



Low Cost, Structurally Advanced Novel Electrode and Cell Manufacturing

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24M Technologies, Inc.
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Project ID#
ES245

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

- 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
 - \$35-40M Series Close: 2016
 - Customer Sampling: 2016
 - Factory Complete: 2H2017



<http://borgsolar.com/solutions/>



<http://bjackcity.com/douglas/index.php?p=powersubstation>



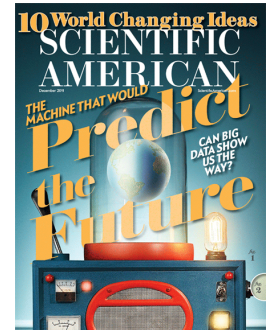
http://photoelectricdreams.blogspot.com/2014_01_01_archive.html

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



Recognition



Our Customers: Architects, Integrators of the Energy Future

Market 1: Grid Integrator

DC Module



DC Rack



Inverter



Source: Schneider Electric



Centralized
(100's MWh)

<http://myrepono.com/blog/The-World-s-Largest-Data-Centres>



Substation
5-20MWh

Source: ABB



Commercial
0.1 – 1MWh

Source: ABB



Residential &
Off-grid
1-20kWh

<http://www.weatherwise.org/Archives/Back%20Issues/2009/July-August%20>

24m



Cell



Market 2: EV OEM

Pack



<https://www.evhangar.com/system/battery-systems/sys-batt-bmw-i3/>



Bus: 300kWh

Source: Proterra

EV: 20-100kWh



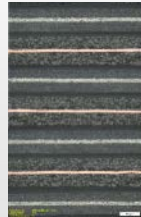
Source: BMW

Li-ion Shortcomings: Too Much Mass, Volume, Cost

Cell Design Challenges

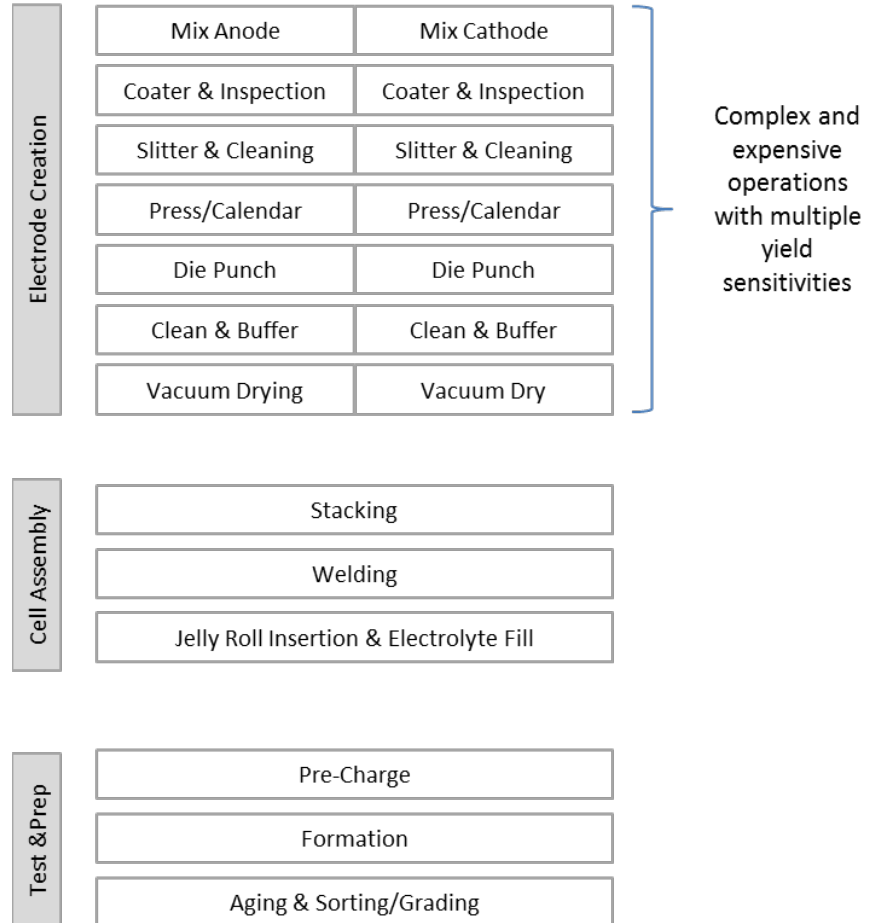


25 separate layers,
14 inactive
material layers in
1mm cross section



Inactive material fraction too high.
Inactive material cost % too high.

Manufacturing Challenge: Complex, wet/dry/wet operations

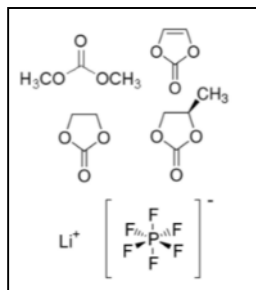
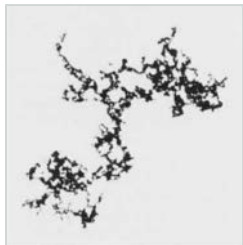




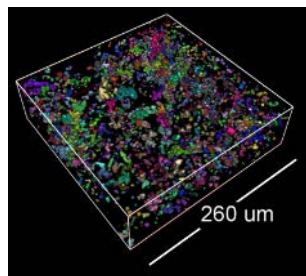
24m

Flowable high energy density lithium-ion electrodes

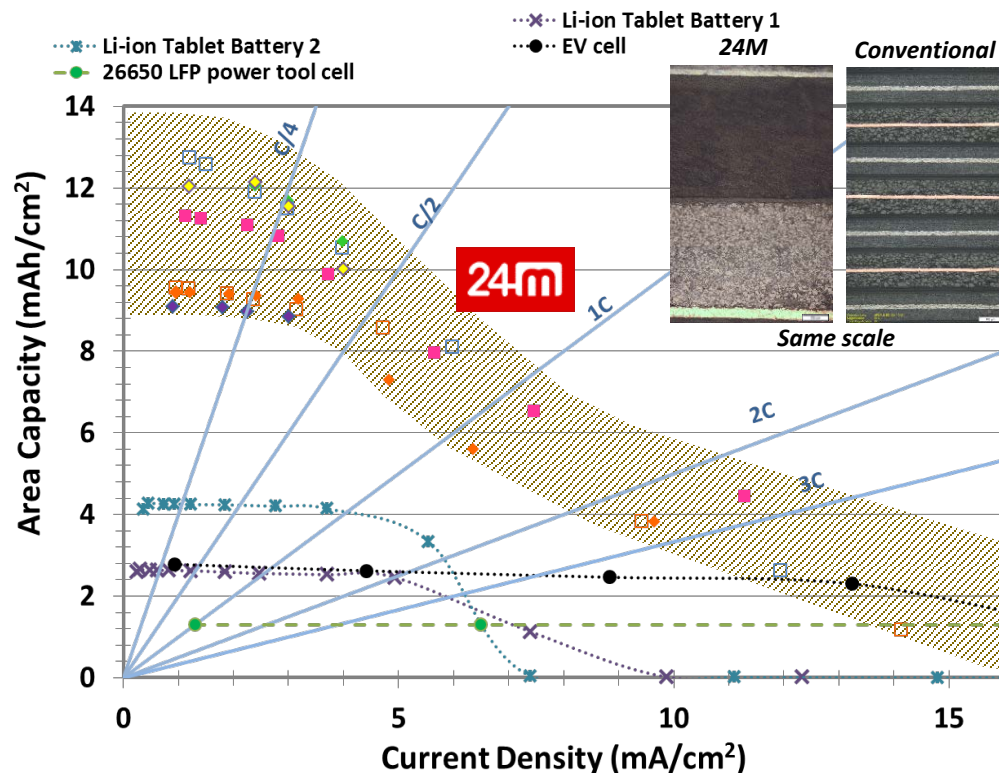
Simpler device architecture, disruptive low-cost manufacturing method



Novel semi-solid electrode form



Materials design

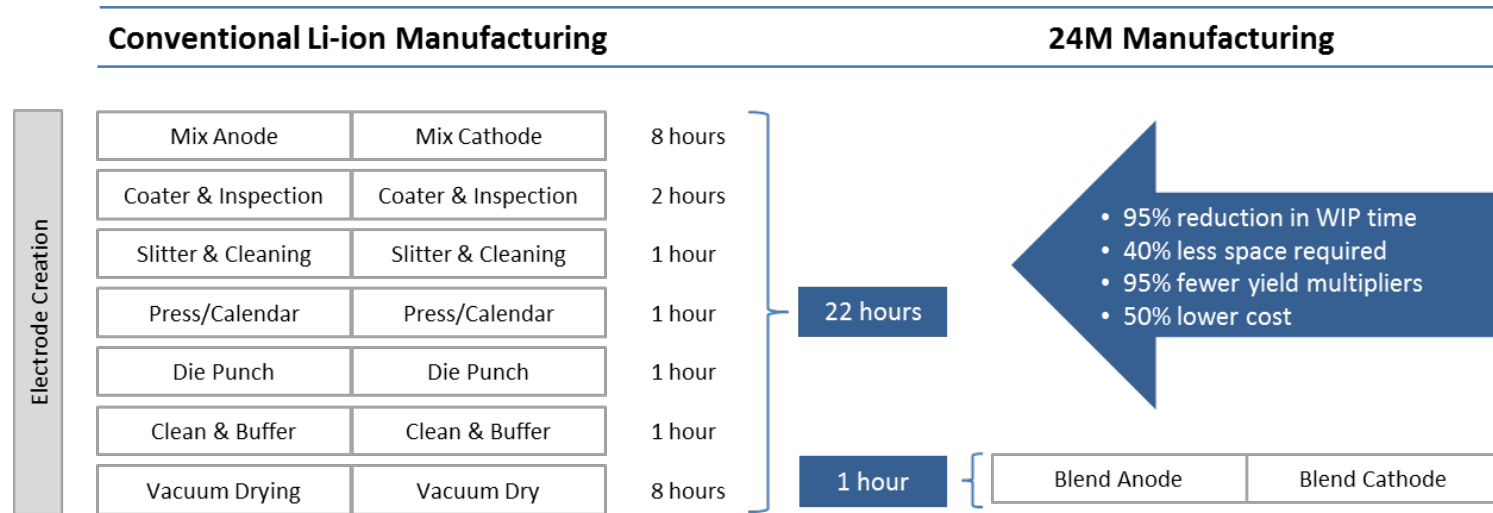


- Program Objective: Re-invent the Li-ion battery from electrode design through high volume manufacturing
 - Demonstrate that 24M's novel electrode and manufacturing approach can be scaled to mass production suitable for automotive applications.
 - Novel electrode architecture that enables abuse tolerant 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



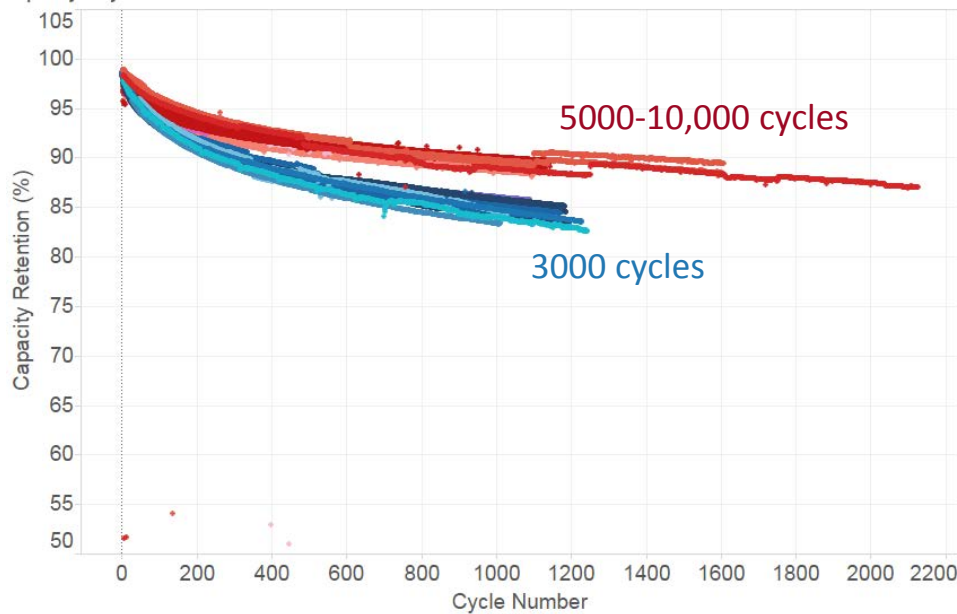
- Fewer unit operations
- 1/3rd the capex of conventional Li-ion
- Ability to reach economies of scale without requiring ~\$500M capital investment

Milestones

Work Stream	Task Description	2014 Q4	2015 Q1	2015 Q2	2015 Q3	2015 Q4	2016 Q1	2016 Q2	2016 Q3
1	Increase anode volume loading percentage	Milestone Complete			Milestone Complete			On Track	
2	Increase cathode volume loading percentage		Milestone Complete				On Track		
3	Implementation of automated forming of anode and cathode electrodes			Milestone Complete					
4	80 cm ² electrode yield			Milestone Complete					
5	80 cm ² format cell manufacturing quality		Milestone Complete		Go/No-Go Deliverables Delivered				
6	Increase electrode footprint 260+ cm ²		Milestone Complete			Milestone Complete			
7	Meet electrode quality metrics for production quality at footprint >260 cm ²			Milestone Complete			On Track		
8	260+ cm ² electrode yield				Milestone Complete				On Track
9	260+ cm ² format cell manufacturing quality						On Track		Deliverables On Track

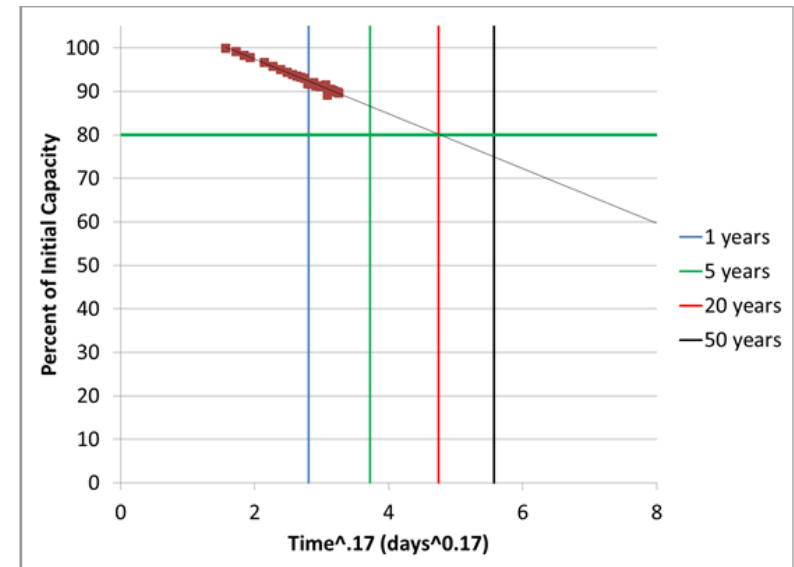
Grid Cell: Cycle and Calendar Life

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



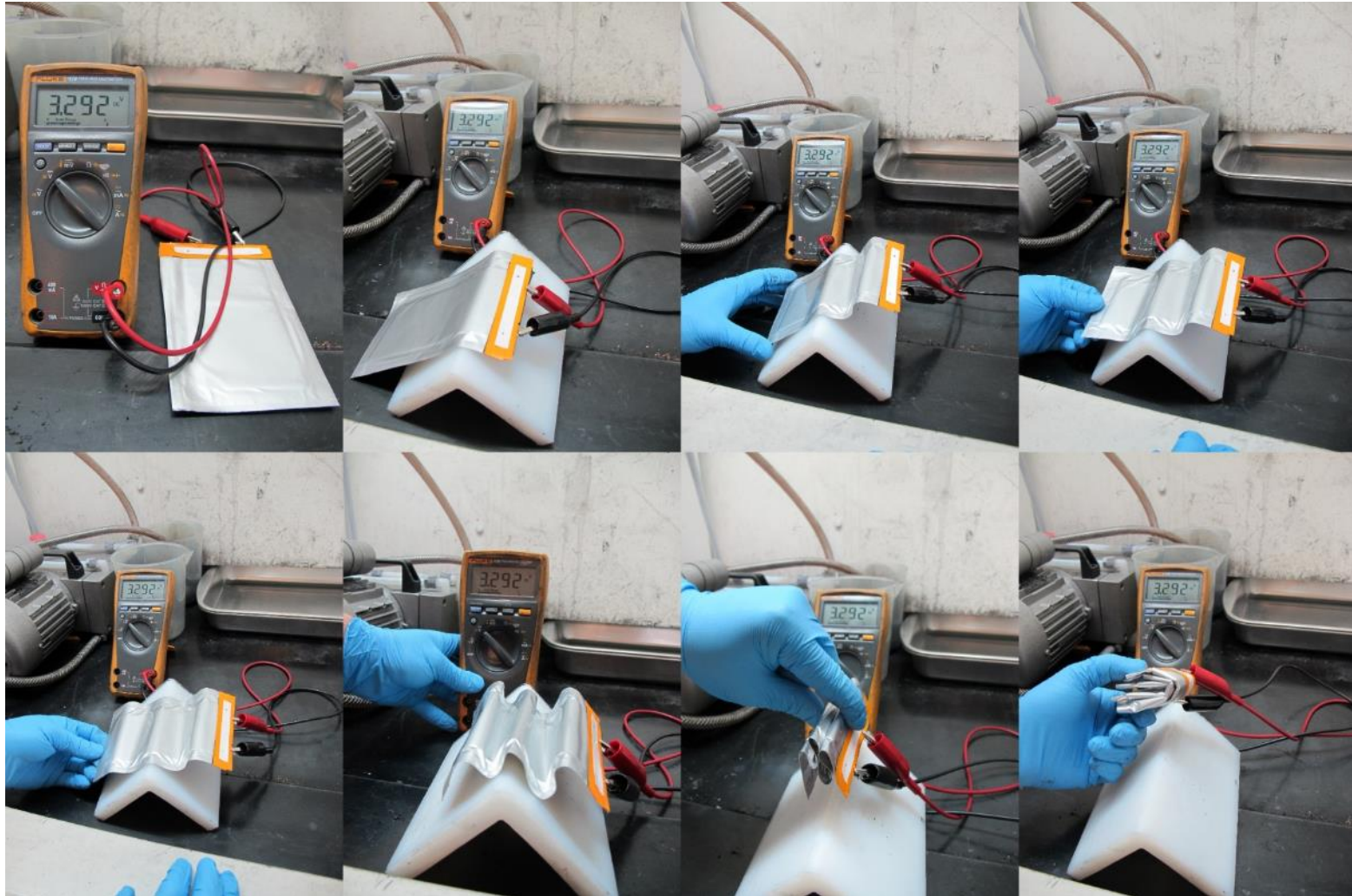
- 20 year projected life to 80% capacity after 36 months of data
- Stored at 100% SOC, 25°C

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: $T_{\max} = 93^{\circ}\text{C}$ - **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, $T_{\max} = 89^{\circ}\text{C}$ - **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



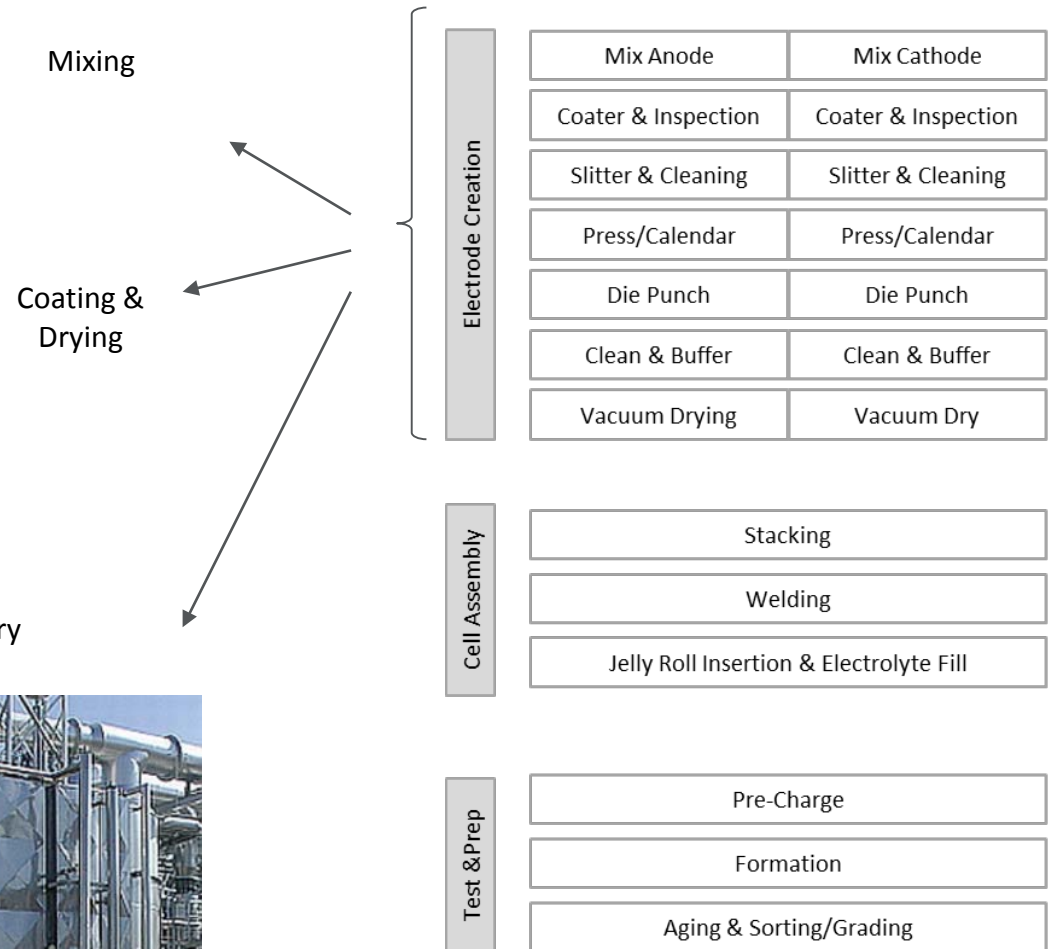
Slitting



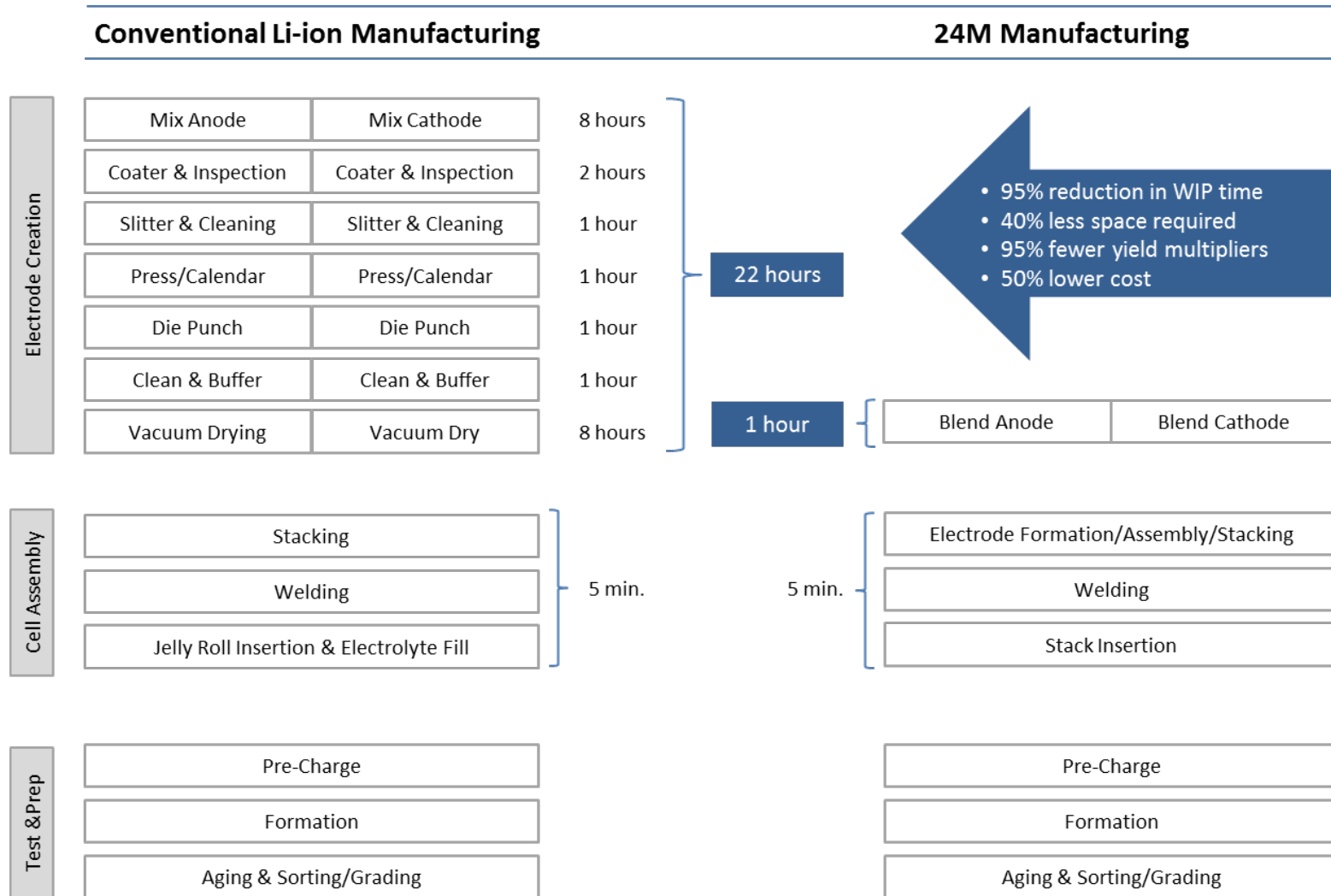
Press/Calendar



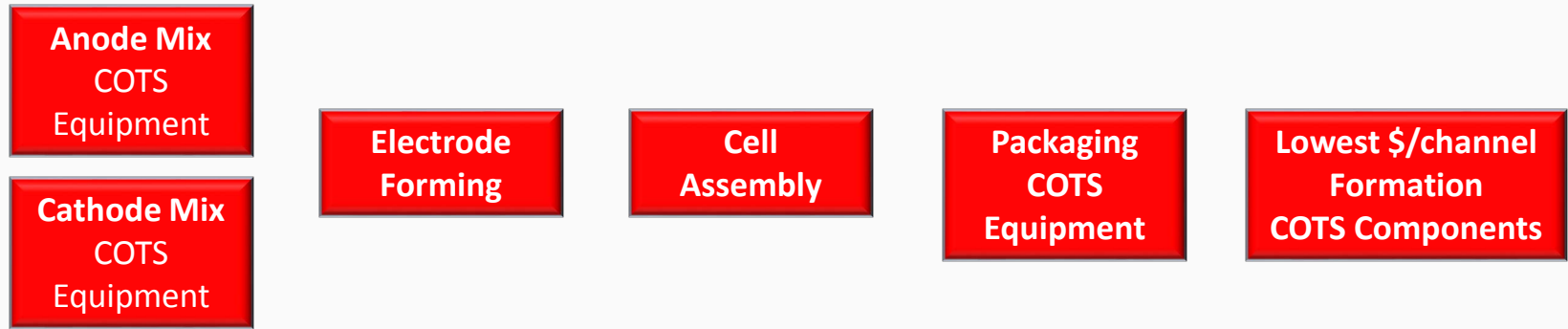
Solvent Recovery



Eliminating Half the Conventional Process



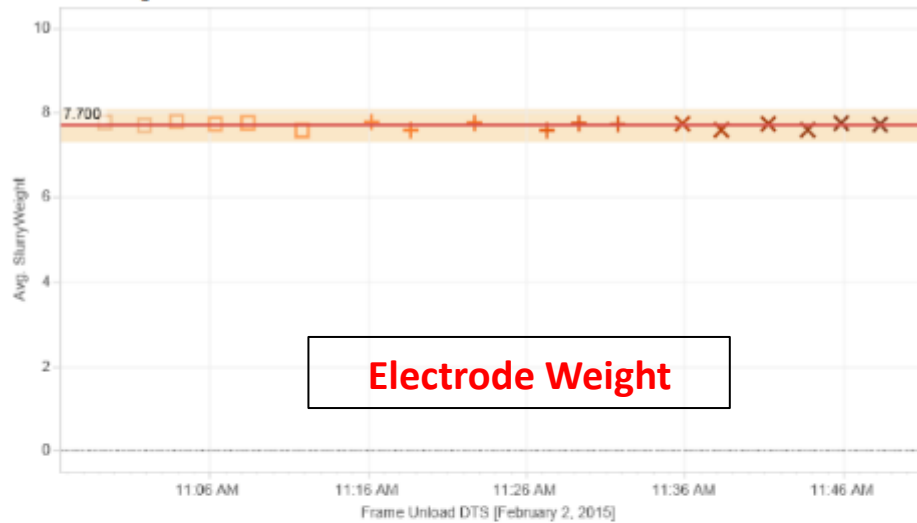
20,000 ft² Facility



- 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

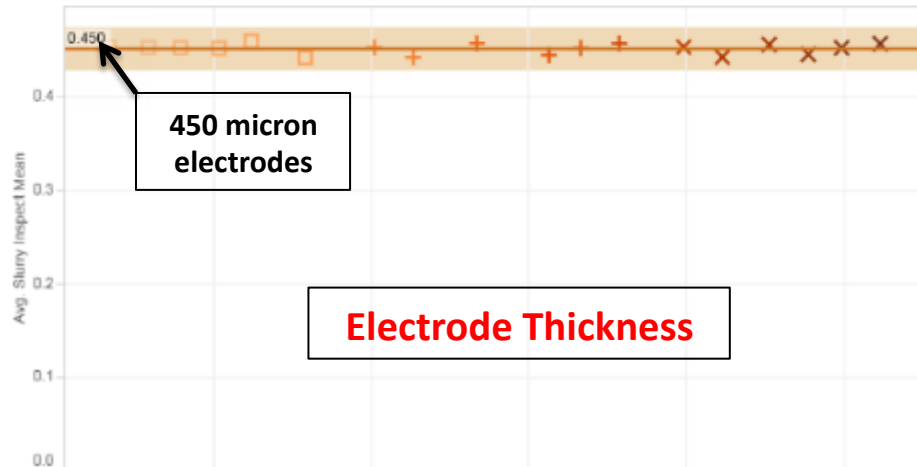
Technical Accomplishments: High Process Consistency in Pilot Plant

Cathode Weight



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

Cathode Thickness



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 $\pm 5\%$
 - Impedance tolerance $\pm 10\%$



Deliverable cells in test fixtures

- “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

- 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

- 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