The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

NEXTENERGY
ask us what's next

Supply Chain Dynamics and Growth Opportunities in Advanced Batteries

EVS27

November 18, 2013

Dan Radomski

Organized by Fira Barcelona, avele

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In collaboration with Ajuntament de Barcelona, EVAAP, EDTA

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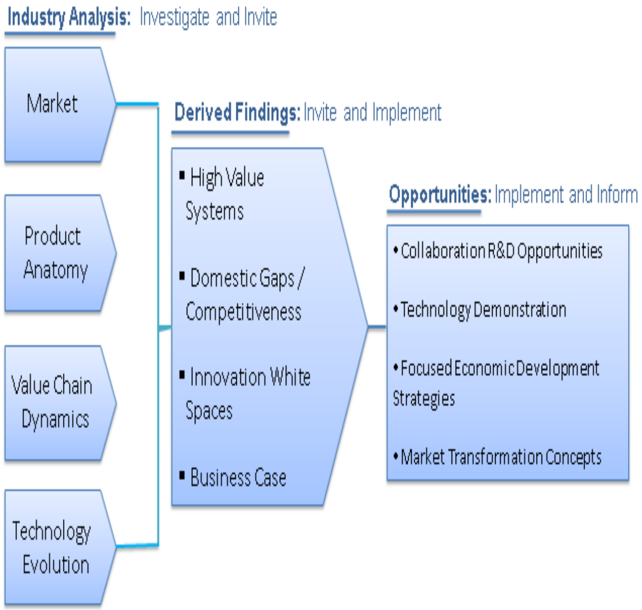
NextEnergy Overview

www.nextenergy.org

Knowledge



- Market Studies
- Supply Chain Analysis
- Value Chain Assessment
- Technology Roadmapping
- Domestic Competitiveness

Relationships

- Funding Pathways
- Go-to-Market Partners
- First Customers
- Link Small & Big Firms
- Collaborative R&D

Technical Facilities

- Technology Proving Ground
- Concept Demonstration
- Validation and Testing

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US Dept. of Commerce Program

Advanced Energy Storage Cluster Initiative

Dept. of Commerce EDA $1.2 million award

NextEnergy and MEDC AESSI Program Partners:

Period of Performance: 2.5 years (10/2011 - 04/2014)

Scope:

- Focus Li Ion Batteries (Vehicles/Grid)- Phase I: Cells, Phase II: Pack
- Commonality in R&D, supply chain, bus. dev., and talent needs
- US Domestic industry diversification/transition opportunities
- US Domestic cluster growth opportunities

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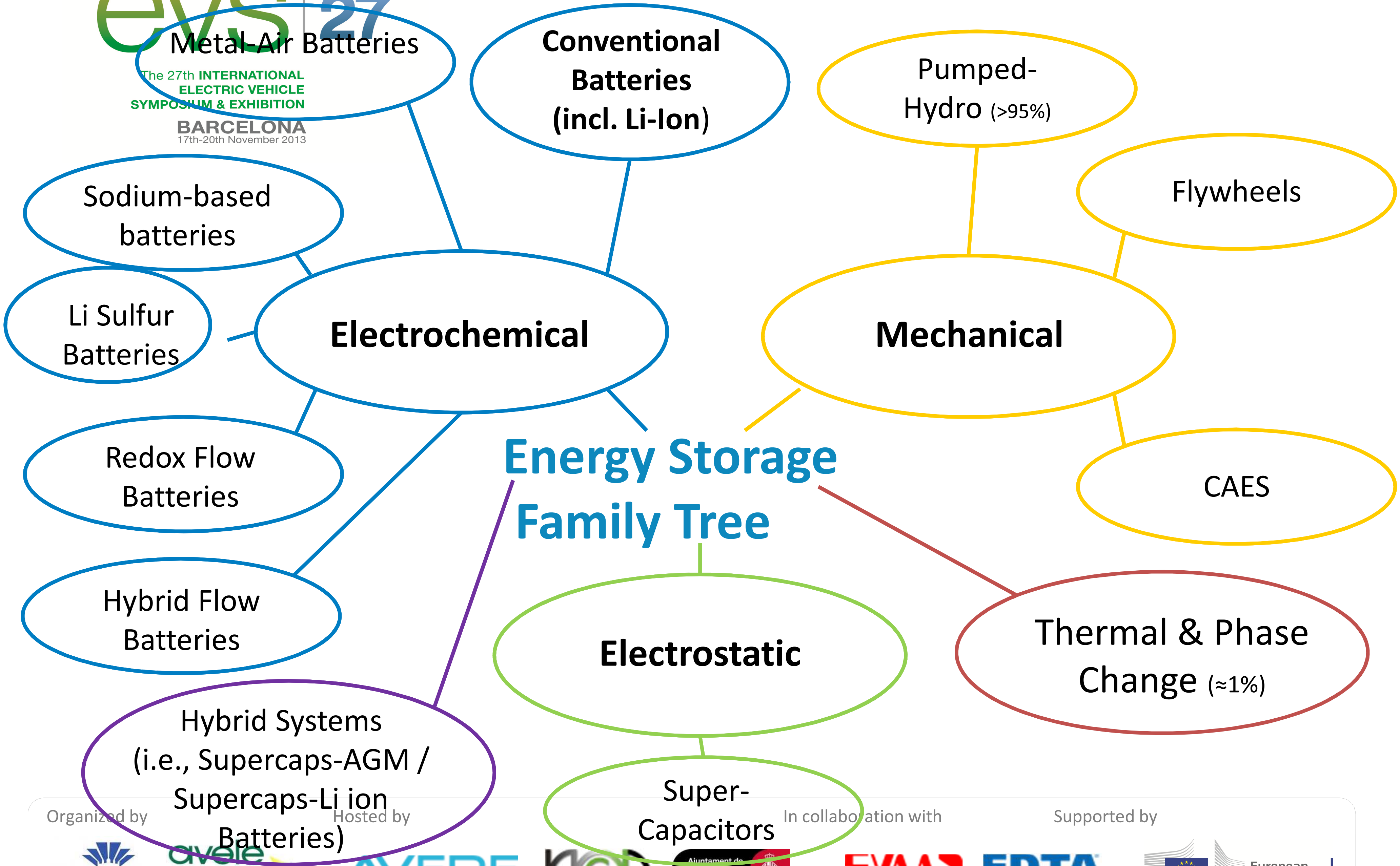

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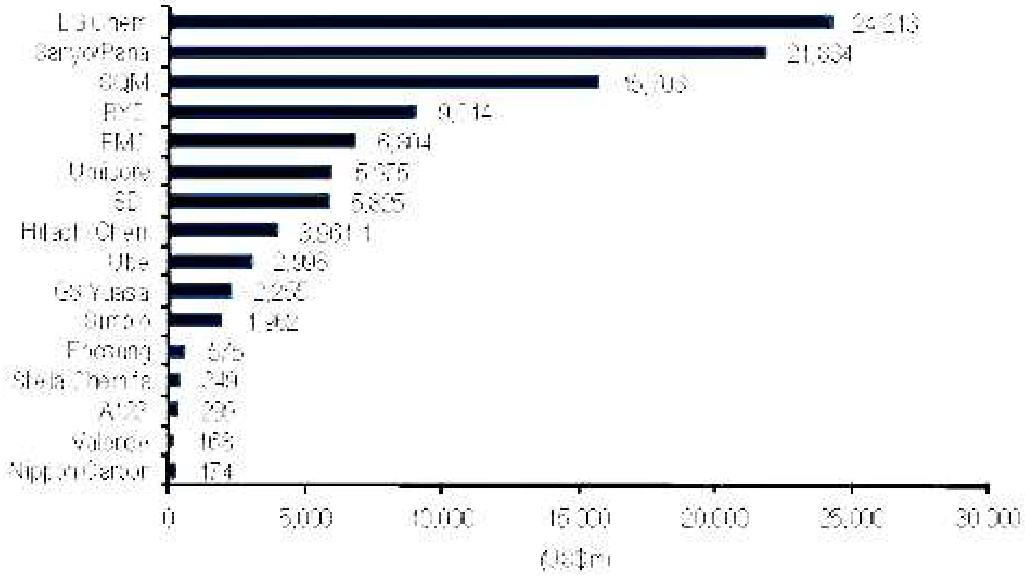
Global Demand

Global Li Ion Battery Market Forecast

▪ Market cap of key global LIB battery-related companies



▪ LiB market forecasts

Source: Daiwa forecasts

$60 bn 236 GWh by 2020

collaboration with

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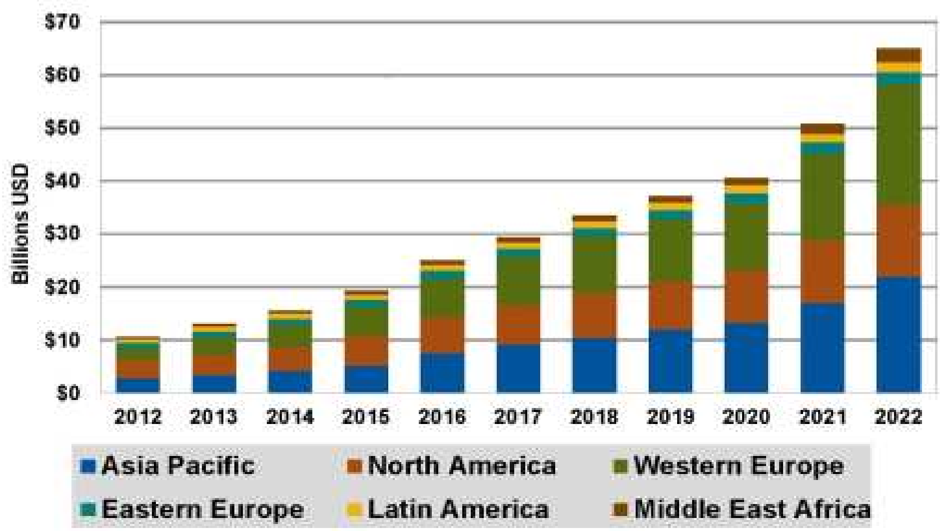
Global Demand

Global Li Ion Battery Market Forecast

Global Forecast of all Li Ion Revenue



Source: Navigant Research

NAVIGANT RESEARCH

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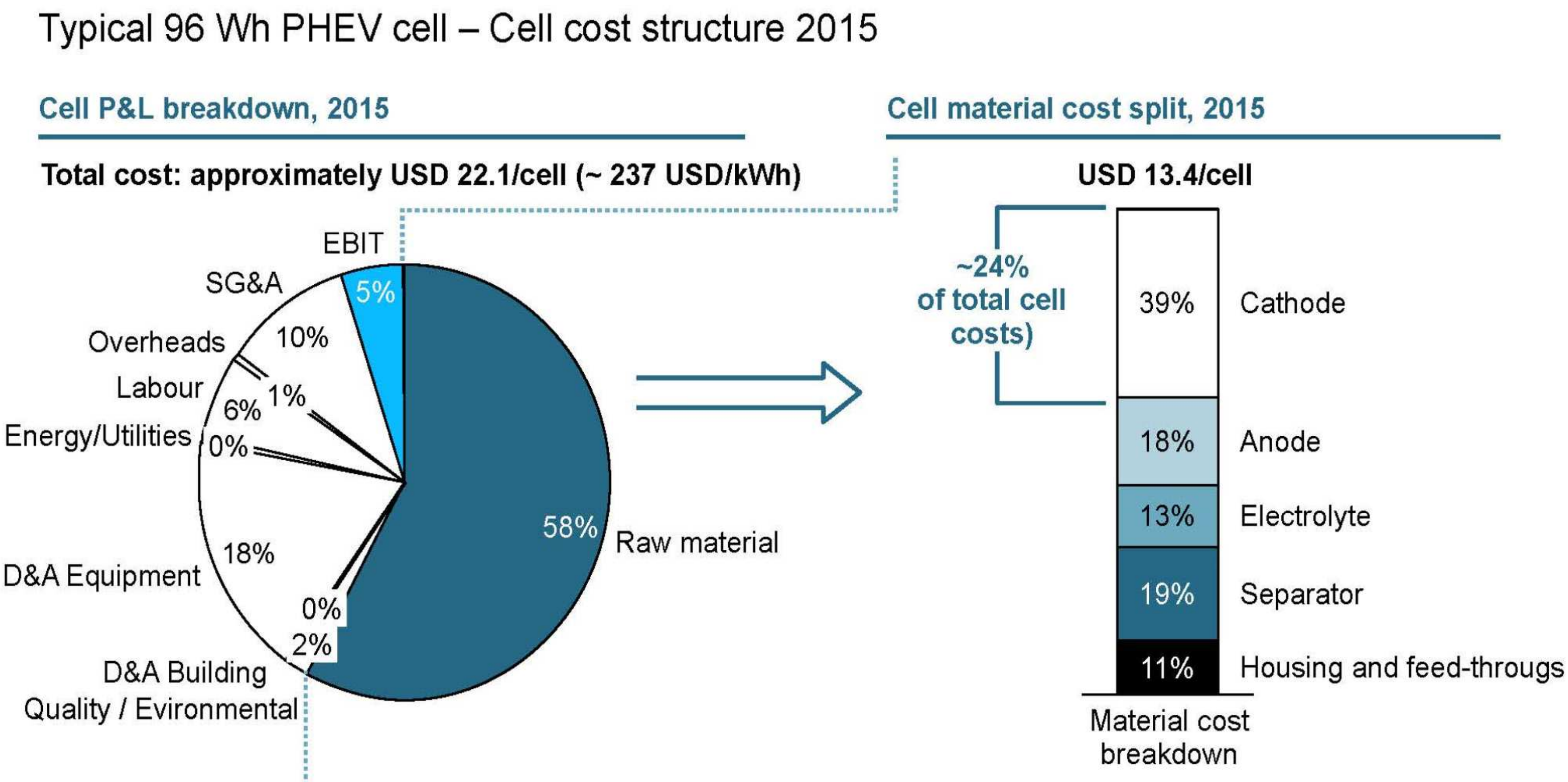
Cost Structure

Typical PHEV (96 Wh) Cell Breakdown, 2015

Source: RolandBerger Strategy Consultants



Common Configurations

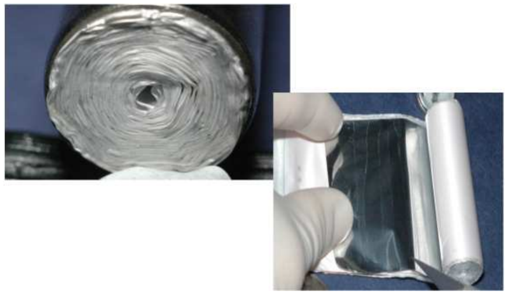
Typical EV Li Ion Battery Cell Architectures

Source: Sion Power Corporation, Janim.net, LG Chem, ecvv.com, and A123

Stacked

Vs.

Wound (Jelly Roll)



Prismatic

Vs.

Cylindrical (Round)

Pouch

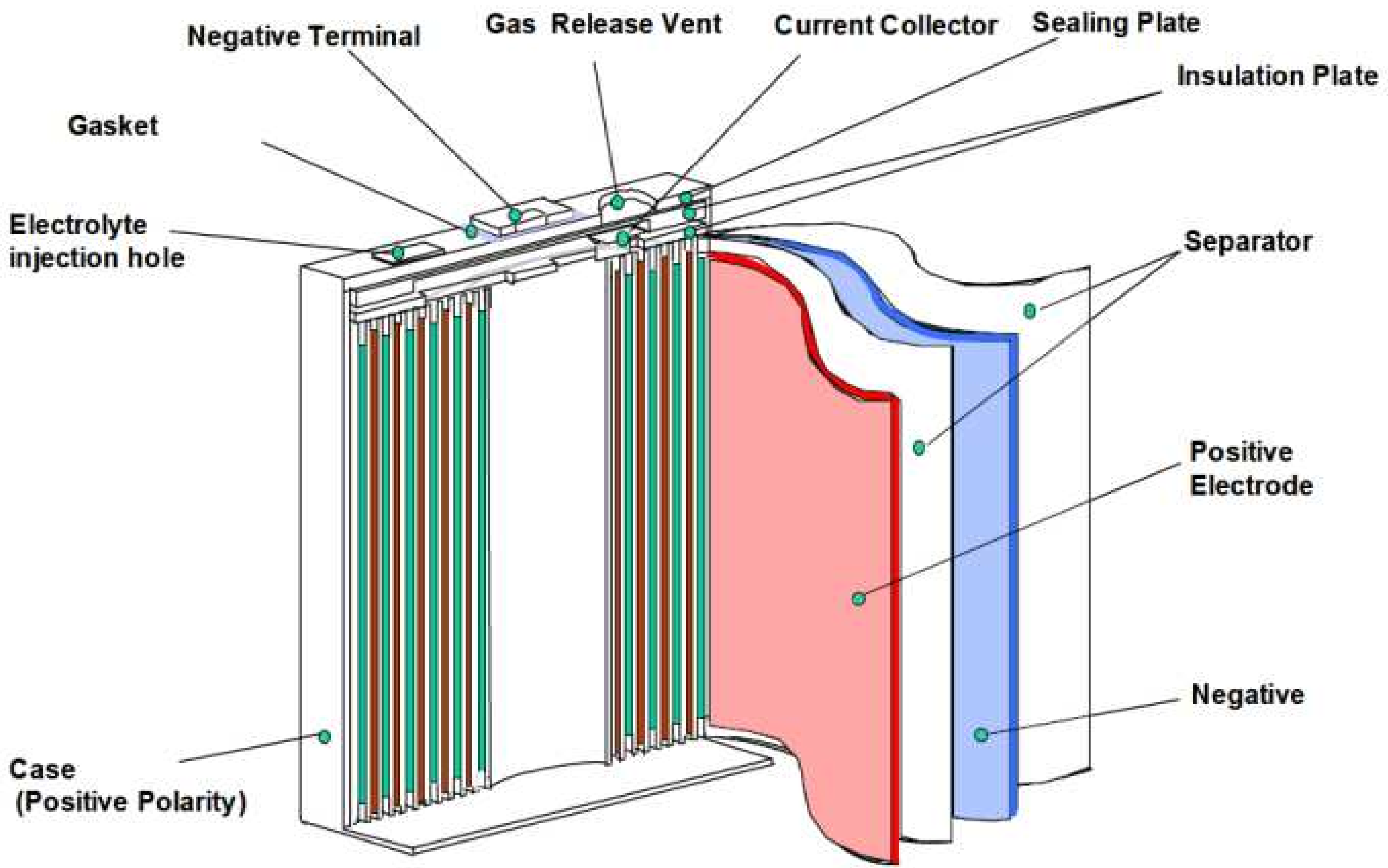
Vs.

Cans

Anatomy of a Li Ion Battery Cell

A Deconstructed Prismatic Cell

Source: Sion Power Corporation, TBS (Total Batery Solutions)



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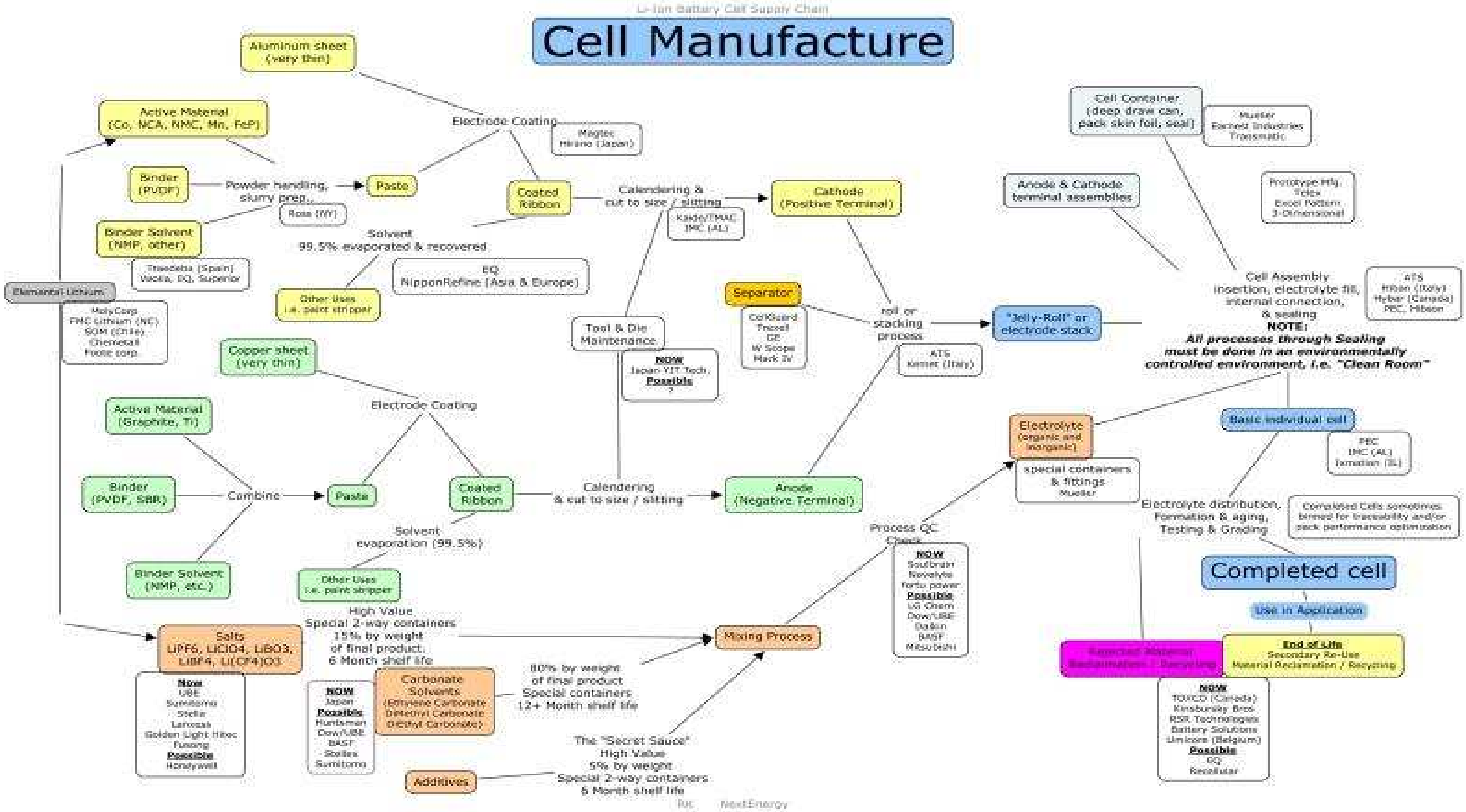
Lithium Ion Cell Production

Li Ion Battery Cell Manufacturing Process Map

Source: NextEnergy



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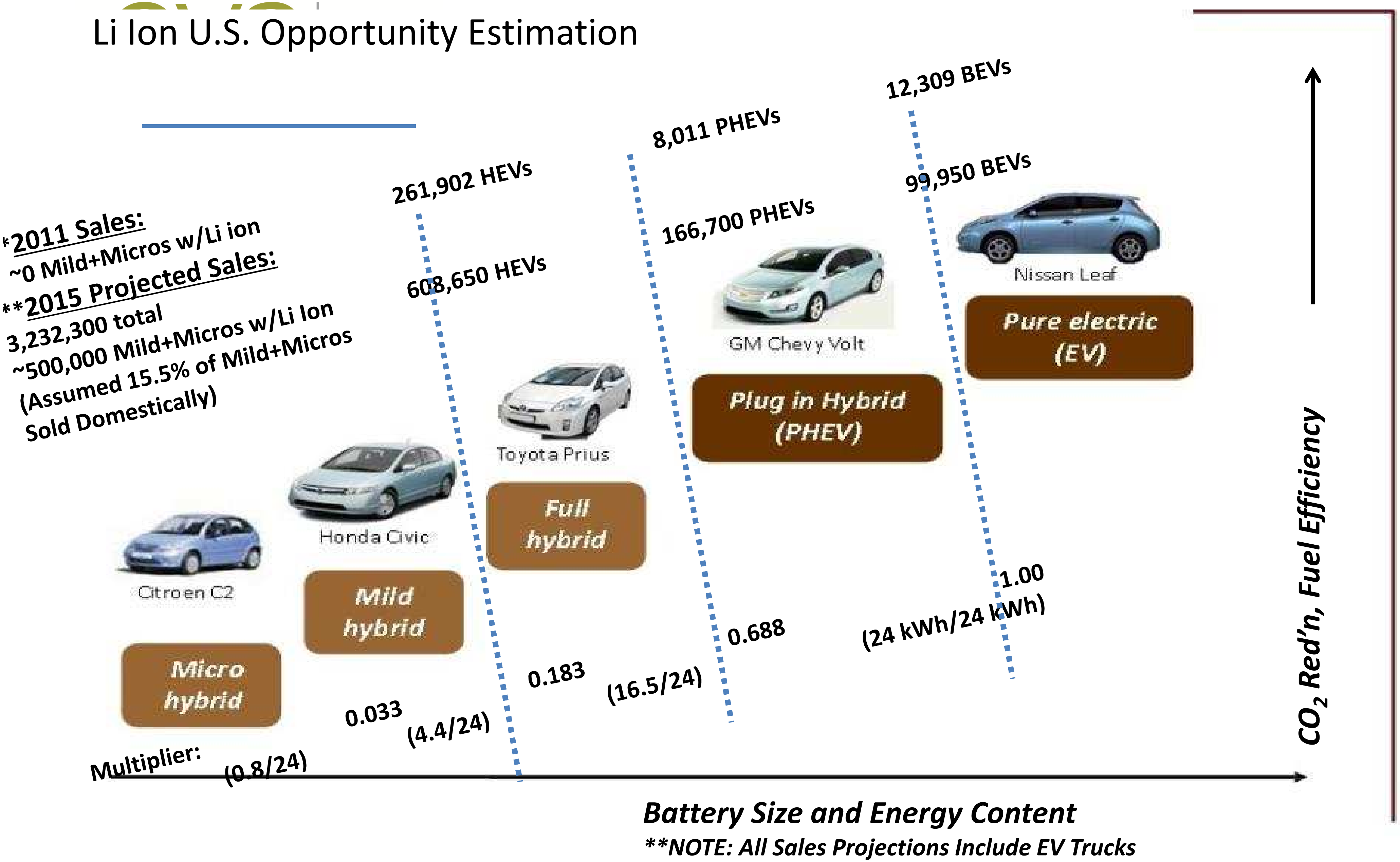
Largest US Domestic Opportunities

Top Li Ion Components /Materials, Based on 2015 EV Domestic Demand

Source: NextEnergy, with source data from: Baum and Associates, JCI, Lux Research, AAB

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

Li Ion U.S. Opportunity Estimation



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Methodology for Determining EV Li Ion Cell Values

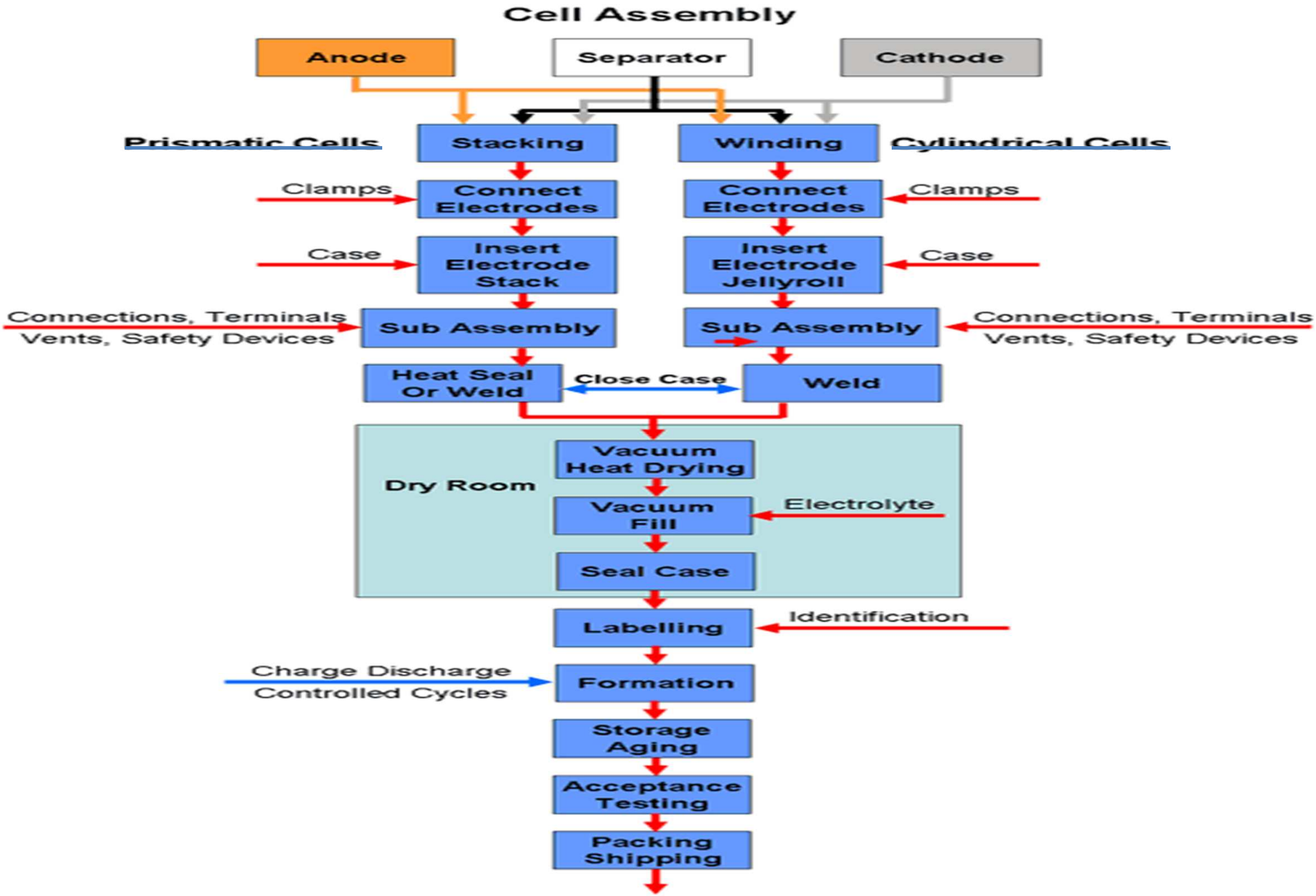
BEV Sample Calculations for U.S. Market Size & Demand Opportunities

Source: 2012 Advanced Automotive Batteries (AAB), NextEnergy, Baum and Associates

Note: Demand and Market Size Calculations are Additive (Data for Mild+Micros, HEVs, PHEVs, + BEVs)

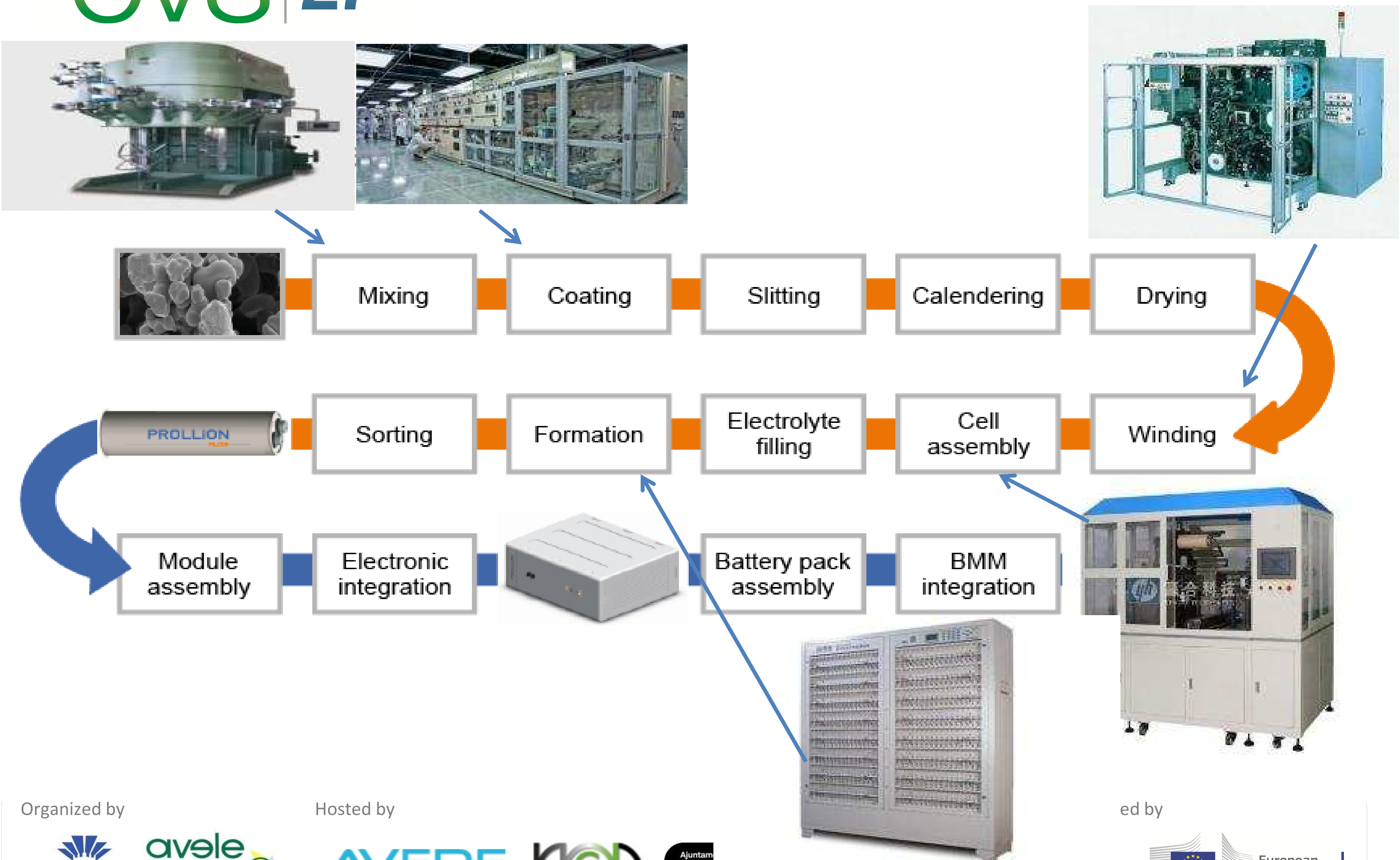
#Cells/ BEV (Nissan Leaf) Battery Pack	**192**				
Current Conversion Rate	$1.00	=	¥78.2498		
2011 BEV US Sales (Source: Baum+Assoc.)	12,309	Vehicles			
2015 Proj. BEV US Sales (Source: Baum+Assoc.)	99,950	Vehicles			

BEV Cell	Amt in a Cell	Unit	2011CY Cost	2011CY $US	US Opportunity for BEVs - 2011
Colum	Column2	Column3	Column4	Column5	Column7
Voltage	3.8	V			
Capacity	33.1	Ah			
Cathode Active Material (i.e., LMO - Li Manganese Oxides)	264.8	g	¥496.50	$6.35	$ 14,995,467.75
Cathode Active Material_2 (i.e., LNO - Li Nickel Oxides)	33.1	g	¥193.10	$2.47	$ 5,832,074.16
PVDF 12%NMP (N-methyl 2-pyrrolidone) Sol'n	85.6	g	¥107.00	$1.37	$ 3,231,651.66
C Black	34.2	g	¥28.50	$0.36	$ 860,767.03
Anode NG Core	158.9	g	¥270.80	$3.46	$ 8,178,796.91
PVDF 12%NMP Sol'n	40.9	g	¥52.30	$0.67	$ 1,579,583.01
Electrolyte - 80% solvent	96	g	¥172.80	$2.21	$ 5,218,966.42
Electrolyte - 15% salts	18	g	¥32.40	$0.41	$ 978,556.20
Electrolyte - 5% additives	6	g	¥10.80	$0.14	$ 326,185.40
Cathode Connector Tab - Al tab with film	1	pc	¥27.50	$0.35	$ 830,564.68
Anode Connector Tab - Ni tab with film	1	pc	¥35.00	$0.45	$ 1,057,082.32
Cathode Current Collector Tab - Al foil	0.72	m^2	¥41.10	$0.53	$ 1,241,316.67
Anode Current Collector Tab - Cu foil	0.79	m^2	¥139.10	$1.78	$ 4,201,147.16
Separator (tri-layer)	1.57	m^2	¥234.90	$3.00	$ 7,094,532.47
Pouch - Al/PP Laminate Foil (packaging)	0.11	m^2	¥84.60	$1.08	$ 2,555,118.98
Total (NOTE: does not include mark-up, warranty, BMS)			¥1,926.40	$24.62	
Material cost per Wh			¥15.32	$0.20	



Cell Assembly
Anode
Separator
Cathode
Prismatic Cells
Stacking
Winding
Cylindrical Cells
Clamps
Connect Electrodes
Connect Electrodes
Clamps
Case
Insert Electrode Stack
Insert Electrode Jellyroll
Case
Connections, Terminals Vents, Safety Devices
Sub Assembly
Sub Assembly
Connections, Terminals Vents, Safety Devices
Heat Seal Or Weld
Close Case
Weld
Dry Room
Vacuum Heat Drying
Vacuum Fill
Electrolyte
Seal Case
Labelling
Identification
Charge Discharge Controlled Cycles
Formation
Storage Aging
Acceptance Testing
Packing Shipping

Battery Production & Testing Equipment



Key Observations

US Domestic Lithium Ion Battery Supply Chain Challenges

Source: NextEnergy, Advanced Automotive Batteries, JCI, Lux Research, Roland Berger

1. There is a global overcapacity problem in the automotive Li ion battery market currently, which will play out for several years.
   - We've seen 300-1,000% overcapacity for automotive applications
   - However, production is expected to pick up again around Fall 2013
2. The battery cell materials supply chain is dominated by Asian suppliers including cell assembly equipment.
3. The battery supply chain is described as having the quality control issues of the pharmaceutical industry, cleanliness concerns of food processing, warranty demands of the automotive industry.
4. Low volume limits prospect for US would-be suppliers in the near-term, since for all but very short shelf-life products, non-US capacity can easily handle North American demand.
   - Short shelf-life products include: salts, additives and solvent (for the electrolyte), copper foil (for current collectors).

US Lith Ion Cell
Raw Material Sourcing Concerns

An Evolving Lithium Ion Battery Supply Chain

Material Sourced		Location of Supply	Lead Time (in days)
Cathode		South Korea	91
Separator Film		South Korea	77
Anode		Japan	84
Al Laminated Pouch		Japan	91
Artificial Graphite		Japan	63
Carbon Black		Belgium	56
Synthetic Graphite		Switzerland	63
Cu Foil		Japan	35
Binder		France	63
Al Foil		South Korea	63
Tab		South Korea	63

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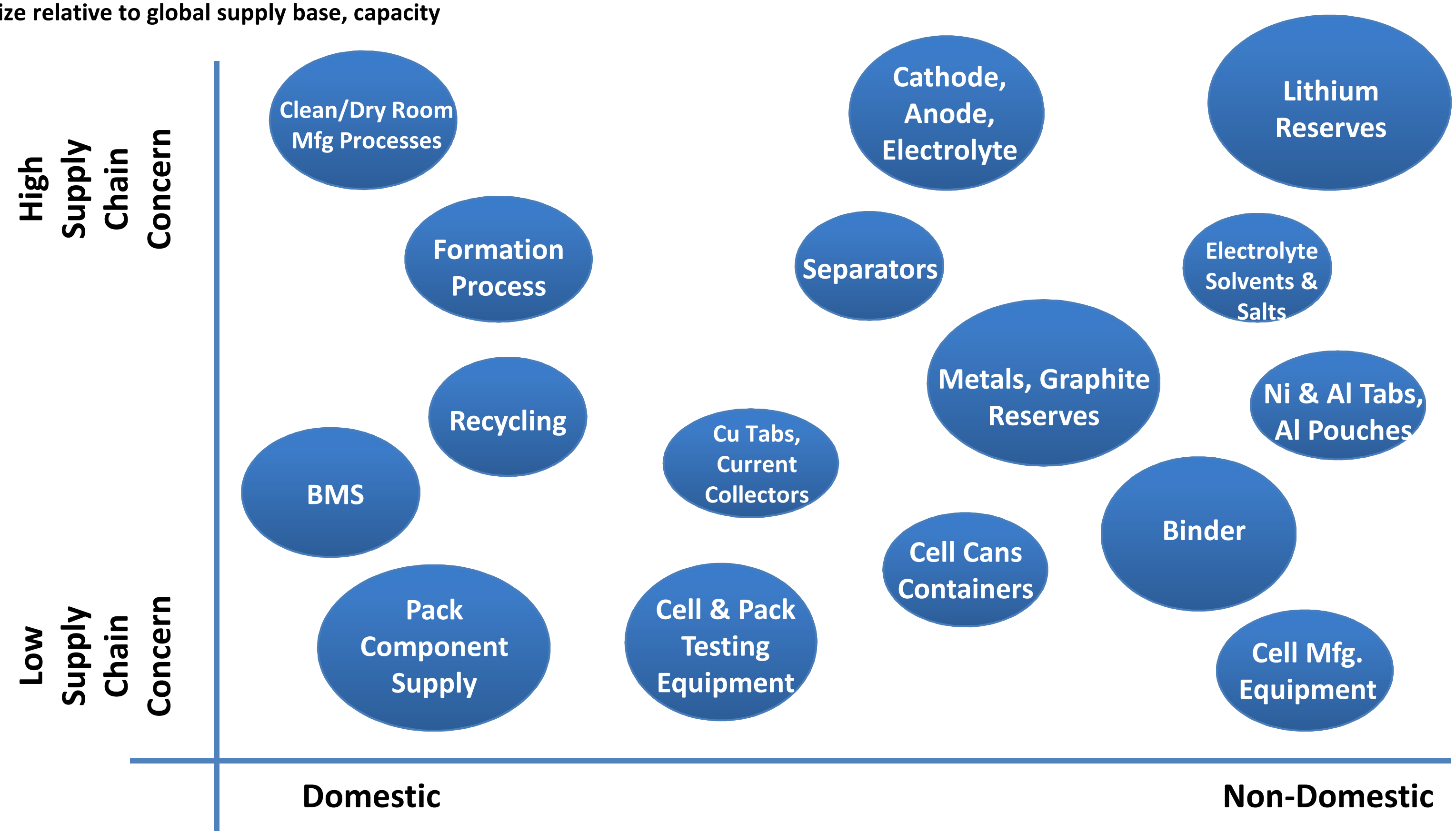
US Domestic Lithium Ion Sourcing Concerns

Battery Supply Chain Gaps:
Cost, # of suppliers, lead time, availability, shelf life, quality

= Bubble size relative to global supply base, capacity



http://news.mst.edu/2012/09/study_outlines_supply_chain_ch

Key Observations

US Domestic Lithium Ion Battery Supply Chain Opportunities

5. Other prospects for domestic suppliers in the near-term include opportunities in pack components and assembly processes
   - 19 components in cell assembly compared to 200+ components in pack assembly
6. Repair, Remanufacturing, Recycling of large format Lithium Ion Batteries is an area of growth, presenting both challenges and opportunities.
7. Strong market growth opportunities exist for stationary energy storage (cell towers, grid applications), consumer electronics and EVs.
8. Micro-hybrids are expected to gain significant automotive battery market share in the next 5-10 years, in large part due to start-stop systems; but most of these are expected to be AGM technology.
   - US Market: 3-5MM units expected by 2015
9. Innovation and IP opportunities on materials, mfg process, next generation batteries.
   - Energy Storage Hub awarded to ANL (Argonne National Labs, www.jcesr.org) – more R&D and beyond lithium technologies focus

Key Observations

Lithium Ion Battery

Production Process Improvement Areas

Material Processing

- Cathode: high voltage, blending/coating of NMC oxides with other active materials, High Capacity Manganese Rich (HCMR) cathode (Envia)
- Anode: active anode materials, natural graphite, graphene/Si materials as replacement for graphite based anode
- Electrolyte: High voltage, non-flammable, solid state
- Aqueous binders to replace the organic solvent NMP, which can reduce manufacturing costs by 50%
- Joining, cutting of these sensitive materials (anode, cathode, separator)
- Design and fabrication of advanced electrode microstructures
- Getting away from wet slurry process to dry deposition thin film process

Key Observations

Lithium Ion Battery

Production Process Improvement Areas

Manufacturing Process Improvements

- Moisture management techniques for cell assembly
- High precision and repeatable welding techniques for cylindrical and prismatic tabs
- In-line automated inspection of weldments of battery cell diodes/electrodes (e.g., laser, ultrasonics)
- Laser processing to produce battery can vent seam for burst pressure tolerance
- Advanced recycling methods using laser processing to recover key materials
- Improve formation process to speed preparation/aging of batteries
- Roll to roll laminated assembly process for cells that use solid state electrolyte
- Processes that avoid clean, dry room operations
- Flexible and modular automation processes for pack assembly

Appendix

- US Domestic Manufacturing Opportunities for Suppliers (EV Focus)
- Lead Acid and Other Energy Storage Systems
- Battery Pack Integration Challenges
- Battery Recycling, Reclamation Opportunities

Production of Lithium Salts

Electrolyte Salts

Description

- Each manufacturer has it's own formulation depending on the chemistry of the cell, but a common salt is $LIPF_6$.
  - Used mainly with propylene carbonate (PC) and dimethoxymethane (DME).

How it's currently produced

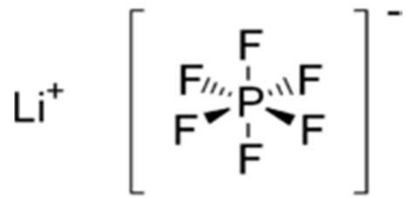
- Li salts (the raw materials) are extracted from mineral springs, brine pools, and brine deposits or produced electrolytically from a mix of fused lithium chloride and potassium chloride.
- Half the world's current known reserves are in Bolivia (near Andes), with 5.4M tons Li.
  - "Li Triangle" – Region in S America rich with Li deposits (Andes, Argentina, Chile).
  - It takes 750 tons of Li brine, and 24 months of prep. to get one ton of lithium.
  - In US, Li is being recovered from brine pools in Nevada.
- One way to produce $LiPF_6$ is a to react LiF and PF_5.

Capabilities to produce

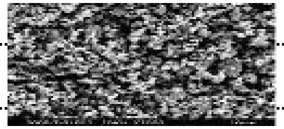
- Large-scale chemical reactors.
- Lithium can also be recycled an unlimited number of times; but recycling could be more expensive than harvesting new supply through mining.
  - The recycled lithium is contaminated, needs much processing.

Common Salts:

- Lithium hexafluorophosphate ($LiPF_6$)
- Lithium perchlorate ($LiClO_4$)
- Lithium hexafluoroarsenate ($LiAsF_6$)
- Lithium Tetrafluoroborate ($LiBF_4$)



Electrolyte Salts



Volume	~0.5g/cell in a micro to 18 g/cell in a BEV, 3.5 kg/BEV pack
Value	$40-100/kg
Projected Demand (2015)	1.2MM kg
Est. Domestic Market Size (2015)	$18MM
Key Ind. Suppliers 	• Golden Light Hi-Tech (China) • Kanto Denka (Jap.) • Lanxess (Germany) • Morita (Jap.) • Stella (Jap.)
Supply Chain Dynamics ***Other types of Li salts include:*** • ***Bis(oxalato)borate (LiBOB),*** • ***Oxalyldifluoroborate (LiODFB) and*** • ***Fluoroalkylphosphate (LiFAP).***	• Salts have only a 6-month stability, shelf life. • No current N.A. sources are close to supplying battery-grade salts and pricing is expected not to significantly decrease with time. • Some companies are packing the solvents with the salts and marking material up significantly more. • Electrolyte additives are 5wt% of the electrolyte and the "secret sauce." • The electrolyte is ~3-5% of the battery cost and the salt/additive ~1.5-2wt% of the total battery bill of materials. • Globally, the biggest suppliers of lithium (raw material) are Chemetall and SQM (Chilean), Tailson Minerals (Australian), FMC (American) and three mining companies in Sichuan, China.

Electrolyte Solvents

Description:

Electrolyte used in lithium-ion batteries is a mixture of lithium salt and organic solvent. Several organic solvents are mixed to decrease the electrolyte's viscosity and increase solubility of lithium salts. This increases the mobility of lithium ions in the electrolyte, resulting in higher battery performance.

Organic solvents:

- **Ethyl methyl carbonate (EMC, $C_4H_8O_3$)**
- **Dimethyl carbonate (DMC, $C_3H_6O_3$)**
- **Diethyl carbonate (DEC, $C_5H_{10}O_3$)**
- **Propylene carbonate (PC, $C_4H_4O_3$)**
- **Ethylene carbonate (EC, $C_3H_4O_3$)**
- **Dimethoxyethane (DME, $C_4H_{10}O_2$)**

How it's currently produced:

- To make DMC, CO_2 and ethylene oxide react in plug flow reactors. Subsequently, the EC that is produced reacts with methanol (CH_3OH) in a second plug flow reactor to yield DMC and ethylene glycol.
  - It is possible to isolate EC after the first step of this process.
- EC is used by downstream producers of polycarbonate (PC) in a non-phosgene process.
  - End products include compact discs, engineering plastics, and more. The expansion activities, buoyed by a steadily growing downstream market, were completed in Nov., 2007.

Capabilities required to manufacture:

Chemical companies can provide carbonates.
(Plug-flow reactors, catalysts, pumps, heat exchangers, etc.)

Electrolyte Solvents

Production Parameters for DMC and EC

Parameters for the production of DMC (Source: ANL, 2012)	
Net energy use (mmBtu/ton DMC)	1.4
Total electricity consumption (mmBtu/ton DMC)	0.087
Natural gas consumption (mmBtu/ton DMC)	1.27
Production rate of DMC (kg/h)	2,080
Production rate of ethylene glycol (kg/h)	9,296
Energy consumption allocated to DMC (%)	18
Feed rate of Ethylene Oxide (ton/ton DMC)	0.58

Parameters for the production of EC (ANL, 2012)	
Total electricity consumption (mmBtu/ton EC)	0.04
Natural gas consumption (mmBtu/ton EC)	0.22
Feed rate of Ethylene Oxide (ton/ton EC)	0.16

Production of Electrolyte Solvents

Volume	3.2 g/cell in micro to 96 g/cell in BEVs, 18.4 kg/BEV battery pack
Value	$20/kg
Projected Demand (2015)	6.5MM kg
Est. Domestic Market Size (2015)	$98MM
Key Industry Suppliers	• **BASF (Germany, Louisiana, acquired Novolyte Technologies)** • **DOW (MI)** • **Honeywell (NY)** • **Hunstmen (TX – EC & PC)** • Mainly Asian (China)
Supply Chain Dynamics	• Solvents have longer shelf-life than electrolyte salts (~1 year vs. 6 mos.) and typically comprise 9-11wt% of the bill of materials for an EV. • US companies with capabilities, but not currently producing electrolyte solvents for batteries domestically • Most electrolyte solvents are sourced through China (hundreds). • Chemical companies can supply the carbonates. • Some companies are packing the solvents with the salts and marking material up significantly more. • Solvents are ~80wt% of the electrolyte mass. (Balance: salts and additives.) • It's estimated that, ~24,000 MT of electrolyte solvents were produced in 2011 and could grow to 80,000 MT in 2015. • A large market exists for a certain solvent at the non-battery grade level (paints, epoxies, etc.). • EC and PC are solid at ambient temperature.

The Oriental Union Chemical Corp. (OUCC) EC plant, with the largest production capacity in the world, produces up to 60,000 tons/year of EC.

Lead Acid Batteries and Other Systems

Key Applications, Systems, and ALABC

Source: NextEnergy, Advanced Automotive Batteries, JCI, Lux Research, Roland Berger

- **Pb-Acid Applications**
  - Engine Starting
  - Motive Power
  - Standby Power
- **Pb-Acid Types**
  - Valve-Regulated Lead Acid Batteries (VRLA)
  - Absorbent Glass Mat (AGM) Lead Acid Batteries (Start-stop, Regen. Braking)
  - Pb-C Anode Lead Acid Batteries (Axion Power)
  - Bi-polar Plate Lead Acid Batteries (Effpower)
- **Others - Hybrid Energy Systems (HES)**
  - Supercapacitors
  - Hybrid Supercapacitors/Lead-Acid Batteries ("Ultrabattery," Maxwell-Exide, inmatech of Ann Arbor is developing a HES solution)
  - Hybrid Pb-Acid/Li Ion Technologies
- **Advanced Lead Acid Battery Consortium (ALABC) – www.alabc.com**
  - Organizes R&D programs aimed at enhancing lead-acid battery performance and marketability for applications such as HEVs, start/stop automotive systems, remote area power supply (RAPS) systems, renewable energy and grid storage applications, and stationary and telecommunication backup systems.

Lead Acid Batteries

Key Manufacturers

Source: NextEnergy, Advanced Automotive Batteries, JCI, Lux Research, Roland Berger

Green indicates a Michigan presence:

- **Advanced Battery Concepts (Clare, MI, GreenSeal Batteries)**
- Atraverda Bipolar (Wales, UK)
- Axion Power (New Castle, PA, Pb-C Negative Electrodes)
- Crown Battery (Fremont, OH)
- Deka / East Penn (Lyon Station, PA)
- **Energy Power Systems (Troy, MI)**
- Exide Technologies (Milton, GA, Restructuring, filed Ch. 11 Bankruptcy)
- Horizon Battery Technologies (Deptford, NJ)
- Johnson Controls, Inc. (Milwaukee, WI)
- Xtreme Power (Austin, TX, partnered with GE)
- Numerous Asian, including GS Yuasa (mostly Chinese, Jap.), and a few European (mostly UK, Ger.)

Electrolyte Shipping Containers

Opportunity – for Shipping Salts and Solvents

Description

- Sealed containers of stainless steel used for transporting the electrolyte and electrolyte precursors to and from the electrolyte plant.
  - Pressurized at 0.2-1.5 bar, purged with N_2, Argon or He.
  - The entire transportation system must be sealed to protect the product from H_2O &O_2.
  - From small sizes (a few gals) for prototype batches to 55 gal drum sizes for production.
  - The containers have to be electro-polished on both the outside and the inside.
- Associated valves, connectors, plumbing must also be sealed. Shipping involves packs of up to 500 lb. containers including a pressure relief valve, gas fitting and product fitting.
- The finished electrolyte product is delivered in sealed containers with a “blanket” of clean, dry inert gas (N_2, Argon or He) to protect the electrolyte from humidity and oxygen.
  - Some of this gas is used by the customer to “push” the electrolyte from the container into the customer cell filling systems.

Capabilities needed to produce

- Rolled steel process including high precision weldments, similar to drum container production; the key is in the electro-polishing.
- Manufacturers must comply with NFPA and HazMat requirements for shipping containers. Shipping reg’s require that batteries be protected from short-circuiting; UN and UL testing requirements specify a minimal requirement for cell external short-circuit Resistance: discharge through a resistance of less than 0.1 Ohm in a 55F environment.

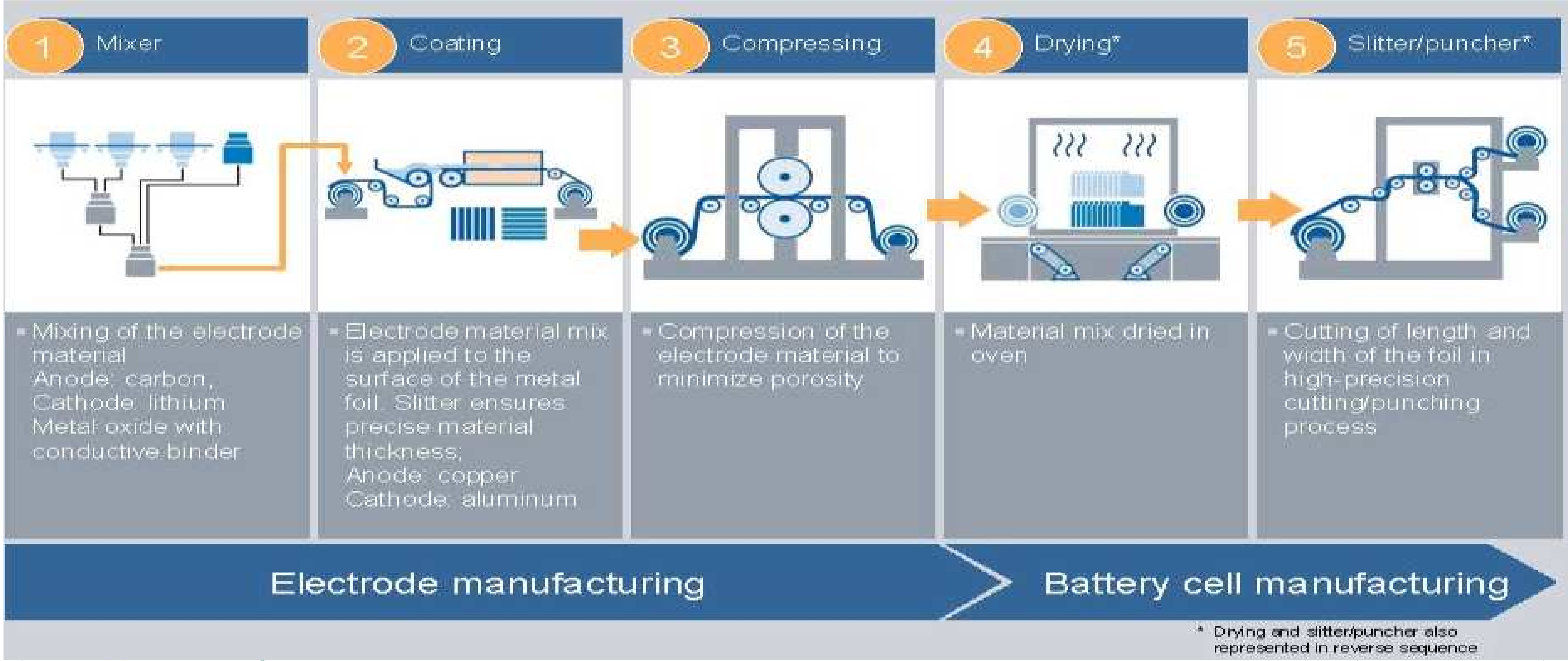
Shipping Containers for Electrolyte Salts & Solvents

Volume	200 kg (55 gal)/container, 2-way containers can also range from 1 - 400 L
Value	$1,800-$5,000 per 200 kg (55gal) container
Projected Demand (2015)	167,000 containers
Est. Domestic Market Size (2015)	~$500MM
Key Ind. Suppliers	Containers: WADA (Jap.), **Paul Miller (Missouri)** Container fittings: **Swagelok (OH)**, Nitto (China), or **Staubli (Duncan, SC)**
Supply Chain Dynamics  ***1-way containers are steel containers with a custom, often flexible liner to protect the product.*** ***2-way containers will be at 3 inventory turns: 1) ~2 months with customer of Electrolyte Mfr, 2) ~1 month with Electrolyte Mfr, and 3) ~1 month in transit.***	• ~40% of the costs are for special fittings, the balance of the cost is for the container itself. • Some large chemical companies could provide containers, if they learned how to properly clean and electro-polish the inside. • Larger ISO containers or tankers are projected to be used in the future as volumes increase, the cleaning protocol, and traceability issues are resolved. • Each electrolyte supplier will develop and deliver thousands of small samples annually in small containers for testing, new product development, and samples, as well as warranty reserves. Most of these will not have fittings and may or may not be 2-way (reusable) containers. • An electrolyte facility with production capacity of at least 10 million kg per year will need 4,000-10,000 x 200-400 kg containers, depending on the distance from the customer, customer logistics, and customer sensitivity to risk and inventory control.

Electrodes – Cathode & Anode

Description and Production Process

- The cathode is the positive electrode and the anode is the negative electrode of a primary cell and the anode is always associated with the oxidation or the release of electrons into the external circuit.
  - In a rechargeable cell, the anode is the negative pole during discharge and the positive pole during charge.



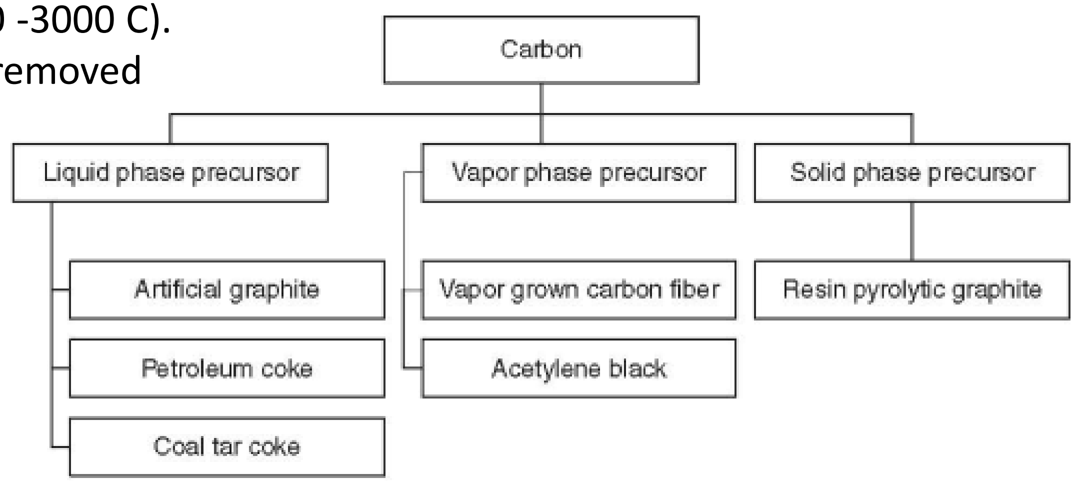
Anode Materials

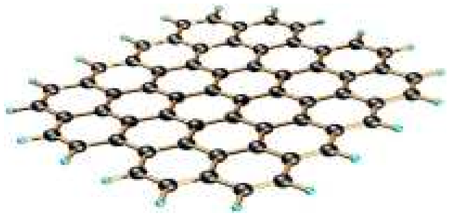
Opportunity

Source: Battery University, Center on Globalization Governance & Competitiveness, Lawrence Berkeley National Laboratory, Linden's Handbook of Batteries

How it's currently produced

- **Si nanoparticles** are encapsulated in electrospun carbon nanofibers; the nanofiber structure will allow the anode to withstand repeated cycles of expansion and contraction.
- Hollow **Fe_3O_4 nanoparticles** are synthesized via a template-free solvo-thermal method using $FeCl_3$, urea and ethylene glycol as starting materials.
- **Other Carbon-based anodes** can be produced using a variety of methods and are most easily classified by the precursor stage, as shown below.
  - **Soft Carbons:** treated at high temps (2,000 -3000 C). Upon graphitization, turbostratic discorder is removed progressively with increasing temp., and material strain is relieved.
  - **Hard Carbons:** Include those prepared from phenolic resin, cannot be easily graphitized, even when treated at 3,000 C.





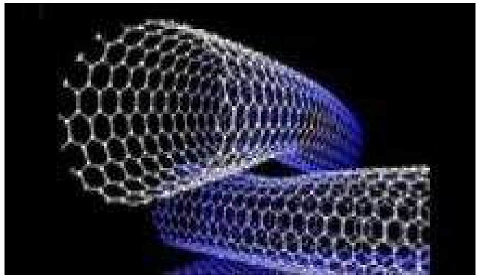
Anode Materials

Source: NC State Univ, American Lithium Energy Corp., US DoE EERE, CGGC, Scientific American, Linden's Handbook of Batteries, XG Sciences, Image:ORNL

Description

- **Natural graphite** anodes are considered commodities.
- Other anode materials include: **Silicon nanoparticles, iron oxides, graphene, lithium, tin, and various combinations of these materials.**
- **Graphene** is a one-atom-thick sheet of carbon that stacks with other such sheets to form graphite—pencil "lead." Physicists have only recently isolated the material (~2004). The pure, flawless crystal conducts electricity faster at room temperature than any other substance.
- **XG Sciences** in Lansing is developing the next-generation Si/graphene anode materials, which achieve much higher capacities.
  - Natural graphite / carbon black: 200-400 mAh/g
  - XG-Si GTM Silicon Graphene Composite Materials for Li-ion Batteries: 800 mAh/g.

Anode Materials

Volume	6.4 g/cell in a micro, 193.1 g/cell in a BEV cell, 37 kg in a BEV pack C black = ~18% of the total anode mass , nat. graphite core = ~82% of total anode mass
Value	Average prices – 2012: $10-$35/kg, depending on quantity and grade 2015 (projected): $11.57/kg for nat. graph. core, $5.61/kg for C black
Projected Demand (2015)	33MM kg domestically
Est. Dom. Mkt Size(2015)	$347.2MM
Key Ind. Suppliers 	• **Amprius (Stanford Univ. spinoff, Sunnyvale, CA, early stage)** • Asian – Morgan AM&T, Ningbo Shanshan, Nippon Carbon , Hitachi Chemical, JFE Holdings, Iljin Materials • **CPreme®, Metaullics Systems and Pyrotek, Inc. (Spokane, WA, and Sanborn, NY, with ConocoPhillips' Phillips Specialty Products Inc.)** • **Dow Energy Materials (Midland, MI)** • **Envia (CA)** • Focus Graphite (Canada) • **Future Fuel Chemical (Batesville, AK) – graphitized anode precursors only** • **Inabata America Corp. (TX, Distributor** • **Prieto Battery (Fort Collins, CO)** • **Superior Graphite (Chicago, IL)** • **Tec-Cel (Cary, NC)** • **XG Sciences (Lansing, MI, mid-stage)**
Supply Chain Dynamics ***There is a transition from hard carbon / graphite to 600+ mAh/g alternatives, such as graphene (XG Sciences) and nano-phase materials.***	• Jap. and Kor. are supplying most finished graphite globally. China accounted for nearly 30% of the global anode raw materials market, leveraging its natural resources and partnering with Jap. firms. • CNT's are expected to be used as an additive in small amts (1-2%); several CNT mfr's have >100 ton per year production capacity for multi- walled nanotubes. • Most current anode materials demand is for portable device applications. • Anode materials account for ~15-20% of the total battery cell cost (before mark-up). • No commercial, high energy Si anode mat's for auto markets currently in prod'n.

Active Cathode Materials

Opportunity

Description

- The positive electrode is comprised of metal oxides; different manufacturers use different active materials. Each develops a specific cell voltage and has advantages and dis-advantages and cost structure (Co is relatively expensive).
  - Originally, LCO (lithium cobalt oxide) was commonly used in lithium-ion batteries for consumer electronics such as laptop PCs, cell phones, and cameras, due to its high energy density.
  - However, battery makers have opted for cheaper and safer alternatives, including LMO (lithium manganese oxide).
- Cathode paste contains these active cathode materials: a binder, carbon material (carbon black, graphite powder, and carbon fiber, etc.) and solvent (typically N-methyl-2-pyrrolidone or NMP). The paste is coated on an aluminum foil current collector, then dried and pressed into the appropriate thickness.
- The cathode is comprised of cobalt, nickel and manganese in the crystal structure forming a multi-metal oxide material to which lithium is added, based on an intercalation process. In this process, the Li-ion is inserted into or removed from the crystal structure of the active material. The oxidation state of the active material, or host, is concurrently changed by gaining or losing an e^-.

How it's currently produced – The "secret sauce"

- Electrode materials can be produced via conversion reactions or electro-deposition.
- This is the basis for a variety of products that cater to different user needs for high energy density and/or high load capacity.

Capabilities needed to Manufacture/Distribute

- Inorganic chemicals producers are capable of manufacturing cathode active materials.
- Organizations with significant catalysis expertise are ideal manufacturers (i.e., catalytic converters producers).

Select Active Cathode Materials

evs 27

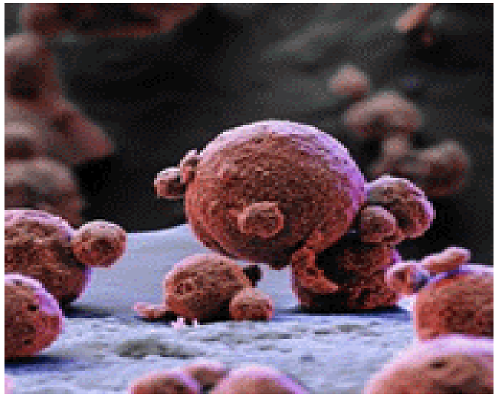
Profile Comparisons

Feature	LCO Li-cobalt oxide $LiCoO_2$	LMO Li manganese oxide $LiMn_2O_4$	LFP Li Iron phosphate $LiFePO_4$	NMC Nickel Manganese Cobalt $LiNiMnCoO_2$	NCA Nickel/Cobalt/ Aluminum Oxide $LiNiCoAlO_2$
Voltage	3.60V	3.80V	3.30V	3.60/3.70V	3.6/3.7V
Charge limit	4.20V	4.20V	3.60V	4.20V	4.20V
Cycle life	500–1,000	500–1,000	1,000–2,000	1,000–2,000	1,000–2,000+
Op. Temp.	Average	Average	Good	Good	Poor
Sp. energy (Wh/kg)	150–190	100–150	90–120	140-180	160-180
Positives	Highest (max.) specific energy	Cost, safety, power	Safety, life expectancy, range of charge, material cost	Energy density, range of charge	Energy density, power, good life span
Negatives	Most expensive, due to relatively high Co content	Life expectancy, unstable energy	Low temp. performance, processing costs	Safety (better than NCA), cost/commodity exposure	Cost, safety, cost/commodity exposure, life expectancy, range of charge, low thermal stability

Active Cathode Materials

Opportunity Snapshot

evs27
The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

Volume	~8 g/cell in a micro to 265 g/cell in a BEV cell, 51 kg in a BEV pack
Value	Average prices – 2012: $24-30/kg, 2015: $12-20/kg LCO-$52/kg, NCA and NMC-$32/kg, LMO-$20/kg, LFP-$18/kg
Projected Demand (2015)	18MM kg domestically
Est. Domestic Market Size (2015)	$270MM
Key Ind. Suppliers 	• A123 Systems (China) • AESC • Altaimano • **BASF Catalysts, LLC (OH)** • BYD • Daejuing (Kor.) • Ener1 • **Envia (CA)** • Evonik • GS Yuasa • Hitachi • JCI/Saft • L&F (Korea) • LG CHem • Lishen • Mitsubishi Chemical • Nichia Chemical (Jap.) • Nihon Chemical (Jap.) • PEVE • Phostech (Canada) • Samsung • Sanyo • Seimi Chemical (Jap.) • SK Corp. • Tanaka Chemical (Jap.) • **TODA America (MI)** • TODA [Kogyo] (Jap.) • Toshiba • **Tronox (OK,** multiple locations, incl. Singapore) • Umicore (Belgium) • Valence
Supply Chain Dynamics ***There is a transition toward materials with lower Co content (LMO, LFP, derivatives) to less costly and less toxic materials (nanophosphates, silicates, etc.).***	• "Secret sauce," with ~1 year shelf life; multiple suppliers. • Cathode materials account for 10-15% of the *overall* battery cost and 34-36% of the *cell* materials cost. • NMC-based active materials /derivatives require ~150% more primary energy to produce, so even though Co content is low, they're still relatively expensive. • Transition from layered oxides, spinels, and olivines rated @ 120-160 mAh/g to layered-layered oxides, metal phosphates, and tailored surfaces @ 300 mAh/g.

Polyvinylidene Fluoride (PVDF) Binder

How it's currently produced

- PVDF may be synthesized from the gaseous (VDF) monomer via a free radical (or controlled radical) polymerization process.
  - This may be followed by processes such as melt casting, or processing from a solution (e.g. solution casting, spin coating, and film casting).
- In the case of solution-based processing, typical solvents used include dimethyl formamide as well as [the more volatile] butanone.
- In aqueous emulsion polymerization, the fluoro-surfactant perfluoronoic acid is used in anion form as a processing aid by solubilizing monomers.[] For characterization of the molecular weight via gel permeation chromatography, solvents such as dimethyl sulfoxide or tetrahydrofuran (THF) may be used.

Capabilities needed to produce

- Processed materials are typically in the non-piezoelectric alpha phase. The material must either be stretched or annealed to obtain the piezoelectric beta phase. The exception to this is for PVDF thin films (thickness in the order of micrometres). Residual stresses between thin films and the substrates on which they are processed are great enough to cause the beta phase to form.
- In order to obtain a piezoelectric response, the material must first be poled in a large electric field. Poling of the material typically requires an external field of above 30 MV/m. Thick films (typically >100 microns) must be heated during the poling process in order to achieve a large piezoelectric response. Thick films are usually heated to 70–100 ° C during the poling process.
- A quantitative de-fluorination process was described by mechano-chemistry, for safe eco-friendly PVDF waste processing.

PVDF Binder

Volume:	• 4.2 g/cell in a mcro EV cell, 126.5 g/BEC cell
Value:	• $20-25/kg Now, $15-20/kg 2015+
Projected Demand (2015):	• 7.9 MM kg
Est. Domestic Market Size (2015):	• $88.9MM
Key Industry Suppliers	• **Arkema** (Kentucky, US) • Golden Copper (Taiwan) • JSR Micro (Jap.) • Kureha (Jap.) • LG Chem (Korea) • MEC (Jap.) • Nikko Metals Taiwan (Jap.) • Showa Denko (Jap.) • Solvay (Fr.) – anode only • TARGRAY (Can.) – SBR and PVDF – Distributor • ZEON Corp. (aq., Jap.)
Supply Chain Dynamics  ***Aq. binders, improve safety & costs via elimination of NMP handling & recovery systems.***	• Limited domestic production options; global capacity is a concern. • PVDF is a commodity now, but with opportunity for innovation in next-gen. materials. • For processing requirements, cost and environmental issues, battery manufacturers are gradually moving away from using PVDF and instead making use of aqueous base materials such as SBR (Styrene Butadiene Rubber) and modified SBR copolymers. • Binder is ~2-2.5wt% of an entire EV battery bill of materials, 3wt% of the cathode, and comprises ~2-3% of the overall battery cell materials cost. • DOE, ANL, Berkley, Saft and FMC recently unveiled a electrode made with PVDF coated graphite and SBR binder.

N-Methyl-2-pyrrolidone (NMP) Solvent

Description

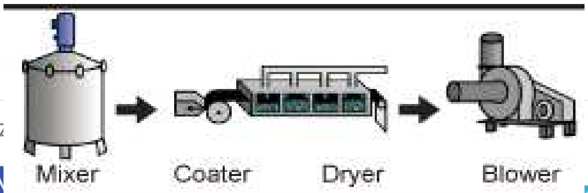
- NMP is used as a solvent during the battery manufacturing process, although none remains in the final battery.
- NMP is a chemical compound with 5-membered lactam structure. It is a clear to slightly yellow liquid miscible with water and solvents like ethyl acetate, chloroform, benzene and lower alcohols or ketones. It also belongs to the class of dipolar aprotic solvents which includes dimethylformamide, dimethylacetamide and dimethyl sulfoxide.
- Only 0.007 tons NMP is used per 1 ton of active cathode material (i.e., $LiMn_2O_4$) consumed during the Li-ion battery manufacturing process, or 0.7%. (Source: ANL, 2012)
  - The ***real*** opportunity is related to recycling and reclamation of NMP. Reclamation to battery-grade NMP is desired, as it is more valuable than non-battery-grade NMP.
- NMP is a chemical compound with 5-membered lactam structure.
- It is a clear to slightly yellow liquid miscible with water and solvents like ethyl acetate, chloroform, benzene and lower alcohols or ketones.
- It also belongs to the class of dipolar aprotic solvents which includes also dimethylformamide, dimethylacetamide and dimethyl sulfoxide.

How it's currently produced

- NMP is produced as the lactum of 4-mehtylaminobutyric acid and a very weak base.

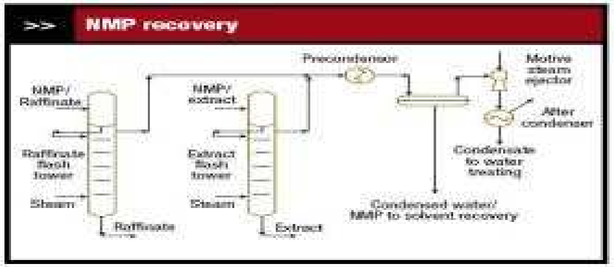
Capabilities needed to produce

- Equipment needed:
  - Large scale chemical reactors, condensers, flash towers, storage tanks, piping.
  - Mixers, coaters, dryers, blowers, flash towers, and R&D lab for battery-grade NMP.



Energy Consumption for the production of NMP (ANL, 2012)	
Total electricity consumption (mmBtu/ton NMP)	1.03
Natural gas consumption (mmBtu/ton NMP)	1.72

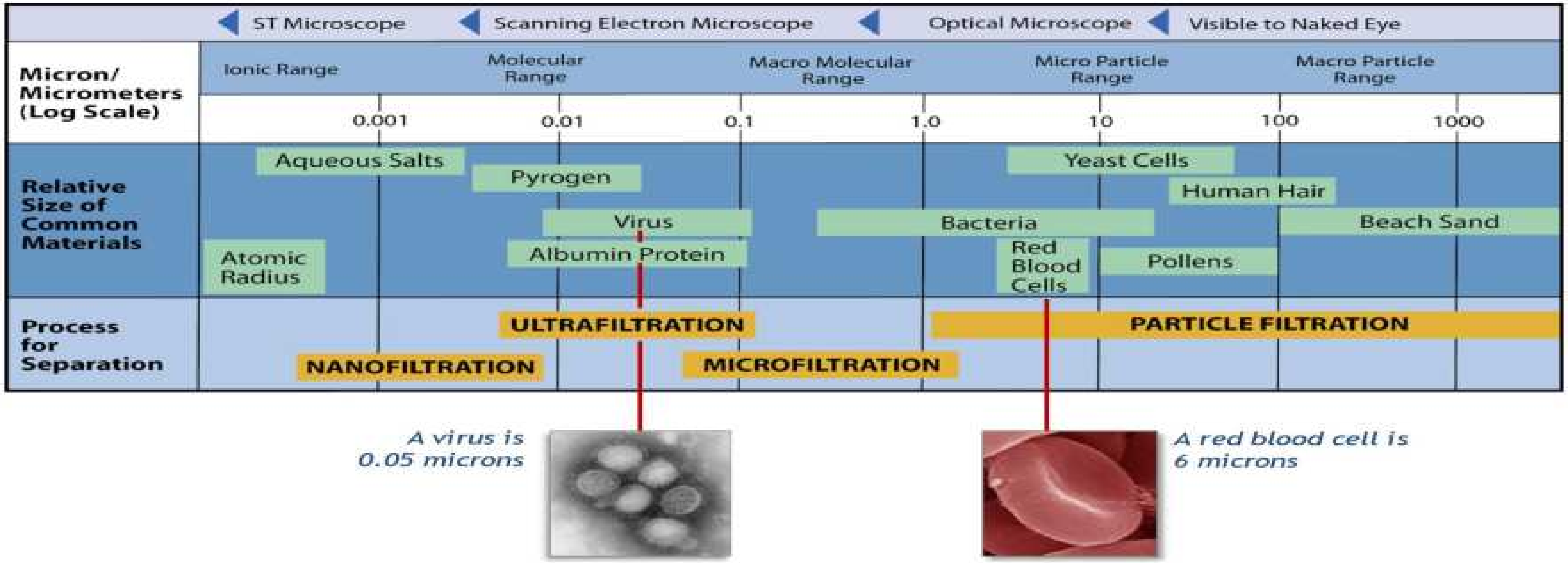
N-Methyl-2-pyrrolidone (NMP) Reclamation

Volume	~120 g/BEV cell, but only ~1g/cell remains in the finished cell
Value	Sold by recyclers @ $15-20/gal
Projected Demand (2015)	• 2.5-5MM gal
Est. Domestic Market Size (2015)	• $73MM for NMP Reclamation
Key Industry Suppliers 	• **Ashland Chemical (TX)- formerly ISP (VA)** • **BASF (Wyandotte, MI – recycling, Louisiana- production)** • **EQ (Non-battery grade, MI)** • **Energetics, Inc. (Seattle, WA)** • Kanto Denka (Jap.) • NanoTechnologies • Nippon Denka (Jap.) • **Nippon Refine (US – battery-grade**) • **Nova Molecular (Recycler)** • **Superior (WI)** • SouthWest • **Traedeba (Spain, northwest Indiana)** • **Veolia**
Supply Chain Dynamics ***Recycled non-battery-grade NMP is sold for use as a paint stripper and industrial solvent.*** 	• NMP is a commodity, which requires high and consistent quality to attain desired slurry quality and coating parameters. Volumes dictate price. • Solvent-less Li ion batteries could threaten NMP markets. Some studies claim that the manufacture of solvent-less Li ion batteries is a much less energy-intensive process. • Significant opportunity to source NMP locally (Ashland, BASF). • About 99.3% of the NMP lost during evaporation during the "paste-making" process is recovered and can be reused, but the balance is combusted and must be replaced. (Source: ANL, 2012). • Recovered NMP is of lower grade but is chemically stable and can play an active role in certain reactions in the chemical, pharmaceutical, and polymer sectors (e.g. hydrolysis, conversion with chlorinating agents, polymerization).

Separators

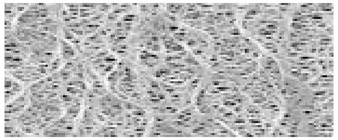
Description

- Polypropylene (PP) is the major constituent of the separator, a porous membrane that measures 20 µm thick and includes a thin polyethylene (PE) middle layer, also porous 16-25.4 µm thick membrane.
  - Uniformity of cell structure, porosity (~50%), flammability, thickness & stability are critical.
- Demands include a lower shutdown temperature, thinner separator, but still with increasing puncture resistance and 10+ year life. Higher T stability (200-250C) also desirable.



Separators

Celgard image



Source: ANL, CGGC, Daiwa Capital Markets

How it's currently produced

- Separators are made from a variety of inorganic, organic, and naturally occurring materials and can be made via dry or wet processes.
  - The **dry process** consists of three steps and is less costly and less complicated, but produces separators weaker in mechanical strength:
    - 1) extruding, 2) annealing, and 3) stretching.
  - The **wet process** also consists of three steps:
    - 1) mixing of the polymer resins, paraffin oil, antioxidant, other additives and heating to produce a homogenous solution, then
    - 2) forcing the heated solution through a sheet die into a gel-like film, and
    - 3) extracting the paraffin oil and other additives with a volatile solvent to obtain the desired porosity.
  - Membranes made by dry processes are more suitable for a high power density battery due to their open and uniform pore structure
  - Wet process products are more suited for a long cycle life batteries because of their tortuous and interconnected porous structure, which suppresses the growth of Li crystals on the graphite anode.

Capabilities needed to produce

- Equipment typical of plastics processing plants – extruders, dies, ind. -scale mixers, extractors, reactors, etc.

Next Slide

More on processes and polymers used to make separators…

Separators

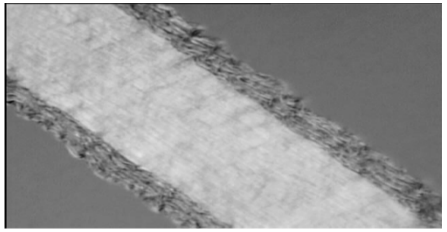
Processes, Polymers and Industrial Applicability

Source: Polypore

Process/Product Type	Polymers	Application
Thermally Induced Phase Separation (TIPS)–Capillary Membrane	Polyolefins (PP, PE, PVDF, PMP)	Microfiltration, oxygenation, membrane distillation, gas separation, deareation
Solvent Induced Phase Separation (SIPS)–Capillary Membrane	PES, PSU, SPES, PA, PAN, PEI, UHPE	Ultrafiltration, microfiltration, battery separators, water capture, dialysis, plasmapheresis
TIPS/SIPS–Flat Membrane	PES, PSU, PA, PVDF, PP, PE, PEI, UPE, PE, PP	Ultrafiltration, microfiltration, battery separators, membrane distillation
Dry-stretch Process–Capillary & Flat Membrane, Contactors	Polyolefins (PP, PE)	Oxygenation, battery separators, deaeration and aeration
Melt Extrusion–Capillary Membrane	PET	Heat exchanger for medical devices
Foam Spinning (supercritical CO2)	PE, PP, PC, PES, PA, PET, EVA	Porous carriers for plastics industry

KEY: PP=Polypropylene, PE=Polyethylene, PVDF=Polyvinylidene fluoride, PMP=Polymethylpentene, PES=Polyethersulfone, PSU=Polysulfone, SPES=Sulfonated polyethersulfone, PA=Polyamide/nylon, PAN=Polyacrylonitrile, PEI=Polyetherimide, UHPE=Ultra high molecular weight polyethylene, PET=Polyethylene terephthalate, EVA=Ethylene vinyl acetate

Separators

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  **Co-extruded separator**	• **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)** • Foshan JinhuiHi-Tech (China) • Idemitsu Kosan • Mitsubishi Chem • Mitsui Chemicals • Shenzhen Senior Technology Material (China) • SK Innovation (Korea) • Ube Industries (Jap.) • Xinxiang Green New Energy
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.

Battery Containers

Summary of Advantages and Disadvantages

Source: Battery University, Daiwa Capital Markets, Sion Power Corporation, Janim.net, LG Chem, ecvv.com

Container Type	Benefits	Drawbacks
Cylindrical (cans) 	Good cycling ability, long calendar life, economical to manufacture	Heavy and have low packaging density.
Prismatic - metal case 	Improved packaging density	Can be more expensive to manufacture, less efficient in thermal management and may have a shorter cycle life.
Prismatic - pouch 	Light and cost-effective to manufacture	Thermal mgt. and cycle life can be an issue - exposure to high humidity and heat can shorten service life.

Production of Battery Cans & Caps

Description

Source: Battery University

- A steel or Al can houses each Li-ion cell. A common cylindrical size is called the "18650" which is 18.6mm in dia. x 65.2mm long.
  - Used in mobile computing and other applications that do not demand ultra-thin geometry.
- 32650 cells are used by a company that makes zinc-air batteries
- If a slimmer pack is required (e.g., tablets), prismatic/pouch Li-ion cell is the best choice. There are no gains in energy density over the 18650, however, the cost of obtaining the same energy may double. The most common size for prismatic cells is 50mm long by 34mm wide.
- Prismatic cases can experience internal pressure rise and swelling. Jelly rolls are connected in parallel in a prismatic cell. The core of a jelly roll and nail protection device are sometimes attached.

Size	Dimensions	R (m)	Ht (m)	Surf. Area (m2)	History
18650	18 x 65mm	0.009	0.065	0.00418	Developed in the mid 1990s for lithium-ion-ion; commonly used in laptop battery packs
26650	26 x 65	0.013	0.065	0.00637	Larger Li-ion battery for industrial applications
26700	26 x 70	0.013	0.07	0.00678	Same as 26650, larger.
32600	32 x 60	0.016	0.06	0.00764	Same as 26700, larger.

Production of Battery Pouches

Description

- Multi-layered flexible pouch into which the stacked electrode and separator “sandwich” is placed. Pouch has a simpler structure than a metal-case prismatic cell and slimness provides good heat dissipation.
- Typically a thin aluminum layer laminated with other materials (polyolefin, polyester) that are required to achieve the desired sealing, strength and protection properties.
  - Dry Laminated Pouches – Used in all types of li ion battery cells.
  - Heat Laminated Pouches – Better suited to high power and high energy applications that don’t require deep forming capability.
- Pouch cells (and prismatic cells) require an external means of containment to prevent expansion when their state-of-charge is high; and the connection tabs must extend out through one or more of the edges of the pouch configuration.
- Desirable characteristics include: vapor/moisture barrier, flexibility, good pouch dealing, good anti-electrolyte resistance, and slimness.

Production of Battery Pouches

Process chain of pouch-cell production

Production of Battery Cans & Caps

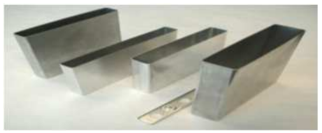
How it's currently produced

- Hermetically sealable battery container (with safety vent) and cover assembly that can be automatically assembled by OEM customers.
- Deep draw process that also uses swaging, laser welding, helium leak testing, torque testing, in house aqueous cleaning is also performed.
- Impact extrusion can be used for (simpler) cans without "burst" features.
  - Coining used for burst features via compressing to a thin container.

Capabilities needed to produce

- Equipment needed: Deep draw stamping equipment, high speed presses, laminating equipment for pouches, coining equipment, swaging equipment, laser welding equipment, helium leak testing and aqueous can wash system. Tooling and manufacturing processes for consistently stamping an integral safety vent feature in the can or cover. The tooling/process can be adjusted to achieve specific "burst" pressure mean values within a controlled range.
- Impact extrusion requires knuckle-joint and hydraulic presses with ram forces of between 20 and 1.400 tons, speeds of 30 and 150 parts per minute are used to produce parts with lengths of up to 420 mm and outer diameters of up to 170 mm. Heat treatment for impact extrusion method is of suitable aluminum alloys that can double their original strength and hardness (up to 550 N/mm^2).

Battery Cans, Caps & Pouches

Volume	1 can / cell, 192 cells (pouch) in a Leaf, 288 cells (prism.) in a Volt
Value	\$3.50-\$4.00 / can, roughly 5-6% of the total battery cost \$6-8/m^2 in an Al pouch
Projected Demand (2015)	63 MM cans and pouches
Est. Domestic Market Size (2015)	~\$110 MM (prismatic and pouch, conservative estimate)
Key Industry Suppliers	Cyl. Cans: **HTTM (JV between Heitkamp & Thumann Group KG in Germany and Trans-matic in Holland, MI and Waterbury, CT), Neumann (VA and Quebec, CAN – acquired by Ball Corp.)** Prismatic Cans: **HTTM (MI)**, **Mueller (MI)**, Karotech Inc., Fuji Exceed, Kuno Metal, Power Precision, IMI/Ozawa, Asian (China) Pouches: DNP, Ohkura Industrial (Asian)
Supply Chain Dynamics  ***Future market demand will rise significantly, if EV's produced overseas are sourced locally.***	• Equipment and processes must be flexible and must accommodate both cylindrical and prismatic metal containers. • Impact extrusion and/or annealing may also be performed for simpler cans without "burst" features. New designs in advanced batteries require more complex burst designs. • HTTM is only US manufacturer of large format, metal containers and cover assemblies. • There is also an opportunity to source the coating the goes on the plates to protect the batteries, before the can is stamped. • Laser welding and electron beam welding are opportunities for domestic suppliers. • For stationary/grid applications, the type of can (cylindrical vs. prismatic) is not as critical as for automotive applications. • The industry requires tight corner radii/tolerance control and a transition to larger container sizes improve energy capacity for large format cells.

Production of Aluminum Current Collectors

Description

- During discharge, the lithium ions move from the anode to the cathode while the electrons travel through the current collectors and the external circuit to perform external work. Al tabs in prismatic (I.e., Volt) cells are welded on the current collector of the electrode.
- Aluminum Foil (cathode) specification:
  - Thickness: 12, 15, 16, 18, 20, 25 +/- 2 µm
    - 0.016mm,0.020mm,0.025mm for power lithium battery.
    - 0.015mm,0.016mm,0.018mm for mobile lithium battery.
  - Mechanical strength Tensile strength (MPa) : >150
  - Purity : Al content 99.5 % min.
  - Trace elements (Mg, Si, Ti, Mn, Fe, Cu, Zn) : < 0.15%

How it's currently produced

- Hot rolling process.
  - Rolling Mill, double finish rolling, separator, annealing furnace, cooling/cutting, inspection shipping.
- Stamped metal sheets.
- Primary options include: smooth un-etched Al foil, anodization-etched Al foil, and etched Al foil covered with a conformal C coating

Aluminum Current Collectors (Tabs)

Volume	0.72 m2/BEV cell (33.1 Ah)
Value	$0.35/pc for the "ears" (Al tab with film or connector tabs) $0.73-1.30 /$m^2$ for the current collectors ("tabs")
Projected Demand (2015)	• **68MM pcs for the "ears" or connector tabs** • **47MM m2 for the current collectors (tabs)**
Est. Domestic Market Size (2015)	• **$1MM for the connector tabs** • **$712K-$1MM for the current collectors**
Key Ind. Suppliers Suppliers	• Alreo • Furukawa –Sky (Jap.) • Gelon China • Kokam (acquired LComm) • Sama (Koreas) • Soulbrain (Korea, acquired LTK from Kokam)
Supply Chain Dynamics  ***There is a trend from metallic (Al, Cu, Ni) current collectors to Carbon nanotubes to decrease device weight, increase energy density.***	• No domestic production currently. • 1 year shelf life; aluminum is subject to pitting corrosion (environmental degradation). • One major US Tier 1 uses Ni-coated aluminum for the anode. • Ni-coated foil used for the anode, just aluminum for the cathode. • Need 50-80 MT per month to justify opening a production facility – Based on 2015 EV projections and 30% market share, domestic demand will be ~2x this capacity. • Demand for better Al foil performance has been increasing due to progress in improving the storage capacity of secondary batteries, which calls for even higher-quality aluminum foil and has led to three-dimensional porous structure foils. • Three Japanese companies – namely Hirano Tecseed, Inoue Kinzoku Kogyo, and Toray Engineering – have a combined dominant share of the electrode-coater market (used to coat electrode materials onto the aluminum and copper foils).

Copper Current Collectors

Opportunity (Electrodes)

Description:

- In addition to being highly conductive and resistant to heat, the negative-current collector in next-generation lithium-ion batteries needs to be strong enough to with-stand volumetric changes in the negative-electrode active material caused by charging/ discharging and demonstrate a high level of adhesion to this material.
- Copper Foil (anode) specification:
  - Thickness : 10-20 ± 1 μm
  - Mechanical strength (MPa) : >300
  - Purity : copper content 99.99% min

How it's currently produced:

- Begin with liquid copper, metal and plate on mandrel foil.
- Thickness is controlled based on speed.
- Electrolytically produced

Capabilities needed to produce:

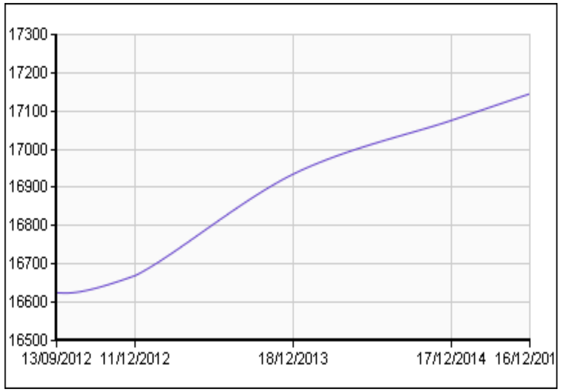
- Equipment needed
  - Foundry-like equipment

Copper Current Collectors

Volume	0.79 m2/BEV cell
Value	\$2.25/m² or ~\$8,080 / ton Now, \$1.50/m² or \$8,000-8,020 / ton Projected 2015+
Proj. Demand (2015)	• 52MM m2
Est. Domestic Market Size (2015)	• \$782K-\$1MM
Key Industry Players	• **CIMCO (metals, scrap, IL)** • Circuit Foil (mfg. in Luxembourg, • warehouse in Montreal, CAN) • FSPG (China) • Furukawa Electric (Jap. & Taiwan, warehouse in Plymouth, MI) • JinYuan Copper International Co. Ltd. (China) • Iljin (Korea) • LS Mtron (Korea) • **Oak-Mitsui (SC)** • **Padnos (US – scrap recycler only, Grand Rapid, MI and Greensboro, NC)**
Supply Chain Dynamics ***An EV needs ~4x more copper than a conventional car.*** 	• A 15 MT facility is ~\$100MM investment; electricity costs ~30% of the plating process. • Oak-Mitsui is the sole U.S. producer of copper foil for anodes. • Cu foil has a short shelf life of 3-6 months with a 3 month guarantee. • Copper foil is used in printed circuit boards (PCBs), so production in Asia makes sense, given their stronger PCB market (not just for Li ion batteries). • Cu prices have risen meteorically from \$1,700 per ton in 2003 to \$6,100 per ton in 2010 to \$8,080 per ton in 2012, but are expected to remain steady for at least a year, and are not expected to decline until 2015 or so. • Hitachi Cable is adding zirconium to copper alloy foil to make it stronger and more resistant to heat, and treating the surface of the foil to make it more adhesive; they claim this makes the batteries last longer than ordinary ones. • Korea's Iljin Materials became the largest copper-foil maker replacing Furukawa in only the past three years.

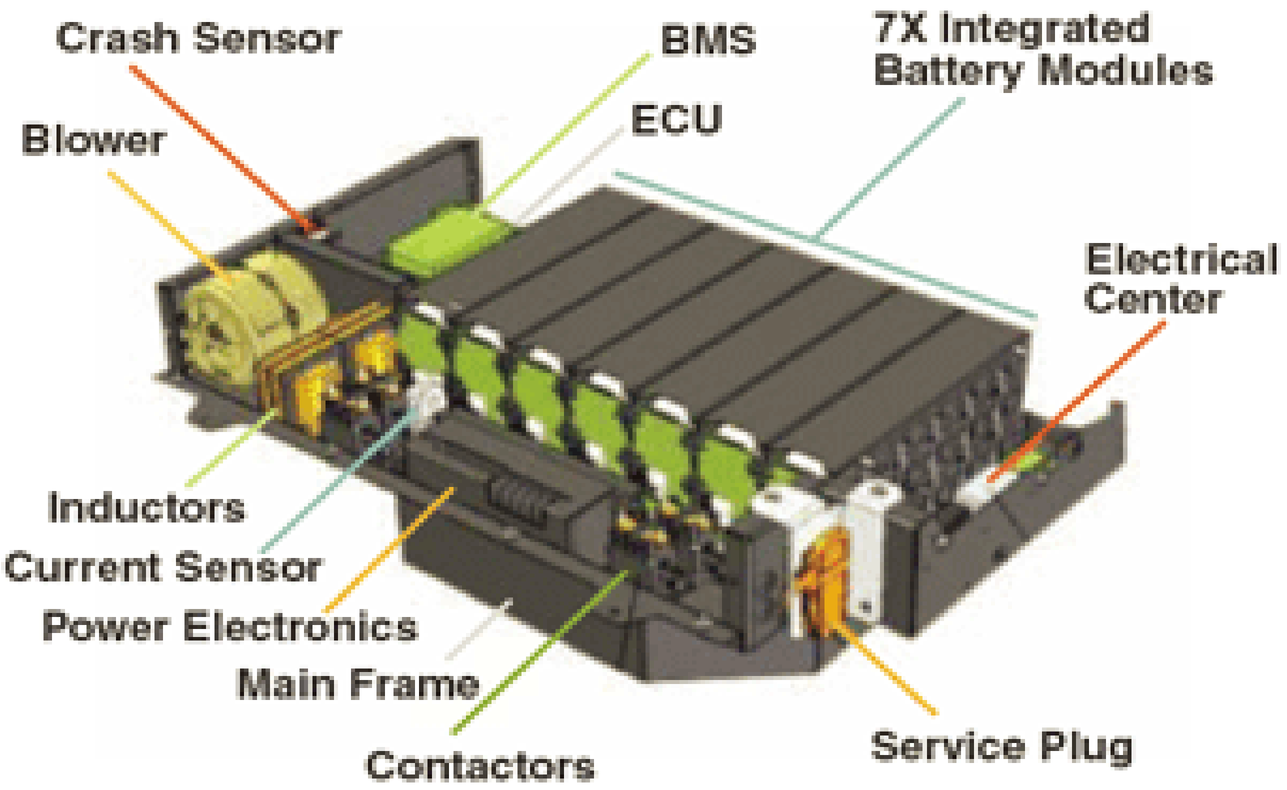
Production of Nickel Connector Tabs

Volume	1 pc/BEV cell
Value	$0.45/piece Now, $0.33/piece Projected 2015+
Proj. Demand (2015)	**66MM pcs**
Est. Domestic Market Size (2015)	**$989K**
Key Industry Players	• Kansai Catalyst (Jap.) • Norilsk Nickel Ltd (Russian mining operation) Sumitomo metal mining (Jap.) • Xstrata Nickel (Can.)
Supply Chain Dynamics	• Ni prices have been volatile, ranging from ~$10,000 per ton in 2003 to ~$23,000 per ton in 2010 and $17,000 per ton in 2012. • Three Largest Ni Producers: 1. MMC Norilsk Nickel - 286MT (Russia) 2. Vale SA - 206MT (Brazil HQ, 38 countries) 3. Jinchuan Group Ltd. - 127MT (China) • The thickness of Nickel plates can be from 0.02mm to 3mm, and width can be from 2mm to 145mm. Length is customizable. • The Ni tab is the anode "ear" or "connector tab" that connects the copper current collector to the terminal assembly.



Battery Pack
Opportunities & Challenges

Source: A123 Systems



Battery Pack Opportunities

Source: GM, Mercedes, tesla, Cobasys

Chevy Volt Battery Pack

Mercedes Hybrid Battery Pack

Tesla Battery Pack

Cobasys Battery Pack

Battery Pack Challenges

Automotive, Li Ion Focused

Source: General Motors

Safety

Safe cell-module-pack, integration in vehicle
Large format-cells, new chemistry/materials
Volume manufacturing systems
Smart integration of thermal and controls

Durability

Battery system with >10 years service life
High capability pack thermal
High voltage interconnects & sensing/controls

Quality

Six sigma design and process capability
Supplier/OEM/R&D teamwork

Thermal Management

Air vs. Liquid Cooling

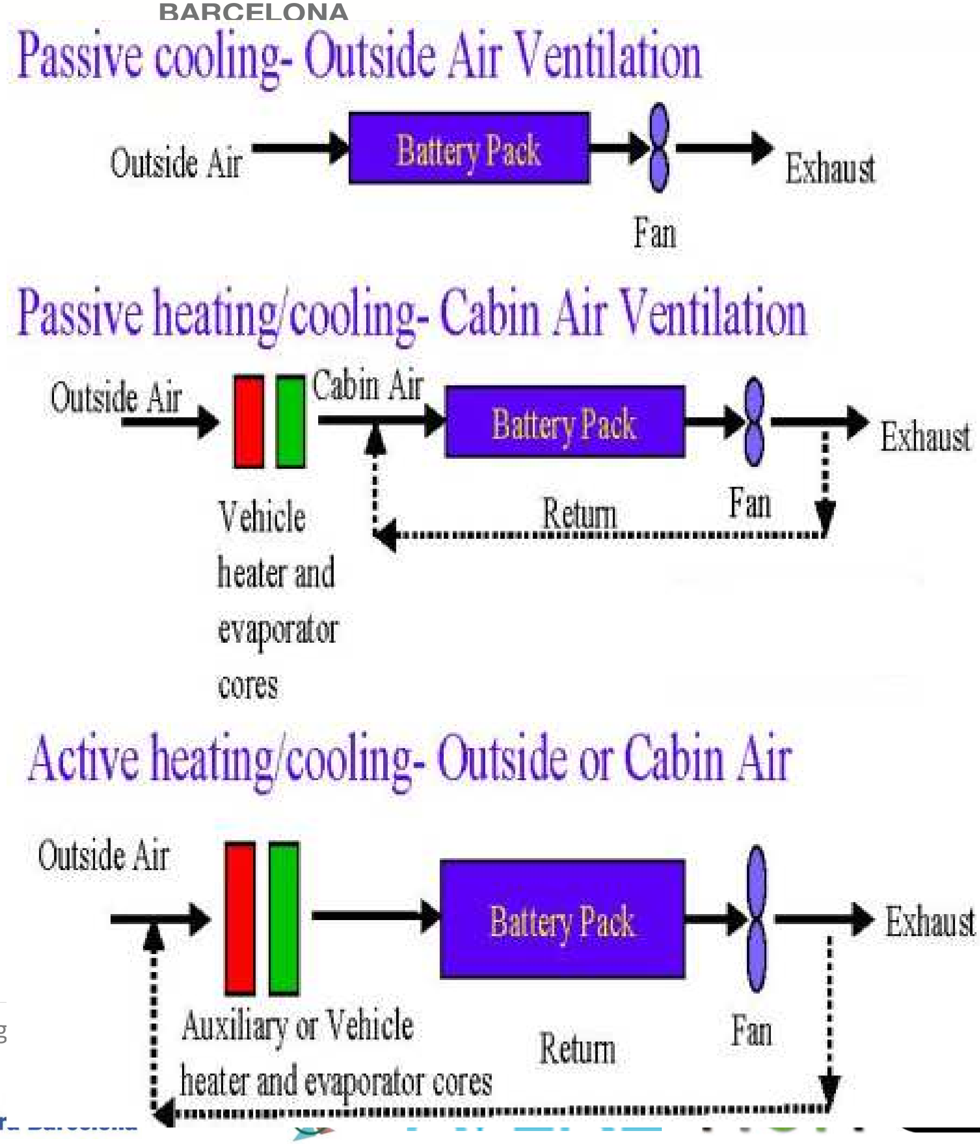
Battery Pack Thermal Management

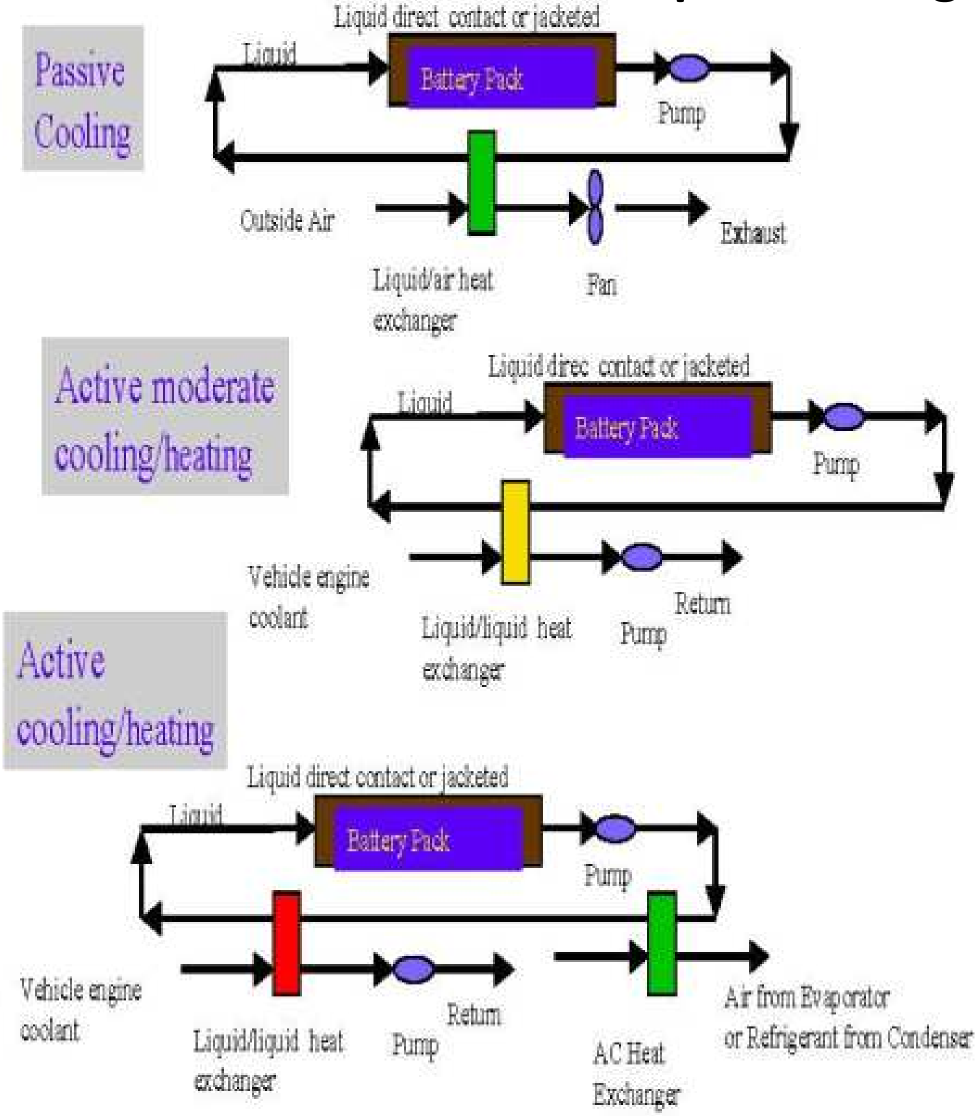
Air vs. Liquid Cooling

Air Cooling	Liquid Cooling
Ducting air	Piping liquid
Direct Contact	Direct Contact – Oils, Indirect Contact – Water/Glycol
Simple Designs	Compact Design, More Parts
Less Effective Heat Transfer	Higher Heat Transfer Rate
Lower Volume Efficiency	High Viscosity and Thermal Mass at Cold Temps.
Lower Cost	Higher Cost
Easier Maintenance	Higher Maintenance
Not Easily Sealed (From Environment)	Could Be Sealed Easier
Location Sensitive	Location Agnostic
Non-disruptive Leak	Potential for Leak - Disruptive

Battery Pack Thermal Management

Air vs. Liquid Cooling





Battery Production Equipment

Mixing, Coating, Calandering Machinery and Issues

Mixing and coating

Source: iwb

Mixing

Mixing

- Planetary mixers
- Magnetic stiring
- Ball mill
- Sonication

Significant influences

- Order of mixing
- Viscosity
- Homogenity
- Particle size
- Solvent

Coating

Coating

- Porosity
- Thickness
- Homogenity
- E-Module
- Humidity
- **Drying**

Calandering

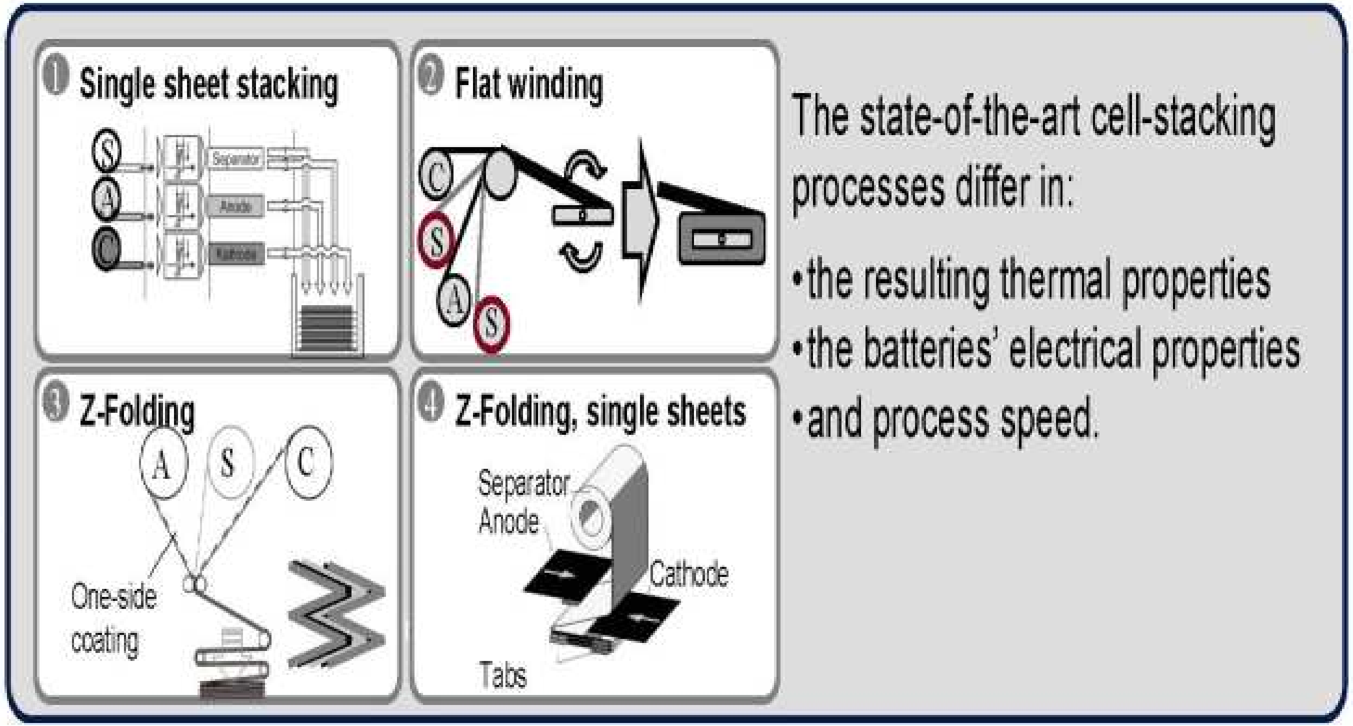
- Homogenous distribution of pressure
- Coating free of damage
- Compression vs. desired porosity

Battery Production & Testing Equipment

Laser, Thermal, & Stacking Machinery and Issues

Laser Terminal Welder / Cutter

Cell Stacking



Thermal Testing

EVS 27

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION

BARCELONA 17th-20th November 2013

Michigan Assets

Battery/Advanced Energy Storage Supply Chain (Li Ion Focus)

Materials/ Components

- TODA AMERICA
- AsahiKASEI
- A123 SYSTEMS
- DOW Dow Energy Materials
- BASF The Chemical Company
- XG sciences
- soulbrain MI

Cell Manufacturing

- LG Chem
- DOW KOKAM
- A123 SYSTEMS
- SB LiMotive (A joint company of Samsung and Bosch)
- fortu Holding AG
- SAKTI3
- Johnson Controls

Component Suppliers

- MAGNA
- trans-matic
- PEP stations LEADING THE CHARGE
- HDS

Pack Mfg

- GM
- Ford
- PISTON AUTOMOTIVE
- DOW KOKAM
- A123 SYSTEMS
- Johnson Controls

Engineering/ R&D/Testing

- element materials technology
- FEV
- HITACHI Inspire the Next
- BRIGHT AUTOMOTIVE
- CHRYSLER
- GM
- Ford
- MAGNA
- RICARDO
- TÜV SÜD
- HDS

Vehicle Assembly

- GM
- Ford
- AM General

Vehicle Integration

- AZD AZURE DYNAMICS
- EATON Powering Business Worldwide
- ALTe POWERTRAIN TECHNOLOGIES

Automation/Mfg/Test Equipment

- A&D Technology, Inc.
- ABB
- AVL
- COMAU
- fives cinetic
- KUKA
- JR AUTOMATION TECHNOLOGIES
- TÜV SÜD America
- RICARDO
- TARDEC

Recycling Repair & Re-Mfg

- BATTERY SOLUTIONS SMART RECYCLING MADE EASY
- EQ
- Sybesma's Electronics
- PADNOS SINCE 1905

NAVITAS SYSTEMS

Intertek

Announced Investment (Since 11/2008) >$5.7B

Organized by: Fira Barcelona, avele

Hosted by: AVERE

In collaboration with: Ajuntament de Barcelona, EVAAP, EDTA

Supported by: European Commission