Low Cost, Structurally Advanced Novel Electrode and Cell Manufacturing

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Project ID#
ES245

Timeline

- Project start: 1 Oct 2014
- Project end: 30 Sept 2016
- Percent complete: 100%

Budget

- Total project funding
  - DOE share: $1,945,774
  - 24M share: $658,940
- Funding received in 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

Executive Summary: Company at Major Inflection Point

- Transitioning from R&D to commercialization:
- Transformative Li-ion battery technology
  - Invented at MIT
  - Commercialized by 24m
- Semisolid Li-ion lowers battery COGS, improves safety
  - Reduces COGS by 30%, targeting < $90/kWh by 2020
  - Proven: 15,000 cells made to date on pilot production line
- Semisolid Li-ion simplifies Manufacturing process
  - ~50% reduction in overall CapEx per MWh of capacity
  - Enables modular, distributed manufacturing
  - Requires only 1/20th the capital per capacity block

Company Summary

24m Reinventing Li-ion

Next generation Li-ion with MIT roots, world class investors, first deal signed, scaling production

Experience

Founders: Yet-Ming Chiang, W. Craig Carter, Throop Wilder

Deep battery & Mfg experience

Direct access to MIT lab advancements

Capital

$75MM in equity
$8MM in US programs

Top-tier venture capital
Global industrial partners

Prestigious programs
ARPA-E, DOE-VT, USABC

Business

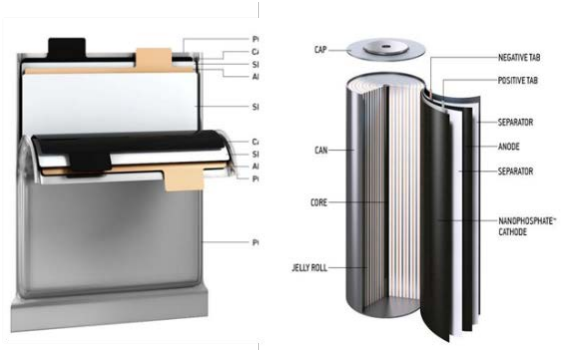
32,000 ft^2 pilot facility
15,000+ cells built

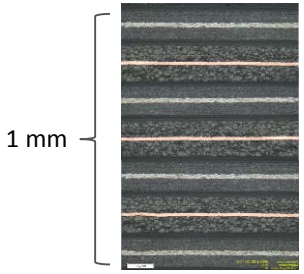
Commercialization begun
First deal signed

33 Patents issued
73 pending globally

Reinventing Li-ion

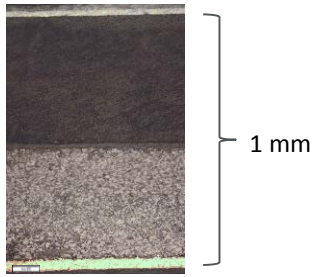
Design Challenge: **Too much inactive material**





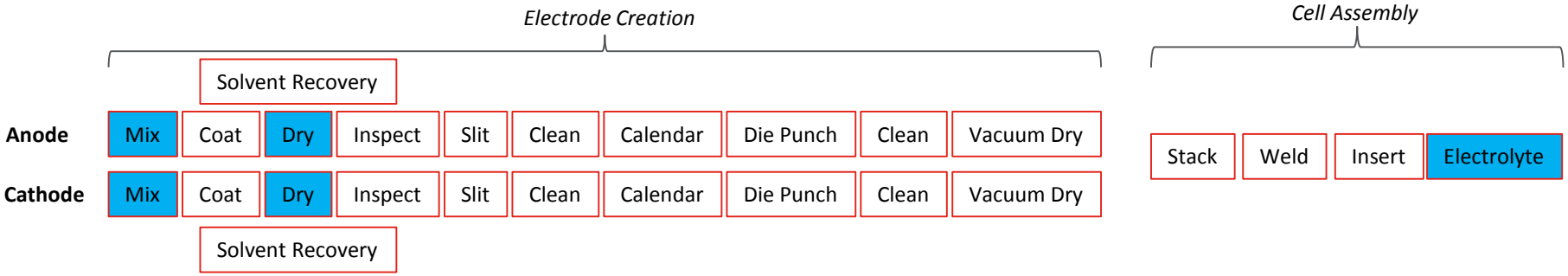
25 layers
14 inactive

Solution: **Semi-solid Li-ion**

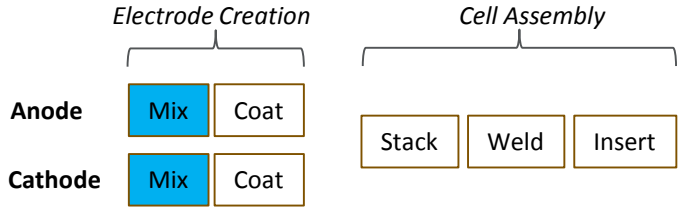


5 layers

Manufacturing Challenge: **Complex, wet/dry/wet operations**



Solution: **Semi-solid Li-ion**



Inherent Materials Cost Advantage

Thick electrodes reduce or eliminate inactive materials, leading to radically cost-reduced and application-enabling economics

Components		24M BOM Advantage Conventional	24M
Cathode	LFP	100%	----
	Carbon	100%	----
	Electrolyte	100%	-4%
	Al. Foil	100%	-61%
	NMP	100%	-100%
	Binder	100%	-100%
Anode	Graphite	100%	----
	Carbon	100%	----
	Electrolyte	100%	-12%
	Copper foil	100%	-63%
	Binder	100%	-100%
Package	Separator	100%	-82%
	Pouch	100%	-49%
	Tab/Tape	100%	-52%
TOTAL:		100%	30%

Use of traditional, off-the-shelf active materials

Drastic reduction of costly inactive materials

Elimination of process-specific components

Lithium-ion Manufacturing

Elimination of many process steps drives down costs and reduces overall footprint

	Traditional	24m
Capital Cost	$200k per MWh	$100k per MWh
Min Efficient Production	500MWh	150MWh
Min Capital Required	$250M	$15M
COGS	$150/kWh	$90/kWh
Operating Costs	-	50%
Footprint	-	**25%**

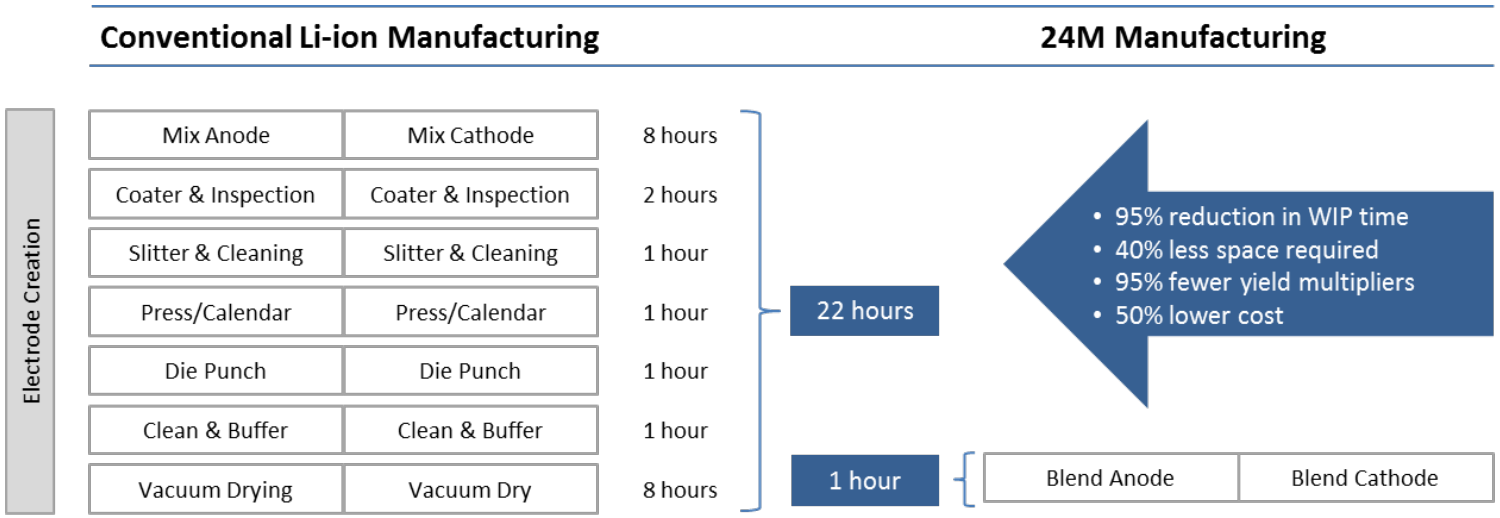
Simpler, lower cost, lower risk.

Relevance

- 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

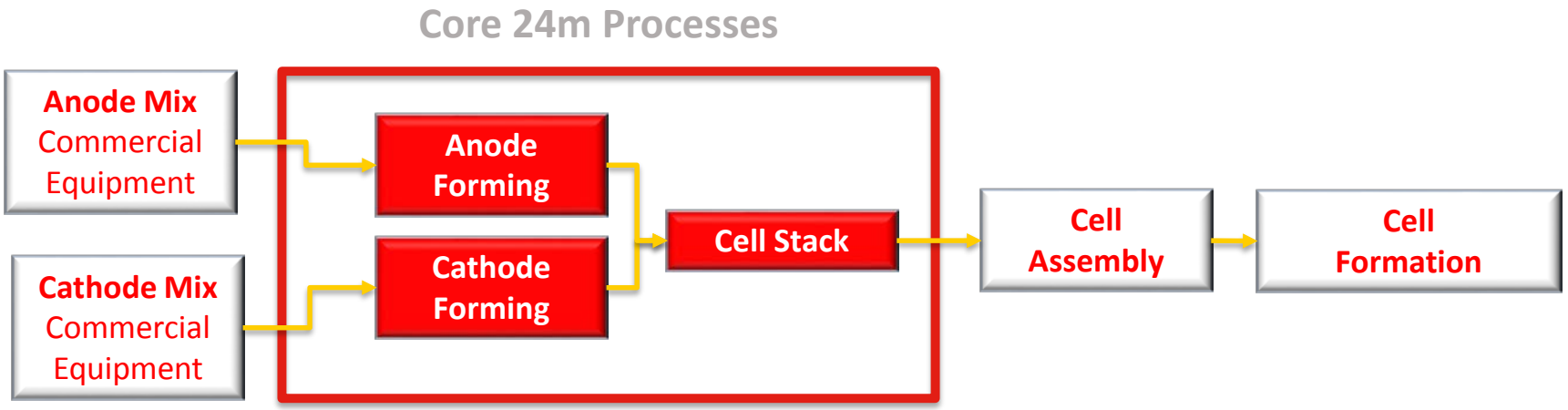
13,000+ prototype cells built

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

120 MWh Line: Capex: $15M, $125k per MWh/yr Throughput



- 24M CapEx is ~50% of conventional for same output
- Requires 1/20th the initial CapEx of conventional Li-ion
- Uses 1/4 the space of conventional plants
- Scalable to GWh in demand-matching steps
- Can place factories near centers of demand

Milestones – ALL Completed

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			Milestone Complete	
2	Increase cathode volume loading percentage		Milestone Complete				Milestone Complete		
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			Milestone Complete		
8	260+ cm^2 electrode yield				Milestone Complete				Milestone Complete
9	260+ cm^2 format cell manufacturing quality						Milestone Complete		Deliverables Delivered

Milestones Achieved

80 cm^2 cell

- Milestone 1.1: Anode volume loading +3%
- Milestone 1.2: Anode volume loading +5%
- Milestone 1.3: Anode volume loading +10%

→ **+10% achieved**

- Milestone 2.1: Cathode volume loading +3%
- Milestone 2.2: Cathode volume loading +5%

→ **+10% achieved**

- Milestone 3.1: F80 electrode quality

→ **Weight and thickness tolerance demonstrated**

- Milestone 4.1: F80 electrode yield

→ **Target electrode yield achieved based on weight and thickness**

- Milestone 5.1: F80 cell yield

→ **Target cell yield 80% yield based on capacity and impedance**

- Deliverable 5.2: 10 cells shipped to ANL

→ **10 cells built and shipped to ANL 10/7/16**

>260 cm^2 cell

- Milestone 6.1: Anode and cathode electrodes with larger footprint

→ **Cathode and Anode electrodes successfully formed with area of 260 cm^2**

- Milestone 6.2: Anode and cathode electrode with larger footprint using HVM

→ **Cathode and Anode electrodes successfully formed with area of 260 cm^2 using high volume manufacturing method**

- Milestone 7.1: F260 electrode quality

→ **Target electrode quality demonstrated in large-format electrodes**

- Milestone 7.2: F260 electrode quality using HVM

→ **Target electrode quality demonstrated in large-format electrodes made using high volume manufacturing method**

- Milestone 8.1: F260 electrode yield

→ **Target large-format electrode yield achieved**

- Milestone 8.2: F260 electrode yield

→ **Target large-format electrode yield achieved**

- Milestone 9.1: F260 cell build yield

→ **Target cell yield achieved with >100 Ah cells based on capacity and impedance**

- Deliverable 9.2: 4 cell shipped to ANL

→ **Target cell yield achieved with >100 Ah cells based on capacity and impedance**

Proposed Future Work

- All program work is completed

Summary

- 24M has met all program milestones
- Specific accomplishments are
  - Increasing energy density of semi-solid electrodes
  - Developing and implementing electrode-level quality metrics
  - Demonstrating quality and yield for the manufacturing method at the 80 cm^2 electrode footprint
  - Delivering demonstration cells to Argonne National Laboratory for independent testing
  - Scaling the electrode forming processes were scaled to a large-format (> 260 cm^2) electrode footprint
  - Demonstrating quality and yield for the large-format electrodes
  - Developing and demonstrating a high-volume manufacturing approach for large-format electrode fabrication
  - Demonstrating quality for the large-format electrodes formed by the high volume manufacturing method
  - Prototyping and delivering large-format cells (> 100 Ah capacity) with consistent capacity and impedance which were delivered to Argonne National Laboratory for independent testing

- 24M continues work on the scale-up for manufacturing processes building off the methods developed and demonstrated during this program