



Group14
TECHNOLOGIES

**Low Cost Manufacturing of
Advanced Silicon-Based Anode Materials**

**PI: Aaron Feaver
June 2016
Washington D.C.**

Project ID: ES268

Overview

Timeline

- Start Date: January 2016
- End Date: December 2018
- Percent Complete: 20%

Budget

- Total Project Funding
 - DOE: \$2.81M
 - G14: \$1.23M
- Funding received in FY 2016
- Funding for FY 2017

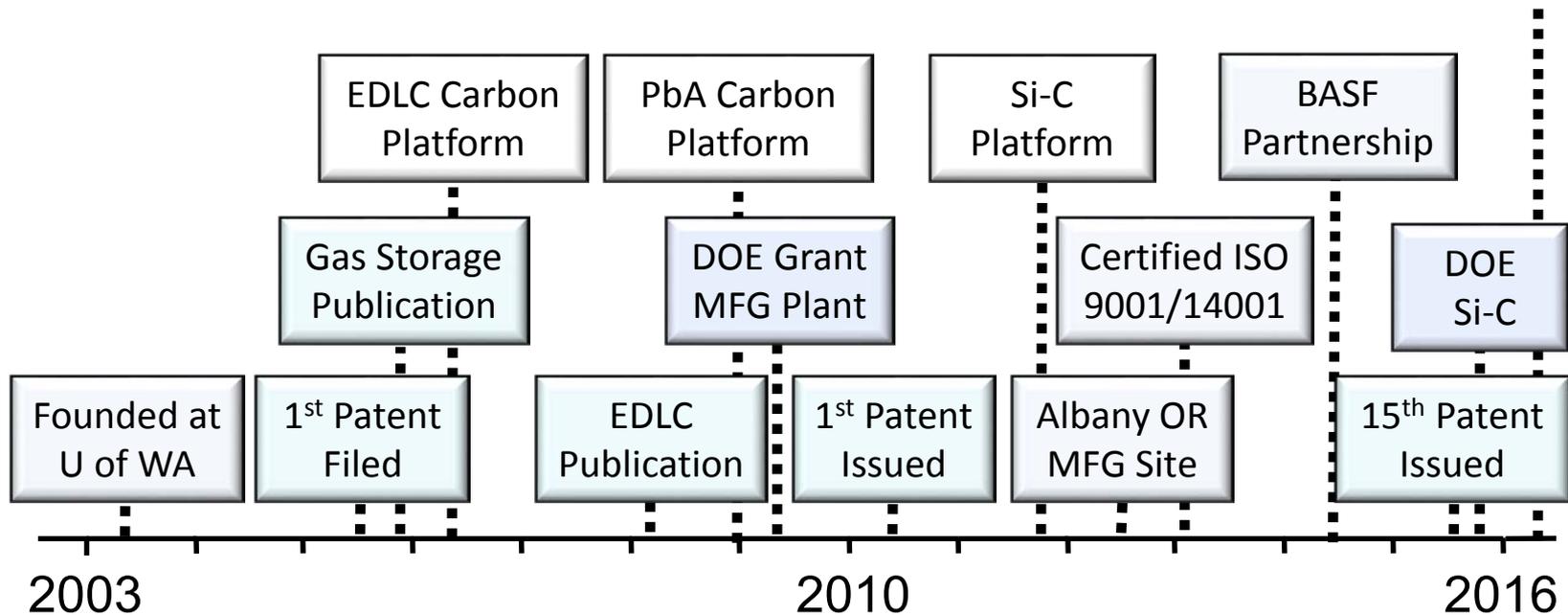
Barriers

- Cost: Anode materials that contribute towards the DOE target of \$125/kWh
- Performance: Silicon based anodes to improve Li-ion energy density for vehicles
- Life: Maintain current cycle life of graphite anode Li-ion batteries

Partners



Group14: EnerG2's Materials Legacy



Developing Stable Silicon Anode for Li-ion

- Silicon-carbon composite developed by EnerG2
 - World's foremost battery carbon technology works with any silicon
 - Internal low-cost nano-featured silicon production approach
 - Group14 is an independent spin-out from EnerG2
- 3-4x improvement in energy density over graphite
 - **Targeting 1000 mAh/g for 1000 cycles**
 - Currently midway to targets, improvement continuing
 - Cheaper than graphite on a \$/Ah basis

Relevance

- **Cost:** Current Li-ion battery cost structure will not enable widespread use of battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV)
 - Current technology trajectory will increase performance, but also increase cost
- **Performance:** BEV and PHEV range needs to be extended by increasing Wh/kg and Wh/L and maintaining power capability
- **Cycle Life:** Batteries with short life time i.e. 2-3 years can be tolerated in consumer electronics but not vehicles
- **Group14 targets:**
 - **Reduce cost** of current graphite based anodes
 - **Improve capacity** – increase EV range
 - **Maintain cycle life** of current batteries

Milestones

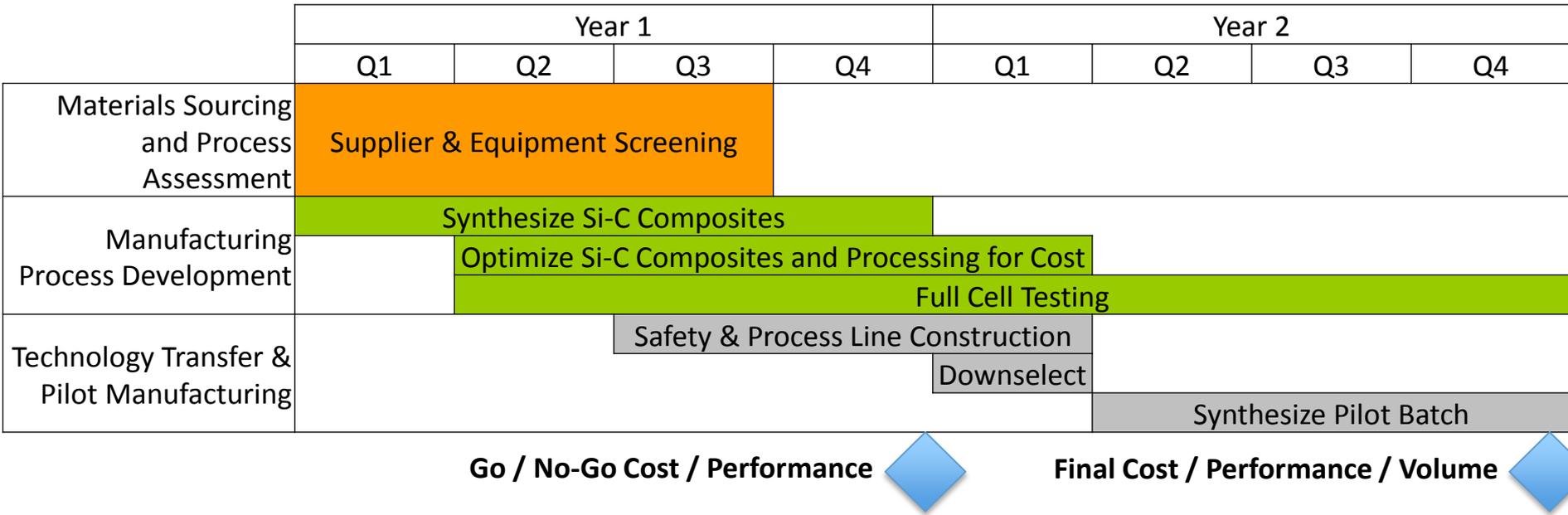
Year 1

Milestone	Type / Timing	Description
Supplier Identification	Technical / Q1	Identify minimum 2 suppliers for each new feedstock material required for Si-C composite. Materials must be available at full scale volume supporting < \$125/kWh.
Sample Down-select	Technical / Q2	Down select to 3 lab-scale silicon samples for performance and cost
Synthesize Si-C	Technical / Q3	Synthesize 1x10g Si-C with 1000 mAh/g
Synthesize Si-C	Go/No-Go / Q4	Analysis indicates that the synthesized 1x10g Si-C with 1000 mAh/g is predicted to achieve 500 cycles at a projected cost of <\$125/kWh

Year 2

Milestone	Type	Description
Synthesize Si-C 1000 cycles	Technical / Q1	Synthesize 1x10g Si-C with 1000 mAh/g; predicted 1000 cycles; < \$125/kWh projected cost
Performance Validation	Technical / Q2	Validate performance of at least one pilot-scale-synthesized material in the lab
Commission Equipment	Technical / Q3	Complete installation and commissioning of all new process equipment
Synthesis with Demo	Technical / Q4	The synthesis of 10 kg completes a demonstration 1000 mAh/g and predicted 1000 cycles at < \$125/kWh at full scale volume

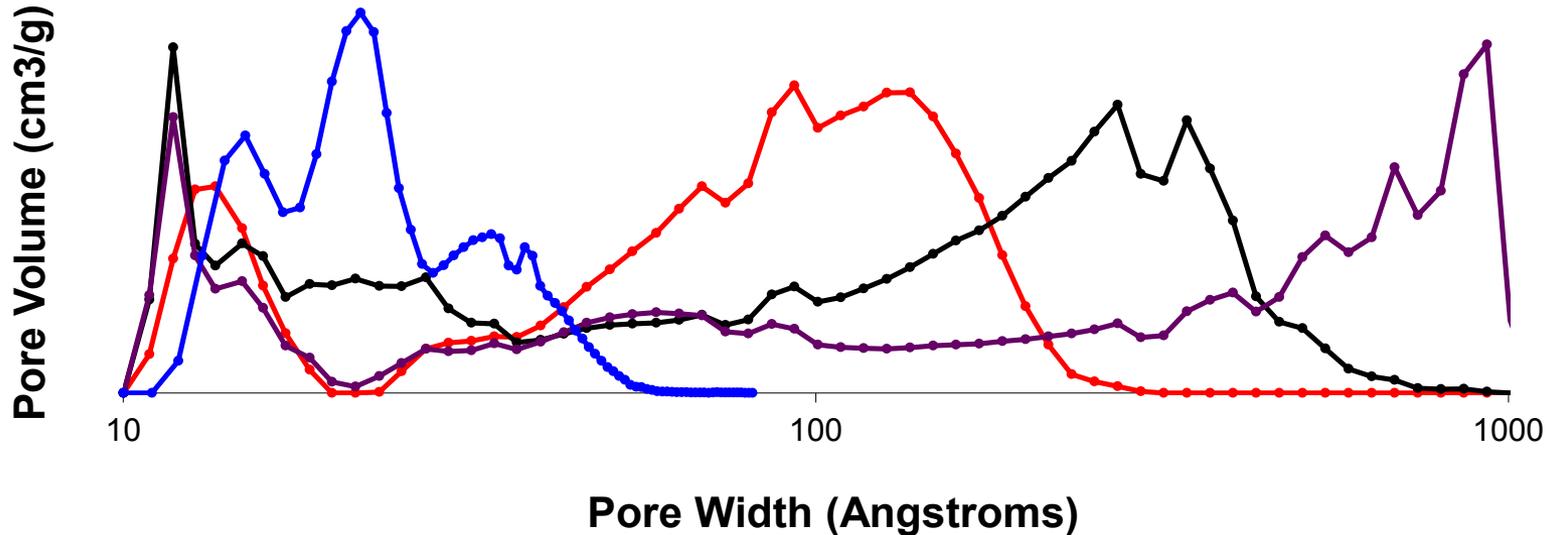
Approach / Strategy



- Leverage EnerG2 expertise in carbon materials manufacturing to create an ideal silicon support matrix material
- Develop and implement low cost silicon synthesis process compatible with the carbon platform
- Demonstrate success of the approach in full cell LIBs
- Manufacture pilot scale material in volumes suitable for qualification with LIB customers using low cost process

EnerG2's Carbon Engineering is Key

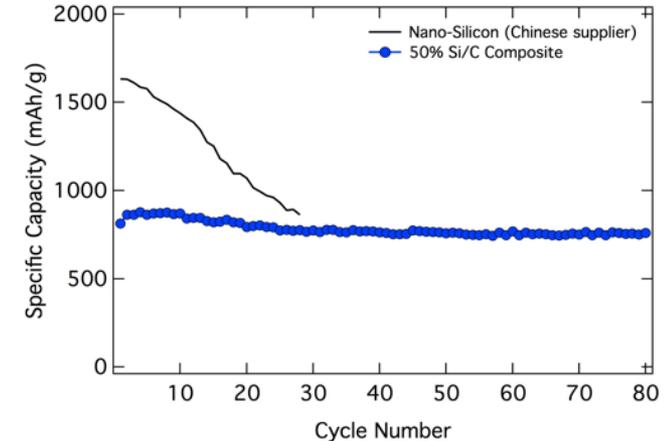
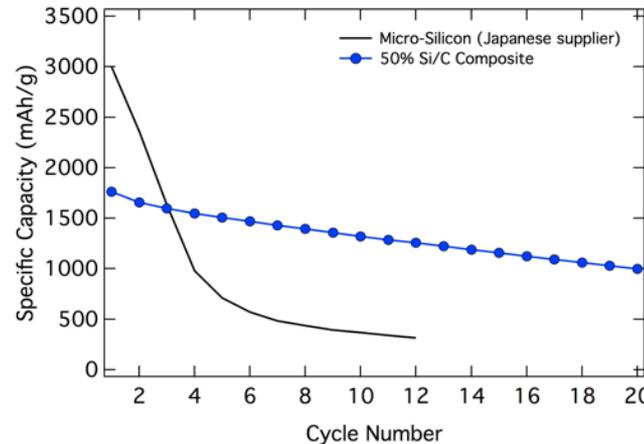
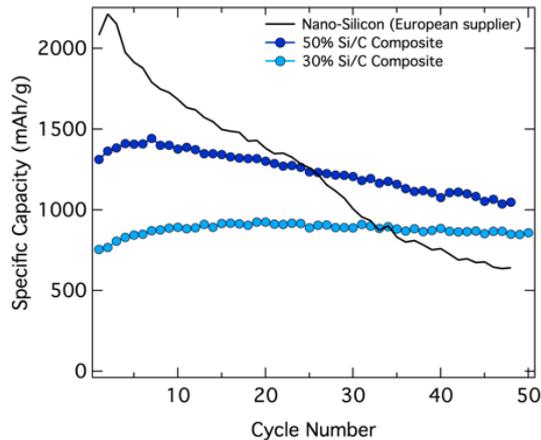
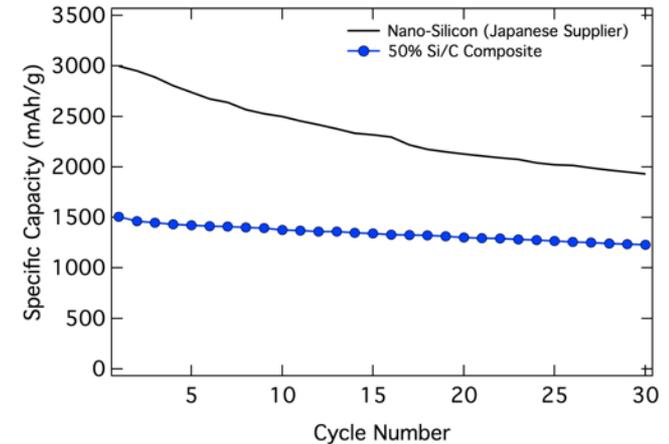
(Technical Accomplishments and Progress – Previous Work)



- Polymer chemistry derived platform allows for tailoring:
 - Pore size distribution
 - Total pore volume and specific surface area
 - Amorphous carbon bonding and structure
 - Ultrahigh purity, strategic incorporation of dopants

EnerG2 Carbon Universally Improves Silicon (Technical Accomplishments and Progress)

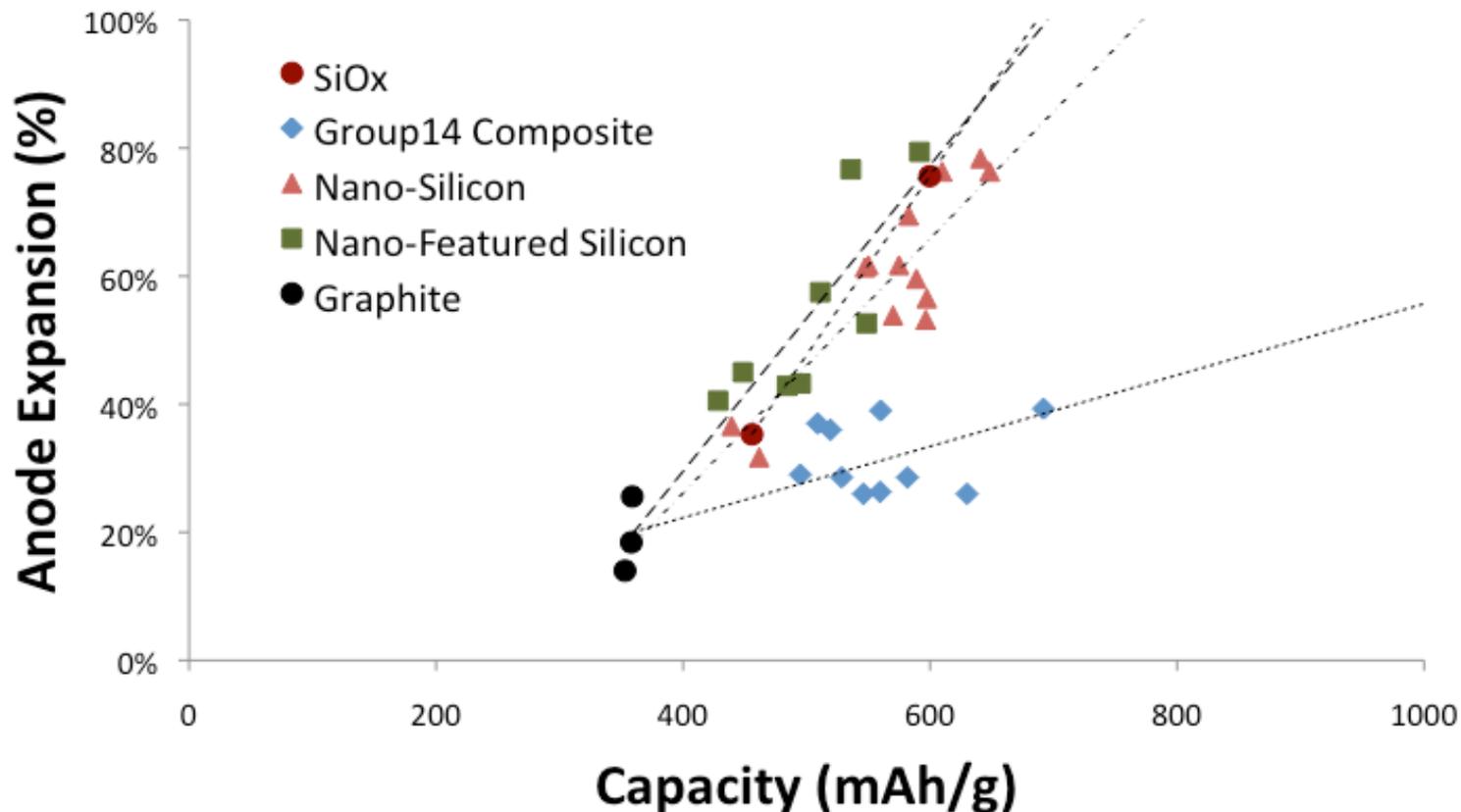
- 5-10x improvement in cycle life over pure silicon electrode
- Compounding process in Albany manufacturing facility
- Novel carbon processes compatible with all silicon materials



Data for half cell coin cells, cycling @ C/5, 0.8-0.005 V, 1/20 hold

Lower Expansion Than Other Si Approaches (Technical Accomplishments and Progress)

Expansion of Group14 SiC Compared to Other Si Technologies

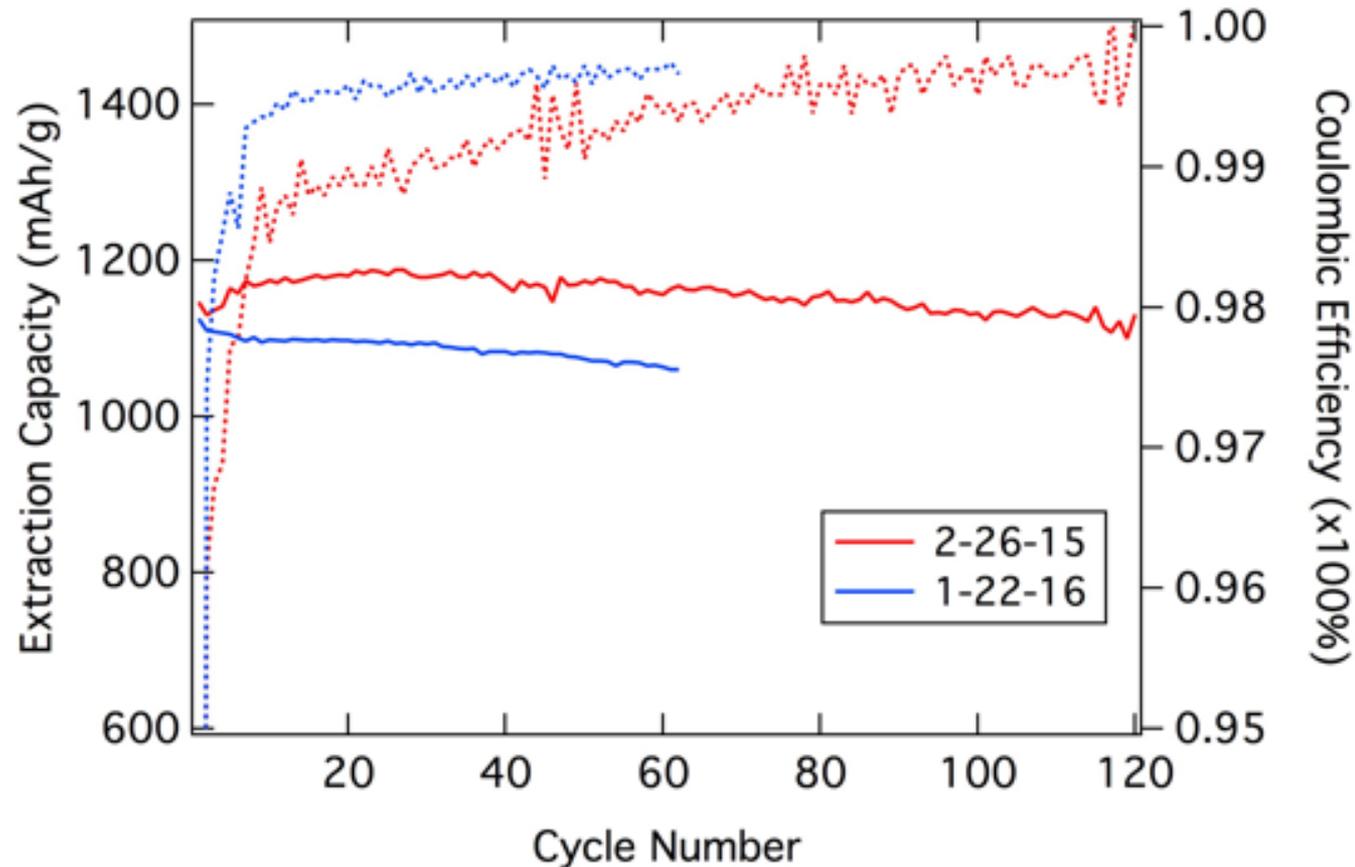


Data for half cell coin cells, graphite blends to achieve ~450 to ~650 mAh/g

Project Baseline Performance

(Technical Accomplishments and Progress)

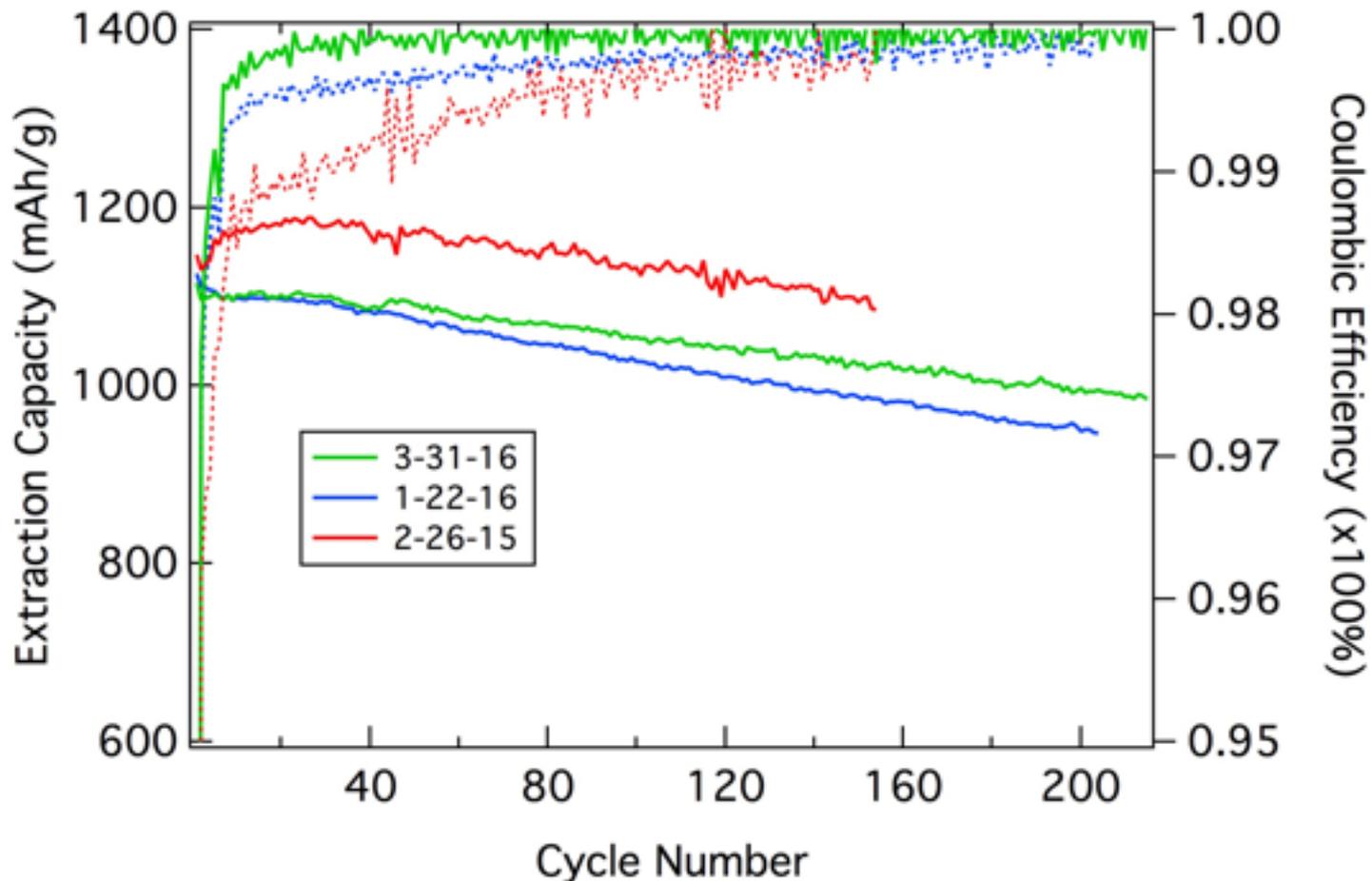
- Since proposal submission (2/26/15), we have continued funding the development of our Li ion anode material, and achieved improved Coulombic efficiency



Project Update – End of Q1 2016

(Technical Accomplishments and Progress)

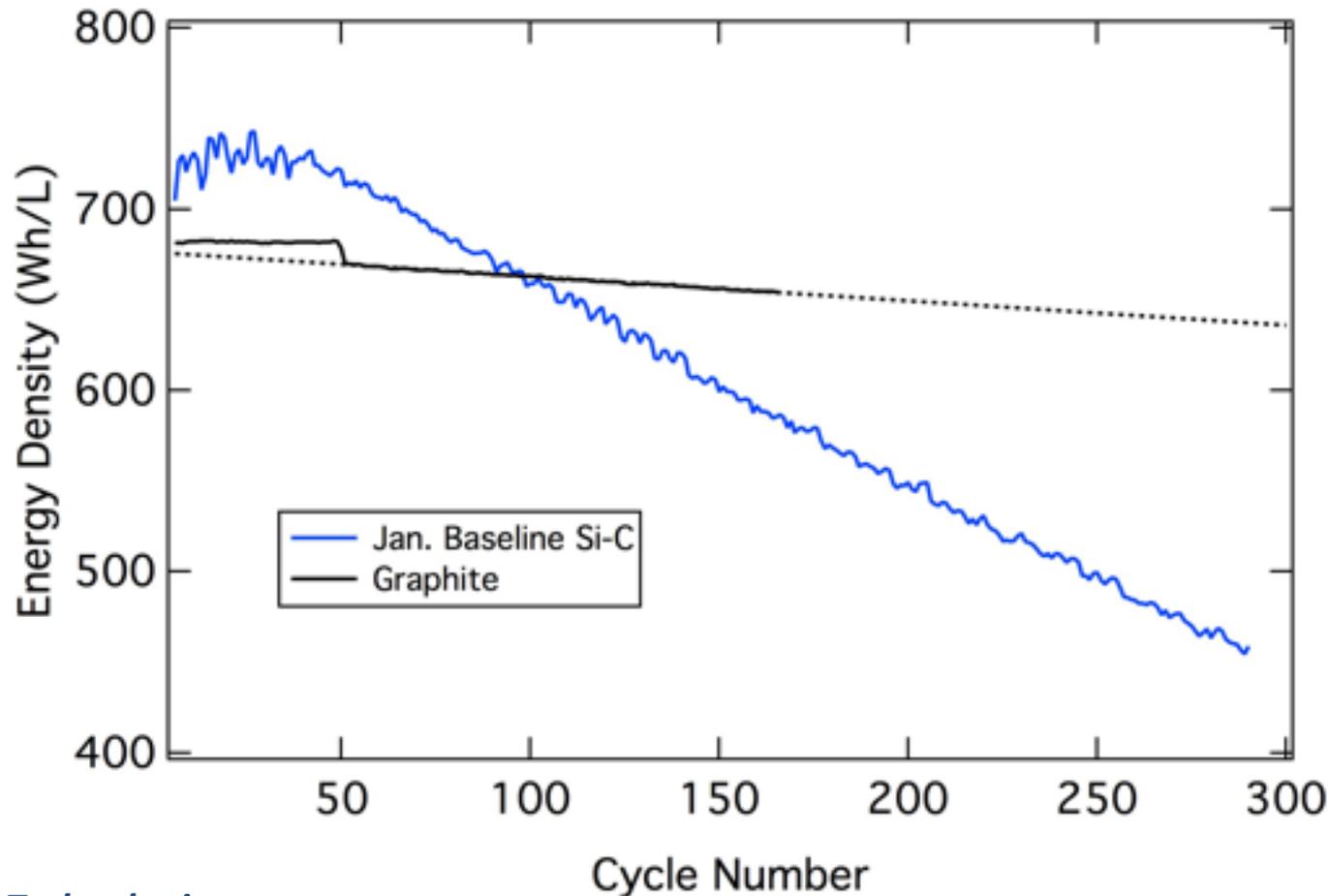
- Since last update, we have continued funding the development of our Li ion anode material, and achieved improved Coulombic efficiency and retention in half cell



Project Update – Full Cell Cycling, End of Q1 2016

(Technical Accomplishments and Progress)

- Full cell, coin cell system, anode comprising Si-C composite, conductive carbon, and binder @ ~650 mAh/g, NCA cathode, cycling @ c/2, 2.0-4.2V, 1/2 hold



Responses to Previous Year Reviewers' Comments

- This project is a new start

Collaboration and Coordination with Other Institutions



- University of Washington Subcontract
- Pauzauskie Lab: Funded graduate student
 - Material modeling
 - Advanced characterization
- PNNL Subcontract
- Chongmin Wang Group: Funded post-doc
 - Insitu TEM of Silicon Expansion
 - Advanced spectroscopy

Remaining Challenges and Barriers

- Develop and prove silicon solution that achieves technical and cost targets
- Validate solution in full cells
- Down-select and optimize material manufacturing process
- Identify, procure and install process equipment
- Commission and validate process strategy
- Produce pilot material and demonstrate full cell performance
- Validate performance and cost according to DOE targets

Proposed Future Work

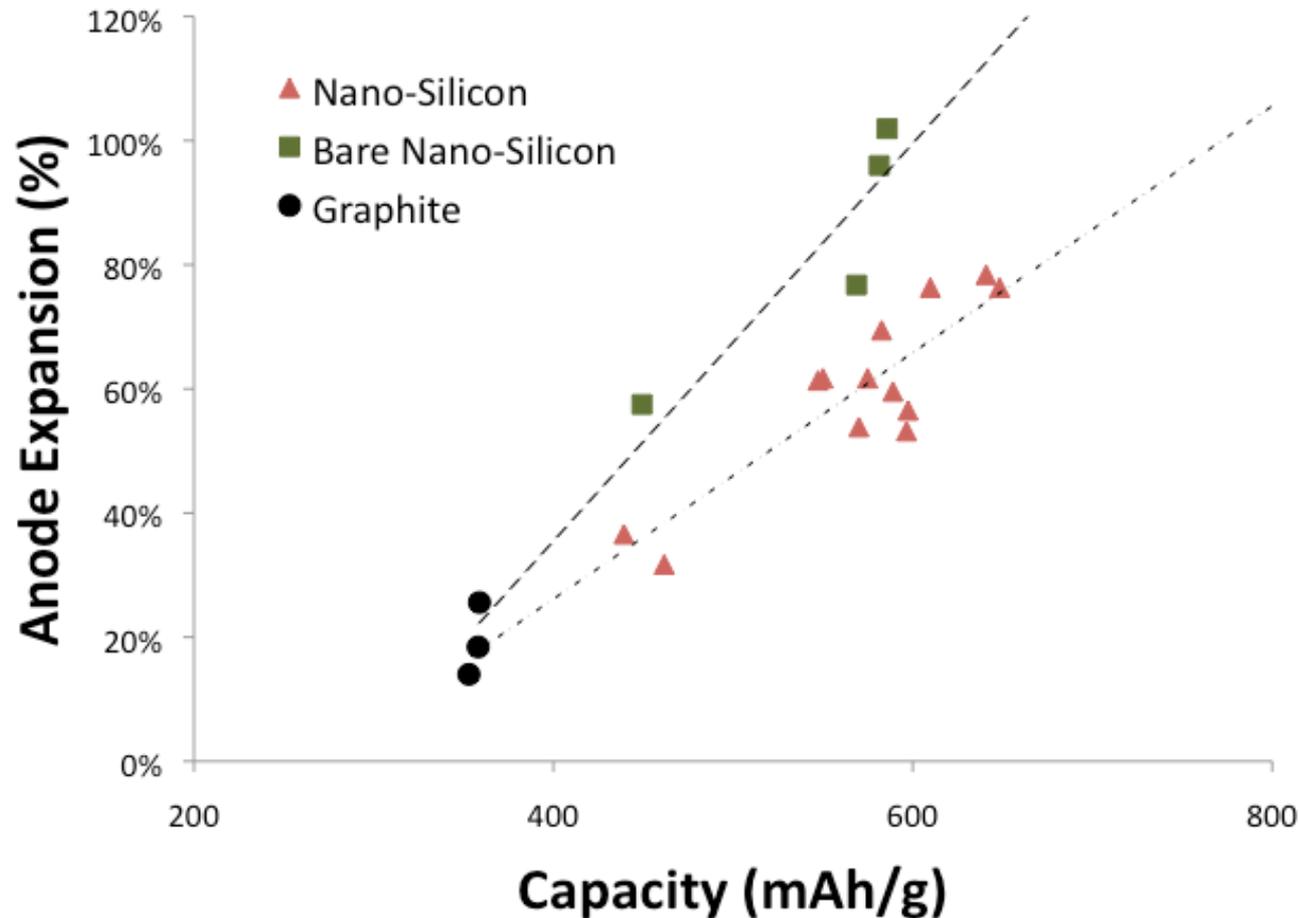
- 2016
 - Continued refinement of physicochemical and electrochemical capabilities, including Li-ion full cell testing
 - Down selection raw materials and process steps / equipment
 - Complete lab-scale materials screening to achieve desired performance in full cells while maintaining projected cost targets
- 2017
 - Pilot scale equipment installation and commissioning
 - Materials and process optimization at pilot scale
 - Pilot-scale validation of performance in full cells while maintaining projected cost target

Summary

- Group14 is combining commercially established carbon expertise to develop low-cost, high performance silicon-based anode materials
- Q1 Milestone achieved
 - Suppliers identified for feedstocks required for Si-C composite
 - Projected costs at volume < \$125/kWh, <\$0.034/Ah anode
- Progressing towards Q2-Q4 goals
 - Improvement of Si-C properties at lab scale
 - Down selection of process / equipment
- Additional activities
 - Mechanistic studies suggest our approach provides an advantage with respect to minimizing silicon volume expansion

Technical Backup Slide

Lower Expansion For Composite vs. Bare Silicon (Technical Accomplishments and Progress)



Data for half cell coin cells, graphite blends to achieve ~450 or ~ 650 mAh/g