Manufacturing of Protected Lithium Electrodes for Advanced Lithium-Air, Lithium-Water & Lithium-Sulfur Batteries

Contract Number EE0005757
PolyPlus/Corning/Johnson Controls Inc.
Project Period: 9/01/2012 to 8/31/2015

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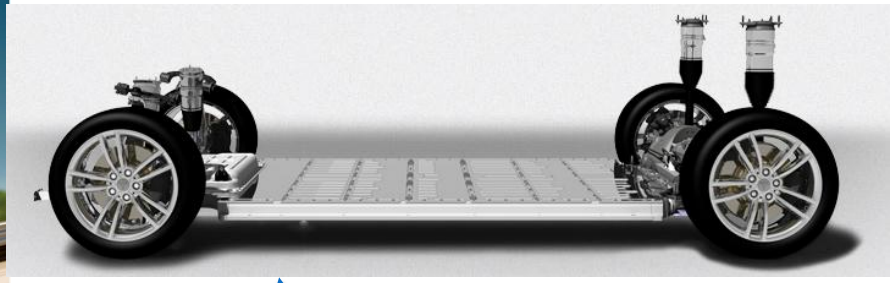
Project Objective



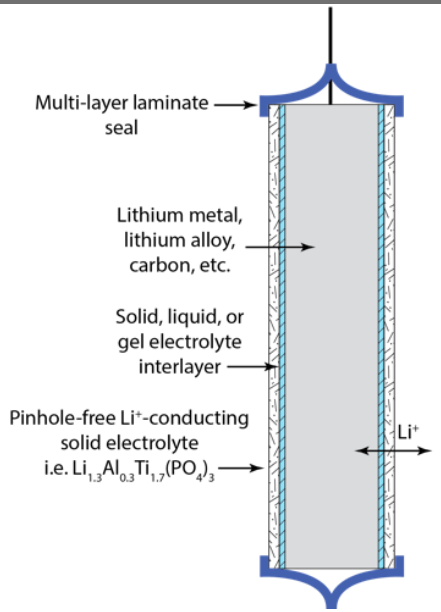
Reduce battery cost by 50%
Reduce battery weight by 50%

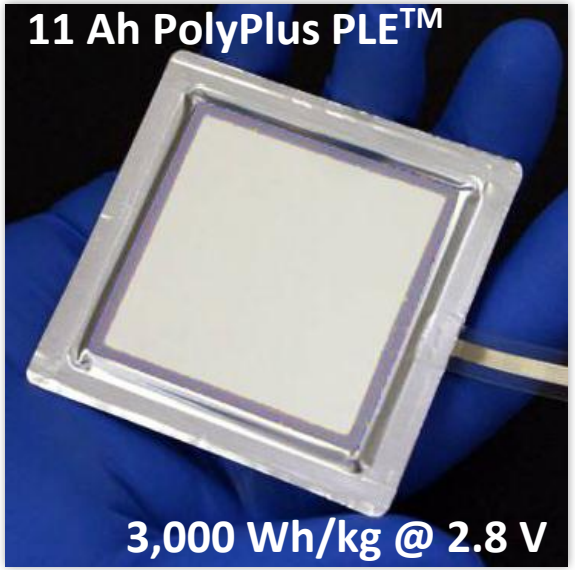
- The problem: Batteries are too heavy and too expensive, and all advanced Li-ion battery manufacturing is centralized in Asia
- Why it's difficult: Asian battery companies have a 20-year head start in Li-ion manufacturing, including well developed supply chains and large captive markets.
- Objectives:
  - Demonstrate and scale manufacturing of PolyPlus' Protected Lithium Electrode (PLE) for next-generation high energy Li-sulfur, Li-air, and Li-seawater battery technologies (PolyPlus)
  - Establish domestic source of ceramic solid electrolyte membranes (Corning Inc.)
  - Scale process for global consumption (Johnson Controls)

Technical Approach

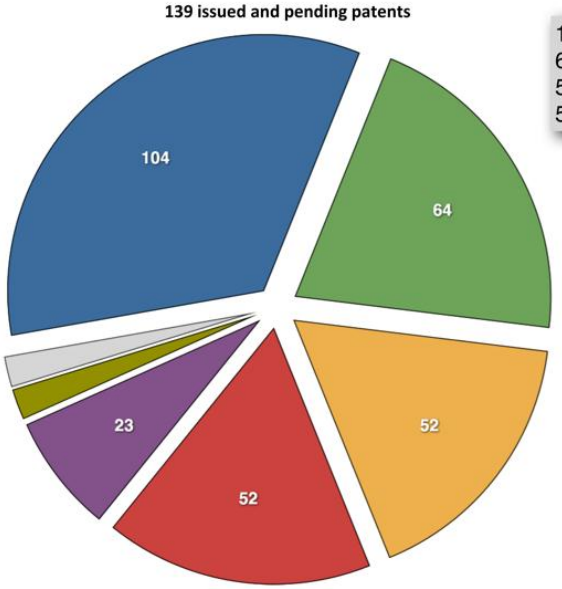
This program is focused on establishing domestic manufacturing of advanced batteries

- Protected Lithium Electrode
  - Safely harness high energy Lithium electrode
  - Completely stable in air, water, aggressive solvents
  - Allows pairing of previously incompatible chemistries (i.e. Li/aqueous)
- Enables Li-sulfur, Li-air, and Li-seawater batteries





Technical Approach (Continued)



104	Lithium/Sulfur
64	Lithium/Air
52	Lithium/Water
52	Protected Lithium Electrode

*Issued and pending patents

- Li/S
- Li/Air
- Li/Water
- PLE
- Protected Anode
- Chemical Protection
- Other

49 U.S. issued patents
43 International issued patents
19 U.S. published pending applications
28 International published pending applications

- **PolyPlus Battery Company** invented and patented the water-stable protected lithium electrode (PLE), has an extensive intellectual property portfolio on advanced Li-air, Li-water, and Li-sulfur batteries, has designed and built the 1st pilot line to produce PLEs, and is coordinating the Corning and JCI efforts.
- **Corning Incorporated** is a world leader in specialty ceramics and supplier of key components to market leaders in the automotive and consumer electronics industries.
- **Johnson Controls** is the largest manufacturer of rechargeable lead-acid batteries in the world and recognized as the only American company with a global presence in advanced lithium-ion manufacturing.

POLYPLUS

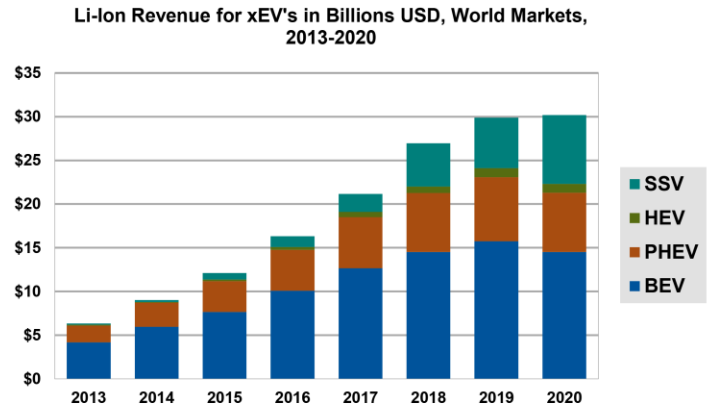
CORNING

Johnson Controls

Transition and Deployment

- Who cares? Everyone. Because everyone needs better batteries - higher energy, lower cost, lighter weight.
- Who will use it? End users are Original Equipment Manufacturers (OEMs) for ultimate EV applications and the US military for light weight primary batteries. PLE-based batteries promise low cost, light weight, safe batteries with non-flammable aqueous electrolytes. They will improve existing applications and enable future systems.

Li Ion for xEV's and SSV's Global Forecast



Source: Navigant Research

- Manufacturing will be dominated by China and Korea
- Eventually, domestic manufacturing will develop on each continent in order to avoid transportation "tax"

NAVIGANT RESEARCH

lower cost

greater range

Transition and Deployment (Continued)

- What is the commercialization approach? First adopters will most likely be the military due to their critical need. In some cases the DoD will provide funding for the establishment of manufacturing facilities for military specific needs. We are also in early talks with electric vehicle companies about potential partnerships to commercialize Li-S batteries for transportation. In this case, we will most likely introduce the technology to the consumer electronics market followed by scale-up for the EV markets.
- What is the technology sustainment model? This AMO funded effort is focused on commercialization of PLEs for lithium-air, lithium-water, and lithium-sulfur batteries. Air, water, and sulfur are abundant and sustainable (if not we are all in trouble). Lithium is also relatively abundant, recyclable, and sustainable.

Lightweight, long life primary batteries

Low-cost, high-energy rechargeable batteries

Measure of Success

Protected Lithium Electrode-based batteries are enabling

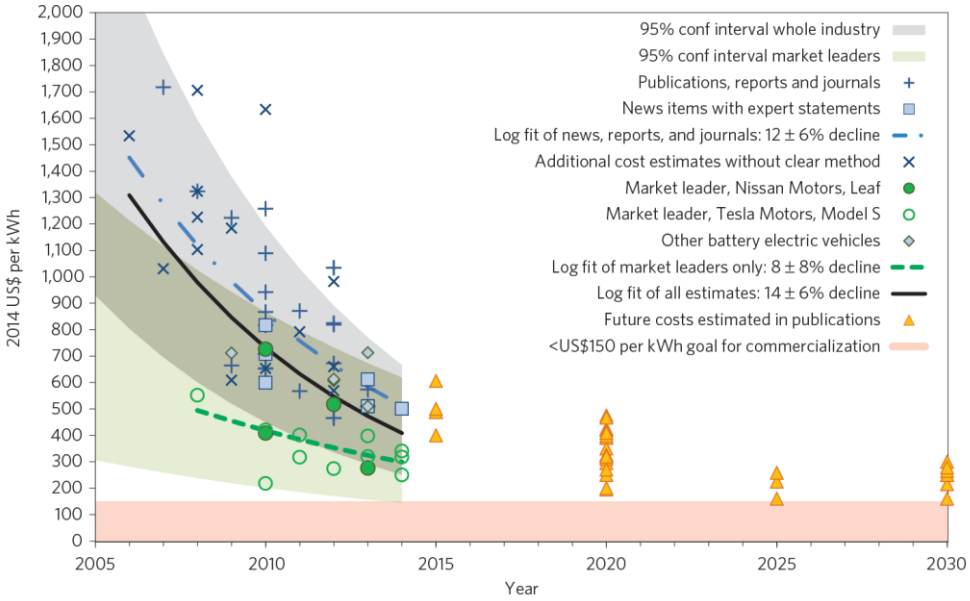


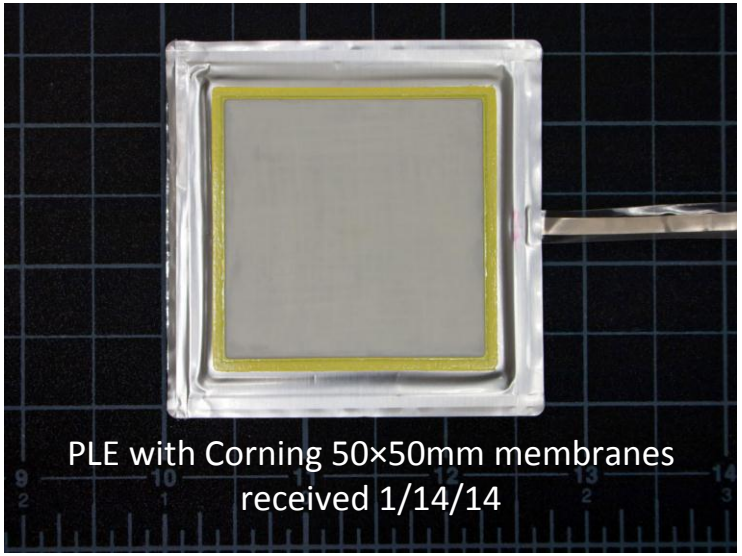
Figure 1 | Cost of Li-ion battery packs in BEV. Data are from multiple types of sources and trace both reported cost for the industry and costs for market-leading manufactures. If costs reach US$150 per kWh this is commonly considered as the point of commercialization of BEV. Source: Björn Nykvist1* and Måns Nilsson, NATURE CLIMATE CHANGE | VOL 5 | APRIL 2015 | www.nature.com/natureclimatechange

- Transportation accounts for 27% of total US energy use
  - 50% of that by light duty vehicles
  - Almost entirely petroleum-based
  - > $20B battery industry
- PLE-based batteries provide potential 50% reduction in cost, 50% reduction in weight (compared to Li-ion)
  - Alleviate range anxiety
  - Directly effect widespread adoption of EVs
  - eGallon is 3x cheaper than gas-powered driving

- Overburdened soldier carries up to 16 lbs of batteries for a 72 hr mission
  - Primary Li-Air batteries have demonstrated 800 Wh/kg, tested by US Army CERDEC
  - Improve mobility, decrease musculoskeletal injuries
- Sub-sea batteries have inadequate energy, lifetime
  - Li-Seawater batteries have demonstrated >1300 Wh/kg
  - Non-toxic, pressure tolerant, safe chemistries

Project Management & Budget

Corning membranes

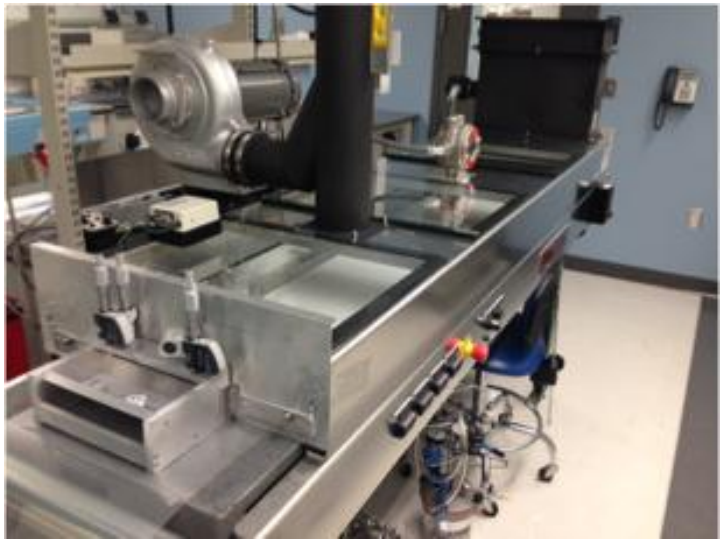


- Duration of the project: 36 months
- Project task and key milestone schedule:
  - Year 1: Membrane and PLE Development
  - Year 2: Process Development
  - Year 3: Commercial Line Development
- Metrics of progress: The PolyPlus-Corning-JCI team performed preliminary market analyses, identified market entry points, and tied milestones criteria to performance metrics that satisfy or exceed those goals.

Total Project Budget	
DOE Investment	$8,999,920
Cost Share	$3,587,090
Project Total	$12,587,010

Results and Accomplishments

- Status Update:
  - Currently in the 31st month of 36 month project.
  - All milestones and Go/no-go decision points met.
  - There is substantial commercial interest in PolyPlus Li-Air, Li-Water, and Li-Sulfur batteries.
- Key Results:
  - First-of-its-kind PLE pilot production line designed, built, shipped, installed and optimized at PolyPlus facilities in Berkeley.
  - Performance of pilot-assembled PLEs exceed manually-assembled PLEs
  - PolyPlus is currently in talks with several potential customers and manufacturing partners for its next-generation battery technology
- Continuing Work:
  - PolyPlus has formulated a winning strategy for manufacturing and licensing its protected electrode technology for incorporation into next generation batteries.



Corning continuous caster for process refinement. Will support eventual EVT process.