
FORGE NANO
A PneumatiCoat Company
Engineering Materials for Next Generation Energy Storage
James Trevey Ph.D
NDIA JSPE May 4, 2017
Break-out Session #19452
www.ForgeNano.com
U.S. Army Photo by BCT, 10th MTN DIV Public Affairs

Forge Nano's proprietary technology and manufacturing processes make angstrom-thick surface coatings fast, affordable and commercially viable for a wide range of materials, applications and industries including Lithium-Ion batteries.

FORGE NANO

ALD Enabled Lithium Ion batteries

Performance

- Increased power density
- Increased cycle life
- Increased energy density

Cost

- Less material
- Improved Processing
- Fewer replacements

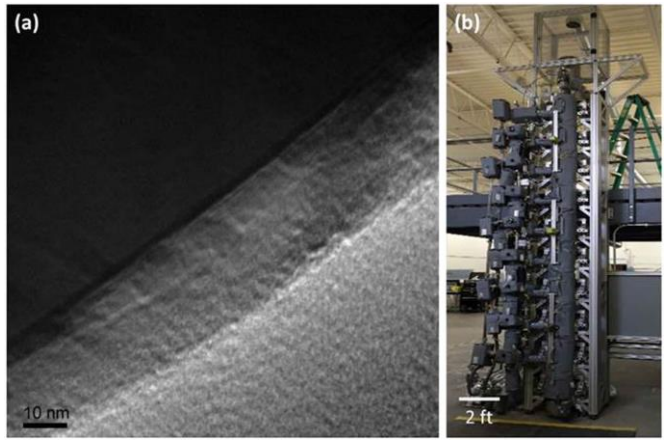
Safety

- Greater abuse tolerance
- Reduced warranty risk

FORGE NANO

Raw Materials

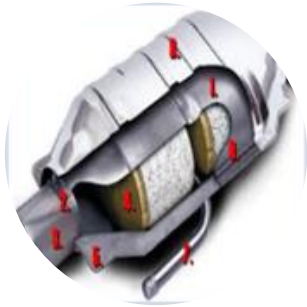
Nano Coatings



Scientific **Reports** | 6:26532 | DOI: 10.1038/srep26532

ALD

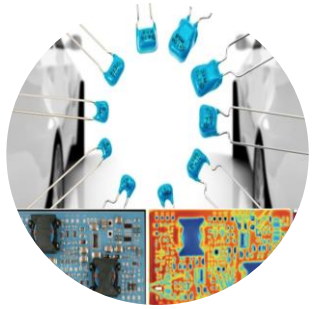
Innovative Products



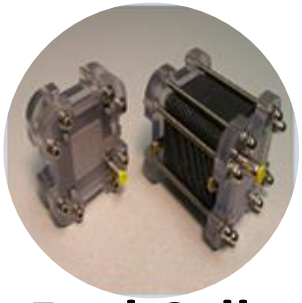
Catalysts

Conductive Inks

Li-ion Batteries



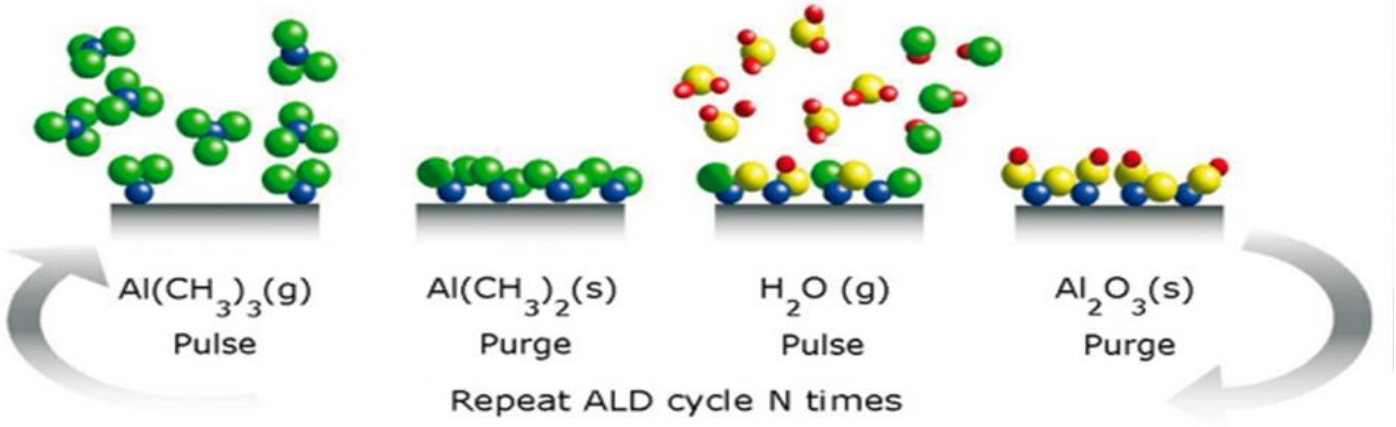
Capacitors

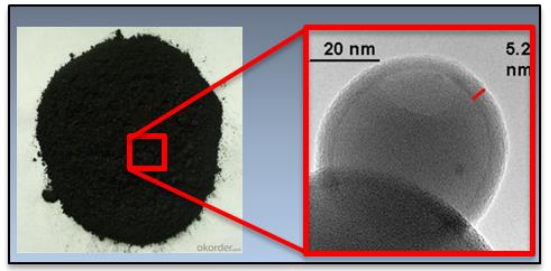


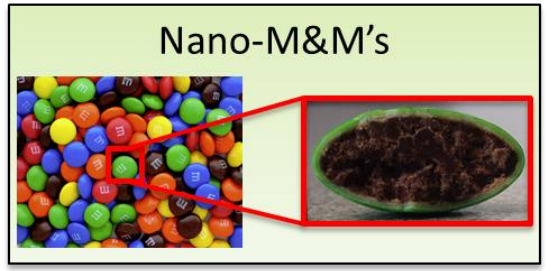
Fuel Cells

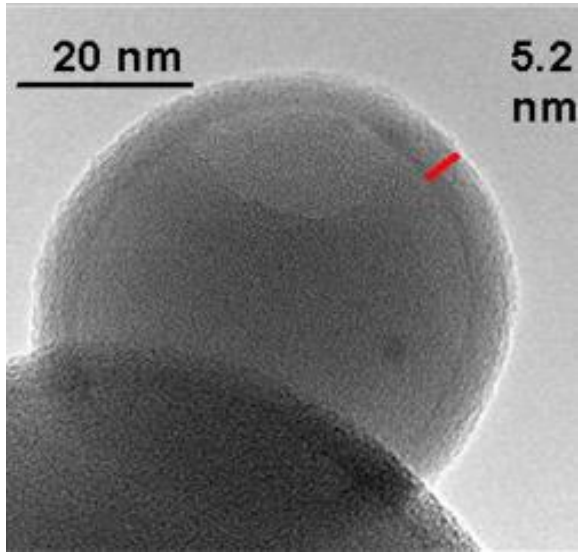
Advanced Ceramics

Atomic Layer Deposition

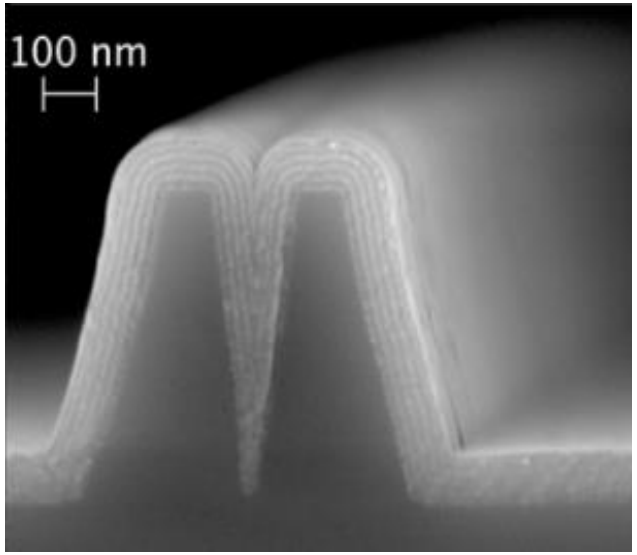




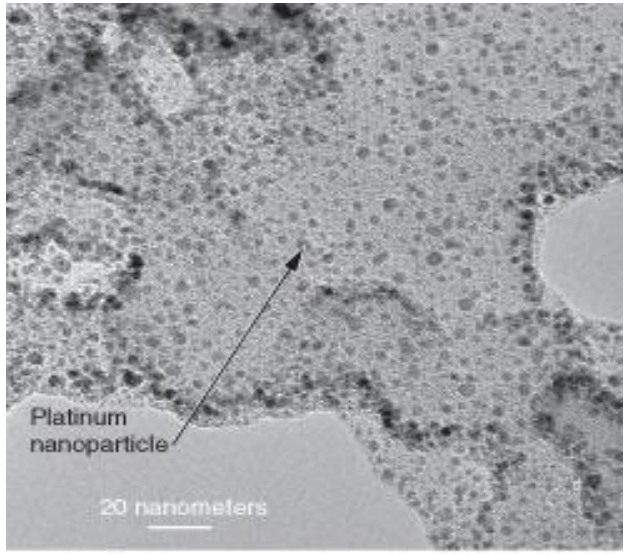




Particle coatings



Multilayers



Nano-islands

- Gas phase process
- Self limiting
- No line-of-sight restrictions
- Sub-nanometer control
- Pinhole free

Forge Nano's Technology Breakthrough

Lab Scale → Production Scale

Conventional ALD has been Historically Slow and Expensive
Lack of Manufacturing Innovation Hindered Commercial Adoption

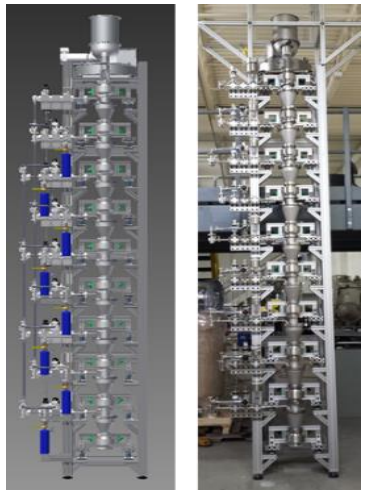
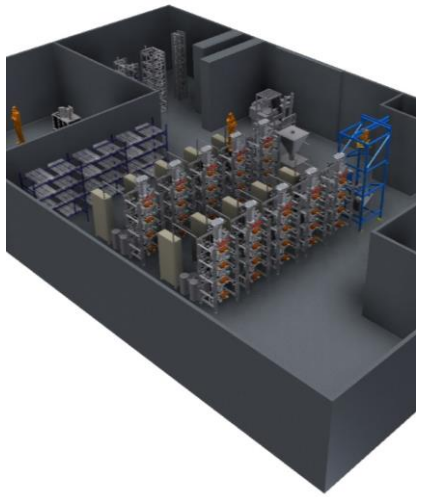
Forge Nano's
Patented Continuous Particle ALD Process is Fast and Economical

- **1977** — Particle ALD Invented (Russia)
- **1992** — Fluidized Bed ALD Implemented In Europe
- **2011** — Forge Nano Tech Validation
- **2012** — 3 kg/hr Prototype
- **2013** — DOE SBIR Phase I & II
- **2014** — Pilot Line Coated 2.5 t/yr
- **2015 & 2016** — 300 ton/year Light Commercial Plant Undergoing Validation
- **2017**

The Only Proven High Throughput ALD Production Tool

Forge Nano ALD Processing

Scale-up Tool Roadmap

1-3 tons/year	10-30 tons/year	300-1000 tons/year	>1000 tons/year
Prototype	Pilot	Light Commercial	Commercial
			
2013/2014	2015/2016	2016/2017	2017/2018

Decreasing costs with increasing throughput

$1,000's/kg → $100's/kg → $10's/kg → $1's/kg

FORGE NANO

Our Patents

- **ALD Manufacturing Apparatus:** US 9,284,643
- **ALD Manufacturing Process:** US 9,546,424
- **Comprehensive ALD Battery IP:** Coated cathode, anode, solid electrolyte, and separators
  - **Forge Nano Filed:** 3 additional pending patents
  - **Licensed IP:** 13 issued and pending patents with exclusive licenses
- **Non-Battery IP:** 1 additional pending patent for coated metal uses
- **Ongoing Research & Licensing with National Labs / Universities:**
  Batteries, Fuel Cells, MLCCs, Supercapacitors, Conductive Inks, Catalysts

PennState

TU Delft

Missouri S&T

Boulder

SCHOOL OF MINES 1874 COLORADO

UNIVERSITY OF OSLO

OAK RIDGE National Laboratory

SBIR · STTR America's Seed Fund

U.S. DEPARTMENT OF ENERGY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

UNIVERSITY OF SOUTH CAROLINA

Li-Ion Batteries: Behind the Innovation Curve

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Safety Pressures

How Lithium Ion Batteries GROUNDED THE DREAMLINER

Official report on Boeing 787 fires tells a cautionary tale about advanced batteries

At 10:21 a.m. on Jan. 7, 2013, about a minute after all 183 passengers and 11 crew members from Japan Airlines Flight 008 disembarked at Boston's Logan International Airport, a member of the cleaning crew spotted smoke in the aft cabin of the Boeing 787.

Cost to Boeing - $600 Million

TESLA SAYS CAR FIRE STARTED IN BATTERY

A Tesla Model S electric car caught fire on Tuesday morning in Washington State, and the company said that the fire began in the car's battery pack after the driver hit debris on a highway.

The Tesla's driver told the police that he had hit metal debris on the freeway and exited, and then, he said, the vehicle caught fire.

Titanium Shields- Adds Cost & Weight

Why is the Samsung Galaxy Note 7 Catching fire? THE LIHIUM-ION BATTERY EXPLAINED

Samsung has permanently stopped production of the Galaxy Note 7 less than two months after its release, as the phone caused hundreds of reported fires and explosions worldwide.

Its flagship smartphone - which retailed at £739 and was initially hailed as one of the best phones of 2016 - issued a global recall of the water-resistant phones, including "safe" replacement devices, amid overheating fears.

Samsung has not confirmed the number of incidents, but estimates suggests that fewer than 150 handsets have overheated and, in some cases, caught fire.

Cost to Samsung - $5.3 Billion

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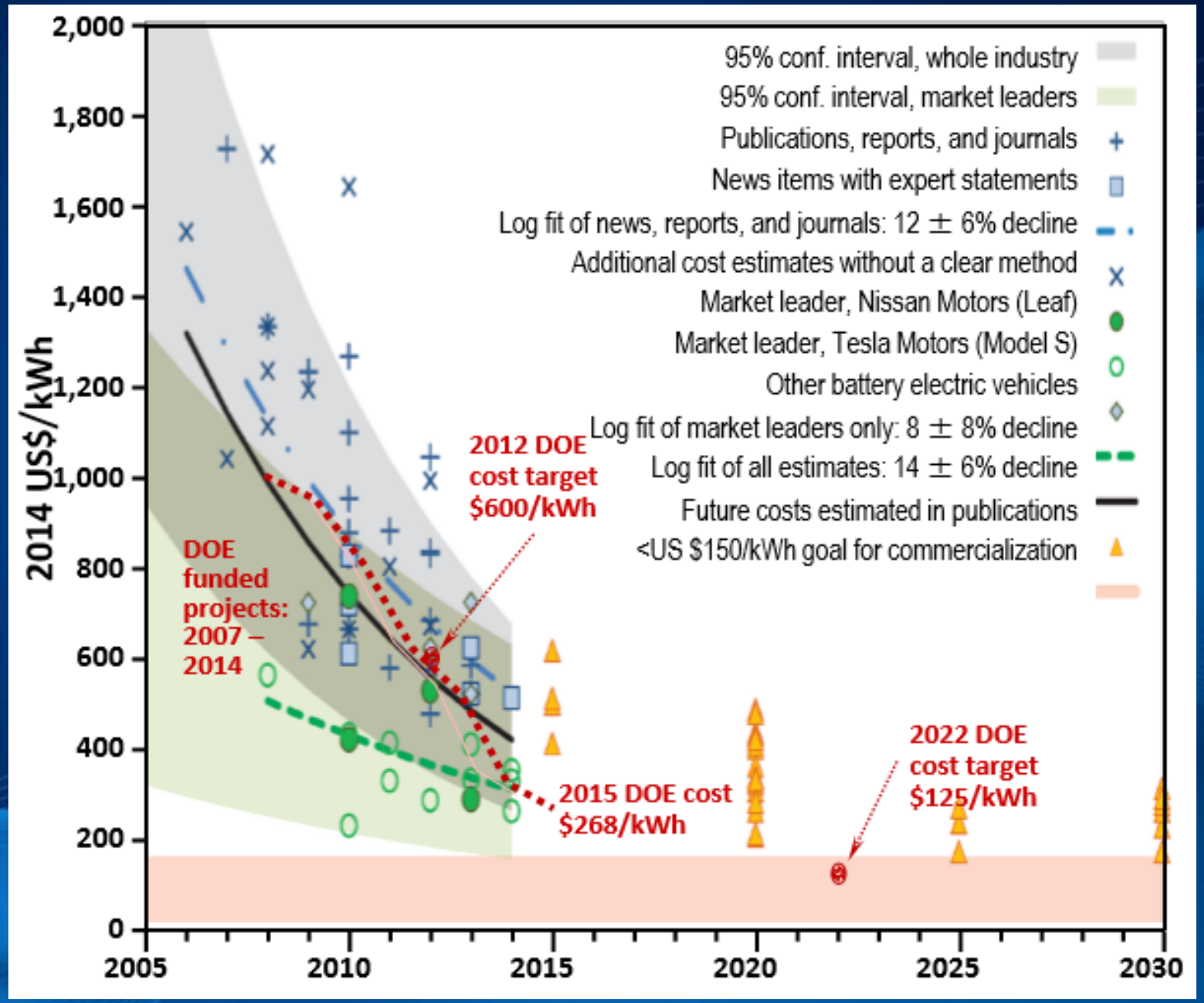
Cost Pressures



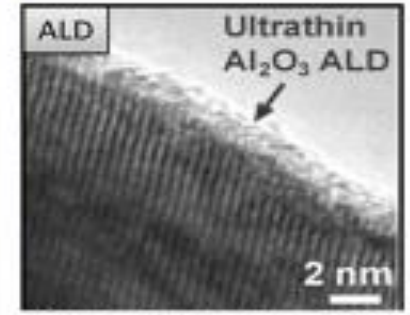
ALD Enabled Cathode Materials

Performance

- *Higher voltage*
- *Higher rate*
- *Increased robustness*

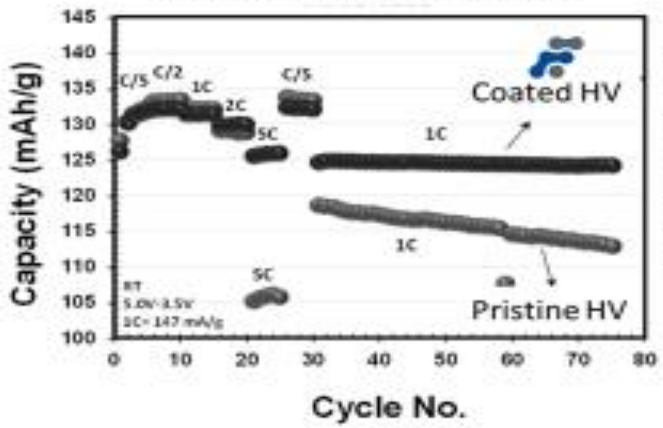
PERFORMANCE

FORGE NANO'S ALD PROCESSING PUSHES CELL CAPABILITIES TO HIGHER TEMPERATURES, FASTER C-RATES AND LONGER LIFETIMES

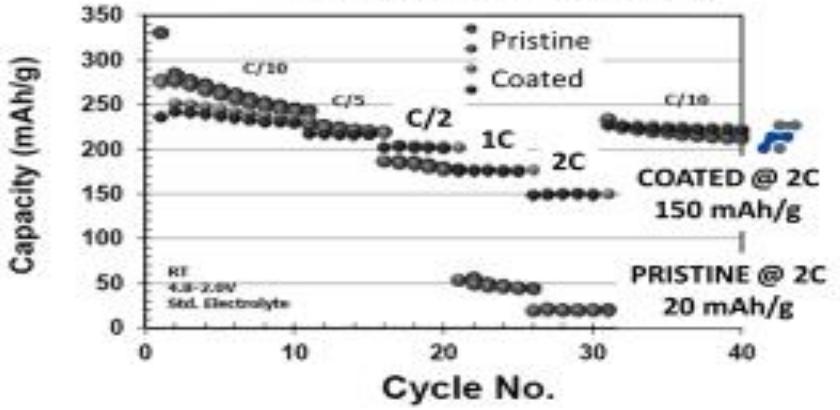


Scott, et al., Nano Letters 2011

HIGH VOLTAGE MATERIALS



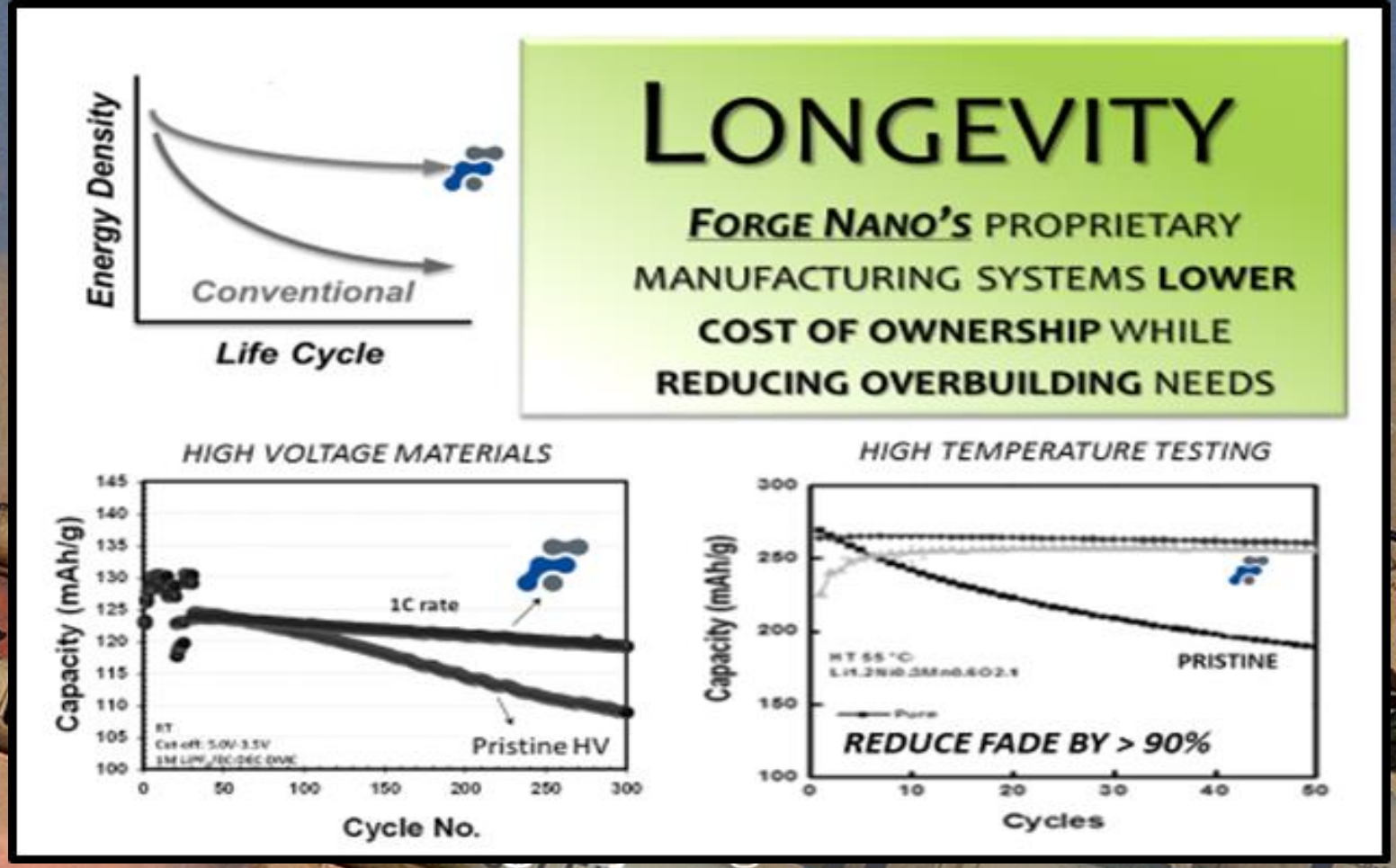
HIGH CAPACITY MATERIALS



ALD Enabled Cathode Materials

Lifetime

- *Reduced capacity fade*
- *Reduced overbuild*
- *Reduced warranty risk*



Scott Nelson

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ALD Enabled Cathode Materials

Safety

- *Lower resistance*
- *Reduced heat generation during cycling*
- *Suppression of thermal runaway*
- *Abuse tolerance*
- *Improved nail penetration performance*
- *Resistance to dendrite growth*

SAFETY

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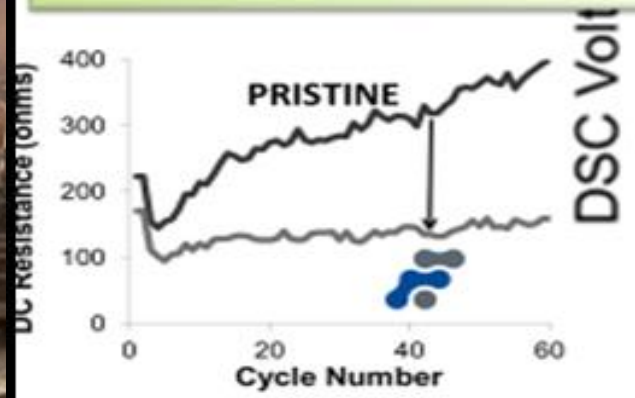
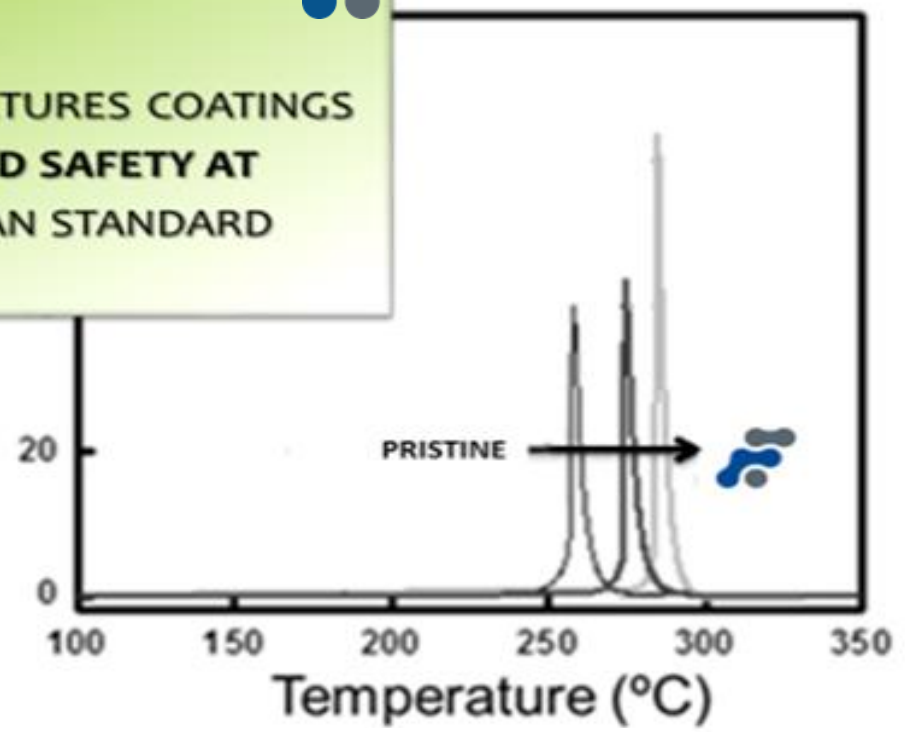
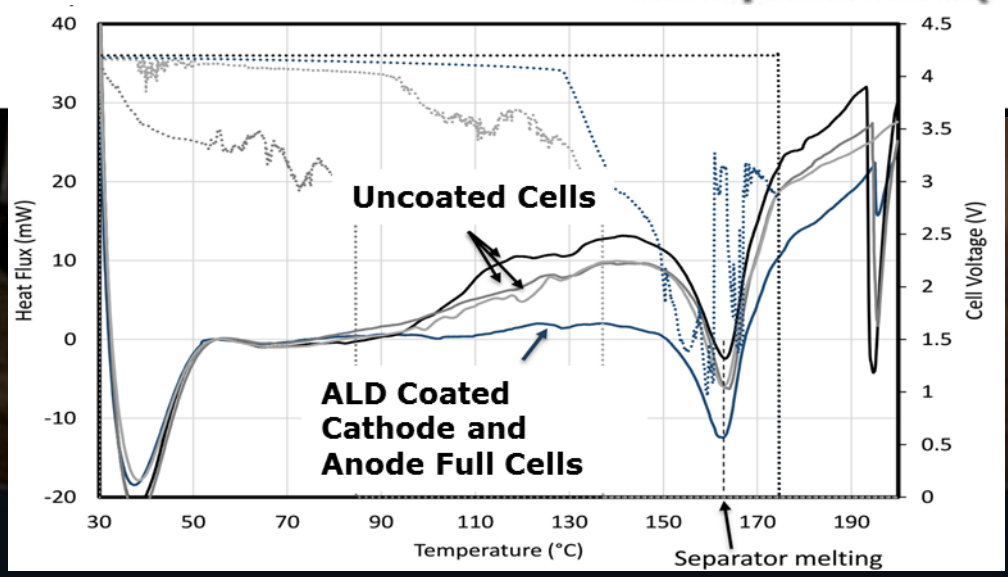
FORGE NANO MANUFACTURES COATINGS THAT DELIVER **IMPROVED SAFETY AT LOWER RESISTIVITY** THAN STANDARD MATERIALS



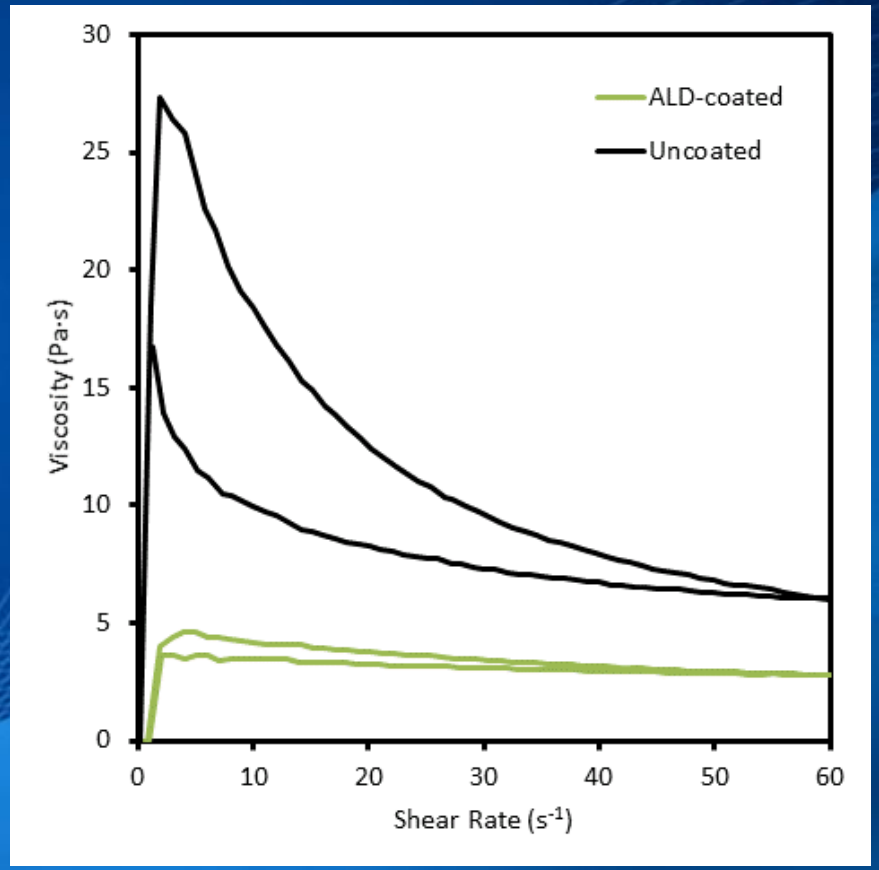




Processing Improvements

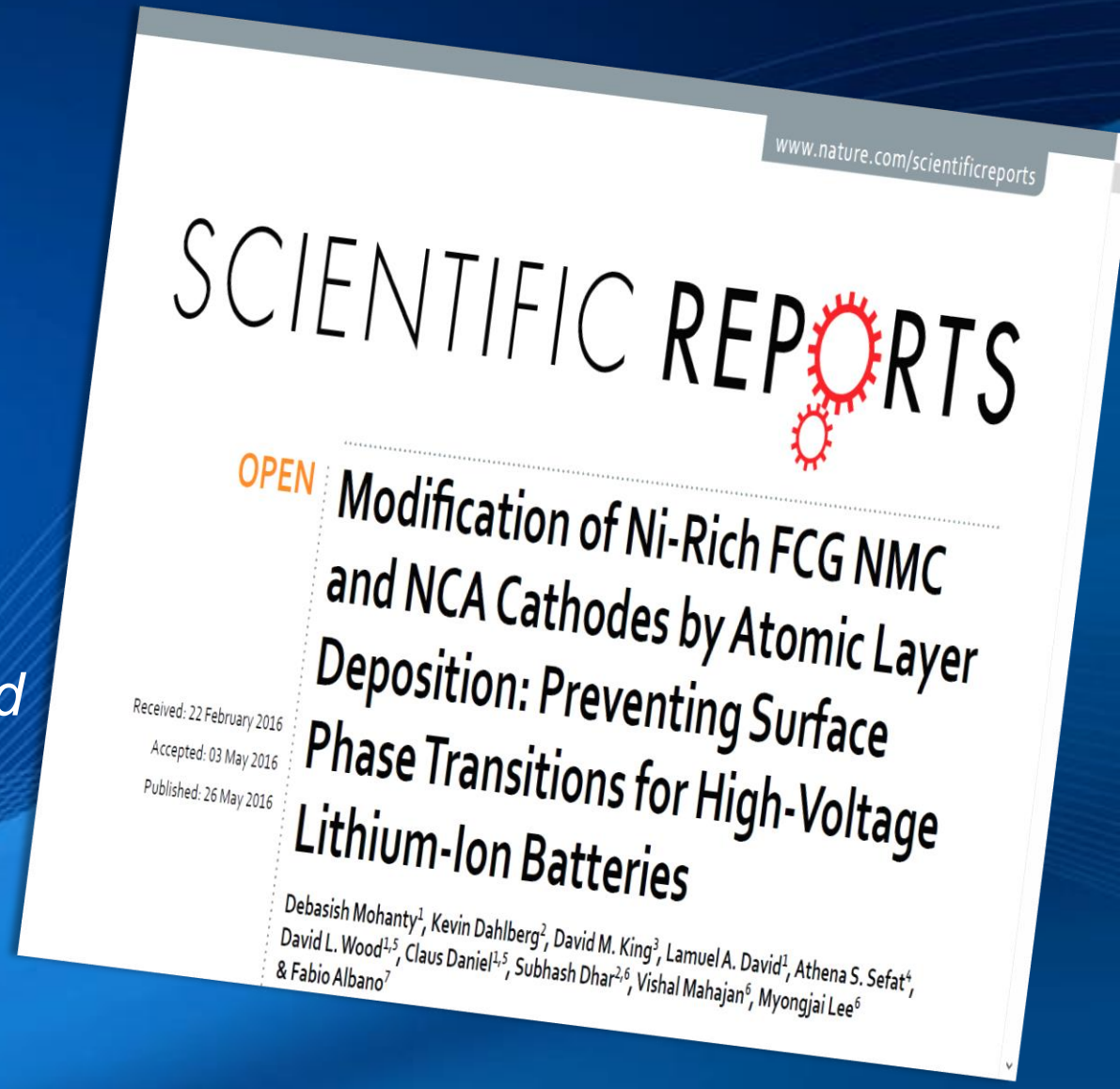
Processing

- *Lower viscosity*
- *Less NMP*
- *Faster drying*



Results:

- *Al_2O_3 and TiO_2 coatings improved NCA capacity retention during high rate (1 C/−1 C) cycling.*
- *Al_2O_3 coating improved NMC capacity retention during low rate (0.3 C/−0.3 C) and high rate (1 C/−1 C) cycling.*



www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Modification of Ni-Rich FCG NMC and NCA Cathodes by Atomic Layer Deposition: Preventing Surface Phase Transitions for High-Voltage Lithium-Ion Batteries

Received: 22 February 2016
Accepted: 03 May 2016
Published: 26 May 2016

Debasish Mohanty[1], Kevin Dahlberg[2], David M. King[3], Lamuel A. David[1], Athena S. Sefat[4], David L. Wood[1,5], Claus Daniel[1,5], Subhash Dhar[2,6], Vishal Mahajan[6], Myongjai Lee[6] & Fabio Albano[7]

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ALD Enabled Anodes

50% Lifetime Improvement at 45°C with 1C Cycling

Results from 2 Ah pouch cells with ALD-Enabled Anode Materials

	Uncoated Graphite	Coating 1	Coating 2	Coating 3	Coating 4
Cycles to 10% Discharge Capacity Fade	87 ± 11	156 ± 13	129 ± 27	118 ± 10	121 ± 3
Relative Cycle Life Improvement	0	79%	48%	35%	39%
Cycles to 20% Discharge Capacity Fade	180 ± 6	*293 ± 28	*265 ± 41	*232 ± 24	*274 ± 18
Relative Cycle Life Improvement	0	62%	47%	29%	52%

45°C, 1C-1C cycling; full NMC-532:Graphite coin cells using pristine NMC
*Projected by linear fit to last 25 cycles

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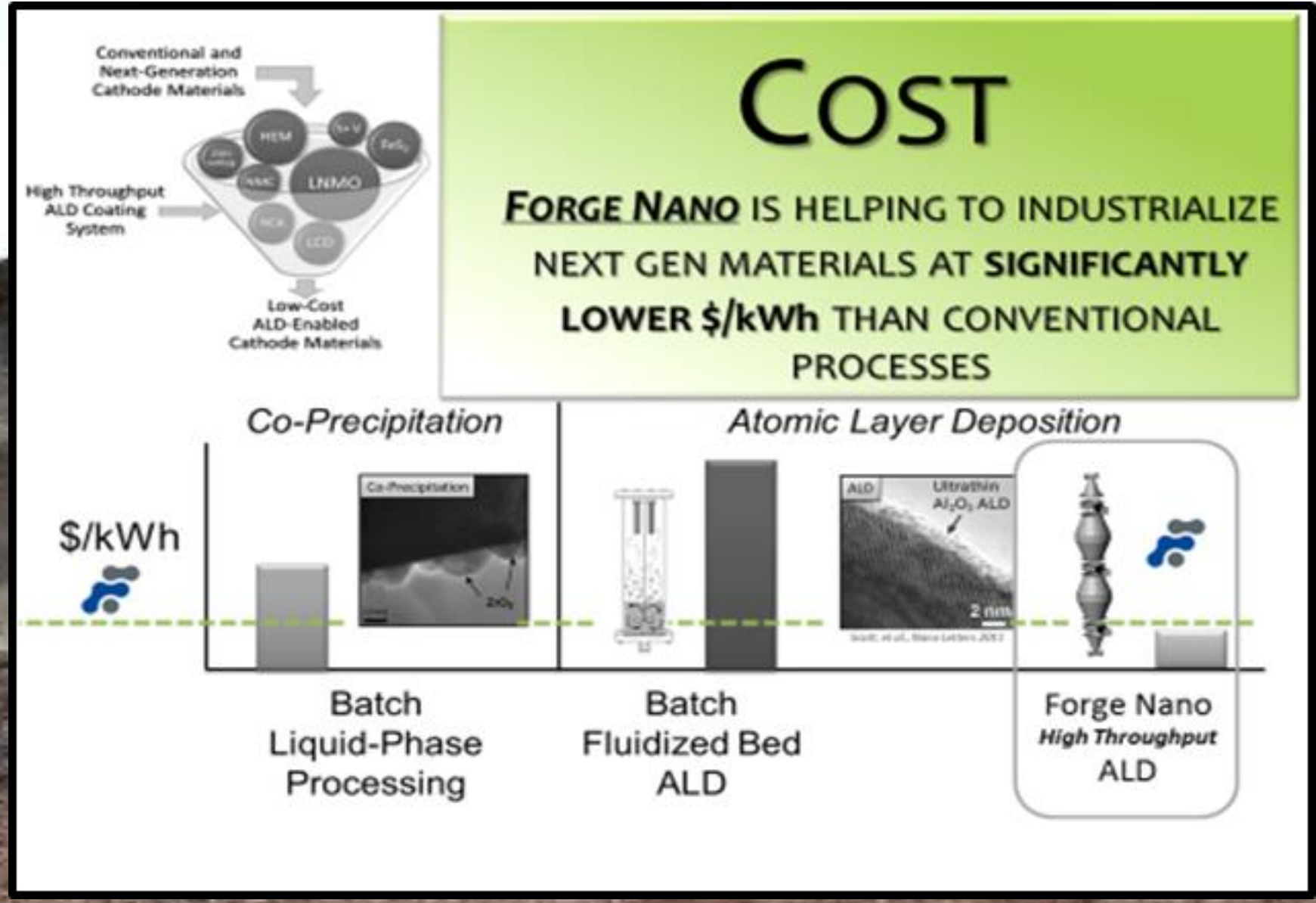
ALD Enabled Li-ion Batteries

Forge Nano Coatings Lower costs

- *Reduced overbuild*
- *Improved Manufacturability*
- *Lower $/kWh for life of battery*



Benefits of ALD Enabled Li-ion Batteries Summary

Performance
- Increased power density
- Increased cycle life
- Increased energy density

Cost
- Less material
- Improved processing
- Fewer replacements

Safety
- Greater abuse tolerance
- Reduced warranty risk

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