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EV Everywhere
Grand Challenge

Battery Status and Cost Reduction Prospects

July 26, 2012

David Howell
Team Lead, Hybrid & Electric Systems
Vehicle Technologies Program
U.S. Department of Energy
1000 Independence Avenue
Washington DC 20585

EV Everywhere Battery Targets

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Battery affordability and performance are critical advances that are needed in order to achieve the *EV Everywhere* Grand Challenge

Chevy Volt

- ~40 mile electric range
- HEV: 32 mpg /300 miles
- 16 kWh / 120 kW battery
- Battery Cost: ~$8,000

Nissan Leaf

- ~75 mile electric range
- ≥ 24 kWh / 80 kW battery
- Battery Cost: ~$12,000

Tesla

- ~ 250 mile electric range
- ≥ 85 kWh / 270 kW battery
- Battery Cost: ~$35,000

EV Everywhere Target Analysis		Current Status	PHEV40	AEV100	AEV300
Battery Cost	**$/kWh (usable)**	**< 600**	**190**	**300**	**110**
Pack Specific Energy	Wh/kg	80-100	150	180	225
Pack Energy Density	Wh/L	200	250	300	425
SOC Window	%	50	80	90	90

Battery Cost Models

USABC

- Detailed hardware-oriented model for use by DOE/USABC battery developers to cost out specific battery designs with validated cell performance

Argonne (BatPaC)

- Inputs : vehicle architecture, pack capacity & power, cell chemistry, production scale
- Outputs: Optimized cell and electrode design for lowest cost pack
- Enables comparison between materials, electrode designs and thermal management
- Peer reviewed and adopted by EPA. Available on the ANL website.

TIAX

- Cost implications of different battery chemistries for a frozen design
- Identify factors that impact cell pack costs (e.g. active materials costs, electrode design, labor rates, processing speeds)

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Battery Technical Targets

Electric drive vehicle battery performance targets are established through detailed Modeling & Simulation and Hardware-In-the-Loop Testing

USDRIVE Energy Storage Targets	PHEV-40	AEV
Equivalent Electric Range (miles)	**40**	**200-300**
Available Energy (kWh)	**11.6**	**40**
Pack Cost	**$300/kWh (2015)**	**$125/kWh (2020)**
Discharge Pulse Power: 10 sec (kW)	**38** (Blended) **120** (EREV)	**80**
Regen Pulse Power: 10 sec (kW)	**25**	**40**
Calendar Life (year)	**15**	**10+**
Cycle Life (deep cycles)	**5000**	**1,000**
Maximum System Weight (kg)	**120**	**300**
Maximum System Volume (l)	**80**	**133**
Operating Temperature Range (°C)	**-30 to +52**	**-30 to +52**
Cold Crank Power:-30 °C/2sec (kW)	**7**	**N/A**

PHEV Battery Performance & Cost Status

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Battery Performance Status

- Data based on current USABC PHEV battery development contracts
- Focus on high voltage/high capacity cathodes & cell design optimization

PHEV 40 Battery Goals	Targets	Status (2011)	Current (2012)
Discharge Pulse Power: 10 sec (kW)	38	~95	~70
Regen Pulse Power: 10 sec (kW)	25	~70	~55
Available Energy (kWh)	11.6	11.6	11.6
Calendar Life (year)	10+	10-15	tbd
Cycle Life (deep cycles)	5,000	5,000+	tbd
Maximum System Weight (kg)	120	~175	~100-130
Maximum System Volume (l)	80	~100	~70-80
System Production Price (@100k units/year)	$3,400 ($300/kWh)	~6,850 ($590+/kWh)	~4200-4800 ($360-420/kWh)

EV Battery Performance & Cost Status

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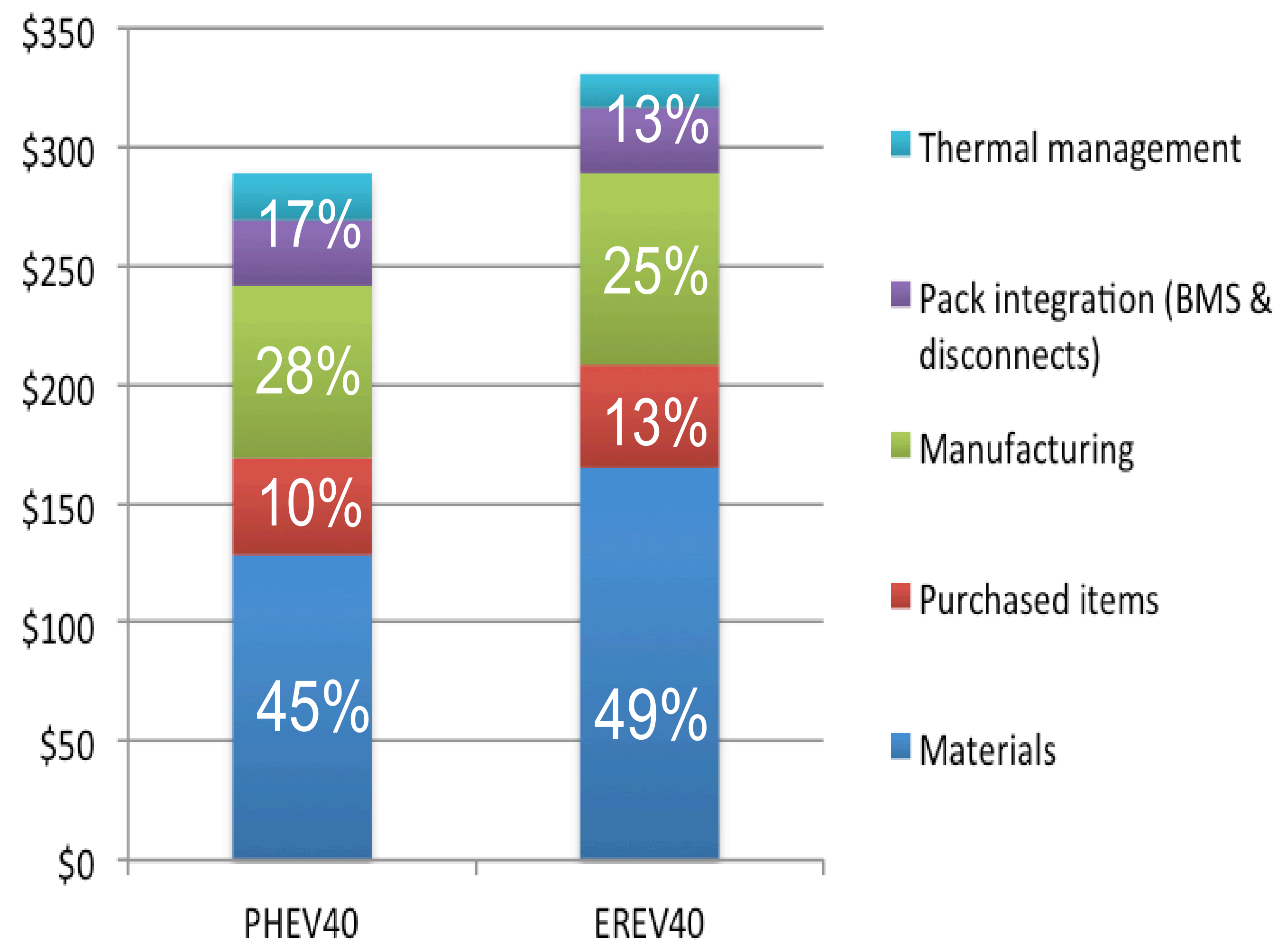
Battery Performance Status

- Data based on initial USABC EV battery development contracts started in 2011
- Focus on high voltage/high capacity cathodes & EV cell design optimization

AEV Battery Goals	Targets	Current
Equivalent Electric Range, miles	200-300	✓
Discharge Pulse Power (10 sec), kW	80-120	✓
Regenerative Pulse Power (10 sec), kW	40	✓
Available Energy, kWh	40-60	✓
Recharge Rate, kW	Level 2	TBD
Calendar Life, years	10+	TBD
Cycle Life, cycles	1,000 deep cycles	500-1000
Operating Temperature Range, ^{o}C	-40 to 60	0 to 40
System Weight, kg	160-240	270-350
System Volume, liters	80-120	170-225
Production Cost (@100,000 units/year)	$125/kWh	$325-500

PHEV Cost Estimates, $/kWh



- Estimates from ANL's BatPaC model.
- Based on 2020 production year & annual production of 100k packs
- Chemistry
  - graphite anode
  - NMC441 cathode
  - EC-EMC-$LiPF_6$ electrolyte
- Liquid cooling
- Manufacturing
  - electrode processing,
  - cell assembly
  - formation,
  - module & pack assembly
- Purchased items
  - cell terminals
  - packaging
  - module and pack jackets

EV Cost Estimates, $/kWh

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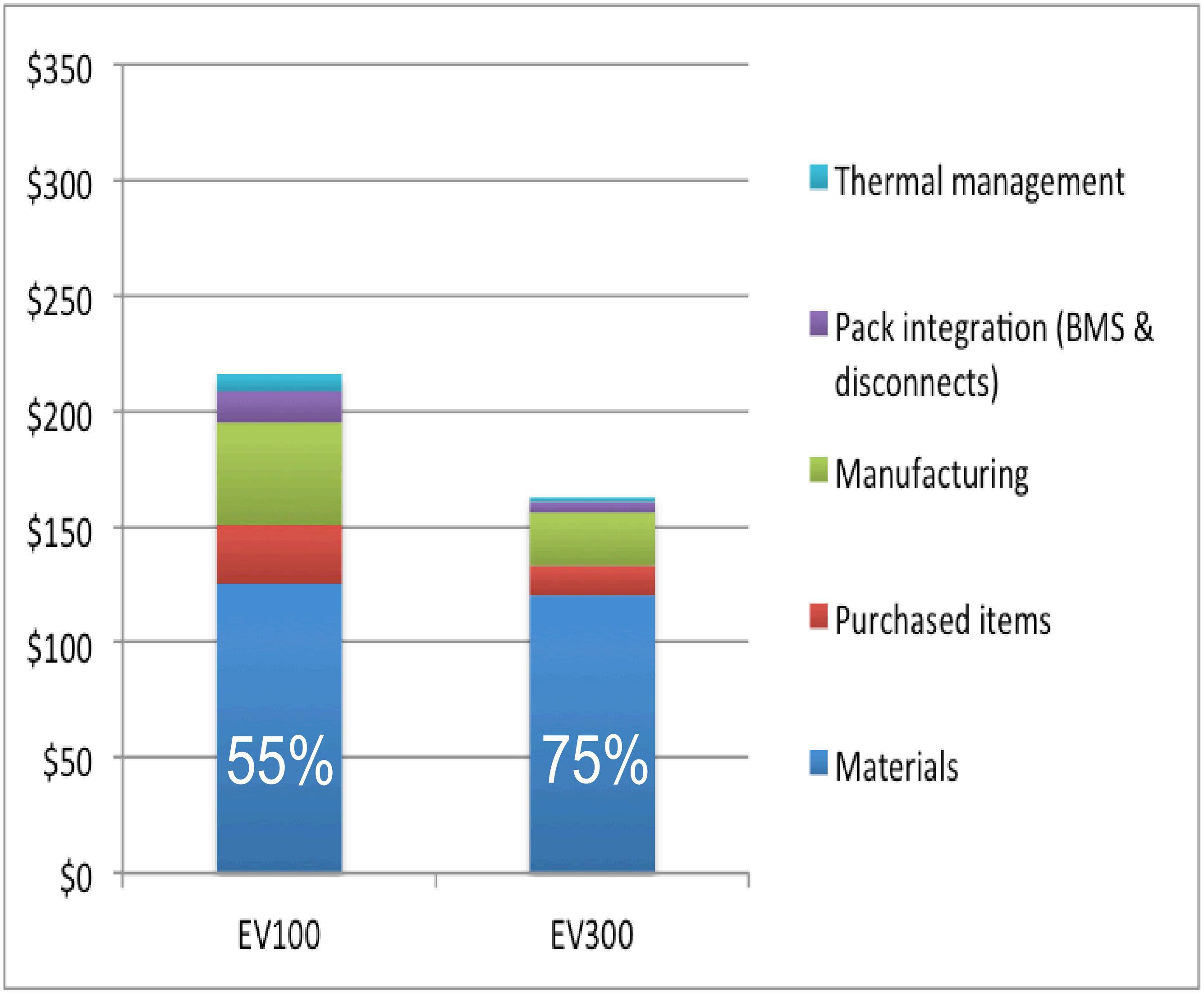

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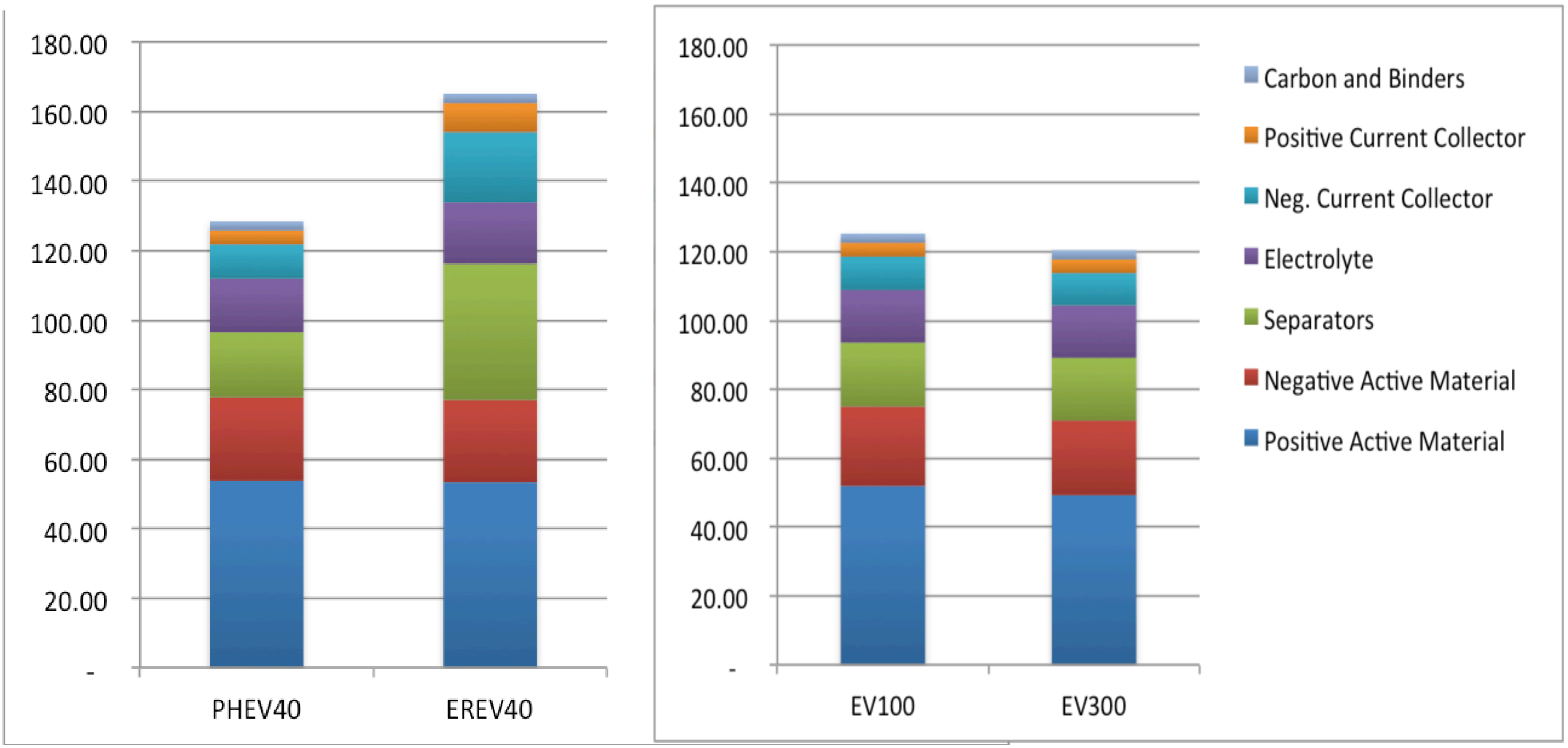
Cost of Key Materials, $/kWh



Non-active materials costs are higher for higher power systems. Material costs for other systems are similar, non-active material costs decrease on a relative basis with increasing AER.

Path Forward for Lithium-Based Batteries

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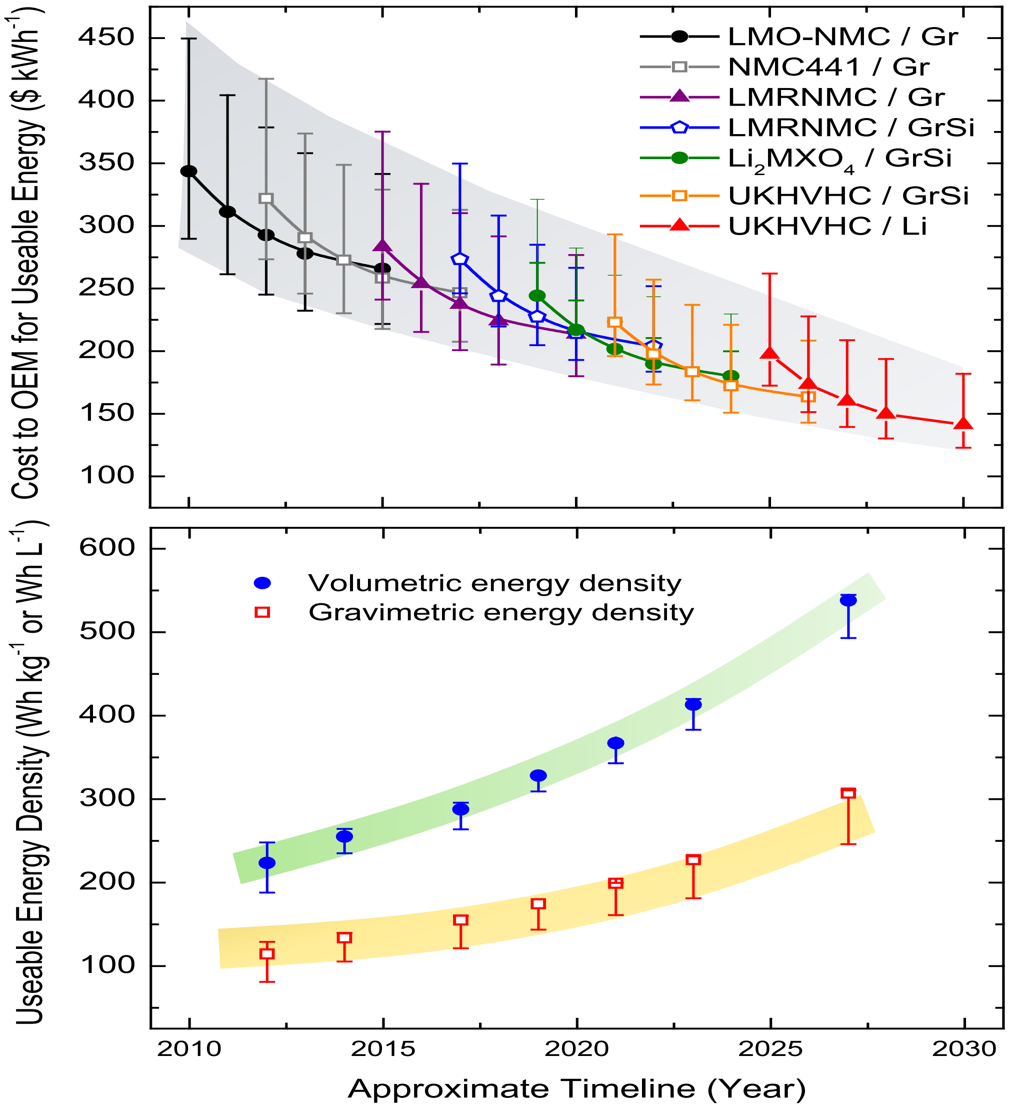
Battery Cost Model Calculations (BatPaC v1.0) **for a 100 mile range Electric Vehicle (EV100)**

- Battery Specs: 30 kWh, 80 kW, 360V
- Total cost to OEM includes purchased battery, battery management system, and liquid thermal management (w/o electric compressor).
- **If high-risk research is successful,** material advances may lead to a 60% reduction in cost and 250% increase in energy density
- Larger batteries (EV200+) will have higher energy densities and lower costs for energy.



Source: Argonne National Laboratory

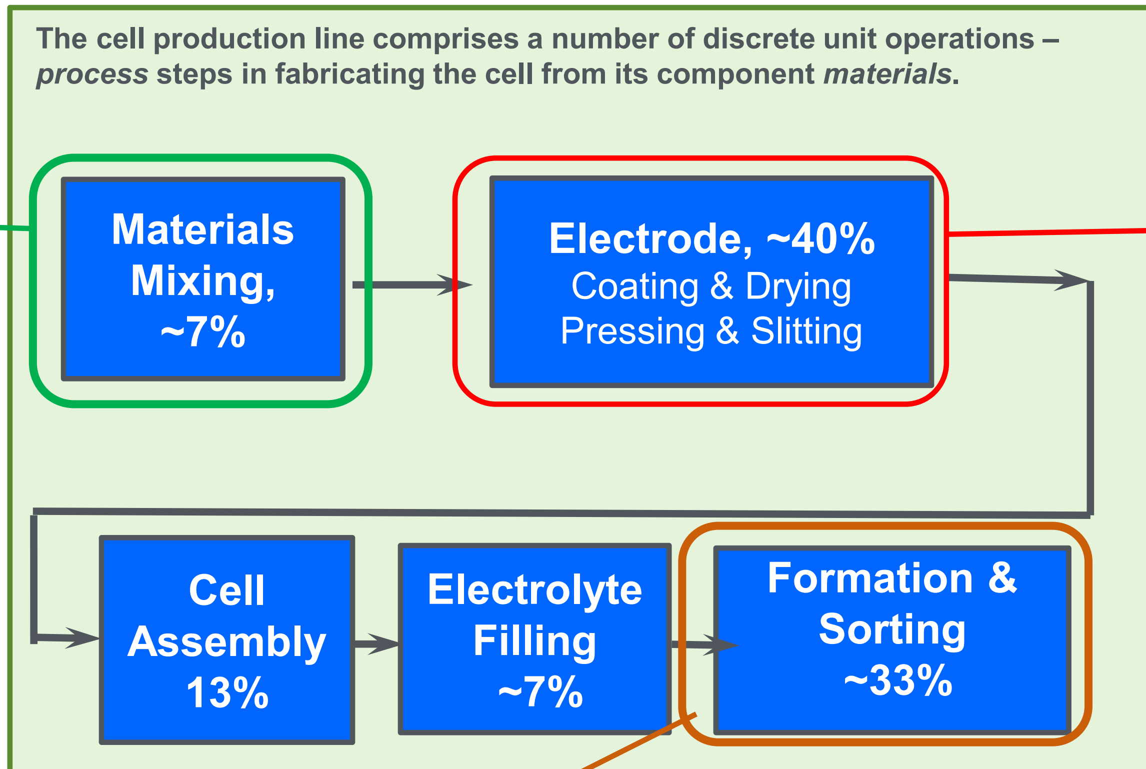
Cost reduction

- Higher energy materials will reduce the cost of batteries.
- However, there are other approaches being pursued that will result in reduced cost. These include:
  - Reduce the production cost of electrolyte, cathode, and anode materials
  - Thicker electrode coatings = less separator, less current collector
  - Thinner and/or reduced cost current collectors and separators
  - Faster and less expensive coating, drying, forming technology
  - Advanced thermal management technology
  - Advanced pack design with reduced non-active material use

Electrode manufacturing and cell fabrication are 25% of battery cost.

Breakthrough Needed?

- NMP solvent substitute
- Dry processing
- Fast curing binders



Breakthrough Needed?

- High-speed deposition
- UV, Microwave, or IR flash lamp drying
- Ultrahigh packing density
- *In situ* separator coatings

Currently: A 2-4 week process that assures performance, life, & safety of a cell

Breakthrough Needed?

- Form SEI layer during material mixing or electrode processing
- High speed In-Situ NDI techniques to detect flaws & internal shorts

Key Observations

- Current high volume EDV lithium-ion battery cost estimates are less than $600/kWh of useable energy.
  - Advanced lithium ion technologies project costs approaching $300/kWh of useable energy. Development and validation are underway.
  - Models project that lithium-ion battery costs of less than $200/kWh of useable energy are plausible.
- Electrochemistry optimization matters
  - Key materials represent 45-75% of total battery pack cost
  - Useable State-of-Charge range has direct impact on cost
  - Capacity fade can dramatically influence total cost of the battery pack
- Cell and Pack design matters
  - Cell power & energy density, thermal performance, and durability have a significant impact on pack cost
- Manufacturing scale matters
  - Increasing production rate from 10,000 to 100,000 batteries/year reduces cost by ~30-40% (Gioia 2009, Nelson 2009)
  - Increased processing speed (2X) can compete with very low labor rates (TIAX)

Current & Future Technologies

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Potential Attributes of Battery Technologies (Battery Pack level)

	Specific Energy (Wh/kg)	Energy Density (Wh/l)	Power (W/kg)	Current Life (cycles)	Safety
Lithium-ion (current status)	50-80	100-150	500-1000	>5,000	Meets SAE J2929
Lithium-ion (future generations)	150-200	**250**	**2,000**	tbd	tbd
Lithium metal polymer	150-200	**250-300**	500	~1000	**+++++**
Lithium metal / Sulfur	**250-400**	180-250	750	~100	Concern
Lithium metal / Air	**400-800**	180-250	Poor	~10	Concern

For Additional Information…

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QUESTIONS?

Dave Howell, Team Lead, Hybrid and Electric Systems
202-586-3148
David.Howell@ee.doe.gov