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NextEnergy Center's Highlights on Global Lithium Ion Battery Supply Chain Dynamics and Domestic Opportunities

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Abstract

Lithium ion batteries are utilized in a range of applications including grid support and powering consumer electronics, medical devices, and electric vehicles. Advocacy for, as well as public and private investment in hybrid cars and electric vehicles has resulted in a surge in research and development (R&D) to create more powerful and cost effective lithium ion batteries. This high level of interest has also led to rapid expansion of battery manufacture capacity and has resulted in the over-capacity and fragmentation of the industry. Due to the disjointed quality of the lithium-ion battery industry, opportunities for collaboration and growth, resulting from numerous innovations throughout the supply chain, are overlooked. [1] Although range anxiety is often portrayed as the primary reason electric vehicle adoption is not growing more rapidly by the general population, the cost of vehicles is actually the larger issue. At present, the battery pack is the highest cost component driving the price of EVs. A year-long study was conducted by NextEnergy to obtain a better understanding of the size, scope, and supply chain dynamics of the lithium ion battery and next-generation energy storage systems industries. One major objective of the study was to better understand and define areas of opportunity for cost reduction, the results of which are presented in this paper.

Keywords: Lithium ion batteries, supply chain dynamics, R&D

1 Background

The study was sponsored by the U.S. Department of Commerce, Economic Development Authority (EDA) and Michigan Economic Development Corporation (MEDC). Matching grant funds and collaborative work was also leveraged with other partners, in addition to NextEnergy and MEDC, including: Automation Alley in Troy, Center for Automotive Research (CAR) in Ann Arbor, Michigan, Corporation for a Skilled Workforce (CSW) in Ann Arbor, and the Michigan Manufacturing Technology Center (MMTC) in Plymouth, Michigan. This study highlighted intelligence gathered through:

- Interviews with over two hundred (200) firms, including:
    - Tier 1 and Tier 2 battery manufacturers
    - Automotive original equipment manufacturers (OEMs)

- Recycling, remanufacturing and reuse firms
  - Other key industry stakeholders
- Market and supply chain data gathered at numerous industry-sponsored conferences and events
- Primary and secondary literature reviews
- Internal communications through NextEnergy's cross-functional team – which including:
  - mechanical, electrical and chemical engineers
  - public policy specialists
  - market analysts
  - specialists in the alternative energy industry sectors related to advanced energy storage systems

The study was divided into two phases, the first of which concluded in the fall of 2012. Phase one was a deep examination of lithium ion battery cell supply chains, with particular focus on select components used in battery cell manufacturing. A major goal was to identify gaps, weaknesses, and opportunities that suppliers could fill. Additionally, market dynamics for other types of energy storage systems were investigated, as highlighted in Figure 1 below.

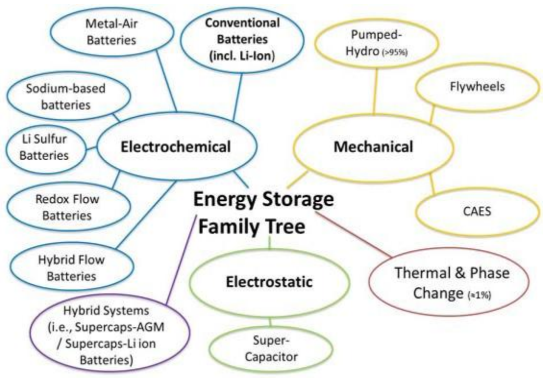


Figure 1: Energy Storage Family Tree Studied by NextEnergy

2 Challenges

On Nov. 13, 2012, Dan Radomski, NextEnergy's Vice President of New Market Services, presented preliminary findings from the study at The Battery Show in Novi, Michigan. [2] One of the most significant revelations was that the lithium ion battery market is currently suffering from overcapacity, in large part due to the inflated projections and unrealistic expectations for sales of EVs. The study indicates at least a 300% overcapacity of lithium ion batteries for EVs for the Tier 1 battery firms in 2012, although some industry sources have estimated the bloating to be higher, from 700% to 1,000% overcapacity, depending on the specific sub-sector and vehicle type considered. Market economic dynamics, the basic law of supply and demand, might suggest that the overcapacity should create significant pressure to lower prices. In a mature market this may be the case, but this market is being driven by (1) acceptance, (2) material costs, and (3) processing costs, none of which are mature. More specifically: [3]

- One major domestic Tier 1 battery supplier has publicized a ~300% overcapacity in the US. This was based on a 2013 supply of 200,000 battery packs x 20kWh/battery pack = 4GWh, with 2013 projected demand being 50,000 packs x 20kWh/pack = 1GWh. [3]
- Globally, and based on industry intelligence, it is estimated that the actual lithium ion battery overcapacity for electric vehicles is from 730-1,000%, depending on the Tier 1 supplier and other details. In the case of one prominent Tier 1 lithium ion battery manufacturer, the 2013 supply was rated at 25-30GWh; 2013 projected demand, 3GWh. [3, 4]

This overcapacity issue implies several challenges and new developments for the industry:

1. This issue will play out for several years. NextEnergy estimates that, the supply-demand curve will start to stabilize between 2015 and 2017. There are many factors at play that could cause a paradigm shift in this curve. Some factors are related not only to the actual sales of EVs, but also to breakthroughs that would allow for much cheaper materials and components to be manufactured on a mass scale. Roughly 60% of the battery cell cost is attributed to the raw materials

used to produce the electrodes, electrolyte, separator, and housing. Growth beyond laboratory scale would translate to a significant price decrease in an EV battery pack. Another factor is the price of conventional fuel (gasoline, diesel) and the price of competing "cleaner" sources of energy, such as natural gas.

2. Suppliers and OEM's are thinking outside of the box when considering applications and platforms for their products. Lithium ion batteries, originally intended for EV use, are being considered for consumer electronics, stationary power, and other applications. Therefore, a "drop-in ready" product that can function in a notebook, yet be stacked with other cells to fulfil the needs of products with higher power ratings in other applications, is desirable.

3. The electric vehicle and advanced energy storage industry, in general, was over-hyped by the media and others. It is normal for a relatively new industry in a depressed economy to have a somewhat slow uptake. Consumers are especially cautious about how they spend their money, and consumers are also weary of EVs that may cause them to experience range anxiety. The industry is still in its embryonic stage despite the vast amount of funding and resources invested and the vast progress made in the last five years. There is still a long way to go to achieve a mature market.

4. NextEnergy is teaming with workforce development agencies on a regional grant funded by the US Dept. of Commerce's Economic Development Administration (EDA), the Small Business Administration (SBA) and the Employment and Training Administration (ETA). The ETA has allocated funding to provide free training to employees in southeast Michigan who need to upgrade their skills in the area of advanced energy storage. Macomb Community College and Wayne State University are the training partners in this grant and have designed a number of courses to upgrade current employee's skills as well as to train dislocated workers to enter the field of advanced energy storage.

Production workers that should benefit from this new development are assemblers, fabricators, metal and plastic workers, as well as electrical, chemical, and mechanical engineers. In addition to the southeast Michigan program, battery manufacturers in West Michigan have partnered with Michigan's Smart Coast Advanced Energy Storage Alliance to train workers in new manufacturing processes for battery production.

Despite the workforce development training and services offered, the overcapacity issue with the industry has caused a lower than expected enrolment rate in the courses.

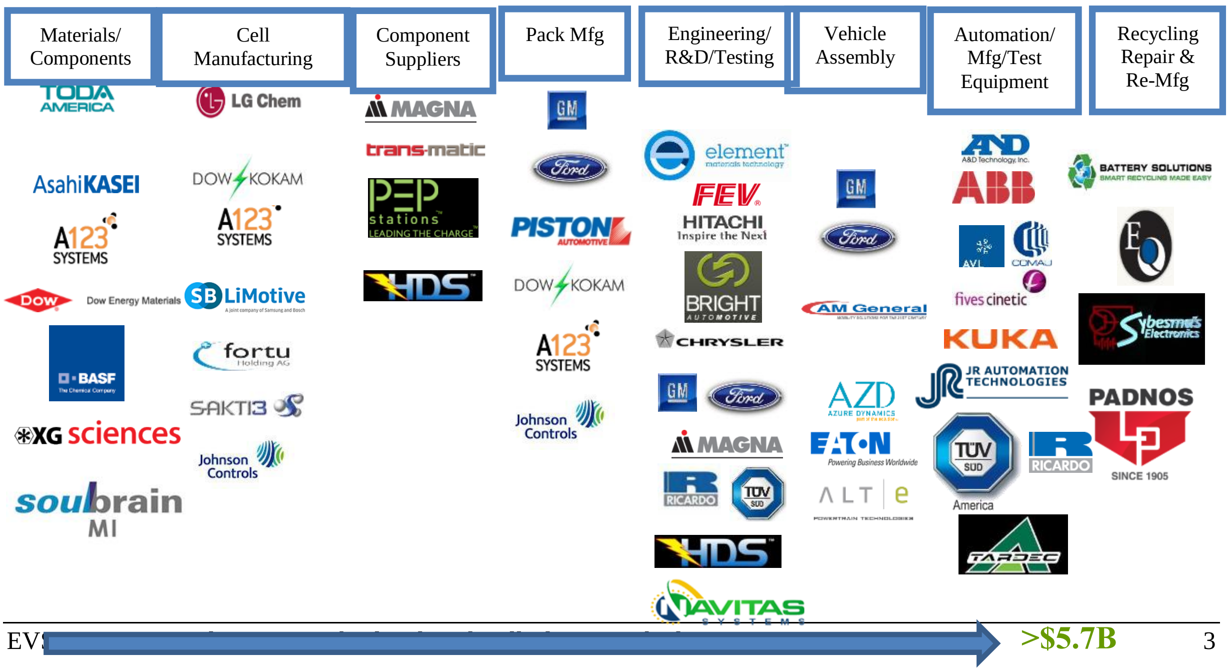


Figure 2: Key Michigan Assets in the Advanced Battery and Energy Storage Family Tree Sector

3 Domestic Opportunities

Despite the current overcapacity issue, the lithium ion and other advanced energy storage supply chain is still thriving, especially in the state of Michigan. Michigan has over 200 companies, universities, economic development agencies, non-profits and other firms currently vested in the sector. The state and the federal government has invested over $5.7 billion US into this sector since 2008, and several firms have Asian or European ties, specifically to Japan, Korea, China, and Germany. [5] Michigan's key assets in the lithium ion battery and advanced energy storage supply chain are shown in Figure 2 above.

Additionally, repair, remanufacturing, and recycling of large format lithium ion batteries is an area of growth, presenting both challenges and opportunities. Batteries will not last forever. When a battery is either defective, does not operate effectively for its intended primary use, or has reached the end of its life cycle of between five to ten years, it may be repurposed or may need to be recycled. These types of batteries present unique challenges in the way of safety, storage, shipping and handling. There are only a few companies in Michigan who have the know-how to effectively address these issues.

Another opportunity exists in micro-hybrids since they are expected to gain significant automotive market share in the next 5 to 10 years, in large part due to the increasing adoption of start-stop systems. However, most of these are expected to utilize lead acid / absorbent glass mat (AGM) technology. NextEnergy has commissioned Baum and Associates to conduct a study to forecast what that market will look like for the US in the next few years. While some studies have estimated the US market for start-stop systems at a demand of five million units by 2015, NextEnergy's and Baum's forecast is much more conservative at a little over three million units by 2015.

4 Opportunity Sizing

In order to quantify the opportunity for domestic suppliers of lithium ion battery materials and components as related to demand on the automotive side, a conservative, yet holistic approach was utilized. The following steps were followed to obtain a projected demand in 2015 for key battery materials and components:

1. A detailed bill of materials (BOM) for a 24 kWhr-rated battery electric vehicle (BEV) was obtained. This BOM included current (2011) pricing and projected (2015) pricing for each separate material/component on a mass, area or volumetric basis (as appropriate) and a cost per unit of measure. This BOM was derived from one of the major automotive OEMs and shared at the 2012 advanced automotive batteries conference. [6]
2. An "energy spectrum" of different types of EVs was created as shown in Figure 3.
3. The purpose of creating this spectrum was to relate this to projected domestic market sizes for different types of vehicles:
   a. Mild and micro-hybrid EVs were grouped

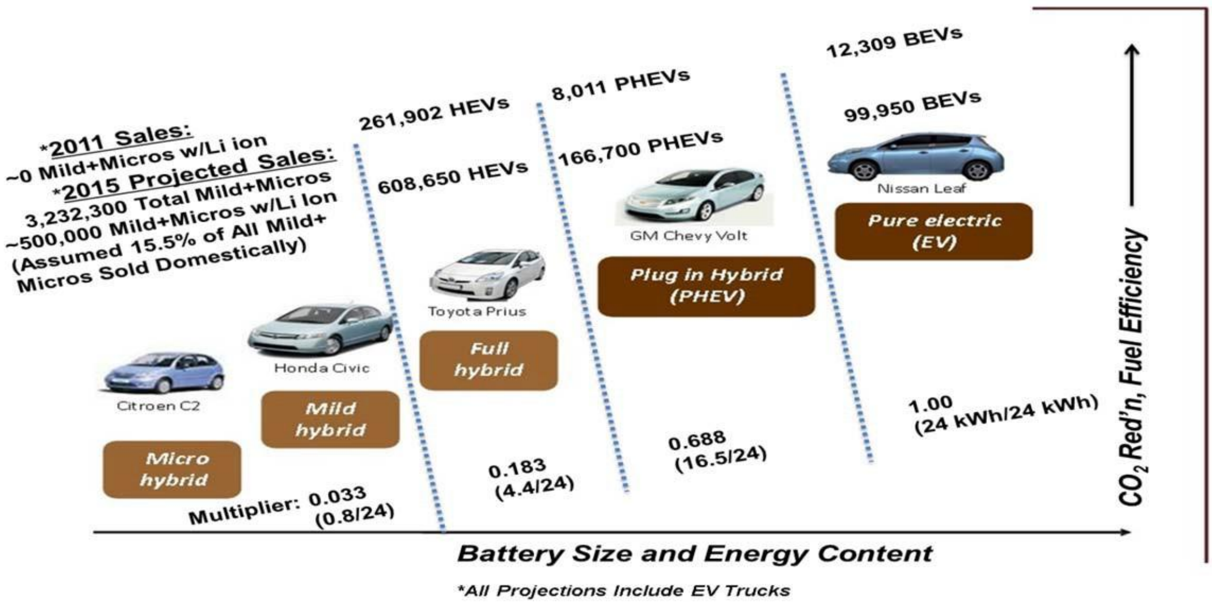


Figure 3: EV Energy Spectrum by NextEnergy with Market Forecasts [7, 8, 9]

together at the low energy requirement end of the spectrum and assumed to have an average requirement of approximately 0.8 kWh of usable energy from a lithium ion battery. Although the Citroen C2 is shown as an example of a vehicle with a micro-hybrid system, and a Honda Civic as the example for a mild hybrid system, the 0.8 kWh was not based solely on the energy of these two particular vehicles. Rather, 0.8 kWh was selected as a reasonable energy content for all mild- and micro-hybrid systems, based on NextEnergy's assessment of other industry reports and data. For this particular group of vehicles, it was also assumed that, approximately 15.5% of the mix sold domestically would contain lithium ion batteries, given that AGM batteries would likely dominate the micro market, and some mild hybrid systems would utilize nickel metal hydride batteries. Other systems, such as supercapacitors coupled with an AGM or a lithium ion battery, also are becoming more feasible and commercially available, further encroaching on the lithium ion battery segment of micro- and mild hybrid systems.

b. Hybrid electric vehicles (HEVs) made up the group with the next highest energy content, assumed to be 4.4 kWh. Examples of HEVs include the 2011 Hyundai Sonata Hybrid, 2012 Infiniti M35 Hybrid, 2012/2013 Ford C-MAX Hybrid, and 2014 Ferrari Hybrid.

c. Plug-in Hybrid Electric Vehicles (PHEVs) and certain Extended Range Electric Vehicles (EREVs) made up the group of vehicles with the next highest energy content, assumed to be about 16.5 kWh. Some examples of other PHEVs and EREVs that fall into this category include the 2012 Toyota Prius Plug-in Hybrid, Ford Escape Plug-in Hybrid, and Ford C-MAX Energi, as well as the 2013 BMW Vision and i8 models.

d. Finally, EVs at the highest end of the energy spectrum were the battery electric vehicles (BEVs), with the Nissan Leaf rated at 24 kWh chosen as the model for this segment. Other examples of BEVs include the 2012 Honda Fit EV, 2012 Audi R8 EV, and 2013 Mercedes SLS E-Cell AMG.

Figure 4: Micro-hybrid systems, such as the one included in this Volkswagen Passat BlueMotion, represent a huge opportunity for lithium ion battery makers and integrator. (Photo credit: Volkswagen.)

4. Conservative sales projections for each of the different groups defined above as well as the entire spectrum of EVs was obtained through a local market research group for the current (2011) year and 2015. Previous projections from this particular market research group were audited against actual sales data and found to be very close – much closer than some other market forecasts that had very inflated sales projections.

5. Armed with the data above – knowing how many cells comprise a BEV battery pack (192 cells per Nissan Leaf battery pack), how many vehicles are expected to be sold in 2015, how much of each material/component is contained in a single lithium ion battery cell, how much that material/component currently costs per given unit of measure and how much each material/component is projected to cost in 2015, market demand was extrapolated for each different component/material that goes into a BEV pack. Then, similar calculations were performed to gauge an estimated market demand for the lithium ion battery cell materials and components that comprise the entire spectrum of EVs, using a multiplier of 0.8 kWh / 24 kWh or 0.033 for the mild and micro-hybrid EVs

group, 0.183 (4.4 kWh / 24 kWh) for the HEVs group, and so on. For example:

a. There are 1.57 m^2 of tri-layer separator material in a single BEV cell and we know the 2011 and projected 2015 costs ($1.91-$2.00/m^2 and $1.07-$1.10/m^2), respectively.
b. We also know that approximately 99,950 BEVs are projected to be sold in 2015.
c. The 2015 estimated domestic market size for separator material in BEVs is therefore:

1.57 m^2 × $1.10 (2015 cost) ×192 cells × 99,950 packs = $33 million (1)

d. Using the multipliers previously identified for the spectrum of EVs, the 2015 estimated domestic market size for separator material in HEVs can also be calculated as:

1.57 m^2 × $1.10 × 192 cells × 2015 proj. sales for HEVs × 0.183 = $XMM HEVs (2)

e. Similar calculations can be performed to obtain the total projected market size for micro- and mild hybrid systems ("$XMM MCMLDs"), the total projected market size for PHEVs ("$XMM PHEVs"), and the total projected demand (m^2 of material) for the separator material for each of these vehicular groups (i.e., how many m^2 of separator material will be needed for mild and micro-hybrid systems in 2015, for HEVs, … and so on).
f. The 2015 estimated domestic (U.S.) market size demand for all EVs is therefore:

$33 million for BEVs + $XMM HEVs + $XMM PHEVs + $XMM MCMLDs = ~$110 million (3)

Components / Materials	Projected 2015 U.S. Demand (Millions)
1. Electrolyte Shipping Containers	$500
2. Anode Materials	$347
3. Active Cathode Materials	$230-270
4. Electrolyte Salts, Solvents, and Additives	$122 ($98 Solvents, $18 Salts, $6 Additives)
5. TIE - Cell Packaging – Cans and Pouches AND Separator	$110 (each)
6. Polyvinylidene Fluoride (PVDF) Binder	$89
7. N-Methyl-2-Pyrrolidone (NMP) Solvent Recycling	$73
8. Current Collectors (Tabs) – Aluminum, Copper, and Nickel	$3.5
9. N-Methyl-2-Pyrrolidone (NMP) Solvent Production	$0.6

Table 1: Lithium Ion Battery Cell Top Domestic Supplier Opportunities in 2015, Ranked by EV Demand ($US, Millions)

After performing this series of calculations priority could be established for current and potential suppliers of lithium ion batteries' components and materials on a cell level. The next step was to socialize this information with key industry representatives under non-disclosure, in order to not only share this new data, but to obtain additional information and audit NextEnergy's work. The top 10 domestic lithium ion battery components/materials opportunities are shown in Table 1 (Note that, item 5 is a tie between the cans/pouches and separator material and therefore should be counted as two distinct components/materials.):

For material suppliers, phase one of the study shows a potential demand for 167,000 units of electrolyte shipping containers by 2015, representing a $500 million market. The next biggest opportunity would be anode materials, valued at ~$350 million, and active cathode materials, which could reach $250 million.

5 Supply Chain Dynamics

By revisiting the Phase 1 study, in addition to sizing up the lithium ion battery cell materials and components, intelligence was also gathered on current and prospective suppliers of these materials on both a domestic and global scale. In keeping with the separators example, for instance, Table 2 highlights some of the key supply chain dynamics, incorporating not only suppliers producing the material on a mass production scale, but also brief highlights on next-generation separators and related R&D work underway. Key intelligence was also gathered on what manufacturing equipment is needed to produce the materials and components identified in Table 1, how they are currently produced and how they may be produced in the future.

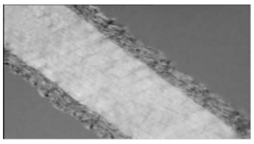
Volume	1.6m²/BEV cell
Value	\$1.91-\$2.00/m² Now, \$1.07-1.10/m² Projected 2015+
Projected Demand (2015)	103MM m²
Est. Domestic Market Size (2015)	\$110MM
Key Industry Suppliers 	• **Applied Materials (CA)** • Asahi Kasei (Jap.) • **Celgard (Polypore, NC)** • Cheil Industries • **DuPont (VA)** • **ENTEK Membranes (OR)** • Evonik Industries (Germany) • Toray BSF (Tonen) (Jap.) – JV with **ExxonMobil (TX)**
Supply Chain Dynamics 	• NC-based Celgard has a ~30% share of the global market. JCI is working with Entek. ExxonMobil is using a catalytic olefin polymerization with metallocenes that uses ¾ gas (UNIPOL™) phase polymerization process, which is expensive. • Leading overseas separator makers are Asahi Kasei, Toray Tonen and SK Innovation. • New types of separators include: separators made from cellulose, low-cost, but to ensure battery safety additives are needed as they lack an auto-shutdown function, and ceramic-coated separators, which use the dry-manufacturing technology (forming multi-layers of polyethylene/polypropylene) of Ube Industries and the inorganic particle-processing technologies (mixing/dispersion, thin-film coating) of Hitachi Maxell.

Table 2: Li-Ion Battery Separators Opportunity Snapshot with Key Suppliers (Domestic Bolded) and Supply Chain Dynamics [10, 11, 12, 13]

6 Conclusions

The primary opportunities and challenges for the lithium ion industry sector, revealed by the phase one NextEnergy study, are as follows:

1. The battery cell materials supply chain, including cell assembly, is currently dominated by Asian suppliers. This is not surprising since they have clusters, such as semiconductors, printed circuit boards, and consumer electronic devices, that leverage the same natural and manufactured resources used to produce lithium ion batteries.
2. It has been suggested that the battery supply chain can be described as having the quality control requirements of the pharmaceutical industry, cleanliness concerns of food processing, warranty demands of the automotive industry, and manufacturing tolerance restrictions of the semiconductor industry.
3. Low volume demand limits the prospects for would-be, US suppliers in the near-term; since, for all but very short shelf-life products, non-US capacity can easily handle North American demand. Limited U.S. capacity exists for short shelf-life products that include electrolyte salts & additives and solvent and copper foil for the current collectors.
4. Other prospects for domestic suppliers in the near-term include opportunities in pack components and assembly processes. There are roughly 19 components that need to be assembled to make a cell, as compared to 200+ components in pack assembly.
5. Innovation and intellectual property (IP) opportunities also abound for the development of new, safer, more cost effective, and more efficient battery materials, manufacturing processes, and next generation batteries. Argonne National Laboratory (ANL) has been selected for an award of up to \$120 million over five years to establish a new Batteries and Energy Storage Hub. The Hub, to be known as the Joint Center for Energy Storage Research (JCESR), will combine the R&D firepower of five DOE national laboratories, five universities, (including University of Michigan), and four private firms in an effort to achieve revolutionary advances in battery performance.

It should be noted that this study is a medium to longer term initiative. The results will be evident around 2015; therefore, presently, it is too early for results to be evident

7 Suppliers' Survey

NextEnergy has formed strong networks with industry and other organizations that can provide potential and existing suppliers with access to other firms who can fulfil certain supply chain gaps. Some of these potential suppliers may possess the capability to produce a given component, for example, but the specific manufacturing process or equipment used or other factors may limit their competency to actually produce the product. For example, in the case of shipping containers for electrolyte materials (salts, solvents and additives), many companies are perfectly capable of manufacturing steel, 55-gallon and larger drums. However, not many of those companies are competent to manufacture electro-polished drums with special valves and fittings that meet the tight quality control and cleanliness requirements of the industry. Through NextEnergy's extensive advanced energy storage network, the organization can link newcomers interested in manufacturing or supplying some of these materials/components to firms who are experts in a given sub-sector, in order to smoothly transition these suppliers from capable to competent and from potential to actual supplier. When domestic supply chain gaps are filled, then the overall price of a battery pack is likely to decrease and the cluster is therefore more likely to thrive.

NextEnergy is hoping to hear from suppliers at each stage in the cell and pack assembly process. The survey is available online at: https://www.surveymonkey.com/s/advenergystorage. NextEnergy wants to hear from existing and potential firms manufacturing or providing key resources related to the following:

- Active Cathode Materials (i.e. nanophosphates/silicates, lithium)
- Iron phosphate, NCA, etc.
- Binders (PVDF, SBR or aqueous-based)
- C-Black/natural graphite graphene/anode materials
- Normal methyl-2-pyrollidone (NMP) solvent
- Carbonates (EC, DMC, etc.)
- LiPF6 electrolyte salts
- Tabs (current collectors and connectors), including aluminium, nickel, and copper polypropylene or polyethylene (or other novel) separators
- Aluminium or steel cans, pouches and other packaging (covers/caps)
- Electrolyte additives
- Polymer precursors
- Electrical components (buss bars, chipsets for battery management systems, etc.)
- Valves and fittings for electrolyte shipping containers
- Thermal management systems
- Cell testing and grading systems
- Pack assembly integrators
- Recyclers (Lithium ion and other battery systems)
- Other energy storage systems – next-generation systems (flow batteries, etc), ultra-capacitor / battery (AGM and Lithium ion) hybrid and other systems.

The lithium ion battery study is funded by a $1.2 million award from the Commerce Dept.'s Economic Development Authority. For more on the study and the survey, click here: or contact Kelly Jezierski at (313) 268 1807 or kellyj@nextenergy.org. The study will run through fall of 2013.

8 Phase 2

The second phase of the study, going on now, is focused on battery packs and the study of the assembly process. The value supply chain map for cells developed from phase one has nearly 60 steps, but for battery packs, it is much more complicated. Because there are numerous combinations and permutations, given the different types of vehicles, different configurations, different battery chemistries, different sets of materials/components, types of batteries and their specifications, the possibilities are numerous. In addition to mapping the pack assembly process, phase two is designed to identify the major players in pack assembly, discover opportunities for vertical integration of multiple steps, and to help identify and connect companies who are performing innovative and novel work in pack integration.

9 About NextEnergy

NextEnergy is a 501(c)(3) non-profit organization established in 2002 to drive advanced energy investment and job creation in Michigan. Located in Midtown Detroit's innovation corridor, NextEnergy serves as a catalyst for advanced energy technology demonstration and commercialization in the state. NextEnergy's mission is to develop and commercialize energy technologies, build and disseminate critical market intelligence, and work with federal agencies on energy strategies, funding priorities, and advise on relevant programs. The organization works with the U.S. Dept. of Energy, U.S. Dept. of Commerce, and local and state groups like the MEDC. NextEnergy also collaborates with local and national businesses to build relationships and cultivate partnerships that foster innovation, efficiency, and economic growth. Since its inception, NextEnergy has helped to attract more than $1 billion of new investment, including over $150 million generated by programs in which NextEnergy has directly participated.

A bird's eye view of the NextEnergy campus is shown in Figure 5. The NextEnergy Center is comprised of eight R&D laboratories, an Alternative Fuels Platform, which houses infrastructure for several types of alternative fueling stations (including biodiesel, hydrogen, and electricity), a Stationary Microgrid Power Pavilion, a 120-person seat auditorium, exhibition space, training rooms, and offices.

In collaboration with the local utility and one of the "Big three" automotive original equipment manufacturers (OEMs), NextEnergy is executing a vehicle-to-grid ("V2G") program. This V2G program is described in Figure 6 on page 9. The testing and validation equipment at NextEnergy complies with SAE J1772 standards where applicable. Minor modifications to the test platform enable the evaluation of various energy storage and discharging devices. Available testing and validation equipment on-site at NextEnergy includes:

- Seven (7) level I AC chargers
- Ten (10) level II AC chargers
- Two (2) level I DC chargers
- Nineteen (19) uni-directional chargers
- Three (3) total bi-directional charging stations
- Two (2) locations for inductive charging

Figure 5: Bird's Eye View of the NextEnergy Center Campus in Downtown Detroit [14]

Figure 6: NextEnergy's Advanced Vehicle Electrification Research Capabilities [14]

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