Ford Battery R&D with U-M Battery Fabrication Lab

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Ford is expanding its electrified vehicle program worldwide, allowing the company to share technology globally, test batteries virtually, in real time, and accelerate advancements.

**Technology**
- Battery development to expand globally into Europe and Asia

**Investment**
- $4.5 BILLION
- Ford to invest $4.5 billion through 2020

**R&D**
- $2.1 million investment in a battery lab at the University of Michigan to boost research and development

**EVs**
- Ford to add 13 new EV nameplates, offering electrification on more than 40% of its vehicle lineup by 2020

**Growth**
- Ford expands EV offerings to growing markets, including Taiwan, Korea and China

**Improvements**
- New Focus Electric, with a projected 100-mile range and all-new DC fast charging capability, projected to deliver an 80% charge in an estimated 30 minutes
Ford’s electrified platform strategy provides global flexibility.

- Portfolio Approach = HEV/PHEV/BEV (customer-driven)
- Global Flexibility = Electrify Highest Volume Platforms
- Best Value = HEVs Remain Highest Volume
- Affordability Remains Key = Sharing Common Components
Sustainability Blueprint

Near-Term
Leverage Existing Technologies at High Volume

Mid-Term
Substantial Weight Reduction & Expand Electrification

Long-Term
High Volume Electrification and Alternative Energies

- Hybrid
- Plug-in Hybrid
- Battery Electric
- Fuel Cell

• Ford’s sustainability strategy, founded on affordability for millions of customers
Ford’s Electrified Vehicle Sales

- Steady growth in electrified vehicle (FHEV) sales through 2012
- Significant increase in sales starting in 2013 with Gen III FHEV/PHEV/BEV products
- 455k cumulative Ford electrified vehicles sold in U.S. through 2015

Data Source: LMC Automotive
U.S. Electrified Vehicle Sales

Electrified vehicle sales as percent of industry

- Gasoline fuel price (per gallon)
- HEV sales (LIB & Ni-MH)
- PEV sales (LIB)

- Electrified vehicle demand moves with fuel price.
## Alternative Fuel Vehicle Sales in U.S., CY2015

<table>
<thead>
<tr>
<th>Rank</th>
<th>Nameplate</th>
<th>Units sold 2015</th>
<th>Units sold 2014</th>
<th>Rank</th>
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<tr>
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<td>Toyota Prius Liftback</td>
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<td>Tesla Model S</td>
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<td>Ford Fusion Hybrid</td>
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<td>Hyundai Sonata Hybrid</td>
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<td>Nissan Leaf</td>
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<td>Honda Accord Hybrid</td>
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<td>Ford C-Max Energi</td>
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<td>25</td>
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<td>Subaru XV Crosstrek Hybrid</td>
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<td>27</td>
<td>BMW X5 Diesel</td>
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<td>28</td>
<td>Honda Civic Hybrid</td>
<td>4,887</td>
<td>5,070</td>
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<td>29</td>
<td>Fiat 500e</td>
<td>4,516</td>
<td>1,503</td>
<td>52</td>
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<td>54</td>
<td>Ford Focus EV</td>
<td>1,582</td>
<td>1,964</td>
<td>47</td>
</tr>
</tbody>
</table>

**Total Sales:** 654,928

### Automotive LIB Supply in U.S., CY2015

- **Number of LIB vehicles sold**
  - Ford: 66,184
  - Nissan: 26,058
  - Hyundai: 32,430
  - GM: 23,605
  - Honda: 19,363
  - Tesla: 26,608
  - Toyota: 4,209
  - BMW: 14,248
  - Volkswagen: 6,639
  - Daimler: 3,475
  - FCA: 4,516
  - Others: 201

- **Number of LIB cells used**
  - Panasonic (Sanyo): 6.45M
  - AESC: 3.72M
  - LG Chem: 7.59M
  - Blue Energy / LEJ: 1.15M
  - Panasonic (18650): 194M
  - SDI: 1.96M

- **Energy of LIB cells used**
  - Panasonic (Sanyo): 324MWh
  - AESC: 443MWh
  - LG Chem: 412MWh
  - Blue Energy / LEJ: 2,163MWh
  - SDI: 378MWh

- **227,536 of LIB vehicles were sold in 2015.**
- **3.8 GWh of LIB cells were installed.**

[http://www.hybrids.com/market-dashboard/]
**Motivation**

**Coin cell level (1-5mAh)**
- Capacity
- Efficiency
- Rate Capability
- Voltage window

**Battery pack level (25-200Ah)**
- Cell Integration
- Electric/Mechanical/Thermal Management
- Vehicle Simulations & Tests

- *Properties measured at the coin-cell scale don’t tell the whole story.*
Motivation, example #1

- Structural stability for high Ni content layered oxide

Case 1: Depth of Discharge (DOD)
- DOD 60%
- DOD 100% swing

Case 2: Elevated temperature

Case 3: Non-uniform cracks

Test durability for 1,000+ cycles

coin half cell(X)
Motivation, example #2

- High capacity Si-Graphite Composite

72%@300 vs. 75%@50

Coin half cell 18650 full cell

ECS Transactions, 1 (26) 73-77 (2006)
• Prototyping LIB cells
  – We need a “stepping stone” scale where the complexities of the modern manufacturing technology are included, but at a scale that is manageable in a research context.
  – The gap between an EV cell (15-60Ah) and a coin cell (1-5mAh) is too large to allow for meaningful extrapolations on:
    • performance
    • durability
    • safety
    • manufacturing feasibility & cost
XALT Energy (Pouch)
A123 (Pouch)
PSU (18650)
ANL (Pouch and 18650)
BIC (18650)
KY-ANL Battery Center
ORNL (Pouch) SNL (18650)
SAFT
LGCMI (Pouch)
U. Michigan (18650, Pouch)
UWM w/ JCI (Pouch)
JCI (Can)

Government funded laboratory
Automotive Cell Mass production
University
UM Phoenix Memorial Lab: Past and Future

- Michigan Memorial Phoenix Project after World War II
- Ford Nuclear Reactor commissioned in 1956

- Lab was renovated and rededicated on Oct 14th 2013
- A joint battery lab project announced officially
- Grand Opening on October 2nd 2015

http://energy.umich.edu/project/battlab
The Partnership

- Building a pilot-scale laboratory in-house would be constrained by budget, personnel, lab space
- UMEI provides facilities and dedicated technical staff
- Access to State and Federal funds ($5M from MEDC, $750k from CERC)
  - A bigger facility with better capabilities
  - Flexible facility that can accommodate multiple cell formats
- Donations + 10-15% Academic discounts
- Better utilization of equipment, higher level of expertise possible in a well-staffed and well-used facility.
- Opportunity for close collaborations with U of M staff, students and other partners.
- New educational, recruiting and research opportunities
• World-class, open access user-facility
  – Multiple scales for cell fabrication
    coin cell, 18650 cell, pouch cell (up to 72mm x 220mm format)
    – Highest quality fabrication equipment

• Key part of battery technology infrastructure in Michigan and U.S.
  – To support multiple start-up companies
  – To support ARPA-E and USABC

• Fabrication and testing of smaller cells has several benefits:
  • Faster, less expensive testing
  • Validation of electrochemical models
  • Exploration of cell designs and robustness of manufacturing processes
Phoenix Memorial Lab Layout

Michigan Memorial Phoenix Laboratory – 2nd Floor

Approximate space allocation:

- Pilot Mixing & Coating: 930 ft²
- -40°C Dew Point Dry Room: 675 ft²
- Laboratory and Characterization: 1130+ft²
Pilot Scale Mixing

Planetary Mixer
- 2-3 hours mixing time
- 3-5L Working volume
- Max 75 rpm (Planetary) and 7500 rpm (Homogenizing Disperser)

Dry Powder Mixing 20-30 min
High Shear 20-30 min
Mixing 60 min
Additional Solvent
Deaeration 10+ min
Pilot Scale Coating

- **Multi-Head Coater**
  - Slot-die, Comma Reverse, Micro-gravure
  - Continuous and Intermittent Pattern Coating
  - 2 drying zones with 4 meter oven, IR heater in 1st zone
  - Edge position and auto tension control
  - Max 5m/min coating speed
Calendering Press
- 60kN Press
- Heated roll, up to 150°C
- Edge position and auto tension control
- Max 10m/min

Slitter
- Multiple material capability
  - Cathode, Anode, Separator
- Spacer changeable knife cartridge
- Max 10m/min
Cell Assembly in Dryroom (1)

Cycle time: 2 min, 13 (+) / 14 (-)  Cycle time: 10s
Cell Assembly in Dryroom (2)

- Cell assembly takes place inside -40°C dew point dry room
- 18650 jelly rolls created on a KOEM automated winder (Single-, Middle-, Multi-tab J/R available)
- 18650 cells assembled on six mPLUS semi-automated machines

18650 cell assembly process
High durability, high capacity baseline lithium ion cell performance demonstrated:
  - Baseline cells showed ca. 90% capacity retention after 500 1C cycles
18650 vs. Automotive Cell

- High capacity cathode
- High capacity anode
- High voltage cathode and electrolyte
- Thin separator & foils

Material breakthrough

• **18650 is a best surrogate size to compare to current technology development trends and prototype cell performances as there are various grades of 18650 cells commercially available to benchmark.**
Potential Projects

- **FMEA Study**
  - Deficient electrolyte

- **Electrochemical Modeling**
  - Graphs showing OCP vs. SOC, Cathode and Anode potential vs. LVL, and Li diffusion coefficient vs. Temperature.
Future Ford’s Automotive LIB R&D

- **Material**
  - Next-generation materials
  - Strategic materials

- **Manufacturing**
  - Cell design & process
  - Performance & Safety testing
  - Cost analysis

- **Management**
  - Electrochemical & Thermal model
  - Prediction of battery performance and degradation under vehicle dynamic conditions
  - Integration with vehicle simulation and control algorithm development

- *The pilot-scale joint lab will provide a key resource for a wide range of development partners and enable stronger interactions with all partners in Ford R&D process.*