AHS International

Transformative Vertical Flight Concepts

NASA Ames

August 4, 2015

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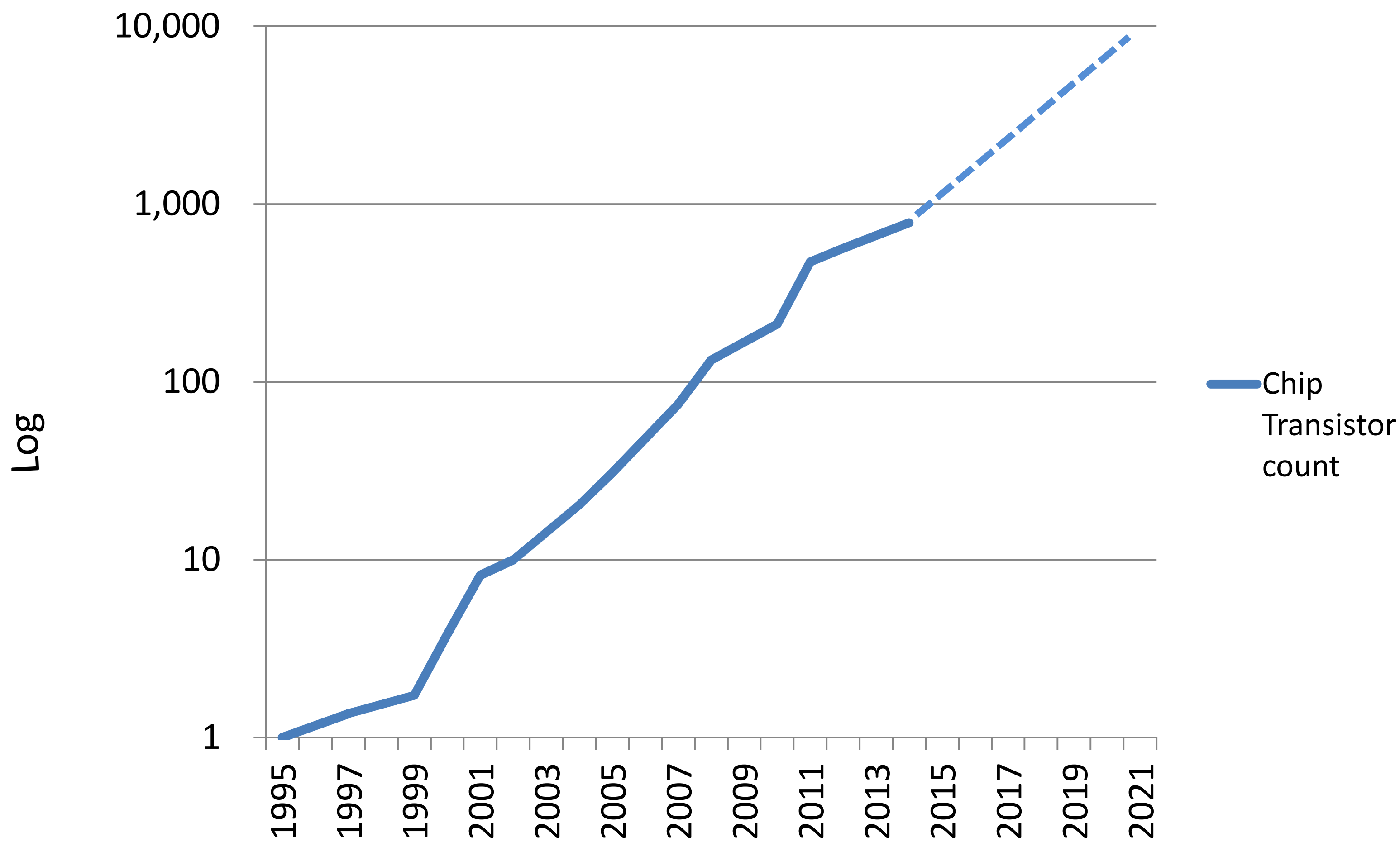
Moore's Law


10,000
1,000
100
10
1
Log
1995
1997
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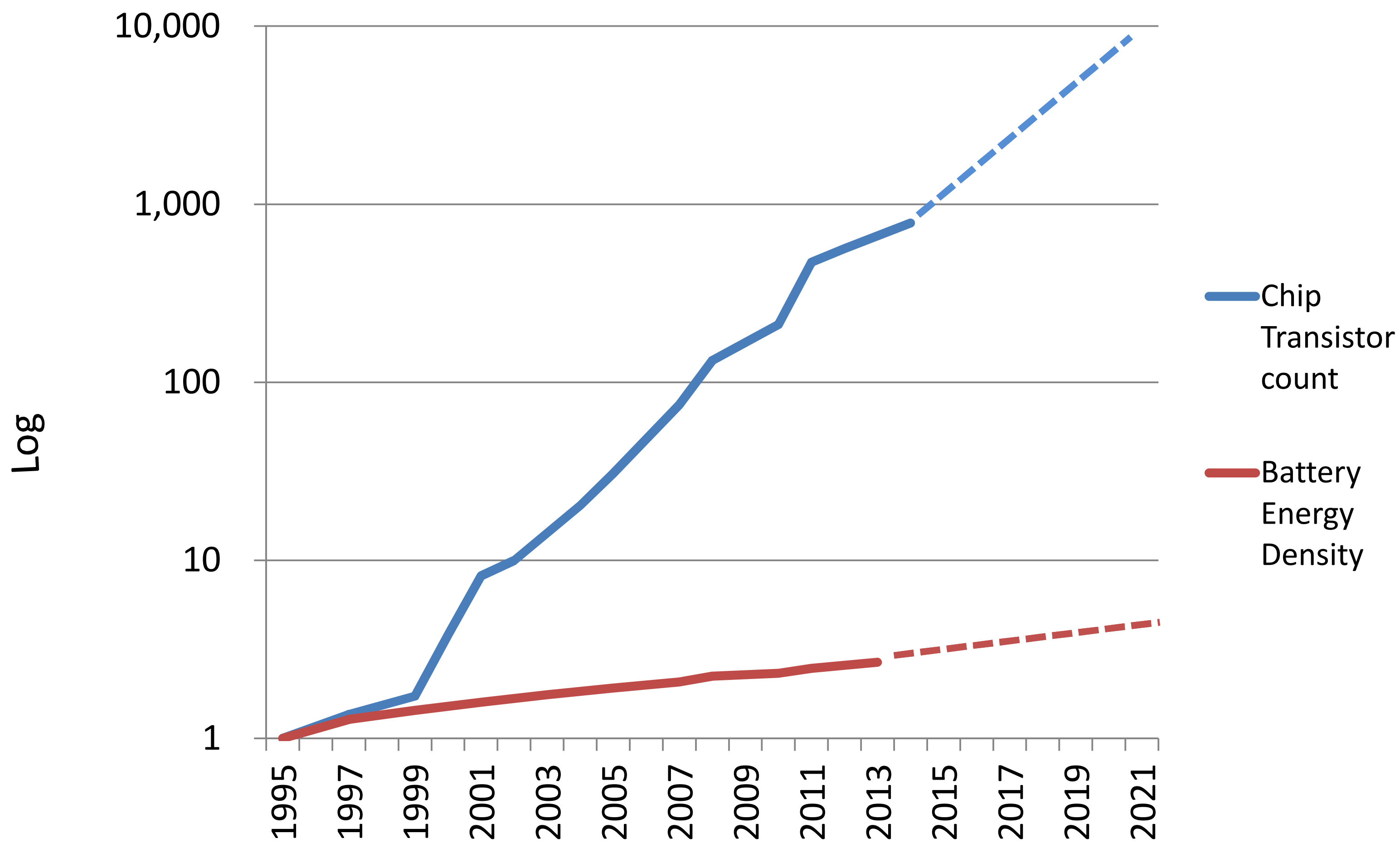
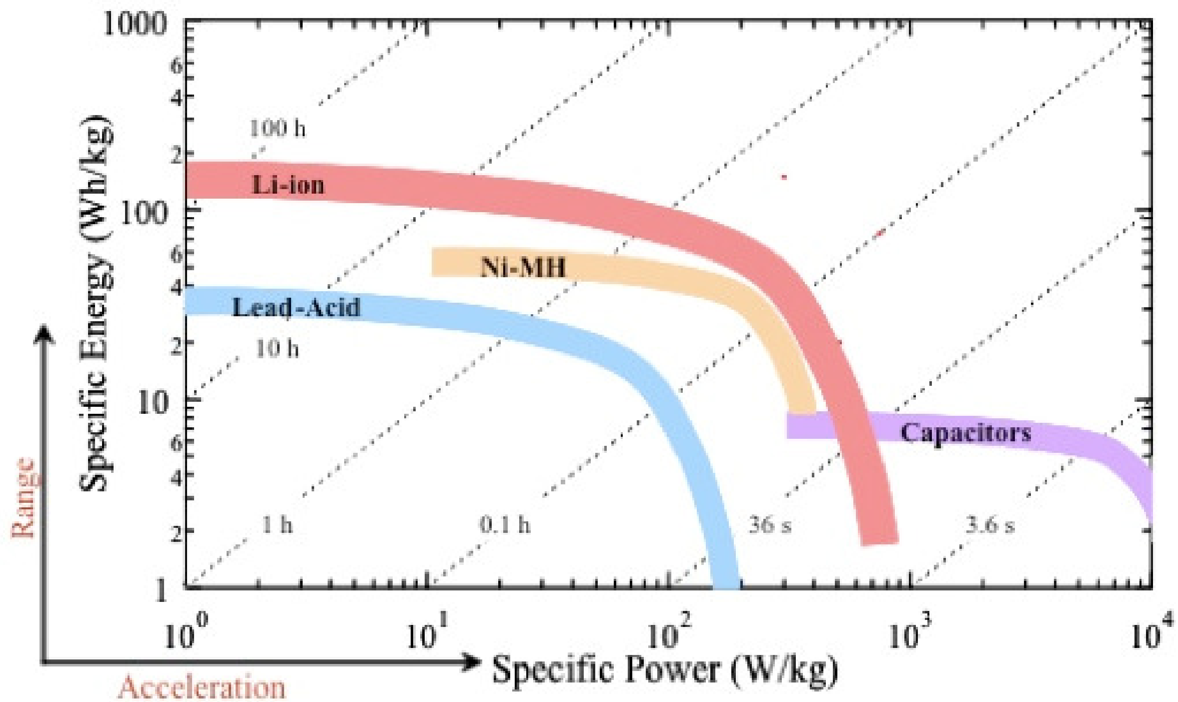
2021
Chip Transistor count

Moore's Law in batteries?




GETTY IMAG

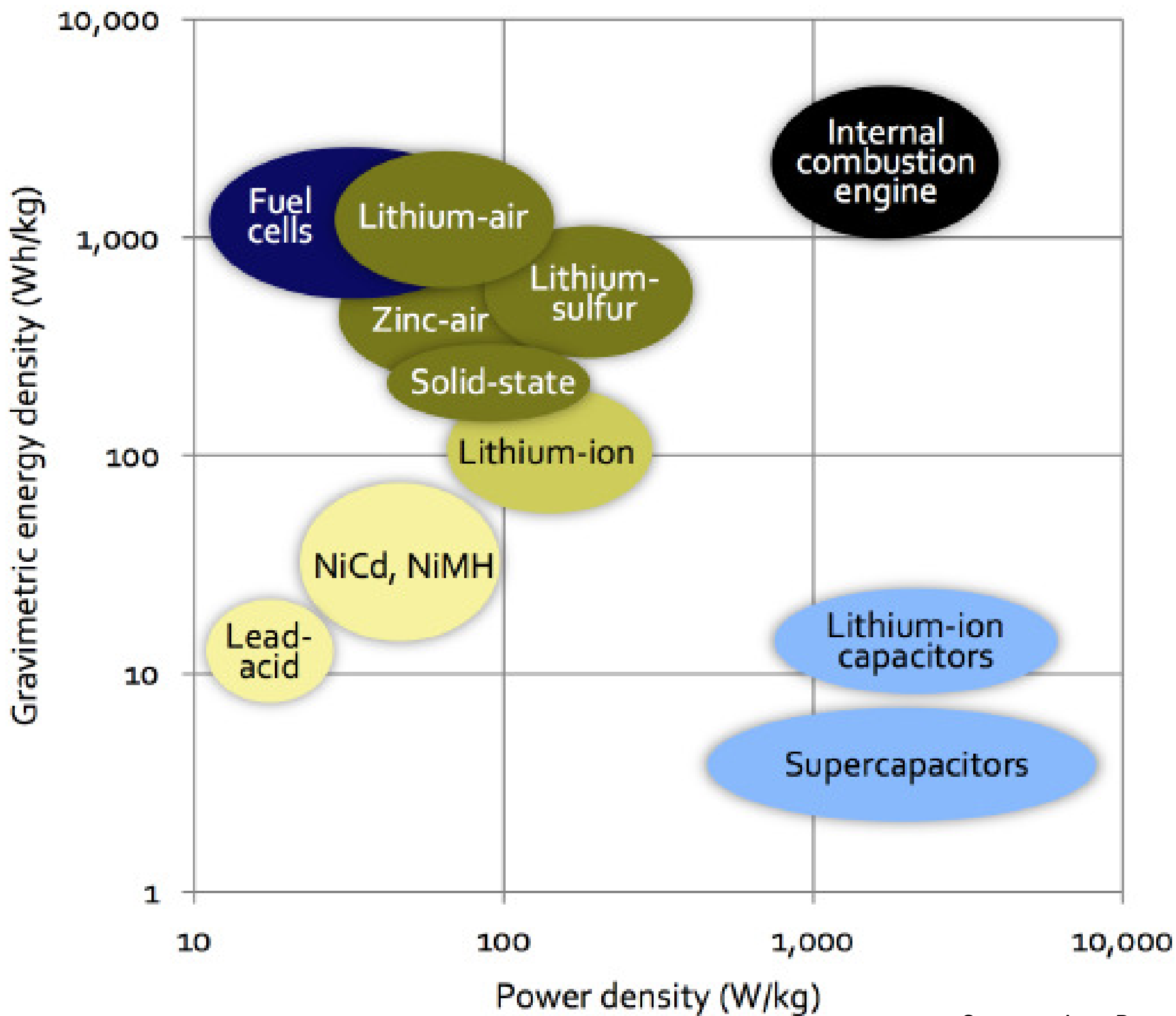
Power versus Energy: Mature Technology



Source: Lawrence Berkeley National Laboratory

- Batteries are all about compromise and lithium ion is the primary choice for most applications
- No one-size-fits-all battery chemistry, even within the lithium ion category
- Cycle life, cost, and safety are also important considerations

Power versus Energy: Next Gen Technology



Source: Lux Research

Can next gen technology compete with Li ion?

Lithium Sulfur

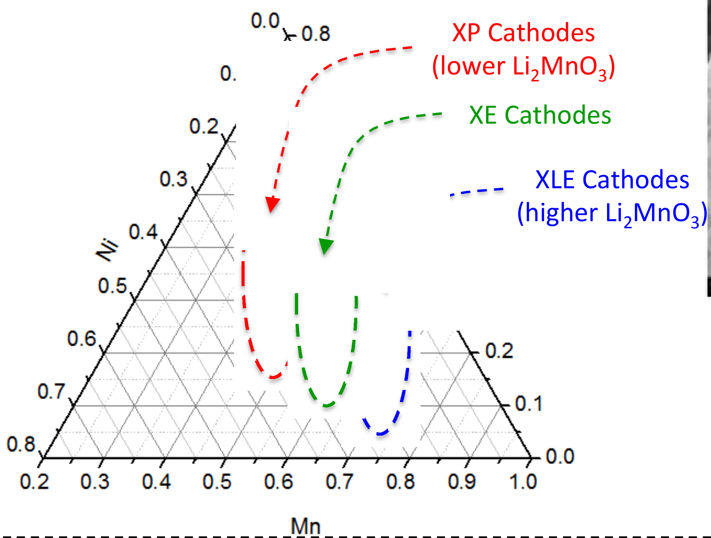
- Pro: High gravimetric capacity, low cost
- During discharge lithium polysulfides tend to dissolve from the cathode in the electrolytes and react with the lithium anode, decreasing cycle life
- Volume expansion of sulfur electrode upon repeated cycling
- Safety concerns

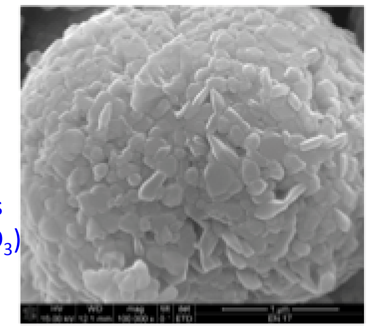
Lithium Air

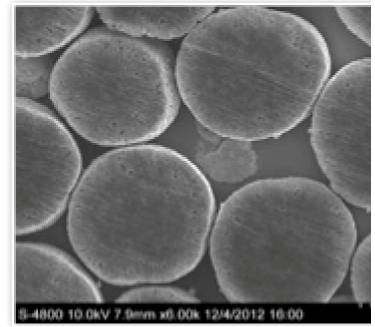
- Pro: Very high theoretical energy density
- Power is lower than lithium ion
- Cycle life issues as a result of dendrite formation, volume expansion, lithium peroxide byproducts
- Safety concerns

Envia's Approach

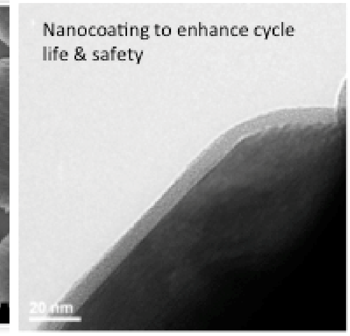
HCMR™ Cathode Phase Diagram





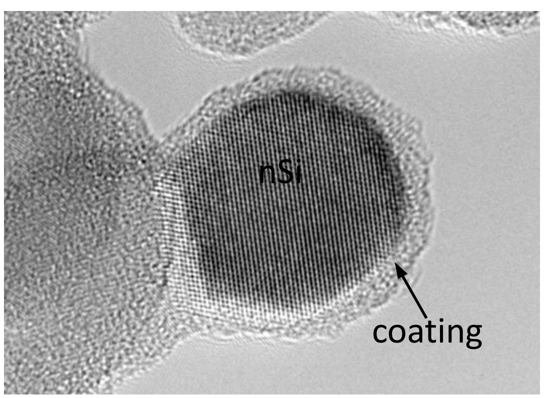


morphology

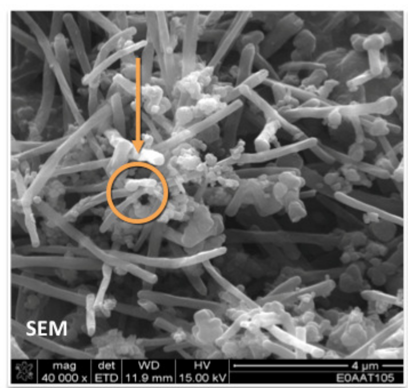


Nanocoating

HCMR™ Cathodes



Electrodes with
Carbon Fibers



Si-based Anodes

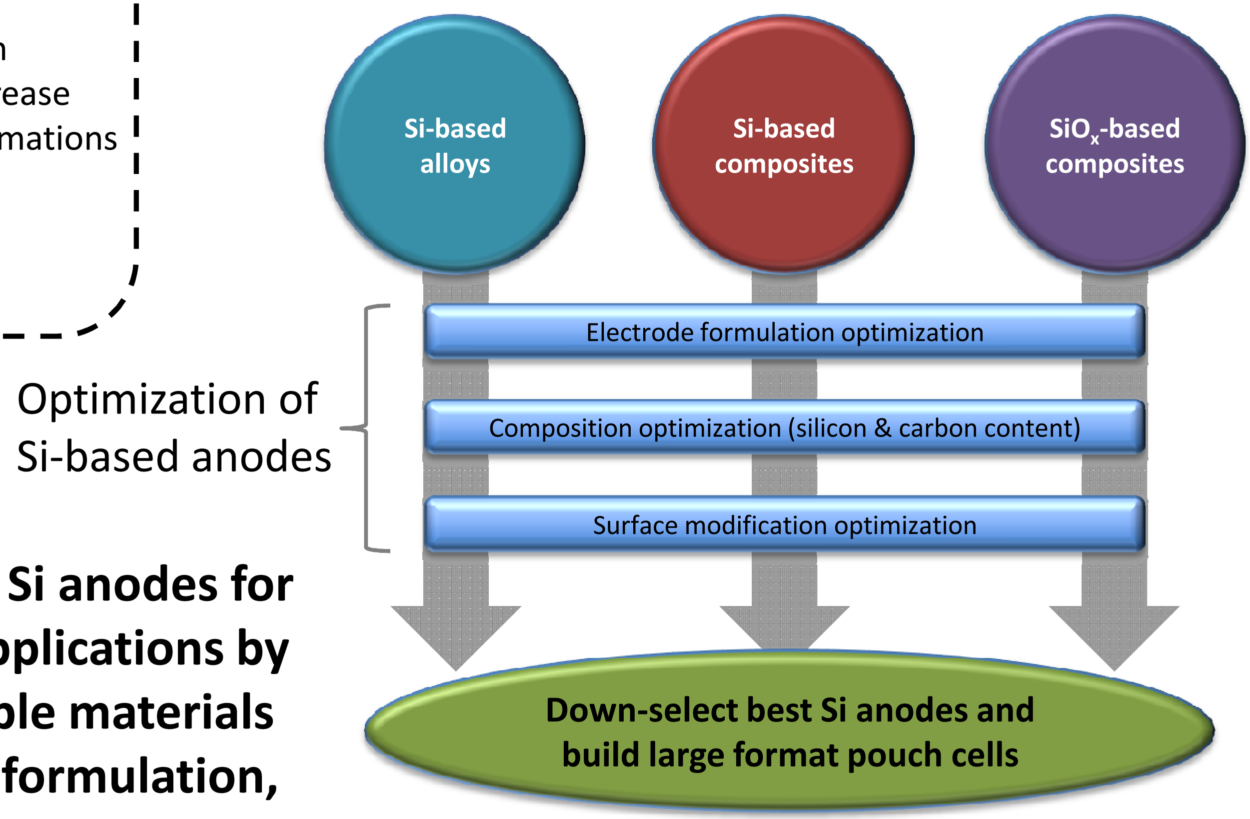
Envia Anode Strategy

Si needs to replace Gr-based anodes to enable high energy density cells (>300Wh/Kg)

Challenges with Si-based Anodes:

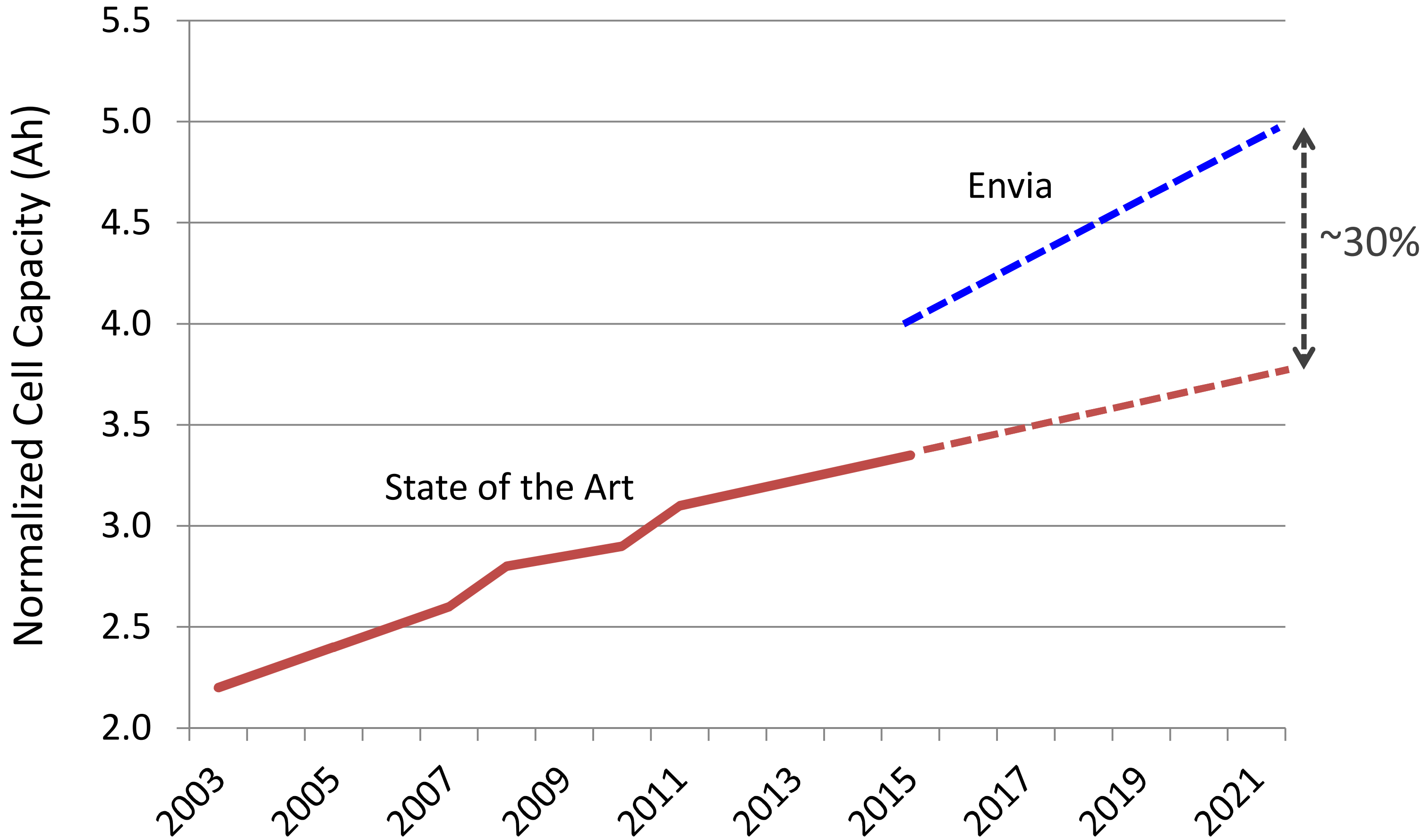
1. **Cycle life**
   - Pulverization
   - Li consumption
   - Resistance increase
   - Phase transformations
2. **IRCL (prelithiation)**
3. **Swelling**

Commercial Si-based anode materials from various vendors



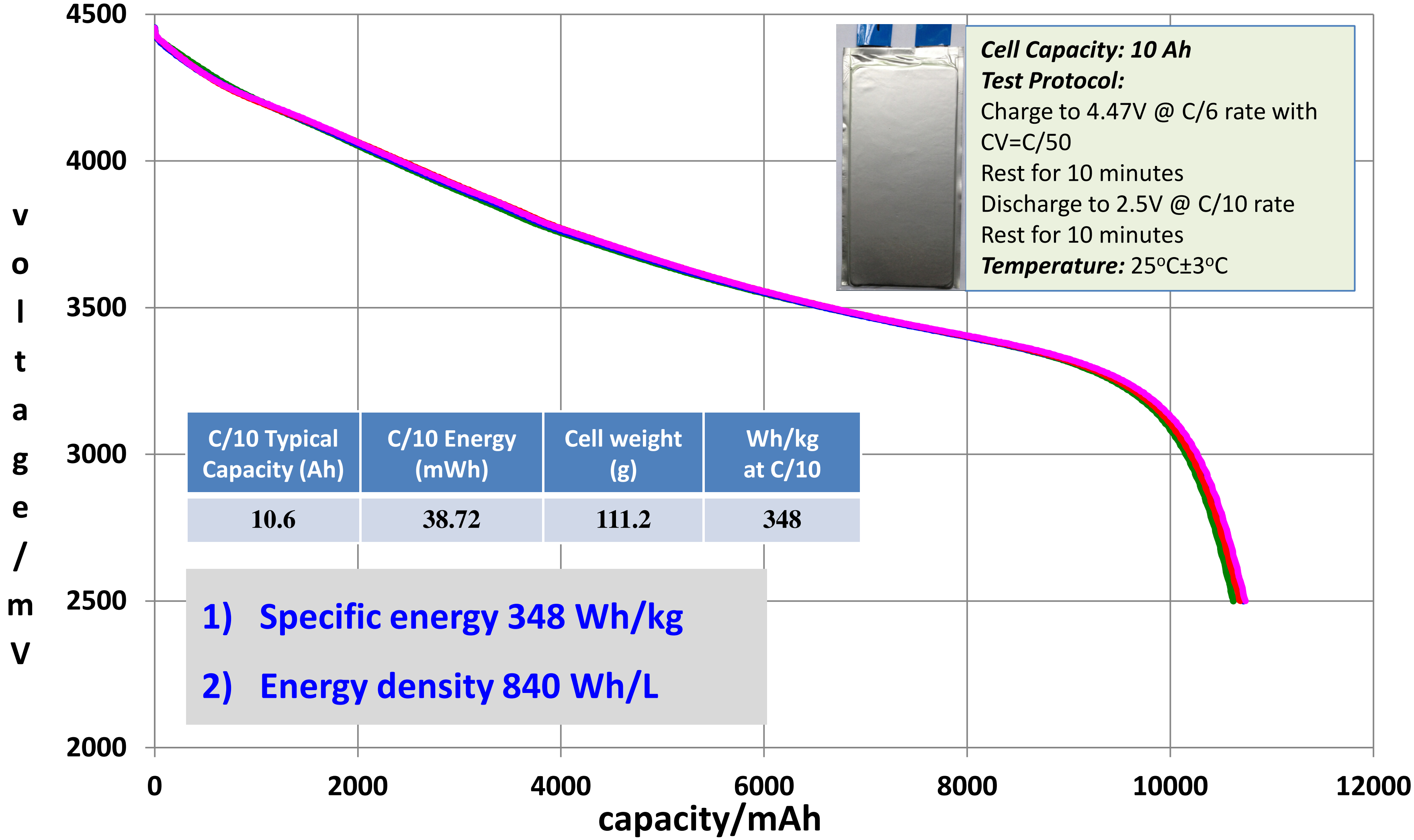
Envia develops proprietary Si anodes for automotive & consumer applications by using commercially available materials and applying its electrode formulation, processing, and coatings know-how

Discontinuity of Industry Trend



And batteries used in many mass market UAVs and EVs are lower energy density than the State of the Art trend

UAV cell

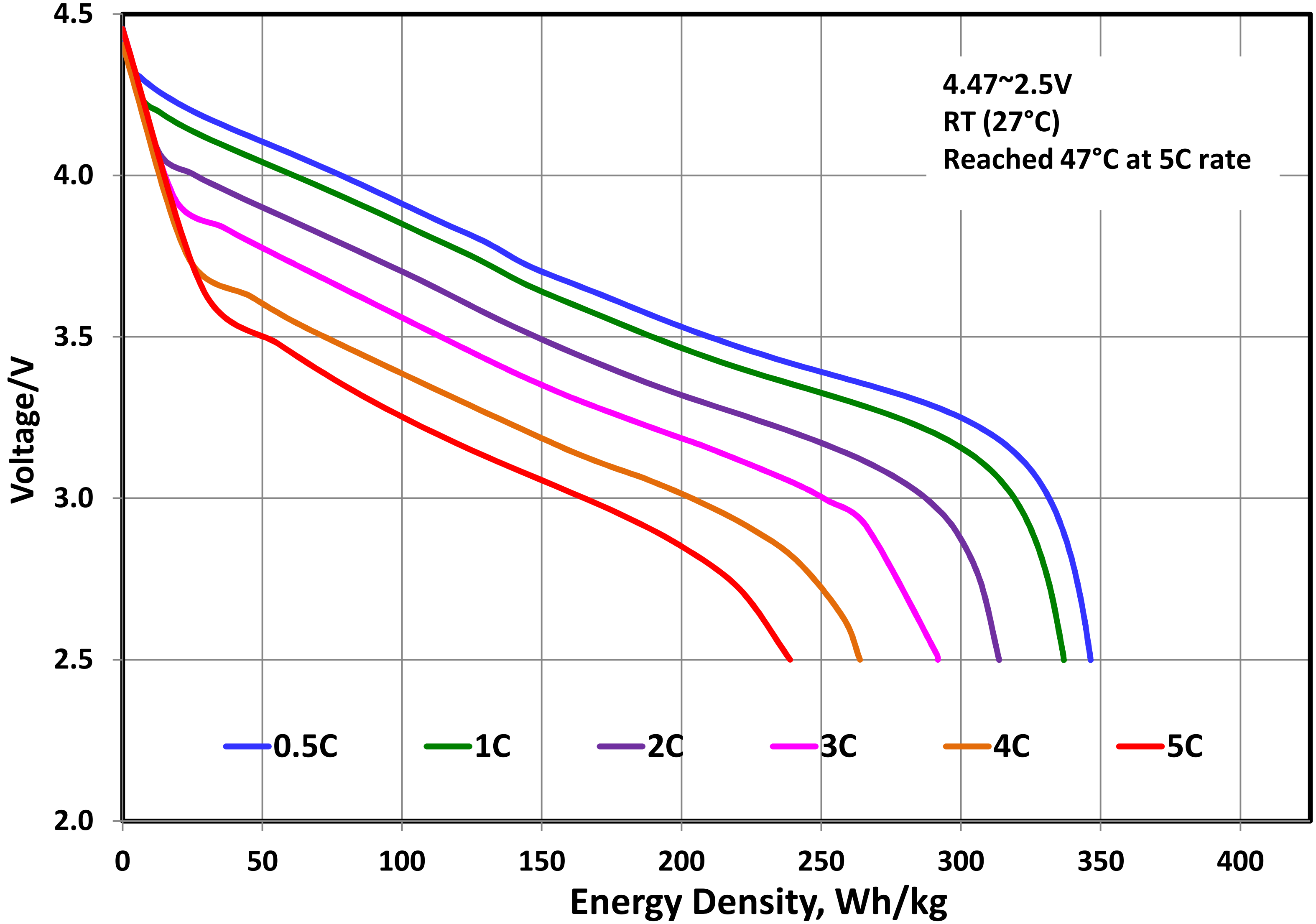


C/10 Typical Capacity (Ah)	C/10 Energy (mWh)	Cell weight (g)	Wh/kg at C/10
10.6	38.72	111.2	348

1) Specific energy 348 Wh/kg
2) Energy density 840 Wh/L

envia

UAV cell Rate Capability



envia

Current drone/UAV projects

- High altitude
  - Applications aimed at bring network capability or communications to rural areas without strong connectivity
  - Low rate applications so Wh/kg is by far the most important factor
- Low altitude
  - Delivery, leisure, or connectivity purposes
  - More complex energy storage needs
    - Smaller battery, so higher power needs (per battery) especially for take off or windy conditions
    - Hybrid battery options

UAV battery Considerations

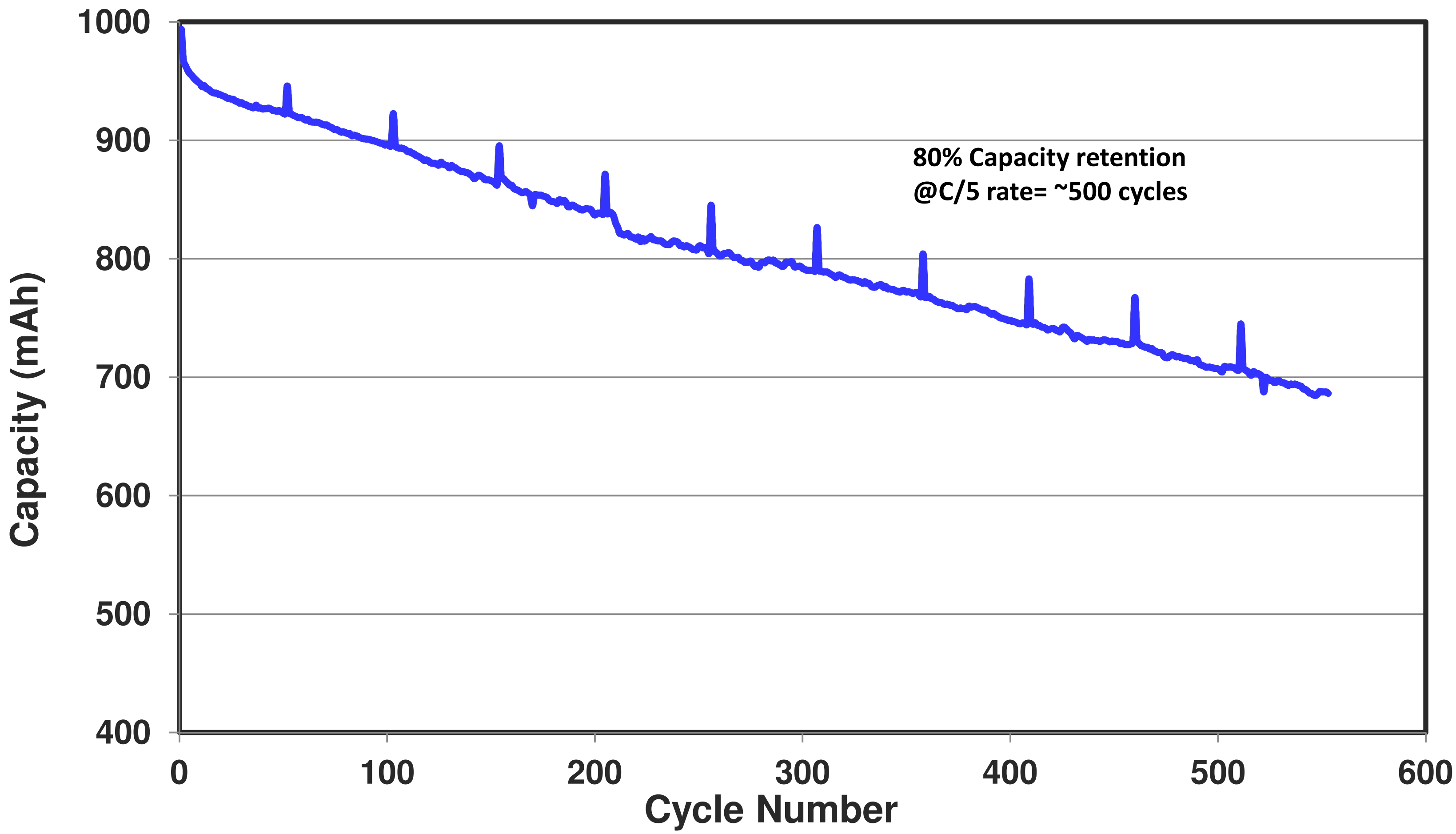
- Energy density
  - The most important metric to increase run time/distance
  - Weight reduction causes a non-linear reduction in power requirements
- Power density
  - Very application dependent
- Cycle life
  - Typically high power batteries have better cycle life (but energy is much lower so cumulative wh may be similar to high energy cells
- Safety
- Cost
  - Increasing Wh/kg to reduce $/kWh is Envia's strategy to reduce total pack cost but there are other strategies

Envia Product Roadmap

	GEN 1	GEN 2
Mobile Devices	700 Wh/L	750 Wh/L
Drone	350 Wh/kg	400 Wh/kg
EV	215 Wh/kg	300 Wh/kg
PHEV	180 Wh/kg	200 Wh/kg

- Energy density by application is determined by other performance needs like cycle life and power
- Critical that cells are designed with an application in mind

Cells for Wearable Device

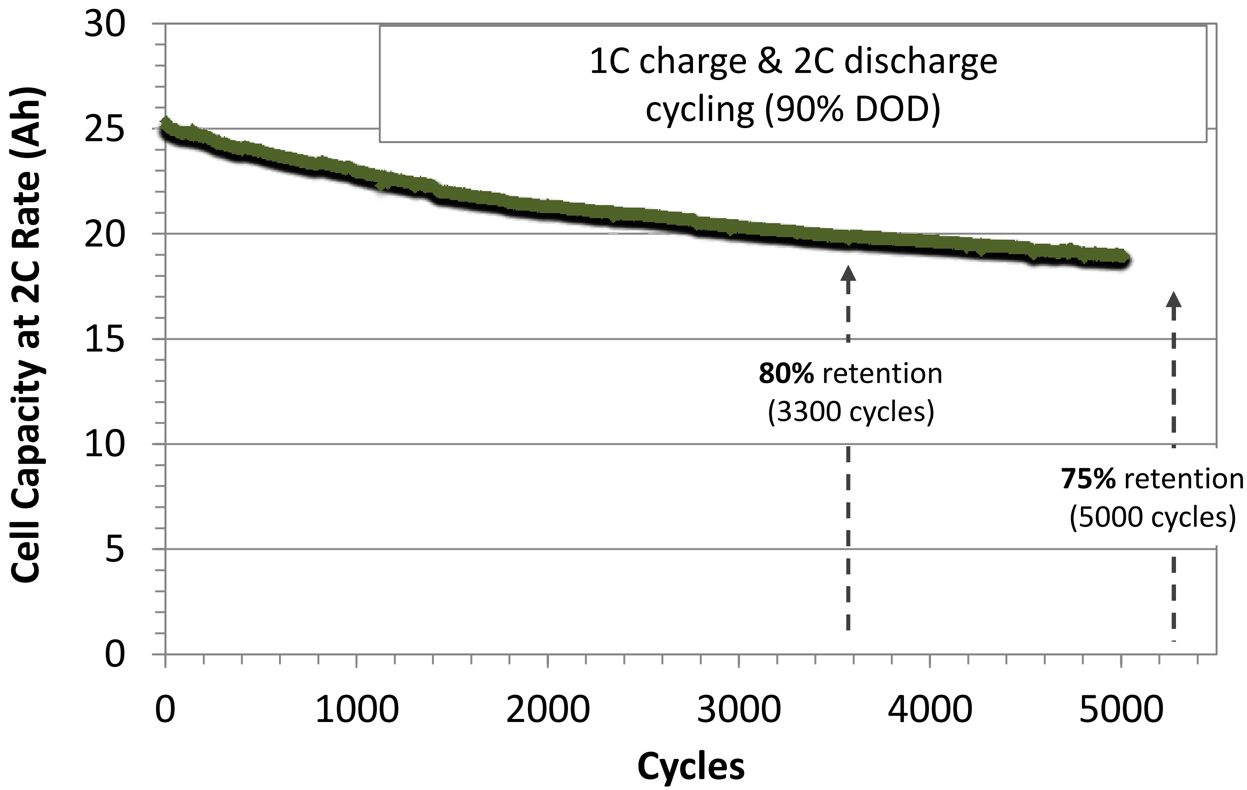


Cells for Electric Vehicles

EV Cell	Metrics
Capacity	40 Ah
Nominal Voltage	3.74 V
Specific Energy @ 1C	215 Wh/Kg
Power Density (EVPC Test) @80% DOD in 1C-30 Sec test	3300 W/L
Cycle Life (1C/1C) @ 80 % DOD	>1000

PHEV Cell	Metrics
Capacity	27 Ah
Nominal Voltage	3.74 V
Specific Energy @ 1C	180 Wh/Kg
Power Density (HPPC Test) @80% DOD in 5C-17 Sec test	4900 W/L
Cycle Life (1C/2C) @ 80 % DOD	>4500

PHEV Cell Cycling



Summary

- Advanced high energy density lithium battery technology
  - Develop custom high energy electrode materials and cells
  - 350 Wh/kg cell for UAV applications
- Leveraging government grants
  - USABC ($7.7M contract)
  - EERE ABR ($3.8M contract): General Motors, LBNL, ORNL
- Addressing key markets – automotive, consumer, UAV
  - Beta stage products in both automotive and consumer electronics markets
  - UAV beta stage product by Q4 2015