Low Cost, Structurally Advanced Novel Electrode and Cell Manufacturing

William Woodford
24M Technologies, Inc.
June 9, 2016

Project ID#
ES245
Overview

Timeline
• Project start: 1 Oct 2014
• Project end: 30 Sept 2016
• Percent complete: 75%

Budget
• Total project funding
  – DOE share: $1,945,774
  – 24M share: $658,940

• Funding received in FY15
  – DOE share: $906,451
  – 24M share: $335,806

• Funding for FY16
  – DOE share: $868,975
  – 24M share: $245,653

Barriers
• Cost – current costs are three times too high on a kWh basis
• Performance – High energy density battery systems are needed to meet both volume and weight targets
• Abuse tolerance, reliability, ruggedness – many Li-ion batteries are not intrinsically tolerant to abusive conditions

Partners
• 24M Technologies - LEAD
About 24M

• Re-inventing the Li-ion Battery
  – Cost reduction down to 50% of today’s cost
  – Higher energy density, safer systems

• Dramatically simpler manufacturing
  – Half the CapEx of conventional Li-ion
  – Scale in small increments (1/10th conventional)

• Unlocks $100B+ market
  – First market: stationary storage
  – First supply MoU signed: NEC (hundreds of MWh)
  – Next market: electric transportation

• Accelerating commercialization
  – Factory Complete: 2H2017
Company Timeline

• 2010: company founded
  – Yet-Ming Chiang, Throop Wilder, W. Craig Carter

• 2014: automated line running
  – 32,000 sq.ft. facility
  – 55+ employees

• IP Capture: 18 issued patents, 75+ pending

• Funding Events: $50M in equity
  – 2010: Series A, $10M VC
  – 2013: B-1, $10M VC, $15M strategics
  – 2014: B-2, $15M strategics

• DOE Grants: $4.5M to date
  – ARPA-e: $2.5M
  – Vehicle Technologies: $2M
Our Customers: Architects, Integrators of the Energy Future

**Market 1: Grid Integrator**
- DC Module
- DC Rack
- Inverter

- Centralized (100’s MWh)
- Substation 5-20MWh
- Commercial 0.1 – 1MWh
- Residential & Off-grid 1-20kWh

**Market 2: EV OEM**
- Cell
- Pack

- EV: 20-100kWh
- Bus: 300kWh

Source: Schneider Electric
Source: Proterra
Source: BMW
Li-ion Shortcomings: Too Much Mass, Volume, Cost

Cell Design Challenges

- 25 separate layers, 14 inactive material layers in 1mm cross section

Manufacturing Challenge: Complex, wet/dry/wet operations

<table>
<thead>
<tr>
<th>Electrode Creation</th>
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- Complex and expensive operations with multiple yield sensitivities

Test & Prep

- Pre-Charge
- Formation
- Aging & Sorting/Grading

Cell Assembly

- Stacking
- Welding
- Jelly Roll Insertion & Electrolyte Fill

Inactive material fraction too high.
Inactive material cost % too high.
Semisolid Lithium-ion

Flowable high energy density lithium-ion electrodes

Simpler device architecture, disruptive low-cost manufacturing method

Novel semi-solid electrode form

Materials design
• Program Objective: Re-invent the Li-ion battery from electrode design through high volume manufacturing
  – Demonstrate that 24M’s novel electrode and manufacturing approach can be scaled to mass production suitable for automotive applications.
  – Novel electrode architecture that enables abuse tolerant battery systems.
  – Reduction of inactive materials that translates to higher energy density battery systems with a simpler architecture

13,000+ prototype cells built
Program Approach/Strategy

<table>
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<th>24M Manufacturing</th>
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<td>Blend Anode</td>
<td>Blend Cathode</td>
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- Fewer unit operations
- 1/3rd the capex of conventional Li-ion
- Ability to reach economies of scale without requiring ~$500M capital investment
## Milestones

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<tr>
<td>1</td>
<td>Increase anode volume loading percentage</td>
<td>Milestone Complete</td>
<td>Milestone Complete</td>
<td>On Track</td>
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<td>2</td>
<td>Increase cathode volume loading percentage</td>
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<td>3</td>
<td>Implementation of automated forming of anode and cathode electrodes</td>
<td>Milestone Complete</td>
<td>Milestone Complete</td>
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<td>4</td>
<td>80 cm² electrode yield</td>
<td>Milestone Complete</td>
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<td>5</td>
<td>80 cm² format cell manufacturing quality</td>
<td>Milestone Complete</td>
<td>Go/No-Go Deliverables Delivered</td>
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<td>6</td>
<td>Increase electrode footprint 260+ cm²</td>
<td>Milestone Complete</td>
<td>Milestone Complete</td>
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<td>7</td>
<td>Meet electrode quality metrics for production quality at footprint &gt;260 cm²</td>
<td>Milestone Complete</td>
<td>On Track</td>
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<td>260+ cm² electrode yield</td>
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<td>9</td>
<td>260+ cm² format cell manufacturing quality</td>
<td>On Track</td>
<td>Deliverables On Track</td>
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Grid Cell: Cycle and Calendar Life

**Cycle Life**
- Application specific optimization
- >3000 cycles (100% DoD) to 80% capacity
- Round trip energy efficiency >90% at C/4 continuous

**25°C Calendar Life**
- 20 year projected life to 80% capacity after 36 months of data
- Stored at 100% SOC, 25°C
Passing all UL, UN safety tests to date

- Tested 6 Ah cells against key UL 1642, UN 38.3, USABC requirements
  - UN 38.3 T3 Vibration: no visible damage/ voltage loss - **PASS**
  - UN 38.3 T4 Shock (150G): no visible damage - **PASS**
  - UN 38.3 T5 Hard external short: $T_{\text{max}} = 93^\circ\text{C}$ - **PASS**
  - UN 38.3 T6 Crush: no voltage loss - **PASS**
  - UN 38.3 T7 Overcharge: pass, swelling, delta $T \sim 8^\circ\text{C}$ - **PASS**
  - USABC Nail penetration (SAND2005-3123): pass, gas generation, $T_{\text{max}} = 89^\circ\text{C}$ - **PASS**
  - UL1642 Heating (130C hotbox): **PASS**
24M Cell Design Has Unique Abuse Tolerance
Li-Ion Today: $500M Up-Front, $250/kWh/year Factory Output

Mixing

Coating & Drying

Electrode Creation
- Mix Anode
- Coater & Inspection
- Slitter & Cleaning
- Press/Calendar
- Die Punch
- Clean & Buffer
- Vacuum Drying

Slitting

Press/Calendar

Solvent Recovery

Cell Assembly
- Stacking
- Welding
- Jelly Roll Insertion & Electrolyte Fill

Test & Prep
- Pre-Charge
- Formation
- Aging & Sorting/Grading

6/9/2016
## Eliminating Half the Conventional Process

### Conventional Li-ion Manufacturing

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### Cell Assembly

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<td>Stacking</td>
<td>5 min.</td>
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<tr>
<td>Welding</td>
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<td>Jelly Roll Insertion &amp; Electrolyte Fill</td>
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<tr>
<td>Electrode Formation/Assembly/Stacking</td>
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<td>Welding</td>
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<td>Stack Insertion</td>
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### Test & Prep

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20,000 ft² Facility

- Anode Mix: COTS Equipment
- Cathode Mix: COTS Equipment
- Electrode Forming
- Cell Assembly
- Packaging COTS Equipment
- Lowest $/channel Formation COTS Components

- 24M CapEx is 30-50% of conventional for same output
- Requires 1/20th the initial CapEx of conventional Li-ion
- Scalable to GWh in demand-matching steps
- Can place factories near centers of demand
Technical Accomplishments: High Process Consistency in Pilot Plant

- Consistently within 3% process constraint
- Metrology on every stage of process
- Full traceability of every cell

**Electrode Weight**

**Electrode Thickness**

450 micron electrodes
Technical Accomplishment – GO/NO GO Deliverable Cells

• 20 pouch cells of 4.3 Ah capacity
  – 10 cells testing at ANL
  – 10 cells at 24M for duplicate testing

• Program target yield 85%, actual 96%
  – Capacity tolerance ±5%
  – Impedance tolerance ±10%
• “The reviewer stated that there needs to be more information to assess the technical accomplishments. There is no cycling data, neither Wh/kg nor Wh/L.”
  – Cycling data shown
Proposed Future Work

• Demonstrate final program target cathode volume loading
• Demonstrate final program target anode volume loading
• Demonstrate final program target electrode quality metrics at 260+ cm² footprint
• Demonstrate final program target electrode yield
• Demonstrate final program target cell manufacturing yield
• Deliver final program deliverables: cells with 260+ cm² footprint exceeding target yield
Summary

• 24M has continued to meet its milestones for increasing energy density of its battery systems by increasing the active loadings of its cathode and anode materials.

• Scale-up for manufacturing processes is in progress with manufacturing equipment installed in its facility.
  – Current manufacturing processes are meeting target quality metrics for production quality.

• On track for delivery of large-format deliverables in Q3 2016