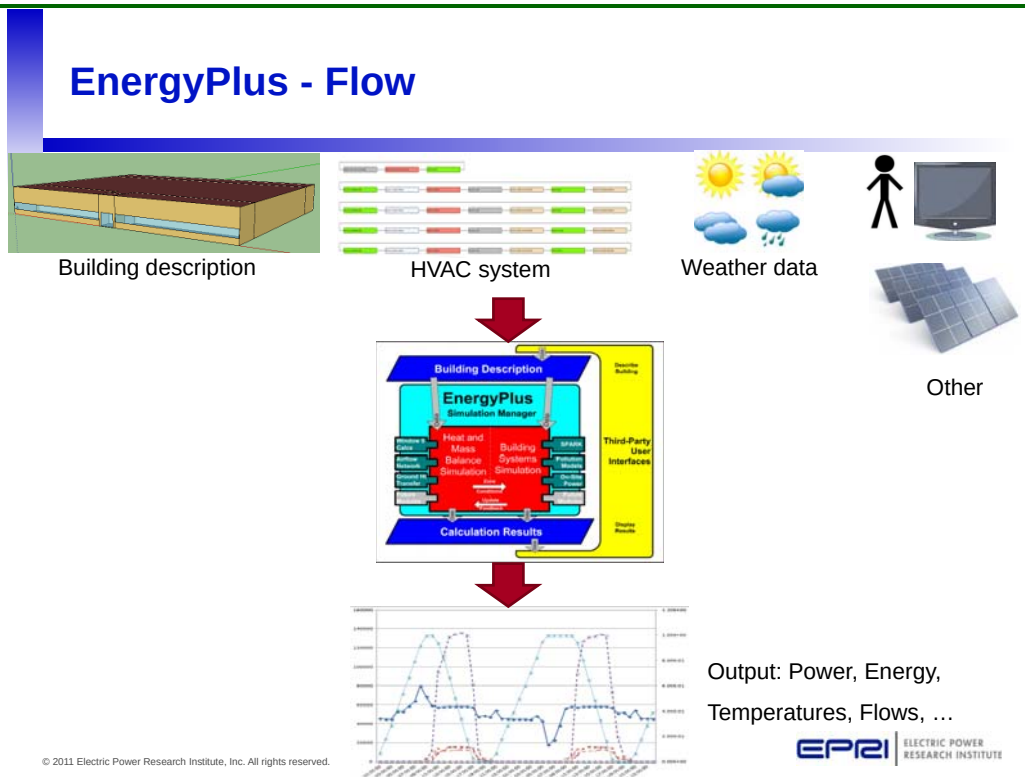

FIGURE 4. ENERGYPLUS TYPICAL WORK FLOW

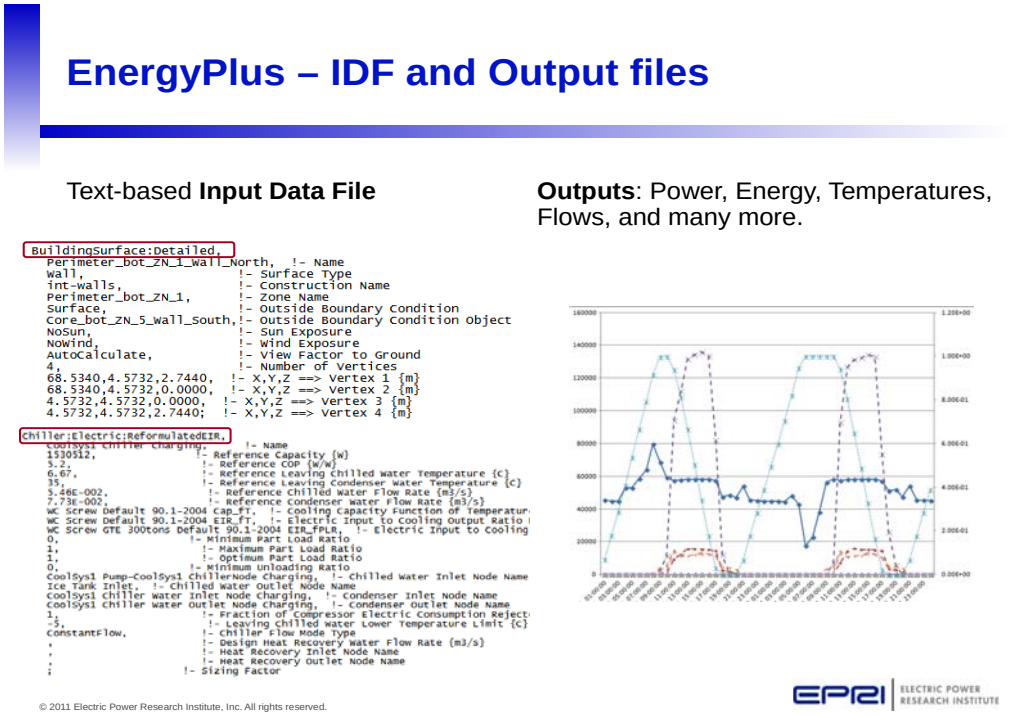

FIGURE 5. ENERGYPLUS - IDF AND OUTPUT FILES

EnergyPlus - Graphical User Interfaces

- BEopt
  - Developed by DOE
  - Easy to use but not flexible for refined modeling
- DesignBuilder SOFTWARE
  - Developed by a third-party
  - Great for architects and designers
- Many other programs, but digging in the IDF is necessary for advanced modeling

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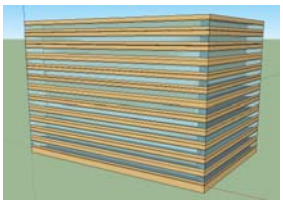
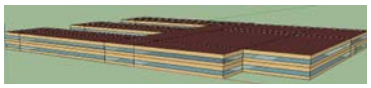
FIGURE 6. ENERGYPLUS – SELECT GRAPHICAL USER INTERFACES

EnergyPlus - Commercial Reference Buildings

- Use of DOE's Commercial Reference Buildings models
- Office building
  - 12-story, 500,000 ft^2
  - ASHRAE Standard 90.1-1989
  - Two water-cooled 1.5 MW chillers, VAV with reheat and plenum zone
  - Scaled up and down to generate sizes from 200,000 to 2,000,000 ft^2
- Educational building
  - 2-story, 210,000 ft^2
  - ASHRAE Standards 90.1-1989 and 62-1999
  - One air-cooled 1.2 MW chillers, MZ-VAV with reheat in most of the building
  - Scaled up and down to generate sizes from 200,000 to 2,000,000 ft^2



Reference Office Building used in the project



Reference Educational Building used in the project

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FIGURE 7. ENERGYPLUS - COMMERCIAL REFERENCE BUILDINGS

ICE TANK MODELING

The Commercial Reference Buildings models were modified to add an ice tank system. The EnergyPlus ice tank system model was available in the EnergyPlus library. The following slides describe:

- The principle of the ice tank model;
- Possible configuration for the integration of the ice tank in the HVAC system model;
- The ice tank control strategy in the model; and
- Some modeling challenges.

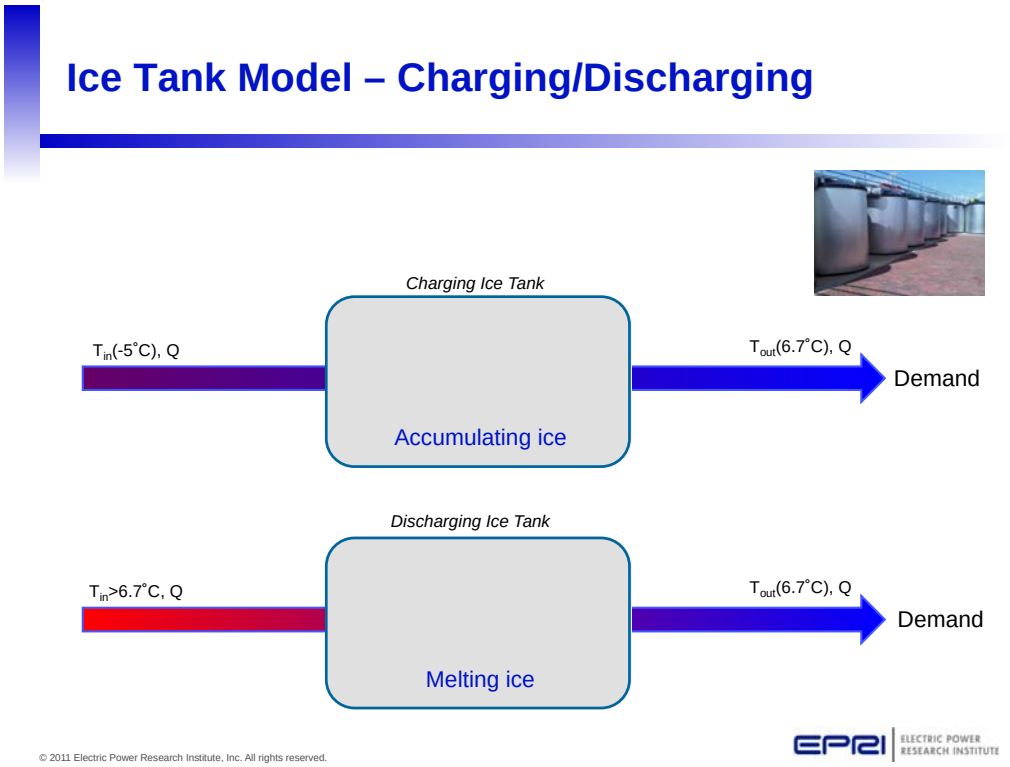

FIGURE 8. ENERGYPLUS ICE TANK MODEL - CHARGING/DISCHARGING DIAGRAM

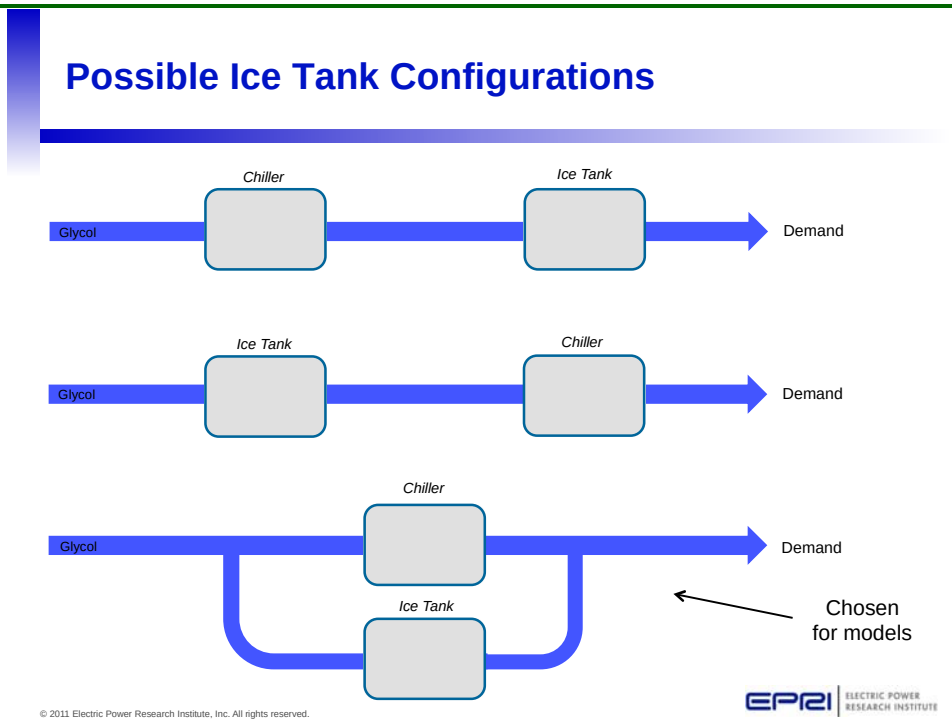

FIGURE 9. ENERGYPLUS - POSSIBLE ICE TANK CONFIGURATIONS

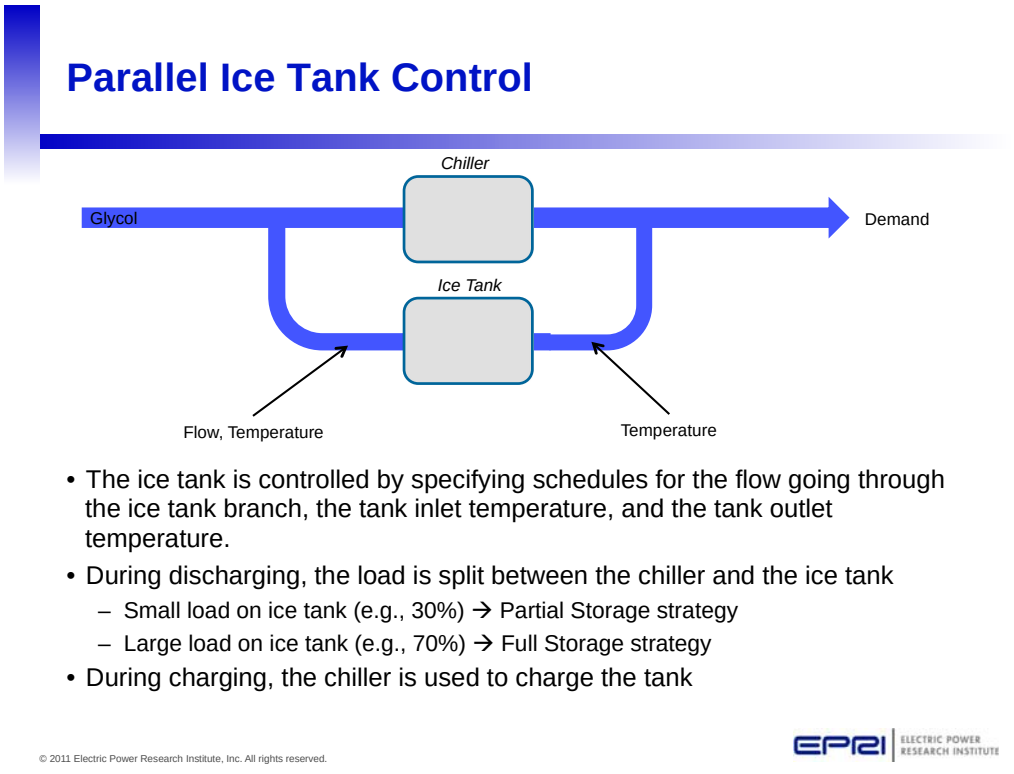

FIGURE 10. ENERGYPLUS - PARALLEL ICE TANK CONTROL

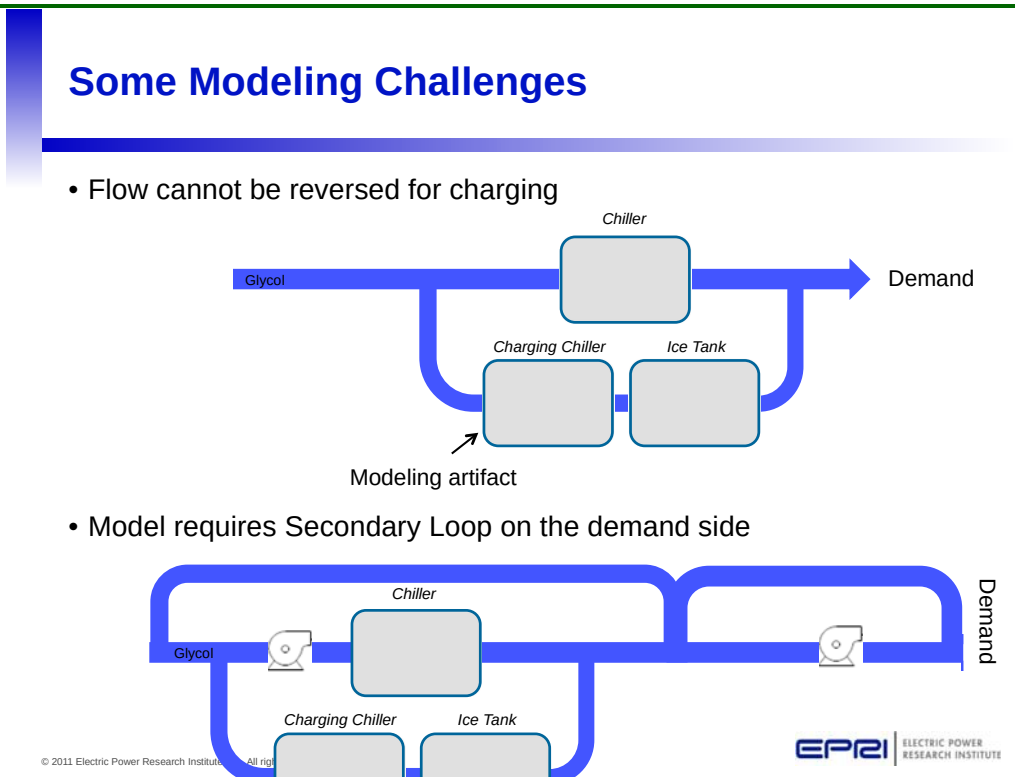

FIGURE 11. ENERGYPLUS - MODELING CHALLENGES

The following figures show examples of simulation results for an ice tank model implemented in an office and an educational building reference model. In these examples, both buildings are 500,000 sq.ft., located in California Climate Zone 8, and the ice tank is used during summer peak hours (12:00 pm to 5:00 pm). For both buildings, we show:

- The total consumption during a typical summer day with and without storage;
- The chiller consumption during a typical summer day with and without storage; and
- The ice tank storage fraction during a typical summer day with storage.

PLS Program Ice Tank Modeling

- Selection of results for
  - 500,000 ft^2 office and educational buildings
  - California Climate Zone 8
  - Using storage from 12 to 5
  - Ice Tank sized to:
    - Keep existing chillers
    - Shed partial or full cooling load on ice tanks
    - Completely discharge tank on peak day
    - Be able to always fully charge in one night

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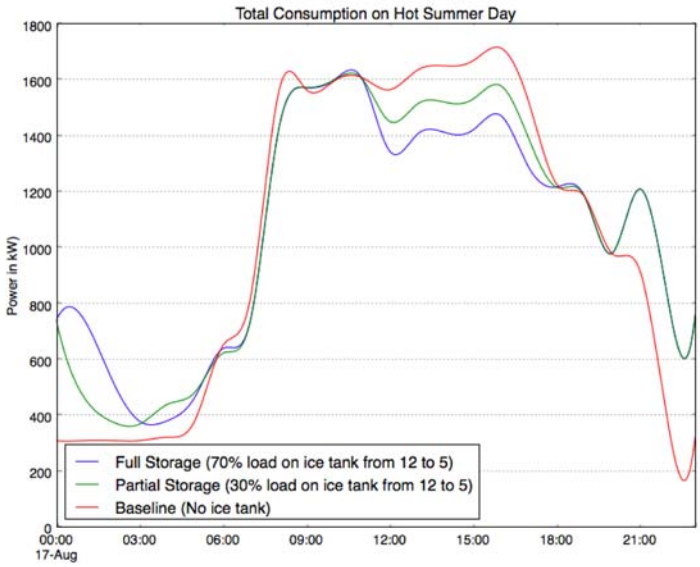
FIGURE 12. ENERGYPLUS - PLS PROGRAM ICE TANK MODELING

Ice Tank in 500,000 ft^2 Office Building



- Full Storage Tank Capacity: 4,600 ton.hours
- Partial Storage Tank Capacity: 2,300 ton.hours

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FIGURE 13. ENERGYPLUS - ICE TANK IN 500,000 SQUARE FOOT OFFICE BUILDING

TANK MODELING

The Commercial Reference Buildings models were modified to add a chilled water tank system. The EnergyPlus chilled water tank system was available in the EnergyPlus library. The following slides describe:

- The principle of the chilled water tank system full and partial storage strategies and integration in the HVAC system model; and
- Some modeling challenges.

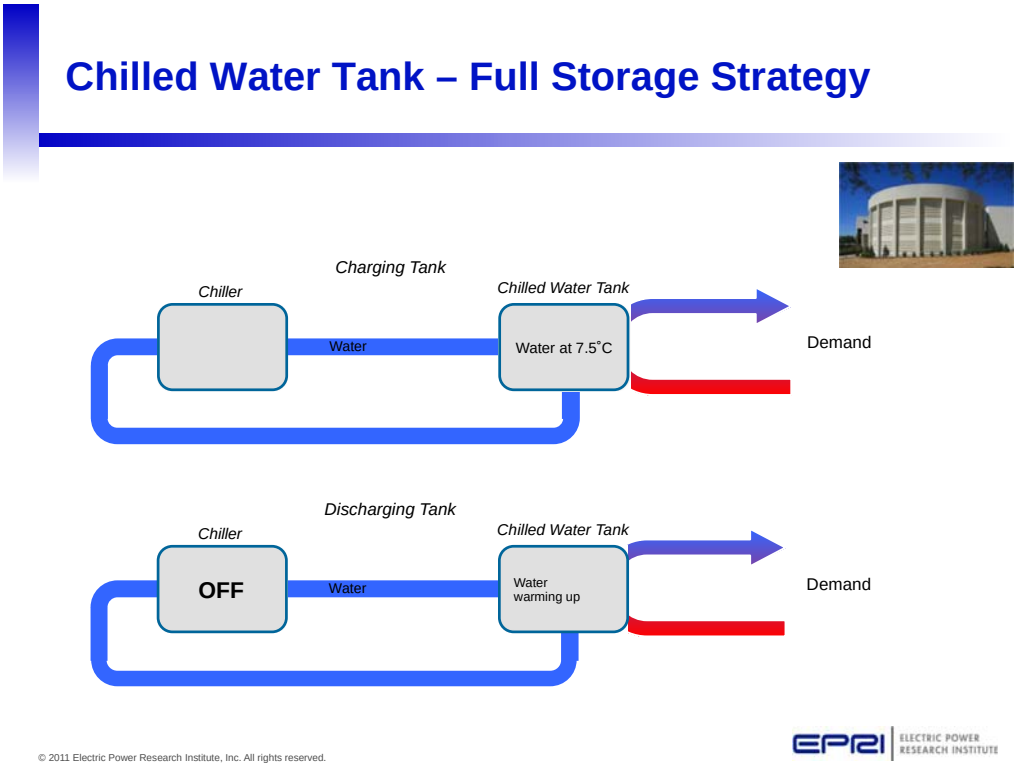

FIGURE 14. ENERGYPLUS - CHILLED WATER TANK FULL STORAGE STRATEGY

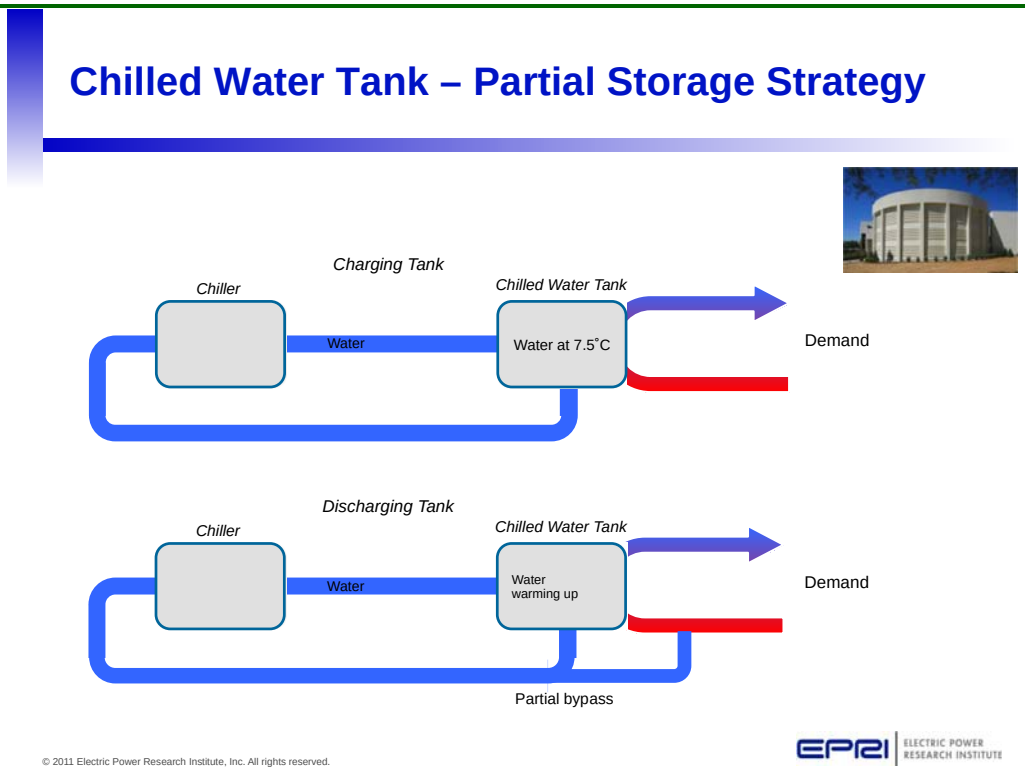

FIGURE 15. ENERGYPLUS - CHILLED WATER TANK PARTIAL STORAGE STRATEGY

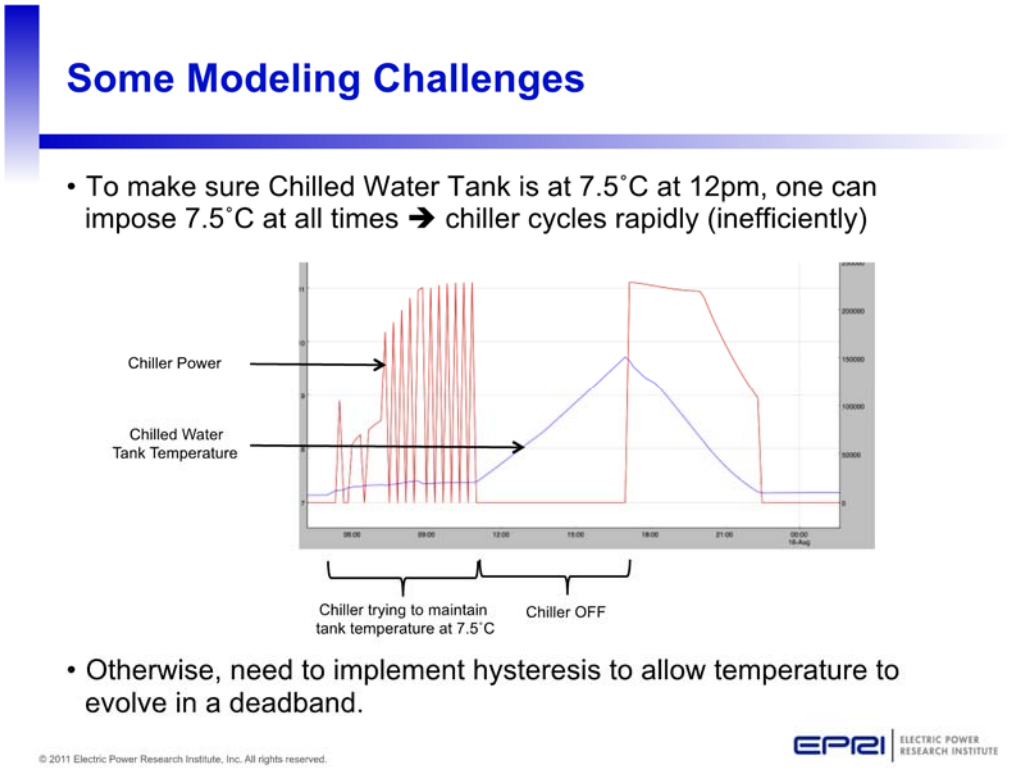

FIGURE 16. ENERGYPLUS - CHILLED WATER TANK SOME MODELING CHALLENGES

The following figures show examples of simulation results for a chilled water tank model implemented in an office building reference model. In this example, the building is 750,000 sqft, located in California Climate Zone 8, and the chilled water tank is used during summer peak hours (12: 00 pm to 5:00 pm). We show below:

- The total consumption during a typical summer day with and without storage; and
- The chiller consumption during a typical summer day with and without storage.

COMPARISON WITH ACTUAL BUILDINGS AND MODEL CALIBRATION

Load data from a total of seven commercial buildings was made available to the project team. Their 15-minute average load is plotted in Figure 17. The sites' maximum, minimum, average, and baseload (total load when HVAC is off) power per square foot are given in Table 2. A typical week's normalized load curve per square foot is shown in Figure 18 for the seven buildings and the corresponding model. Table 2 summarizes the level of similarity between the actual sites and their models.

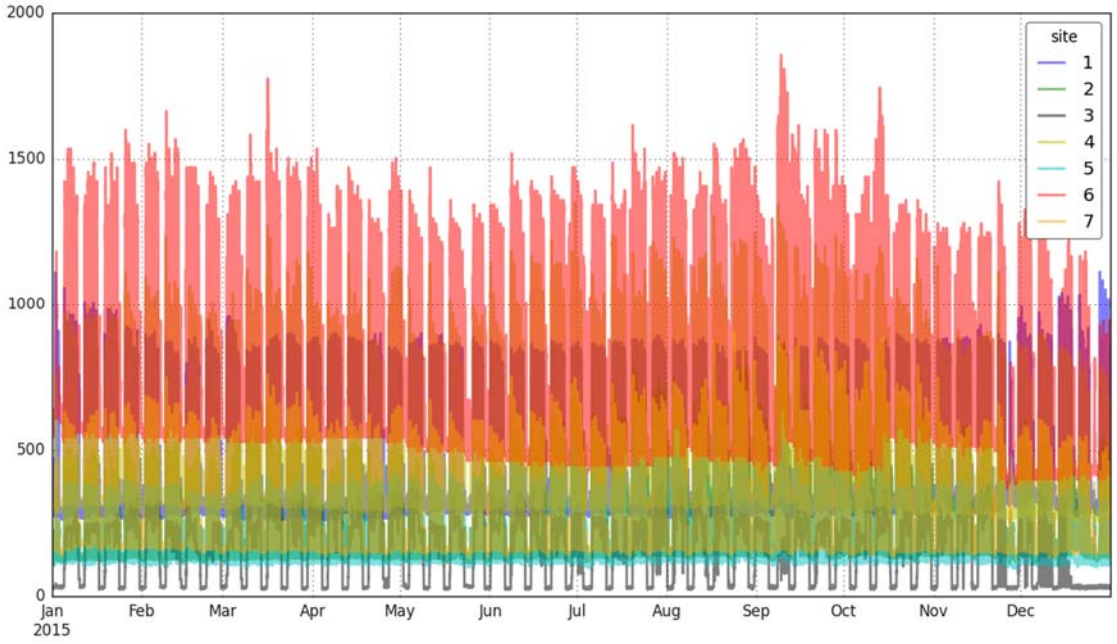

FIGURE 17: AVERAGE POWER (KW) IN SEVEN SITE USED FOR CALIBRATION OF TESS

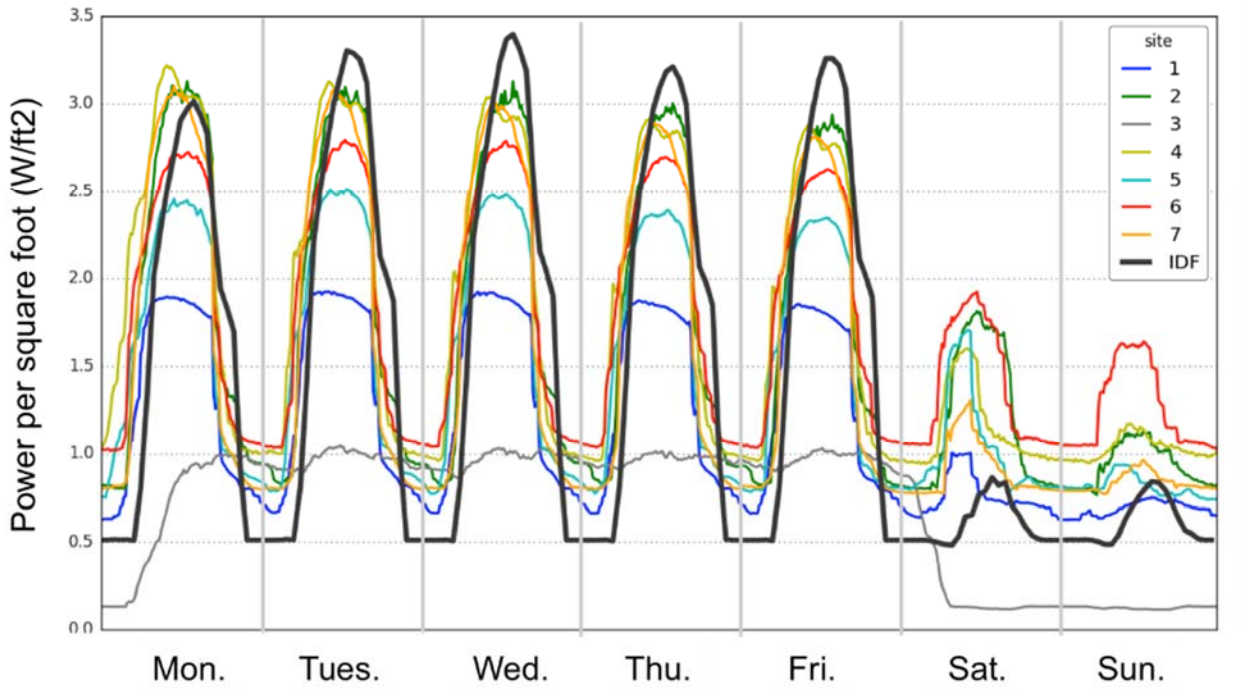

FIGURE 18: TYPICAL WEEK'S LOAD CURVES COMPARED TO TESS (IDF)

TABLE 1. ADDITIONAL CALIBRATION NOTES FOR COMPARATIVE SITES

SITE	LEVEL OF SIMILARITY	EXPLANATION
1	Low	Unusually high night load
2	Good	
3	Very low	Unusually high night load Very low load overall
4	Good	
5	Average	Unusually high off-peak load
6	Average	Unusually high off-peak load
7	Good	

From the data, it is clear that some buildings, especially Site 3, behave abnormally. Site 2 seems to be the building with the most standard load curve; it was used to conduct a proof-of-concept calibration effort. The plot of daily consumption per square feet vs. exterior temperature for Site 2 before calibration is shown in Figure 19. The difference in monthly energy use between the actual Site 2 and the model, before calibration, is approximately 20%.

The calibration consisted in modifying:

- The exterior temperature used by the model by using actual temperatures experienced by the building during data collection.
- The occupancy schedules used by the model. More realistic occupancy schedules were generated by analyzing the load data.
- The same plot after calibration is shown in Figure 20. Comparison of simulation vs. data is also shown in Figure 21.

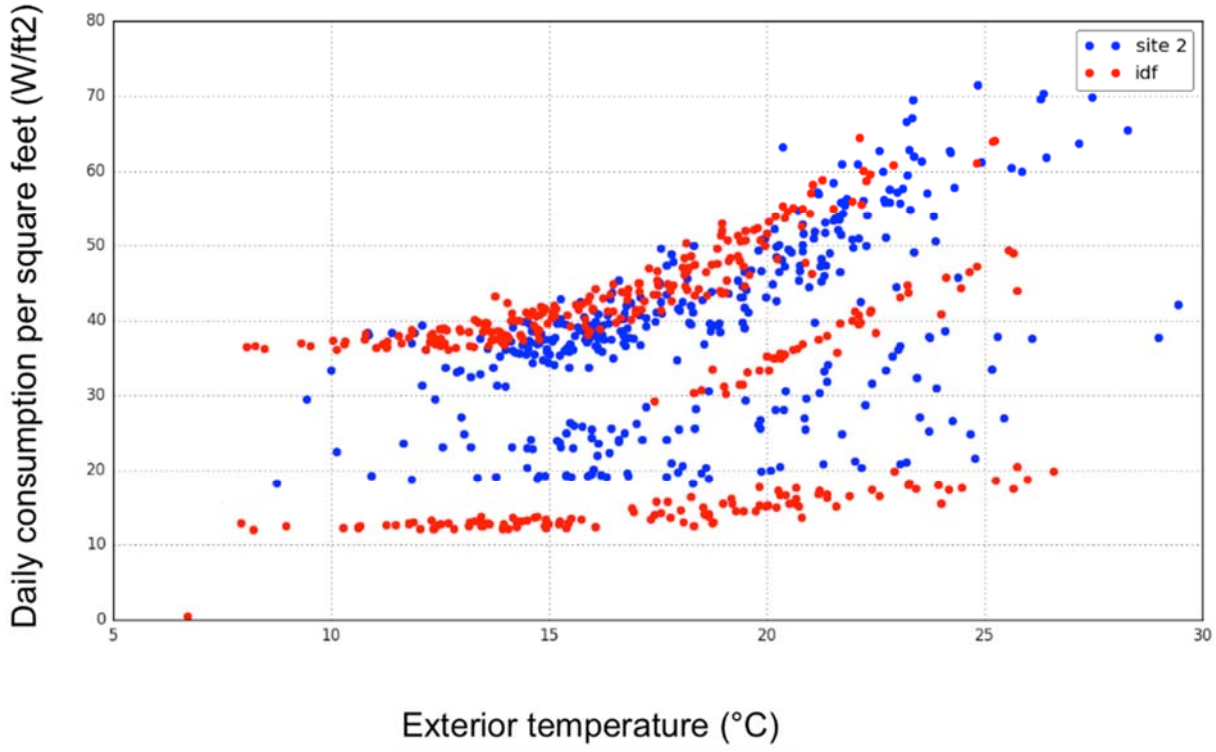

FIGURE 19: DAILY CONSUMPTION & EXTERIOR TEMPERATURE (SITE 2) VS. MODELED

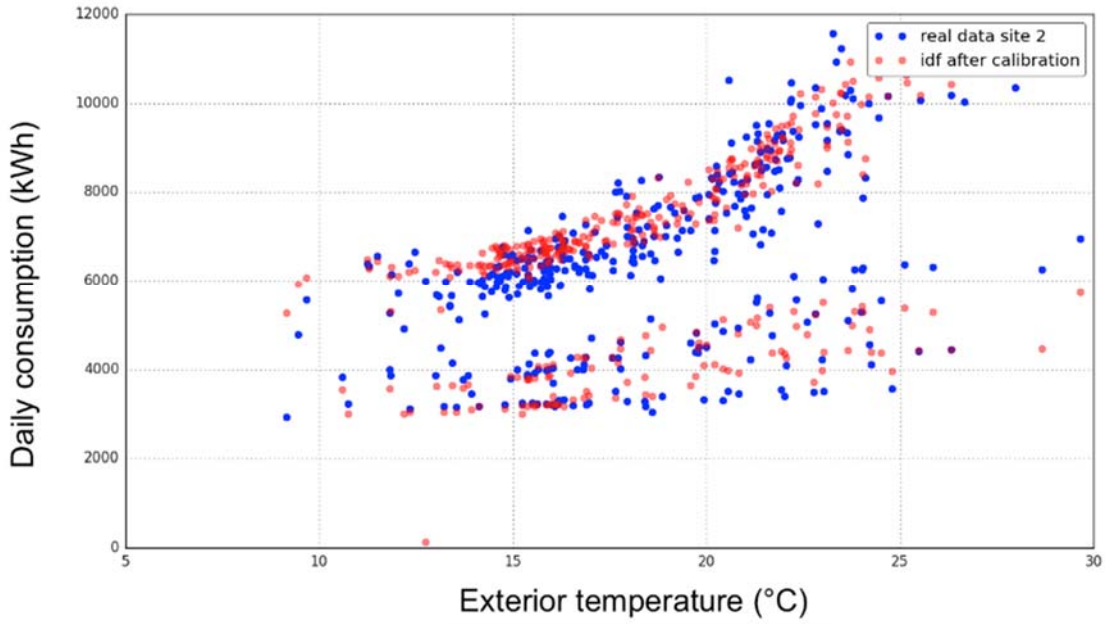

FIGURE 20: DAILY CONSUMPTION & EXTERIOR TEMPERATURE (SITE 2) VS. MODELED

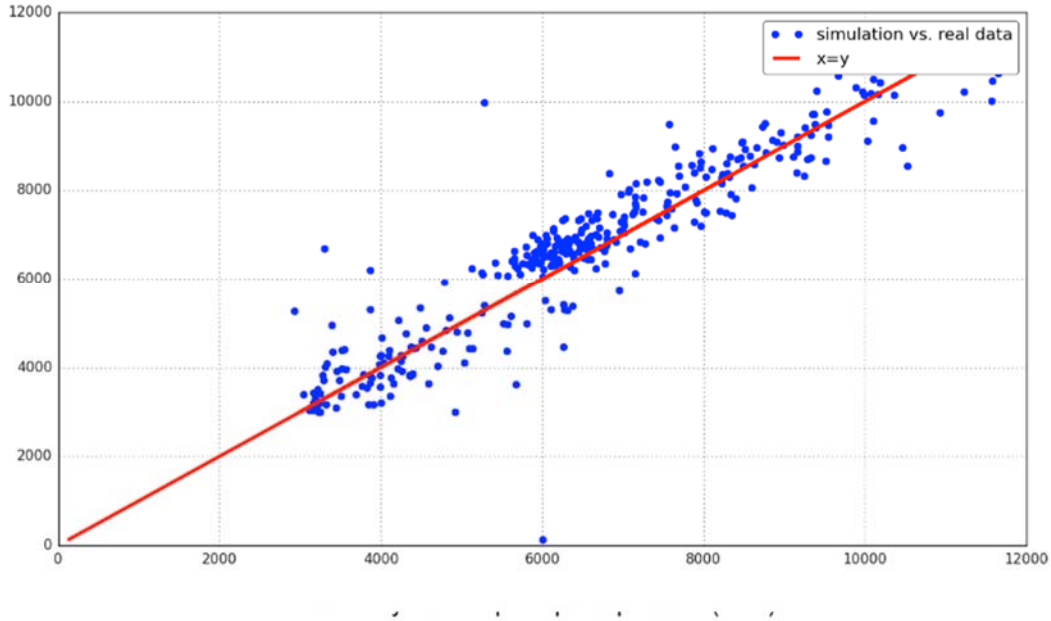

FIGURE 21: DAILY CONSUMPTION & EXTERIOR TEMPERATURE (SITE 2) VS. MODELED

THERMAL ENERGY STORAGE SCREENER (TESS) TOOL

As part of this project, a PLS predictive tool was developed called the Thermal Energy Storage Screener (TESS) tool. The TESS tool was created to support the existing statewide PLS Program by helping to quickly evaluate thermal energy storage (TES) systems at no cost. Evaluating feasibility of TES systems can be costly to building owners, as large scale audits are typically required to determine if TES makes fiscal sense. At times, a building owner can be asked to spend money on an audit without any guarentee that TES will make sense at their site, or without any guarentte of receiving a financial incentive from the PLS program. This programmatic scenario has made incenting customers to install TES systems a difficult proposition. The TESS tool was created to help mitigate some of this issue by using a large presimulated calibrated dataset as the foundation for and quick and easy to use feasibilty tool. The tool is unique in its structure with an ability to scale models to match building characteristics with multiple levels of scaling; first for building size and then for annual energy use and finally for monthly peak demand. The tool is completely open-source and was calibrated using real data provided by SCE's PLS Program. The overall objective of this work is to increase participation in the statewide PLS Program by providing customers and program implementers with easy to use resources.

The EnergyPlus simulation tool and models described in the previous chapter were used to generate a library of models and load curves, described as follows:

- Office and educational buildings from 200,000 to 2,000,000 ft^2
- Six CA climate zones in the Los Angeles area
- Ice Tank for buildings up to 500,000 ft^2 and Chilled Water Tank for buildings up to 2,000,000 ft^2
- Three storage strategies (baseline, partial storage, and full storage)

The tool is available online to SCE and its subcontractors through the Analytica Cloud Player at https://www.analyticacloud.com/acp/ClientAs3/AcpFlex.aspx?inviteId=123&inviteCode=942263&subName=Lumina

TOOL SCREENSHOTS

This section is a compilation of tool screenshots illustrating the input screen, operation and available outputs from the tool. Analytica is a modular and flexible software program that can be easily adapted to provide additional outputs without custom coding. Future efforts can extend the tool to provide other functions such as predicting DR availability using AMI data and DR program targeting using AMI data.

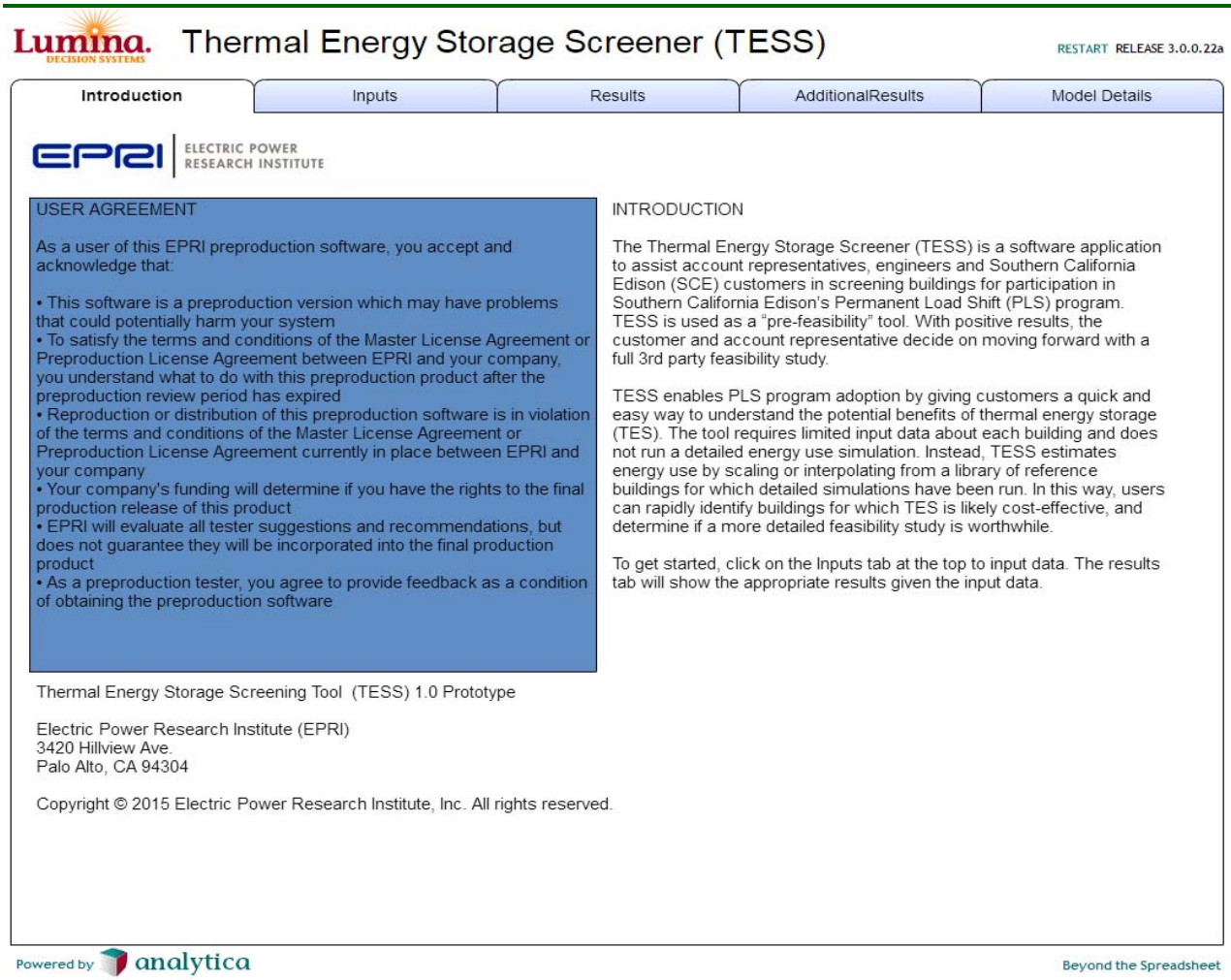

FIGURE 22. INTRODUCTION TAB OF THE THERMAL ENERGY STORAGE SCREENER (TESS) TOOL

INPUTS

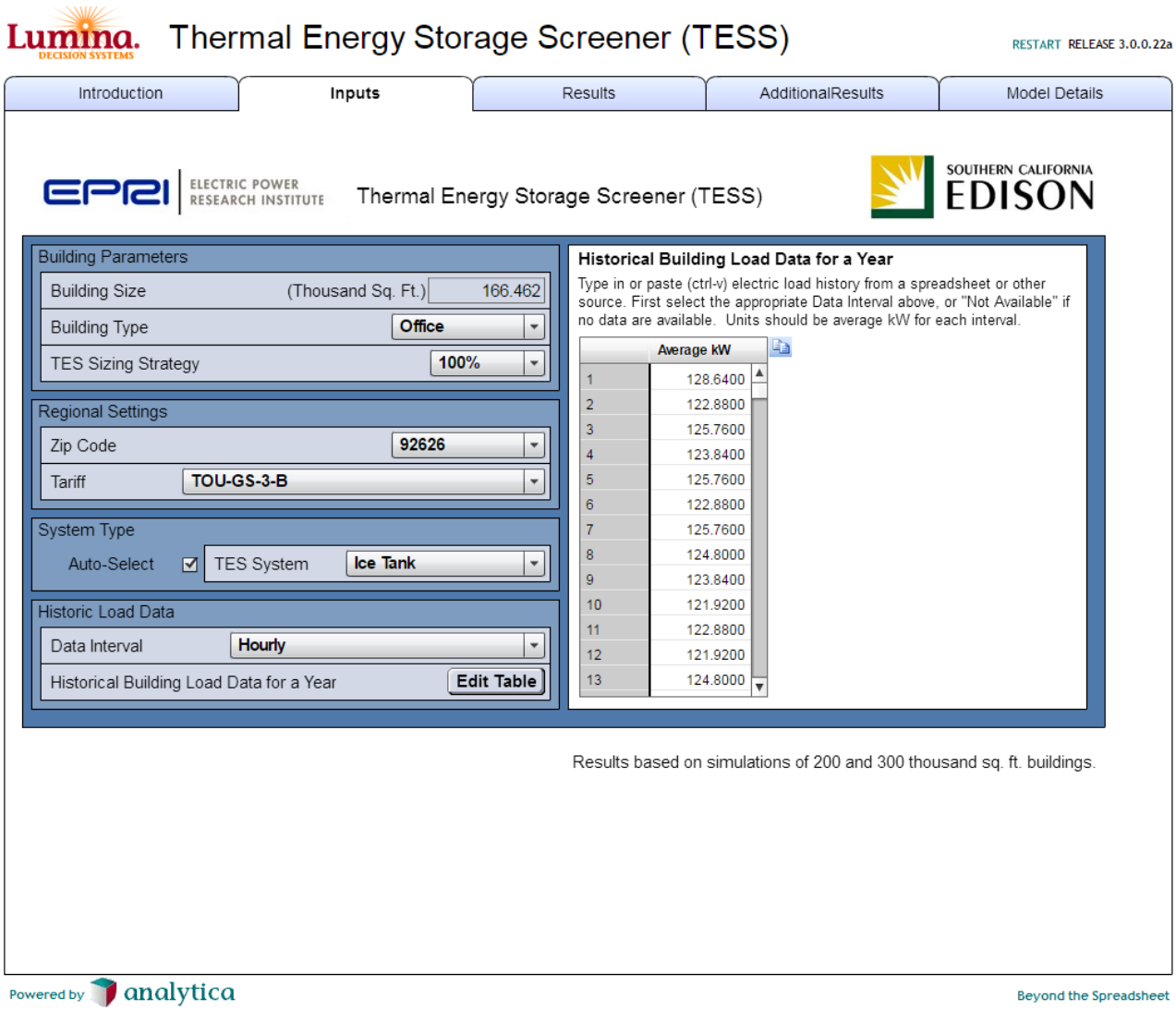

FIGURE 23. SCALING OF MODEL IN TESS BASED ON HISTORICAL BILLING DATA

RESULTS

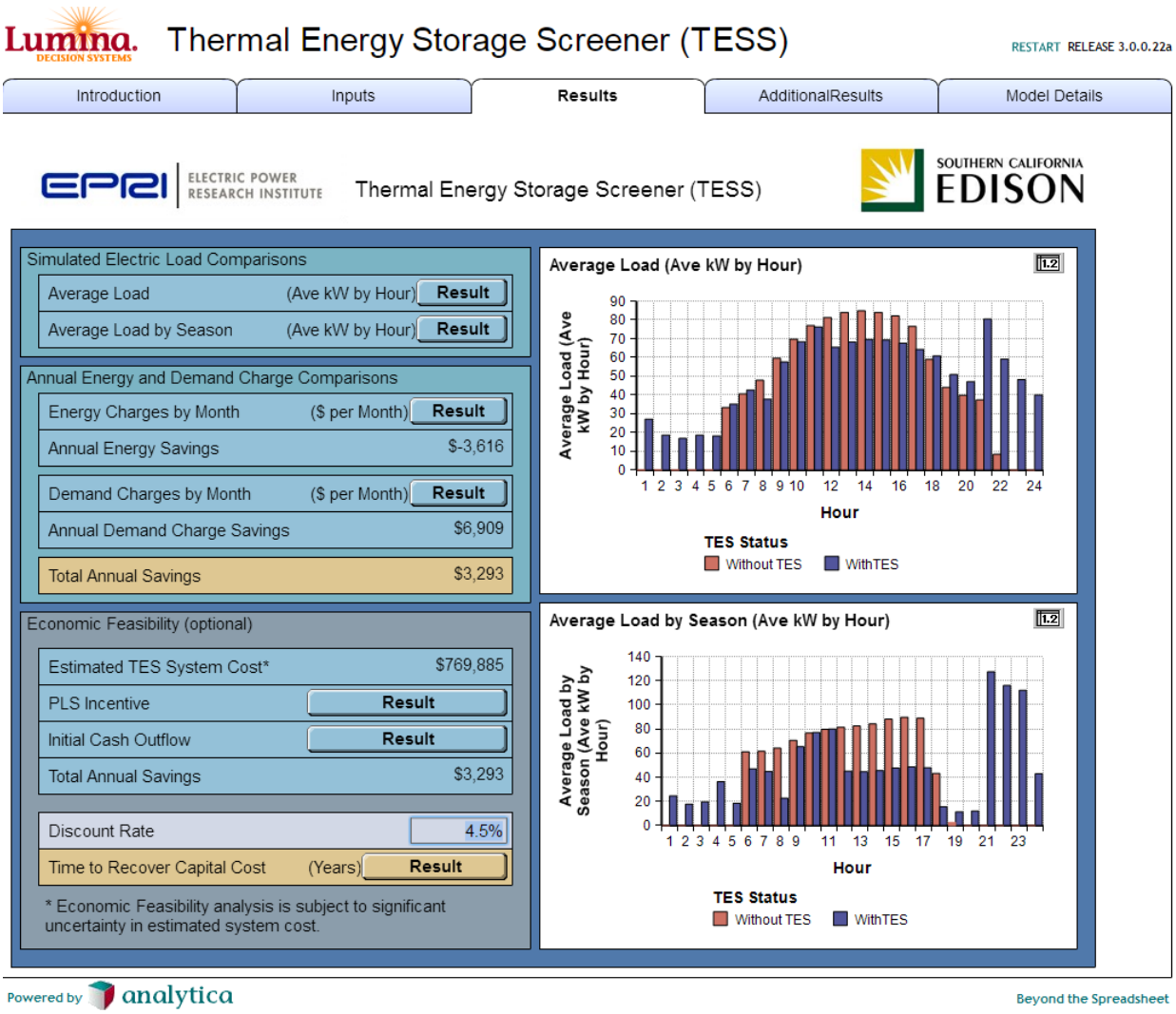

FIGURE 24. TESS RESULTS PAGE SHOWING COMPARISON W/ TES

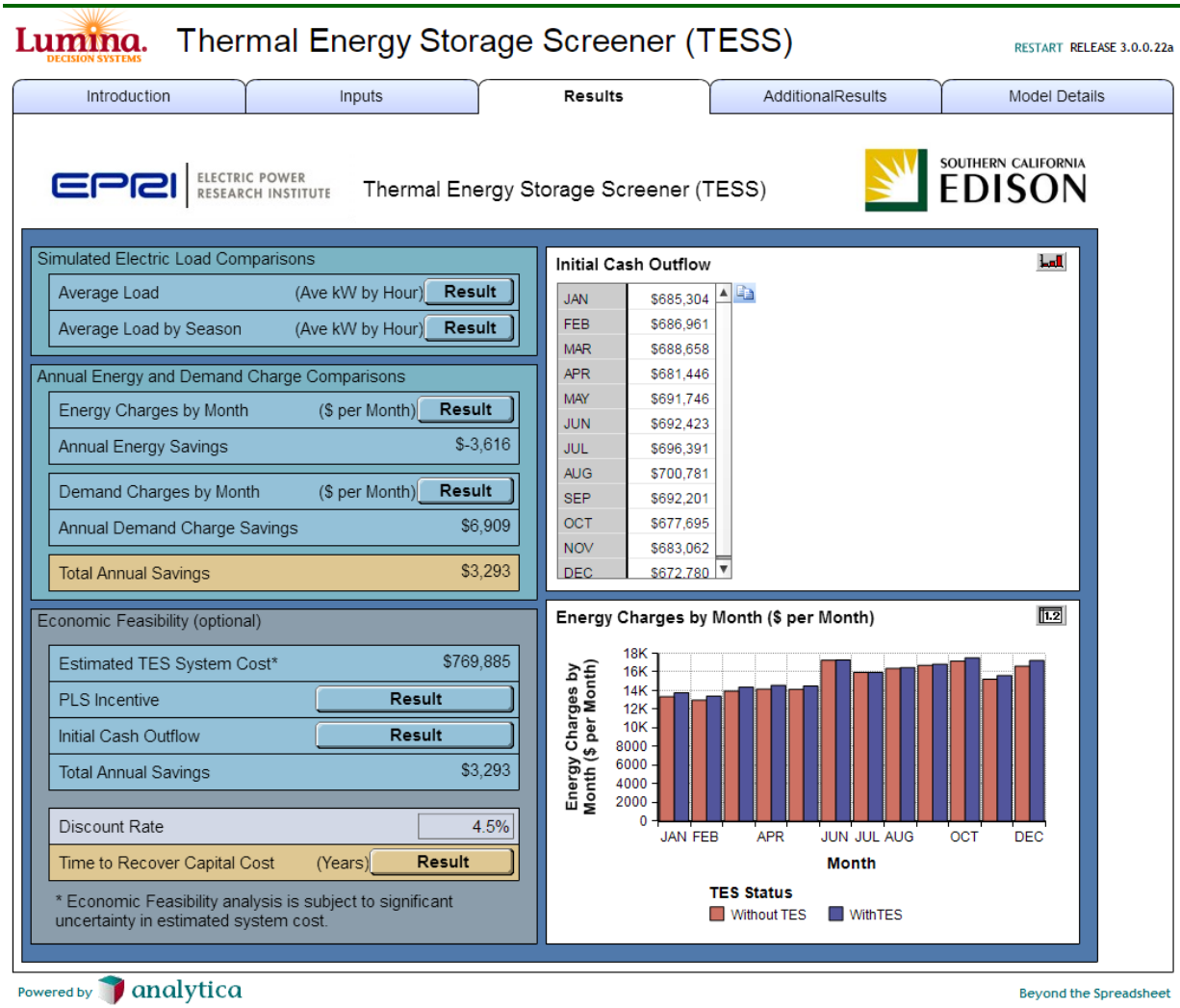

FIGURE 25. SUMMARY OF ASSOCIATED CHARGES WITH TESS

TESS EXAMPLE RESULTS

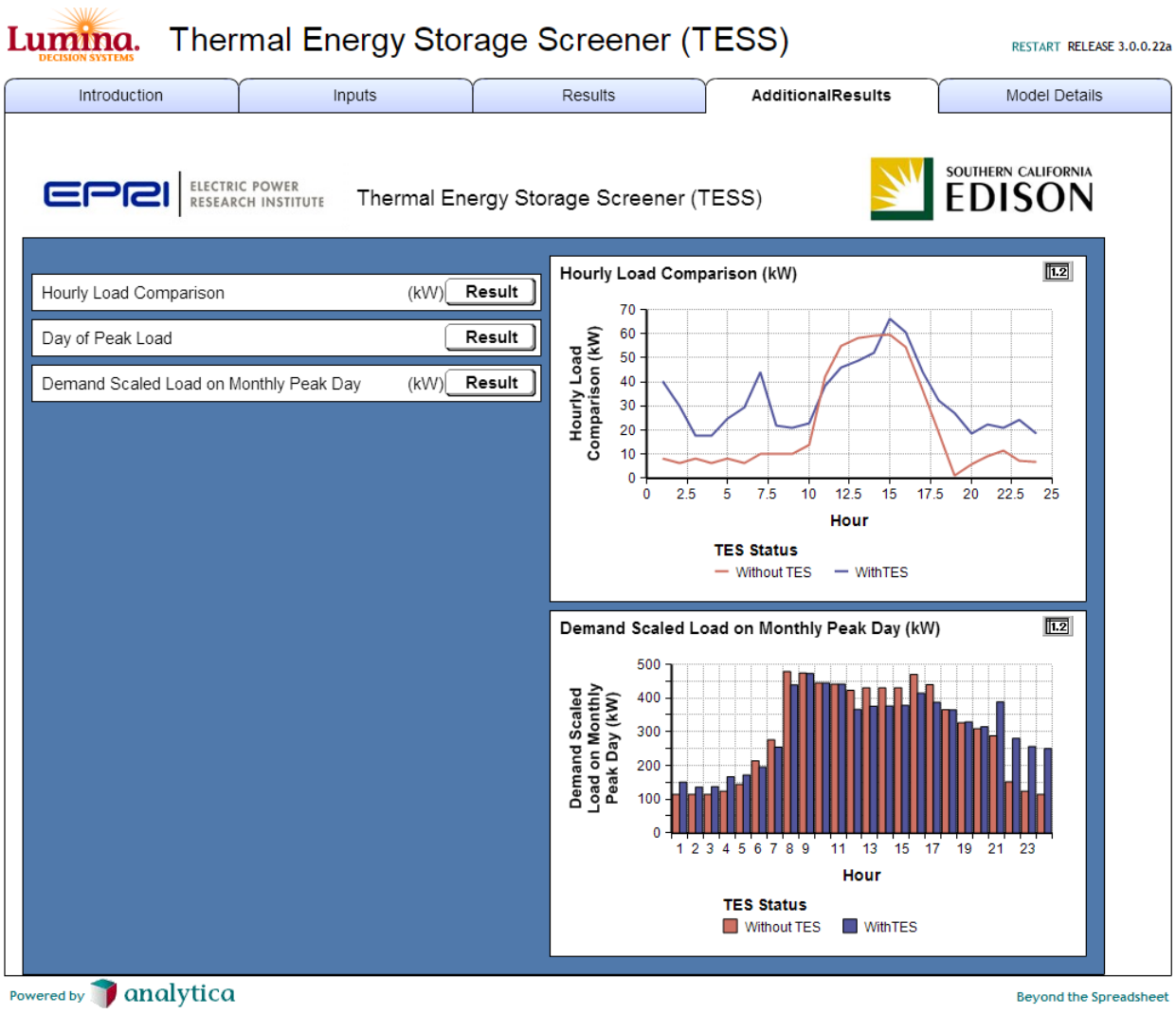

FIGURE 26. HOURLY AND MONTHLY LOAD PROFILES FOR CALCULATED CASE

MODEL DETAILS

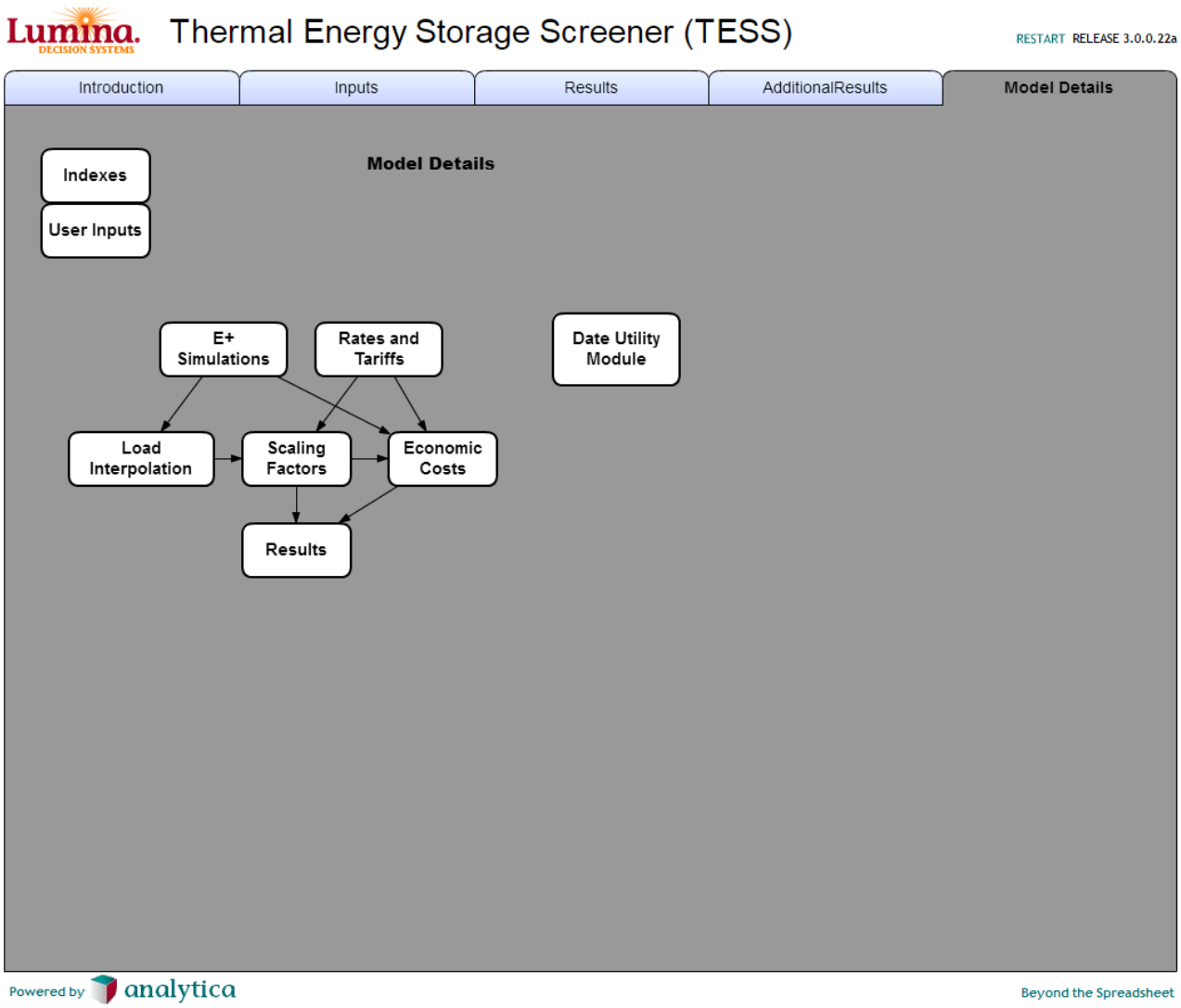

FIGURE 27. ANALYTICA BACK-END SCHEMATIC ARCHITECTURE FOR TESS

CONCLUSIONS

The project conducted an extensive investigation into Permanent Load Shift (PLS) programs and technologies, as well as developing an online software tool that can utilize AMI data to provide an initial analysis of feasibility of PLS application. The technology review became an evolving document through the project due to advancements in energy storage technology through the course of the project. The review included both a technical review as well as interviews with a limited set of product providers on their strategy and technology. The interviews are also illustrated in the report.

A PLS predictive tool was developed called the Thermal Energy Storage Screener (TESS) tool. The TESS tool was created to support the existing statewide PLS Program by helping to quickly evaluate thermal energy storage (TES) systems at no cost. Evaluating feasibility of TES systems can be costly to building owners, as large scale audits are typically required to determine if TES makes fiscal sense. At times, a building owner can be asked to spend money on an audit without any guarentee that TES will make sense at their site, or without any guarentte of receiving a financial incentive from the PLS program. This programmatic scenario has made incenting customers to install TES systems a difficult proposition. The TESS tool was created to help mitigate some of this issue by using a large presimulated calibrated dataset as the foundation for and quick and easy to use feasibilty tool. The tool is unique in its structure with an ability to scale models to match building characteristics with multiple levels of scaling; first for building size and then for annual energy use and finally for monthly peak demand. The tool is completely open-source and was calibrated using real data provided by SCE's PLS Program. The overall objective of this work is to increase participation in the statewide PLS Program by providing customers and program implementers with easy to use resources.

The development of the TESS tool was planned as a multi-step process. The difficulty in assessing potential for PLS application (or for DR) is that while there is AMI data available at the whole building level, there is not sufficient knowledge of energy use of HVAC system and other loads. Building energy models can provide breakdown of energy-use by load, but modeling every single building is not a feasible approach. EnergyPlus, the most common and most detailed modeling tool was utilized, due to its open availability and its capability to model thermal energy storage. To bridge the gap between models and real operations, the project adopted a unique approach where a database of EnergyPlus models and their output was developed to cover a spectrum of building sizes and types. The models were developed and run for both the TES and non-TES cases. This meta-database could then be extrapolated and interpolated for a variety of sizes and even multiple TES options.

To extend EnergyPlus models to real buildings and to provide a user-friendly interface, Analytica software was utilized to provide the Analysis engine. Given need for access from both SCE personnel and subcontractors, the software is set up as a cloud-based access, with limited set of use licenses. The software currently can analyze educational and office buildings, rangining from 50,000 sq.ft. to 2 million sq.ft., the size for PLS system seen as most probably by SCE. The user can select building size and the type of TES system and run it either as a building without data (only modeled performance) or use available building energy data (calibrated to actual building operations). The building data can be monthly, daily, hourly or 15 minute intervals, with or without peak load. The results can be obtained both for cost savings and energy-use in operations and can be visualized in many different variations, including tables and graphs.

One of the unintended benefits of tool development was that it showed a pathway to actually understand DR potential of buildings using measured AMI data. The same philosophy as used for PLS evaluation can be extended to estimate lighting, plug and process loads, which can provide a better understanding of the DR capabilities, and required technologies. The tool can also be extended to other types of buildings beyond the limited building set targeted towards the PLS program.

APPENDIX A – THERMAL STORAGE TECHNOLOGIES

BALTIMORE AIR COILS

Technology: The BAC ice storage system also operates by using the air conditioning chillers in these buildings to form ice during the off-peak hours and then cooling the building in conjunction with the chillers during the peak hours (daytime). There is no refrigerant circulation to the ice tanks, only glycol is circulated. The ice forms on the outside of the tube when the glycol is circulated at temperatures of 20F or lower. The evaporator temperature is lower, but so is the outdoor temperature during ice make, and the overal chiller COP is only marginally impacted. However, the chiller capacities might be reduced during ice making conditions. The difference with the Calmac system is that system is an external melt ice-on-coil system. In an external melt system, water is circulated on the outside of the tubes (no glycol circulation during discharge) and the water melts the ice from the outside in. External melt systems lose their efficiency as the percentage of charge decreases because of reduction in ice surface area. The product is offered in a container form with the heat exchanger comprised of hot-dipped steel tubes with tube sheets.

FIGURE 28. BAC ICE STORAGE SYSTEM

Performance Characteristics: Then tanks are provided with insulated panels with an R-value of 18. This reduces standby losses in the system. With an external melt system, the discharge rates can be much higher than an internal melt system, and can be a good fit for process loads. These systems can provide chiller water at temperatures as low as 34F, which can substantially reduce piping requirements in large industrial and district cooling applications.

Maturity and Market Status: BAC focsues on evaporative coolers and cooling towers characteristic of larger water cooled chillers and power plants. This product is offered mainly for the large commercial and industrial segments through their existing channels as part of providing a complete solution to the customer. BAC also provides these systems for large district cooling applications. The individual modules are rated in the 1100 T-hr range and can be combined to create larger ice storage banks.

Cost-Effectiveness: These systems are installed in most cases as part of a complete solution including chillers and pumps and piping. Installed cost of these systems range from $100 - $250/T-hr with a payback of less than 5 years in most cases.
Safety: Rated to UL standards as a heat exchanger.

Environmental Considerations: Address restrictions on use of propylene glycol in certain jurisdictions.

CALMAC ICEBANK

Technology: The Calmac system operates by using the air conditioning chillers in these buildings to form ice during the off-peak hours and then cooling the building in conjunction with the chillers during the peak hours (daytime). There is no refrigerant circulation to the ice tanks, only glycol is circulated. The ice forms on the outside of the tube when the glycol is circulated at temperatures of 25F or lower. During discharge, glycol is circulated inside the tubes and the ice melts, cooling the glycol. The evaporator temperature is lower, but so is the outdoor temperature during ice make, and the overal chiller COP is only marginally impacted. However, the chiller capacities might be reduced during ice making conditions.

The product is offered as a packaged tank high heat transfer surface area containing a spiral-wound, polyethylene-tube heat exchanger surrounded with water. ICEBANK tanks are available in a variety of sizes ranging from 45 to over 500 ton-hours.

There are other advantages to this system. Due to the lower glycol temperatures during the cooling period, the cooling coils can remove greater humidity and cool the air to a lower temperature. This allows the chillers to operate more efficiently. At the same time, the amount of air flow required for cooling is reduced resulting in benefits such as smaller ducts, which in turn increases the available building space for tenants. In operation, the product can operate in five modes:charging, charging with nighttime cooling, chiller cooling, ice storage, and cooling and chiller + ice storage cooling.

FIGURE 29. CALMAC ICEBANK SYSTEM

Performance Characteristics: The round trip energy efficiency of the system varies between 90 – 110% based on the location, chiller efficiency, and

configuration. The charging and discharging rates can be varied as a function of the chiller size. The nominal hours of charge is 10 hours, but they can be charged in as few as 6 hours with little capacity impact. The charging rate is nearly constant because of the design of the heat exchanger. The discharge can be controlled through glycol mixing valves to vary the proportion of cooling provided by the chiller and ice storage system. From a modeling perspective, the system can be modeled as providing full-flexibility in discharge in line with building and grid needs.

Ice Storage
Control Mode Definition

Mode	Chiller Pump	Chiller	Ice Valve	Blend Valve	Distribution Pump
Chiller Only	On	Enable CHWSP 42°F	55°F (0% Ice)	40°F (100% to load)	Modulate on remote ΔP
Ice Only	On	OFF	42°F	40°F (100% to load)	Modulate on remote ΔP
Chiller & Ice	On	Enable CHWSP 42°F RLA Limit 30-50%	42°F	40°F (100% to load)	Modulate on remote ΔP
Make Ice	On	Enable CHWSP 23°F	15°F (100% to ice)	80°F 0% to load)	Off
Make Ice & Cool	On	Enable CHWSP 23°F	15°F (100% to ice)	42°F	Modulate on remote ΔP
Off	Off	Off	-	-	Off

©Trane (Ingersoll Rand)

FIGURE 30. ICE STORAGE CONTROL MODE DEFINITION

Maturity and Market Status: The Calmac IceBank systems have been installed in more than 4000 buildings in the last 30 years in medium and large commercial buildings and in industrial applications around US and in 37 other countries. 80% of their installations go with air cooled chillers. Calmac is partnered with Trane, with Trane actively selling the product through their sales channels.

Cost-Effectiveness: These systems have been installed without incentives in many buildings through first cost reduction in chiller size, duct size and better dehumidification. Because of the capability of these systems to be modular and to be located in many possible locations on the building premises, the incremental installation cost of these systems is in the order of $100/kWh if installed as an added system. However, for most new construction and chiller rehabs, the system can be installed at almost no additional first cost through reducing chiller capacities. The cost and channel partner are key reasons why these systems constitute the bulk of installed systems under the current PLS program.

Safety: Rated to UL standards as a heat exchanger.

Environmental Considerations: Address restrictions on use of propylene glycol in certain jurisdictions.

ENERGY STORAGE WATER HEATER

Technology: A new generation of water heaters have evolved that are grid connected and provide energy storage at the residential and small commercial level. These units operate similar to solar thermal systems in that they have the capability to raise the temperature of the water to 180F, and then use mixing valves to temper the water temperature to customer settings. The water heaters are larger water heaters in the 80 – 120 gallon range (normal water heaters are in the 40 – 50 gal range). The storage can be generated using either heat pump water heaters or from electric elements. This technology is very flexible with the capability of fast response to variability in renewable generation.

Performance Characteristics: The units are normally equipped with either a 4.5 or 9 KW electric element. If it is set up as a heat pump, then the normal operating kW is around 1.5 kW, but the auxiliary element is 4.5 kW. However, most of water heating occurs in the early morning hours and there is not substantial overlap with summer peak demand times. As California moves towards the 33% RPS, CAISO is increasingly concerned about the requirements for flexibility as expressed in their "duck" curve. Heat pump water heaters can be very well suited to fil the mid-morning valleys while still mitigating the steep afternoon ramps. EPRI is currently conducting research with Midwestern and Hawaiian utilities to assist with balancing wind.

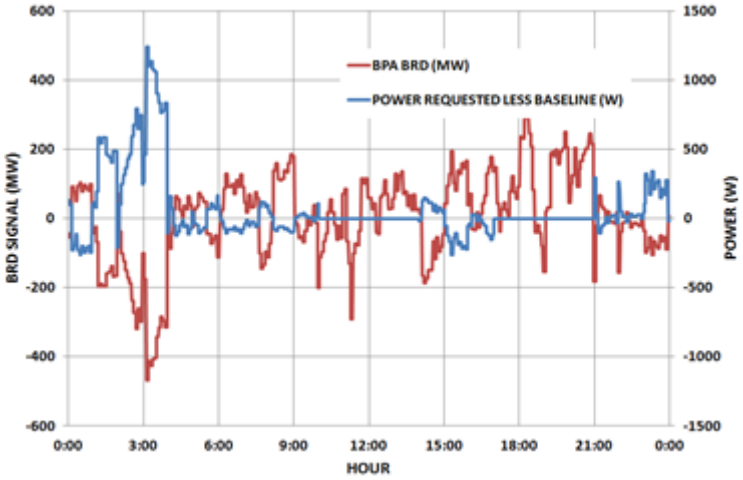

FIGURE 31. ENERGY STORAGE WATER HEATER

Maturity and Market Status: The product is commercially available through Steffes Corporation and Dimplex (used in Ireland). There are also other vendors such as Carina Corp. and Sequentric Corp. that produce retrofit controllers for the same purpose.

Cost-Effectiveness: As a retrofit controller, the cost is in the order of $300 per controller, which converts to approximately $60/KW and approximately $20/kWh. This is highly cost-effective for utilities that have a high penetration of electric water heaters in their territory.

Safety: Rated to UL standards as a water heater.

EVAPCO

Technology: Evapco's main product line is evaporative condensers and cooling towers. Their ice storage system grew out of their work with large commercial and industrial customers. The Evapco storage system also operates by using the air conditioning chillers to form ice during the off-peak hours and then cooling the building in conjunction with the chillers during the peak hours (daytime). There is no refrigerant circulation to the ice tanks; only glycol is circulated. The ice forms on the outside of the tube when the glycol is circulated at temperatures of 20F or lower. This system is also an external melt system where water is circulated on the outside of the tubes (no glycol circulation during discharge) and the water melts the ice from the outside in. It decreases because of reduction in ice surface area. The product is offered as a heat exchanger comprised of hot-dipped steel tubes with tube sheets. These heat exchangers are then inserted into site built concrete tanks.

FIGURE 32. EXTRA PAK ICE COILS

Performance Characteristics: The performance is very customizable and the systems are engineered to specifications. From a modeling perspective, the inputs can be varied as required to meet the load management objectives.

Maturity and Market Status: Evapco produces evaporative coolers and cooling towers for large industrial, district cooling and power plants. This product is offered through their existing channels as part of providing a complete solution to the customer. The individual modules are customized in size to the engineering design requirement.

Cost-Effectiveness: These systems are installed in most cases as part of a complete solution including chillers and pumps and piping. Installed cost of these systems range from $100 - $250/T-hr.

Safety: Rated to UL standards as a heat exchanger.

Environmental Considerations: Address restrictions on use of propylene glycol in certain jurisdictions.

ICE BEAR

Technology: The Ice Bear is a packaged thermal storage unit that uses underutilized air conditioning capacity at night to create cold storage in the form of ice that is discharged during the day to avoid air conditioner operation during the peak hours. The system is unique in that it works with refrigerant-based air conditioing systems that are common in residential and small commercial buildings. It connects to both split system and rooftop air conditioners found in these building types. These systems are designed to be connected through a network and can be controlled as a bulk resource.

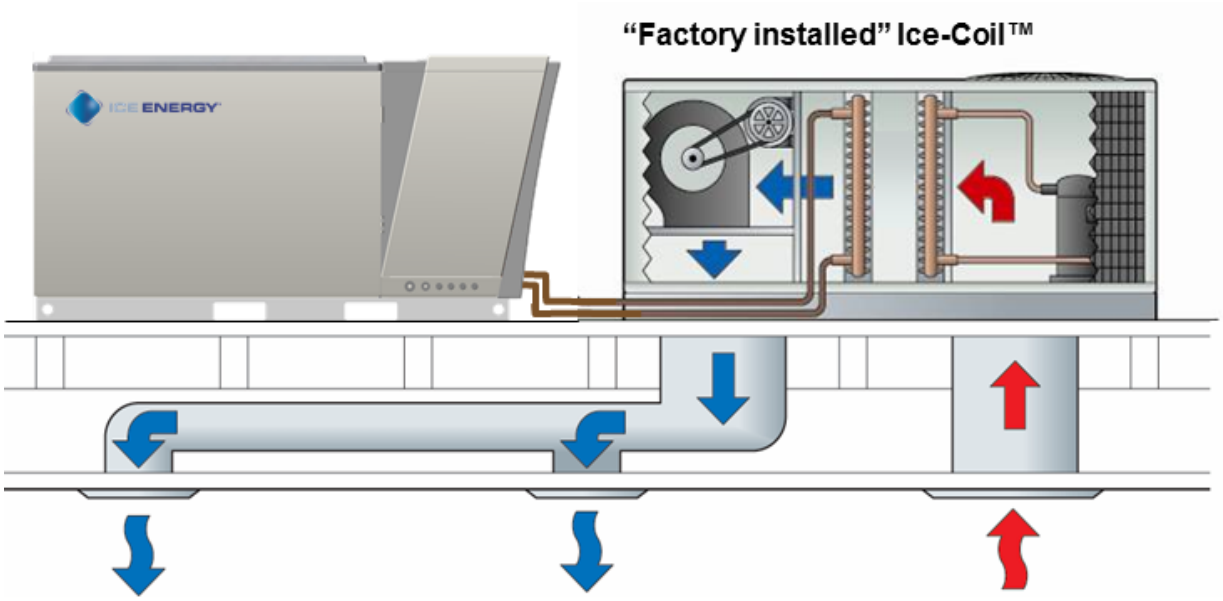

FIGURE 33. ICE BEAR

Performance Characteristics: The Ice Bear is available as a 30 T-hr. system with its own ice making apparatus. A 30 T-hr. system will eliminate approximately 30 kW-hr of peak load, with a greater displacement when the air conditioning units are older. The round trip efficiency is a function of the outdoor temperatures during the charging and discharging periods, but is close to 100% when the difference between daytime highs and nighttime lows is approximately 22F. The charging of the system takes between 8 and 12 hours depending on the nighttime outdoor temperatures. The discharge rate is a function of the cooling system being displaced and can vary between 3 and 7.5 tons of cooling (4 to 10 hours of operation). The rated discharge rate is 5 tons designed to run through a 6-hour peak period.

Maturity and Market Status: The product has been commercially available since 2006 and a few thousand units have been deployed. Many utility evaluations have been conducted and results have demonstrated the capacity and performance of the system. The product is also available through commercial HVAC channels such as Carrier and Trane.

Cost-Effectiveness: The storage unit is available at an approximate cost of $150/kWh. Including the cost of installation which can vary depending on the site and the cost of connectivity, the total installed cost is approximately $300/kWh.

Safety: The system has been rated to UL 1995 standard (similar to air conditioning equipment) and is qualified for application in residential, commercial and industrial buildings.

Environmental Considerations: The system uses water as its storage medium. The water is filled on-site and is not used during operation. The manufacturer recommends using fungicide tablets to avoid biological growth.

STORAGE CONDENSING UNIT (SCU)

Technology: The storage condensing unit is manufactured by IE technologies with a brand name of GreenPeak. This unit is designed to be an "add-on" unit that will reduce energy usage of air conditioners at peak by improving peak system efficiency. The unit stores energy in the form of cold water when the air conditioner is operating during non-peak hours, and then discharges the cold storage at on-peak hours. It does so by directing refrigerant flow leaving the condenser through the cold water tank to increase subcooling and hence evaporator (cooling) capacity without a much smaller increase in compressor power.

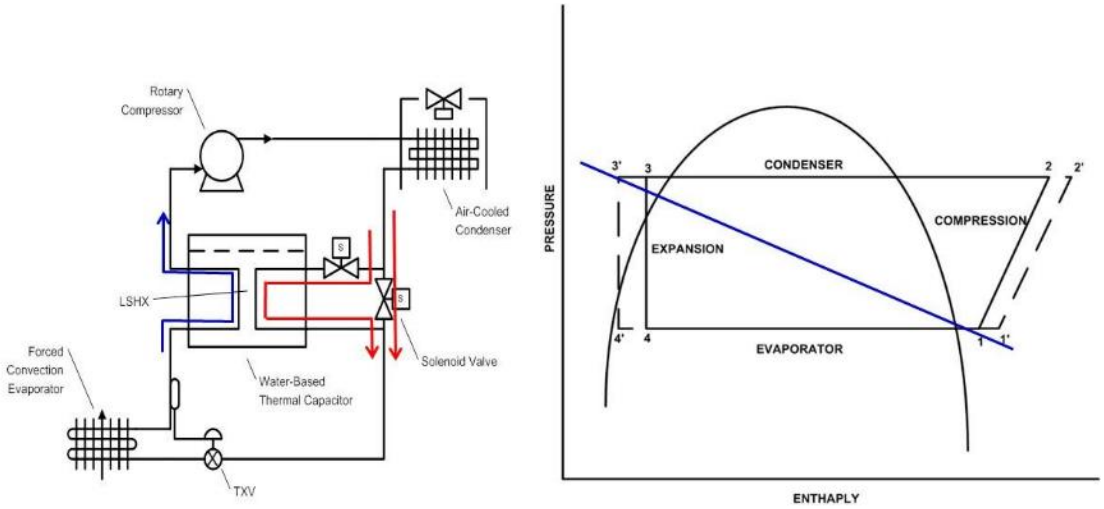

FIGURE 34. STORAGE CONDENSER UNIT

Performance Characteristics: The roundtrip energy efficiency of the storage condensing unit is dependent on the outdoor conditions and is being evaluated in the EPRI labs in Knoxville, TN. The unit is designed to be trickle charged over many hours of air conditioner operation and discharges rapidly. The discharge rate varies with the amount of charge and is high during the first hour and discharges quickly during the later hours.

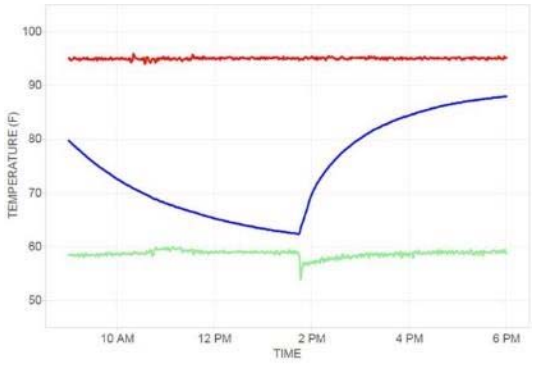

FIGURE 35. SCU PERFORMANCE CHARACTERISTICS

Maturity and Market Status: Early prototypes are being tested. The product which will be released into the market through channel partners such as Carrier and Trane, is proven effective.

Cost-Effectiveness: The estimated cost for the unit is $100/kWh installed. The manufacturer claims it can be even lower for new residential air conditioning units that have the storage integrated into their design. However, no data exists to justify the cost.

Safety: Not UL rated.

Environmental Considerations: Ensuring that there is no refrigerant leakage during retrofitting.

ELECTRIC STORAGE TECHNOLOGIES

AMBRI[1]

Technology: Ambri uses two metals, Magnesium and Antimony, in combination with a salt to create a unique all-liquid design liquid metal battery. The manufacturer claims that this results in using higher voltage and lower cost chemistries while avoiding cycle-to-cycle capacity fade.

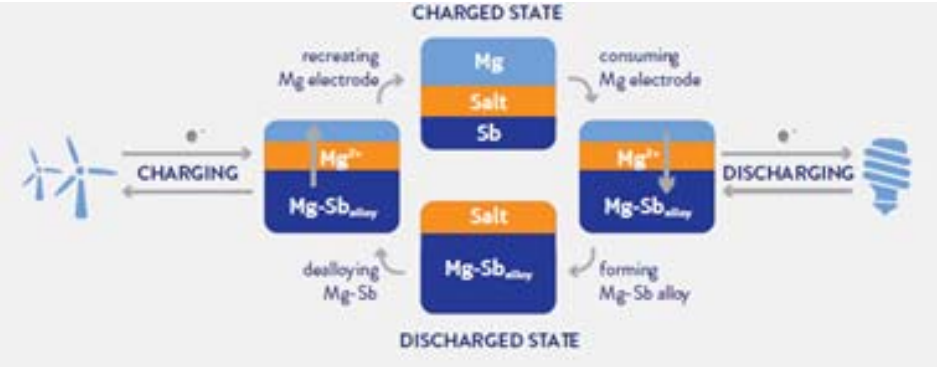

FIGURE 36. AMBRI ELECTRIC STORAGE

Performance Characteristics: Ambri's liquid metal battery is modular which allows for repeatable manufacturing and easy transport. Cells are stacked into refrigerator-sized modules that are placed into a 40-foot shipping container rated at 500 kW and 2 MWh storage capacity. Ambri uses an alloying/de-alloying process in order to charge and discharge—discharging by using the cell voltage to drive electrons from the top electrode to the external load and charging by using power from an external source to deliver electrons to the bottom layer to de-alloy the two metals. This enables the battery to exceed 70% round-trip efficiency without degradation.

Maturity and Market Status: Ambri is in the market for grid services. While Ambri is currently in the process of redesigning the 'lab' cell into a 'commercial' cell, the company has plans to commercialize prototypes in 2014 and move towards full commercialization in 2015.

Cost-Effectiveness: While still in its laboratory state, there have been no exact costs. However, Ambri claims that it achieves low cost through the use of inexpensive, earth-abundant materials and a design that can take advantage of the economies of scale inherent to electro-metallurgy and conventional manufacturing.

Safety: Not UL rated.

Environmental Considerations: During testing, the battery did not exhibit obvious signs of corrosion of the solid state cell components.

[1] http://www.ambri.com/technology/

AQUION ENERGY[2]

Technology: Aquion Energy uses their patented Aqueous Hybrid Ion (AHI™), a unique saltwater electrolyte battery technology, to provide energy storage. The manufacturer claims that the AHI batteries are cost-effective, safe, reliable, and sustainable to meet the needs of storage applications.

Performance Characteristics: The AHI battery is modular and can be scaled to desired sizes. The rate of charge for the battery varies, having a higher efficiency when charge rates are lower and a lower efficiency at higher charge rates. For example, the round trip energy efficiency for the AHI battery is greater than 95% for a 2 Coulomb cycling rate and in excess of 90% for current loadings as high as 6C. Prototype cells with AHI technology show <10% capacity fade after up to >5,000 cycles at over 50% DOD and >15,000 cycles following the Sandia National Lab "partial state of charge" rapid cycling protocol. Aquion's battery also has an energy density of 25 Wh/liter under 5 hours. Although this value is lower than many existing battery chemistries, Aquion notes that it is also significantly higher than many stationary storage solutions.

Maturity and Market Status: Aquion has established initial scale production and will begin commercial manufacturing in 2013 at the in-construction 350,000+ sq. ft. facility in SW Pennsylvania. The company is going after four markets: grid services, commercial & industrial, off-grid & microgrids, and wind & solar integration.

Cost-Effectiveness: Aquion claims that the AHI technology delivers the best value for stationary energy storage applications due to its high efficiency, extensive calendar and cycle life, no thermal management and associated costs, little to no maintenance, and low acquisition costs.

Safety: Aquion's AHI technology is not flammable or explosive. The technology uses inherently safe chemistry and no dangerous or toxic components. The use of water allows the technology to have a near-neutral pH and be fire resistant.

Environmental Considerations: AHI technology is sustainable because it uses environmentally benign materials, no corrosive acids or noxious fumes. It is both non-flammable and non-explosive. The manufacturer claims that a leak or spillage will not have any measurable impact on the environment due to the neutral pH of the water-based AHI technology. The materials used in the battery are recyclable and landfill safe. Because the materials are sustainable, it makes the AHI batteries suitable for global deployment.

[2] http://www.aquionenergy.com/technology

AXION POWER INTERNATIONAL[3]

Technology: Axion Power International uses a Lead-Carbon technology to manufacture a "multi-celled asymmetrically supercapacitive lead-acid-carbon hybrid battery." The main difference in the *PbC®* battery is the replacement of the lead negative electrode with an activated carbon electrode that does not undergo a chemical reaction. Instead, the very high surface area activated carbon electrode stores the protons (H^+) from the acid in a layer on the surface of the electrode. The manufacturer claims that as a result, reduced acid concentration swings from the charged to discharged state which reduces grid corrosion on the positive electrode and leads to longer life of the positive electrode. Axion Power uses this technology in their energy storage systems called the PowerCube.

Performance Characteristics: Axion Power International's Lead-acid battery is modular and can be scaled to desired sizes. The manufacturer claims that Axion's PbC battery goes through a complete charge-discharge cycle every 7 hours to a 100% depth of charge. The prototypes in the lab have withstood over 2500 cycles before failure and recharge 2 to 4 times faster than Lithium-Ion batteries. Axion Power's PbC battery has demonstrated round trip energy efficiency of 85% and the manufacturer claims that the battery offers dynamic charge acceptance rates that are a 10x improvement over conventional lead-acid. Multiples of the PbC make up the PowerCube which can be scaled up to the MW range. Each PowerCube can deliver up to 1MW of power for 30 minutes and can be combined with other PowerCubes.

Maturity and Market Status: While Axion Power International does not manufacture PbC batteries, the batteries have been designed to be manufactured in any lead acid battery facility in the U.S. and hundreds of facilities worldwide. Since 2004, Axion has been testing laboratory prototypes.

Cost-Effectiveness: Axion's technology for the PbC battery is significantly less complicated in regards to battery management and thermal management systems. Therefore, the PbC battery is much less expensive. It is also easy for module replacement and requires minimal maintenance.

Safety: Axion Power's Residential Energy Storage Hub ("HUB"), using the PbC technology, has achieved certification to UL1741, IEEE 1547, and Canadian Standards Association (CSA) safety standards. Axion Power's batteries are UL listed and available. The wide temperature range of the battery allows for a safer, more stable product. The PowerCube has a fire suppression system integrated with a dual gas monitoring system.

Environmental Considerations: The PbC battery can be recycled in existing lead acid battery recycling facilities. This allows the lead, plastic, and acid to be reused in new PbC batteries. The PbC batteries are sealed cell, lead acid batteries with pressure release vents to prevent leakage.

[3] http://www.axionpower.com/Technology

TEMPORAL POWER[4]

Technology: Temporal Power has developed an energy storage solution using flywheel technology and is distinguished by the compactability of their product. Temporal Power claims that their technology will reposition flywheels as a leader in the stationary energy storage market. The manufacturer asserts that this flywheel solution offers the highest power-to-energy ratio in a compact 50 kWh module and holds fifty times the energy of most available commercial systems.

Performance Characteristics: Temporal Power's flywheel product is a dynamic and scalable storage technology. The product offers flexibility by being customizable from 10 kW to 500 kW for different applications. The manufacturer claims that standby losses result in a 5% energy loss over 10 hours. The flywheel technology is unaffected by cycle life or depth of discharge, allowing a longer lifetime for the product.

Maturity and Market Status: Temporal Power is currently in the pilot stage with two pilot projects in place. Once commercialized, the manufacturer plans to go after three markets:renewable energy support, grid management, and commercial & industrial.

Cost-Effectiveness: The manufacturer claims that significant cost improvements for flywheels have been achieved and claims that Temporal Power offers amongst the lowest total cost of ownership of any distributable grid scale storage technology.

Safety: Temporal Power employs high quality control on reliable materials from world leading suppliers and they also have their systems operate at a high factor of safety and are designed with containment. They place the flywheel in a vault that can withstand extreme grade.

Environmental Considerations: Temporal Power is currently working on a demonstration representing one of the world's largest wind integration projects utilizing flywheel storage technology. The manufacturer claims that the flywheel storage technology is expected to significantly reduce GHG emissions in Canada and in the rest of the world.

[4] http://temporalpower.com/technology/

SUSTAINX[5]

Technology: SustainX uses isothermal compressed air energy storage (ICAES) technology to enable a site-anywhere, zero-emissions storage solution. The technology is not limited by the geographical location like many other CAES facilities, and uses an isothermal rather than an adiabatic cycling. The manufacturer claims that the patented isothermal cycling technology using pistons rather than turbines to generate electricity results in a storage system with inherently low cost, long lifetime, and low maintenance. A key element of SustainX's ICAES energy storage process is the use of a water spray that keeps the compressed air at a constant temperature which is then stored in above ground storage vessels while the heated water is stored in a constant-temperature reservoir. The storage is converted to energy when the compressed air drives the pistons which then drive an electric generator.

Performance Characteristics: SustainX's ICAES is modular and can be scaled to desired sizes. The power needs of a project can be met in MW increments by selecting the number of ICAES compressor/expander modules. The company's technology can go through over 15,000 cycles with a ~70% round-trip efficiency without cogeneration, ~88% with cogeneration.

Maturity and Market Status: SustainX is still in the pilot stage with a pilot plant in Seabrook, New Hampshire, with planned filed demonstrations for 2014. SustainX plans to go into renewable integration, T&D substitution, peak power capacity, cogeneration, and ancillary services.

Cost-Effectiveness: SustainX claims that they are able to deliver a levelized cost of energy disruptively low in comparison to competing storage technologies by using mature industrial components in their products.

Safety: SustainX uses no hazardous materials or chemicals in their product.

Environmental Considerations: ICAES's efficient isothermal gas expansion does not require the burning of natural gas, resulting in zero emissions and independence from fossil fuels.

[5] http://www.sustainx.com/technology-isothermal-caes.htm

DEEYA ENERGY

Technology: Deeya Energy's Storage Platform is based on redox flow battery technology using electrolytes stored in separate storage tanks rather than in the power cell of the battery. The manufacturer claims that their flow battery technology is the most cost-effective and reliable solution for the energy storage requirements of mission-critical applications.

Performance Characteristics: Deeya Energy's battery is modular and its design can be optimized for the power rating needed since it is independent of the amount of electrolyte. The battery has a discharge to charge ratio > 1.0 and an unlimited cycle life due to its no solid state reaction. A specific product of Deeya Energy is their ESP3-2.5-10 (2.5kW, 10 kWh) flow battery. The discharge time is 4 hours at 2.5 kW load with a charge time of < 4 hours at a charge power of 5.3 kW. [6]

Maturity and Market Status: Deeya Energy is going after markets such as buildings, grid services, renewable, and wireless telecom towers. They are commercial to small scale emerging markets such as banking with rural ATMs, signaling stations for railways, and wireless phone towers and are still in the lab for large scale markets.

Cost-Effectiveness: The ESP System is fully-integrated and factory-tested prior to delivery and no on-site conditioning or commissioning cycles are required. Site preparation is limited to pouring a reinforced concrete slab. Power conditioning electronics are included for telecom applications. Installed cost for the system is estimated to be at $3000/kW based on installations for telecom centers.

Safety: The technology is temperature independent, making the flow battery operable at a wider range.

Environmental Considerations: Deeya Energy's systems do not have heavy metals and release no poisonous or hazardous fumes. The technology also utilizes environmentally benign materials and is infinitely recyclable.

[6] http://www.deeyaenergy.com/wp-content/uploads/2013/02/Deeya-Data-Sheet-ESP3-25-10.pdf

GREENSMITH

Technology: Greensmith specializes in turnkey distributed energy storage systems (DESS) called the PowerVault supported by multiple battery manufacturers in order to maintain a "battery agnostic" technology. The PowerVault does real-time battery module measurement and reports voltage, current, temperature, cell capacity, SOC, efficiency and SOH. Greensmith's PowerVault also has a power conversion system which is a bi-directional inverter that can also control real and reactive power at fully-rated KVA. The manufacturer claims that their DES system is an optimal energy management strategy.

Performance Characteristics: Greensmith is modular to have scalable, flexible solutions. Their current products range from 50 kWh, 150 kWh, 300 kWh Distributed Energy Storage Units. For example, the 50 kWh power vault has a 25 kW charge or discharge with a <2 seconds ramp time at maximum power. At rated power, the round trip efficiency is > 85% with >1,000 cycles at 100% DOD and >2,000 cycles at 90% DOD. However, the software pairs with any battery the customer chooses. Greensmith's active balancing system can also improve round-trip efficiency of battery systems from the high-70 to low-80 percentage range all the way up to 88 percent.

Maturity and Market Status: Greensmith's technology is at a mature stage with 14 units already up and running. Markets for Greensmith include residential, commercial, and industrial markets.

Cost-Effectiveness: The unit is configured for sale to utilities and designed to provide centralized control in a manner complementary to existing or planned demand side management, AMI, and overall Smart Grid initiatives[7].

Safety: The battery operating system of the PowerVault has a protection mechanism as well as a fire suppression system for an additional level of protection.

[7] http://www.reuters.com/article/2008/12/02/idUS134321+02-Dec-2008+BW20081202

CODA ENERGY[8]

Technology: CODA energy uses lithium ion technology in conjunction with proprietary battery and thermal management systems to build scalable energy storage solutions. The entire system is managed through a sophisticated power source controller. The manufacturer claims that this turnkey solution results in a smarter, cleaner, and more reliable grid for commercial & industrial end users and can be adapted for utility, community, and residential applications.

Performance Characteristics: CODA energy uses a modular design to be scaled for different applications. The design features vertical energy towers that operate in concert but are managed independently.

Maturity and Market Status: CODA is going after a two markets: electric transportation and buildings. In San Diego, a community-scale CODA ESS is helping an apartment complex reduce peak electricity consumption and utilize the excess solar power it generates during the day at night. In San Francisco, two InterContinental hotels use CODA ESSs to reduce peak electricity consumption and associated demand charges.

Cost-Effectiveness: CODA's energy storage system is designed with cell agnostic architecture and utilizes commercially available cells, allowing each storage system to be optimized for specific applications.

Safety: CODA energy's in-house battery management system (BMS), including their thermal management system (TMS), keeps the batteries operating under safe electrical and thermal conditions. Simultaneously, the BMS and TMS systems extract maximum performance from the batteries, and provide feedback on the batteries' charge level, capacity, and condition

[8] http://www.codaenergy.com/solutions/

LG CHEM[9]

Technology: LG Chem manufactures lithium-ion polymer cells with laminated packaging with mixed cathode chemistry and safety reinforced separators. The manufacturer claims that this technology results in a high level of safety, high power capabilities, and a long battery life-span.

Performance Characteristics: The technology LG Chem uses in their batteries is modular and can be scaled, for example, to a 10 kWh RESU battery or a 5 kWh RESU battery. For the 10 kWh RESU, the nominal electrical output is 4 kW, while for the 5 kWh, the nominal electrical output is 5 kW.

Maturity and Market Status: LG Chem serves three markets: transportation, utility, and stationary. The batteries are commercialized and have gone through rigorous testing. The cells have been validated by General Motors, Ford, Volvo, Eaton, Hyundai, and Renault.

Cost-Effectiveness: LG Chem's technology and packaging design is at low cost while maintaining high quality and reliability that is easy to scale up.

Safety: The final version of the RESU will be designed, manufactured, and tested according to the latest applicable standards including, but not limited to IEEE, ANSI, NEC, NEPA, UL, and NEMA. The batteries have unique safety-reinforced separators (SRS) that have higher mechanical strength to minimize potential thermal runaways due to internal short.

Environmental Considerations: The safe laminated packaging of the battery prevents possible leaks. The "Mixed Cathode" chemistry also improves the abuse-tolerance of the batteries.

[9] http://www.lgcpi.com/bpack.shtml

SAFT

Technology: Saft uses a lithium ion technology for on grid solutions. The manufacturer claims that their Li-ion technologies deliver high performance, long service life, and low/zero maintenance requirements even in extreme conditions. Saft claims that their storage systems relieve network capacity constraints and increase their renewable hosting capabilities in order to reduce feeder congestion during demand peaks, provide voltage support, and enable black start and islanding.

Performance Characteristics: Saft's battery is modular and can be scaled to various sizes based on the unit battery. The home battery system, Intensium, has a capacity of 4kWh with a continuous charge rate of 12.1 kW and continuous discharge rate of 15.1 kW at 50% SOC. The system can run over 7,000 cycles at 60% DOD with a discharge time of 3s at 50% SOC. Saft's Li-ion batteries offer an energy density of 135 Wh/L.

Maturity and Market Status: Saft's batteries are targeted towards the residential, commercial, and industrial markets. The company is mature with thousands of commercial products sold. The batteries are manufactured internationally, including Florida, Brazil, UK, France, Germany, Sweden, Poland, India, and China.

Cost-Effectiveness: The manufacturer claims that their lithium ion technology included in their systems are cost-effective. Saft also explains that the long expected lifetime and low maintenance of the systems make having the system more cost-effective.

Safety: Saft's unit battery is UL compliant and listed. Concerns for the Saft battery include overheating and gas leakages. In order to address this, Saft includes in the system a battery management system and a temperature management system. The company also has power functionalities to maintain voltage requirements.

Environmental Considerations: Saft has available a MSDS for their product. In the case of accidental release, Saft recommends evacuation if contaminated until fumes disperse. Also, as a precautionary measure it is good to for the leakage to avoid sewage, surface water, and underground water contamination upon accidental release. In order to clean any leaks, absorb exuded material with sand, earth, or vermiculite and dispose in accordance with local regulation.

GENERAL ELECTRIC (GE)

Technology: General Electric utilizes a sodium nickel chloride technology for their batteries. The manufacturer claims that the technology results in a safer, reliable, and high performing energy storage system for a variety of stationary and motive applications.

Performance Characteristics: GE's battery can be scaled to various sizes due to its modular design. The unit battery, Durathon E620 Battery, has a capacity of 100 kWh and charges at a rate of 50 kW and discharges at a rate of 50 kW for every 2 hours. The Durathon Battery can go through 4,500 cycles.

FIGURE 37. GE MANUFACTURING FACILITY

Maturity and Market Status: GE targets an industrial market for their battery. GE is at a mature stage with over 1,000 commercial products in use. In Schenectady, NY, a manufacturing battery factory for GE was open with a work force of 450 people.

Cost-Effectiveness: GE claims that their batteries have a long life span and can replace diesel, making the battery more cost-effective.

Safety: Each cell using GE's technology is hermetically sealed within its own metal case, and is strung together with other cells in a thermally insulated battery module, that ensures the battery's external surfaces remain within 10°C to 15°C of the surrounding ambient temperature. All Durathon Batteries are also managed by the Durathon Battery Management System, which controls and protects the battery and relays information for monitoring the battery's condition. The battery is engineered to contain the cell's contents within a welded, sealed steel case upon the breakage of a separator. It is also designed to allow any active materials passing through the separator to become inert without damaging the cell's outer case.

Environmental Considerations: There is a possibility of leaks due to uncommon use but is also addressed by the battery's metal casing. A hazardous material included is the electrolyte solution with more information included in their MSDS.

FIAMM TECHNOLOGY

Technology: FIAMM uses a Sodium Nickel Chloride technology, nicknamed SoNick, for their batteries. The technology uses sodium and nickel as active materials with solid ceramic electrolyte. FIAMM boasts the battery as 70% lighter and 30% smaller than conventional batteries.

FIGURE 38. FIAMM TECHNOLOGY

Performance Characteristics: FIAMM's SoNick battery is modular and can be scaled for different applications. The capacity of the SoNick battery is 7.7 kWh with a bus voltage charging range between 53 to 59V and a max continuous discharge current of 65 Amps. The SoNick battery goes through over 4,000 cycles at 80% DoD.

Maturity and Market Status: FIAMM is going after two markets: industrial and transportation. FIAMM has three different manufacturing plants for their industrial batteries including plants in Avezzano, Italy, Waynesboro, GA, and Wuhan City, Hubei.

Cost-Effectiveness: The SoNick battery is cost-effective due to its lack of rare earth elements. Sodium nickel batteries use earth abundant materials that lower the cost of their battery. The batteries are also three times lighter and smaller than lead acid batteries.

Safety: The battery has an internal working temperature of 270ºC. The manufacturer claims that this guarantees high performance and durability regardless of the ambient temperature.

Environmental Considerations: SoNick battery does not use any toxic or harmful materials and requires no maintenance. FIAMM claims that the battery does not expel any harmful emissions and has entirely recyclable parts.

BEACON POWER

Technology: Beacon Power uses a flywheel technology called the Gen 4 Flywheel. Beacon's flywheel has a carbon-fiber composite rim supported by a metal hub and shaft with a motor/generator mounted on the shaft. This all creates the rotor which draws power from the grid and charges when the rotor accelerates to a higher speed. Upon discharging, the motor is switched into generator mode and electricity is injected back into the grid due to the inertial energy of the rotor.

Beacon Flywheel Primary Components, 100 kW & 25 kWh model

FIGURE 39. BEACON POWER FLYWHEEL

Performance Characteristics: Beacon's technology allows their flywheels to be connected in order to scale the storage for certain applications. The Gen 4 Flywheel has a capacity of 100 kW and a discharge rate of 25 kWh. It has a discharge time of 15 minutes and a voltage support of 480 V. The manufacturer also claims that the Gen 4 Flywheel technology can reach up to 100,000 equivalent full charge/discharge cycles over a 20-year design life with no degradation.

Maturity and Market Status: Beacon Power's main market is the industrial market. The company is at a mature state with hundreds of commercial products already manufactured. Beacon Power manufactures their flywheels at Massachusetts.

Cost-Effectiveness: Beacon claims that the Generation 4 Flywheel has a very low cost per full depth of discharge cycle.

Safety: The flywheel rotor is within a vacuum-sealed housing in order to minimize friction in the system.

Environmental Considerations: The Beacon Gen 4 Flywheel does not contain any hazardous materials and can be recycled. Its technology also does not consume fossil fuel nor produce carbon dioxide or other emissions during its operation.

Eos

Technology: Eos has developed a zinc hybrid cathode battery technology, Znyth, in order to meet energy storage needs. The manufacturer claims that their technology resolves the challenges of zinc-air rechargeability by addressing the battery architecture, electrolyte composition and management, materials, systems and manufacturing processes.

FIGURE 40. EOS GENESIS AURORIA

Performance Characteristics: Eos technology is modular. The Eos Aurora uses the zinc hybrid cathode battery technology. It has a 6 MWh capacity at a discharge rate of 1 MW. This is made of 2 kW/12 kWh building blocks. Eos' battery is designed for 6,000+ true cycles and 30 calendar years of operation.

Maturity and Market Status: Eos is currently scaling up battery prototypes for initial manufacturing in 2013 and expects the first delivery of its MW scale systems in 2014.

Cost-Effectiveness: The company has an expected low capital cost of $1000/kW and $160/kWh. The system does not require periodic replacement of components and therefore has a low operating cost.

Safety: The Znyth technology is non-flammable and has a stable, self-healing battery operation.

Environmental Considerations: Eos' technology does not use toxic electrolytes and materials. The battery is environmentally benign and stable.

SEEO

Technology: Seeo uses a Li-Ion technology that is distinguished through its use of a solid electrolyte. The manufacturer claims that this results in a capability for high energy densities while preserving safety by incorporating high energy electrodes with non-flammable solid electrolyte.

Performance Characteristics: The Seeo battery is modular and can be scaled to any sizes that are desired. The battery modules contain several kWhs of energy and have nominal voltages between 48 and 320V. The modules can be arranged to meet customer voltage and capacity requirements.

Maturity and Market Status: Seeo is going after four markets: electric transportation, grid services, buildings, and telecom backup power. At the building level, Seeo has developed a partnership with SunEdison to deploy 10 kWh batteries and help commercial customers supplement solar production in late evenings and cover the peak demand period. Cell R&D, pilot production and testing are carried out at Seeo's Hayward, CA facility. The Seeo San Diego facility manages module/pack design, standard and custom testing programs, as well BMS design and software optimization.

Safety: Require fire suppression system; Li-ion is flammable. In contrast to existing liquid and gel-electrolyte battery technologies, Seeo's electrolyte is entirely solid-state with no flammable or volatile components. Solid battery materials are inherently safer than liquids, which are more vulnerable to fires under crush or overvoltage conditions.

Environmental Considerations: The battery's solid state prevents the possibility of leaks in the battery. Seeo's DryLyte technology has a transformational solid-state battery technology based on a nanostructured solid, using fewer raw materials.

SILENT POWER

Technology: Silent Power uses a lead acid technology in their power system called OnDemand. The OnDemand system reduces expensive demand charges by automatically dispatching stored energy when preset kW output levels are surpassed.

Performance Characteristics: Silent Power's OnDemand system has two options, one with a capacity of 11.8 kWh and another with a capacity of 23.6 kWh. The system has a discharge rate at 9.2 kW and a maximum charge rate at 2.8 kW. Each lead acid battery has a rated capacity at a 20 hour rate of 246 Ah at 12 V each. The system includes either the 4-battery option or 8-battery option.

FIGURE 41. SILENT POWER LEAD ACID BATTERY

Maturity and Market Status: Silent Power's OnDemand battery systems operate independently and are not modular. The company manufactures their batteries in Minnesota and currently participates in multiple demonstrations. The targeted markets for Silent Power includes residential, commercial and industrial.

Safety: Silent Power's batteries are sealed without need for venting. OnDemand also complies with UL certifications and is UL listed.

Environmental Considerations: Silent Power's batteries are sealed in order to prevent leakage. The batteries are highly recycled products and can be recycled at local recycling centers.

REDFLOW

Technology: RedFlow's core product is the ZBM which uses a Zinc-Bromine technology. The manufacturer claims that their ZBM battery has a prime position in energy applications that require multi-hour discharges without significant degradation.

FIGURE 42. REDFLOW BATTERY

Performance Characteristics: The ZBM battery is a modular building block to enable flexible voltage and capacity configurations from ~10kWh to MWh. The battery has a capacity of up to 8kWh of energy and can discharge up to 3kW of continuous power. RedFlow's battery has a 75% net energy efficiency DC-DC max.

Maturity and Market Status: RedFlow is going after the industrial market, using their battery mostly for the grid. Their storage systems have been in the field since 2008 and currently have over 30 MWh of cycling done in the field and in testing.

Cost-Effectiveness: The RedFlow ZBM can only be bought within RedFlow's developer kits or demonstrator systems. They are priced based on application.

Safety: The ZBM battery has the ability to stop reactions and isolate the electrolyte in the tank. In the event of a short circuit, the safety is enhanced by the ZBM's unique current-limiting capability. The battery has on-board intelligence to monitor the condition of the battery and can shut down upon detection of abnormalities. RedFlow's UL listing for the ZBM is currently pending.

Environmental Considerations: The batteries are made of recyclable plastics and metals and the electrolyte can also be recycled in other ZBM systems if there has been no contamination. There are no heavy metals or toxic materials in ZBMs.

ENERDEL

Technology: EnerDel's systems use a lithium ion technology that is distinguished as one of the highest density cells on the market. The manufacturer claims that the battery has excellent balance between energy and power based on the choices of materials used in the cell. EnerDel uses hard carbon for the anode material as opposed to graphite which the manufacturer claims will provide higher power density and smaller volume changes when charged and discharged to encourage longer mechanical stability and life expectancy.

FIGURE 43. ENERDEL LITHION ION BATTERIES

Performance Characteristics: EnerDel's batteries are modular and can be scaled to desired sizes. The product has a nominal capacity of 17.5 Ah and has an energy density of 147Wh/kg. EnerDel also claims the battery is durable and has a low self-discharge, retaining more than 80% of initial capacity after more than 2500 cycles at 100% DoD. In combination, the batteries make up the SE100-590 Secure+ Grid ESS and SP90-590 Secure+ Grid ESS. These systems have a capacity of 100kWh and 90kWh and a discharge rate of 100kW and 180kW respectively.

Maturity and Market Status: EnerDel is aiming for the industrial and transportation markets. The company has two facilities in the Indianapolis area and a manufacturing facility in Korea. In 2012, EnerDel launched a joint venture with Wanxiang Electric Vehicle Co. to manufacture, sell, and distribute battery cells and packs for China's transportation and grid energy storage markets.

Safety: EnerDel's lithium ion technology is made safe through the choices of materials and packaging. EnerDel's use of hard carbon is more resistant to degradation reactions such as dendrite formation and offers more chemical stability.

Environmental Considerations: EnerDel mitigates leaks by packaging their cells in laminate with appropriately-sized tabs sealed with high mechanical strength. The packaging includes a multi-layer laminate consisting of aluminum foil sandwiched between layers of electrically-insulating polymers to eliminate the risk of shorting to the metal case. The tabs are also plated to make the cell less prone to corrosion. The manufacturer claims that this maintains low contact resistance and result in less heat and longer life expectancy.

DEMAND ENERGY

Technology: Demand Energy's Joule.System includes intelligence, big data analytics, and simple management to enhance the grid's stability and control the way electricity is generated and consumed. The Joule.System is a cloud-based platform that gives users control to optimize their electricity usage.

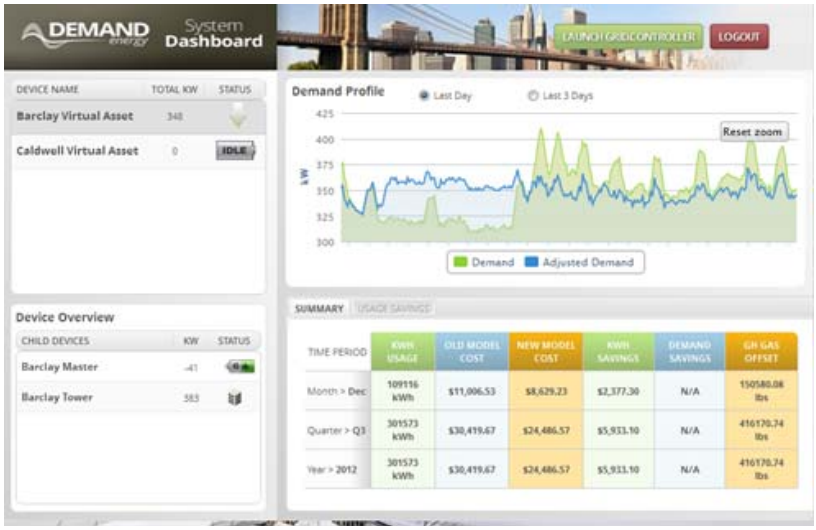

FIGURE 44. DEMAND ENERGY SYSTEM DASHBOARD

Maturity and Market Status: Demand Energy is going after two markets, the commercial and industrial markets. Since 2010, Demand Energy Networks, Inc. has installed multiple Joule.Systems including in New York and Tianjin China.

CELLSTROM GMBH

Technology: Cellstrom Gmbh uses Vanadium Redox Flow battery technology in their CellCubes. The CellCube energy storage system can be used in conjunction with photovoltaic, wind power stations, biogas generators, or in parallel grid operation. The manufacturer claims that the vanadium redox flow battery technology guarantees an uninterrupted power supply.

Performance Characteristics: Cellstrom's CellCubes are modular and can be used in different combinations ranging from 100 kWh to 1600 kWh. The charge and discharge rates are also dependent on capacity; the higher the capacity, the higher the charge and discharge rates. The CellCube FB 10/20/30 kW ran up to an 80% efficiency for a cycle while the CellCube FB 200 kW had up to 70% full-cycle efficiency.

Maturity and Market Status: Cellstrom Gmbh has their products aim towards the residential, commercial, and industrial markets. The company currently has thousands of installations around the world and has recently launched modular systems in the MW range in 2012.

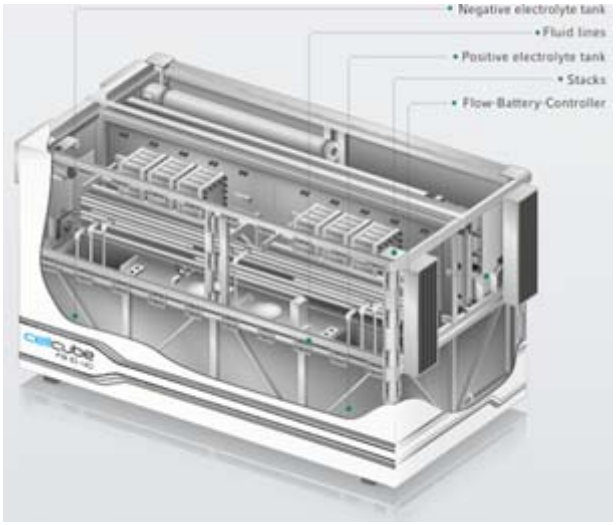

FIGURE 45. CELLSTROM GMBH CELL CUBE

Safety: The technology used in the CellCube system is non-flammable and non-explosive. The turnkey energy storage is weatherproof and is in securely protected housing.

Environmental Considerations: The stacks within the energy storage system have been tested for 100% leak tightness. The manufacturer also claims that there is no use of hazardous materials.

MCV ENERGY

Technology: MCV Energy uses a lithium ion technology in their energy storage systems. The manufacturer claims that MCV DESS "utilizes advanced control functions hardware that can switch system operations in 25 microseconds, and make a round trip switch in two cycles."

FIGURE 46. MCV ENERGY

Performance Characteristics: MCV Energy's system is modular and can be scaled from 35 kWh/35kW according to customer needs. The base system the MCV Energy currently has and is testing has a capacity of 35 kWh and a discharge rate of 35 kW. At 100% DOD, the energy storage system can cycle through over 2,000 cycles.

Maturity and Market Status: The distributed energy storage system is currently being tested by MCV Energy to prove that the DESS can meet generation requirements such as regulation response, real-time dispatch and daily load shifting.

Cost-Effectiveness: Due to MCV's distributed energy storage system's current testing stage, no commercial systems have been produced with prices.

Safety: MCV Energy's DESS is UL compliant and certified. The battery management system is autonomous and has self-protecting lithium iron phosphate technology.

Environmental Considerations: MCV Energy's battery management system determines whether the battery is in suitable operating conditions. It maintains the temperature by turning on fans to prevent overheating and can stop the battery flow upon leakage.

PRIMUS POWER

Technology: Primus Power uses a Zinc-Flow battery technology in their energy storage solutions. They created the EnergyPod which the manufacturer claims is five times as dense, leading to 80% less of a footprint.

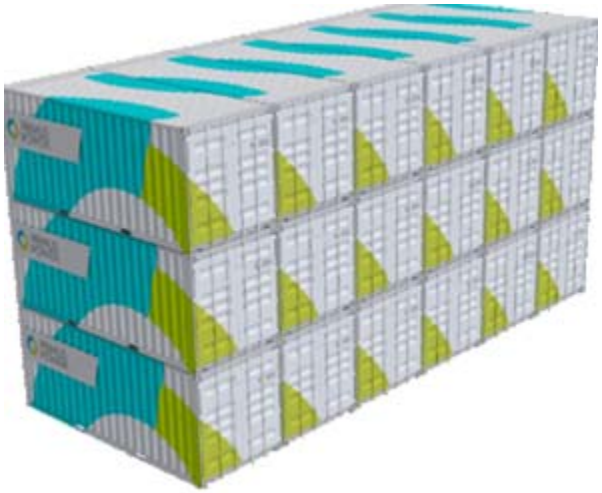

FIGURE 47. PRIMUS POWER ZINC-FLOW BATTERY

Performance Characteristics: The EnergyPod energy storage system is made of 250 kW modular units that can be added incrementally to meet desired sizes. The capacity of each EnergyPod is 1 MWh that discharges at a rate of 250 kW. Each EnergyPod is made up of 14 flow batteries providing 2MW of storage and more. The product has a 70% energy efficiency for a full cycle.

Maturity and Market Status: Primus Power is aiming for the commercial and industrial markets. The first EnergyPod was deployed in 2012 and began shipping commercially in early 2013.

Safety: The control system in Primus Power's product allows for safe operation with the grid.

SAMSUNG

Technology: Samsung uses Lithium Ion battery technology in their energy storage systems. Samsung provides high-capacity energy storage solutions to accelerate the commercialization of energy storage systems and to meet global needs.

FIGURE 48. SAMSUNG ENERGY STORAGE SOLUTION

Performance Characteristics: The products that Samsung have manufactured can be scaled for specific applications. Samsung offers a residential and community energy storage system as well as a peak shifting energy storage system. The residential system has a capacity between 7-10 kWh, a discharge rate of 3-7 kW and can run for 5,000 cycles at 100% DOD. The community energy storage system has a capacity of 25 kWh and a discharge rate of 25 kW for 1-3 hours. It also cycles 8,000 times at 100% DOD. The Peak Shifting product has a 500 kWh capacity and has a discharge rate of 2,000 kW.

Maturity and Market Status: Samsung provides energy storage solutions for the residential, commercial, and industrial markets. Samsung has deployed their products in their Jeju Smart Grid Project and Daegu Residential ESS Project.

Safety: Samsung's lithium ion batteries are UL compliant and listed. The battery can withstand overcharging by applying a 5-way safety stop in order to mitigate overheating. The lithium ion batteries also include a protection circuit to prevent over-charge/discharge/current and short circuit.

Environmental Considerations: Samsung has mostly metal oxides, carbon, and electrolytes in their battery products. Samsung has an MSDS available for their lithium ion batteries used within their energy storage systems.

TESLA

Technology: Tesla uses lithium ion technology in their products. In conjunction with SolarCity, the manufacturer claims that Tesla and SolarCity have produced a home energy storage system that is cost-effective, small yet powerful.

FIGURE 49. TESLA LITHIUM ION 10 KWH BATTERY

Performance Characteristics: Tesla currently has two models, a residential system with a capacity of 10 kWh with a discharge time of 2 hours, and a commercial system with a capacity of 60 kWh and discharge time of 2 hours.

Maturity and Market Status: Tesla currently has systems in the testing stage with their 5 kWh systems. Tesla and SolarCity are targeting the residential and commercial markets for their systems.

Cost-Effectiveness: Tesla's home energy storage system is currently projected to be $1000-1300/kWh. The target price for the systems is $500/kWh. The home energy storage system is jointly located with PV and includes a 10-year warranty on their product.

PANASONIC

Technology: Panasonic Smart Energy Storage System (SESS) utilizes lithium ion technology. The manufacturer believes that the SESS is a solution to fluctuations in power distribution and also reduces natural gas and serves as emergency power.

Performance Characteristics: Panasonic has different solutions depending on the application of the Smart Energy Storage System as well as a modular design to scale the products. Panasonic offers Smart Energy Storage Systems with capacities of 4.0, 6.8, 27, 100, and 1000 kWh.

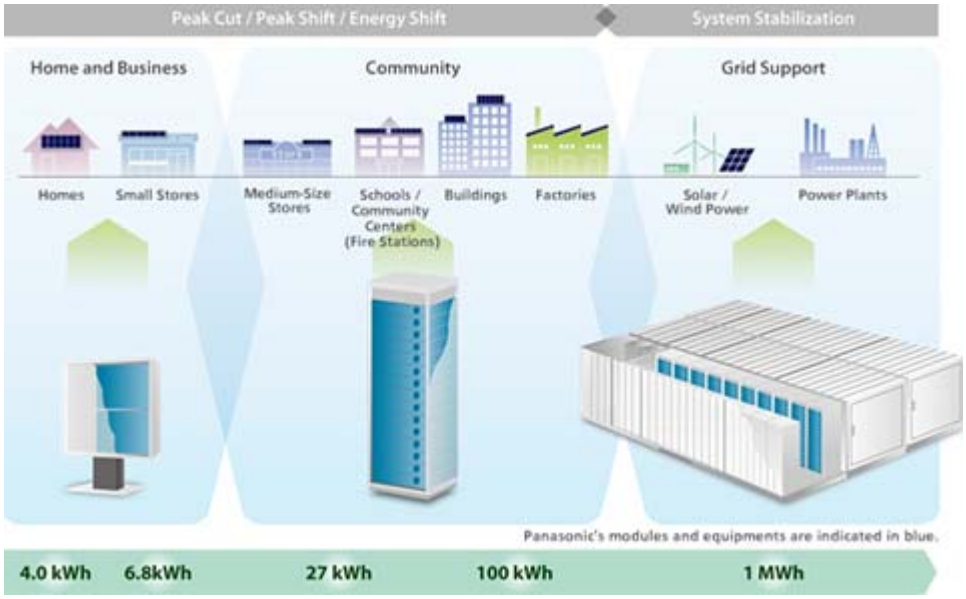

FIGURE 50. PANASONIC SMART ENERGY STORAGE SYSTEM

Maturity and Market Status: Panasonic is going after a few markets: residential, commercial, and industrial. While Panasonic has prototypes of their products, Panasonic recently began manufacturing home systems for the residential market in Germany.

Safety: Panasonic's individual lithium ion batteries include a safety guard circuit. Toxicity of batteries may come from the vapor generated from burning batteries.

Environmental Considerations: The manufacturer claims that the SESS will play a critical role in reducing carbon emissions in the future.

ELECTROVAYA

Technology: Electrovaya's SuperPolymer uses a lithium ion technology in their cells. The manufacturer claims that their technologies provide the basis of a technology platform that is independent of anode and cathode chemistry.

FIGURE 51. ELECTROVAYA SUPERPOLYMER TECHNOLOGY

Performance Characteristics: The Company's lithium ion cells are modular and consist of a flat "pouched" design. Their batteries, made with a lithiated manganese material, have an energy density of 170 to 210 Wh/kg and a peak power of up to 2,000 W/kg for 10 seconds. Electrovaya's battery can perform over 1,000 cycles at 100% DOD to 80% capacity with over 7 years of calendar life. The company offers an intelligent battery management system (iBMS) to optimize the battery system with other vehicle components. Electrovaya has launched a residential lithium ion energy storage system that is available in sizes from 3 kWh – 20 kWh.

Maturity and Market Status: Electrovaya is going after the transportation market and eventually the industrial. Currently, the company manufactures their batteries in Canada and the U.S. and is looking to grow into Europe and Asia.

Safety: The chemicals in the batteries are contained in sealed enclosures to prevent leakage and exposure. The enclosure also prevents the electrolytes from being in contact with water which may generate harmful hydrogen fluoride gas.

Environmental Considerations: Electrovaya mitigates leakage by placing their batteries in a sealed enclosure. Hazardous chemicals may be the electrolytes when in contact with water. The company also has a unique clean manufacturing process that does not use N-Methyl Pyrrolidone which has been found to be a reproductive toxicant.

XTREME POWER

Technology: Xtreme Power's Xtreme Active Control Technology (XACT) does not have a specific battery technology and is capable of seamlessly integrating any battery technology with their power conversion systems. Xtreme Power is able to prioritize applications based on customer needs and provide multiple applications simultaneously.

FIGURE 52. XTREME POWER ACTIVE CONTROL TECHNOLOGY

Performance Characteristics: The Company's systems are modular in design and can be scaled to desired sizes for different applications. Xtreme Power has installed 77 MW of integrated energy storage systems to date. The capacity of each system is dependent on application and differs between projects.

Maturity and Market Status: Xtreme Power is going after the industrial market. To date, Xtreme Power has deployed over 10 projects using their integration system. They have charged/discharged 7,000 MWh.

Safety: Xtreme Power is able to mitigate potential hazards through the self-containment of each DC block in their energy storage system.

Environmental Considerations: Xtreme Power's technology integrates other systems with the grid and is able to do so through their XACT platform which is able to provide high power output within 50 milliseconds while still maintaining safety protocol.

SUNVERGE ENERGY

Technology: Sunverge Energy utilizes a lithium ion technology for their energy storage systems. The distributed energy storage system, Sunverge SIS (Solar Integration System), captures solar power for storage in the batteries and is remotely controlled and managed by cloud software.

Performance Characteristics: Sunverge's energy storage system is modular and can be scaled up to desired sizes based on application. The base system is 10 kWh and runs for approximately 2,000 cycles.

Maturity and Market Status: Sunverge is targeting the residential market for their energy storage systems. Currently, Sunverge Energy has approximately 50 systems on the market and manufactures systems through International Battery who provides the lithium ion battery systems.

Cost-Effectiveness: The Sunverge unit is estimated to cost $3,000 - $4,000/kW for a fully-integrated system. This includes load management and controls capability for buildings, which can provide sufficient benefits by overcoming requirements for controls upgrades.

Safety: The Solar Integration System is made up of a steel fire-proof cabinet to contain and mitigate the chances of fires. The system is externally mounted and designed to fit next to residential meters. The system is also UL certified and conforms to both UL and IEEE standards.

Environmental Considerations: Sunverge Energy's cloud software has a battery management system to mitigate leaks within the battery cells.

QUANTUM POWER

Technology: Quantum Power's products use a flywheel technology. The manufacturer claims that this company offers a low-cost product as an energy storage solution.

Performance Characteristics: Quantum Power's flywheel products have a capacity of 150 kWh and discharge at a rate of 60 kW. The flywheel has an 85% AC/AC Roundtrip efficiency. At 100% Depth of Discharge, the flywheel can run over 20,000 cycles, and at 80% depth of discharge, the flywheel can go through 100,000 cycles.

Maturity and Market Status: Quantum Power is currently working on a prototype of their product and expects to be completed by the end of 2013. By mid-2014, the company plans to have a product ready.

Cost-Effectiveness: The goal for the flywheel product is to have a capital cost of $75/kWh. In total, the cost for the complete system including power electronics is estimated at $300/kWh.

Safety: Flywheels do not have chemical components, but only mechanical components that renders them safer from an environmental point of view. However, these systems because of their high speed operation are preferably located underground to ensure that there are no safety concerns in case of mechanical failure. The systems are not yet UL rated.

CONTROLS BASED TECHNOLOGIES

INTEL – DATA CENTER POWER MANAGEMENT

Technology: Intel is developing a new technology called Cabezon Peak Technology that can be used to reduce energy use of data centers for limited time periods. The technology uses load shifting of computing processers to reduce overall computing loads and then also dispatches some of the available energy storage used for backup power in the data center using a DC bus to provide load reduction and send power back into the grid.

Performance Characteristics: This system is designed for very quick response, which lends itself well for providing ancillary services such as frequency regulation and Volt/VAR control. Intel estimates that the response time can be in milli seconds, and the available computing capability results in very low communications time periods. The actual available response is a function of the size of the data center and the loading.

The technology is in its very early stage is undergoing its first field demonstration this year. It is expected that the total available load shed is of the order of 10% of total data center load. The charging and discharging rates can be can be as high as 100 kW/sec, but the performance numbers are yet to be validated.

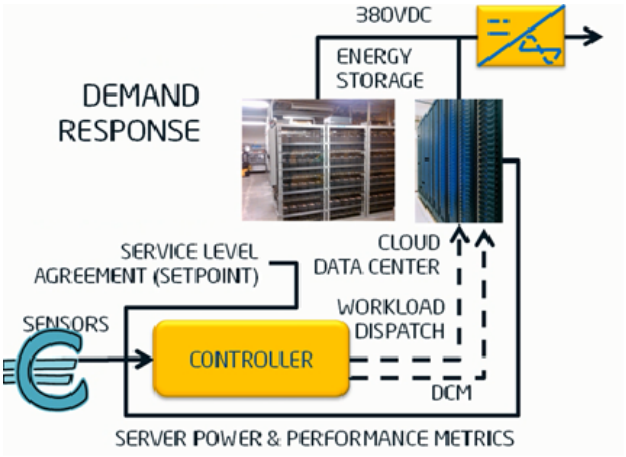

FIGURE 53. INTEL CABEZON PEAK TECHNOLOGY

Maturity and Market Status: Intel is currently conducting its first evaluation along with EPRI as part of a BPA demonstration project.

Cost-Effectiveness: The cost of the system is limited to the controller, and it can be very minimal. For a 200 kW datacenter, the cost can be in the low $100s/kW.

Safety: No significant safety considerations, except that the data center should not be running mission critical services.

REFRIGERATION SYSTEM STORAGE

Technology: Grocery stores have significant amount of thermal mass in terms of produce and canned goods that can be used as energy storage. FDA regulations require that the produce be maintained at a temperature of 41°F or lower. However, getting very close to the freezing point also presents dangers for both fresh produce as well as meat. Freezing of the water in the veins of both produce and blood in animals will render them unfit to be sold as fresh produce or meat. Newer refrigeration technology that can more tightly manage temperatures in cases can enable usage of the units as energy storage. In addition, vending machines that dispense drinks and cake racks that operate at higher temperatures have a greater capability for temperature floating that again can provide some significant energy storage capability.

Maturity and Market Status: Intel is currently conducting its first evaluation along with EPRI as part of a BPA demonstration project.

Cost-Effectiveness: The cost of the system is limited to the controller, and it can be very minimal. For a 200 kW datacenter, the cost can be in the low $100s/kW.

Safety: No significant safety considerations, except that the data center should not be running mission critical services.

COMMERCIAL OFFICE BUILDING CONTROLS – Q COEFFICIENT

Technology: Grocery stores have significant amount of thermal mass in terms of produce and canned goods that can be used as energy storage. FDA regulations require that the produce be maintained at a temperature of 41°F or lower. However, getting very close to the freezing point also presents dangers for both fresh produce as well as meat. Freezing of the water in the veins of both produce and blood in animals will render them unfit to be sold as fresh produce or meat. Newer refrigeration technology that can more tightly manage temperatures in cases can enable usage of the units as energy storage. In addition, vending machines that dispense drinks and cake racks that operate at higher temperatures have a greater capability for temperature floating that again can provide some significant energy storage capability.

Performance Characteristics: This system is designed for very quick response, which lends itself well for providing ancillary services such as frequency regulation and Volt/VAR control. Intel estimates that the response time can be in milli-seconds, and the available computing capability results in very low communications time periods. The actual available response is a function of the size of the data center and the loading.

The technology is in its very early stage and is undergoing its first field demonstration this year. It is expected that the total available load shed is of the order of 10% of total data center load. The charging and discharging rates can be can be as high as 100kW/sec, but the performance numbers are yet to be validated.

Maturity and Market Status: Intel is currently conducting its first evaluation along with EPRI as part of a BPA demonstration project.

Cost-Effectiveness: The cost of the system is limited to the controller, and it can be very minimal. For a 200 kW datacenter, the cost can be in the low $100s/kW.

Safety: No significant safety considerations, except that the data center should not be running mission critical services.

COMMERCIAL OFFICE BUILDING CONTROLS – BUILDING IQ

Technology: Grocery stores have significant amount of thermal mass in terms of produce and canned goods that can be used as energy storage. FDA regulations require that the produce be maintained at a temperature of 41°F or lower. However, getting very close to the freezing point also presents dangers for both fresh produce as well as meat. Freezing of the water in the veins of both produce and blood in animals will render them unfit to be sold as fresh produce or meat. Newer refrigeration technology that can more tightly manage temperatures in cases and can enable usage of the units as energy storage. In addition, vending machines that dispense drinks and cake racks that operate at higher temperatures have a greater capability for temperature floating that again can provide some significant energy storage capability.

Performance Characteristics: This system is designed for very quick response, which lends itself well for providing ancillary services such as frequency regulation and Volt/VAR control. Intel estimates that the response time can be in milli-seconds, and the available computing capability results in very low communications time periods. The actual available response is a function of the size of the data center and the loading.

The technology is in its very early stage is undergoing its first field demonstration this year. It is expected that the total available load shed is of the order of 10% of total data center load. The charging and discharging rates can be can be as high as 100kW/sec, but the performance numbers are yet to be validated.

Maturity and Market Status: Intel is currently conducting its first evaluation along with EPRI as part of a BPA demonstration project.

Cost-Effectiveness: The cost of the system is limited to the controller, and it can be very minimal. For a 200 kW datacenter, the cost can be in the low $100s/kW.

Safety: No significant safety considerations, except that the data center should not be running mission critical services.

COMMERCIAL OFFICE BUILDING CONTROLS – VIRIDITY ENERGY:

Technology: Grocery stores have significant amount of thermal mass in terms of produce and canned goods that can be used as energy storage. FDA regulations require that the produce be maintained at a temperature of 41°F or lower. However, getting very close to the freezing point also presents dangers for both fresh produce as well as meat. Freezing of the water in the veins of both produce and blood in animals will render them unfit to be sold as fresh produce or meat. Newer refrigeration technology that can more tightly manage temperatures in cases and can enable usage of the units as energy storage. In addition, vending machines that dispense drinks and cake racks that operate at higher temperatures have a greater capability for temperature floating that again can provide some significant energy storage capability.

Performance Characteristics: This system is designed for very quick response, which lends itself well for providing ancillary services such as frequency regulation and Volt/VAR control. Intel estimates that the response time can be in milli-seconds, and the available computing capability results in very low communications time periods. The actual available response is a function of the size of the data center and the loading.

The technology is in its very early stage is undergoing its first field demonstration this year. It is expected that the total available load shed is of the order of 10% of total data center load. The charging and discharging rates can be can be as high as 100kW/sec, but the performance numbers are yet to be validated.

Maturity and Market Status: Intel is currently conducting its first evaluation along with EPRI as part of a BPA demonstration project.

Cost-Effectiveness: The cost of the system is limited to the controller, and it can be very minimal. For a 200 kW datacenter, the cost can be in the low $100s/kW.

Safety: No significant safety considerations, except that the data center should not be running mission critical services.

APPENDIX B – TECHNOLOGY SUMMARY

Manufacturer	Product	Technology	Product Performance					Product and Org Maturity								
			Capacity (T-hr /	Charge Rate (kW)	Discharge Rate (kW)	No. of cycles	Disch. Time (hr)	Number of comm. Systems					First Install	Company	Manufacturing	Funding Source
								None	Few	10s	100s	1000s				
Thermal Storage																
Ice Energy	Ice Bear	Packaged Ice Storage w/ ref.	30 T-hr	3 - 5 KW	Max 7.5 KW	4000	6				x		2004	2003	Glendale	PE
IE Technologies	GreenPeak	Sub-cooler for cond. Units	2 T-hr	~.2 KW	Max 2 KW	4000	2	x						2003	N/A	VC
Calmac	IceCoil	Modular glycol ice storage	100 T-hr	Var	Var	5000 +	6					x	1978	1972	NJ	Corp
CBI		Site built stratified chilled water tanks and controls	10000 T-hr+	Var	Var	5000 +	6			x			1986		Chicago	Corp
BAC	IceChiller	Large packaged ice storage	500 T-hr+	Var	Var	4000	6				x		1982	1938	MD	Corp
Evapco	Extra-Pak	Large packaged ice storage	500 T-hr+	Var	Var	4000	6				x		1985	1976	MD	Corp
Transphase		Encapsulated PCM	500 T-hr+	Var	Var	2000	6		x				1990	1988	N/A	PE
Cryogel		Encapsulated PCM	500 T-hr+	Var	Var	2000	6			x			1992	1988	N/A	Corp
Electrical Storage																
Tesla	SolarCity EMS	Li-Ion (Tesla)	10 60	2.5 15	5 30		2 2			x				2003		
Seeo	DryLyte	Li-Ion	10	2.5	5					x				2007	Shanghai	VC
Silent Power	OnDemand	Lead Acid Batt	11.8 23.6	2.8 4.8	4.6 9.2									2002	MN	
Saft	Intensium	Li-Ion	4	50% SOC	50% SOC	60% DOD						x	1918	1913	Brazil,	Corp
Sharp																
RedFlow	ZBM	Zinc-Bromine Battery	8	8	8						x		2008	2001	Australia	
Panasonic	Smart Energy Storage System (SESS)	Li-Ion	4 6.8 27 1000	1 1.7 6.75 250	4.6 4.6 7.2 1000								2010	1918	Korea	Corp
Greensmith	PowerVault	Lithium Iron Phosphate	50 158 300	25 30/50/75 50/75/100	25 30/50/75 50/75/100	1000+ @ 3000+ @ 3000+ @				x			2011	2008	MD	Corp
LG		Li-Ion	Var		Var							x	1998	1995	Korea	Corp
GE	Durathon E620	Sodium Nickel Chloride	100	50	50 kW/2hrs	4500						x	2011	1876	NY	Corp
FIAMM	OASIS Zero OASIS One	Lead Batteries Sodium Nickel Chloride	20 to 250 250	2.5/5.0/7.5 5/10/20 kW	5/10/15 kW 10/20/40											
Demand Energy	Joule.System	Lead Acid Batt							x				2012	2008	WA	
CODA Energy	(CUSTOM)	Li-Ion	Var	Var	Var				x					2012	CA	
Axion Power	PowerCube	Lead-Carbon battery	500	2000	2000	2500	7	x					2009	2003	PA	

			Product Performance					Product and Org Maturity								
								Number of comm. Systems								
Manufacturer	Product	Technology	Capacity (T-hr /	Charge Rate (kW)	Discharge Rate (kW)	No. of cycles	Disch. Time (hr)	None	Few	10s	100s	1000s	First Install	Company	Manufacturing	Funding Source
CellStrom Gmbh	CellCube	Vanadium Redox Flow	40/70/100 400/800/1	10/20/30 200	10/20/30 200							x	2004	1999		
Eos	Eos Aurora	Zinc Hybrid Cathode	6000	500	1000	6000	6	x					2014	2004	NJ	
Electrovaya	EnergyBlock	Li-Ion	3-20 kWh	5	10	1000								1996	Canada	
EnerDel	SE100-590	Li-Ion	100	25	100	3000	1								Korea	Corp
MCV Energy		Li-Ion	35	8.5	35	2000+		x					2010	2009	San	
Primus Power	EnergyPod	Zinc Bromine Flow	1000	250	250			x						2011	Hayward	VC
Xtreme Power	(CUSTOM)	Integrator	Var	Var	Var					x			2006	2004	TX, Beijing	PE
Sunverge	SIS	Li-ion	10	2.5	5	2000			x					2010	Stockton, CA	
Samsung	Residential Energy Storage	Li-Ion	7-10kWh	2.5	3-7kW	5000										
	Community Energy Storage	Li-Ion	25	8.25	25	8000	1-3hr								Korea, Austin TX	
	Peak Shifting	Li-Ion	500	125	2000									1970		Corp
Quantum Power		Flywheel	150	60	60	100000+ @80%DOD		x								
Controls and Computing																
Intel		Advanced Virtualization														
NREL		Laptop batteries														
Danfoss	Eco-Flow	Refrigeration Controls														
Stem		Li-Ion and Controls														
Viridity Energy	VPower™	Controls												2008	PA	
Q Coefficient		Building Controls market bid														
Enernoc		Building Controls - Temp reset														

		Markets								Environmental and Safety			
		Size	Product Cost ($/kW-		Residential	Med Commer	Large Commer	Industrial	Transportation	Key Safety Feature	UL Complia	UL Listed	MSDS Hazmat
Manufacturer	Product	Range	Unit	Installed									
Thermal Storage													
Ice Energy	Ice Bear	30 T-hr	150	270	x	x				Water		x	None
IE Technologies	GreenPeak	2 T-hr	40	150	x					Water	x		None
Calmac	IceCoil	60 - 2000	80	200		x	x					x	None
CBI		10000 +		100			x	x			x		None
BAC	IceChiller	300 - 3000	120	200			x	x				x	None
Evapco	Extra-Pak	300 - 3000	120	200			x	x	x			x	None
Transphase		2000+		200			x	x		Corrosive			PCM salts
Cryogel		2000+		200			x	x		Corrosive	x		PCM salts
Electrical Storage													
Tesla	SolarCity EMS	10, 60,			x	x				cooling systems; 1850 cells	x	x	x
Seeo	DryLyte				x	x			x	Solid			
Silent Power	OnDemand				x	x	x	x			x	x	
Saft	Intensium				x	x	x	x		effect		x	
Sharp													
RedFlow	ZBM							s		On-board	x	x	None
Panasonic	Smart Energy Storage System (SESS)	4.0 kWh - 1MWh			x	x	x	x					
Greensmith	PowerVault				x x x	x x x	x x	x		Fire			
LG					x	x			x	Fire	x	x	Available on request
GE	Durathon E620							x					During
FIAMM	OASIS Zero OASIS One	20kWh -											
Demand Energy	Joule.System						x	x					
CODA Energy	(CUSTOM)				x	x			x	Fire			
Axion Power	PowerCube	MW			x	x	x	x		Fire,	x	x	Sulfuric

		Markets								Environmental and Safety			
Manufacturer	Product	Size Range	Product Cost ($/kW-Unit	Installed	Residential	Med Commer	Large Commer	Industrial	Transportation	Key Safety Feature	UL Complia	UL Listed	MSDS Hazmat
CellStrom Gmbh	CellCube	100kWh - 400kWh -			x	x	x	x					
Eos	Eos Aurora		160/kWh	1000/kW				x	x	Water,			
Electrovaya	EnergyBlock				x			x	x	Fire			Electrolytes
EnerDel	SE100-590	100kWh -						x	x	Cell			
MCV Energy		MW				x		x			x	x	
Primus Power	EnergyPod		500/kWh				x	x					
Xtreme Power	(CUSTOM)						x	x		Fire			
Sunverge	SIS	MW			x					Fire	x	x	
Samsung	Residential Energy Storage Community Energy Storage Peak Shifting	3-10kW 10-25kW MW			x	x	x	x			x	x	
Quantum Power			75	300	x	x	x	x					
Controls and Computing													
Intel													
NREL													
Danfoss	Eco-Flow												
Stem													
Viridity Energy	VPower™					x	x	x					
Q Coefficient													
Enernoc													

APPENDIX C – TECHNOLOGY SURVEY RESULTS

The survey consisted of two parts. The first part asked for general description and the second part consisted of specific questions aimed towards the manufacturers.

Part A consisted of:

- Technology
- Performance Characteristics
- Maturity and Market Status
- Cost-Effectiveness
- Safety
- Environmental Considerations

Part B consisted of the following questions:

1. Can you explain some unique facets of your technology?
2. Have you had any new products released in the last two years?
3. What are the adaptations you have made to your product in the last two years?
4. Do you work with multiple battery chemistries?
5. How many field installations do you have?
6. Have you or are you working with electric utilities?
7. Do you have reliability data on the systems?
8. Do you have any planned product releases?

Ambri

Technology: Ambri is commercializing an innovative electricity storage technology known as the Liquid Metal Battery (LMB) for use in electricity grid-scale energy storage applications. It is unique from any storage technology currently available or in development today – low cost, long lifespan, operationally flexible and safe. Ambri's LMB technology was invented at the Massachusetts Institute of Technology (MIT) in the lab of Professor Donald Sadoway. Research at MIT was funded by the U.S. Department of Energy through the ARPA-e program, Total, and other partners. Ambri was founded in 2010 to commercialize the technology. Ambri's investors include Bill Gates, Total, Khosla Ventures, KLP Enterprises and Building Insurance Bern (GVB). To date, Ambri has raised over $50 million and has contracts to deploy seven energy storage systems to customers in 2015 and 2016.

Performance Characteristics: Ambri's systems have DC-DC efficiencies approaching 90%. If constantly cycled at C/5 (C-rates determine the speed at which the battery charges or discharges, (e.g., C/5 corresponds to a five hour charge and five hour discharge cycle.), the DC-DC round-trip energy efficiency is 80%. It's important to note that these systems are capable of functioning at different C-rates and therefore providing varied levels of power outputs depending on the needs of customers. For example, for solar integration, a customer may benefit from

operating the battery at C/2 during short periods of cloud cover, but lower C-rates when discharging overnight. Overall system efficiency increases as the C-rate decreases (e.g., C/2 operation is less efficient than C/12 operation.). During renewable integration applications, the battery will be charged and discharged at a variety of c-rates over the course of the day. Ambri has tested its battery against a renewable integration profile and found that the overall roundtrip efficiencies were greater than 88%.

- **Capacity fade:** Ambri has seen negligible fade rate of its cells in lab testing (e.g., 0.0002% per cycle, measured by taking the variance in overall system output in Amp-hours sequentially each cycle). Extended life-cycle testing continues at Ambri, with the expectation that these cells will be operational for decades.
- **Response time:** Ambri's LMB can respond to system signals in less than 50 milliseconds. Unless fully charged or discharged, the battery system will be able to switch from charging to discharging instantaneously.
- **Ramp rate:** Ambri has tested the ramp rate of LMB cells. An individual cell can respond with a ramp rate of 470 Watts per second. When scaled to a 1 MW system, the system can ramp from 0 MW to +1 MW in 1/20th of a second. Ambri expects its battery systems to attain ramp rates as high as 240 MW/minute.

Maturity and Market Status: Ambri is planning to deploy six (6) prototype battery systems in the next year with customers in Massachusetts, Connecticut, New York, Alaska, and Hawaii for renewable integration, demand reduction, congestion alleviation, and Department of Defense applications. Ambri has been awarded a contract alongside Raytheon to deploy a 1 MWh system to Joint Base Pearl Harbor Hickham through a contract with Raytheon.

Cost-Effectiveness: Ambri is not public about its costs, but believes that it will be competitive with all technologies on the market and in development.

SafetyAmbri has conducted a thorough assessment of the potential hazards of our product, including operation at an elevated temperature, chemical, and electrical hazards. We take these concerns very seriously, and have designed all Ambri systems to the highest safety standards, resulting in a battery chemistry and integrated system that we believe have fundamental safety advantages over many other conventional cell chemistries including the following:

- High temperature tolerance above and beyond the operating temperature;
- Non-flammable, inorganic electrolyte that is stable with cell materials and ambient conditions.

1. Can you explain some unique facets of your technology?

Ambri's LMB is the only battery where all three active components are in liquid form when the battery operates. Each cell is a steel crucible container, and the three liquid layers float on top of each other because they are different densities and different levels of immiscibility. The cathode liquid metal is on the bottom; a molten salt is in the middle; and a molten metal anode is on the top.

The liquid nature of the active components leads to the long lifespan nature of battery; the liquid electrodes do not experience the same degradation mechanisms that are common in solid state batteries, like particle cracking and dendrite formation. The LMB operates at 475°C. The Mg||Sb chemistry (depicted in the brochure on our website) is illustrative and not the chemistry Ambri is

commercializing. In a charged state, there is potential energy between the top metal layer and the bottom metal layer which creates a cell voltage. To discharge the battery, the cell voltage drives electrons from the Mg electrode, delivering power to the external load (e.g., light bulb), and the electrons return back into the Sb electrode. Internally, this causes Mg atoms to shed electrons and dissolve into the electrolyte as positively charged ions, then pass through the salt and alloy with Sb, forming an Mg-Sb alloy. To recharge, power from an external source (e.g., wind turbine) pushes electrons in the opposite direction, pulling Mg from the Mg-Sb alloy, forcing it through the electrolyte as an ion, and re-depositing Mg back onto the top layer, returning the system to three distinct liquid layers.

2. ***Have you had any new products released in the last 2 years?***

   N/A

3. ***What are the adaptations you have made to your product in the last 2 years?***

   N/A

4. ***Do you work with multiple battery chemistries?***

   No.

5. ***How many field installations do you have?***

   (See above and below, question 9.)

6. ***Have you or are you working with electric utilities?***

   Several electric utilities are engaged in Ambri's first demonstration projects, including Con Edison in New York, the Hawaiian Electric Company and Alaska Power and Telephone.

7. ***Do you install products on the customer side of the meter, utility side or both?***

   Both.

8. ***Do you have reliability data on the systems?***

   N/A

9. ***Do you have any planned product releases?***

   We will be deploying six systems in 2015 and 2016. Customers include the following entities with the value proposition in parentheses:

   - Joint Base Cape Cod (lower costs, reliability, onsite renewable integration)
   - Naval Submarine Base (lower costs, reliability, onsite renewable integration)
   - SunEdison, Hawaiian Electric Company, and Hawaii Natural Energy Institute (lower costs via reduced diesel consumption, more renewable resources and grid stability)
   - Con Edison, NYSERDA (lower costs, grid resiliency)
   - University of Alaska Fairbanks, Alaska Power and Telephone (Lower costs via reduced diesel consumption, more renewable resources and grid stability)
   - Joint Base Pearl Harbor Hickam (lower costs, reliability, onsite renewable integration)

Aquion

Technology: The Aquion Energy Aqueous Hybrid Ion (AHI) battery is a novel electrochemistry whose discharge/charge mechanism is based on multiple ion intercalation mechanisms. The AHI products use a water-based electrolyte with multiple ions (including sodium and lithium), a manganese oxide cathode, and a carbon/titanium phosphate anode. This novel electrochemistry combines the best attributes of other aqueous systems (cost, safety, ease of integration, self-balancing) with the strong and robust cycling attributes of intercalation based batteries (deep discharge and partial state of charge cycle life). Deep discharge cycle life is at least 3,000 cycles and these batteries have been specifically formulated to provide high efficiency (>85%) at long durations (4 hours and longer). This electrochemistry is inherently safe while using non-toxic and non-flammable materials. The Aquion Energy S-Line and M-Line classes of products exclusively use the AHI battery chemistry configured into 48V units. These units can be stacked together in parallel and in series to match the voltage, power, and energy requirements of any application.

Performance Characteristics: The AHI battery has been tailored for daily cycling in long-duration discharges in unpredictable applications (partial state of charge). The products can be discharged from 4 to 20+ hours and are robust to operating at partial states of charge and a wide ambient temperature range. Our batteries deliver all the best attributes of several common chemistries without the common pitfalls: lithium ion cycle performance and stability without the safety and cost concerns; similar cost, safety and ease of integration as lead acid without the negative environmental attributes.

Maturity and Market Status: Aquion S-Line and M-Line products are currently being manufactured in Aquion's facility in Westmoreland, Pennsylvania and are commercially available for sale. Over 100 projects have been deployed since launch in 2014.

Cost Effectiveness: Aquion's products are priced on par with high performance lead acid batteries, well below $500/kWh in 2015 with a path to sub-$200/kWh in the coming five years. This pricing means that Aquion products, coupled with PV, can easily deliver cost savings over diesel and other fossil fuel power generation sources.

Safety: Using a water-based electrolyte means that the AHI battery does not have the same safety concerns of other advanced batteries that use a highly flammable organic solvent. AHI batteries do not require fire suppression or individual battery management to maintain safe operation. As compared to lead acid, there are no toxic metals in the AHI battery and the electrolyte, unlike sulfuric acid, is non-caustic. The chemistry is inherently more tolerant to overcharge and overdischarge, no safety concerns in normal or even abusive operation.

Environmental Considerations: The S-Line AHI product has earned the Cradle to Cradle Institutes Bronze certification. This is the only energy storage product that has earned a full sustainability certification by an independent third party. Using environmentally benign materials, no corrosive acids or noxious fumes, the product is suitable for broad deployment globally.

1. ***Can you explain some unique facets of your technology?***

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2. ***Have you had any new products released in the last two years?***

Aquion has released several product iterations of its S-Line battery stack product; each improving the value proposition to the end-customer through increased energy density and better rate performance. The latest product, the S20-P08F delivers the best rate performance to date (4-8 hour discharges) while maintaining Cradle to Cradle certification and a lead acid battery competitive price position.

3. What are the adaptations you have made to your product in the last two years?

Aquion's technical team continues to drive continuous improvement in the S-Line and M-Line products. Good engineering design improvements have cut the stack impedance in half which improves overall rate performance and energy delivery in the voltage window of 48V commercial off the shelf inverters.

4. Do you work with multiple battery chemistries?

No. Aquion only manufactures Aqueous Hybrid Ion batteries.

5. ***How many field installations do you have?***

Aquion has roughly 100 installations in the field totaling over 5 MWh to date.

6. Have you or are you working with electric utilities?

We are engaged with a broad spectrum of customers from residential end-users to system integrators to the electric utilities themselves. The AHI battery chemistry has applicability for applications in all of these market segments and we are pursuing as appropriate.

7. Do you install products on the customer side of the meter, utility side or both?

Both

8. Do you have reliability data on the systems?

Aquion's fielded systems are roughly one year in the field, so to date we have no statistically significant reliability data other than we've experience no field reliability issues in the past 12 months.

9. Do you have any planned product releases?

Aquion has a very robust technology and product roadmap and will continue to release products with continuous improvements to robustness, rate capability, and energy density over the coming 4-5 years. These product releases will occur at roughly 9-12 month intervals and will progressively improve the overall $/kWh position of the product against both lead acid and lithium ion products.

Eos

Technology: Eos' rechargeable zinc hybrid cathode (ZnythTM) technology has nonflammable electrolyte, is inherently safe, and low-cost. Eos' battery system is comprised of sealed, static batteries containing an aqueous, near-neutral pH electrolyte. The chemistry and design eliminate the need for a membrane separator, cutting out significant cost and a common source of cell failure. Hybridization of multiple cathode reactions improves round-trip

efficiency and enables flexible performance, such that the battery can provide short surges of power with immediate response time in addition to multi-hour discharge at nominal power levels.

The product of the past several years of development and commercialization work, Eos' Aurora 1000|4000 battery system, utilizing the Znyth technology, will be ready for commercial deployment starting in 2016. The Eos team believes that further development of the Znyth technology and Aurora system will lead to increased cycle and calendar life. Further cost reductions are forecasted and can be attributed to performance improvements in the technology, manufacturing processes, operational improvements, and the realization of minimal economies of scale.

Performance: The Aurora 1000|4000 system, utilizing Eos' proprietary zinc hybrid cathode (ZnythTM) technology, will have the following performance specifications:

- **Power|Energy:** 250 kW sub-system with 4 hours of continuous discharge; 1MW|4MWh standard system size.
- **Retail Price:** $160/kWh for volume purchases of 10MW or greater
- **Round Trip Efficiency:** >75% @ 100% DOD, and 87% @ 50% DOD
- **Cycle Life:** 5,000 cycles
- **Expected Calendar Life:** 15 years
- **Self-Discharge:** 15% per month
- **System Voltage:** 320-960 min/max VDC; 768 nominal VDC
- **O&M:** No periodic replacement of components, low operating and maintenance costs
- **Density:** Compact footprint for use in dense urban load centers or space-constrained areas
- **Response Time:** millisecond response
- Inherently safe, using nonflammable electrolyte and nonhazardous materials

Maturity: Eos successfully manufactured and delivered the company's first AC-integrated Aurora battery system for installation in Rochester, NY. The 6 kW|18 kWh integrated and containerized Eos battery system is currently being tested in a variety of behind-the-meter applications, including peak load shaving, and demand charge management.

- European energy giant GDF SUEZ has purchased a second Eos Znyth™ battery system in 2014. The 8 kW|24 kWh integrated and containerized Eos battery system will be tested at GDF Suez' Laborelec testing facility for solar PV integration, wholesale market arbitrage, and frequency regulation applications. The sale marks the next phase in Eos' pilot program and sets the stage for commercial deployment in major European markets.
- In 2014, Eos expanded its manufacturing capability through contract manufacturing partnerships to scale towards commercialization and the capacity to produce MW-scale batteries in 2015/16.
- Eos is currently accepting orders for its 1 MW|4 MWh Aurora product for deliveries starting in 2016.

- Eos has recently closed its Series C round of funding for approximately $22MM.

Cost Effectiveness: Eos intends to sell its proprietary rechargeable ZnythTM (zinc hybrid cathode) battery for $640/kW or $160/kWh, with costs confirmed by DNV GL to be in the range of $91.08kWh to $116.00/kWh at 100MW production volume. Using Eos' DC battery system, Eos expects its AC system up to 30% less expensive than the next lowest cost competitor. At this price point, the Aurora system can supply peaking capacity at lower cost than new combustion turbines in almost all locations. Eos is able to achieve this price by engineering materials to be low cost, and by employing exclusively low-cost, highly standardized manufacturing processes.

Safety: Successful 3rdparty testing with DNV GL confirms stable battery performance and safety. The chemistry used in the Eos electrochemical couple is exceptionally non-reactive under conditions that can cause thermal runaway in other systems. DNV GL has conducted 3rd-party evaluation of Eos cells, finding that after significant abuse testing (short-circuit, high temperatures, overcharging, etc.), there was no incidence of fire, explosion, venting, or leaking. Furthermore, all cells were able to continue functioning after abuse with no lasting effect. Eos' electrolyte is non-flammable and does not have a flash point.

Environmental Considerations: Eos' battery system is designed to be inherently safe and environmentally friendly. The water-based electrolyte is non-flammable, and non-toxic. Eos uses a series of electrolyte additives and catalysts that prevents any hazardous or toxic gases from being generated. Heat generation during battery operation is expected to be minimal.

1. ***Can you explain some unique facets of your technology?***

   (See above, with emphasis on price)

2. ***Have you had any new products released in the last 2 years?***

   Respondent skipped this question.

3. ***What are the adaptations you have made to your product in the last 2 years?***

   Reduced cost and lowered manufacturing CapEx.

4. ***Do you work with multiple battery chemistries?***

   No, Eos only works with a proprietary zinc hybrid cathode system (Znyth), using abundant, low cost materials. The aqueous, near neutral electrolyte enables the technology to provide high energy capacity while remaining inherently safe.

5. ***How many field installations do you have?***

   Eos plans to install 1MW/4MWh of systems in the second half of 2015 and the first quarter of 2016, and then will start shipping MW-scale units to customers.

6. ***Have you or are you working with electric utilities?***

   Yes, much of Eos' near-term sales and marketing efforts have been focused on engagement of large, strategic customers through a formalized and collaborative effort called the Eos Genesis Program. This early adopter program entails partnership

with approximately seven major utilities with highly characteristic applications that have and will continue to participate in the development and demonstration of Eos' first generation product. High levels of back-and-forth engagement with these Genesis Partners continue to allow Eos to refine and optimize its final product offering to best serve the needs of these select customers—and by extension the needs of similar customers. Current Genesis partners include NRG, ConEdison, American Electric Power, GDF Suez, Enel, National Grid, Exelon, and PNM.

7. Do you install products on the customer side of the meter, utility side or both?

We do both utility-scale and behind-the-meter projects.

8. Do you have reliability data on the systems?

We have reliability data from our 6 kW|18 kWh system and from numerous other Eos systems and batteries tested internally and externally.

9. Do you have any planned product releases?

We're focusing on our MW-scale product but plan to release other products in the near future.

Imergy

Technology

- Vanadium Redox Flow Battery.
- Unlike Incumbent VRB providers or other flow technologies, Imergy uses a proprietary electrolyte formulation providing unprecedented operational flexibility and performance at low cost.
- While conventional energy storage products self-consume (degrade) over time, Imergy provides a long life asset in the form of non-degradable electrolyte.

Performance: We released ESP5 and ESP30 in 2014 and ESP250 in 2015.

Maturity: IMERGY has introduced three platforms addressing the whole range of applications allowing to address a range of Markets/Applications:

- **ESP5:** small load, DC-coupled 5 – 7kW / up to 30 kWh
- **ESP30:** medium load, AC-coupled 30 – 50 kW / up to 200 kWh
- **ESP250:** large load, AC-coupled 250 kW / 1200 kWh

Cost-Effectiveness: there are two metrics of used by energy storage industry participants to describe the cost competitiveness of an energy storage technology: cost per kWh of storage capacity and levelized cost of energy, or 'LCOE.' Using either metric, Imergy offers one of the lowest cost means of storing electrical energy available today.

Imergy's proprietary electrolyte formulation and stack design allows reductions in the product and operational costs, enabling our energy storage solutions to achieve the lowest total cost of ownership, or LCOE, in many applications. Also delivering very low LCOE.

Safety: Imergy's ground-breaking Energy Storage Platform (ESP) provides an affordable energy storage solution that dramatically reduces the physical dangers and environmental toxicity inherent in traditional batteries. The ESP is constructed with non-flammable, non-explosive materials, and an innovative electrolyte made from recycled vanadium which has no cycling limitations and does not degrade over time.

Environmental Concerns: By implementing manufacturing and operating strategies with a low environmental impact, Imergy provides a truly sustainable energy storage solution:

- Where others supply a consumable needing periodic full replacements, we offer a long life asset.
- Proprietary electrolyte formulation allows us to use lower grade. recycled vanadium reducing cost and environmental impact.
- The balance of plant is composed of common fully recyclable components making the Imergy ESPs cradle to cradle systems.

1. ***Can you explain some unique facets of your technology?***

- Proprietary Electrolyte formulation vs traditional VRB for increased operational range and non-degradable, re-usable asset value
- Proprietary Stack Design for reduced cost and added reliability
- Turnkey containerized AC systems
- Safety (Non-poisonous, Non-flammable, Non-explosive)
- Low environmental impact (cradle to cradle)

2. ***Have you had any new products released in the last two years?***

   We released ESP5 and ESP30 in 2014 and ESP250 in 2015.

3. ***What are the adaptations you have made to your product in the last two years?***

   All ESP platforms use identical core technology and components, enabling scale economics and common operations:

   - Same stack design
   - Same electrolyte formulation
   - Same operational monitoring and control methods
   - Same safety systems

4. ***Do you work with multiple battery chemistries?***

   <blank>

5. ***How many field installations do you have?***

   250

6. ***Have you or are you working with electric utilities?***

   Yes

7. Do you install products on the customer side of the meter, utility side or both?

Both

8. Do you have reliability data on the systems?

Yes

9. Do you have any planned product releases?

We have a roadmap of new releases but have not publicly announced the details at this point.