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II. The *EV Everywhere* Challenge

II.A Background

In March 2012, President Obama announced the *EV Everywhere* Grand Challenge—to produce plug-in electric vehicles (PEVs) as affordable and convenient for the American family as gasoline-powered vehicles by 2022. Realizing the promise of PEVs is one of the grand challenges of this era. Today, our transportation system is still dependent on internal combustion engines and oil. In fact, 93% of our transportation fuel is derived from petroleum and much of this is imported. PEVs can decouple personal mobility from oil, cut pollution and help build a 21st Century American automotive industry that will lead the world.

America is the world's leading market for electric vehicles and is producing some of the most advanced PEVs available today. Consumer excitement and interest in PEVs is growing — in 2012, PEV sales in the U.S. tripled, with more than 50,000 cars sold, and a plug-in electric vehicle (the Chevrolet Volt) beat all other vehicle models in Consumer Reports' owner satisfaction survey for the second time. In 2013, PEV sales are on pace to nearly double prior year sales, with nearly 100,000 annual sales of PEVs projected.

PEVs have won critical acclaim with awards such as 2011 World Car of the Year (Nissan Leaf), 2013 Motor Trend Car of the Year (Tesla Model S) and 2012 Green Car Vision Award Winner (Ford C-MAX Energi). To maintain this leadership, strong growth in the U.S. PEV sector will need to continue.

The Department of Energy (DOE) developed an *EV Everywhere* "Blueprint" document that provides an outline for technical and deployment goals for PEVs over the next five years. DOE will pursue these targets in cooperation with a host of public and private partners. The technical targets for the DOE PEV program fall into four areas: battery R&D; electric drive system R&D; vehicle lightweighting; and advanced climate control technologies. Some specific goals include:

- Cutting battery costs from their current \$500/kWh to \$125/kWh
- Reducing the cost of electric drive systems from \$30/kW to \$8/kW
- Eliminating almost 30% of vehicle weight through lightweighting

These numbers represent difficult to reach "stretch goals" established in consultation with stakeholders across the industry—including the *EV Everywhere* workshops held during the summer and fall of 2012. When these goals are met, the levelized cost of an all-electric vehicle with a 280-mile range will be comparable to that of an ICE vehicle of similar size. Even before these ambitious goals are met, the levelized cost of most plug-in electric vehicles — and of all-electric vehicles with shorter ranges (such as 100 miles) — will be comparable to the levelized cost of ICE vehicles of similar size. Meeting these targets will help to reduce the purchase price for plug-in electric vehicles

The *EV Everywhere* "Blueprint" document also describes the deployment programs related to charging infrastructure and consumer education. Efforts to promote home, workplace, and public charging can also help speed PEV deployment.

II.B *EV Everywhere* Technical Targets

DOE defined *EV Everywhere* technology targets using an analytical framework that evaluated the performance of component technologies as well as vehicle cost and performance. We synthesized data about future vehicle potential by using expert projections of component technology to create virtual vehicles of the future via computer modeling and simulation. The range of vehicle costs and efficiencies made possible a comparison of the degree to which the portfolio of these technologies must progress, in both performance and cost terms, to yield PEVs that are cost-competitive, as measured by the initial vehicle purchase price and the fuel expenditure accrued over a 5-year ownership period. Ultimately, an analysis of this balance yielded technical targets at the technology progress frontier: *EV Everywhere* targets are consistent with what experts see as very aggressive but still possible within the *EV Everywhere* timeframe.

The complete set of *EV Everywhere* technical targets are presented in the Blueprint document. The specific technical targets that pertain to batteries are listed in Table II - 1.

Table II - 1: *EV Everywhere* energy storage targets for 2022

		Current Status	Target
Battery Cost	$/kWh (usable)	500	125
Pack Specific Energy	Wh/kg	80-100	250
Pack Energy Density	Wh/L	200	400
Pack Specific Power	W/kg	500	2000

II.C *EV Everywhere* FY2013 Highlights

1. Progress in Lithium-Ion Battery Technology

DOE has reduced the cost of lithium-ion batteries by nearly 70% and improved their energy density by 60% during the last five years.

DOE-sponsored R&D has reduced the cost of PEV batteries by nearly 70% over the last five years. As shown in Figure II - 1, the modeled cost of PHEV batteries under development has been reduced from $1,000 per kilowatt-hour of useable energy in 2008, to a current cost of $325 per kilowatt-hour. Three USABC battery developers have made significant advances in cost reduction using improved cathodes. These battery development projects focus on advanced cathodes, processing improvements, cell design, and pack optimization. Standard electrolytes and graphite anodes were used by each developer. These battery cost projections are derived by the manufacturer using USABC's battery manufacturing cost model based on a production volume of 100,000 batteries per year for specific battery cell and module designs that meet DOE/USABC requirements for power, energy, and cycle life as well as calendar life.

Concurrently, the size and weight of PEV batteries have also been reduced by over 60%. As shown in Figure II - 1, battery energy density has increased from 60 Wh/liter in 2008, to 150 Wh/liter in 2013.

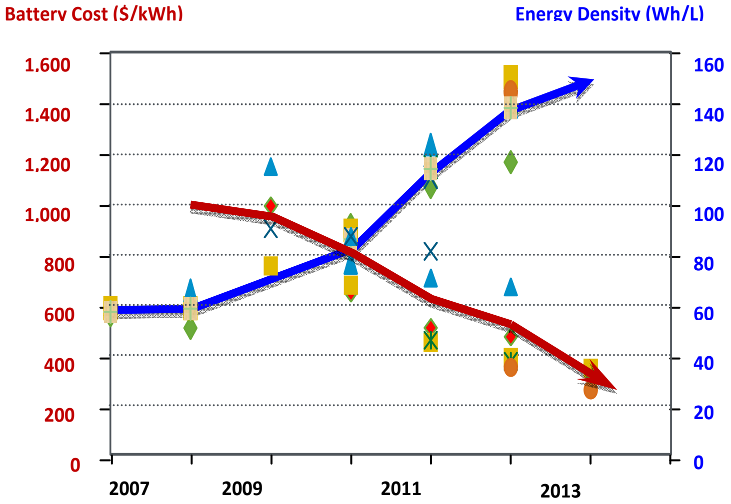


Figure II - 1: Modeled cost and energy density of PHEV batteries developed and tested

2. Estimating Battery Pack-Level Energy Density, Specific Energy and Cost for *EV Everywhere* Goals

A free BatPaC model is a tool for estimating Li-ion battery costs for vehicles. The model estimates that an advanced Li-ion cathode paired with a silicon-alloy or a lithium-metal anode can reach EV Everywhere's *cost and performance goals for a 100 kWh (~300 mile) battery.* **(Argonne National Laboratory)**

The ability to predict the cost of batteries made using advanced materials is critical to correctly focusing research efforts. The battery performance and cost (BatPaC) model developed at ANL represents the only public model that captures the interplay between design and cost of Li-ion batteries for transportation (available free-of-charge from the ANL BatPac site). This model has been subject to peer-reviews by experts in academia and industry. The first version of BatPaC was distributed on November 1st, 2011, since then, more than 1,000 independent downloads have occurred worldwide.

The *EV Everywhere* initiative has challenging battery goals (i.e. $125/kWh, 400 Wh/l, 250 Wh/kg). The potential of battery chemistries to reach these goals have been quantified using BatPaC. The systems-level energy density, specific energy, and cost for select lithium batteries are illustrated in Figure II - 2.

The representative Li-ion cell chemistry graphite/$\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$ (Gr/NMC333) is commercially available today and likely to see incremental improvements, several percent per year, over the next decade through achieving long life with thicker electrodes, larger capacity cells, and more efficient peak power designs. Also considered is the lithium- and manganese-rich high capacity cathode (LMRNMC). Finally, a composite silicon-alloy anode is considered.

Both the Li/LMRNMC and Si/LMRNMC couples meet the goals for a 100 kWh battery. These estimations show both the promise of future battery chemistries and the challenges that remain.

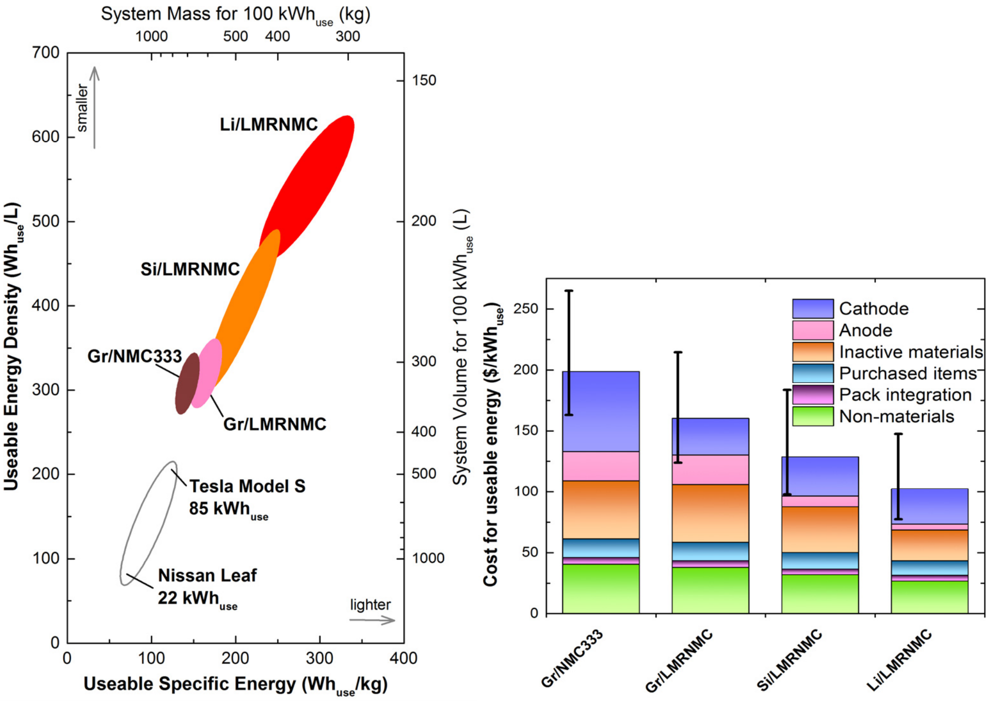


Figure II - 2: Estimated useable specific energy, energy density, and cost for a 100 kWh$_{use}$, 80kW$_{net}$ 360V battery produced at 100k/year

3. Johnson Controls Inc. Increases Cell Energy Density by 25%

JCI has increased prismatic PHEV-20 cell energy density from 275 Wh/L to 345 Wh/L through a concerted multi-disciplinary effort involving material stabilization, novel processing, and cell design innovations.
(Johnson Controls Inc.)

JCI's $4.1 million, 2 year program is focused on reducing the cost to capacity ratio of a standard format prismatic cell through a multidisciplinary pursuit of volumetric energy improvement. Building on JCI's Gen-1 prismatic NMC-graphite cell developed in the preceding USABC program, the work targets a medium-range PHEV20 application.

Cost to capacity ratio reduction is being achieved directly through increased energy density of the cell (increased mAh/g) which drives down battery size and cost. Indirectly, contributing improvements in the critical enablers of abuse tolerance and cold temperature performance are needed to be able to fully harness the opportunity of energy density gains. Development efforts focus not only on inherently low-risk materials, seeking to exploit their full, unrealized potential, but also on process development and mechanical design innovations.

The following highlights from each major work stream illustrate progress made during this contract.

- Multiple cathode materials representing a broad spectrum of stabilization approaches and stoichiometries were evaluated. Two candidates remain after exhaustive down selection trials
- Paste mix processing was evaluated as a potential enabler of solvent reduction goals, and increased active material loadings. Promising results were obtained, attaining the high electrode densities needed for the cell energy density targets. Further testing will assess high solids processing potential.
- Upper voltage limits of 4.2V and 4.3V were evaluated in parallel with extensive electrolyte development to enhance stability. Excellent results have allowed increasing the upper voltage from 4.1V to 4.2V, and expanding the state of charge window usage from 70% to 80%. The latest build's capacity retention at 4.2V compares to the baseline chemistry at 4.1V, showing only 7% fade after 135 days at 60˚C, a remarkable achievement.
- Mechanical design efforts yielded mandrel elimination, current collector optimization, coated area increase, and fill-hole closure method down-selection, each of which increases the cell capacity.
- Abuse tolerance work focused on a Thermal Protective Barrier anodic coating, ceramic separators, electrolytes and cathodes with functional overcharge additives, all leading to enhanced over-charge results and understanding.
- Mid-program cells demonstrate a 25% increase in capacity, while the projected final cell design translates to a 30% cost reduction at the system level. Both of these achievements showcase the meaningful progress made to JCI's technology (see Figure II - 3).

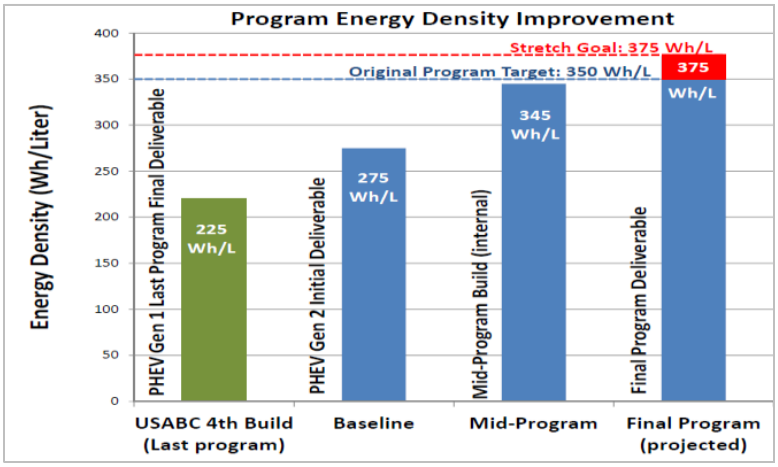


Figure II - 3: Progression of achieved cell-level energy density increases

4. High Energy NMC Cathode/Si Alloy Automotive Cell

3M demonstrates a 50% increase in energy over NMC/graphite cells using synergistically matched Core-Shell NMC cathode and Silicon alloy anode. **(3M)**

Electrification of the vehicle is fast becoming a reality around the world. Reducing the cost of the battery is one of the keys to success. In order to reduce the cost of the battery ($/Wh), new active materials (anodes and cathodes) are needed to increase battery energy. These new active materials need to be carefully matched to enable the highest energy density. With DOE support, 3M has integrated new cathode materials, anode materials and electrolytes that can increase cell energy by 50% over the industry standard $Li(Ni_{1/3}Mn_{1/3}Co_{1/3})O_2$ (NMC)/Graphite cell.

3M™ Core-Shell NMC Cathode: 3M's cathode materials are mixed nickel, manganese, and cobalt oxides with a high Ni core (for high energy) and high Mn shell (for high voltage stability). These materials have high capacity, high voltage, and good cycle stability.

3M™ Silicon (Si) Alloy Anode: 3M's Si alloy anode materials enable high energy density and have proper structure (amorphous active phase), particle morphology, and surface chemistry leading to controlled volume expansion upon lithiation and good cycling.

The Importance of the System: New cathode materials that have a Cathode Energy Factor (CEF) beyond the traditional NMC materials invariably require charging to higher cell voltage. To maximize the energy of the system, the cathode irreversible capacity should also "match" the irreversible capacity of the alloy anode. In addition, for cell balance and control of lower cut-off cell voltage, it is desirable if the irreversible capacity of the composite cathode be slightly larger than that of the anode. The electrolyte and separator must be designed to be stable against the two electrodes, across the complete cell voltage range, to mitigate any parasitic reactions. The 3M™ Core Shell (C/S) high-energy cathode material has a CEF 45% higher than NMC as shown in Table II - 2. When this cathode is combined with 3M™ Si anode in an 18650 cell a 50% improvement in energy (Wh/L) is demonstrated, as shown in Figure II - 4.

Next Steps: Cycle life optimization is underway and will be reported in the future. 3M™ Silicon Si alloy anode materials have been scaled into production. Cathode materials have been scaled to the kg level.

Table II - 2: CEFs for different cathodes—irreversible factor accounts for the irreversible loss of the matched active materials

	Oxide	X	Capacity (Ah/g)	X	Density (g/cc)	X	Voltage (V)	X	Irreversible Factor	=	CEF
Automotive	NMC		0.16		3.3		3.90		0.98		2.02
	NMC		0.16		3.3		3.90		0.95		1.96
Core Shell	126M		0.23		3.4		3.84		0.95		2.85
	126T		0.22		3.4		3.88		1.00		2.90

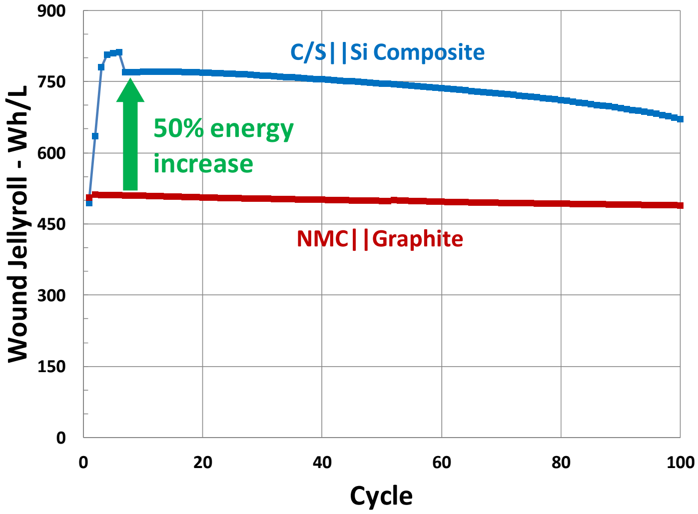


Figure II - 4: 18650 data demonstrating a 50% energy improvement for the C/S||Si composite over the NMC||Graphite design

5. Process Development and Scale-up of Advanced Cathode Materials

Scale-up process development is a key missing link between basic research and commercialization and provides kilogram quantities of advanced cathode materials for R&D purpose and industrial evaluation.
(Argonne National Laboratory)

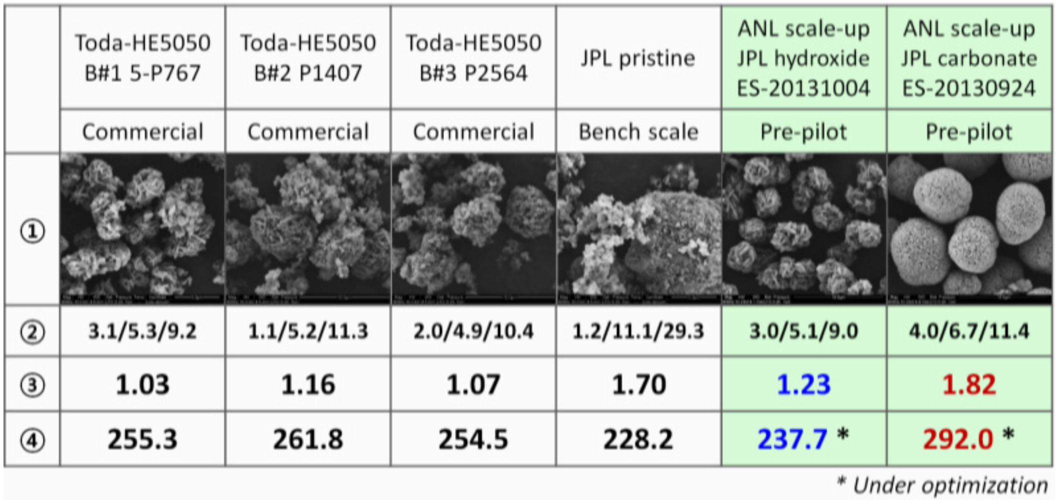
Process development and scale-up of advanced cathode materials is a critical step between discovery of advanced battery materials, market evaluation, and high-volume manufacturing. This project produces large quantities of the target lab-scale candidate materials with equal or better quality. The performance of cathode material such as capacity, tap density and life is strongly affected by the synthesis process and its optimization even though it has the same composition. Additionally, development of cathode synthesis processes that are economically feasible is important to reduce the cost of the full battery pack.

A high capacity/voltage cathode development project through JPL/NASA had produced a cathode ($Li_{1.5}Ni_{0.16}Mn_{0.68}Co_{0.16}O_{2.5}$) with high capacity (~230 mAh/g) and high tap density (>1.7 g/cc) at the bench scale, but JPL had difficulties scaling the material in kilogram scales for commercial evaluation. Toda America has produced this composition (HE-5050) at high capacity (~250 mAh/g) but at a much lower tap density (~1.0 g/cc). In FY2013, Argonne's cathode scale-up program was tasked to scale this composition and produce high capacity, high tap density material for evaluation. The target properties are:

- Composition:$Li_{1.5}Ni_{0.16}Mn_{0.68}Co_{0.16}O_{2.5}$
- Tap density: >1.5 g/cc
- Capacity: ~240 mAh/g (1st discharge)
- Cycle life: ~200 cycles

The first approach was to optimize a hydroxide based process to synthesize the material. ANL was able to achieve a higher tap density than the Toda hydroxide based material but with a tradeoff of lower capacity - not meeting the JPL specifications. ANL then focused on a carbonate based approach and were able to exceed capacity and tap density specifications, producing kilogram quantities of material for evaluation (see Table II - 3 and Figure II - 5).

Table II - 3: Comparison of 6 cathode materials with the same composition: ① SEM (8000x), ② D10/D50/D90 (μm), ③ tap density (g/cc), ④ initial discharge capacity at C/20 (mAh/g)



	Toda-HE5050 B#1 5-P767	Toda-HE5050 B#2 P1407	Toda-HE5050 B#3 P2564	JPL pristine	ANL scale-up JPL hydroxide ES-20131004	ANL scale-up JPL carbonate ES-20130924
	Commercial	Commercial	Commercial	Bench scale	Pre-pilot	Pre-pilot
①						
②	3.1/5.3/9.2	1.1/5.2/11.3	2.0/4.9/10.4	1.2/11.1/29.3	3.0/5.1/9.0	4.0/6.7/11.4
③	1.03	1.16	1.07	1.70	1.23	1.82
④	255.3	261.8	254.5	228.2	237.7 *	292.0 *

** Under optimization*

The precursor and cathode materials were produced by a reproducible, scalable process and were delivered to Argonne's Materials Screening team and to JPL for evaluation.

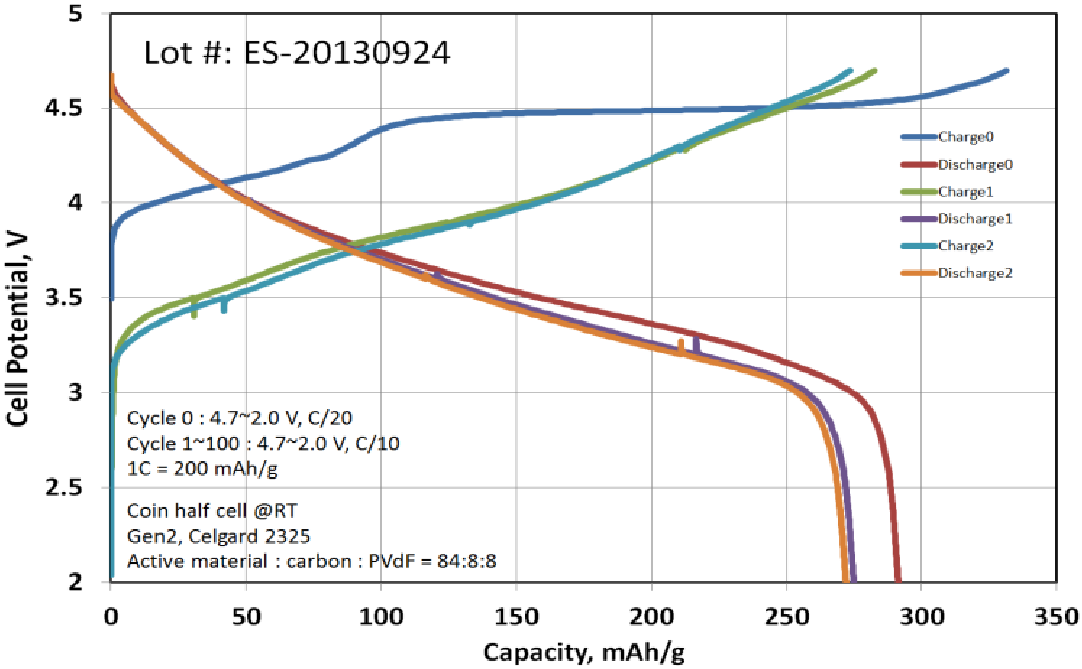


Figure II - 5: Voltage profile of the Argonne scale-up JPL carbonate material

6. Scale up and Production of Low Cost Nickel/Manganese/Cobalt Cathode Material

BASF has developed and scaled up the production process for three nickel/manganese/cobalt cathode materials. Two such materials are currently in production in BASF's plant in Elyria Ohio, and the final material is to be produced in its production plant. ***(BASF)***

According to multiple cost models from DOE National Laboratories and from battery developers, the cathode material dominates high-energy battery cost. The production of low cost cathode materials depends on the proper selection of raw materials and a cost effective production process. There are also many requirements for chemical purity, physical characteristics, and electrochemical performance that must be met.

This project aimed to scale up and reduce the production cost of nickel/manganese/cobalt (NMC) cathode materials. As a result of this project, BASF has developed and scaled up the production process for NCM 111, 523 and 424 (numbers represent the relative ratios of the three components). The first two materials are in production in BASF's plant in Elyria, Ohio, and the final material will be produced there. BASF has been able to qualify both NCM 111 and NCM 424 for use in EV and PHEV applications through independent testing by SKC PowerTech.

BASF has recently shifted much of the research and development work to the production of NCM 424. Results from the initial lab work have been used to identify the major production elements that are critical for the end product performance. Work with NCM 424 has progressed through the pilot plant stage. BASF has demonstrated that with its existing pilot plant equipment it can produce NCM 424 consistently with minimal lot variation. Figure II - 6 shows 2C (5 ampere) charge discharge cycle life results from cells made with blends of BASF’s NMC111 and LMO, where LMO is $LiMn_2O_4$ spinel, and another cell using a blend of NMC424 and LMO. BASF will continue to focus on precursor improvements and modifications in order to improve the quality of the NCM 424.

BASF has also worked on the production of the high energy NCM (HE-NCM). Although there is still ongoing research to improve the material, BASF has made progress improving its performance as well as understanding the critical production parameters. BASF has produced enough HE-NCM to sample to customers and research partners during the past year.

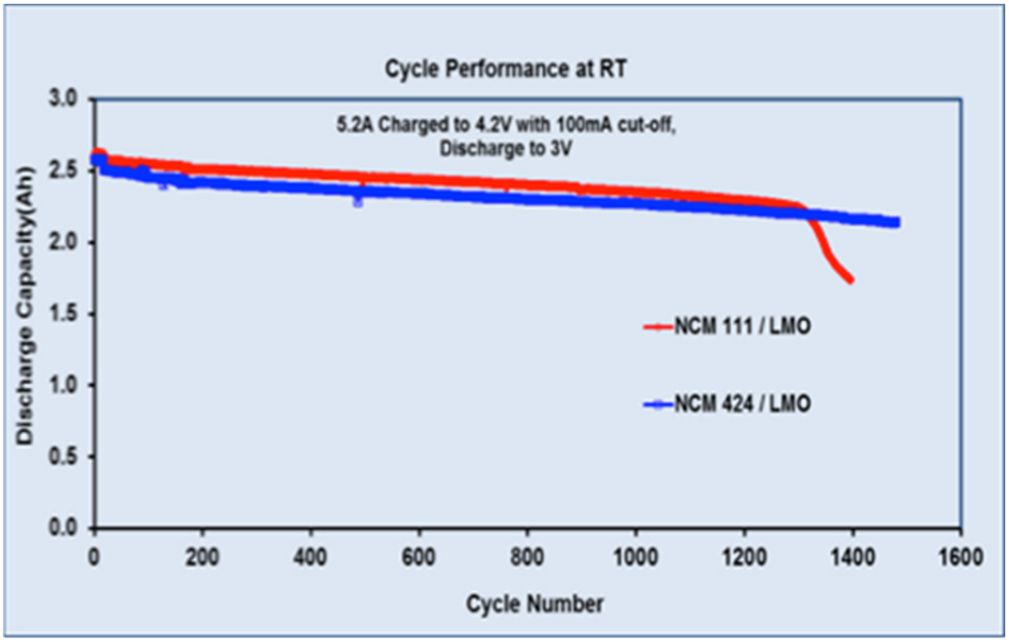
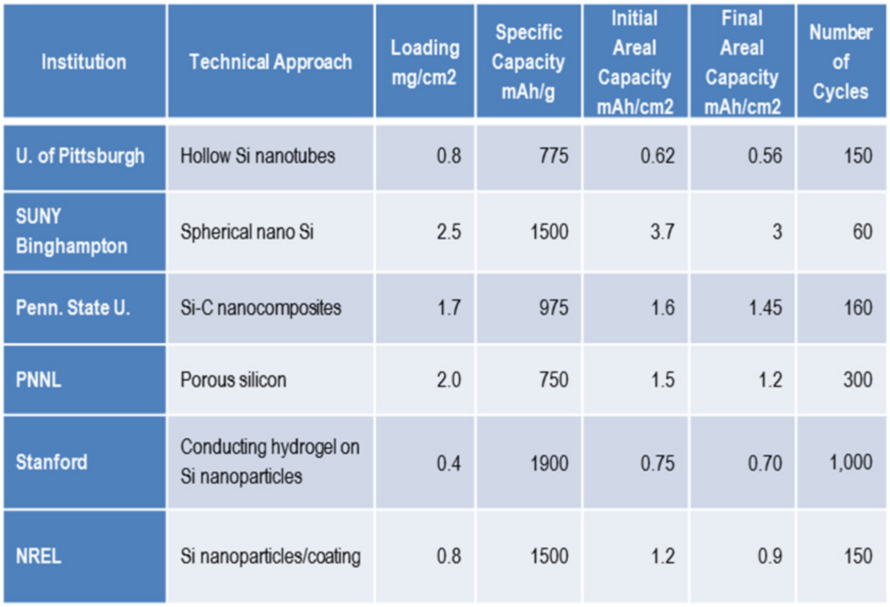


Figure II - 6: Cycle life data of NMC111/LMO blend and NMC424/LMO blend at room temperature (RT), appropriate for long-range PHEV and EV applications

7. Progress in Silicon Anodes

Many developers in the battery industry, supporting by the modeling results of BatPaC, have concluded that abundant and inexpensive Silicon-based anodes are needed to meet the DOE *EV Everywhere* battery performance and cost goals. Si offers 4,200mAh/g vs. 350mAh/g for currently used graphite. However, numerous technical hurdles remain, including the large volume change during cycling, which leads to loss of contact between particles, and electrolyte consumption leading to rapid capacity fade and cell failure. Several institutions are exploring approaches to mitigating the volume change problem. These approaches, and some of their progress, are listed in Table II - 4.

Table II - 4: Progress in Si Anodes



Institution	Technical Approach	Loading mg/cm2	Specific Capacity mAh/g	Initial Areal Capacity mAh/cm2	Final Areal Capacity mAh/cm2	Number of Cycles
U. of Pittsburgh	Hollow Si nanotubes	0.8	775	0.62	0.56	150
SUNY Binghampton	Spherical nano Si	2.5	1500	3.7	3	60
Penn. State U.	Si-C nanocomposites	1.7	975	1.6	1.45	160
PNNL	Porous silicon	2.0	750	1.5	1.2	300
Stanford	Conducting hydrogel on Si nanoparticles	0.4	1900	0.75	0.70	1,000
NREL	Si nanoparticles/coating	0.8	1500	1.2	0.9	150

8. Technologies for Improved Safety of Li-ion Batteries

TIAX has developed a non-invasive, chemistry-agnostic technology for detecting incipient internal short circuits in Li-ion batteries even before they pose a thermal runaway threat. **(TIAX, LLC)**

Li-ion batteries are a key to enabling widespread deployment of plug-in electric vehicles (PEV). However, concerns regarding safety of Li-ion batteries could hinder their rapid adoption in PEVs. Essentially, under various triggers, Li-ion batteries can undergo violent thermal runaway accompanied by smoke and flames. Many of the potential triggers have been studied over the years and solutions for preventing the possibility of thermal runaway from these triggers have been developed and incorporated into battery packs.

However, one particular trigger, the internal short circuit, has not received much attention, and new technologies are needed to manage the outcome from this trigger. Internal shorts are particularly insidious because they can promote thermal runaway under otherwise normal operating conditions. At TIAX, using a combination of experiments and numerical simulations, we have investigated the mechanism of short initiation and growth, as well as the conditions needed to promote thermal runaway. Based on insights gained from these investigations we are developing solutions to manage internal short circuits in Li-ion. Here, we report on an exciting new technology to detect incipient internal shorts before they pose a thermal runaway threat. Once detected, several approaches are available to intervene and prevent thermal runaway.

The TIAX internal short detection technology includes a combination of proprietary non-invasive sensors and signal processing algorithms to enable real-time detection of incipient internal shorts in Li-ion cells. Figure II - 7 shows an example of internal short detection in a Li-ion cell in a pack subjected to a FTP75 automotive duty cycle (that has been accelerated by 8x). A 100 Ω internal short (which is 25 times weaker than that needed to induce thermal runaway) was introduced in one of the cells at ~ 43 s and removed at ~ 170 s. As seen in the top figure, voltage traces that a conventional battery management unit (BMU) would record show no indication of the internal short, illustrating the inability of conventional BMUs to detect such low-level shorts. The bottom figure shows the output from TIAX's sensor system, clearly indicating successful detection of the internal short even amidst wildly fluctuating automotive duty cycles. This patent-pending technology has been demonstrated at the breadboard level for a wide range of chemistries, cell designs, and automotive temperatures. We are now in discussions to commercialize the technology.

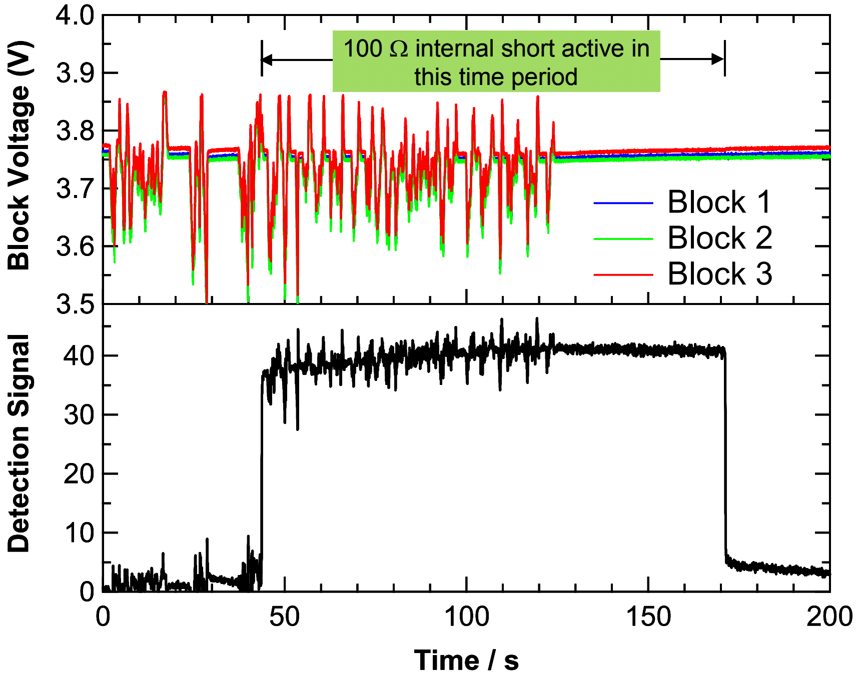


Figure II - 7: Experimental demonstration of TIAX's real-time internal short detection technology in a battery pack under an automotive duty cycle

9. Safe Electrolytes Based on Imide Salt Solutions in Fluorinated Solvents

Leyden Energy developed electrolytes that are up to 85% by weight non-flammable components. NFi ™ electrolytes demonstrate great safety, long cycle life, good rate and low temperature performance. ***(Leyden Energy)***

Regular Li-ion cells use highly flammable electrolyte solutions of $LiPF_6$ in organic solvents. Under abuse conditions, the electrolyte may ignite, often resulting in a battery fire or explosion. Previous attempts to formulate non-flammable electrolytes included ionic liquids formulations or addition of a flame retardant to regular solvents. Both approaches failed to combine in one formulation good safety and fast lithium transport that allows quick charge and discharge over a wide temperature range.

Leyden Energy's approach was to use lithium imid salts solutions in non-flammable solvents. Imide salts have significantly higher solubility in fluorinated solvents compared to regular salts such as $LiPF_6$, $LiBF_4$ and LiBOB. This approach allowed Leyden's R&D to formulate electrolytes with up to 85% non-flammable components by weight. Small amounts of carbonates are preserved in the electrolyte for efficient SEI formation; limited amounts of esters or linear carbonates assist rate and low temperature performance.

Electrolytes were extensively tested in 18650 and pouch cells and demonstrated long cycle life at up to 60°C (see Figure II - 8), discharge capability at as low as -30°C, rate up to 5C and vastly improved safety under abuse conditions. Electrolytes did not ignite when the cells vented; cell safety improvements were seen in overcharge, hot box, nail and impact tests. Leyden findings and results of the development were independently verified by Mobile Power Solutions test lab and Exponent Failure Analysis. Additional tests included a cone calorimetry measurement test (see Figure II - 9), when a fully charged battery is burned and the amount of heat generated by this process is recorded. Remarkably, total heat release is about half of the heat compared to the same cell with a regular electrolyte such as 1M $LiPF_6$/EC:DEC1:2.

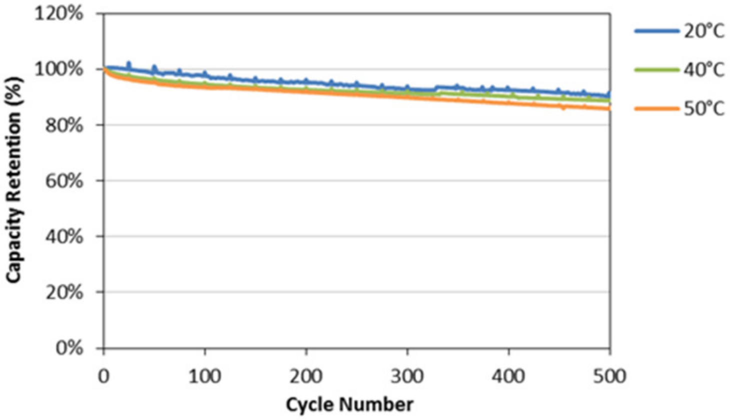


Figure II - 8: Cycle life of the 2.0Ah NCM pouch cell with NFi™ electrolyte

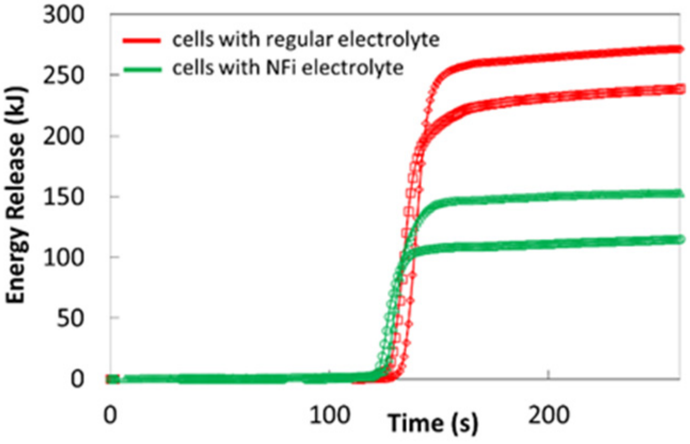


Figure II - 9: Heat release measured by using cone calorimetry in 2.0Ah NCM cells

10. Lowering the Cost and Improving the Performance of Separators for Lithium-ion Batteries

Development and installation of advanced manufacturing processes and research into new material formulations have resulted in improved separator quality and lower cost. ***(ENTEK Membranes LLC)***

In 2009, ARRA provided $1.5 billion in funding to support the establishment of Li-ion battery manufacturing facilities in the United States. One goal of this investment was to reduce the cost of the battery for plug-in electric vehicle (PEV) applications. It was recognized that an important step for the electrification of the nation's light duty transportation sector is the development of more cost-effective, long lasting, and abuse-tolerant PEV batteries.

The separator is a critical component of the battery that impacts both performance and safety. The thin (≤25 microns), microporous membrane provides an electrically non-conductive barrier between the positive and negative electrodes and also a network of pores that can be filled with electrolyte to allow ionic flow between those electrodes. In addition to preventing contact between the electrodes, it enhances safety by collapsing its pores and shutting down ion flow when the battery temperature rises to a hazardous level.

The cost of the separator membrane can be a significant fraction of the material cost of the Li-ion battery, particularly in high-power designs such as for HEVs. Depending on the battery design, the separator may be 25% or more of the materials cost of a cell. Thus a reduction in separator cost is necessary to help meet the battery cost goal of $125/kWh by 2022.

With the assistance of ARRA funding, ENTEK has made improvements to one of its existing production lines and constructed an entirely new line with advanced process capabilities and higher throughput. The ENTEK production facility has state-of-the-art online characterization equipment and a clean room for slitting master rolls. These improvements have contributed greatly toward meeting the aggressive cost targets of less than $1/m^2 for high volume purchases.

ENTEK has also received funding through the United States Advanced Battery Consortium (USABC) for the development of an inorganic-filled separator. The material produced from this work has a new formulation that has demonstrated improved high-voltage stability, improved power capability, and improved thermal stability compared to standard microporous polyethylene separators. The higher power capability can contribute to lower battery costs by reducing the size of batteries needed to meet low temperature performance requirements.

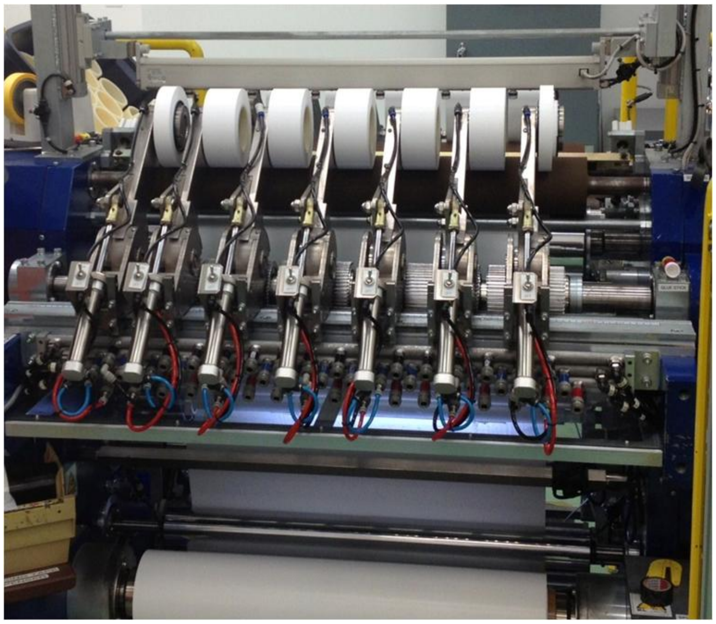


Figure II-10: Nishimura slitter installed in ENTEK's new separator production facility, utilizing ARRA funding

II.D *EV Everywhere* Planned Activities

An important step for the electrification of the nation's light duty transportation sector is the development of more cost-effective, long lasting, and abuse-tolerant PEV batteries. The cost of today's batteries is over four times too high. In addition, PEV design optimization and performance is often hindered by the size and weight of the battery.

Current battery technology is very far from its theoretical energy density limit. In the near-term (2012–2017), with advances in lithium-ion technology, there is an opportunity to more than double the battery pack energy density from 100 Wh/kg to 250 Wh/kg through the use of new high-capacity cathode materials, higher voltage electrolytes, and the use of high capacity silicon or tin-based intermetallic alloys to replace graphite anodes. Despite current promising advances, much more R&D will be needed to achieve the performance and lifetime requirements for deployment of these advanced technologies in PEVs.

In the longer term (2017–2027), "beyond Li-ion" battery chemistries, such as lithium-sulfur, magnesium ion, zinc-air, and lithium-air, offer the possibility of energy densities that are significantly greater than current lithium-ion batteries as well as the potential for greatly reducing battery cost. However, major shortcomings in cycle life, power density, energy efficiency, and/or other critical performance parameters currently stand in the way of commercial introduction of state-of-the-art "beyond Li-ion" battery systems. Breakthrough innovation will be required for these new battery technologies to enter the PEV market.

The energy density increases described above will be critical to achieving the *EV Everywhere* cost and performance targets. Additional R&D efforts including pack design optimization and simplification, manufacturing improvements at the cell and pack level, materials production cost reduction, and novel thermal management technologies will also contribute to battery cost reduction. Also, achieving the *EV Everywhere* battery power density target (2000 W/kg) is important to assure that technology breakthroughs meet the discharge power requirements for a wide range of PEV architectures and to enable the battery to be rapidly charged. Fast-charging may be important for consumer adoption of certain PEVs.

In 2013, U.S. DRIVE updated its Electrochemical Energy Storage Roadmap which describes ongoing and planned efforts to develop electrochemical energy storage technologies for plug-in electric vehicles (PEVs) and can be found at the EERE roadmap page.

In support of the *EV Everywhere* Grand Challenge, DOE released a Funding Opportunity Announcement (FOA) in March 2013, soliciting proposals in the areas of energy storage, electric drive systems, lightweight materials, and auxiliary load reductions. DOE announced the selection of 38 awards from the FOA in September 2013.

In the area of advanced batteries, 13 projects totaling $22.5 million were awarded. The projects will help improve cell chemistry and composition, develop advanced electrolytes and create new battery design tools – helping to further reduce costs. Broadly, the projects aim to cut battery size and weight in half, while improving efficiency and performance. These projects, which were initiated in September 2013, fund R&D in pursuit of the *EV Everywhere* goals and will be described in more detail in next year's annual report.