



Pyrotek[®]

Environmentally Clean Production of
Graphite Anode Materials

Jeremy Schrooten, Ph.D.
Edward Buiel, Ph.D. (Coulometrics)
[Booth #18]

Presentation Outline

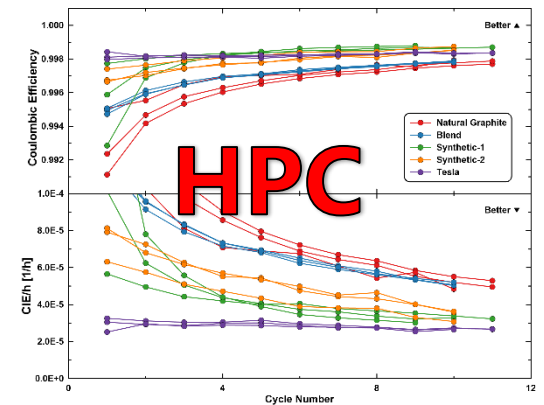


- Pyrotek has developed automotive-grade graphite for LIBs
- Near zero emission process – 100% hydroelectric power
- Cost competitive < \$5/kg in high volume

Graphite

LIBs

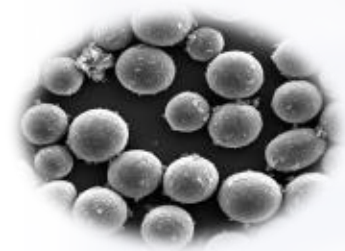
HPC



Pyrotek Milestones



1993



Pyrotek-Metaullics worked with Moli Energy to graphitize MCMB and other carbon materials

2006



Collaboration with ConocoPhillips on CPreme begins

2009



US Department of Energy award enables expansion to 4,000 MT production per year

2014



Pyrotek acquires all anode intellectual property from ConocoPhillips

2014+



Development of anode materials continues with industry leaders

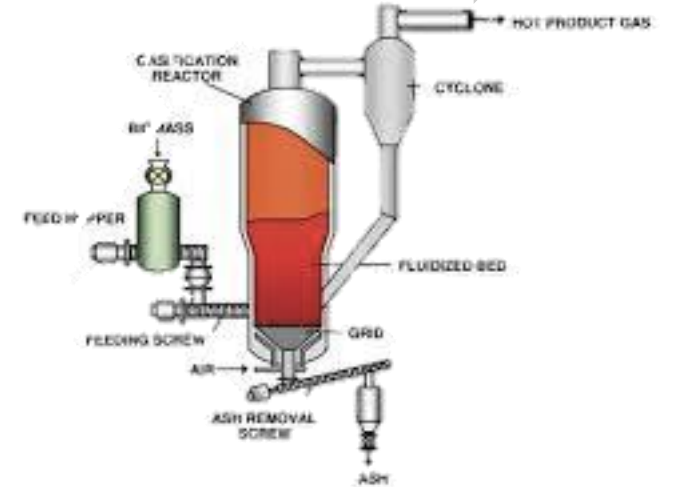
The Pyrotek Process - Natural Graphite



Natural Graphite

Purification

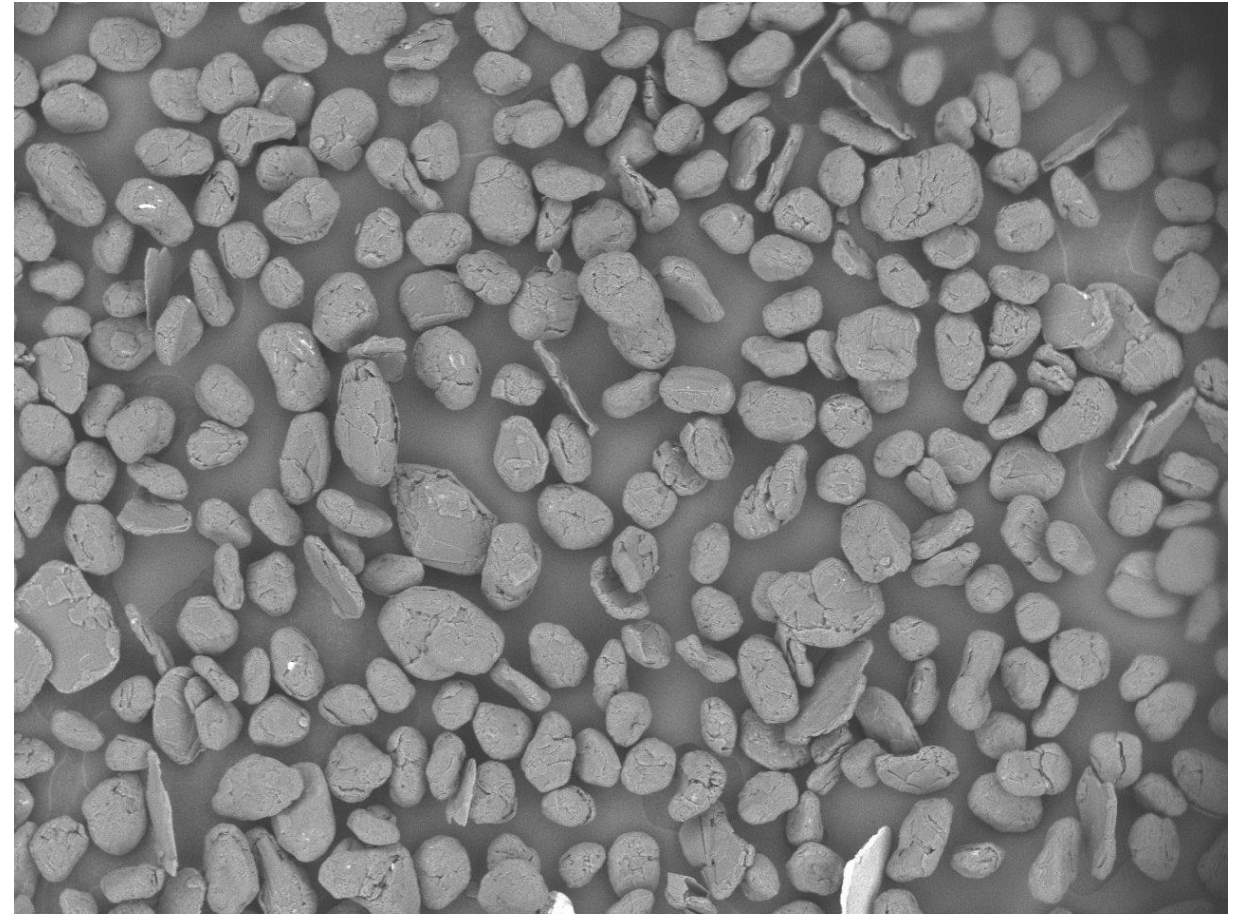
Coating



Pyrotek Natural Graphite Product



ID	Analysis	Value	Units
G16-0220	Tap Density	1.06	g/cc
	BET Avg.	3.73	m ² /g
	D ₁₀	11.09	μm
	D ₅₀	20.38	
	D ₉₀	32.17	
	LOI – Ash Content	>99.995	% Carbon
	Capacity	365	mAh/g
	1 st Cycle Efficiency	94	%



Natural Graphite
Coulometrics, LLC
2016/12/09 12:25 D4.6 x150 500 μm

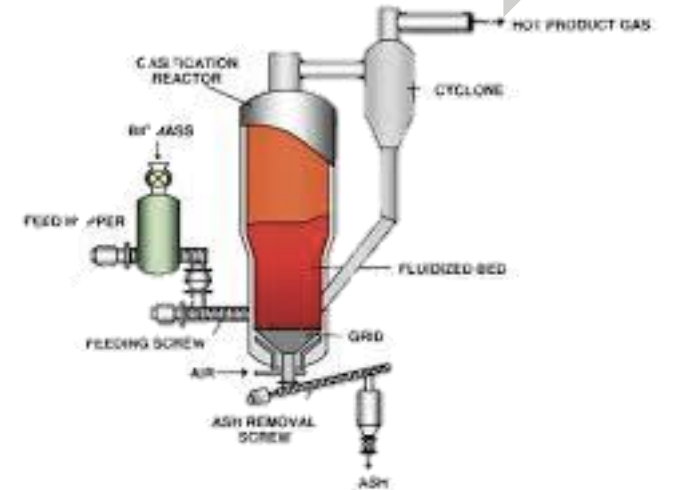
The Pyrotek Process - Synthetic Graphite



Petroleum Coke

Graphitization

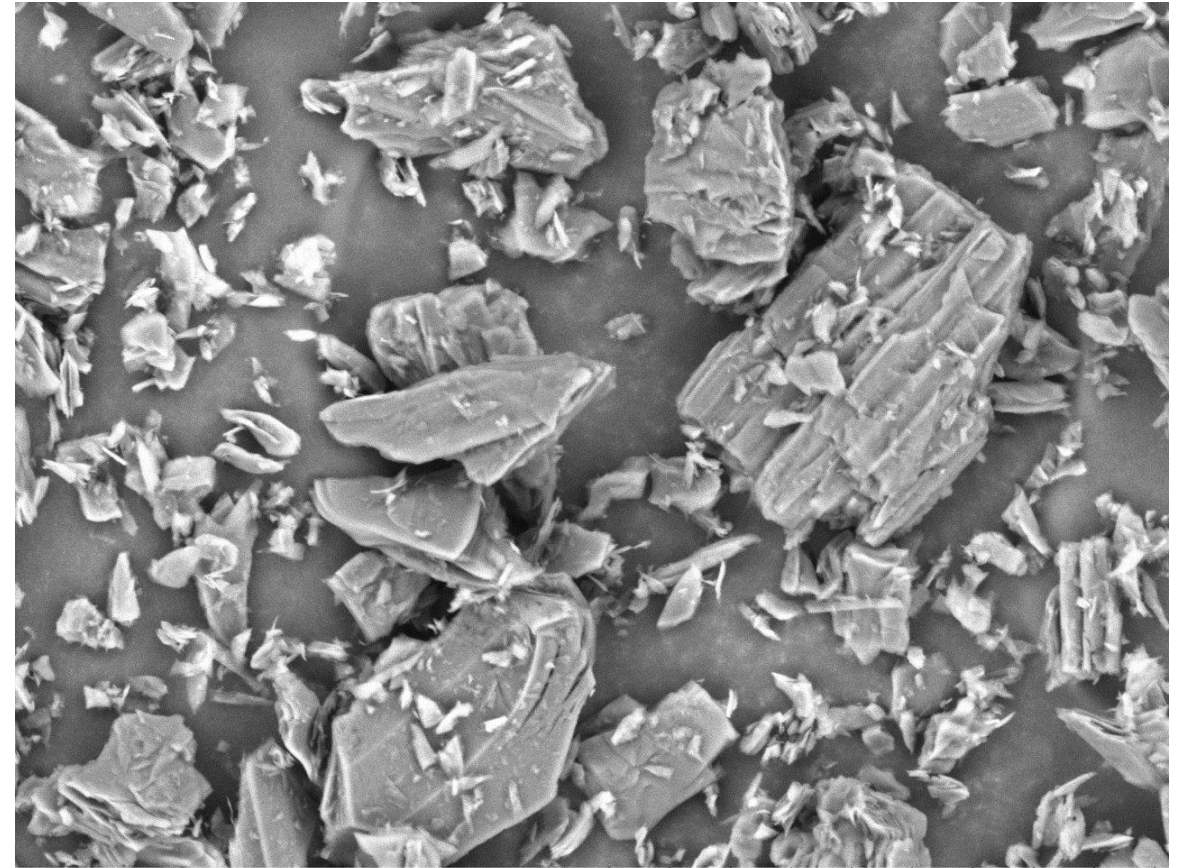
Coating



Pyrotek Synthetic Graphite Product



ID	Analysis	Value	Units
G17-0006	Tap Density	0.94	g/cc
	BET Avg.	2.11	m ² /g
	D ₁₀	9.60	μm
	D ₅₀	26.7	
	D ₉₀	49.7	
	LOI – Ash Content	>99.995	% Carbon
	Capacity	340	mAh/g
	1 st Cycle Efficiency	95	%



Synthetic Graphite
Coulometrics, LLC.

2017/01/09 11:13 D4.8 x1.0k 100 um

The Pyrotek Process - Clean



“High Tech” Supply Chain is Under Scrutiny

Bloomberg

How Tesla Motors Inc's electric car batteries are adding to China's pollution woes

ELISABETH BEHRMANN, BLOOMBERG NEWS March 14, 2014 12:18 PM ET
More from Bloomberg News



The Washington Post



MIT
Technology
Review

“The batteries that power our high-tech lifestyle are built using materials extracted in dirty, often life-threatening conditions.”

The Pyrotek Process - Clean



Today's common anode processing technology is toxic

Chemical Purification



Acheson Graphitization



The Pyrotek Process - Clean



Pyrotek anode processing is clean

Renewable Hydropower

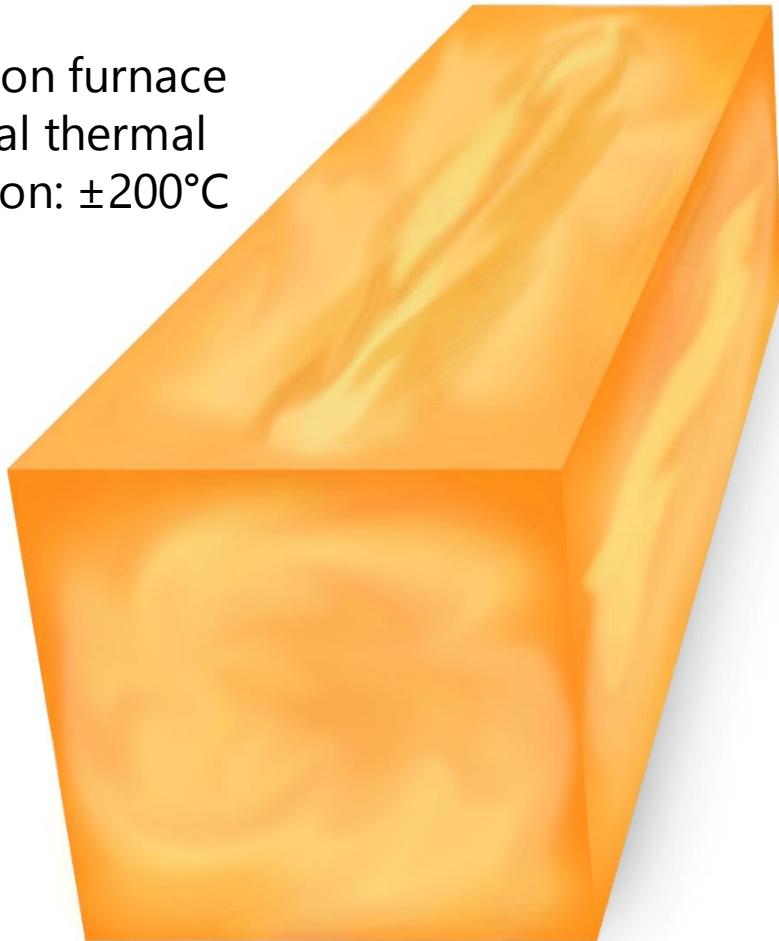
State of the Art Facility with near zero emissions



Comparative Thermal Consistency



Acheson furnace
typical thermal
variation: $\pm 200^{\circ}\text{C}$



Schematic of Acheson
Furnace Thermal Variation

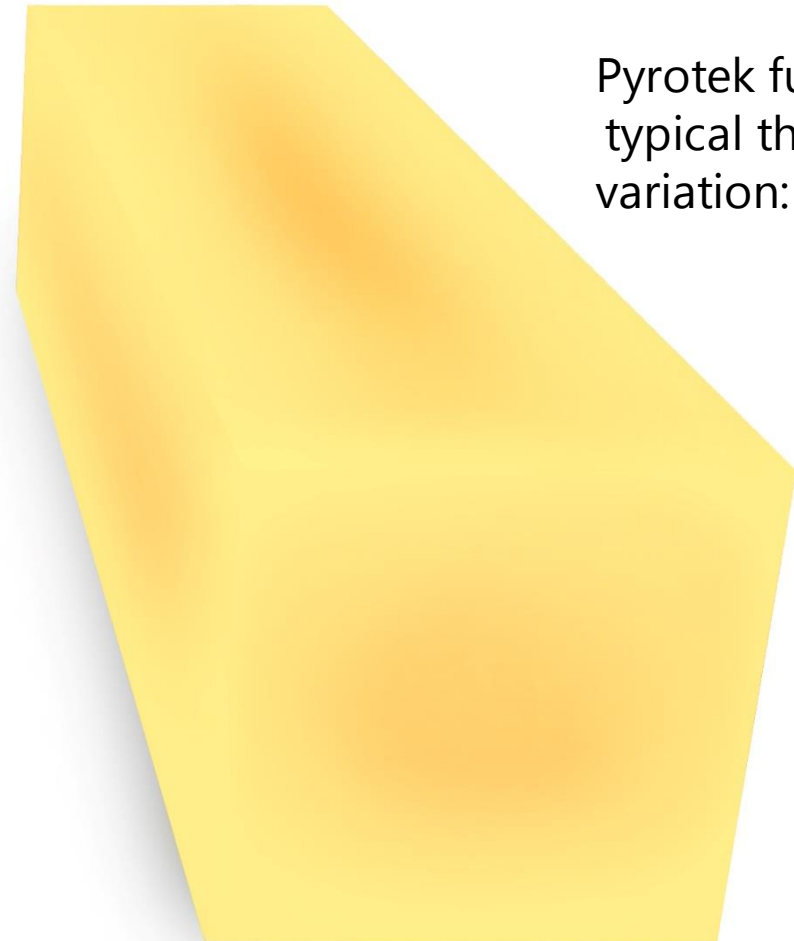


2000 3000

Temp (K)

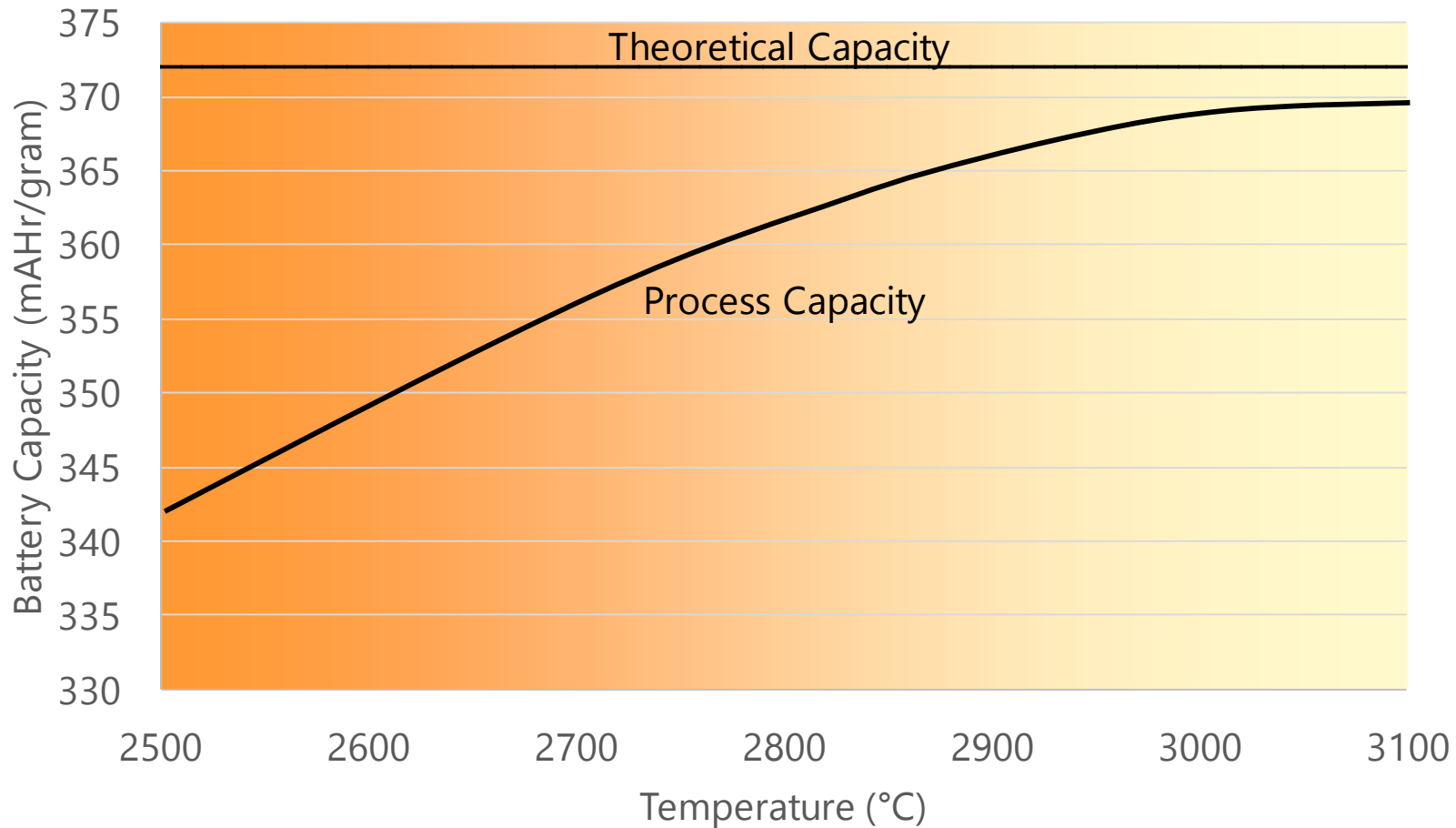
Blackbody
radiation color
scale

Pyrotek furnace
typical thermal
variation: $\pm 50^{\circ}\text{C}$



Schematic of Pyrotek
Furnace Thermal Variation

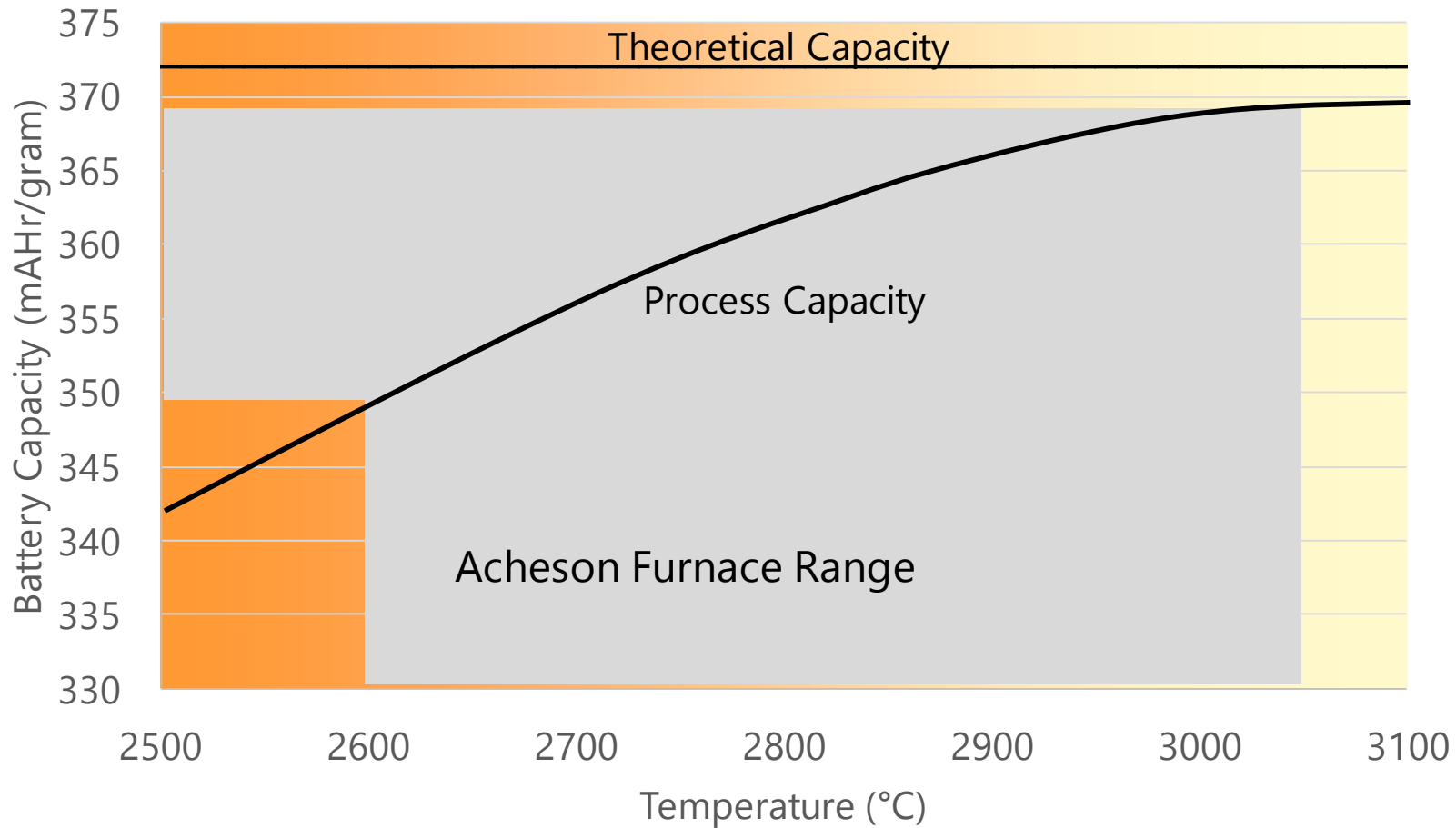
Why do we care about Consistency?



- Tightly controlled and consistent thermal parameters create uniform end product qualities and predictable battery performance
 - Higher temperature relates to improved anode capacity
 - A narrower temperature range provides higher nominal performance and minimizes capacity variance

*Chart data is approximate and is for comparative purposes only

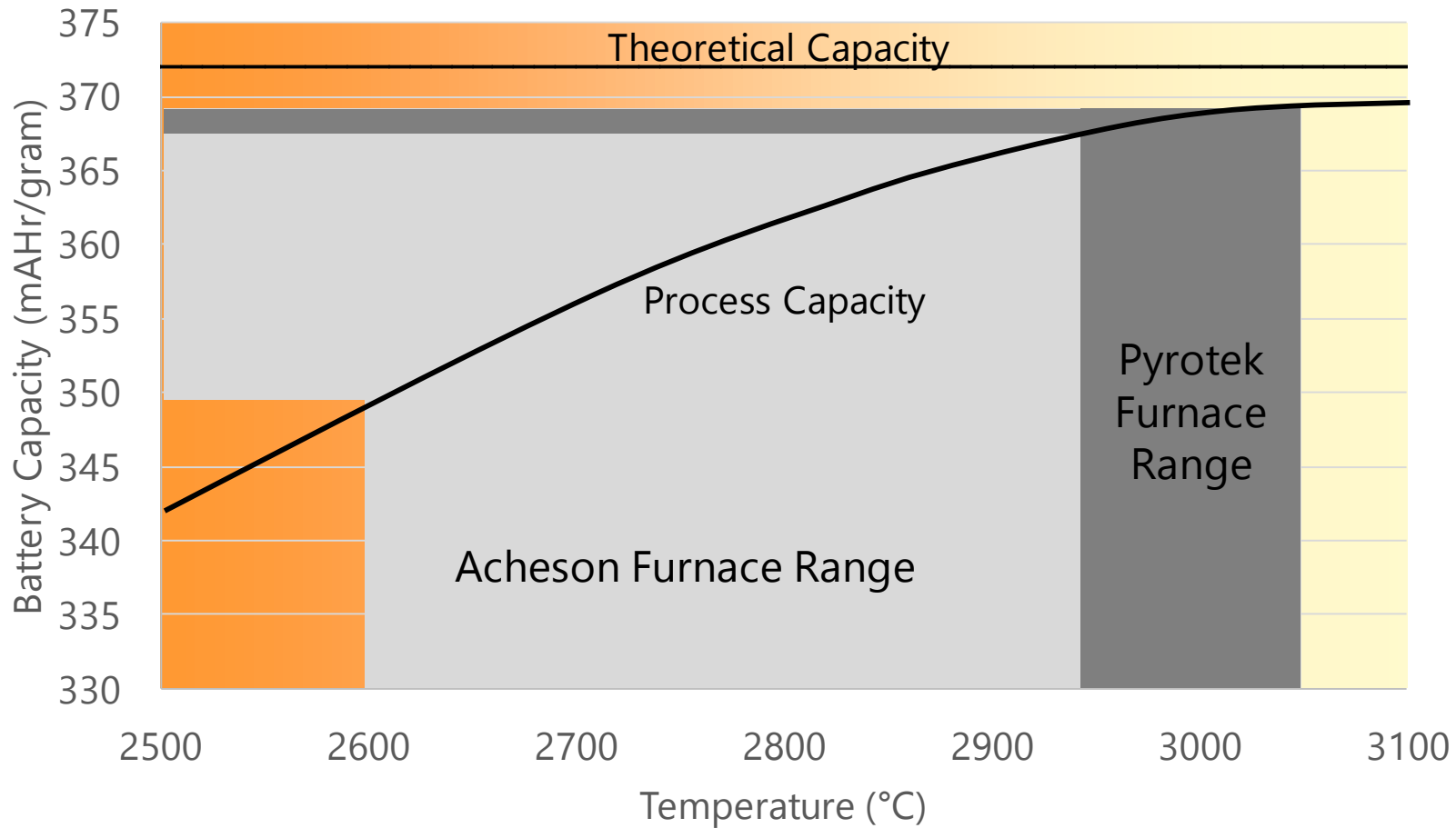
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Coulometrics

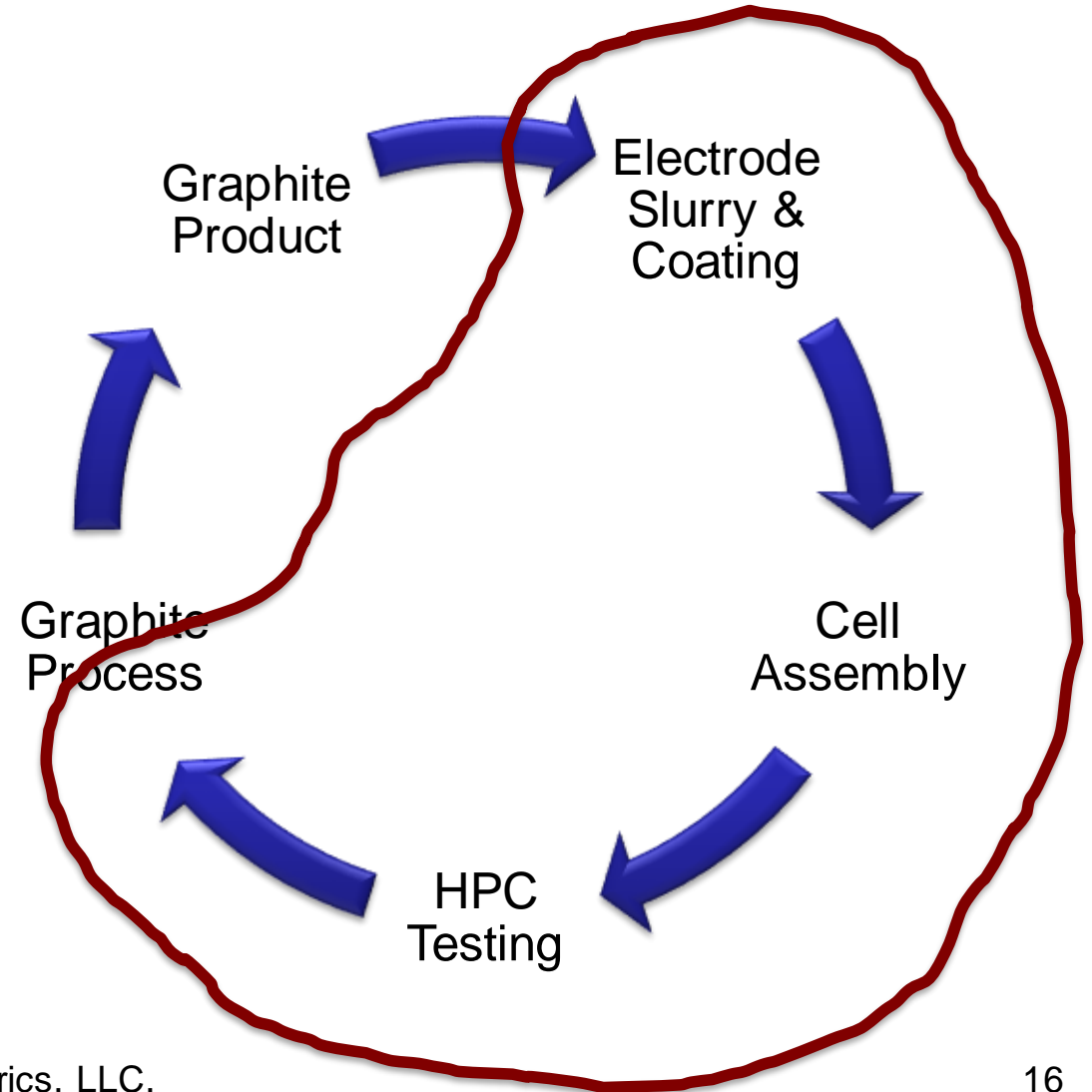
ADVANCED BATTERY CONSULTING AND MANUFACTURING

Prepared by: Dr. Edward R. Buie
President and CEO
Coulometrics, LLC.

Date: January 30, 2017

Coulometrics Capabilities and Technology

- New Graphite Materials through New Processes
- Full slurry development
- Electrode coating, calendaring, and slitting
- Cell life testing using HPC at 40°C



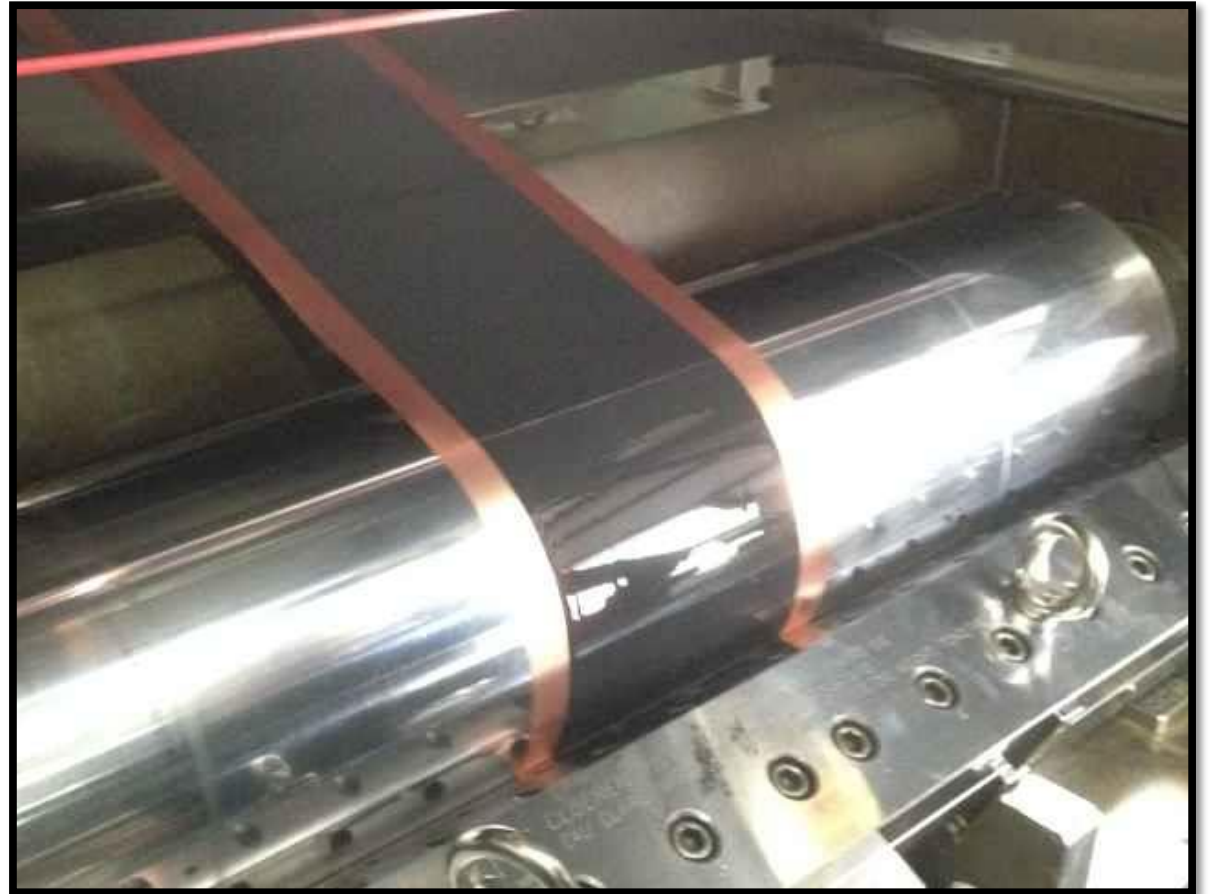
Slurry Development

- Mix graphite with conductive additives to develop a slurry suitable for slot-die coating
- Properties:
 - + Carbon black must be well dispersed
 - + Good stable dispersion
 - + No agglomeration
- **Stable dispersions** are developed for each graphite material regardless of how long it takes



Electrode Coating

- Electrode coating is critical to good battery performance:
 - + No clogging of the die
 - + Good uniform coating
 - + Good adhesion
 - + Stable for at least 48h



Electrode Coating

Pilot Scale Coating



Production Scale Coating



Calendering and Assembly

Electrode Roll Pressing

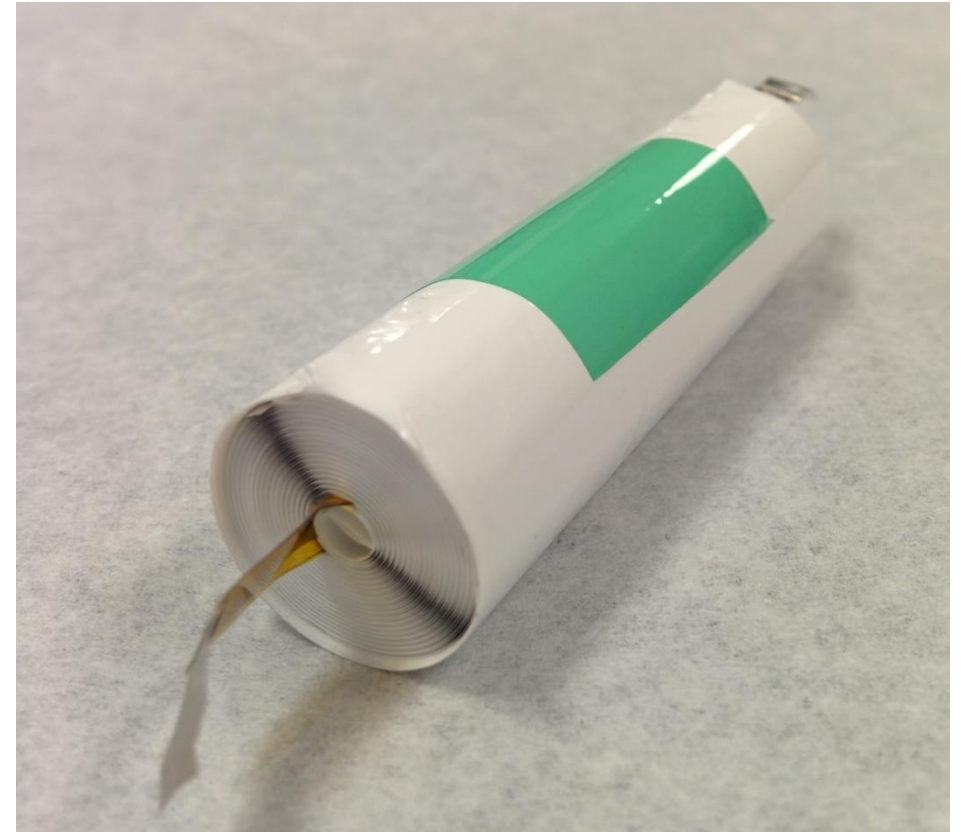


Cell Winding



Cell Assembly and Testing

- 18650 batteries are assembled
- Cathode:
 - + NMC 111
- Electrolyte
 - + EC/EMC 3:7 + 1M LiPF₆
 - + Additives:
 - Standard LIB Additives
 - Coulometrics proprietary additives for improved SEI layer formation and improved life
- Typical capacity:
 - + 2.2-2.4 Ah



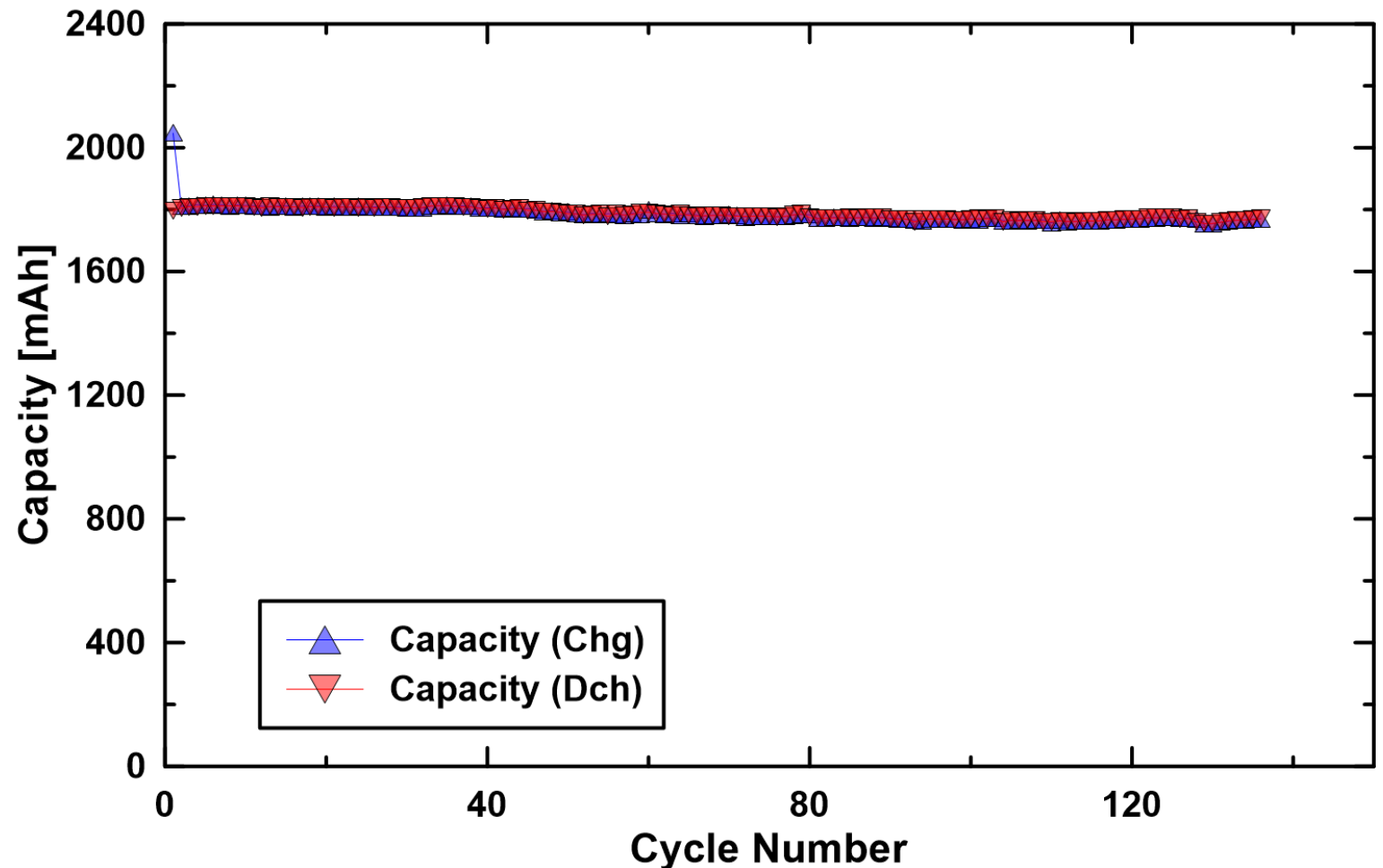
Cell Testing

- Initial formation is completed using Neware system
- Cell capacity is measured
- Cell is cycled 5-10 times



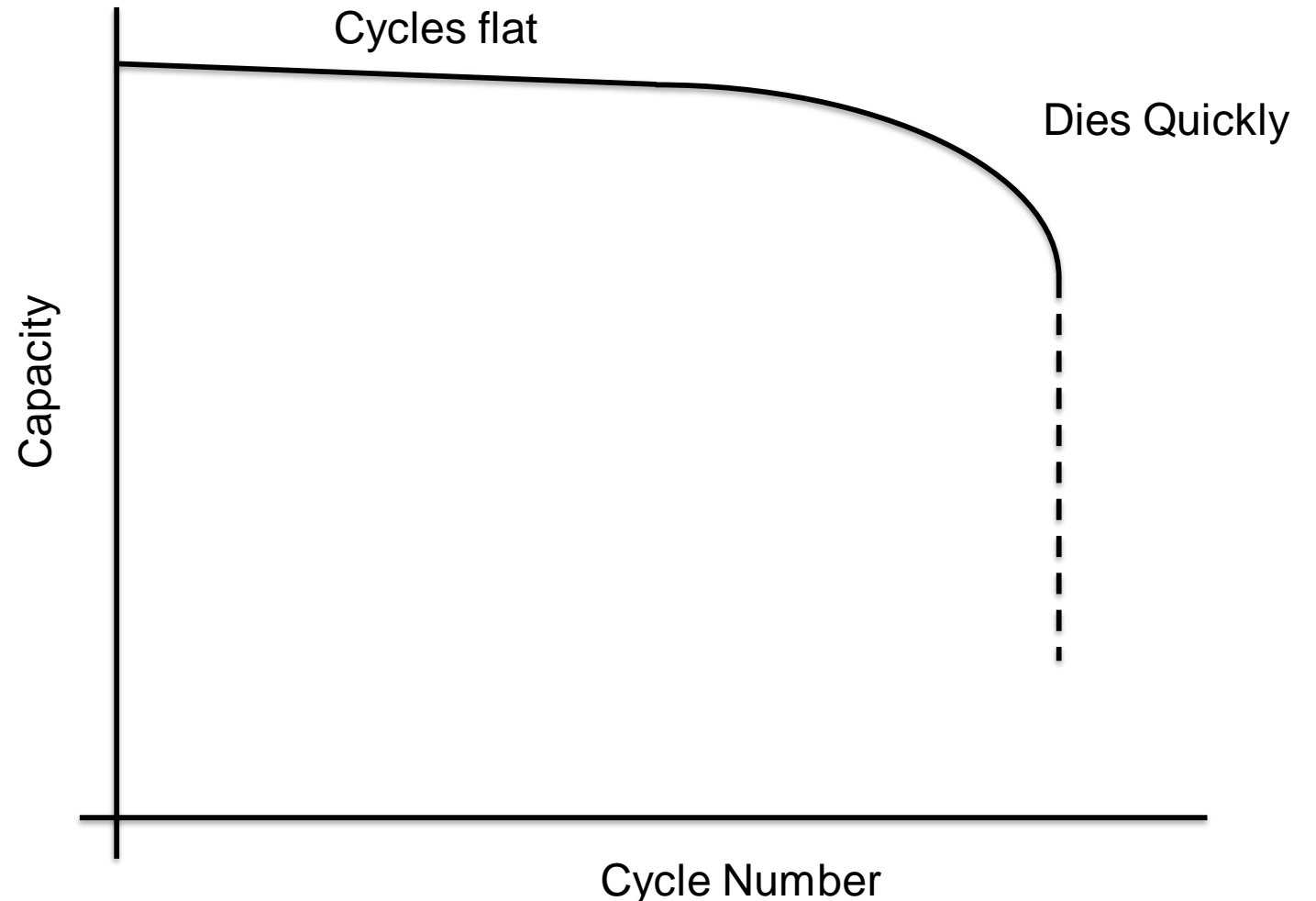
Standard Cell Cycling at 21°C

- Cells cycle with limited capacity loss
- Variation in cell capacity are more a reflection of temperature stability than cell capacity loss



Cell Cycling

- How do you test for cell life?
 - + If you cathode / anode are good (and they should be) then the same amount of lithium
 - + Cell will cycle with almost constant capacity and then die quickly
 - + Can take 1-2 years to cycle a cell at 40°C
 - + Higher temperatures can lead to new failure mechanisms
- What can you do?
 - + High Precision Coulometry
 - Measure loss of electrons per cycle due to oxidation/reduction of the electrolyte





jeff dahn win talk



All

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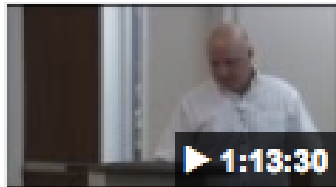
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Tools

About 127.000 results (0,36 seconds)

Professor Jeff Dahn - WIN Seminar Series - YouTube



<https://www.youtube.com/watch?v=9qi03QawZEK> ▼

Sep 6, 2013 - Uploaded by Waterloo Institute for Nanotechnology

On July 30th, 2013, Professor **Jeff Dahn** of Dalhousie University delivered ...

Professor **Jeff Dahn** - WIN ...

Lithium-Ion Battery Expert Jeff Dahn About To Start At Tesla Motors ...

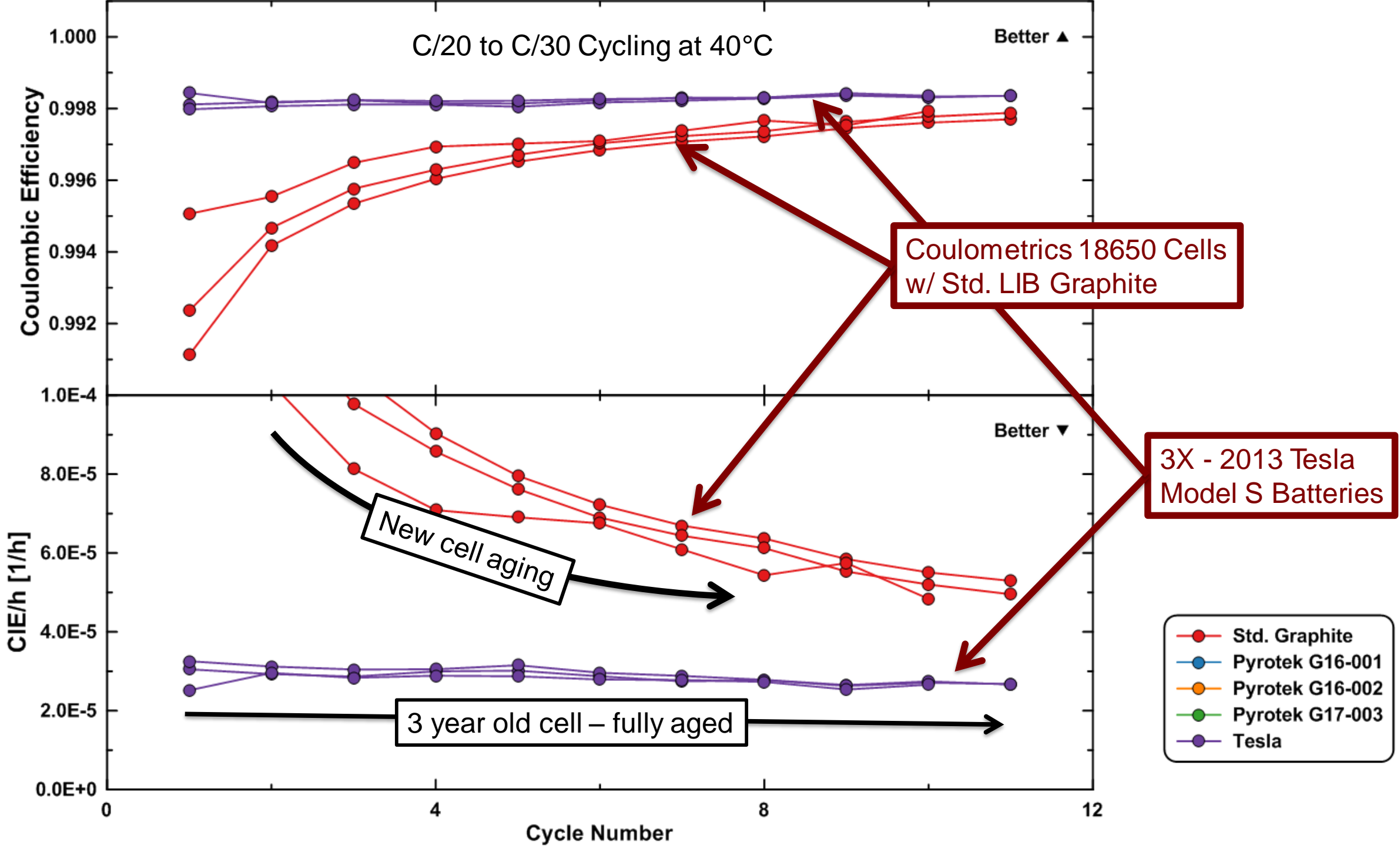
<https://cleantechnica.com/.../lithium-ion-battery-expert-jeff-dahn-start-tesla-motors/> ▼

May 30, 2016 - **Jeff Dahn** was quoted by Quartz as saying that the research goals for his work with Tesla are pretty much the standard ones in the industry Can we talk now lithium Solid State for Tesla? ... 7 Reasons Why Solar & Wind Win.

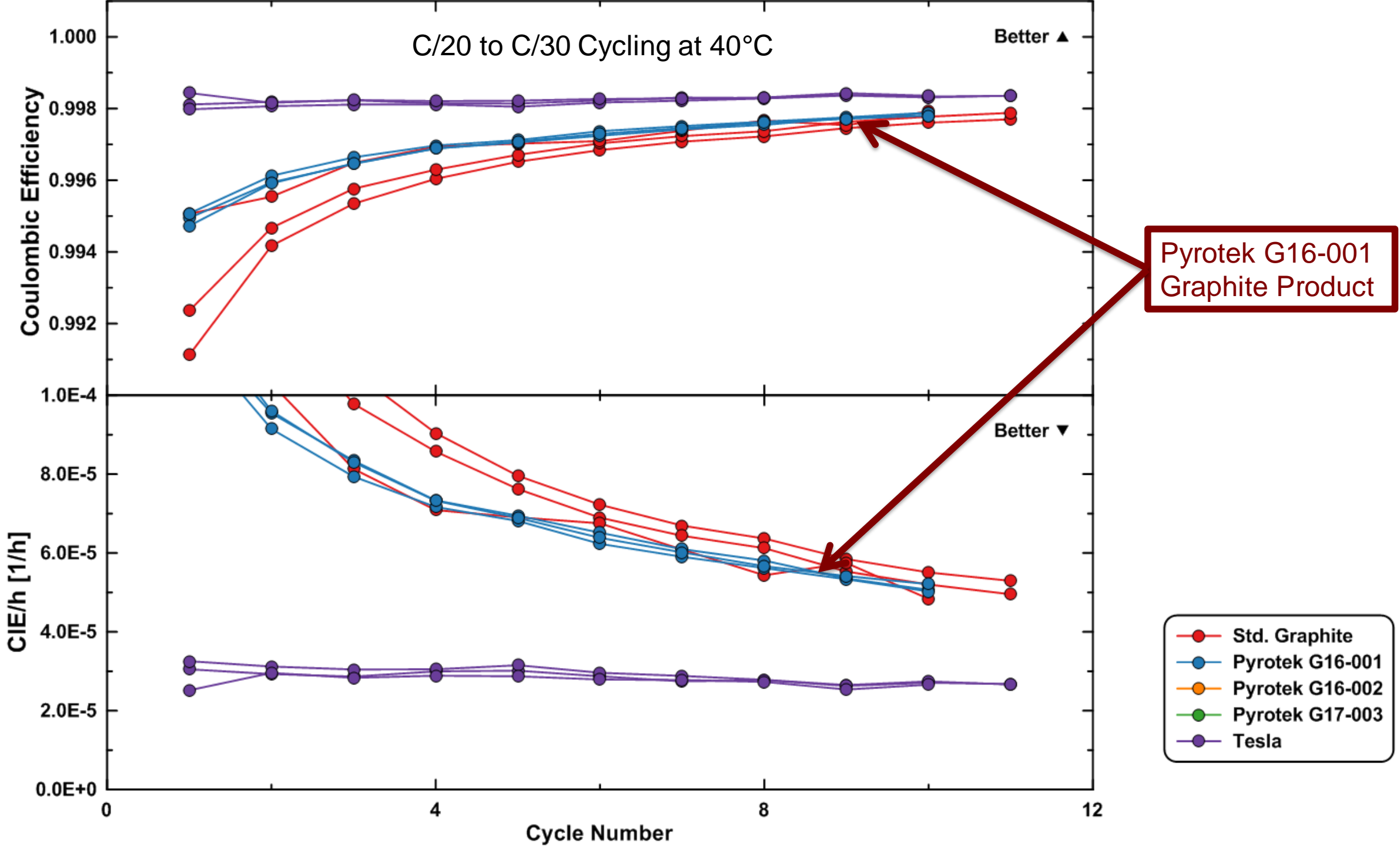
Professor Jeff Dahn Win Seminar Series - World News

https://wn.com/Professor_Jeff_Dahn_Win_Seminar_Series ▼

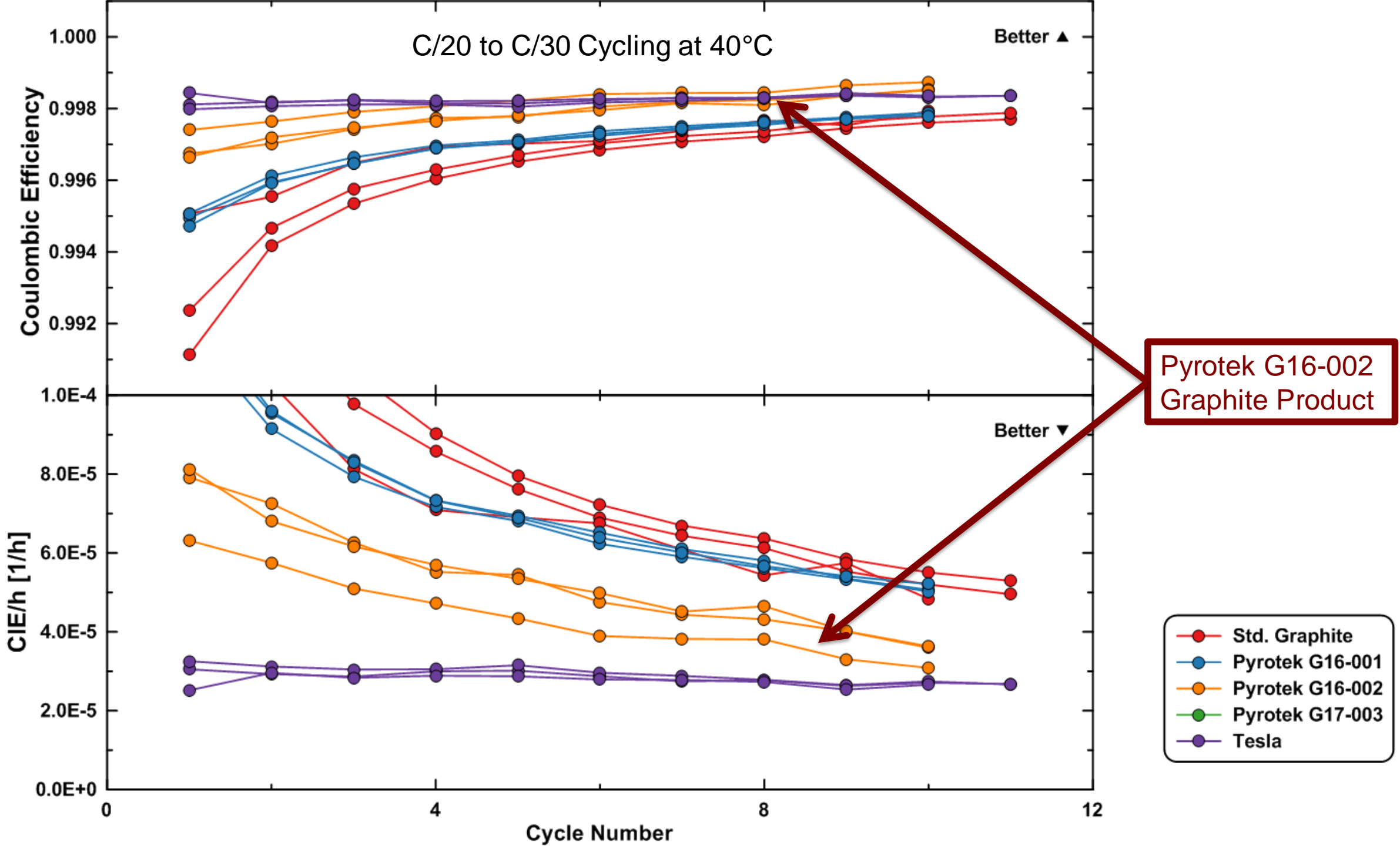
Professor **Jeff Dahn** - WIN Seminar Series, How the Movies are Fooling Us | **Jeff Dahn** | TEDxHalifaxWestHigh, **Jeff Dahn** Wins Governor General's Award - CBC ...

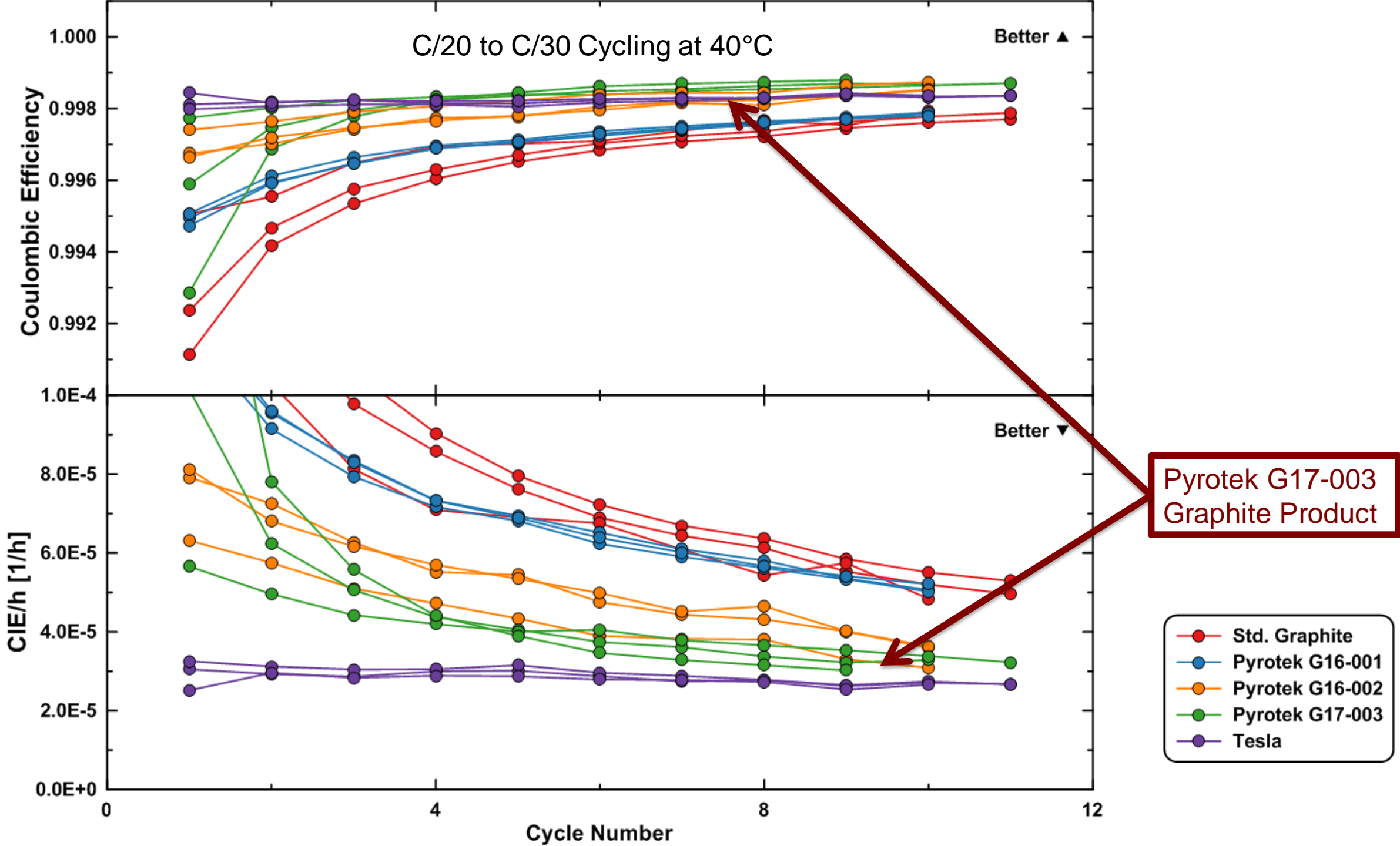


C/20 to C/30 Cycling at 40°C



C/20 to C/30 Cycling at 40°C

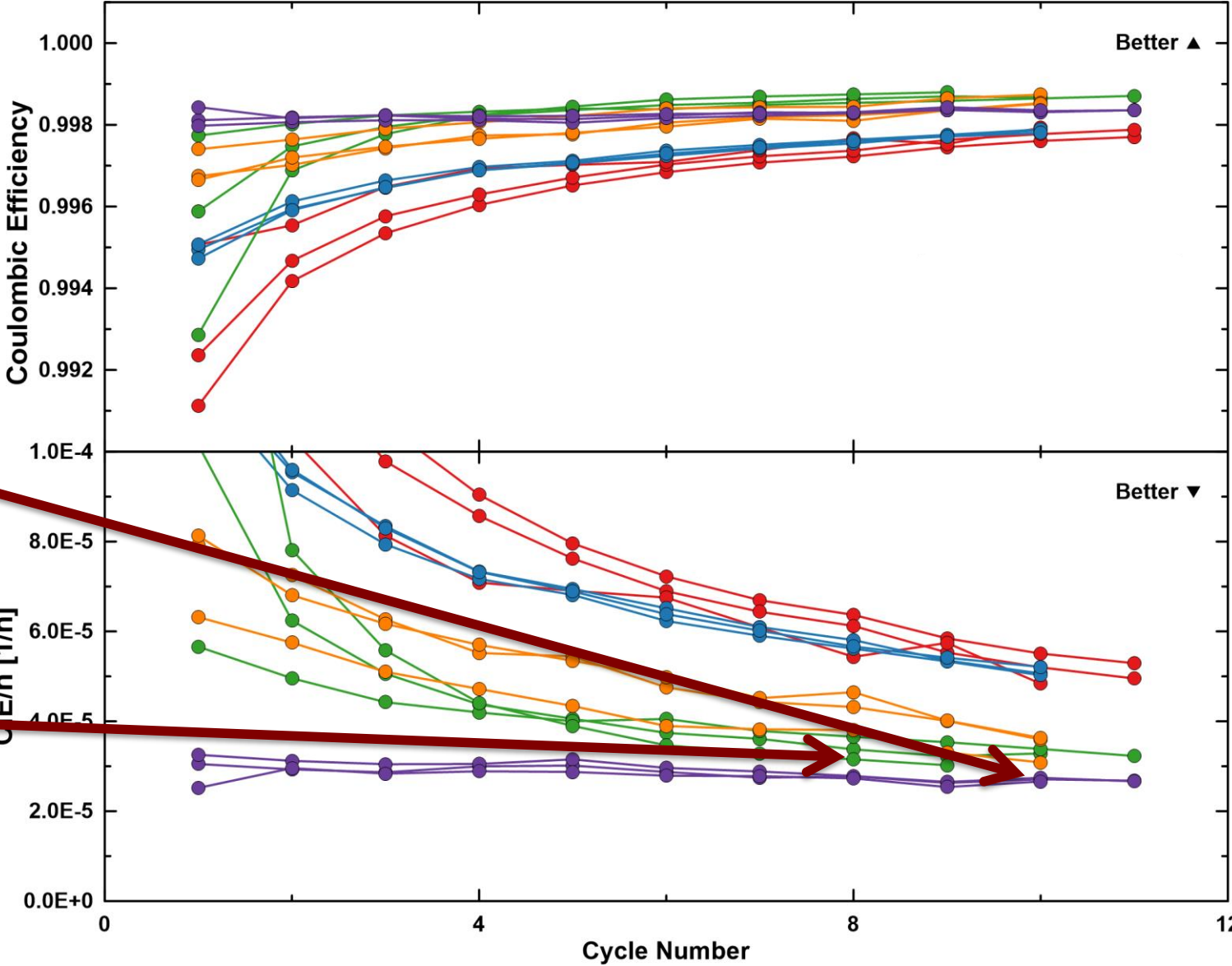






HPC Testing

- HPC Testing results
- Tesla Cells
 - + 2013 Model S
 - + Removed from damaged vehicle
 - + 2.7-3.0 CIE/h
- STD Natural Graphite
 - + 5.0-6.0 CIE/h
- Pyrotek Graphite
 - + 2.9-3.0 CIE/h



Cells showing similar performance to 3 year old Tesla cell after just 10 cycles!

Summary



- Both natural and synthetic graphite materials are being developed by Pyrotek/Coulometrics
 - Graphite has a significant impact on cell life
 - Pyrotek produces large quantities of graphite with an environmentally friendly process
 - Current capacity 4,000 tpy
 - Easily scalable to over 100,000 tpy
 - Target pricing with large volume is <\$5/kg

Contact Pyrotek



Michael J. Sekedat

ENERGY GROUP BUSINESS MANAGER
micsek@pyrotek.com

Skype: pyrotek-micsek

T. +1 (509) 921-2854
M. +1 (509) 994-8998

pyrotek.com

Corporate Headquarters
705 West 1st Avenue
Spokane, WA 99201 USA

www.pyrotek.com/graphite

See us at Booth 18!