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Recovery Act – Solid State Batteries for Grid-Scale Energy Storage

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Disclaimer

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Executive Summary

The purpose of this project was for Seeo to deliver the first ever large-scale or grid-scale prototype of a new class of advanced lithium-ion rechargeable batteries. The technology combines unprecedented energy density, lifetime, safety, and cost. The goal was to demonstrate Seeo's entirely new class of lithium-based batteries based on Seeo's proprietary nanostructured polymer electrolyte. This technology can enable the widespread deployment in Smart Grid applications and was demonstrated through the development and testing of a 10 kilowatt-hour (kWh) prototype battery system. This development effort, supported by the United States Department of Energy (DOE) enabled Seeo to pursue and validate the transformational performance advantages of its technology for use in grid-tied energy storage applications. The focus of this project and Seeo's goal as demonstrated through the efforts made under this project is to address the utility market needs for energy storage systems applications, especially for residential and commercial customers tied to solar photovoltaic installations. In addition to grid energy storage opportunities Seeo's technology has been tested with automotive drive cycles and is seen as equally applicable for battery packs for electric vehicles.

The goals of the project were outlined and achieved through a series of specific tasks, which encompassed materials development, scaling up of cells, demonstrating the performance of the cells, designing, building and demonstrating a pack prototype, and providing an economic and environmental assessment. Nearly all of the tasks were achieved over the duration of the program, with only the full demonstration of the battery system and a complete economic and environmental analysis not able to be fully completed. A timeline over the duration of the program is shown in figure 1.

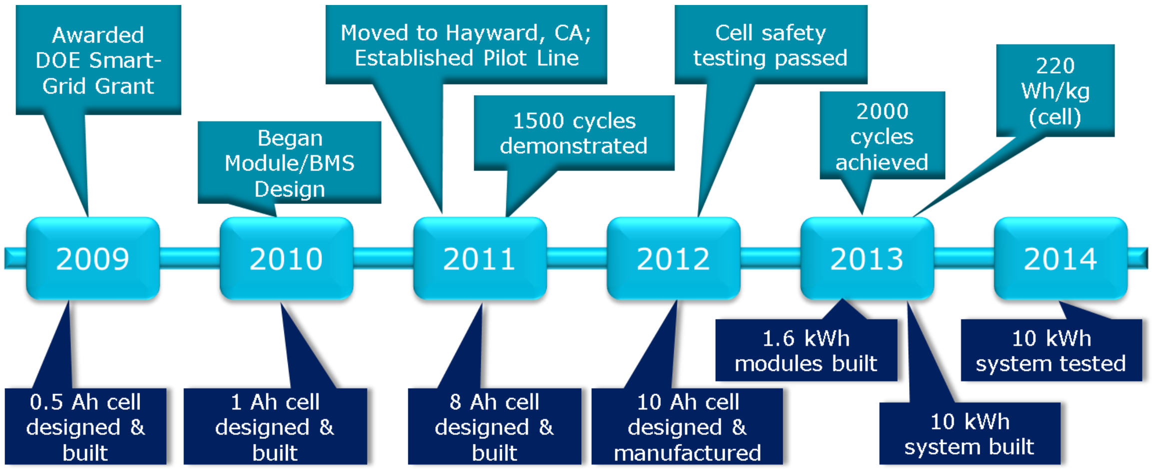


Figure 1: Timeline of program and major achievements

Source: Seeo, Inc.

The following are the main achievements of this project:

- The core technology, the solid polymer electrolyte was scaled up from lab size batches to production sized batches. Seeo has developed and demonstrated a low cost manufacturing process of the polymer and that the solid polymer electrolyte can be manufactured using high volume commodity materials.
- Seeo has scaled up cells from small Research & Development (R&D)-sized cells to large format cells with 100 times the capacity and energy of the R&D cells.
- Seeo has invested in and installed a pilot manufacturing line in Hayward, California allowing Seeo to produce the large format cells on pilot line manufacturing equipment according to processes that are easily transferable to a high volume manufacturing set-up.
- Seeo further designed and built a prototype battery pack based on the large format cells developed. This battery pack had 10 kWh of energy and was of a size that is particularly relevant for residential energy storage applications when paired with a photovoltaic array. Seeo performed internal testing where the system performed as intended. The system was then installed at an off-site field site and demonstration was started. Initial performance showed that the battery system performed as designed. Unfortunately, after a few weeks of testing the system did experience a failure that resulted in a thermal event and a loss of the system. Based on a thorough failure analysis it was determined that an overvoltage from the inverter and/or improper setting of the voltage limits in the battery management system was the most probable cause of the

incident. Due to the loss of the system the data that was required to perform the final data analysis was not compiled and the final evaluation was not accomplished.

- As part of the project the University of California, Berkeley (UCB) was to incorporate the data gathered from the battery system in an impact analysis. However, even though it was not possible to include the field data, to provide a partial delivery on this task UCB did provide to Seeo a report that amongst others concludes that energy storage in the form of low cost batteries will be an important contributor to mitigating greenhouse gas emissions in the future.

Seeo continues to develop its technology and is on a path to achieving 300-400 Wh/kg in cells, is aggressively pursuing market opportunities, sees strong and growing interest from potential customers and strategic partners for its technology, and is committed to commercializing its proprietary technology. Seeo expects to further to expand its activities in the US and California.

Seeo would like to thank the United States Department of Energy, and specifically the Office of Electricity Delivery and Energy Reliability (OE), which manages the Smart Grid Program. Seeo would also specifically thank Dr. Imre Gyuk and his team for their support and guidance during this project.

Introduction

Background

Seeo was founded in 2007 with the goal of creating a new class of high-energy rechargeable lithium-ion batteries based on a nanostructured polymer electrolyte initially developed at the Lawrence Berkeley National Laboratory under funding from the Department of Energy's Batteries for Advanced Transportation Technology (BATT) program. Seeo has continued the development solid-state lithium-ion batteries based on this proprietary dry polymer electrolyte technology, and offers superior energy density and lifetime performance. The core technology developed by Seeo is the dry, solid polymer electrolyte (DryLyte™), which is non-flammable and non-volatile. The company is headquartered in and has its pilot line manufacturing facility in Hayward, California.

Lithium-ion batteries in today's markets face challenges with combining the requirements demanded by the market for superior safety, lifetime, energy density, and low cost. Chemical degradation leads to premature failure in existing applications, and poor lifetimes prevent lithium-ion cells from addressing new key markets. The efforts to increase energy density and to provide longer operating duration while at the same time minimizing cost has exposed the vulnerability of this system. The safety performance and high cost of lithium-ion cells are major concerns, and this becomes especially critical for larger energy storage capacities required for electric vehicles and grid-connected applications. Wide scale deployment of lithium-ion technology and other energy storage technologies faces obstacles due to such concerns.

Seeo has developed a proprietary polymer electrolyte platform that enables a new generation of rechargeable lithium-ion batteries. Performance results are included in this report. Seeo's technology, which was developed and demonstrated here in California, represents a unique solution for addressing critical national needs for electric vehicles and large-scale renewable energy storage.

Seeo Solid-State Battery Technology

Seeo's solid-state battery technology offers batteries with 220 Wh/kg in the present generation developed under this project, and is already demonstrating cells in the 300-400 Wh/kg in the latest generations of the technology. The technology also offers batteries, with long reliability and the promise of lower costs. The key to these products lies in Seeo's solid DryLyte™ electrolyte, which replaces the liquid electrolyte typically found in other lithium-ion batteries, and enables the use of a lithium metal anode that provides a significant boost in energy density. A battery, such as a lithium-ion battery, consists of an anode (negative electrode), a cathode (positive electrode), a separator in between the anode and cathode that insulates the anode and cathode from each other, and an electrolyte that provides the transport of ions from one side of the battery to the other. The direction of the transport of the ions depends on whether one is charging or discharging the battery.

The unique characteristics of Seeo's DryLyte™ solid polymer electrolyte is that it functions both as a separator and an electrolyte, and allows Seeo to safely use the lightest and most energy efficient anode material, lithium metal. In this way, Seeo cells use standard cathode materials and manufacturing processes and achieve at least 50 percent higher energy density than other existing lithium-ion technologies. The structure of Seeo's unique technology is shown in Figure 2.

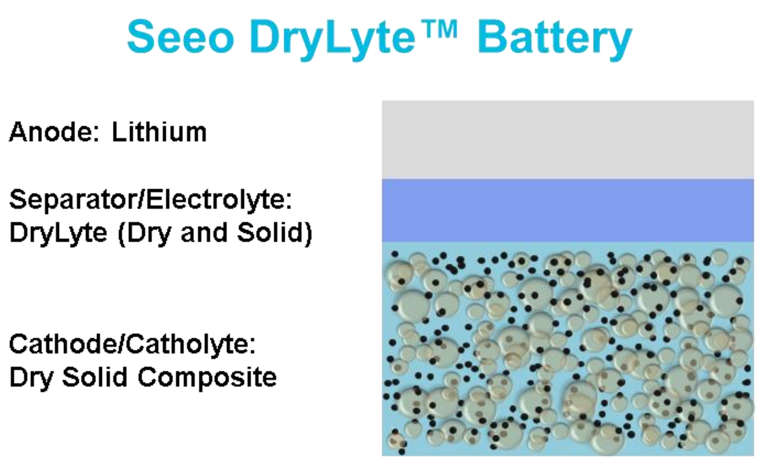


Figure 2: Structure of Seeo DryLyte™ Cell

Source: Seeo, Inc.

Smart Grid Program

The funding for this project was received as a cooperative research agreement under the Department of Energy's Smart Grid Demonstration Program – Demonstration of Promising Energy Storage Technologies (Program Area 2.5) of FOA DE-FOE-0000036.

The intent of this Smart Grid Demonstration project was to build a large scale battery pack based on Seeo's solid state lithium-ion technology and show the improvements the technology offers in energy density, lifetime, safety and cost relative to state-of-the-art lithium-ion batteries. Originally this was outlined as a 25 kilowatt-hour (kWh) battery pack, but was later proposed and agreed with DOE to change to a 10 kWh battery pack that was found to be a better fit with the residential or commercial applications that it would be tested toward. The

Seeo core technology difference is its electrolyte: it is entirely solid state, with no flammable or volatile components. This solid polymer electrolyte material is able to transport lithium-ions while providing inherently safe and stable support for high-energy electrodes. As a result, the batteries can make transformational and quantifiable improvements in cost, energy density, safety, and lifetime.

The scope of the DOE Smart Grid Program was to range from fundamental studies and improvements of the active materials associated with the Seeo's technology to building a proof of concept demonstration unit to assess the benefits of the technology to address the utility market needs for Community Energy Storage System (CESS). Significant functional activities would involve material optimization, material synthesis and cell assembly process development, and pack design, assembly, testing and demonstration.

CHAPTER 1: Project Objectives and Phases

1.1 Project Objectives

The main objectives to be achieved over the four year duration of the project are listed in the below Table 1 with the results that were achieved.

Table 1: Program Objectives and Achievements

Project Objectives	Results Achieved
First-ever demonstration of a 25 kWh battery pack based on Seeo's solid state lithium-ion technology	A 10 kWh* battery pack was designed, built and tested in 2013. In internal testing the battery pack performed as intended. When installed in the field a thermal event and loss of the system occurred due to a likely significant overvoltage condition (discussed elsewhere in this report).
10-15+ years' operating life with 3,000-5,000 or more cycles	Seeo demonstrated R&D cells with over 2,000 cycles, and large format 10 Ah cells with over 1,000 cycles that project to 3,000 cycles (with more than 80% of initial capacity remaining).
A safe materials platform with no volatile or flammable components	The solid polymer electrolyte (DryLyte™) that is the core technology developed by Seeo is a non-flammable and non-volatile electrolyte and a safety improvement over existing liquid electrolytes used in lithium-ion cells.
Greater than 50% improvement in weight and energy density over existing lithium-ion batteries	Seeo has achieved large format 10 Ah cells that achieve 220 Wh/kg, which represents 40% or greater improvement in specific energy density versus existing large format lithium-ion cells on the market today.
A 35% cell cost reduction from existing lithium-ion batteries	Seeo is confident that this cost target can be achieved with a high volume manufacturing set-up and with the improvements in cell energy density. Today Seeo is manufacturing at low volumes for sampling to customers and it is therefore not realistic to have achieved this target today.

* Note: It was agreed with DOE to change the size of the pack to a 10 kWh battery to match the DOE Sunshot project Seeo had been awarded. Functionality is the same for a 10 kWh and a 25 kWh system.

Source: Seeo, Inc.

In addition, or as part of the larger objectives listed in the above table a number of other key tasks were to be performed. These tasks included qualification of the prototype battery pack, and specifically:

- Demonstration of charging and discharging
- Performance evaluation and validation of specifications

The battery pack performed full charge and discharge cycles both at Seeo and after being installed in the field. The pack also went through internal testing at Seeo before being shipped to the field demonstration site, and showed that the battery was fully functional and performed as specified and intended. After installation at the off-site location the field demonstration was not completed due to technical issues that occurred after one month of field set up and various trials, and in advance of the full scale field testing that had been planned. The pack suffered a thermal event during charging of the battery system, where the battery pack suffered significant damage and there was heat and smoke damage to an adjacent circuit panel and conex.

Seeo conducted a thorough failure analysis and root cause analysis of the incident. The battery pack had been paired with a photovoltaic array and a bi-directional inverter and overvoltage from the inverter and/or improper setting of the voltage limits in the battery management system was determined to be the most probable cause of the incident.

As a result of this incident Seeo determined that a redesign of the battery modules and pack electronic system would be required that would go beyond the duration of this project. In discussions with DOE it was agreed to end the project and proceed to complete the final close out of the project.

Data collection was limited due to the loss of the battery pack, which impacted the longer term data collection that would be shared with UCB and amongst others used for the data analysis and conclusion of the measurable benefits of pairing a battery system with renewable energy sources.

Independent analyses of the environmental and economic impact of lithium-ion battery improvements and, specifically, those improvements offered by Seeo's technology demonstration in the United States, including:

- Baseline technological and economic gap analysis of lithium-ion technology for utility storage applications
- Correlation of how improvements in performance can affect market penetration as well as the economic and environmental impact of lithium-ion technology
- Creation of a general template for impact analysis in grid-tied distributed energy storage

- Analysis of data from Seeo's demonstration project as a full scale impact analysis case study.

Seeo engaged University of California Berkeley (UCB) as part of this project to perform the economic and environmental analysis, and they completed an in-depth study of the impact of various grid-tied energy storage systems (including low cost batteries) that is referenced in this report. Due to the lack of the battery pack data from Seeo the UCB report is a stand-alone document but the main conclusions of the report are included as they are judged to be valuable input to the overall evaluation of energy storage. As intended longer term data collection from Seeo's battery pack was not achieved it was not possible to incorporate this into the UCB report.

The benefits derived from the work performed and achieved during this project have been the stimulation of the United States and California economies and advancement of high technology and manufacturing capabilities are as follows:

- Partnership of key utility-scale energy storage stakeholders in manufacturing, technology development, system integration, and academia.
- The direct creation and/or retention of over 20 full time engineering positions in in the development of advanced rechargeable battery technology for the benefit of the grid, renewable energy technologies and automotive (plug-in electric vehicles) applications.
- Demonstration of a technology that can be manufactured in scale in the United States, with the potential for creating roughly 1,500 direct and indirect jobs per 100 MWh produced.

All of these three objectives were achieved with Seeo engaging with a number of potential customers in the utility and renewable energy sector, building up a complete battery system and getting the system installed in the field paired with a photovoltaic array. Seeo has a dedicated team of engineers and skilled laboratory and manufacturing technicians, with a fully functional pilot line in Hayward building large form factor cells for sampling to potential customers.

Beyond the detailed project objectives and impacts described in this section, this demonstration project was intended to represent a seed for a new United States advanced rechargeable battery industry, one that leverages domestic technology innovation and a domestic supply chain to gain a competitive advantage in the global market. With continued demonstrated successful customer development there is significant market potential for Seeo's products in markets that already multi-billion USD markets.

1.2 Project Phases

Based on the goal of achieving the objectives over the four years of the program the project work was split into three phases as follows:

Phase I - Project Definition and NEPA Compliance

Phase I of this project was to include all activities needed to provide the foundation for initiation of a successful program. The project manager worked with all relevant stakeholders to undertake a comprehensive review, update, and approval of the project plan, including all activities, targets, budgets, deliverables, baseline standards, and all other aspects of the project. The project manager also coordinated National Environmental Policy Act (NEPA) compliance and any other logistical or regulatory approvals necessary before the project began. The tasks in this phase were defined as follows:

Task 1.1 – Update Project Management Plan (PMP)

Task 1.2 – Nationals Environmental Policy Act (NEPA) Compliance

Task 1.3 – Develop Interoperability and Cyber Security (I&CS) Plan

Task 1.4 – Develop Metrics and Benefits Reporting Plan

The work performed in Phase I is not directly reported in this report as these items were accomplished at the start of the program and were approved by DOE before proceeding to Phases II and III where the development, scale-up and demonstration work took place.

Phase II - Scale-up and Performance Optimization

In Phase 2, Seeo's technical team completed all activities related to scale up, optimization, and validation of Seeo's battery cell technology at the scale needed for the final demonstration. This work consisted of three parallel development efforts, through which materials were optimized for best-in-class performance (by materials and cell technology teams), materials syntheses were scaled to demonstration-level yields (by materials team), and cell processes were scaled to allow for production of cells at demonstration-level capacities (by cell technology team). Cell-level battery performance was qualified in-house and in conjunction with independent testing labs, and was benchmarked against targets for project gating.

Phase III - Pack Design/Demonstration, and Economic/Environmental Analysis

Phase III consisted of integrating Seeo's now-validated cells into a full demonstration pack prototype. Seeo's technology team designed and constructed a 10kWh battery pack with full systems to allow for optimal performance and qualification testing, with additional oversight and input from industry and utility supporting organizations. Pack performance in the design and construction phase was to be tested on an iterative basis by both Seeo and an outside partner. Testing of the final demonstration pack was originally intended to be validated by an independent testing lab (e.g. Exponent Associates). Data collected from final pack testing, in addition to all data collected over the course of the project, was intended to be compiled and distributed to DOE, and analyzed for public dissemination in journal publications and conferences. Demonstration data collected in Phase II was to be analyzed by UCB Energy and Resources Group as part of an ongoing economics and environmental impacts research program that would span the entire project duration and culminate in a comprehensive impacts assessment and projection.

1.3 Milestones

The milestones for the project were outlined with target dates for achieving the milestones. Seeo achieved the major milestones of building and demonstrating the performance of the technology in high capacity cells, scaling up the core polymer technology, manufacturing over 1000 cells, and designing, building and testing a 10 kWh battery system. However, Seeo was not able achieve the final two milestones as they related to longer term pack testing and validation and the impact analysis that had been planned based on the longer term testing. The milestones are listed in the Table 2 below, which summarizes when the milestones were actually achieved and where there were any variances to the original milestones.

Table 2: Project Milestones

Milestone Number	Milestone Title	Milestone Status	Milestone Planned Finish Date	Milestone Actual Finish Date	Milestone Variance Narrative
1	High capacity cell packaged - no performance losses	Complete	6/30/2011	6/30/2011	
2	Polymer temperature and voltage assessment complete	Complete	9/30/2011	9/30/2011	
3	Produce a total of 1000 cells with optimized power and energy	Complete	12/31/2011	3/31/2011	Milestone achieved in 2011 for smaller form factor cell, and in 2013 over 1000 large format (>10 Ah) cells produced on pilot line
4	Polymer scale up (10+kg) and analysis complete	Complete	12/31/2011	12/31/2011	Polymer batches of >10 kg manufactured and scale up of >100 kg achieved for core polymer materials
5	Finalize pack design	Complete	6/30/2012	6/30/2012	Module, BMS and thermal management for prototype pack designed
	Complete prototype test plan	Complete	10/31/2012	7/15/2013	
6	Prototype pack assembly complete	Complete	1/15/2013	7/15/2013	Delivered in July'13 for PV array demo
7	Complete prototype pack performance testing and validation	Incomplete	6/30/2014	6/30/2014	Seeo performed internal testing and validation, and one month of field testing was performed. Full testing was not able to be completed due to failure of system.
8	Presentation of Final Economic & Environmental Findings	Incomplete	6/30/2014	6/30/2014	General findings were achieved through UC Berkeley report, and Seeo business plan. However complete analysis not achieved due to lack of field data as a result of pack failure.

Source: Seeo, Inc.

1.4 Budget and Funding

The total budget for this DOE Cooperative Agreement was $12,392,000, with the federal government's funding of $6,196,060. The cost share for the project was 50% and Seeo has provided funding of $6,196,062.

CHAPTER 2: Phase II - Scale-up and Performance Optimization

As mentioned, the goals of this phase of the program were to develop and scale up the materials, including Seeo's proprietary and unique solid polymer electrolyte, transfer the material developments in to cells, scale up both the cell size and the manufacturing of the cells. This work required efforts in optimizing the materials and cell, and testing and evaluating cell performance characteristics was also critical.

2.1 – Task 2.1. Cell Scale-Up

The goal of this part of the project was to scale-up the technology from using small single electrode cells (Research & Development [R&D] cells) to large format cells, including incrementally scaling up and validation testing of polymer synthesis, electrode coating and cell fabrication. The large format cells were to be used for the demonstration pack.

2.1.1 - Electrode Fabrication Scale-Up

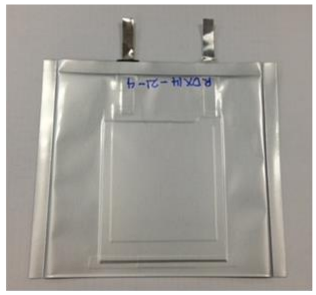
One of the essential steps was for Seeo to transition from a small R&D coater to a large form factor coater that could coat both the cathode material and the polymer onto a substrate that would match the commercially available dimensions of lithium metal anode material.

Seeo invested in and installed a pilot line coater in its facility in Hayward in 2011. Seeo also hired key personnel that had previous experience in successfully transferring and scaling-up lithium-ion technology from research and development level technology to large scale manufacturing of lithium-ion electrodes and cells. Part of this transition was to switch from the lab scale coating to consistent high quality coating on a pilot coating machine that has the same quality levels as the high volume coating machines that would be required for mass production.

The results of the successful collaboration between the R&D and the pilot production teams at Seeo in achieving the transition of the technology from R&D to pilot production are demonstrated in the following sections.

2.1.2 - Cell Fabrication

Seeo employs a R&D cell with a capacity of 50-100 milli-Ampere-hour (mAh) as the platform with which it carries out the primary development work. This is both from a practical point of view as many iterations are required to find the ideal combination, and it is also a more cost-effective way to perform the development work as less materials (and hence less costs) are required for each experiment and trial. Figure 3 shows an image of a R&D cell, with dimensions and capacity of these R&D cells listed below the image.



R&D Cell
Capacity: < 100 mAh
Size: 95 x 95 x 0.4 mm

Figure 3: Seeo R&D Cell

Source: Seeo, Inc.

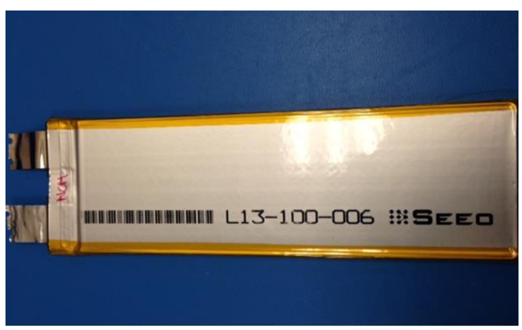
Once the basic experiments and development work was performed Seeo transitioned the technology to large form factor cells. It is important to note that incorporating the technology developed in the R&D cells to the larger form factor cells was not a trivial matter and required extensive focus on reproducibility and quality, as the surface areas are increasing exponentially and potential for inconsistencies in quality increase many fold. Seeo therefore elected to take a two-step approach whereby it first transferred and demonstrated the technology on what Seeo identifies as Large Format Cell 1 (or Single-bundle cell). The Large Format Cell 1 has a capacity of about 2 Ampere-hour (Ah) (see Figure 4 for an image and for further details), in other words twenty (20) times the capacity of the R&D cells. This scale-up allowed for a measured transition of the technology to larger form factors, and also reflected a lower cost approach as it is a cell of about 20 percent of the capacity of the final large format cell that was required for the battery pack.

Large Format Cell 1
Capacity: ~2 Ah
Size: 72 x 234 x 2 mm

Figure 4: Seeo Large Format Cell 1

Source: Seeo, Inc.

Once the performance had been verified in the Large Format Cell 1 (Single-bundle cell) Seeo proceeded to combine five of these into a single Large Format Cell 2, which has a capacity of over 10 Ah. The five single bundle cells of 2 Ah each were connected together through a tab-welding process before being inserted in the pouch material that makes up the outside packaging material of the final cell. An image of such a cell is shown in Figure 5, with the dimensions and capacity of the cell noted.



Large Format Cell 2
Capacity: 10-20 Ah
Size: 72 x 234 x 9 mm

Figure 5: Seeo Large Format Cell 2

Source: Seeo, Inc.

In 2012 and 2013 Seeo successfully transitioned through these phases and achieved a fully functional Large Format Cell 2 that was used to build up the battery pack system in addition to performing testing and evaluation. This 10 Ah cell could be used in battery systems for both electric vehicle use and grid energy storage systems.

2.1.3 - Development of Solid-State Manufacturing Process

In addition to the electrode fabrication, which is one of the most critical processes in the manufacturing of quality lithium-ion cells, Seeo also built up a pilot production line at its facility in Hayward, California. Seeo's manufacturing process is very similar to traditional lithium-ion manufacturing with four main differences:

- No need for anode coating – Seeo's technology employs a lithium metal anode
- Seeo employs a second coating on the cathode to apply its proprietary polymer electrolyte – however, this eliminates the electrolyte filling for traditional lithium-ion cells mentioned below
- No need for electrolyte filling – Seeo avoids the more cumbersome and quality sensitive process step in traditional lithium-ion cell fabrication as those cells require a liquid electrolyte.
- No formation required – time consuming and costly investment in traditional lithium-ion manufacturing.

All of the other manufacturing process steps are essentially the same as with traditional lithium-ion manufacturing. In Figure 6, the flow diagram and images illustrate Seeo's cell manufacturing process. The images are of the actual equipment installed at Seeo's facility in Hayward, California.

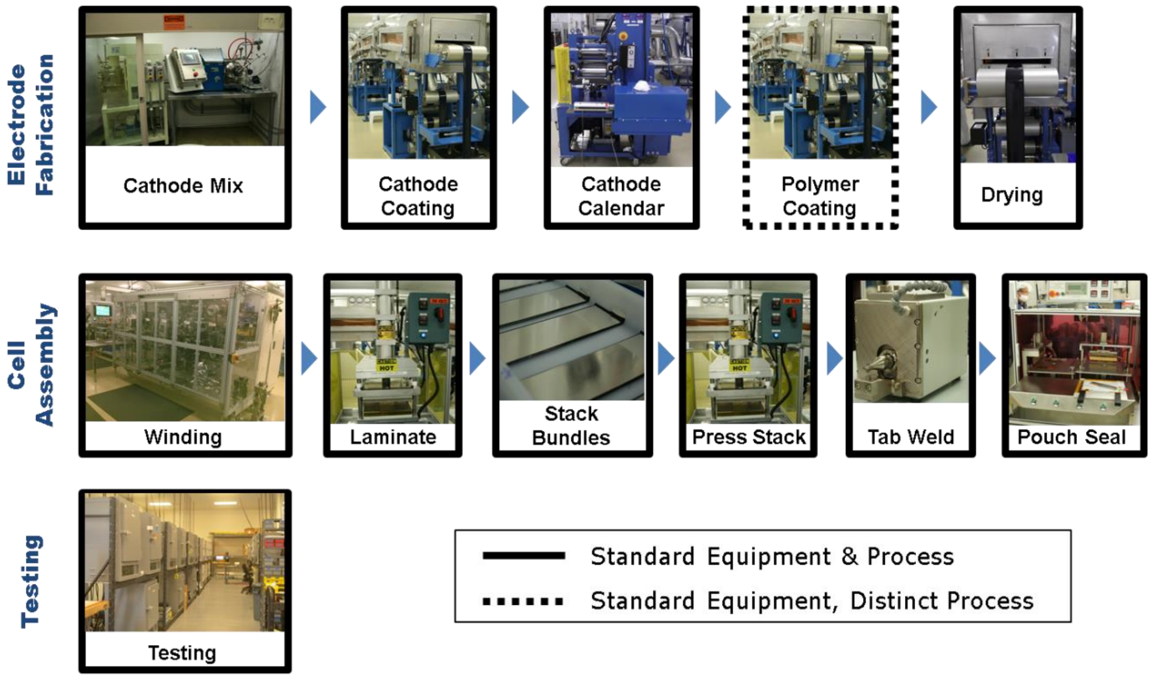


Figure 6: Process Flow – Seeo Pilot Manufacturing Line

Source: Seeo, Inc.

Seeo's manufacturing process therefore offers cost benefits versus existing lithium-ion fabrication due to the elimination of two steps in the manufacturing process: electrolyte filling and the lengthy formation process.

2.1.4 - Achievements and Results

Seeo made significant progress in its scale-up of the cell manufacturing over the duration of this project. Seeo has matured the technology from small R&D sized cells to large format cells with a capacity greater than 10 Ah. At the same time, the company made great strides in achieving a high level of maturity in its manufacturing of the large format cells, both in terms of duplicating the performance from the small R&D cells, but even more importantly achieving a consistent output from the pilot line in Hayward.

In 2013, Seeo manufactured 1,100 large form factor cells and the yields from the manufacturing line were greater than 95 percent for the whole year, with the first and fourth quarter of the year achieving 99 percent yield (see Figure 7). These are values that are the targets for volume manufacturing in order to have a high quality and cost effective production. Seeo is already achieving this on its pilot line, and the processes being employed on the pilot line are all transferable to high volume manufacturing.

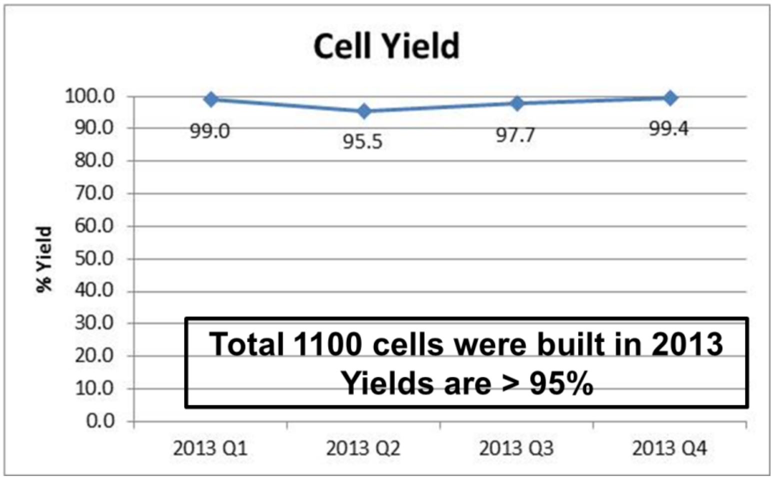


Figure 7: Yield from Seeo Cell Pilot Production (2013)

Source: Seeo, Inc.

The data in the following table and figure further reinforces the high level of quality in the output from Seeo's pilot production line. Table 3 shows data for 152 cells that were manufactured sequentially in 2013, with some of the key performance and quality characteristics of the cells listed, including cell weight, impedance and capacity. All cells are according to specifications set by Seeo, and have a very tight distribution of the values.

Table 3: Cell Characterization Data from Continuous Cell Build (2013)

Performance Characteristic	Unit of Measure	Average	Standard Deviation
Cell Weight	Grams	173.5	1.362
Equivalent Series Resistance (ESR)	mOhm	16.36	0.55
Capacity @ C/5	Ah	11.2	0.09
Energy Density, Gravimetric	Wh/kg	221	1.77

Source: Seeo, Inc.

The 220 Wh/kg in gravimetric (specific) energy density represents an improvement of greater than 40% over existing large format lithium-ion cells, with the exception of the latest generation 18650-cell, and was a substantial improvement over the lithium-ion cells available at the start of this project.

Figure 8 shows the cycling performance of small R&D cells and large form factor production cells. The solid line shows that the R&D cells have demonstrated 2,000 cycles (100% depth-of-discharge) with 80% of original capacity remaining. The dotted line shows the large form factor production cells, which are showing better capacity retention than the R&D cells, and have achieved 1,000 cycles with capacity retention at about 95%. These cells are projecting that they would achieve 3,000 cycles with greater than 80% of capacity remaining. These large format cells are demonstrating an improvement in the cycle life performance versus the R&D cells and confirm that transferring the technology and scaling it up into larger format cells has been achieved.

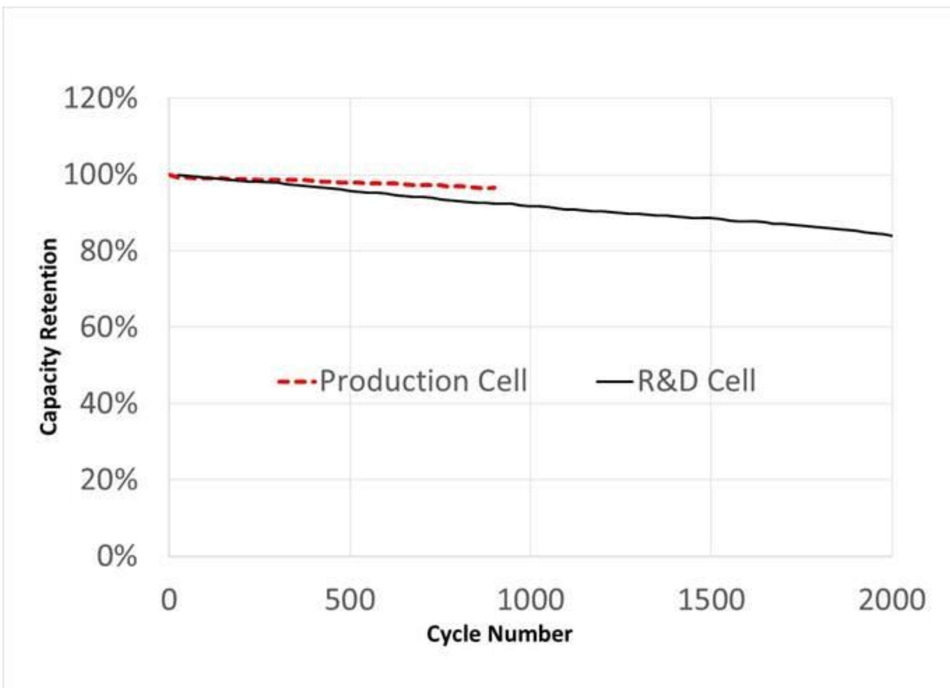


Figure 8: Cycle Stability of R&D and Large Format Cells

Source: Seeo, Inc.

Through these results, the scale-up of the cells was demonstrated and the data from the large form factor cells showed the same or better performance than the R&D cells, and a uniform high quality. With this performance data it was concluded that the cell technology was of such a consistent and uniform high quality standard that the project could proceed to designing, assembling and demonstrating the technology in a battery system.

2.2 – Task 2.2 Materials Scale-Up

The goal of this task was to optimize the material properties of Seeo's proprietary polymer electrolyte and to scale-up the polymer from lab-scale amounts to amounts required for prototype manufacturing (i.e., at least 10 kg batches).

2.2.1 - Development of Polymer Materials

The mechanical rigidity and ionic conductivity of Seeo's proprietary solid polymer electrolyte are crucial to the low-cost, efficient, safe, and long-life performance promised by Seeo's solid-state lithium-ion batteries. Seeo's core solid polymer electrolyte is a composite with multiple polymers covalently bonded as a block copolymer, with one block responsible for mechanical stability and one for high conductivity. Previous attempts to develop an electrolyte compatible with rechargeable lithium metal anodes have failed. For instance, cross-linked polymer electrolytes have at best achieved a mechanical storage modulus on the order of only 1 Mega Pascal (MPa), 1000-fold less rigid than what is theoretically required to cycle stably against lithium metal anodes. Seeo's electrolyte demonstrates achieving the required properties to allow for stable cycling of lithium metal based cells.

2.2.2 - Scale-up of Polymer Materials

Seeo's technology evolved from fundamental research originally performed at UCB's Lawrence Berkeley National Laboratory (LBNL). At that stage, the polymer materials were synthesized in small quantities using laboratory techniques capable of producing tens of grams per batch. These early techniques had extreme sensitivities and required dangerous synthetic methods in order to achieve the high molecular weight polymers that resulted in the best electrochemical performance. As successive generations of the technology have come on-line, Seeo's materials research team has explored numerous synthetic approaches keeping cost, safety, and scalability in mind. By taking this approach, Seeo has developed an extremely low-cost, energy-efficient and scalable synthetic process for volume manufacturing of high molecular weight copolymers useful in energy applications. Seeo's current generation solid polymer electrolyte can be manufactured using high volume commodity reagents that help ensure a long term cost-down approach as demand for the electrolyte grows. Figure 9 shows actual images from the fabrication of Seeo's solid polymer electrolyte in larger quantities.

Polymer collection & centrifuge | **Polymer vacuum drying** | **Final polymer bagged**

Figure 9: Scale-Up of Seeo DryLyte™ Polymer

Source: Seeo, Inc.

Through various development stages, Seeo has partnered with different chemical companies to produce its proprietary solid polymer electrolyte material. Using an approach of separating the syntheses of the different components of the copolymer amongst different partners, Seeo has demonstrated that crucial know-how can be compartmentalized and that intellectual property (IP) security can be maintained.

2.2.3 - Achievements and Results

Scale-up of core material has been demonstrated in large volume (greater than 100 kg) batches using techniques and equipment easily modified to multi-ton batch sizes. Table 4 shows the progress Seeo has made over the years since its start in 2007 in increasing the batch size and scaling the process of fabricating the DryLyte™ solid polymer electrolyte. The polymer materials are meeting performance and quality specifications and requirements for high-capacity cells, as demonstrated in the cells that Seeo has manufactured on Seeo's pilot line facility in Hayward, California.

Table 4: Polymer Scale-Up Timeline

Year	Polymer Scale-Up
2007-2009	50-100 g lab batches synthesized at Seeo
2010	500 g lab batches synthesized at Seeo
2011	Scalable process demonstrated at Seeo, 500 g synthesized
2012	Scalable process tested outside Seeo at 3rd party, 10 kg synthesized
2013	Scalable process used to manufacture polymer in >100 kg batches
2014	On-going cost down optimization

Source: Seeo, Inc.

2.3 – Task 2.4 Polymer Power and Temperature Optimization

Polymer optimization was carried out in two parallel paths. The first path focused on improving the low temperature rate performance of Seeo's system. The second path dealt with improving rate performance of the high temperature system while maintaining high reliability.

Efforts directed at lowering the operating temperature of the system dealt with changing the chemistry of the polymer electrolyte. The focus was on preventing crystallization of the polymer and on increasing the flexibility of the polymer chains at the molecular level in order to facilitate faster ion movement at low temperatures. Concurrently, it was necessary to maintain electrochemical stability with the electrode systems. Numerous polymer chemistries were explored to reach this goal. Seeo attempted to co-polymerize novel monomers with the conventional polymeric systems as well as to develop architectural variations at the polymer chain level that could improve ion conduction. Figure 10 below shows the conductivity results of some of this work as compared to the conventional polyether based electrolyte. While improvements in conductivity were attained at low temperature with new systems when compared to the low temperature conductivity of the conventional electrolyte, the resulting conductivities were still not high enough for practical rate performance at low temperature.

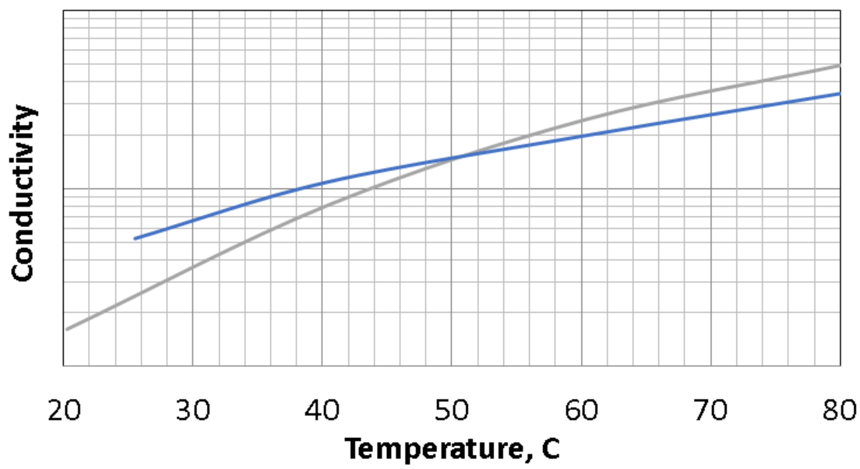


Figure 10: Conductivity comparison of a material developed under this program to that of the conventional polymer electrolyte.

Source: Seeo, Inc.

Efforts directed at improving rate performance at high temperature were carried out in this program as well. The focus at high temperature was on optimizing the phase ratio of the nanostructured electrolyte, optimizing salt concentration, and altering molecular architecture to maximize conductivity while maintaining reliability of the system. The challenge with the approach dealt with the trade-off in conductivity and mechanical strength. The conductivity of the system could be increased with a decrease in the reliability and vice versa. Trying to overcome this fundamental limitation led to new architectural designs at the molecular level. Also through this effort, a novel means of synthesizing the polymer electrolyte was developed and has been applied to large scale production of the polymer electrolyte. The data in Figures 11 and 12 below detail some of the efforts made at optimizing high temperature performance with regard to salt concentration and phase ratio.

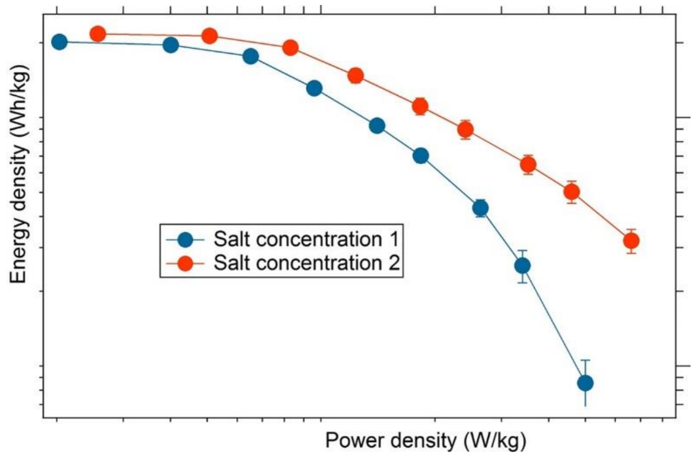


Figure 11: Rate capability improvements attained through optimization of salt concentration.

Source: Seeo, Inc.

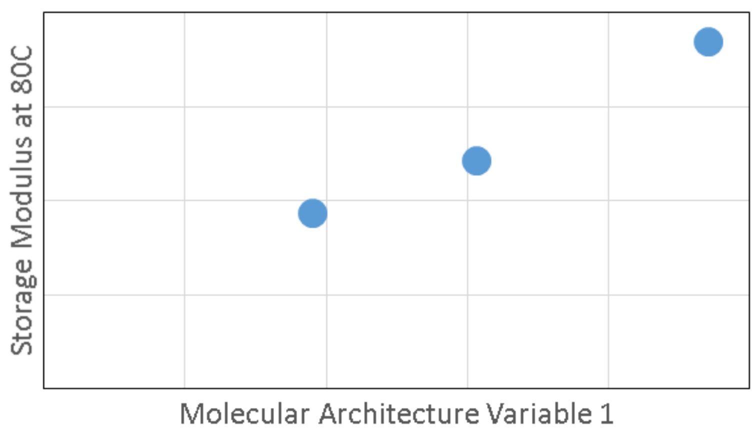


Figure 12: Improvements to modulus attained though optimizing the phase ratio and molecular architecture.

Source: Seeo, Inc.

2.4 – Task 2.5 Polymer Voltage Stability and Energy Density Optimization

One of the goals of this program was to alter the polymer electrolyte to increase stability at higher voltages. With a high-voltage-stable system, alternative electrode materials could be employed in the cathode with the outcome of increasing energy density. This task was approached in two ways. The first approach involved screening commercially available polymer materials for high voltage stability. The second approach dealt with synthesizing new monomers and pendant groups for improved polymer stability. While some promising initial results were attained regarding voltage stability, the polymers were not ionically conductive enough to be practical. Figure 13 shows two examples of materials made with improvements to voltage stability over the conventional polymer electrolyte. Due to the low conductivity, it was determined that this aspect of the project would not be feasible with the given resources and desired time schedule. The preliminary work done, however, set the foundation for another project focused solely on this goal of high-voltage-stable electrolytes. Further work was carried out in a parallel effort with separate funding from DOE.

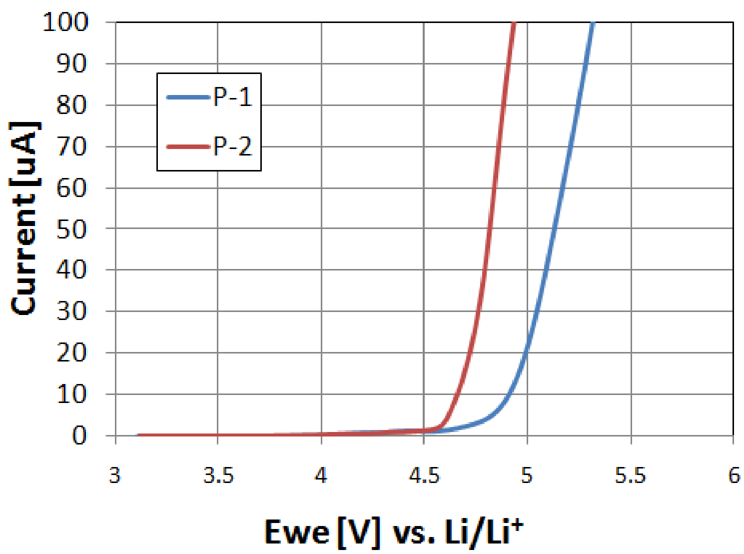


Figure 13: Cyclic voltammetry results of two of Seeo's catholyte polymers.

Source: Seeo, Inc.

CHAPTER 3: Phase III - Pack Design/Demonstration & Economic/Environmental Analysis

The goal of this task was to design, build and perform validation testing of a battery pack for grid-tied demonstration and performance testing. Originally this had been planned as a 25 kWh system, but was later in agreement with DOE revised to be a 10 kWh battery pack. The background for this change was that Seeo had been awarded a project under the DOE's Sunshot program where a 10 kWh battery pack was a more relevant system size when paired with a 10 kW photovoltaic system for a proposed field demonstration of a combined photovoltaic and energy storage system. The overall battery pack architecture would be identical whether it was a 25 kWh or 10 kWh system, only with lower energy content, and would therefore serve the same purpose. In the original objectives of the project it had been intended that Seeo would work with a third party systems (pack) developer to design and assemble the battery system. However, in 2011 Seeo set up a systems team with employees that had experience from automotive battery pack design and development. The design, assembly and testing of the battery system according to the objectives of this project were therefore performed in house.

3.1 – Task 3.1 Pack Design and Construction of Prototype

In order to achieve a 10 kWh battery pack it was determined that a total of 288 cells, each with a capacity of 10 Ah, would be required. As part of Seeo's system development effort Seeo designed a module that would be a sub-system and a building block for designing the complete battery pack. The module consisted of 48 cells that were coupled in series to achieve the desired voltage. Each module had an energy content of 1.6 kWh and was an ideal building block for other energy storage systems, be they for grid energy storage or use in electric vehicles.

3.1.1 – Pack Design

The design of the 10 kWh battery pack consisted of the following components:

- 288 cells of 10 Ah each
- Six Modules of 1.6 kWh each
- Mechanical parts
- Insulation
- Heating elements
- Cooling system (including fan)

- Battery Management System (electronics hardware and software)
- High Voltage Direct Current
- High Voltage Power Distribution
- Outer enclosure (metal cabinet)

The architecture of the 10 kWh battery system can be seen in Figure 14. The battery pack consisted of six modules, coupled two in series and three in parallel, to achieve the desired voltage and capacity of the battery system. In addition to the modules the various other components, including cooling system, high voltage circuit and connectors, display panel and metal cabinet to house the complete system are illustrated. Seeo chose a metal cabinet that was of an environmental standard such that the complete battery system could be installed outdoors.

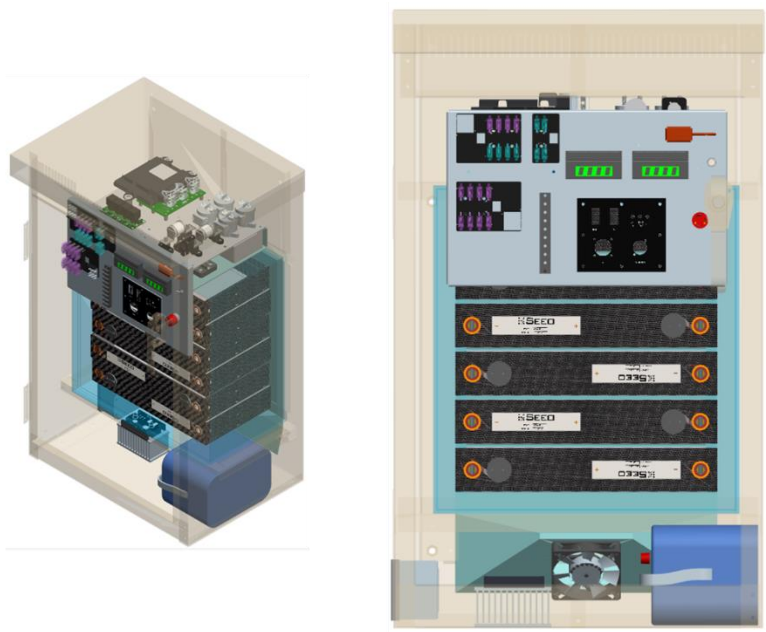


Figure 14: Architecture of Seeo 10 kWh Energy Storage System

Source: Seeo, Inc.

3.1.2 - Fabrication of Cells and Modules

In preparation for the assembly of the battery system, Seeo manufactured the 288 cells required for the system on its pilot production line in Hayward during 2013. As mentioned earlier, Seeo manufactured a total of 1100 cells of the 10 Ah Large Format Cell 2 during 2013, all of which were used for various forms of testing, evaluation and for assembly into modules. The modules that were built by Seeo were either used for various forms of testing by Seeo or tests specified by and performed in collaboration with potential partners. For the 10 kWh battery pack encompassed by this project, six modules were used.

The most critical part of the assembly of the pack is the actual assembly of the module, which is the building block for the system. Each module consists of 48 cells, heating elements, battery management system to monitor and control the cells, and the mechanical parts to hold the various components. Seeo specifically designed the module with lightweight mechanical parts to ensure that the already superior energy density of the cell technology was reinforced by the mechanical construction of the module. Figure 15 shows an image of the module with the main specifications of the module listed in the table on the right.

1.6kWh Module
Configuration – 48S1P

Electrical Specification	
Capacity (Ah)	10.0
Nominal Voltage (V)	164
Energy (kWh)	1.6
Continuous Power (kW)	0.8
Specific Energy (Wh/kg)	150
Energy Density (Wh/l)	185
Mechanical Specification	
Dimensions (mm)	445 x 79 x 250
Volume (l)	8.8
Weight (kg)	10.5
Temperature Specification	
Operating Temp (°C)	-40 to +70
Other Specification	
Environmental	IP68, IP6K9K
Communication Protocol	CAN 2.0B Modbus 1.03

Figure 15: Specification of Seeo 1.6 kWh Module

Source: Seeo, Inc.

Assembly of the cells into the modules, the assembly of the module with its additional electrical and mechanical components, and subsequently assembly of the complete battery pack was performed by Seeo internally. Seeo performed extensive testing and validation of the modules.

3.1.3 - Assembly of Prototype Pack

Seeo successfully assembled the 10 kWh battery pack in house by our own employees. From the cell fabrication through the electrical and mechanical assembly of the modules and pack, Seeo designed and built up a complete battery pack.

In Figure 16 is a photograph of the 10 kWh battery pack and the specifications of the battery pack are also listed in the table on the right. The housing of the battery pack was specifically chosen to meet requirements for the system to be able to be installed outdoors. In addition to the assembly of the battery pack, it was also tested at Seeo to confirm full functionality.

Electrical Specification	
Min. Capacity (Ah)	30.0
Nominal Voltage (V)	328
Cutoff Voltage Discharge	240
Cutoff Voltage Charge	345
Continuous Power (kW)	5.0
Mechanical Specification	
Dimensions (in)	36 x 18 X 24
Weight (kg)	180
Temperature Specification	
Storage Temp (°C)	-20 to 65
Lifetime Specification	
Cycle Life[1]	3000
Calendar Life (years)	15
Other Specification	
Environmental	NEMA4
Communication Protocol	CAN 2.0B Modbus 1.03

[1] Dependent on customer application requirements

Figure 16: Specification of Seeo 10 kWh Energy Storage System

Source: Seeo, Inc.

3.2 – Task 3.2 Demonstration, Data Collection, Analysis and Dissemination

The original plan was to test the prototype battery pack in-house followed by testing by an independent battery testing group. Subsequently the latter step was modified in agreement with DOE to be a field demonstration. Data from this field demonstration was intended to be used for further data analysis.

3.2.1 - Test Plan and Testing of Prototype Pack

The goal of this task was to demonstrate the performance capabilities and advantages of the battery technology in simulated testing of a grid-tied energy storage device. As the project progressed Seeo was awarded a separate program by the DOE's Sunshot Program. As a result of this development, it was decided to use some of the testing parameters from this program in the testing of the 10 kWh battery pack that was built.

From the start of the project, the intention had been to develop a prototype test plan using utility-derived specifications. Later it was decided to base this testing on the test protocol recommended by the photovoltaic collaboration partner on the Sunshot program. The discharge profiles were derived from *2009_CA_Retail_PV_ESS Data*, which is a duty cycle for an energy storage system paired with a photovoltaic array that was used to test the energy storage system.

Seeo performed initial testing of the battery pack at Seeo, with simulated discharges and charges. An example of this testing is shown in Figure 17, which shows the voltage, current and temperature of the cells.

The objective of this testing was to validate the pack, ensuring the various subsystems were working: communication, battery management system (BMS) functions (state-of-charge [SOC] calculations, power limits, charge control, discharge control), thermal management and safety management.

The profile used for testing was a series of discharge pulses with a low rate charge to simulate load leveling. In addition, a continuous three-hour (C/3-rate) discharge followed by a full charge was also performed. Following the full discharge and charge, the module then resumed the load leveling testing.

The results validated the master control modules ability to monitor SOC and control the pack within its operating conditions. The thermal management system proved capable of maintaining the cells in the specified operating temperature window.

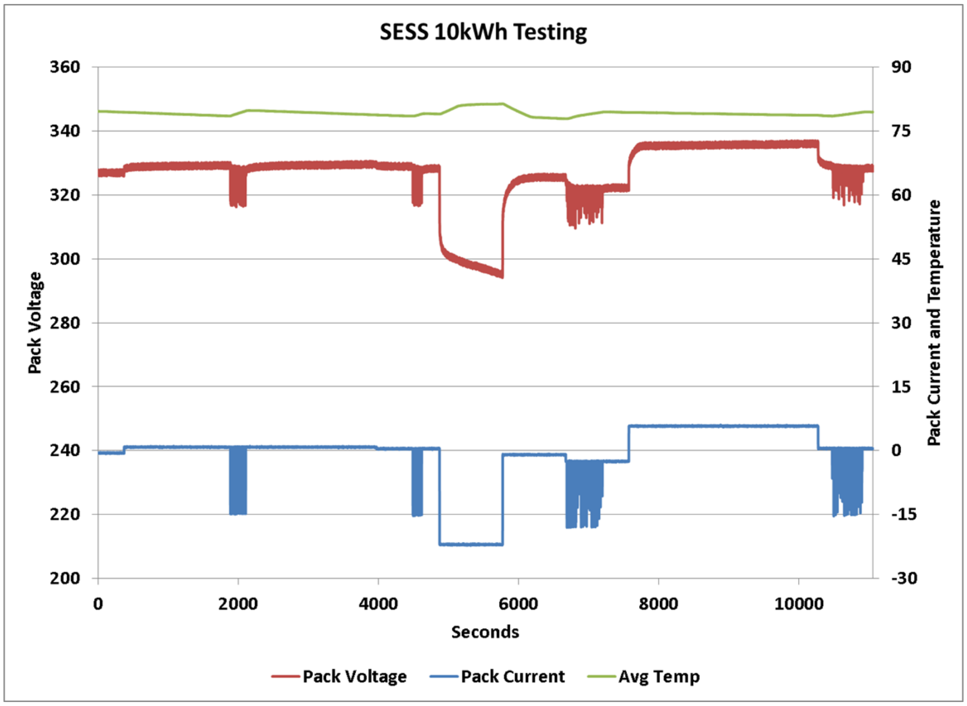


Figure 17: System Testing Data of Seeo 10 kWh Energy Storage System

Source: Seeo, Inc.

3.2.2 - Pack Demonstration and Data

The battery pack was initially tested at Seeo to ensure all performance parameters were functioning as designed. Subsequently the battery pack was installed at the SolarTAC field location in Colorado and paired with a photovoltaic array and a bi-directional inverter. Images from the field location are shown in Figure 18.

Figure 18: Field Installation of Seeo 10 kWh Energy Storage System

Source: Seeo, Inc.

In Figure 19 two weeks' worth of field test data are illustrated. This data, which is based on using the *2009_CA_Retail_PV_ESS Data* for charging and discharging, shows the battery pack receiving charge from the photovoltaic array during the day and discharging during night time.

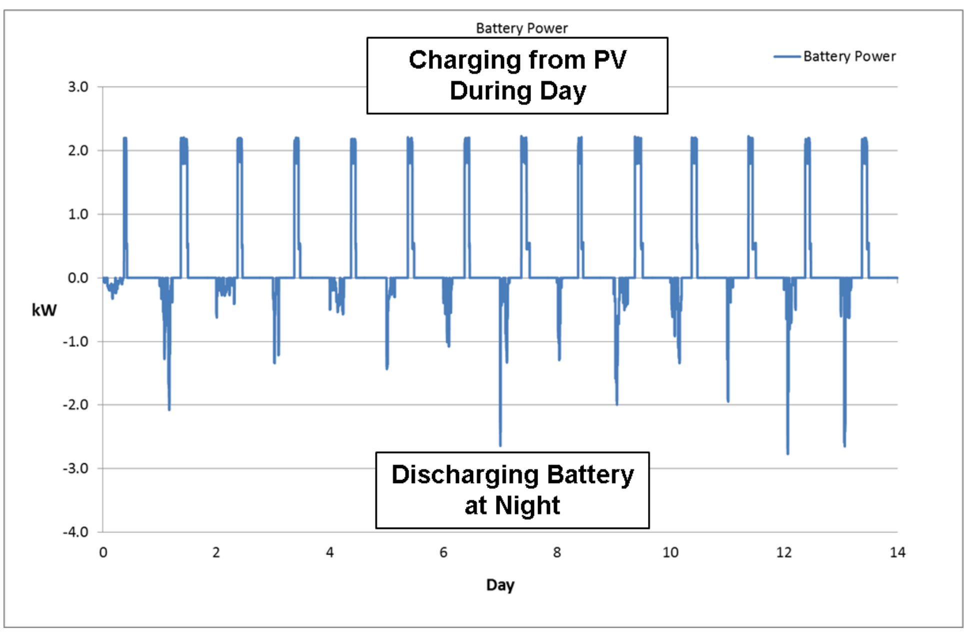


Figure 19: Field Testing Data from Seeo 10 kWh Energy Storage System

Source: Seeo, Inc.

The field demonstration was not completed due to technical issues that occurred after one month of field set up and various trials, and in advance of the full scale field testing that had been planned. The pack suffered a failure that took place during charging of the battery pack, which resulted in a thermal event where the battery pack suffered significant damage and there was heat and smoke damage to an adjacent circuit panel and conex. There were no injuries and no other damage.

Seeo conducted a thorough failure analysis and root cause analysis of the incident. The battery pack had been paired with a photovoltaic array and a bi-directional inverter and the battery had been functioning as intended for several weeks despite the inverter repeatedly triggering the battery management system to automatically shutdown of the battery system. After one month the incident occurred during charging of the battery pack that resulted in the battery pack suffering significant damage. Overvoltage from the inverter and/or improper setting of the voltage limits in the battery management system was determined to be the most probable cause of the incident.

As a result of this incident Seeo determined that a redesign of the battery modules and pack electronic system would be required to ensure such an incident would not occur again and that the system was more adequately protected against overvoltage exposure from sources outside the battery system. It was determined that the redesign of the electronic and battery management system would go beyond the duration of this project. In discussions with DOE it was agreed to end the project and proceed to complete the final close out of the project.

Seeo has continued its efforts independently and has completed a complete redesign of the battery management system (hardware and software), and will be building modules and systems based on the improved architecture in 2015.

Though the planned field testing and analysis of the test data from the field testing was ultimately not completed, the data both from Seeo's initial internal testing and the limited field demonstration shows the battery pack had the required functionality and validated the use of energy storage coupled with an intermittent renewable energy source such as a photovoltaic array. It was also concluded that the initial design of the electronic hardware and software of the system did not have the necessary robustness required, which has since been corrected by Seeo.

3.2.3 - Economic and Environmental Analysis

The goal of this task was to provide an economic and environmental impact analysis of energy storage for grid-tied applications, as well as outline a business plan for how Seeo would intend to commercialize the technology encompassed by this project. UCB was tasked by Seeo as part of this project to perform the environmental and economic impact analysis. Part of this analysis was to be performed based on data and models already developed or under development by UCB, and in addition it had been the intention that Seeo would provide further data from the demonstration as additional input to this analysis. The latter part was not achieved due to the field demonstration project being cut short, but UCB had gathered data from other sources and was able to perform an extensive impact analysis, which is summarized below and available as a separate document.

3.2.4 - Summary of University of California Berkeley Report

UCB conducted an environmental and economic impact analysis of energy storage for grid-tied applications using the SWITCH model ("a loose acronym for solar, wind, conventional and hydroelectric generation and transmission" according to "Switch: A Planning Tool for Power Systems with Large Shares of Intermittent Renewable Energy," Matthias Fripp, published in Environmental Science & Technology, April 16, 2012). A report in connection with this project, titled "Exploring Cost-Effective deployment of Storage Technologies in the WECC Power System with the SWITCH Model" by UCB's Renewable and Appropriate Energy Laboratory (RAEL), is available as a separate reference document. The data contained in this report is from other sources than Seeo's 10 kWh battery pack as it was not possible to provide this data for reasons described above, but encompasses and discusses various storage technologies including low cost batteries which Seeo's technology represents. Seeo therefore sees the report as having value as an input and contributes to the discussion and promise represented by lithium-ion battery systems, including Seeo's technology.

The report is focused on the area of the Western Electricity Coordinating Council (WECC). It explores the power system composition and operations under scenarios meeting a greenhouse gas (GHG) emissions reduction target between present day and 2050. The report takes into consideration traditional and renewable energy sources, transmission, and energy storage. Its stated goal is "to incorporate into a single investment framework the ability to account for both the additional flexibility requirements imposed by intermittency, such as the need for additional reserves and frequent cycling and startups of generation, and the flexibility that can be provided by existing and yet-to-be-deployed technologies" ("Exploring Cost-Effective deployment of Storage technologies in the WECC Power System with the SWITCH Model" by

UCB’s Renewable and Appropriate Energy Laboratory (RAEL)). The report discusses the various available electricity sources in the region, including renewables such as wind and solar photovoltaic, and specifically addresses energy storage as an important component and solution in the years through 2050.

The report finds that storage with duration of several hours can complement solar photovoltaic generation on a daily basis, charging in the middle of the day when excess photovoltaic energy is available and releasing in the evening and at night when the sun goes down. In the results shown, storage deployment can be cost-effective throughout WECC, but its economics may be particularly favorable in regions where large-scale solar photovoltaic deployment may also take place, such as California and the rest of the Southwest.

The UCB report’s main assumption is that GHG target for 2050 is 80% below 1990 levels. The report emphasizes that different GHG emission reduction pathways may have different balancing requirements and operational timescales for storage. Solutions that are designed with several hours of energy storage, for example, may not be sufficient to balance wind-dominated power systems, as wind power in WECC exhibits large seasonal variability and several hours of storage may therefore not be sufficient.

The following are excerpts of the main conclusions regarding energy storage from the report:

- Solar photovoltaic deployment is a main driver of storage deployment: its daily generation cycle provides opportunities for daily arbitrage that storage with duration of several hours is well suited to provide
- Storage operation is very different from present day patterns – storage tends to charge during the day when solar photovoltaic is available and discharge in the evening and at night
- Similarly, the ability to shift loads to the daytime solar peak could have cost-reduction benefits for the system
- If low solar photovoltaic costs and low battery costs are achieved, the two technologies may be deployed at large-scale, displacing concentrated solar power (CSP) with thermal energy storage (TES) in order to achieve the target GHG levels mentioned
- The combination of SunShot solar technology and advanced battery technology has the largest impact on total storage capacity deployment and potential savings between present day and 2050

The report finds that storage is a critical element of power systems with a high penetration level of renewables and low GHG emissions. Lowering the cost of storage in the near- and mid-term is indispensable to containing the overall cost of these systems in the future. According to the report, among its most important findings is that the combination of achieving the DOE's SunShot initiative targets (for photovoltaic) and the Low-Cost Batteries targets set by Advanced Research Projects Agency-Energy (ARPA-E) would result in the lowest cost of all the scenarios that are investigated in the report. The report states that the SunShot and Low-Cost Batteries scenario projects "the average cost is less than $147 per MWh in 2050," and "also provide substantial savings in the near- and mid-term." The report concludes that policy ought to be designed to promote technological learning and cost reductions through performance incentives and gradual scale-up targets.

Seeo finds that the report validates the support and funding by the DOE for energy storage technologies, such as Seeo's technology, and that energy storage solutions, and especially low cost batteries, will be crucial to climate change mitigation. The report does state that the most significant impact of energy storage will come after 2030, but points out that R&D funding of new technologies (such as that represented by Seeo's technology) and deployment of energy storage technologies and especially batteries now and in the years to come is important in order to drive the costs down. Even though initial costs today may be higher than the target costs, these costs will be small in comparison to the overall costs of the power system as the storage component represents a smaller component of the overall system in these initial years until economies-of scale are achieved, leading to cost reductions that then can lead to higher levels of deployment of battery storage.

3.3 – Task 3.3 Develop Manufacturing Scale-Up Business Plan

3.3.1 - Seeo Business Plan and Scale-Up

Through the work performed under this project, which was made possible by the support of the Department of Energy, Seeo has been able to scale-up both its core solid polymer electrolyte technology and cell technology, as well as demonstrating that Seeo's technology can be mass-manufactured. Seeo is committed to commercializing the technology here in the United States and in California and intends to further scale up its manufacturing capability to be able to more widely sample and qualify its technology with potential customers.

The funding provided by the DOE for this project has involved the participation and engagement of over 20 full-time employees, represented by both existing employees and hires during the early part of the project. Though it is hard to predict, Seeo expects to expand its work force as required in connection with continued expansion of its customer opportunities in both grid energy storage projects and electric vehicle programs. Seeo's technology is equally well suited to both of these applications. Initially this increase in employees will be modest, perhaps up to a doubling of the present workforce over 1-2 years to match the sampling of Seeo's product to customers for testing and qualification, but as progress towards commercializing the technology the hiring could lead to substantially higher numbers.

Seeo is targeting market opportunities in both the grid energy storage segment and the electric vehicles as these markets will be utilizing the same cells as the automotive industry. The battery packs will be different for the various applications but the base cell is expected to be the same to leverage the cost advantages offered by high volume demand from both of these markets. There are many projections for the potential size of these market segments over the coming years, and Seeo has made the following projections in Figure 20 based on various market projections:

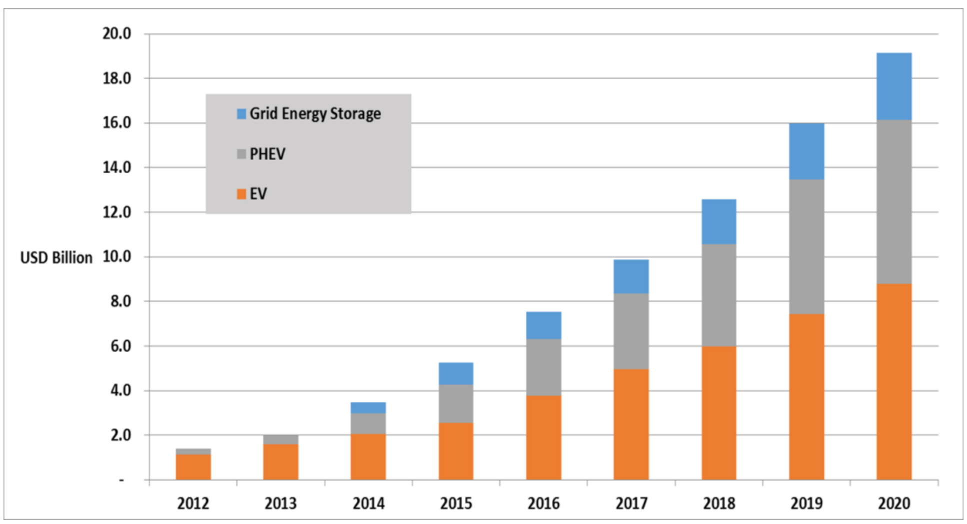


Figure 20: Market forecast for Plug-in Electric Vehicles and Grid Energy Storage

Source: Seeo, Inc. estimates based on data from B3 (2012), AABC (2013); Pike Research (2012)

As can be seen, these market segments expect to see significant market growth over the coming years, with the market reaching over $20 billion early in the next decade. At that time it would be double the size of the existing lithium-ion market for portable electronics. Seeo's technology is ideally suited for these applications that require light and high energy density batteries.

Seeo's first step in addressing the market is to further scale up its manufacturing capability to be able to more widely sample and qualify its technology with potential customers. Seeo already has established testing and evaluation of its present technology with customers. The initial step will be to expand its existing pilot line in Hayward and Seeo has plans to increase the capacity ten-fold from its present 2-300 kWh production capacity to 2-3 MWh of cell production. Seeo expects to expand its workforce as required in connection with continued expansion of its customer opportunities in both grid energy storage projects and electric vehicle programs.

From there Seeo expects to build a high volume manufacturing plant with one or more strategic partners. Seeo will leverage the manufacturing expertise and capital base of these potential strategic partners to most efficiently build out and continually expand the manufacturing capacity. Seeo will bring its unique technology and process knowhow and experience with our technology to the partnership. Seeo expects to have a significant ownership stake in these partnerships, which likely would take the form of joint ventures.

Seeo has already made significant progress with two strategic partners and is therefore well prepared to take this step once the technology is deemed mature and customers have been signed up to enter high volume production. Seeo has adopted this partnership strategy to allow it to go to market in a measured manner with experienced partners, which also builds the confidence of potential customers.

The following Figure 21 illustrates the anticipated scale up and commercialization timeline that Seeo expects to achieve. This schedule assumes that one of the strategic partnerships mentioned earlier is established and the manufacturing plant will be set up starting from late 2016.

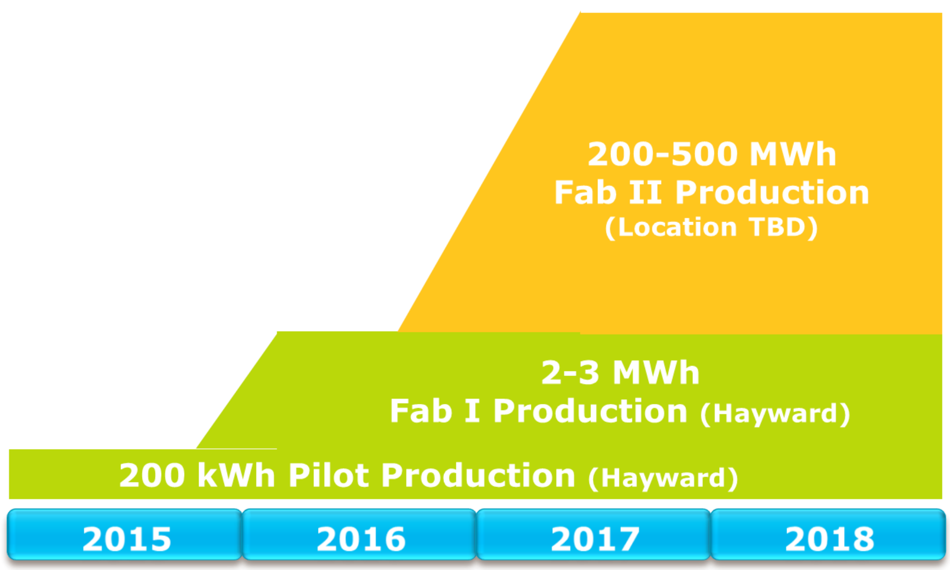


Figure 21: Seeo forecasted Manufacturing Capacity Expansion

Source: Seeo, Inc.

Seeo has actively been pursuing and engaging with customers in the United States and globally in both the automotive and grid storage market segments. Seeo has and continues to receive strong interest from a broad range of well-recognized companies in both of these market segments. This has been witnessed on various testing and evaluation of Seeo's technology by these companies. The activity is expected to increase in 2015 as the company continues to improve its technology. Seeo will use the increased capacity of its line in Hayward to sample and proceed through the qualification process with several of these customers. The expanded pilot line would have an output of up to 200 battery systems per year depending on the size of the systems, which should initially be sufficient for the anticipated qualification process.

The large scale manufacturing coming online in late 2016 and 2017 should match requirements from customers for production quality units, and achieving high volume manufacturing later in 2017 and into 2018.

3.3.2 - Cost Model and Estimate

Cost is an important competitive parameter in the battery industry. Cost is typically defined in $/kWh, especially for batteries for electric and plug-in hybrid electric vehicles, while $/kW is a more relevant comparison for batteries for hybrid electric vehicles where the power capability is the competitive parameter. As Seeo's technology is a high energy technology the $/kWh value is discussed. Seeo is still in the pre-production phase of the company and revenues are of only expected to be of a limited character from samples to be delivered in 2015. Seeo has developed cost models for its technology based on the knowledge of present market prices of materials and projections for future development. An important contributor to the projected decrease in the cost is the achievement of higher energy density cells. Even though these higher energy density materials may have a slightly higher projected cost, the significant jump in energy density they provide lead to substantial improvements in the cost per kilowatt-hour.

Figure 22 illustrates the cost development that Seeo is forecasting for its high energy technology for the period 2016 to 2020. Two curves are shown, one for a yearly production capacity of 400 MWh (equivalent to about 6 million cells with a capacity of 17Ah each) and the other for a capacity of 1GWh (1000 MWh). A continuous cost improvement is expected with the significant decreases in early 2017 and early 2018 coming from increases in energy density from 300Wh/kg to 350 Wh/kg (2017) and 350 Wh/kg to 400 Wh/kg (2018).

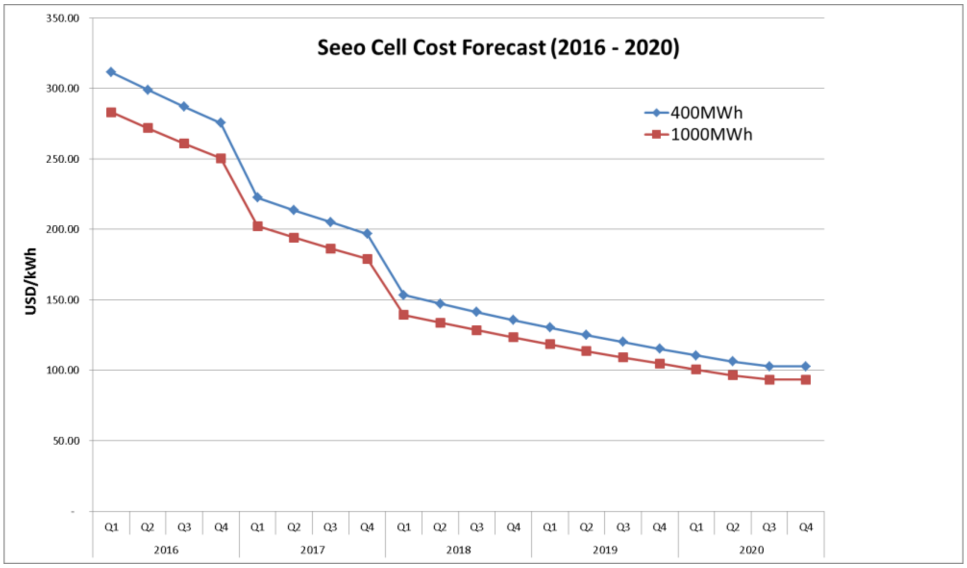


Figure 22: Seeo Forecasted Cell Price 2016 to 2020

Source: Seeo, Inc.

The cost projections for 2020 meet the long term targets set by the United States Automotive Battery Consortium and should prove highly competitive.

3.3.3 - Intellectual Property

As part of the work performed during the duration of this project a number of patents were filed further strengthening Seeo's competitive position. Sixteen patents were filed and are listed as Appendix B. The patents encompass cell electrochemistry and mechanical design, as well as specific battery management characteristics of Seeo's battery systems.

3.3.4 - Conclusions – Seeo Business Plan

Seeo's business plan and interest from potential customers and strategic partners demonstrates the strong interest for Seeo's technology. Seeo intends to commercialize its technology both in California and globally through these opportunities. Seeo is confident the materials and manufacturing of the technology can be achieved in a highly cost competitive manner allowing for the mass adoption of Seeo's technology for electric vehicles, as well as for grid energy storage, applications. The partnership strategy the company is pursuing will also allow the company to leverage both its own expertise and the manufacturing and industry experience of its partners allowing for a lower risk and more market driven entry into the markets for Seeo's technology.

3.4 - Lessons Learned and Benefits

From the start and reflected in the objectives of this project was an ambitious effort. It included not only cell development, but also cell size scale-up from small R&D sized cells to large format cells with a capacity of 11 Ah. In addition, Seeo scaled up the manufacturing from R&D lab environment fabrication of cells to a full pilot line capable of manufacturing the 11 Ah large format cell on equipment employing the same manufacturing processes as in large volume manufacturing. Finally, the project also encompassed developing and assembling a complete energy storage system of 10 kWh.

- Support of DOE and the milestones were instrumental in achieving the majority of the goals and objectives defined for this project
- Though most of the goals and objectives were achieved, with the broad span of objectives of this project it was perhaps not surprising that the final milestones associated with the energy storage system were not fully completed. As such it may have been more advantageous to have the development, fabrication and field testing of the energy storage system as a separate follow-on project.
- The learning curve and benefits to Seeo from this project have been tremendous and provided Seeo strong market competitiveness versus its competition in developing and commercializing solid-state batteries.
- The failure of the energy storage system at the end of the project exemplifies that there are many complexities for a small start-up company to achieve
- Funding from DOE was instrumental in the success of the project and has positioned Seeo well to commercialize the technology in the coming years
- The public-private partnership between the government represented by DOE and the private funding provided to Seeo by its investors demonstrates through the accomplishments in this project a successful model for cooperation between these two sectors

The benefits from Seeo's technology are that it enables batteries with higher energy densities, greater reliability, and lower cost when in full volume production. Seeo's cell technology has been scaled up into large form factor cells that can be assembled into battery packs from a few kWh's to over 100 kWh for grid energy storage solutions and plug-in electric vehicles.

With the higher energy density of Seeo's present and future technology it offers the advantage of more energy for a given weight making the batteries lighter and more compact. The higher energy density also allows for a higher throughput (per kWh) in production and hence lower costs, making the batteries more affordable for Seeo's customers and ultimately consumers.

Energy storage solutions, like Seeo's, offer the benefit of storing energy from renewable energy sources, such as photovoltaic arrays that are intermittent in their generation, and using the energy at later times when needed. This offers the opportunity for greater flexibility and reliability in the use of renewable energy, offers further expansion of renewable energy sources and making them more economical while reducing GHG emissions.

Energy storage solutions also provide the advantages of a more stable and secure grid as the batteries can be a good solution for when there are peak demands on the grid, and also in the event of any interruptions in the grid supply of energy.

Appendix A: Risks

At the beginning of the project a number of potential risks were identified. These are listed in Table 5 below, with dates when the risks were retired and relevant comments tied to the findings in addressing the risks.

Table 5: Identified Risks Associated with Project and Specific Actions and Outcomes Taken to Eliminate Identified Risks

Risk_Identifier	Risk_Title	Risk Retired or Realized	Date Retired	Description
Phase I - 1	Difficulty in finding qualified new hires	Retired	3/31/2011	Key hires include VP Manufacturing and Director of Product (for module and battery pack design). Remainder of hires will be cell and module technicians.
Phase II - 1	Polymer backbone flexibility compromises mechanical performance	Retired	10/31/2010	Succesful composition of mechanical block with flexible backbone block
Phase II - 2	Improved backbones or pendant compositions unstable at either	Retired	9/30/2011	Improved flexibility of backbone block does not impact stability; no significant impedance growth at the
Phase II - 3	Single ion conducting pendants decrease conductivity due to poor dissociation	Retired	6/30/2010	High transference number achieved, at the expense of conductivity. Approach deemed unsuitable for cells.
Phase II - 4	Single ion conducting pendants increase interfacial resistance	Retired	6/30/2010	High transference number achieved, at the expense of conductivity. Approach deemed unsuitable for cells.
Phase II - 5	Salt precipitation occurs in low temperature system over time	Retired	9/30/2011	Use high temperature system for required cell power
Phase II - 6	Increasing stiffness of polymer for interfacial stability compromises conductivity of electrolyte	Retired	9/30/2011	No effect; successful decoupling of mechanical and conductive properties after proper annealing
Phase II - 7	Electrode coatings compromise charge transfer kinetics	Retired	3/31/2013	Conductivity suitable for stationary applications
Phase II - 8	Electrode coatings prohibitively increase electrode cost	Retired	5/31/2011	Electrode coatings not prohibitively costly; equipment sourced and process established.
Phase II - 9	Electrolyte impurities mask true nature of system's stability	Retired	3/31/2010	Impurities successfully removed with no impact to stability
Phase II - 10	Delays in obtaining required equipment	Retired	10/31/2012	Pilot scale equipment for the project secured
Phase II - 11	Large scale synthesis process does not achieve material specification	Retired	12/31/2011	Large scale batches of polymer meet specification.
Phase II - 12	Large scale synthesis process proves prohibitively costly	Retired	12/31/2011	Process developed for pilot scale demonstrates path to low cost synthesis in high volume.
Phase II - 13	Reduced electrode uniformity in larger area coatings	Retired	10/31/2012	Large area coatings demonstrated in roll-to-roll process with uniform thickness and performance.
Phase II - 14	Defects or inhomogeneities resulting from cell stacking	Retired	10/31/2012	Stacking deemed unsuitable for high volume production. Multilayer cell design demonstrated using wound cell construction with expected performance.
Phase II - 15	Difficulty obtaining required width metallic lithium anode foil	Retired	10/31/2012	Large area Li foil obtained
Phase III - 1	Large format cells do not meet expected capacity	Retired	10/31/2012	Capacity of large-format cells meets expectation
Phase III - 2	Cells do not pass safety tests	Retired	9/30/2012	Large-format cells pass required safety tests

Source: Seeo, Inc.

Appendix B: List of Patents

Seeo Inventions made under US DOE Contract No DE-OE0000223

Seeo Reference	Title	Inventors	Date Reported	DOE S-Number
SE-035	Metal free synthesis of block polymer of PPO-PEO	Jin Yang Hany Eitouni	11/05/2010	S-126,441
SE-036	Cyclohexanone as a casting solvent and plasticizer	Humberto Joaquin Russell Pratt Michael Geier Mohit Singh	11/05/2010	S-126,442
SE-037	Novel New Geometry for Mass-Produced Prismatic Lithium Metal Cells	Daniel Freschl Michael Geier	11/05/2010	S-126,443
SE-038	Wound Prismatic Cells with Lithium Metal Anodes	Daniel Freschl Michael Geier	11/05/2010	S-126,444
SE-039	High Temperature Lithium Cells with Solid Polymer Electrolytes	Jin Yang Hany Eitouni Mohit Singh	11/05/2010	S-126,445
SE-040	Block Copolymer Materials Having Copolymers of Polyphenylene Oxide as the Mechanical Blocks	Bing Hsieh Jin Yang	11/05/2010	S-126,446
SE-041	Symbiotic Battery Pack	Mohit Singh	11/05/2010	S-126,447
SE-042	Small domain-size multi-block copolymer electrolytes	Jonathan Pistorino Hany Eitouni	11/05/2010	S-126,448
SE-043	Synthesis of PS-PEO multi-block copolymers	Russell Pratt	11/05/2010	S-126,449
SE-044	Procedure for functionalizing poly(ethylene oxide)	Russell Pratt	11/05/2010	S-126,450
SE-045	Method for determination of extent of endgroup functionalization of high molecular weight poly(ethylene oxide)	Russell Pratt	11/05/2010	S-126,451
SE-050	Synthesis Of High Molecular Weight PEO Using Non-Metal Initiators	Jin Yang Kulandaivelu Sivanandan Jonathan Pistorino Hany Eitouni	9/12/2014	S-140,281
SE-051	Acrylonitrile Grafted To Pvdf	Jin Yang Hany Eitouni Yan Li	9/12/2014	S-140,282
SE-058	Poly(Ethyleneoxide)	Kulandaivelu	9/12/2014	S-140,283

Seeo Inventions made under US DOE Contract No DE-OE0000223

Seeo Reference	Title	Inventors	Date Reported	DOE S-Number
	Functionalization Through Alkylation	Sivanandan Hany Eitouni Yan Li Russell Pratt		
SE-060	Solid-State Active Switch Matrix For High Energy, Moderate Power Battery Systems	Larry Deal Peter Paris Changqing Ye	9/12/2014	S-140,284
SE-061	Data Driven/Physical Hybrid Model For Soc Determination In Lithium Batteries	Changqing Ye Peter Paris Larry Deal Scott Allen Mullin Mohit Singh	9/12/2014	S-140,285

Appendix C: List of Abbreviations

Ah	**Ampere-hour**
ARPA-E	**Advanced Research Projects Agency-Energy**
ARRA	**American Recovery and Reinvestment Act of 2009**
BMS	**battery management system**
C (rate)	**Current, rate of discharge or charge of cell or battery, e.g. C/3 is defined as a 3-hour discharge or charge of cell or battery**
CAES	**Compressed Air Energy Storage**
CESS	**community energy storage system**
CSP	**concentrated solar power**
DOE	**United States Department of Energy**
ESR	**equivalent series resistance**
FOA	**Funding Opportunity Announcement**
G	**Gram**
IP	**intellectual property**
Kg	**Kilogram**
kWh	**kilowatt-hour**
LBNL	**Lawrence Berkeley National Laboratory**
MPa	**Mega-Pascal**
PV	**Photovoltaic**
RAEL	**Renewable and Appropriate Energy Laboratory**
R&D	**research and development**
SOC	**state-of-charge**
SWITCH	**Solar, Wind, Conventional Hydroelectric generation and Transmission**
UCB	**University of California, Berkeley**
WECC	**Western Electricity Coordinating Council**