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# Advanced Anodes and Electrode Coating Technology for High Energy Lithium Ion Batteries

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# Outline

- Who is Navitas
- Navitas high capacity anode
- Navitas advanced electrode drying technology
- Navitas high energy cell demonstration

# Who are we?

- Navitas is a Small, Women owned, company Headquarter in Chicago, IL with manufacturing facilities in Ann Arbor, Michigan.
- Navitas is a Cell and battery design and manufacturing company with Electrical Assembly (PCB), Cable and Harness design and contract manufacturing capabilities
- Navitas has a state of the Art Research and Development facilities and full Product Engineering team with extensive Cell and Battery development and manufacturing experience and capabilities

# Navitas Capability

| | Lithium Battery Solutions | System Design and Assembly | Electronics & Battery Management Systems (BMS) | Custom Cell Development | Analytical and Testing | Cell Chemistry R&D Advanced Chemistry and processing |
|---|---|---|---|---|---|---|
| **Capability** |  |  |  |  |  |  |
| **Scope** | • Custom battery development, prototyping, and manufacturing<br>• 12V NATO 6T Battery<br>• 24V NATO 6T Battery<br>• Multi-kWh motive application batteries<br>• PowerForce™ Idle Reduction Battery<br>• Frontierion™ Photovoltaic Interface + Energy Storage<br>• Mission-critical UPS Systems | • Cell form factor and chemistry agnostic<br>• >1kWh solutions<br>• System mechanical and electrical design<br>• Custom power electronics<br>• Finite element analysis<br>• Thermal modeling<br>• Prototype and low-volume assembly in house | • Custom PCBA and wiring harness design and assembly<br>• In-house SMT line<br>• Customized configurable software<br>• Box builds | • Custom prismatic cells<br>• 2x2 to 12x22 cm form factors<br>• In house slot-die coating<br>• 650 sq. ft. dry room<br>• Various Li-ion chemistries developed<br>• Extreme high power and high energy density chemistries available; 100-600 Wh/L | • 500+ MACCOR test channels<br>• Environmental control -70 to +200°C<br>• Electrochemical Impedance Spectro-scopy<br>• Scanning Electron Microscope with elemental mapping and inert gas sample transfer device<br>• Analytical chemistry instrumentation<br>• Cell tear down analysis | • Wet lab<br>• Controlled atmosphere tube furnaces for synthesis<br>• Custom anode, cathode, and electrolyte development<br>• Battery materials and concepts evaluation<br>•Advanced Chemical processing |

# Si Anode Overview

**Goal:** Produce a practical and economical high capacity silicon-based anode material for lithium ion batteries

| Anode Property | Metrics |
|---|---|
| Primary particle size (nm) | 50 - 200 |
| Secondary particle size (µm) | 1 - 10 |
| BET surface area ($m^2/g$) | < 20 |
| Tap density ($g/cm^3$) | 0.85 |
| Specific capacity (mAh/g) | 650 - 1350 |

**HIGH CAPACITY**

650 – 1350 mAh/g reversible capacity: 70% ~ 385% higher than graphitic carbon anodes (350 mAh/g).

**HIGH REVERSIBILITY**

Proprietary process reduces initial capacity loss below 12%.

**CYCLE LIFE**

>800 cycles at 80% DOD in a Li ion cell (with Si anode 650 mAh/g and 3 $mAh/cm^2$ loading).

**LOW COST**

Based on commodity pricing for micron-sized silicon starting materials and using scalable, low-cost processing.

**TAP DENSITY**

0.85 $g/cm^3$ comparable to commercial anode powders.

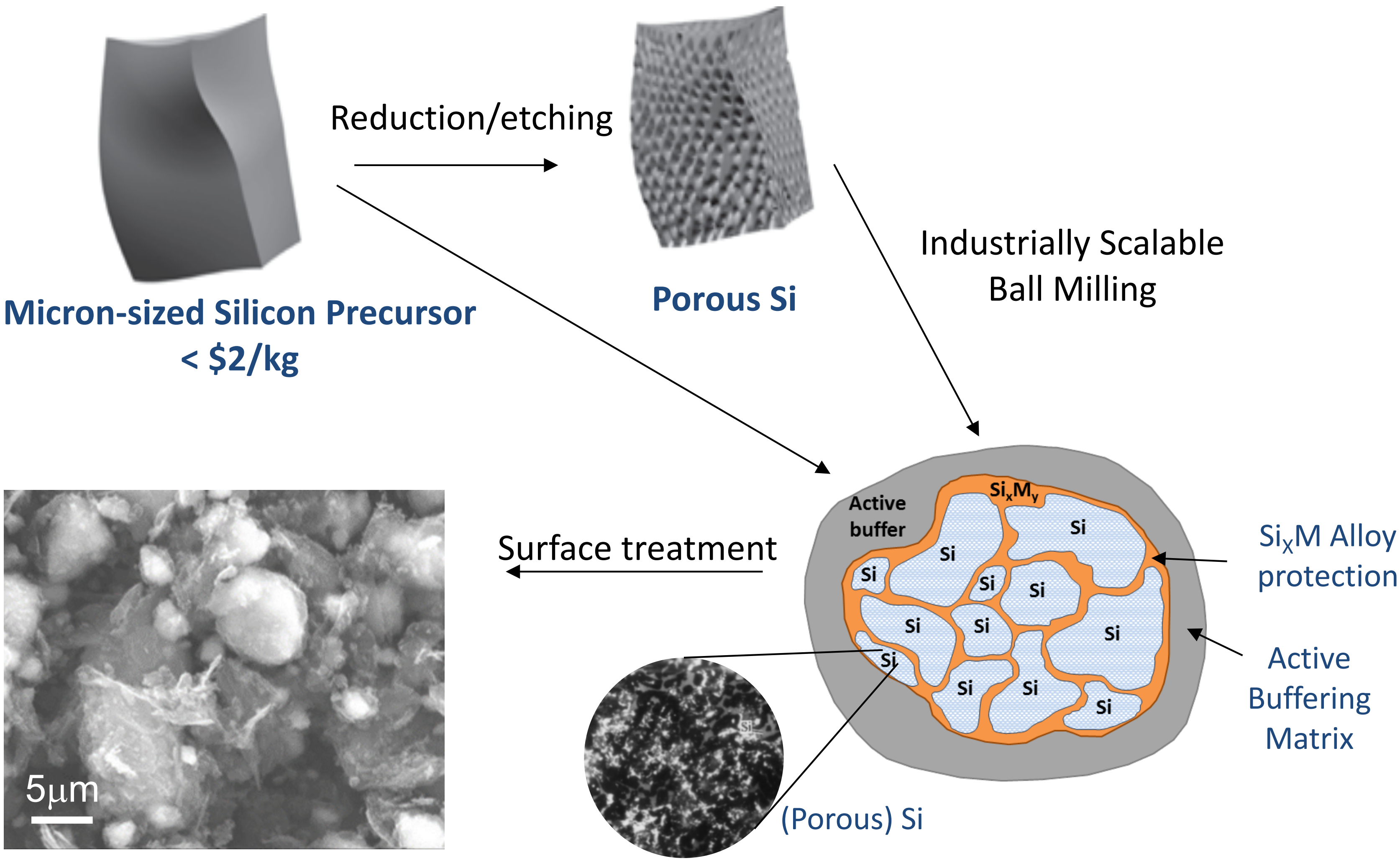
**HIGH POWER**

>90% capacity retention at 2C (at 3 $mAh/cm^2$ electrode loading).

**PROCESSING**

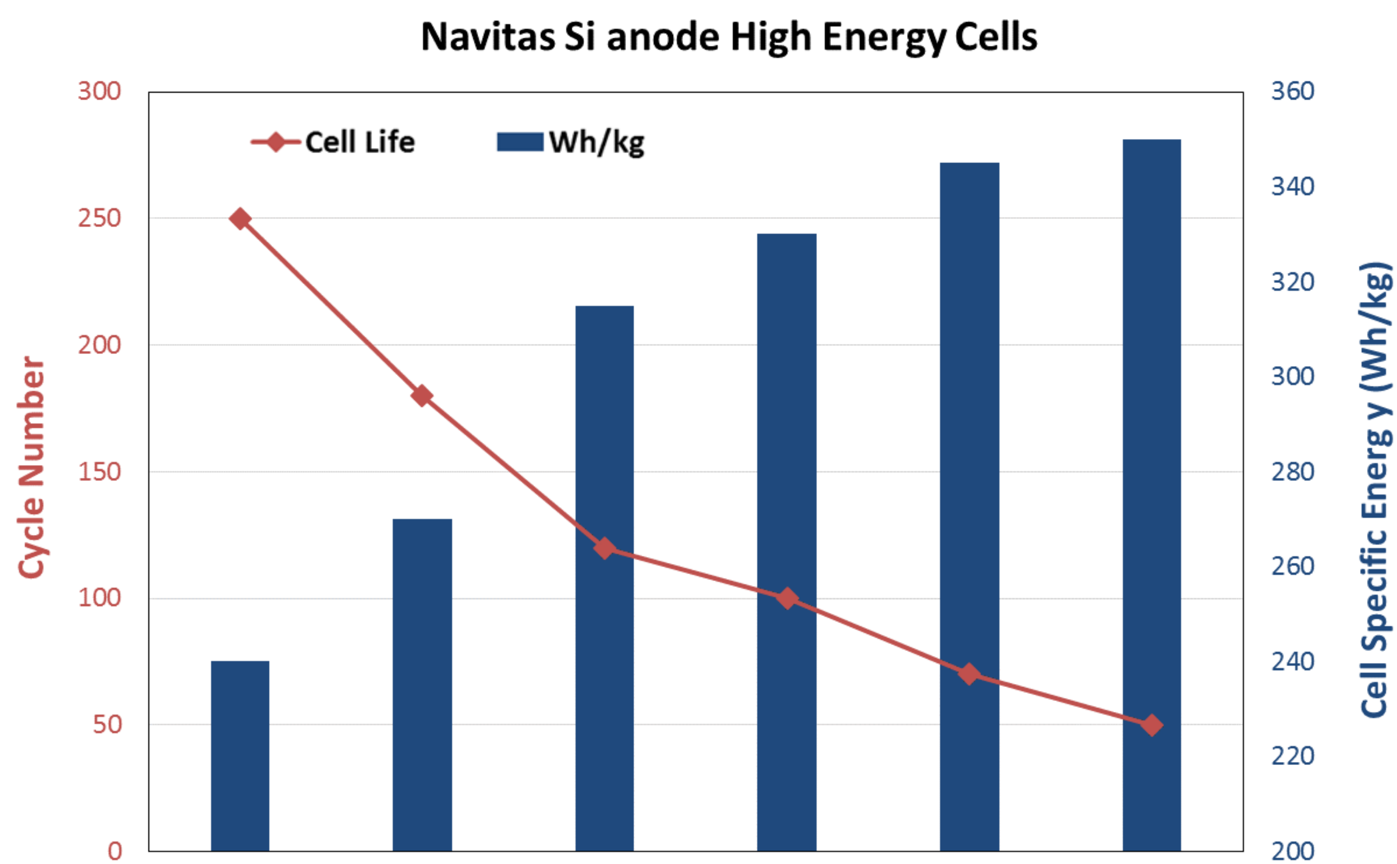
Slot-die coated electrodes from stable slurry using established water-based binder formulation.

# High capacity Si composite with a cost comparable to graphite




**Si Composite**

# Si Anode Cell: Energy vs. Cycle Life



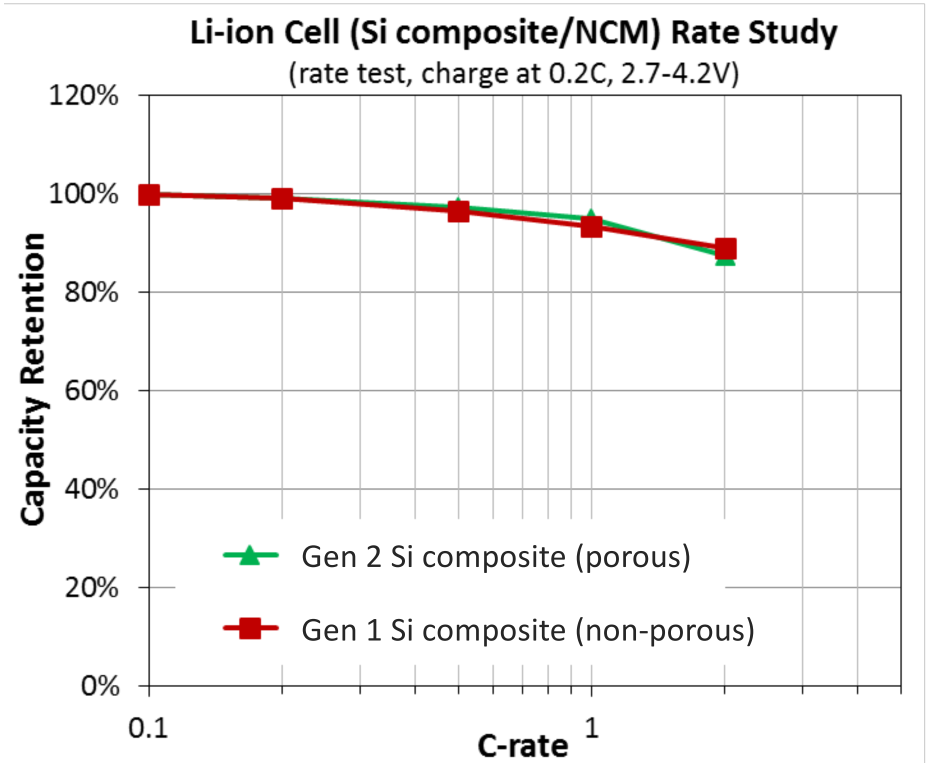

- Navitas Si anode high energy cell cycle life vs. specific energy
  - Customized cell design to balance life and energy
  - Higher energy density cells have shorter cycle life than lower energy ones

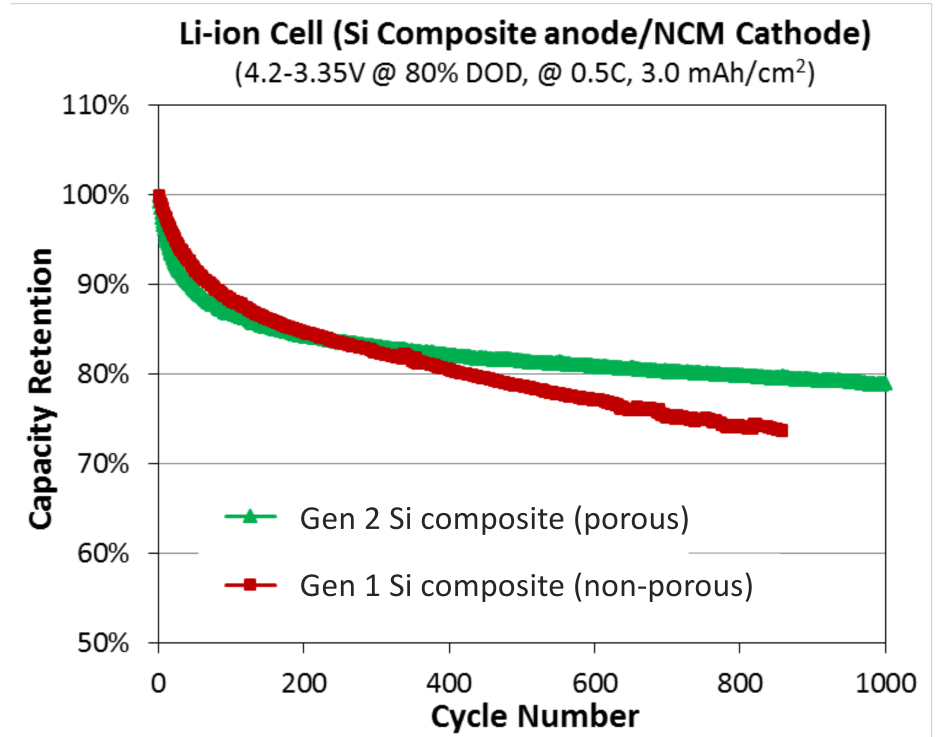
# Si Anode Fabrication

- Pilot scale electrode production readily scalable to manufacturing

| | |
|---|---|
| Electrode loading ($mAh/cm^2$) | 3.0 – 8.0 |
| Active material content | 92 wt.% |
| Binder | Aqueous binder |
| Porosity | 30 - 45% |
| Coating method | Slot-die |
| Double sided | Yes |
| Roll-to-roll | Yes |

# Si Composite Anode Full Cell Demonstration

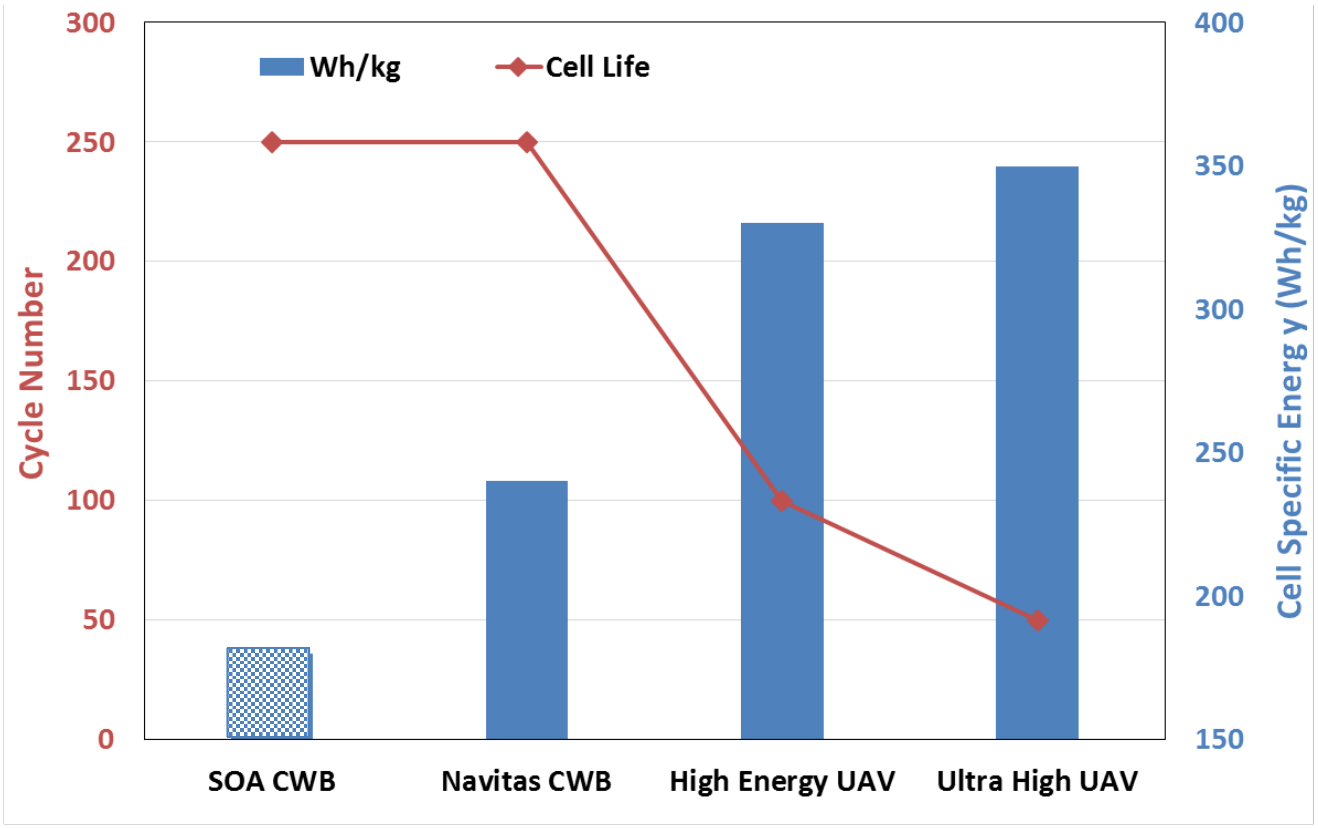



- Electrode fabrication
  - Si anode: 92% active with aqueous binder
  - Si composite capacity 650 mAh/g
  - NCM cathode: 93% active with PVDF binder
  - Loading 3.0 $mAh/cm^2$ and A/C = 1.1
- Cell assembly:
  - 250 mAh double-layer-pouch cell (active area: 47 $cm^2$)
  - 270 Wh/kg if in EV format (cell level)

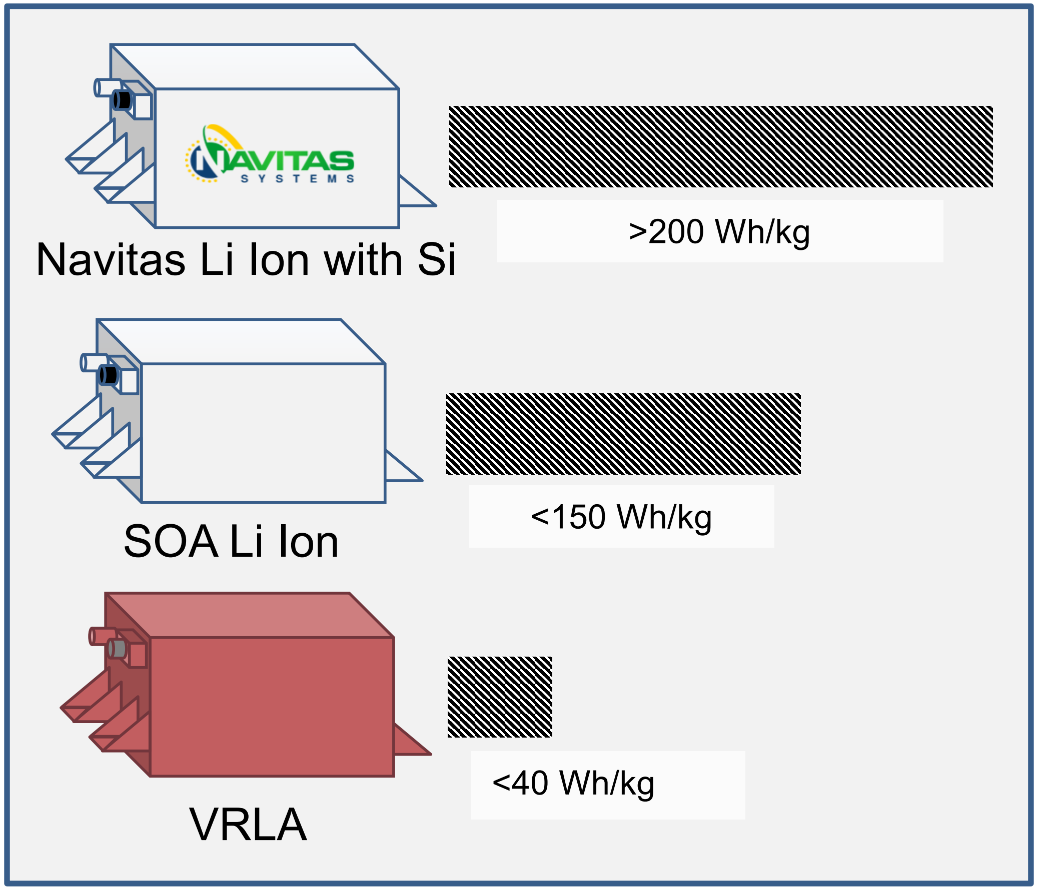
- Rate capability: 90% capacity retention at 2C
- >800 cycles at 80% DOD and 80% capacity retention (or 250 cycles at 100% DOD)
- LiB cells with mpSi composite anode showed 2X life performance improvement over reference

# Navitas Si Anode Cell: Energy Comparison
## Conformal Wearable & UAV




- Navitas reinforced Si anode in CWB and UAV cells:
  - Significant weight saving
  - Energy advantage 30-100% more energy than SOA LiBs
  - Superior safety and abuse tolerance

# Si Composite Anode: Energy Comparison
## Aviation Battery




- Navitas reinforced Si anode Aviation LiB:
  - Significantly lower weight
  - Has 400% and 40% higher energy density than that of VRLA and SOA LiB
  - Superior safety and abuse tolerance

# Future Work on Si Anode

**Future work**

- Conduct critical performance evaluations on the large format cells:
  - Cycle life demonstration
  - Dimensional stability (swelling, gassing) during cycling
  - High temperature storage
  - Abuse tolerance (e.g., over-charge, over-discharge, short-circuit, and nail-penetration) larger format cells (≥ 2 Ah )
- Establish cost model for the Si material
- Continue to develop next generation Si anode with enhanced safety

# Strategy to High Energy Li-ion Cells

## MATERIALS & PROCESSING

**MATERIALS:**

- High capacity proprietary Si anode 500 - 1000 mAh/g
- High nickel content lithium metal oxide cathode

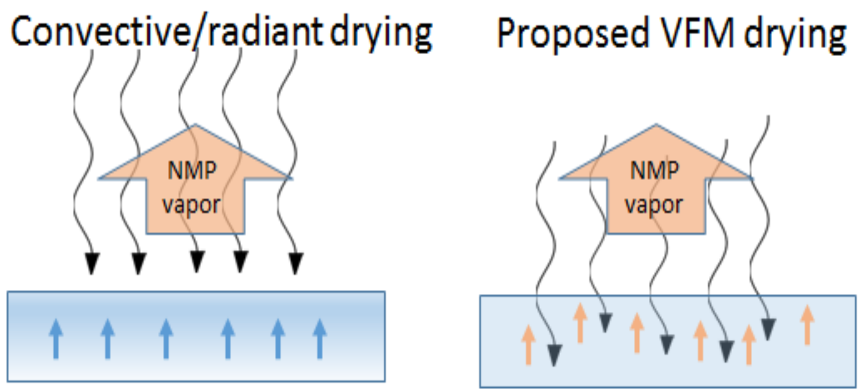
**PROCESSING:**

- High loading electrode up to 8 $mAh/cm^2$
- Enabled by an advanced drying process (ADP)

| Cell Type | Baseline | High Energy | Advanced High Energy |
|---|---|---|---|
| Cathode | NCM811 | NCM811 | NCM811 |
| Anode | Graphite (360 mAh/g) | **Si Composite (1000 mAh/g)** | **Si Composite (1000 mAh/g)** |
| Electrode Loading ($mAh/cm^2$) | 3.5 | 3.5 | **7.0** |
| Specific Energy (Wh/kg) | 260 | 300 | 354 |
| Energy Density (Wh/L) | 500 | 610 | 685 |

# How does Navitas get to 7 $mAh/cm^2$ Cathode?

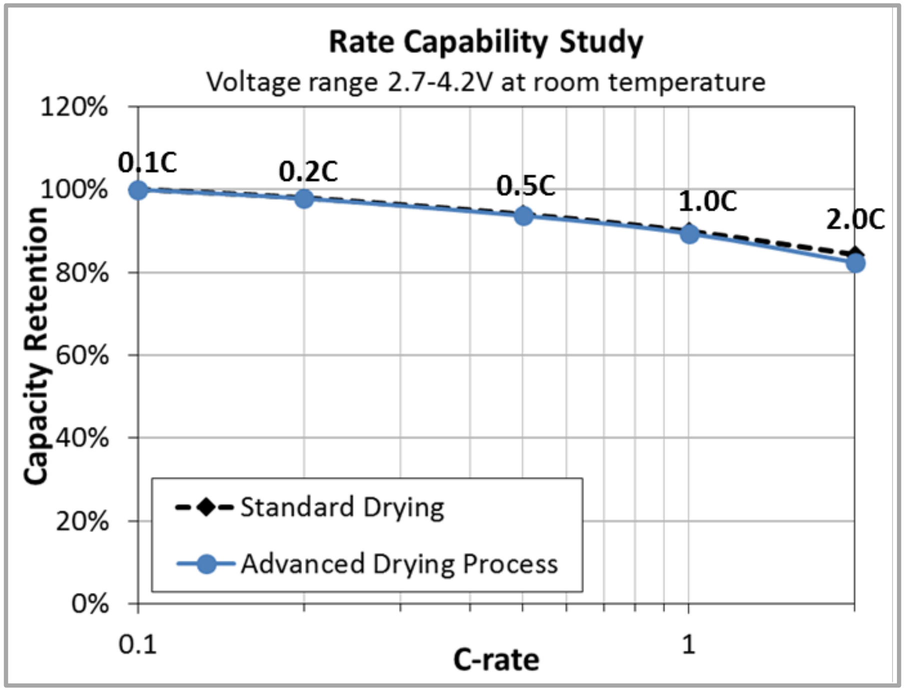
# Advanced Drying Process (ADP)
## VFM & Hot Air

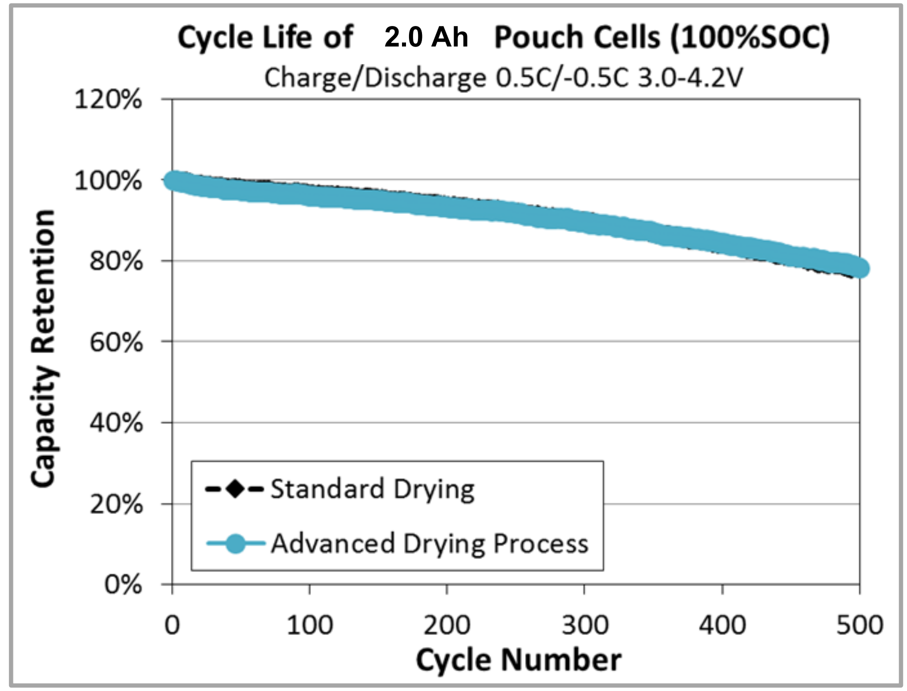



**Compared to baseline convective electrode drying, VFM transfers energy to the electrode bulk, vaporizing NMP (orange) and avoiding dragging electrode binder (blue arrows) which creates a gradient with low binder content at the current collector interface.**

- Electrodes slurries, especially thicker coatings are slow to dry because of the surface heating by convection or infrared radiation (IR frequency is much higher than microwaves).
- Use Variable Frequency Microwaves (VFM) to penetrate the thickness of the thick slurry electrode coatings.
- Water and other solvent molecules are polar. Microwaves selectively target these polar molecules and sets these molecules into rotation.
- The enhanced mobility rapidly drives the water or solvent vapors out of the electrode coatings.
- The hot air flowing over the electrode carries these solvent vapors away through the exhaust ports on the equipment.
- The result is a rapid drying cycle which saves drying time and cost.

# Navitas Continuous Coating/Drying:
## Validation in 2 Ah Li ion Cell




| Drying Method | | Loading ($mAh/cm^2$) | Initial Capacity (mAh/g) | # Life Cycles @ 100%SOC (C/2 rate) |
|---|---|---|---|---|
| Anode | Cathode | | | |
| Navitas | Navitas | 3.1 | **141.9** | **500** |
| ADP | ADP | 3.1 | **142.6** | **500** |

✓ ***Pilot continuous drying using ADP confirms that the process does not sacrifice cell performance when compared to standard drying***

# ADP Electrode: Rapid Drying

| Electrode | Drying Method | Loading ($mg/cm^2$) | Drying speed (mm/min) | Drying length (m) |
|---|---|---|---|---|
| Anode (graphite, water based binder) | Standard | 10.4 | 500 | 2.5 |
| | Advanced drying | 10.6 | 500 | 0.5 |
| | **ADP Advantage** | **5X** | | |
| Cathode (NCM523, NMP based binder) | Standard | 18.2 | 350 | 2.5 |
| | Advanced drying | 18.9 | 225 | 0.5 |
| | **ADP Advantage** | **3X** | | |

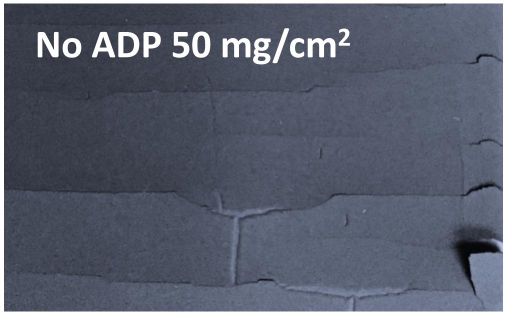
- Electrodes were coated using Navitas pilot coating system and dried using either standard or advanced drying process (ADP)
- Electrode testing at Navitas constituted: solvent content, adhesion, binder distribution experiments
- Electrochemical validation included: full lithium ion electrochemical testing

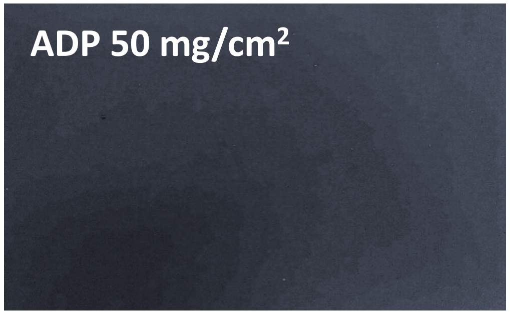
**Advantage of using ADP over conventional drying system was 5X for aqueous anodes and 3X for NMP based cathodes**

# Ultra-High Loading Cathode:
## Coating Characterization

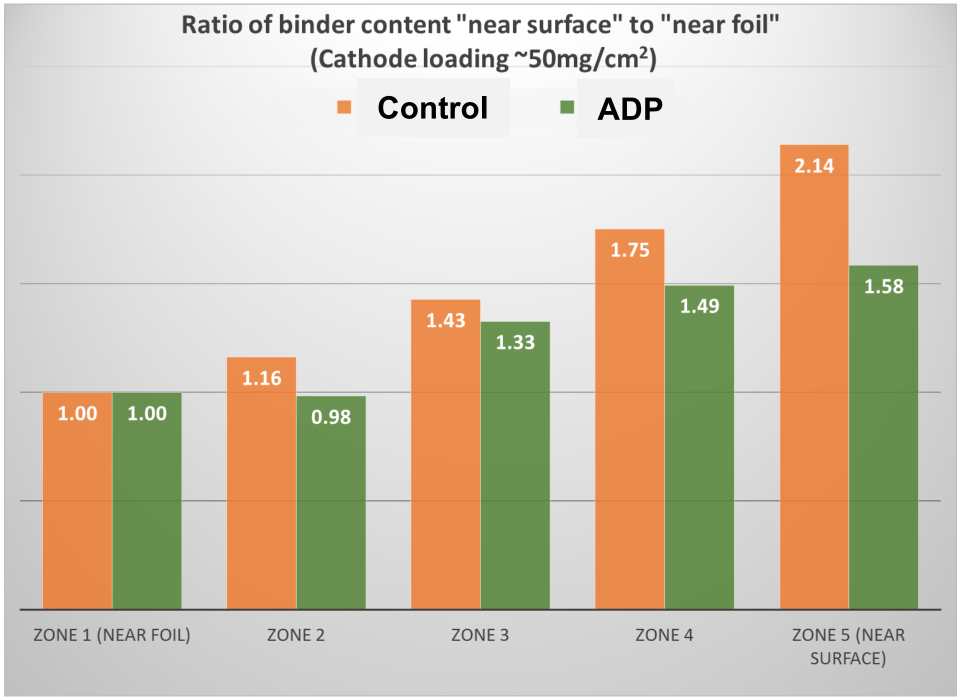
### Slot-die NCM cathode coatings dried with and without ADP

**Without ADP:** surface cracks and non-uniform spots




**With ADP:** No surface defects



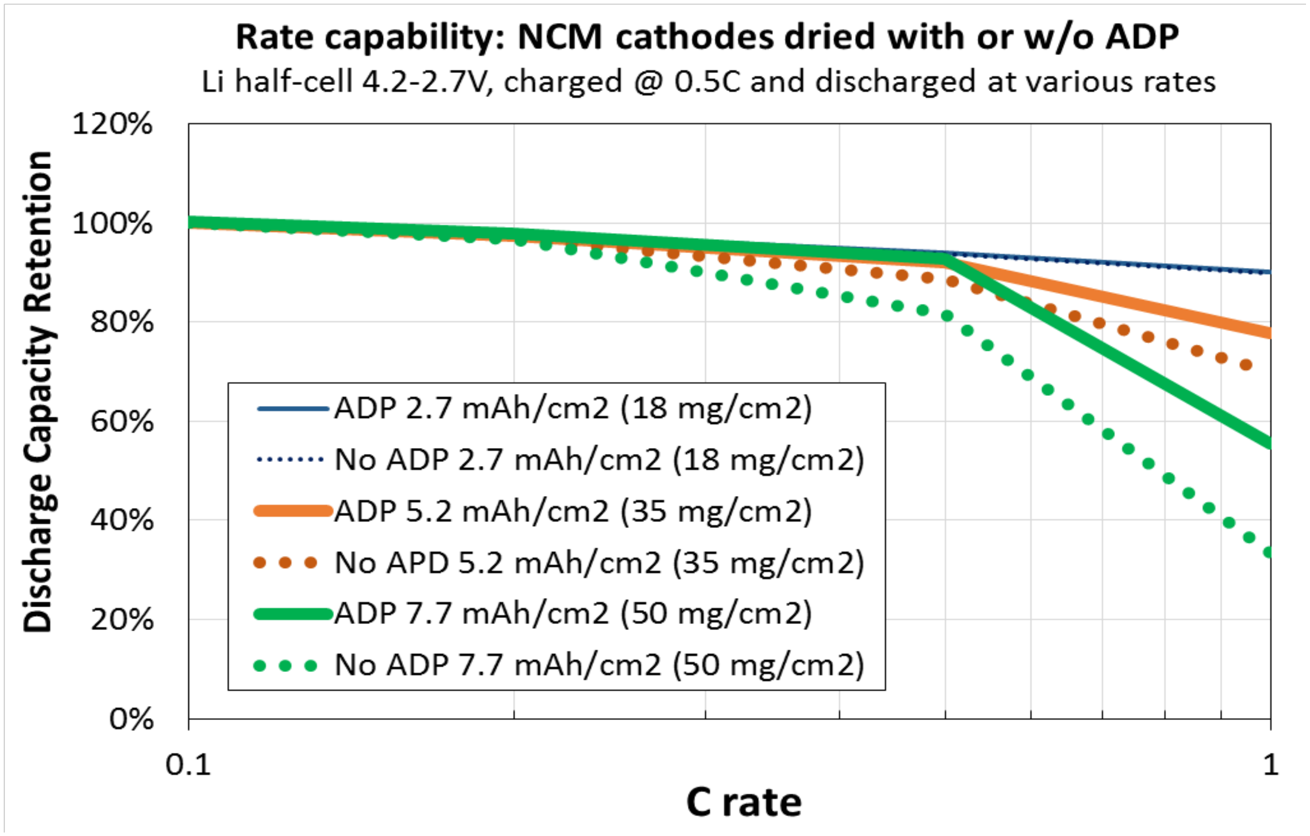

### Binder Distribution

- ADP dried sample shows lower level of binder migration than control
- ADP dried sample shows more uniform binder distribution than control

***Characterization method***

- *Divide the electrode cross-section to five zones (Zone 1 near the foil → Zone 5 near the surface)*
- *Use SEM/EDS to analyze binder ("F") content and compare the ratio among different zones (normalized to Zone 1)*

# Ultra-High Loading Cathode:
## Rate Capability




- At high loadings (>5 $mAh/cm^2$), ADP dried electrodes show improved performance compared to the control samples
- The ADP dried electrodes maintain the rate capability up to 0.5C with the loadings from 2.7 to 7.7 $mAh/cm^2$
- The ADP dried electrodes also show lower impedance than the control samples by using EIS characterization

# High Energy  Li-ion Cell Chemistry

Adaptable chemistry platform; based on lithium metal oxide cathode and Si composite anode; capable of being packaged into a wide variety of cell form factors

| **Cell** | Navitas HEC | |
|---|---|---|
| **Mechanical Design** | Form Factor | Prismatic Pouch Cell |
| | Dimensions | 55 x 105 mm |
| | Terminals | 10mm wide Ni(-) & Al(+) |
| **Performance** | Capacity | 2 – 10 Ah |
| | Voltage | 3.6-3.7 V |
| | Discharge Rate | 0.5C continuous |
| | Specific Energy (Wh/kg) | 240 - 350 |
| | Energy Density (Wh/L) | 500 - 700 |
| | Cycle Life* | 50- 250 cycles |
| *Higher energy density cells have shorter cycle life than lower energy ones | | |

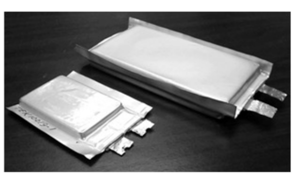
# Navitas High Energy Cell Capability

## Electrode Coating

- Lab/Pilot Slot-Die Coater
- 2 Gallon Anode and Cathode Mixers
- Small Scale Mixer for Experimental Materials
- Efficient Coating Development at 1g – 5kg Batch Levels
- Materials Coated: Graphite, Silicon Anodes, LTO, LFP, NCM, NCA, LMO, LCO

## Cell Prototyping

- Custom Cell Development
- 700 sq ft Dry Room
- Enclosed Formation
- Semi-Auto Cell Assembly Equipment
- Pouch and Metal Can Packaging Supported



# Acknowledgement

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- Defense Advanced Research Projects Agency (DARPA)
  - High energy cell development
- Department of Energy (DOE) SBIR
  - High performing low cost Si anode
- DOE VTO OPPORTUNITY (two programs)
  - Porous Si process
  - Advanced Drying Process
- US Navy SBIR
  - High energy aviation battery (with Si anode)