



# Efficient Production of Low-Cost LFP and LMFP

Continuous process for producing high-quality LFP or LMFP

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# TDA Research, Inc. - Company Overview

- In business for more than 37 years
  - Privately held
  - 140 employees, 35 PhDs in Chemistry and Engineering
- Facilities
  - 80,000 ft<sup>2</sup> laboratory and office space near Denver Colorado
- Technologies
  - LFP/LMFP using continuous hydrothermal technique
  - Polymer solid electrolyte
  - Artificial CEI coatings for extreme-low temperature Si/C-NMC
  - Cathodes for sulfur batteries
  - Low-cost catalysts for electrolyzers
  - Thermally stable nanoporous membrane for PEM fuel cells
- Business Model
  - Identify opportunities with industry
  - Perform R&D
  - Develop prototype/carry out field testing
  - Secure intellectual property
  - Commercialize technology via manufacturing, spinoff, licensing, joint ventures, and internal business units



# LFP Technology Overview

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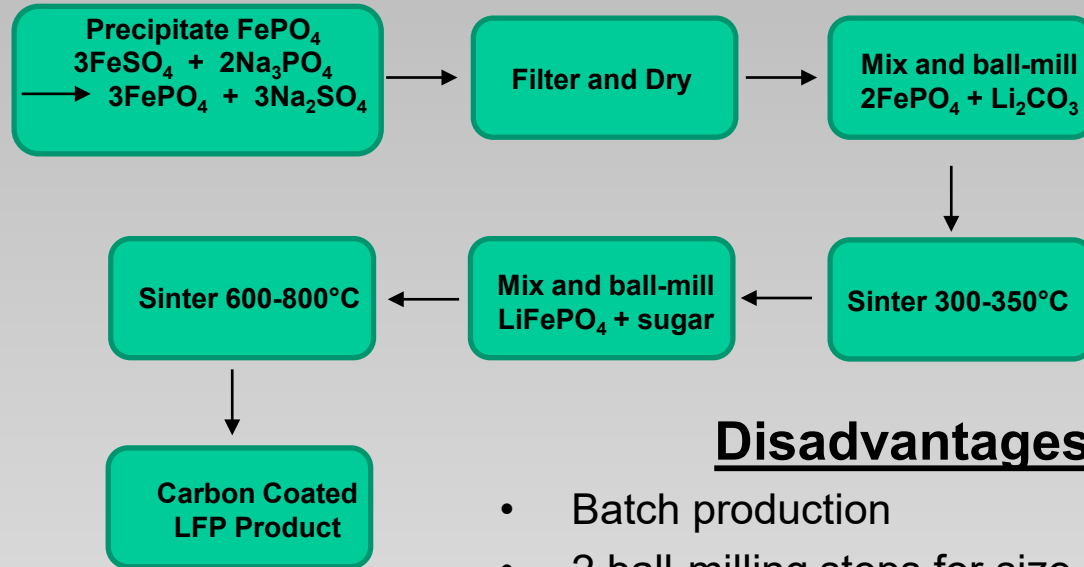
- TDA is developing a novel process to manufacture  $\text{LiFePO}_4$  (LFP) electrode materials for use in lithium-ion batteries (LIBs) for DoD use
  - Economically viable
  - Environmentally friendly
- Cost is the main driver
  - Most other cathode materials contain cobalt which is expensive and scarce
- Currently all major manufacturers of LFP materials are in China
  - BYD, A123, Contemporary Amperex Technology
- National security need for a domestic LFP supply chain

## TDA's Objective

- Develop an efficient low-cost continuous method for producing large quantities of high-quality LFP

# LFP Process Comparison

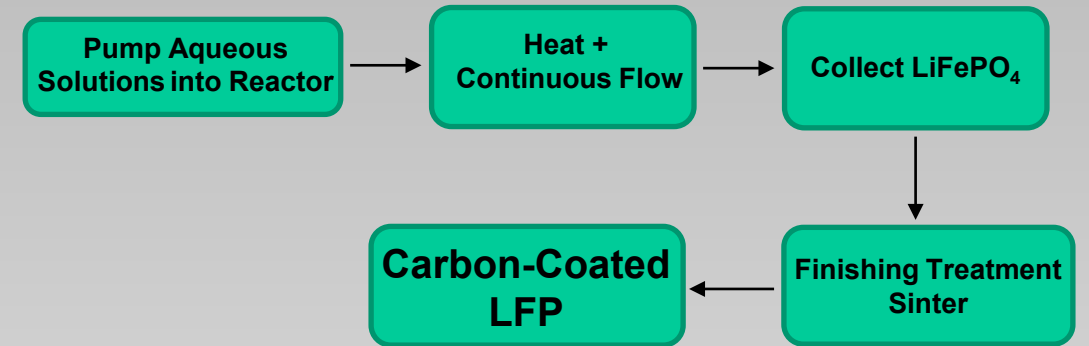
## Solid-state Batch Production Method



### Disadvantages

- Batch production
- 2 ball-milling steps for size reduction
- 3 mixing steps
- Energy-intensive

## **TDA** Hydrothermal Continuous Method



### Advantages

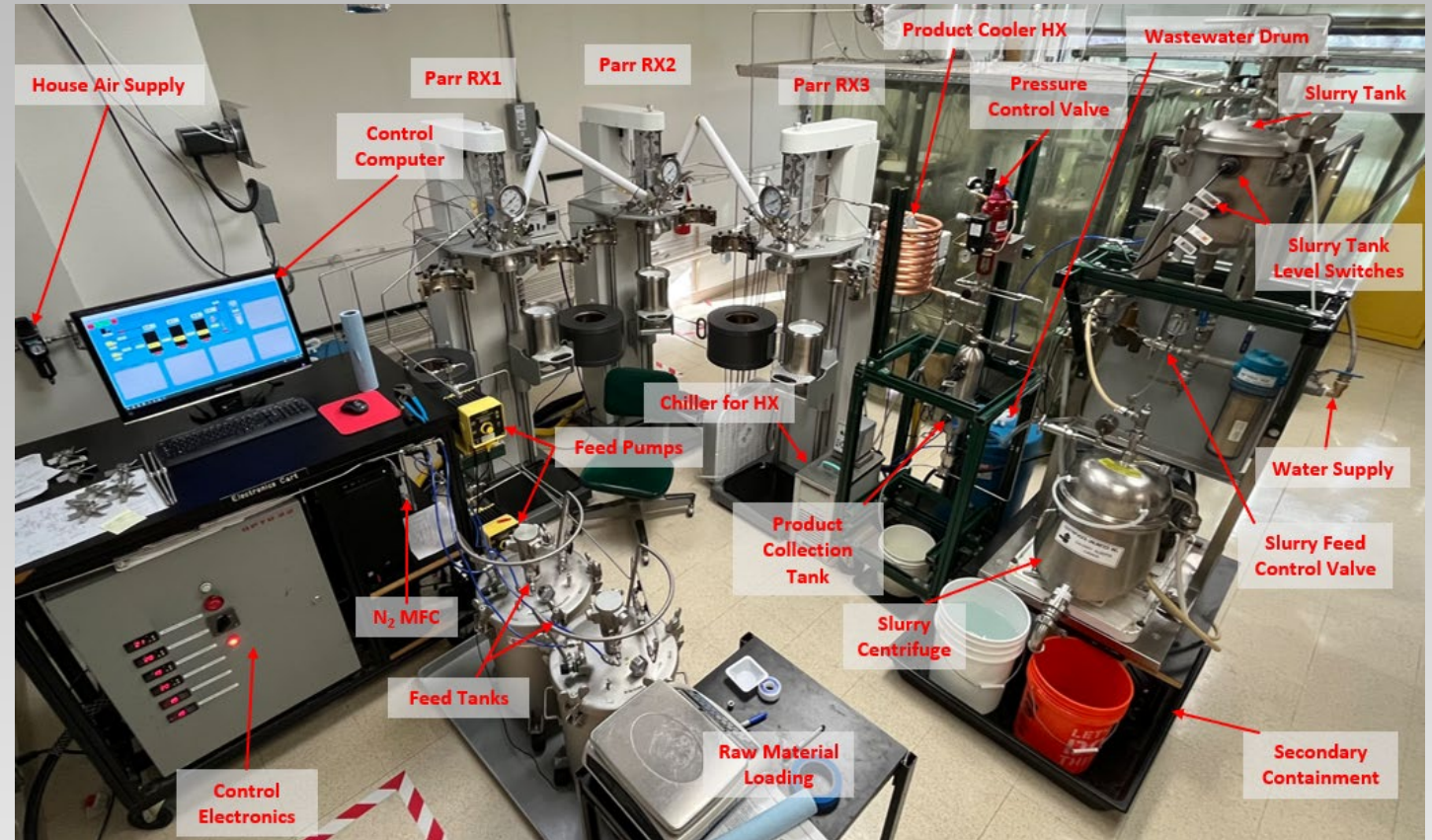
- Continuous production - easy scale-up
- Lower energy requirements
- No size reduction ball-mill steps
- Smaller particle sizes
- At scale, 90% of cost is raw material costs (cost of production is low)

**We welcome collaboration opportunities from chemical and battery manufacturers.**

# Continuous Process Design

## LFP and LMFP for Li-Ion Batteries

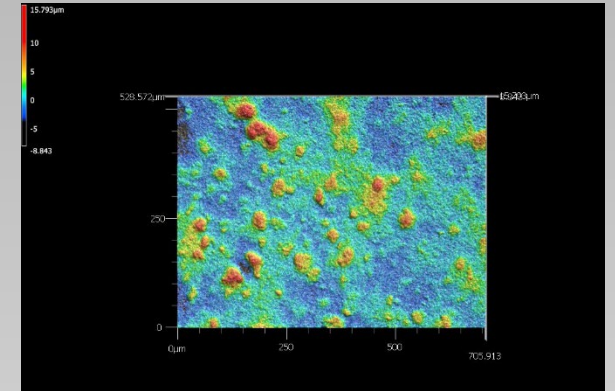
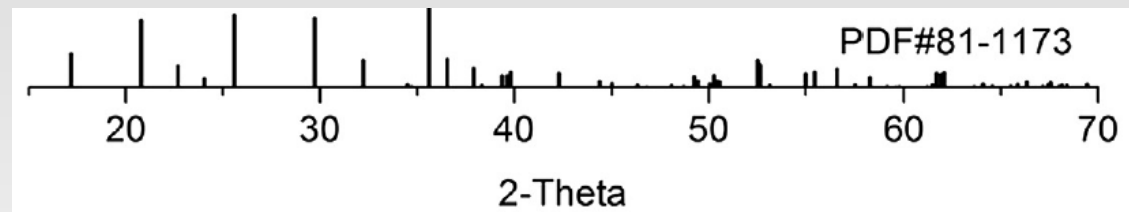
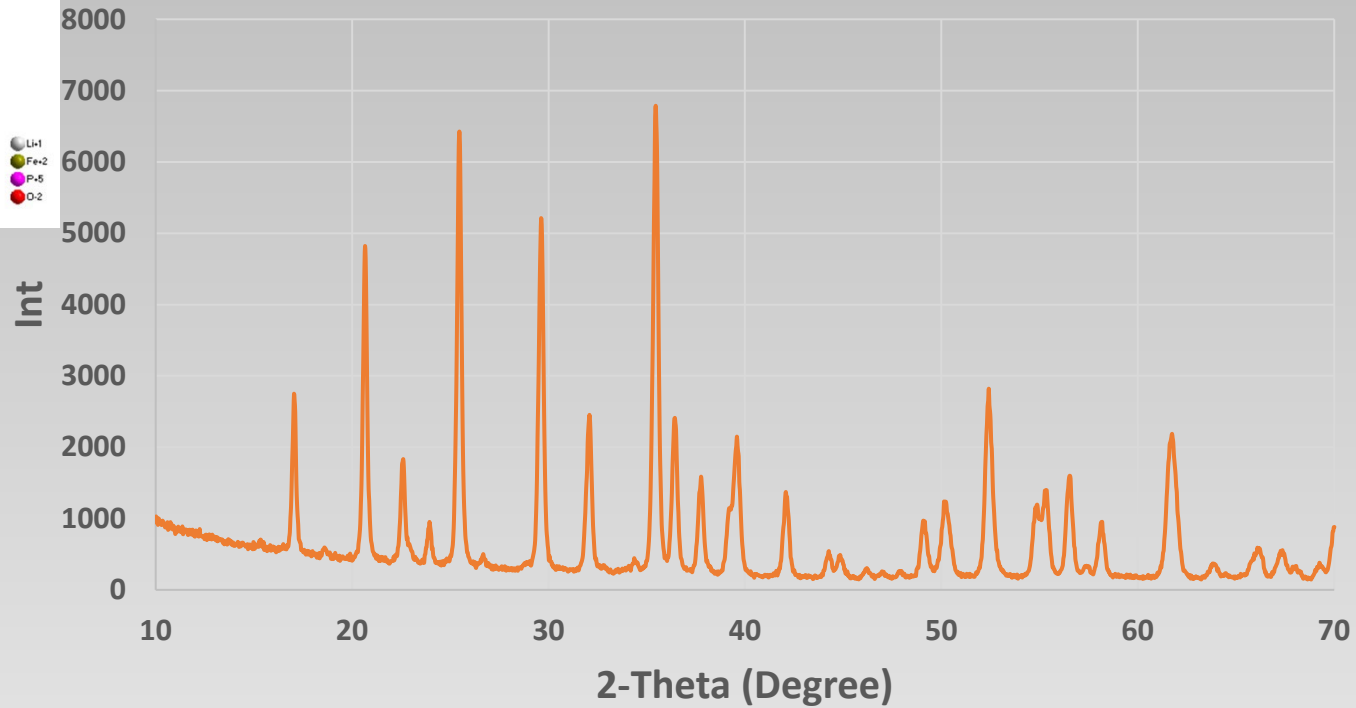
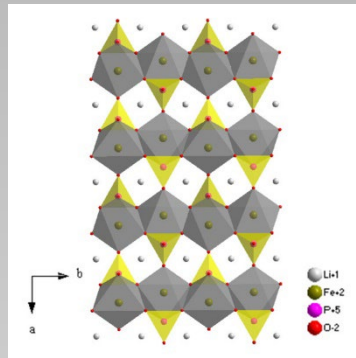
- We are currently scaling up our continuous LFP/LMFP technology
  - Fully funded by the DoD
  - Fully automated and computer-controlled
  - Production rate of 10kg/day
- TDA's LFP has been evaluated in independent testing
  - Military battery manufacturer
  - Excellent results
- TDA's goal
  - Not to develop a new material
  - Engineer a higher quality LFP
  - Lower cost continuous production method
  - Manufactured in the USA
- Patent(s) Pending



Layout of TDA's LFP pilot plant

# Quality Analysis

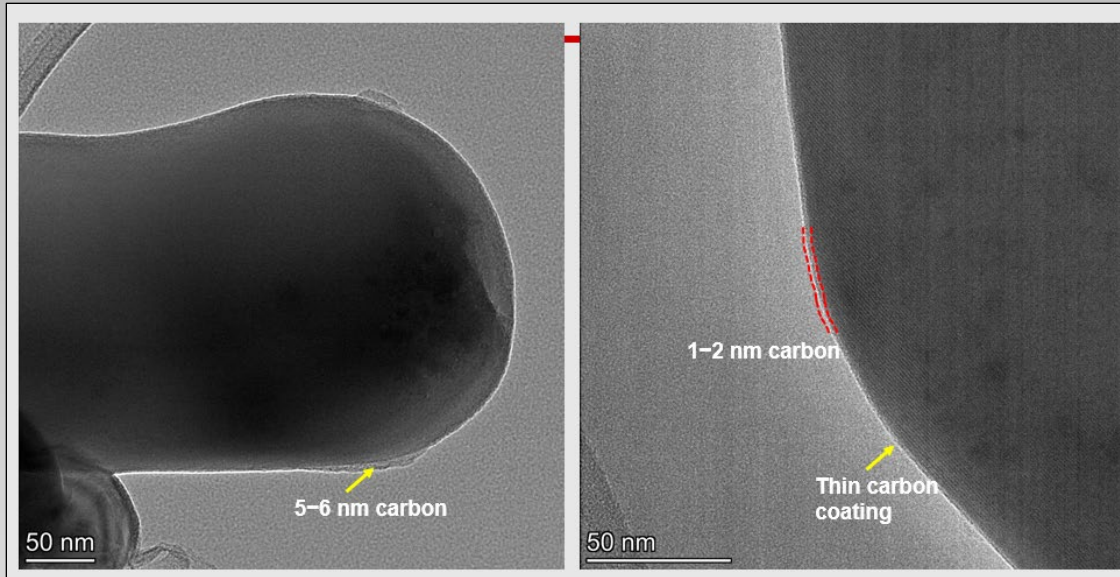
- XRD matches perfectly for LFP
- TDA's LFP Crystallinity: > 99% Purity



Cast

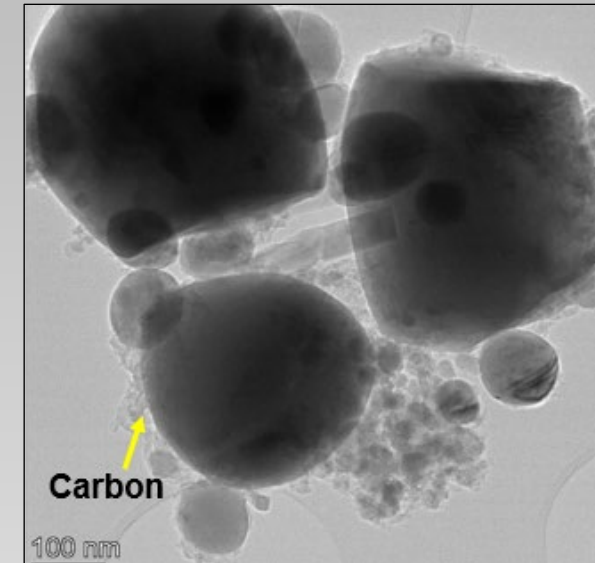
# LFP Carbon Coating

TDA



- Uniform and thin carbon layers
  - 1-6 nm
- Provides electron conductivity
- Does not limit lithium diffusion

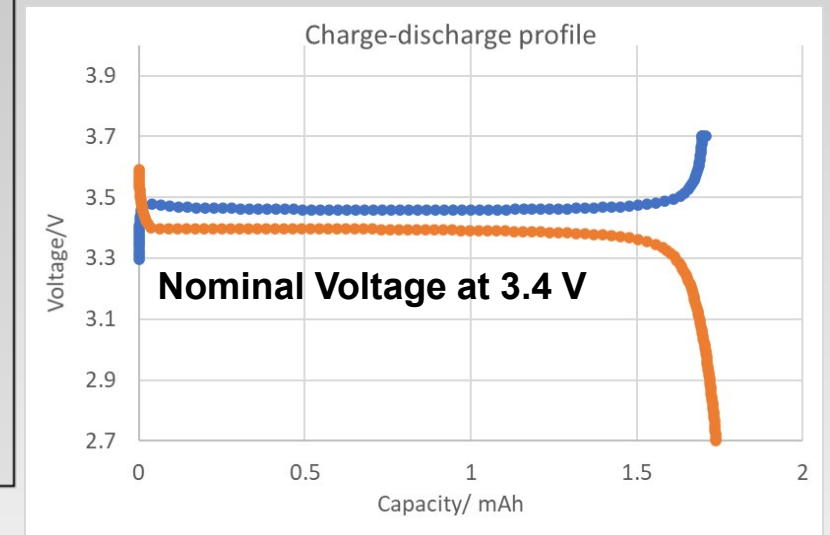
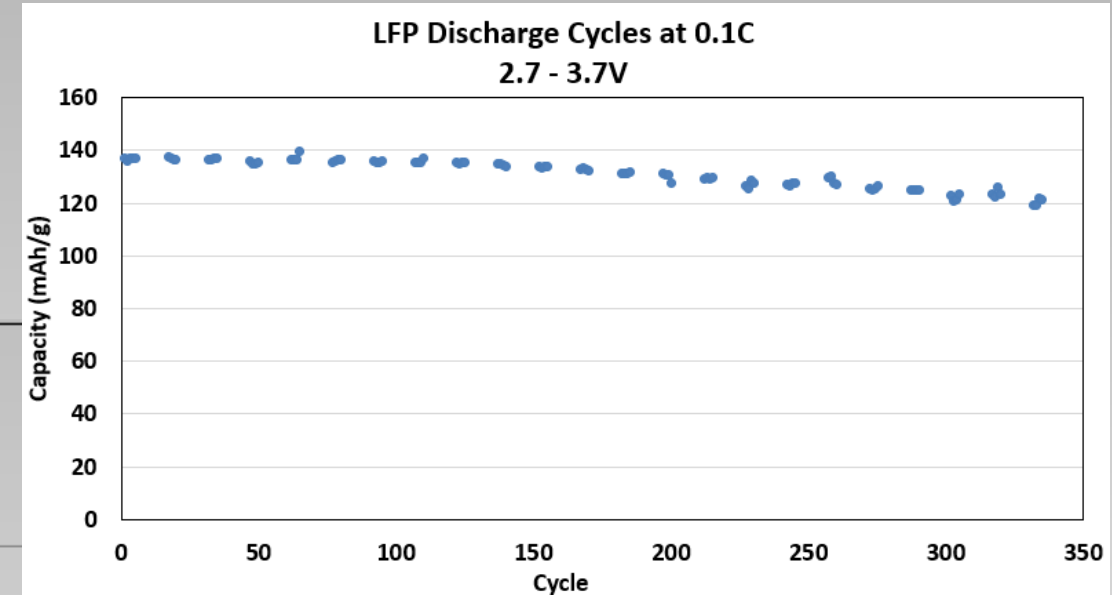
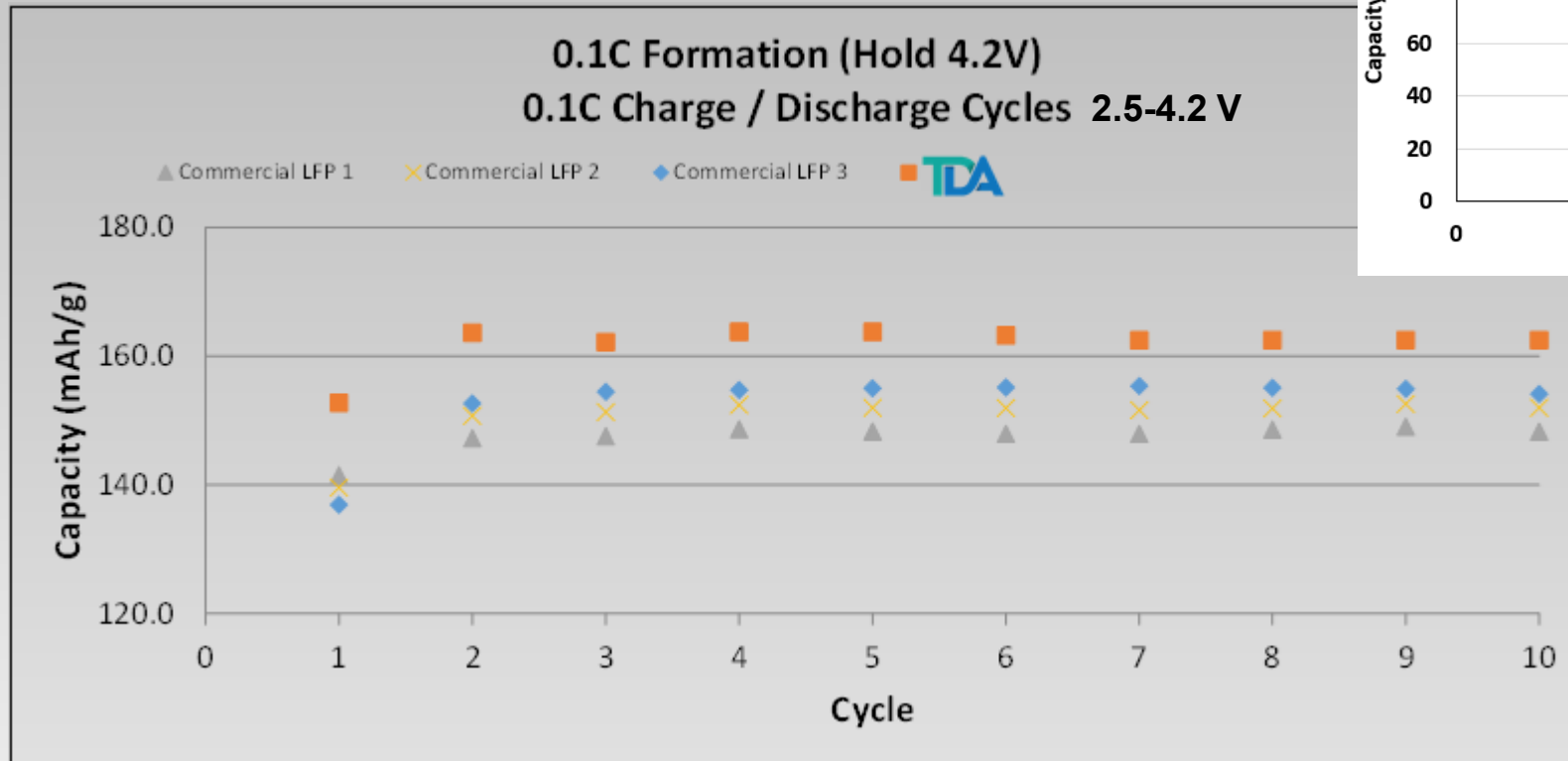
Commercial



- Carbon randomly mixed in with LFP
- Uneven electron conductivity

# Electrical Performance of TDA's LFP

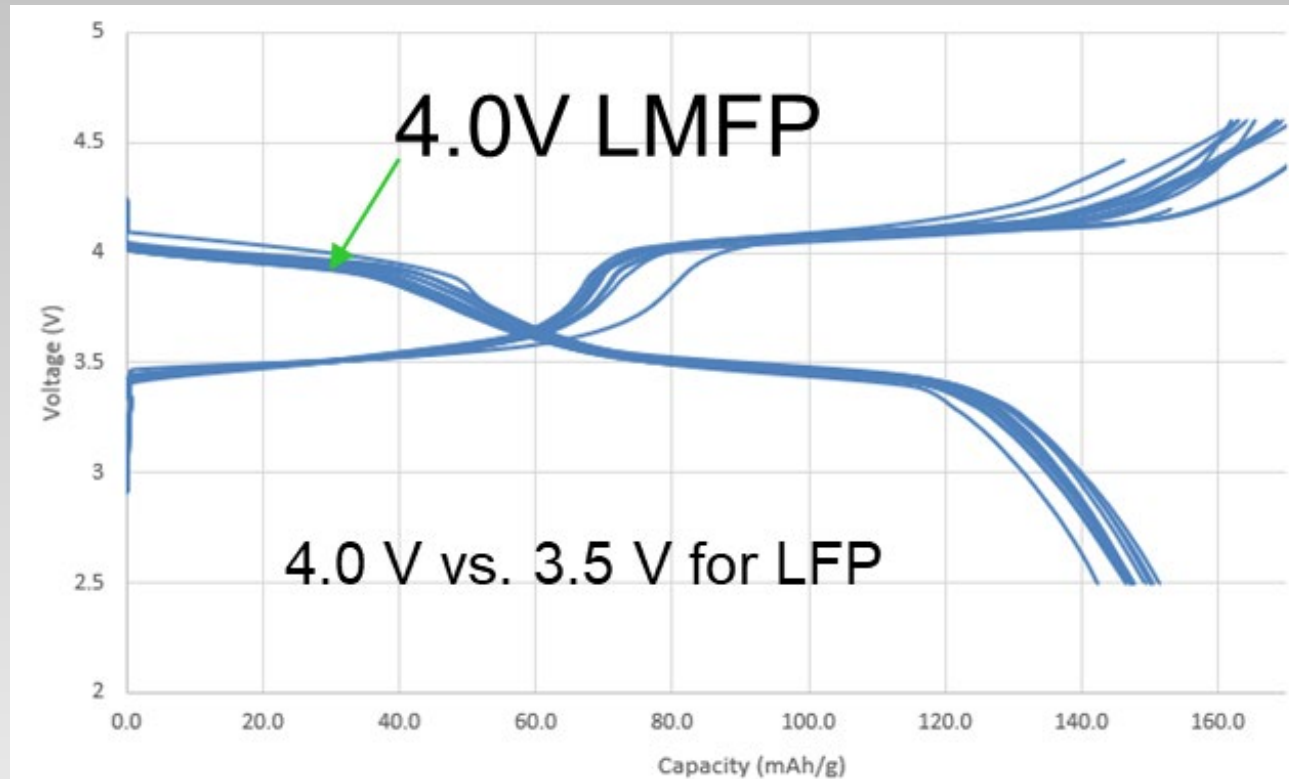
- Higher capacity than commercial LFP
- Retain 90% of capacity after 325 cycles in half cells (Li metal as anode)





# TDA's LMFP Performance

With only a simple additional modification to the process, we can manufacture LMFP using the same techniques



- LMFP Characterization at TDA
  - > 99% Purity
  - > 96% Yield
  - ~ 30 nm Particle size
- Higher voltage
- Greater overall energy density

# Testing at Saft

	Charge	Discharge	Efficiency
C/20	164.5 mAh/g	161.4 mAh/g	98.14%
C/10	162.2 mAh/g	161.7 mAh/g	99.67%

- Charge and discharge capacity are highly reversible with > 98% efficiency
- All coin cells show high capacity (> 160 mAh/g)

- We are in the process of supplying multikilogram samples to Saft for pouch cell fabrication in their pilot-scale production line



# Summary

- TDA has developed a novel process to manufacture domestic LFP/LMFP
  - Low-cost
  - Continuous Process
  - High-quality LFP
- Continuous process has many advantages over batch
  - Easily scalable
  - More consistent particle size
  - Improved electrical performance



# Related Technologies

## Existing COTS 18650 Cells

Good performance 10-35 °C

Flammable

Cycle life issues at low temperature and/or high discharge rates



Not great at discharge rates higher than 2C

## TDA's new 18650 Cells



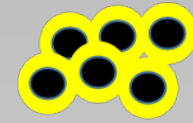
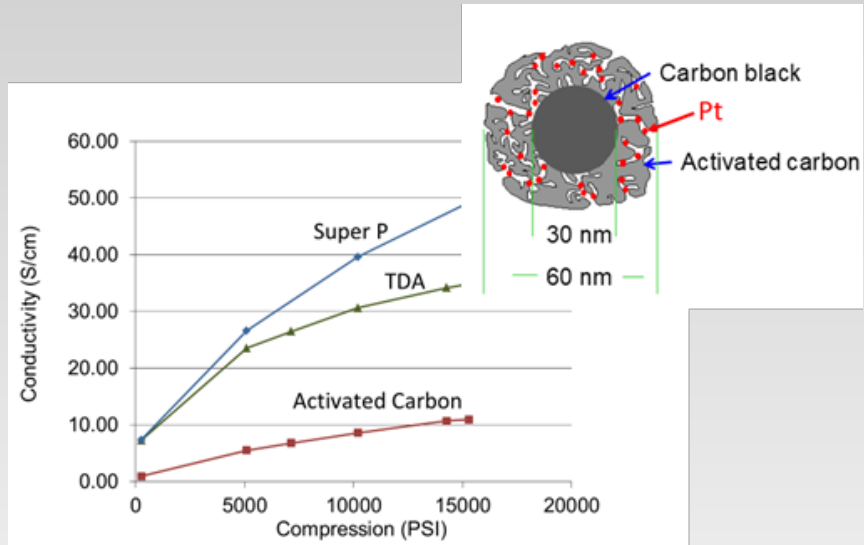
Performs -60 to +60 °C

Less flammable

Better cycle life at low temperature and/or high discharge rates

Discharge rates higher than 20C

## Artificial CEI coatings for extreme-low temperature Si/C-NMC

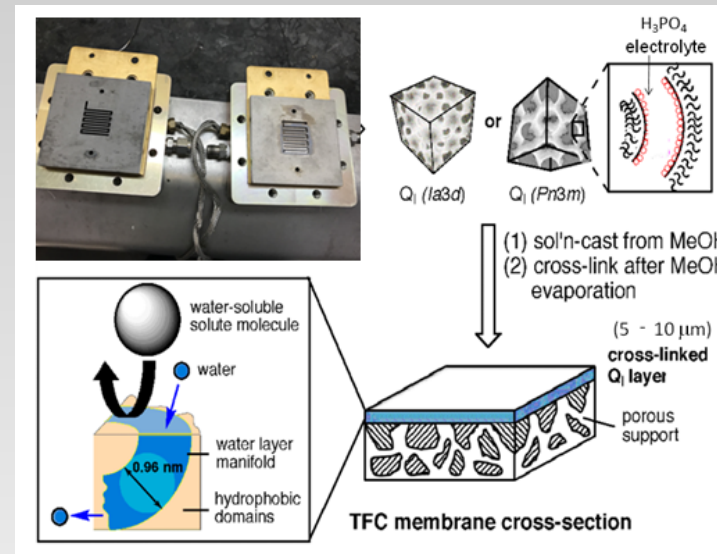


Sulfur coated Carbon black



Nanoporous carbon with sulfur in pores

## Cathode Material for Li-S Batteries



## Thermally Stable Nanoporous Membrane For PEM Fuel Cells

## Novel Catalysts for PEM & AEM Electrolyzers

