SAND2013-8833C

Performance and Life Cycle Analysis of Energy Storage Devices

Summer Ferreira and Wes Baca

October 25, 2013

Sandia National Laboratories

Exceptional service in the national interest

With gratefully acknowledgment of the support of Dr. Imre Gyuk and the Department of Energy's Office of Electricity Delivery & Energy Reliability for supporting testing of energy storage technologies.

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

SNL Energy Storage System Analysis Laboratory

Sandia National Laboratories

Mission:

Develop and implement analytics to assess the performance and life of energy storage technologies to advance the adoption of stationary storage solutions.

Problem:

- Current testing methods differ by lab, manufacturer and customer leading to excessive and “apples to oranges” results
- Life of storage technologies uncertain yet critical to validating economics
- Potential storage customers, i.e. utilities, without experience in storage, are reluctant consumers.

Approach:

Develop advances through:

- Test protocols, using direct research and standards activities
- high precision testing spun off as an ARPA-E grant recipient in 2013

Provide ongoing:

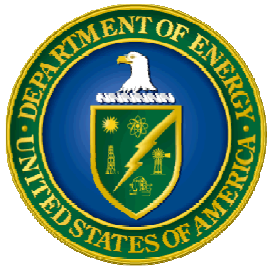
- expertise in testing programs to customers
- verification of specific technologies

Participation in Standards Activities

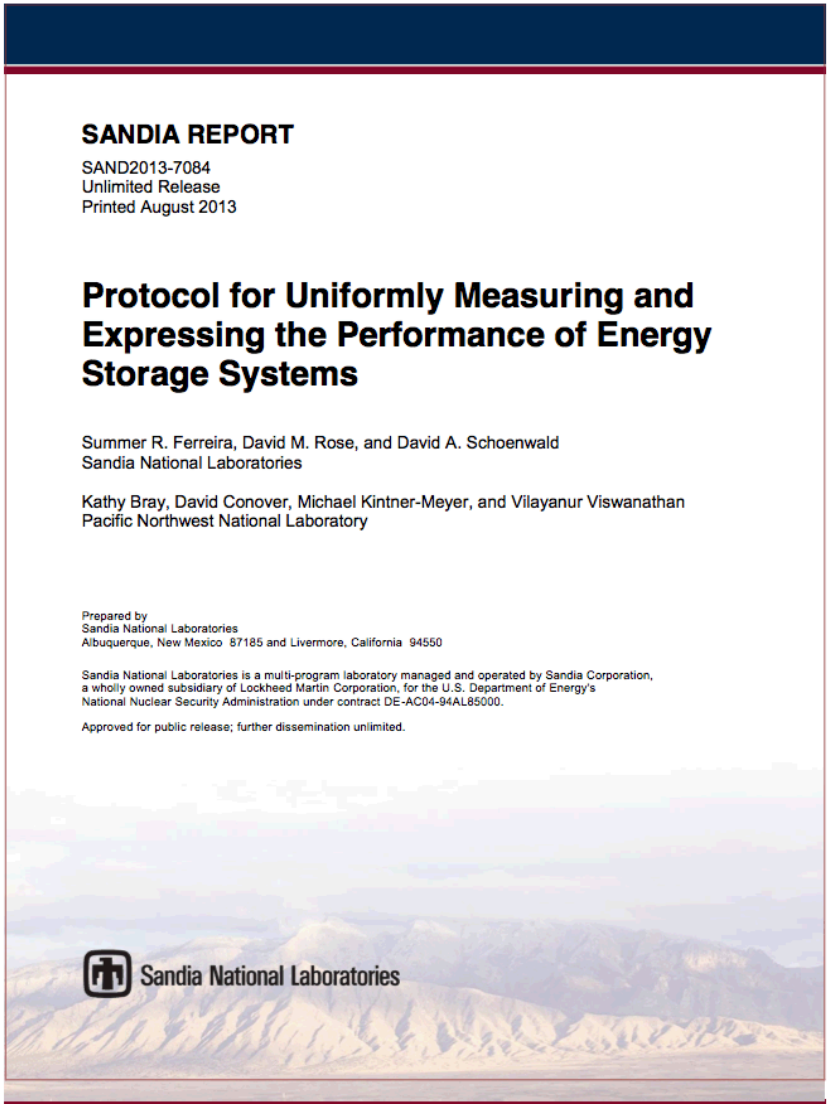
Sandia National Laboratories

DOE Performance Protocol

- Included broad input from utility and manufacturing side.
- Initial testing and comments are welcome.



In the last two years there has been a call for standard language and testing, with definitions. In response standards development has been a large priority.



SANDIA REPORT

SAND2013-7084
Unlimited Release
Printed August 2013

Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems

Summer R. Ferreira, David M. Rose, and David A. Schoenwald
Sandia National Laboratories

Kathy Bray, David Conover, Michael Kintner-Meyer, and Vilayanur Viswanathan
Pacific Northwest National Laboratory

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

http://www.sandia.gov/ess/pubs_tech.html

SNL Energy Storage System Analysis Laboratory

Sandia National Laboratories

Providing reliable, independent, third party testing and verification of advanced energy technologies for cell to MW systems

Testing Capabilities Include:

- Expertise to design test plans to fit technologies and their potential applications
- OE supported testing
- CRADA opportunities
- WFO arrangements

Cell, Battery and Module Testing

- 14 channels from 36 V, 25 A to 72 V, 1000 A for battery to module-scale tests
- Over 125 channels; 0 V to 10 V, 3 A to 100+ A for cell tests

72 V 1000 A Bitrode (2 Channels)

Energy Storage Test Pad (ESTP)

System Testing

- Up to 1 MW, 480 VAC, 3 phase
- 1 MW/1 MVAR load bank

SNL **Energy Storage System Analysis Laboratory**

Sandia National Laboratories

Analysis Laboratory capabilities include:

- 125+ Cell test channels: 0 V to 10 V, 3 A to 100+ A
- 14 Battery test channels: 36 V, 25 A to 72 V, 1000 A

Expanded Capabilities in FY '12:

- **34 test channels from 5 V – 60 V to 15 A – 500 A**
- **Potentiostat/galvanostats for spectral impedance**
- **Multimeters, shunts and power supply for high precision testing**
- **Temperature chambers**
- **IR camera**

Expanded number of test channels by 25% including other lab capabilities

72 V 1000 A Bitrode (2 Parallel Channels)

FY 2013 testing activities

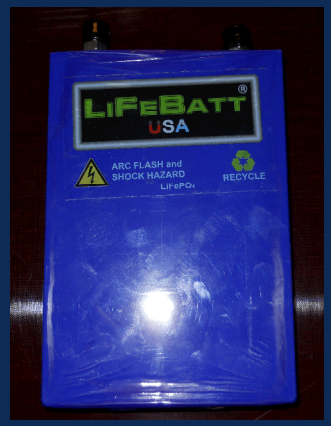
Sandia National Laboratories

Cell Level Testing

Altairnano Lithium-titanate Gen II 13 AH

Altairnano Lithium-titanate Gen II 13 AH

International Battery 160 Ah Li-$FePO_4$ Cells

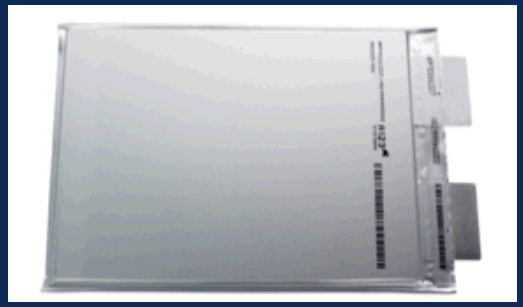


LiFe Battery Lithium-Fe 20 AH

String Level Testing

Encell Ni-Alkaline Battery

Profile Testing



A123 14 Ah pouch

FY 2014 Projects

http://www.sandia.gov/batterytesting/

Visit our website or e-mail us to pursue 3rd party testing at Sandia

Aquion: sodium ion batteries

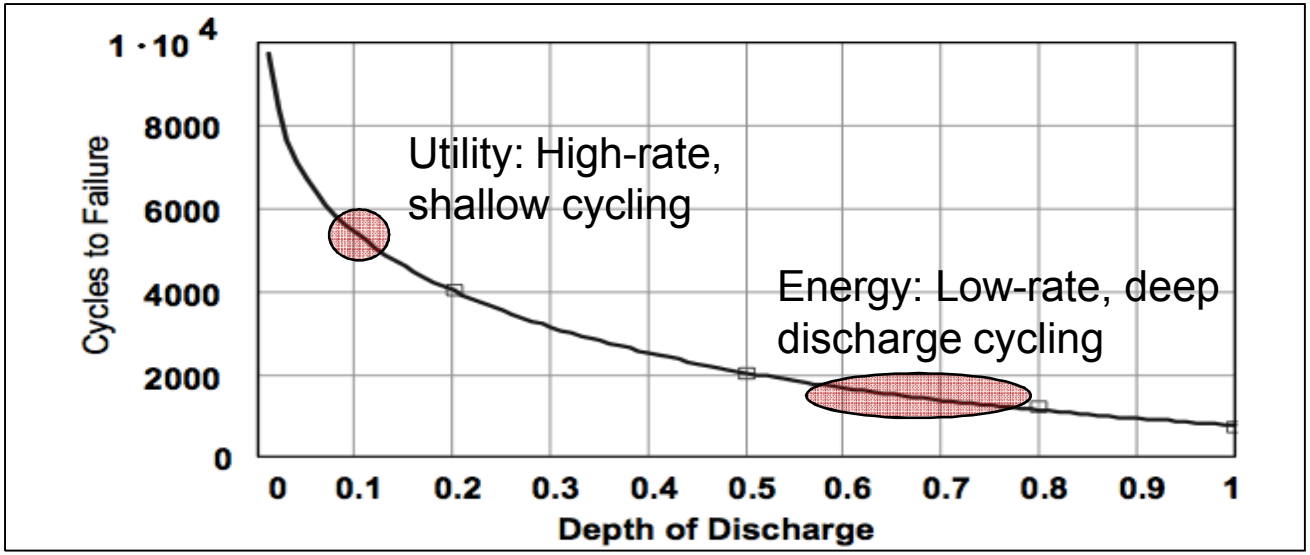
CUNY: Ni-Zn Flow battery modules

GE: Sodium-nickel battery

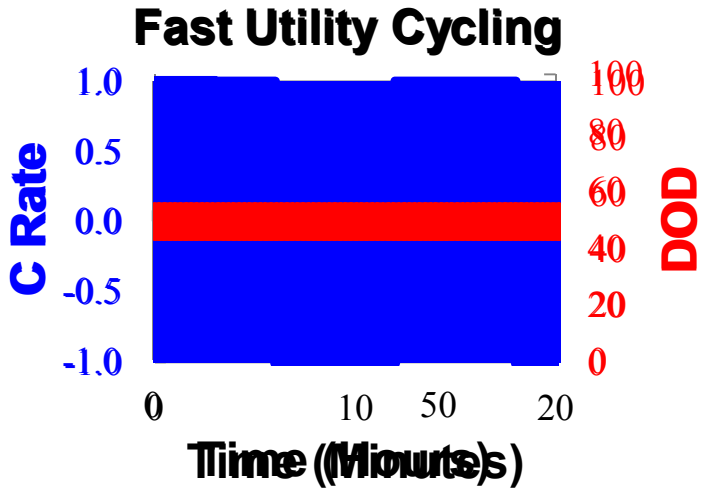
Altairnano: Generation II 60 Ah cells Generation III 14 Ah

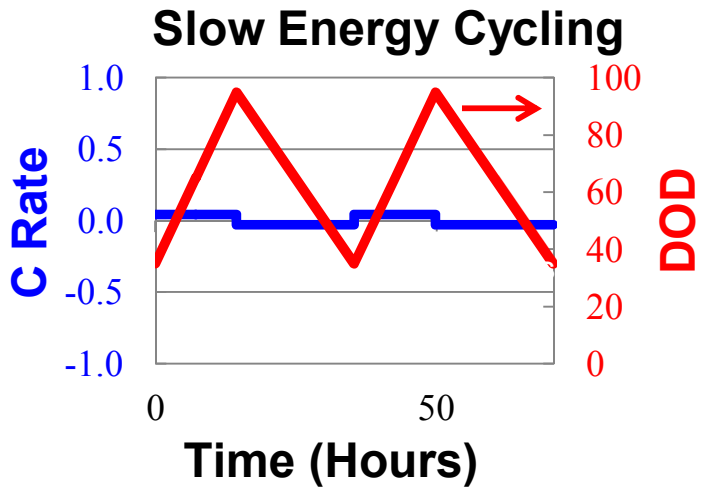
Continue analysis of projects for Encell, LiFe, Altairnano, A123 technologies

Cycling protocols employed in testing



VRLA Life cycle data *S. Drouilhet, B.L. Johnson, 1997 NREL*

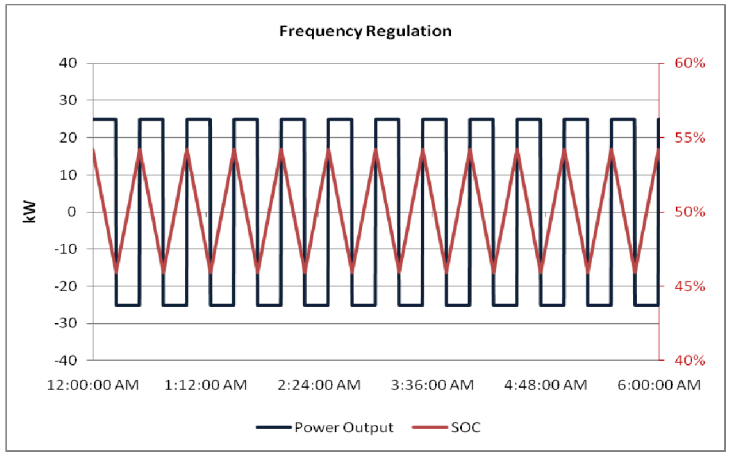




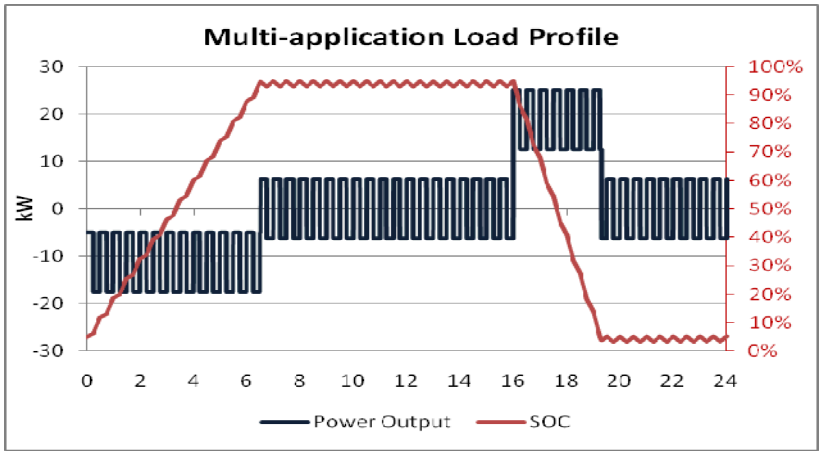
Waveform Testing

Sandia National Laboratories

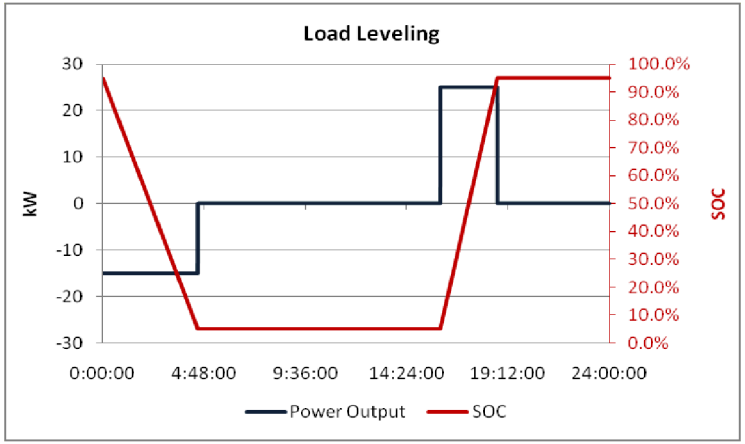
State of the Art: Power profile



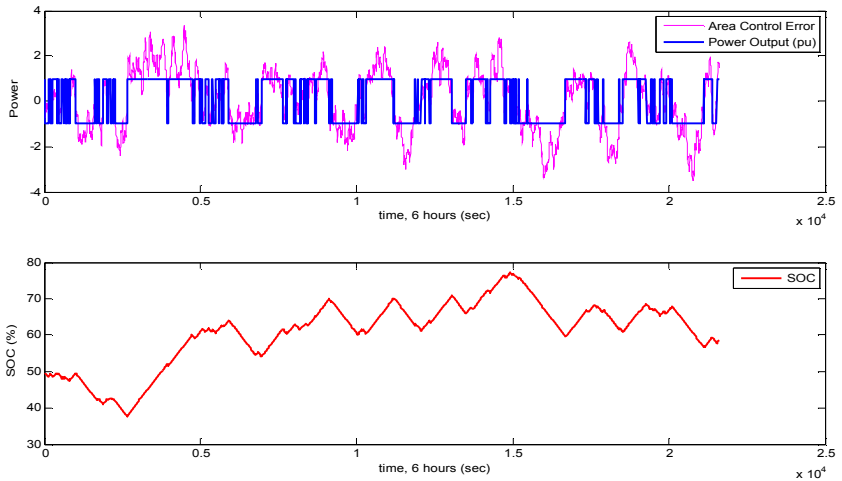
Stacked Applications: Working with KEMA



State of the Art: Energy profile



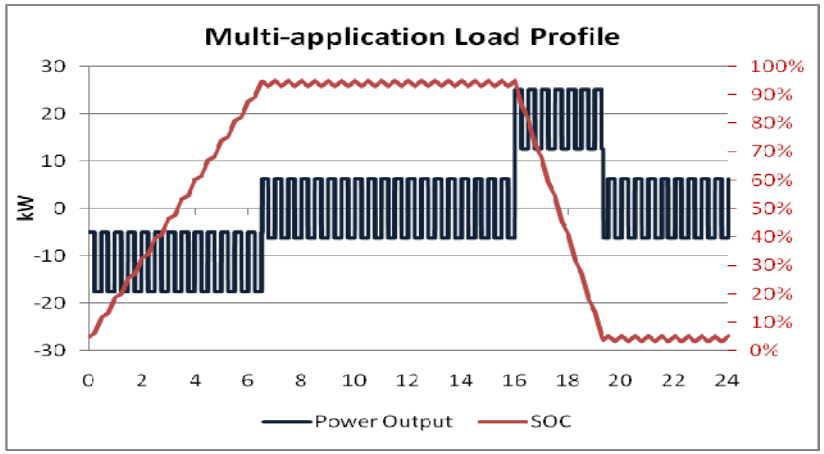
Stochastic Application Modeling:

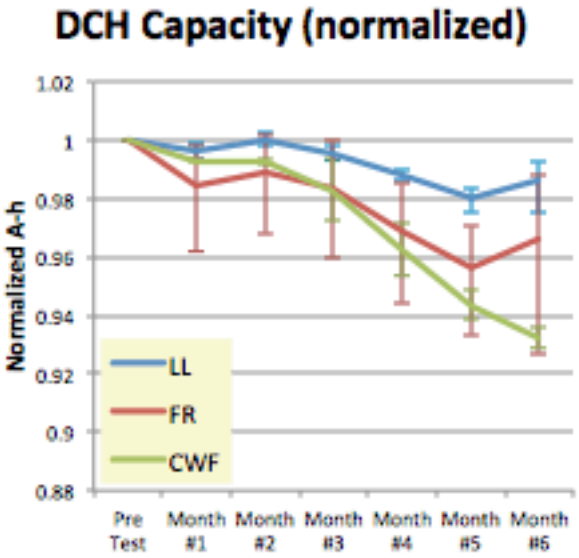


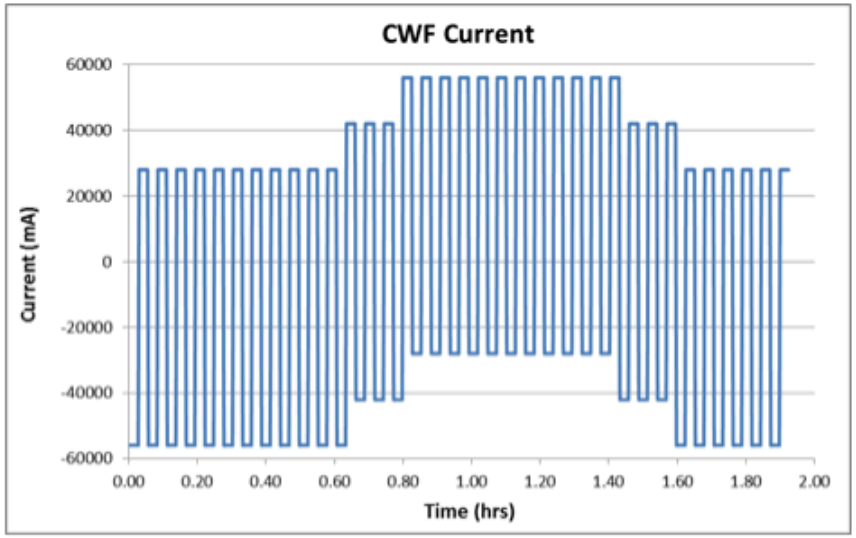
Evaluating a Combined Waveform Profile

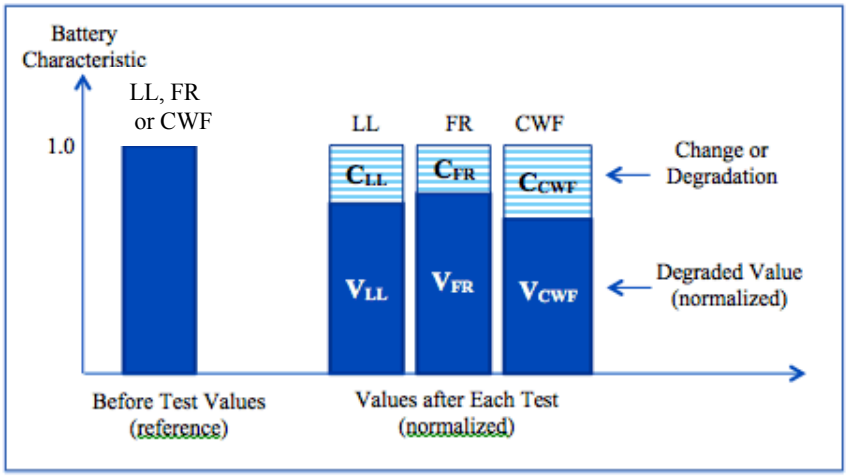
Sandia National Laboratories

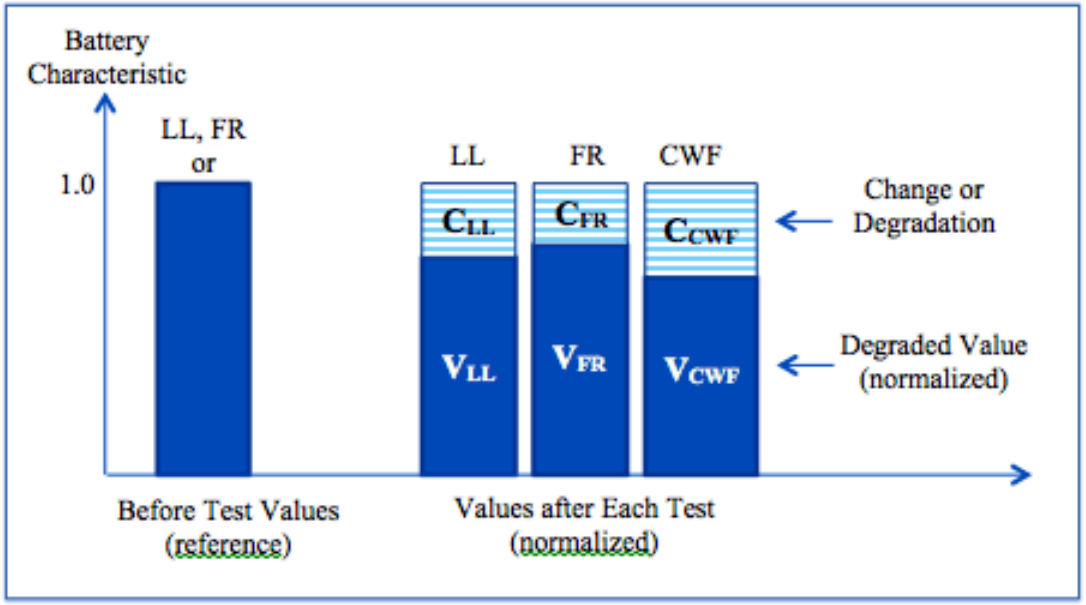
Stacked Applications: Working with KEMA



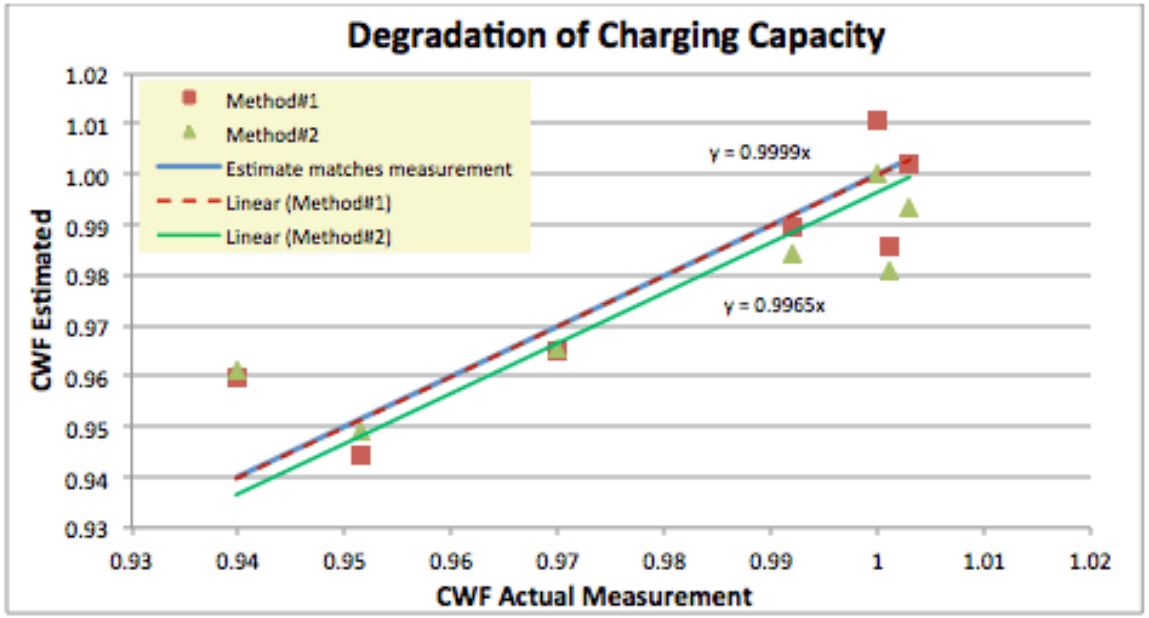








$$C_{CWF} = K_2 (C_{LL} + C_{FR})$$



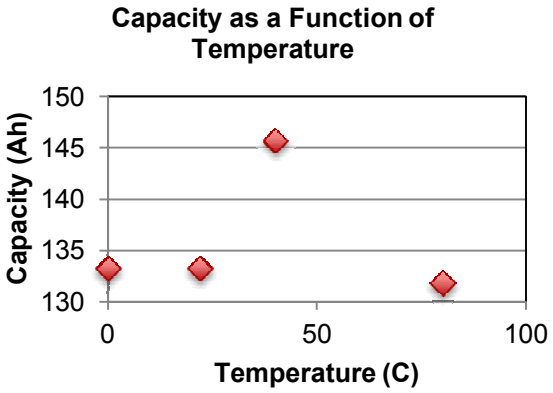
Effective DOE/Industry collaborative R&D test cycle

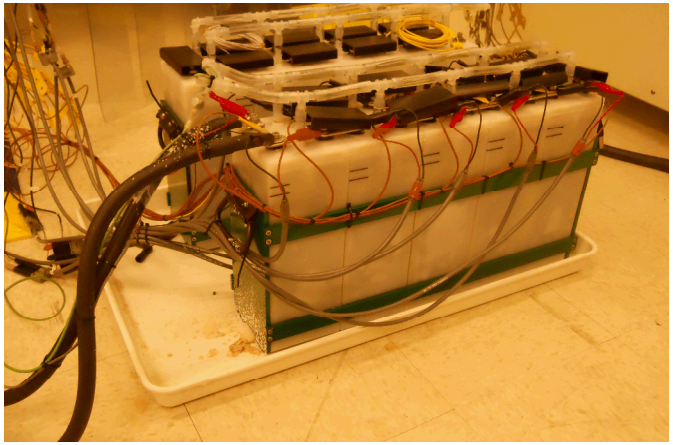
Sandia National Laboratories

Office of Electricity support

Evaluated Alpha design of an Encell rechargeable nickel alkaline battery

- Average capacity of 133 Ah at ambient temperature
- 20% self discharge after 28 days





Manufacturer Funded WFO

- Further testing and analytical techniques to evaluate
  - Results feed into beta design improvements
- FY '14 beta testing to begin for life cycle testing

Office of Electricity support

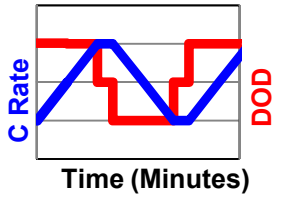
FY '14 plans to run beta testing

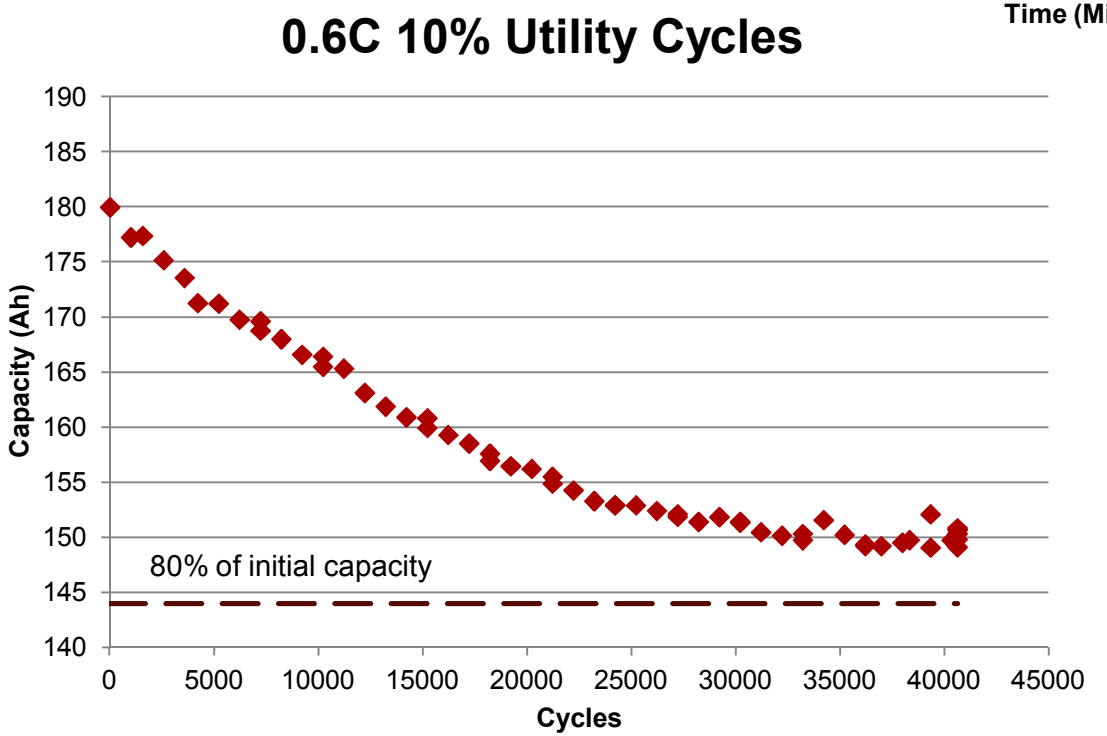
ENCELL technology

International Battery Still Running after 40K cycles

Sandia National Laboratories

International battery Li-ion $FePO_4$ large format prismatic 160 Ah cells





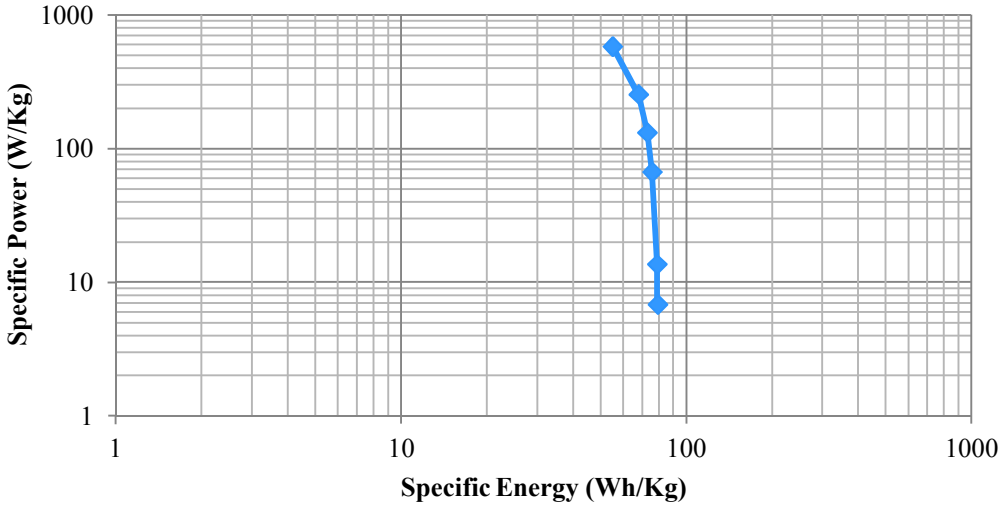
Equivalent throughput energy of 4,000 full discharge cycles

~17% capacity loss after 40,000+ cycles

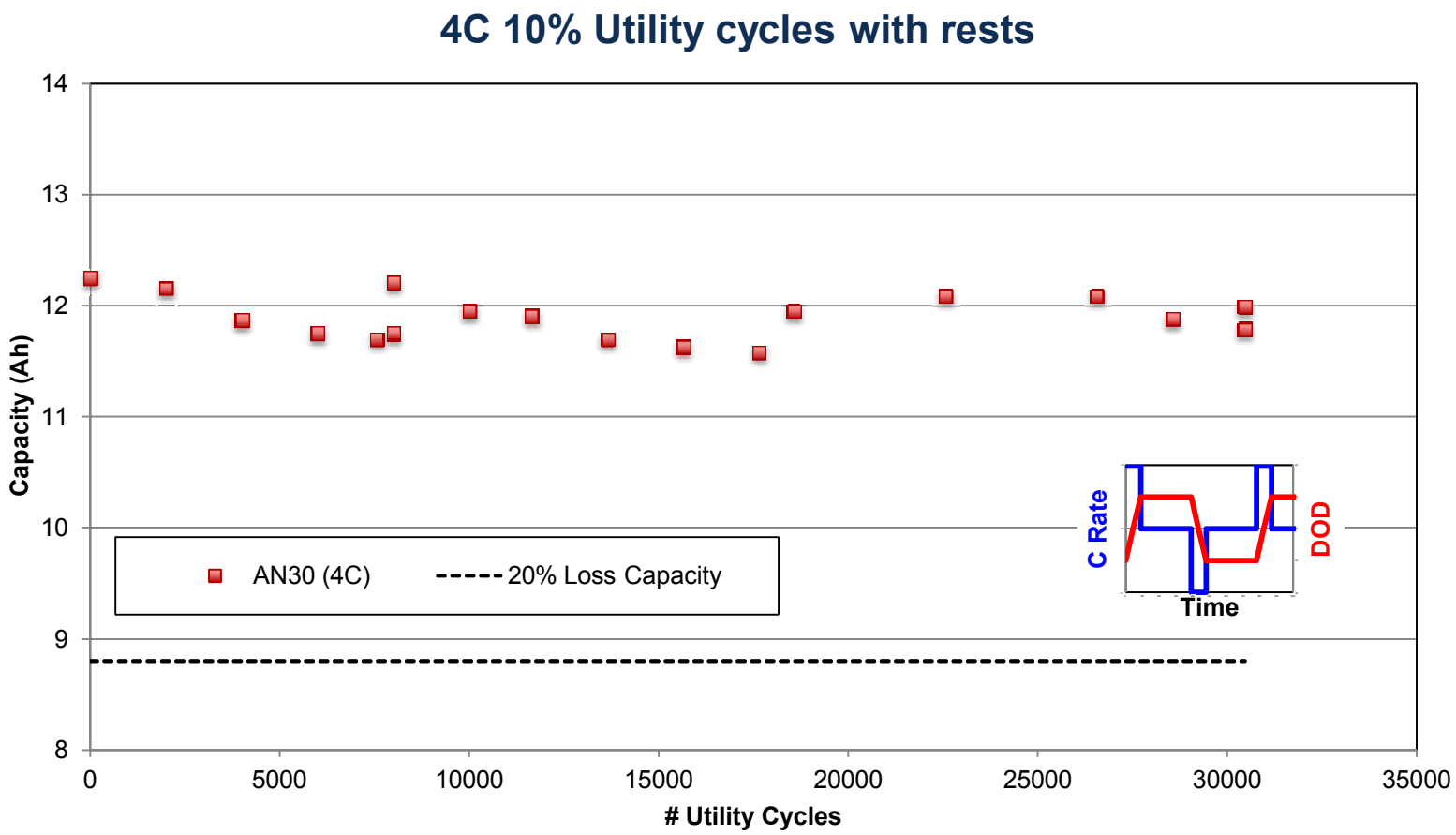
Altairnano Characterization

	Average	Standard Deviation
Capacity (Ah)	12.58	0.06
Voc (V)	2.531	0.006
R (μΩ)	2642	147
Mass (kg)	0.367	0.001
3 Month Self Discharge	4.825%	0.025%

Lithium-titanate oxide cells



Altairnano Lifecycle testing continuing



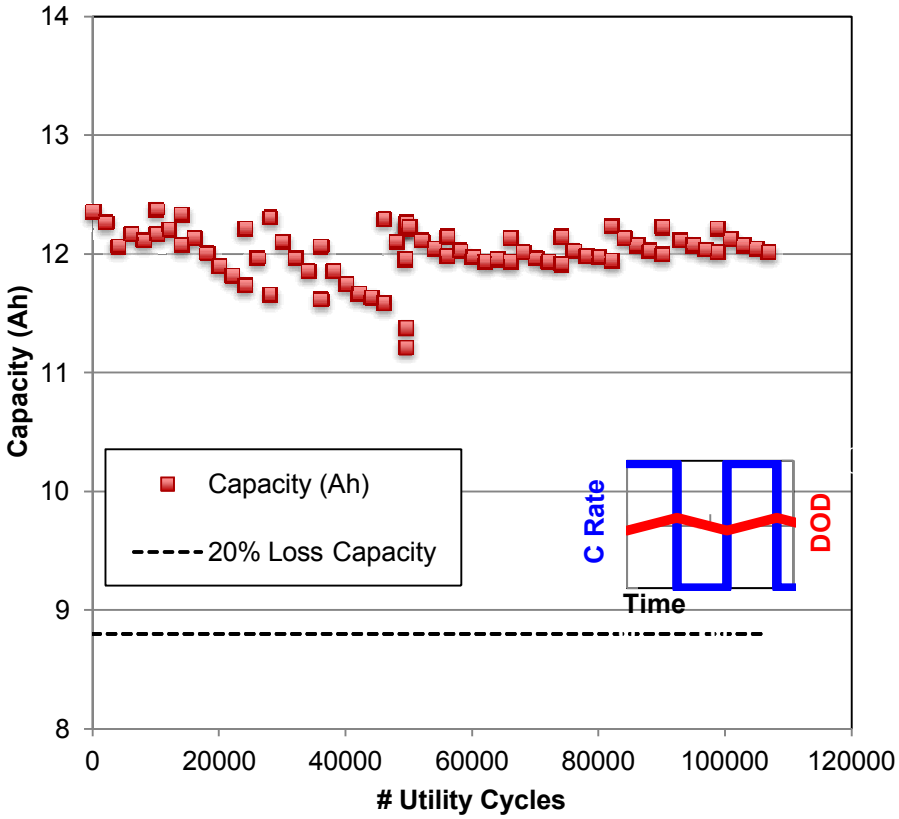
Equivalent throughput energy of 3,000 full discharge cycles

~2% capacity loss after 30K+ cycles

Altairnano Lifecycle testing

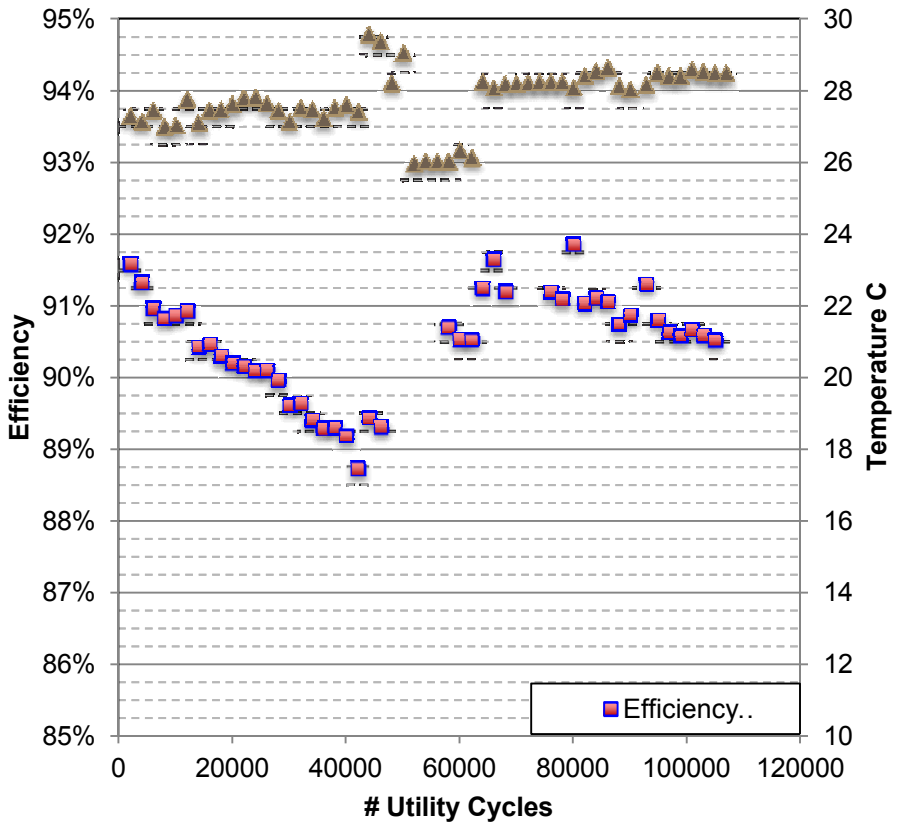
Sandia National Laboratories

2C 10% Utility cycles without rests



Equivalent throughput energy of 10,000 full discharge cycles

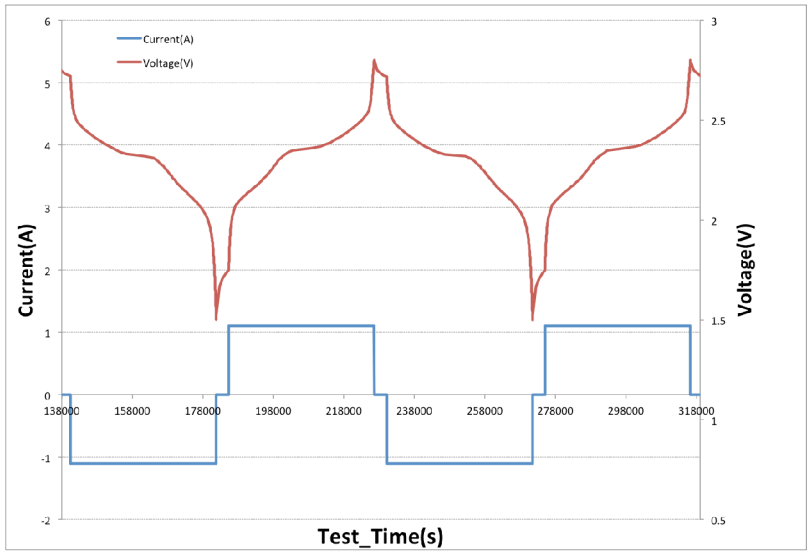
Efficiency and Temperature during Cycling



~3% capacity loss after 100K+ cycles

High Precision Commercial Tester Development

- With Arbin Instruments and Ford Motor company received an ARPA-E grant to develop and validate a **commercial high precision and high power battery tester**
- First prototype expected this year for evaluating
- Goal is fast prognostics of battery life from high precision measurements



Summary

- DOE Pre-protocol report released. Activities in developing and using test regimes is central to our mission. More aggressive tests, and varied protocols including stacked testing under investigation with initial promising results for stacked waveform testing.
- Third party validation and long term cycling continues for a variety of chemistries considered for stationary applications.
- Longer lifecycles demand efforts in prognostics. Expanded activities in high precision testing supported by outside funds.

Contact Information:

Summer Ferreira: srferre@sandia.gov
Advanced Power Sources R&D
Manager Thomas Wunsch tfwunsc@sandia.gov

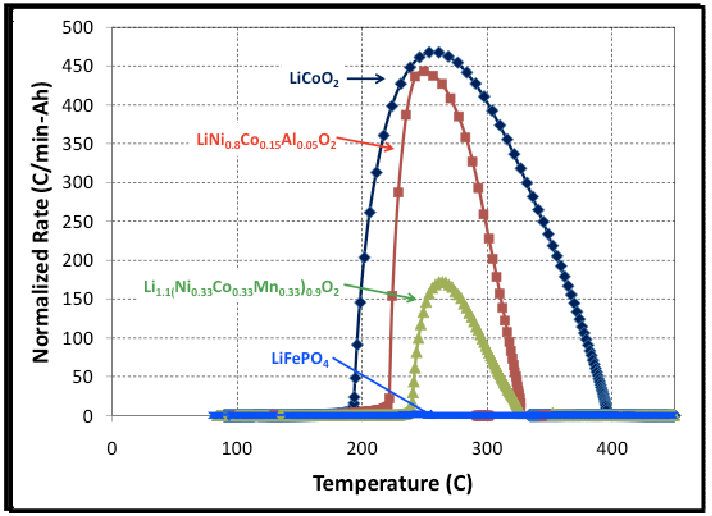
With grateful acknowledgment of Dr. Imre Gyuk for support of storage testing

SNL Battery Abuse Testing Laboratory

Battery testing, cell measurements, and materials development to support the development of inherently safe lithium-ion chemistries

- Safety and abuse tolerance evaluation of energy storage devices from cells to kWh batteries:
  - Mechanical abuse
  - Thermal abuse
  - Electrical abuse
- Understanding degradation mechanisms that lead to cell failure
- Provide experimental data to support abuse and thermal modeling
- Cell prototyping facility for materials development

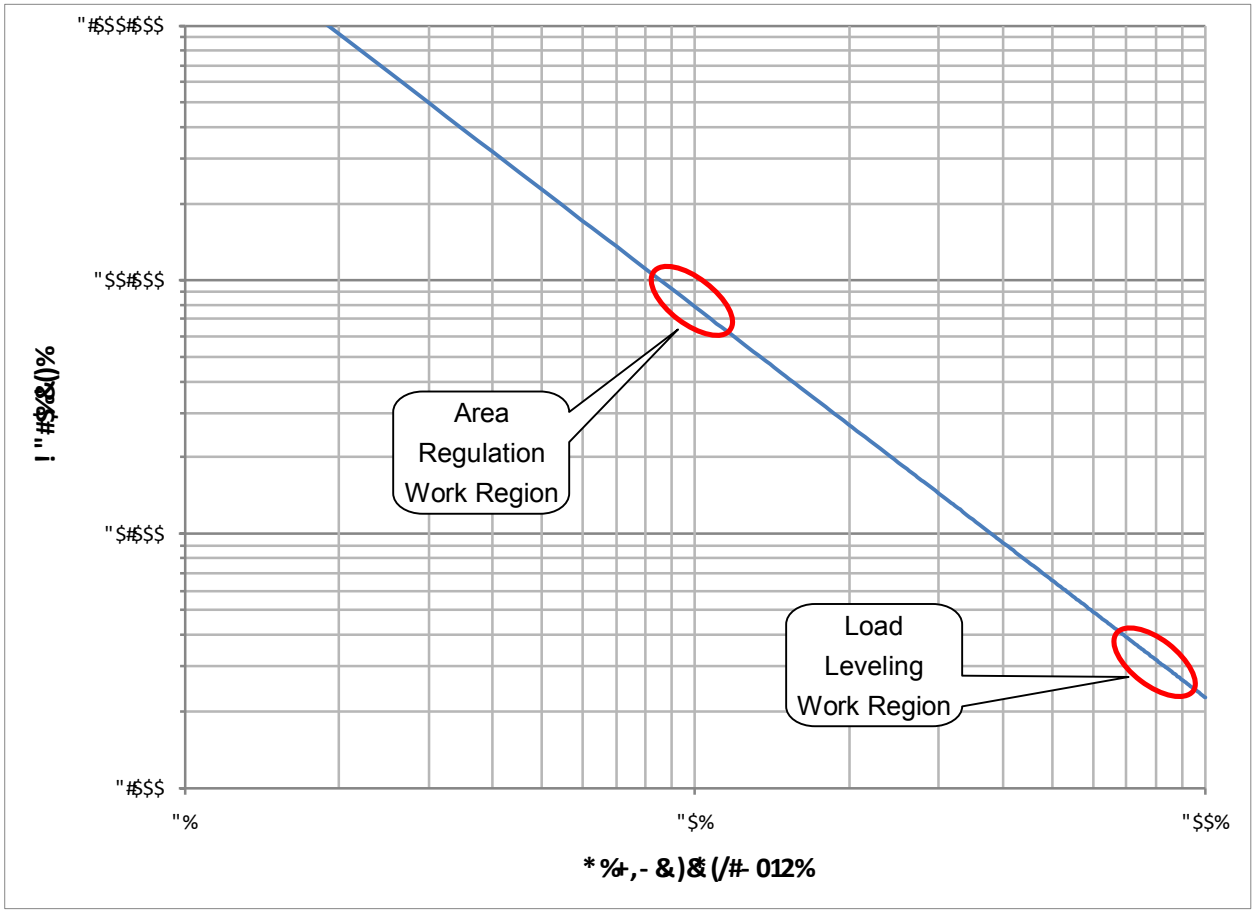
Understanding abuse tolerance



50 Wh failure event

5 Wh failure event

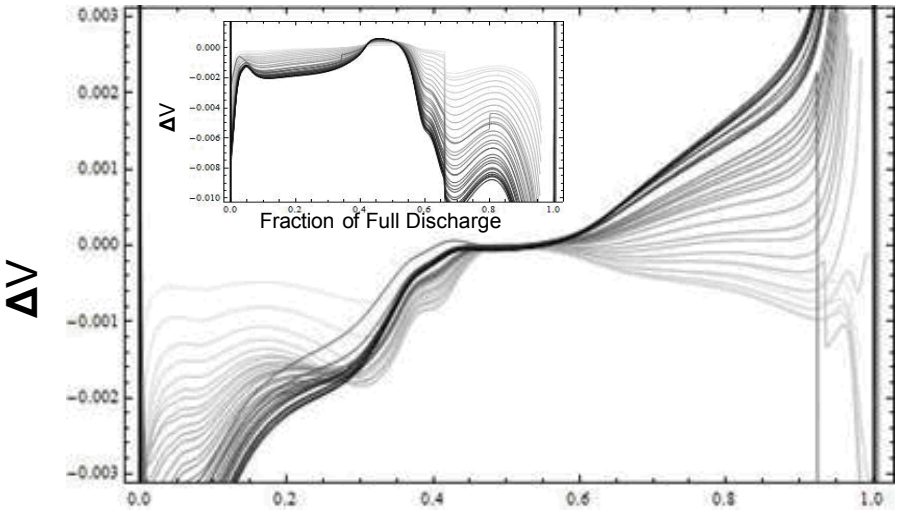
Waveform Testing



Precision Testing Motivated by Jeff Dahn Group

Custom high-precision testers

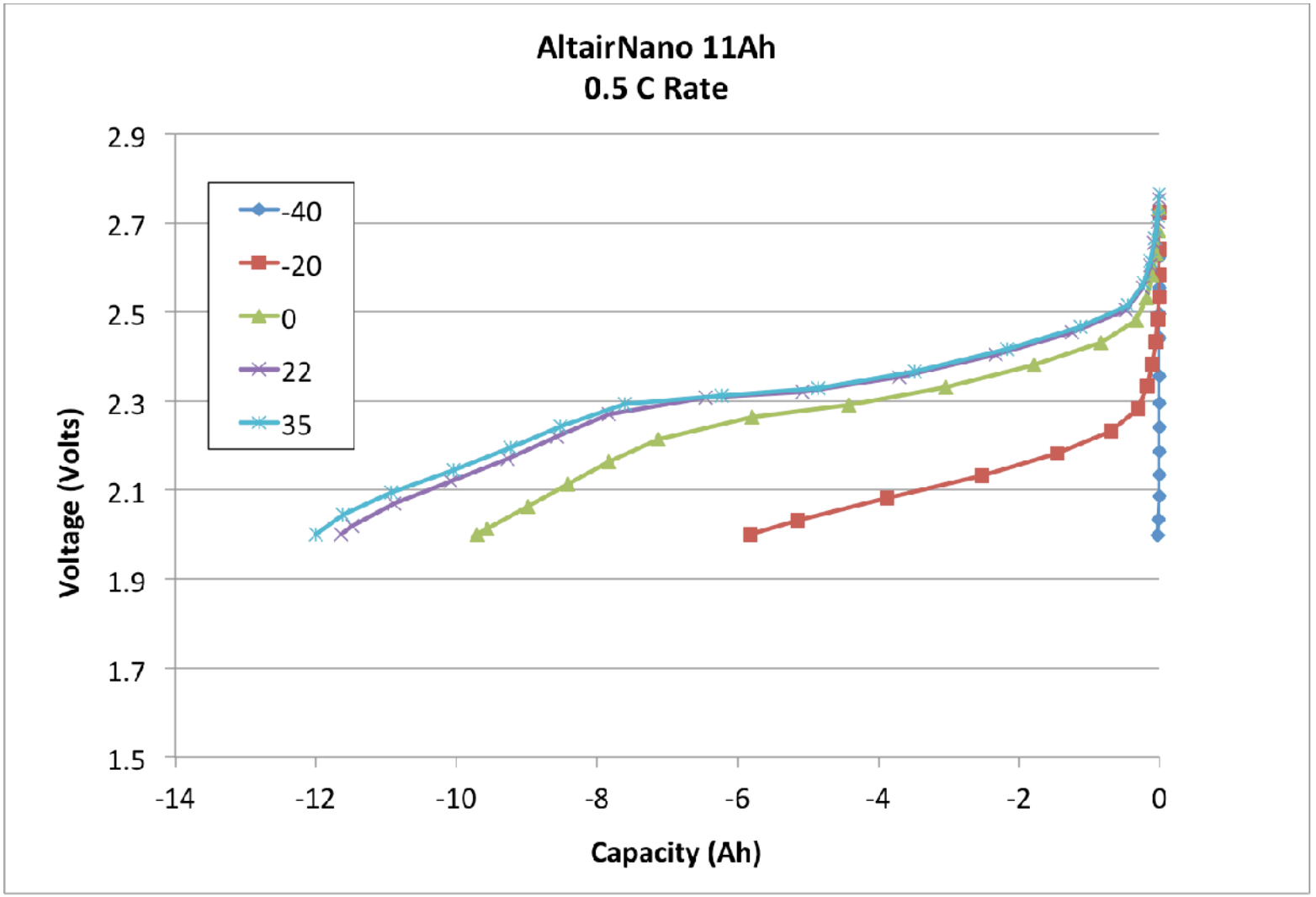
Precision Equipment



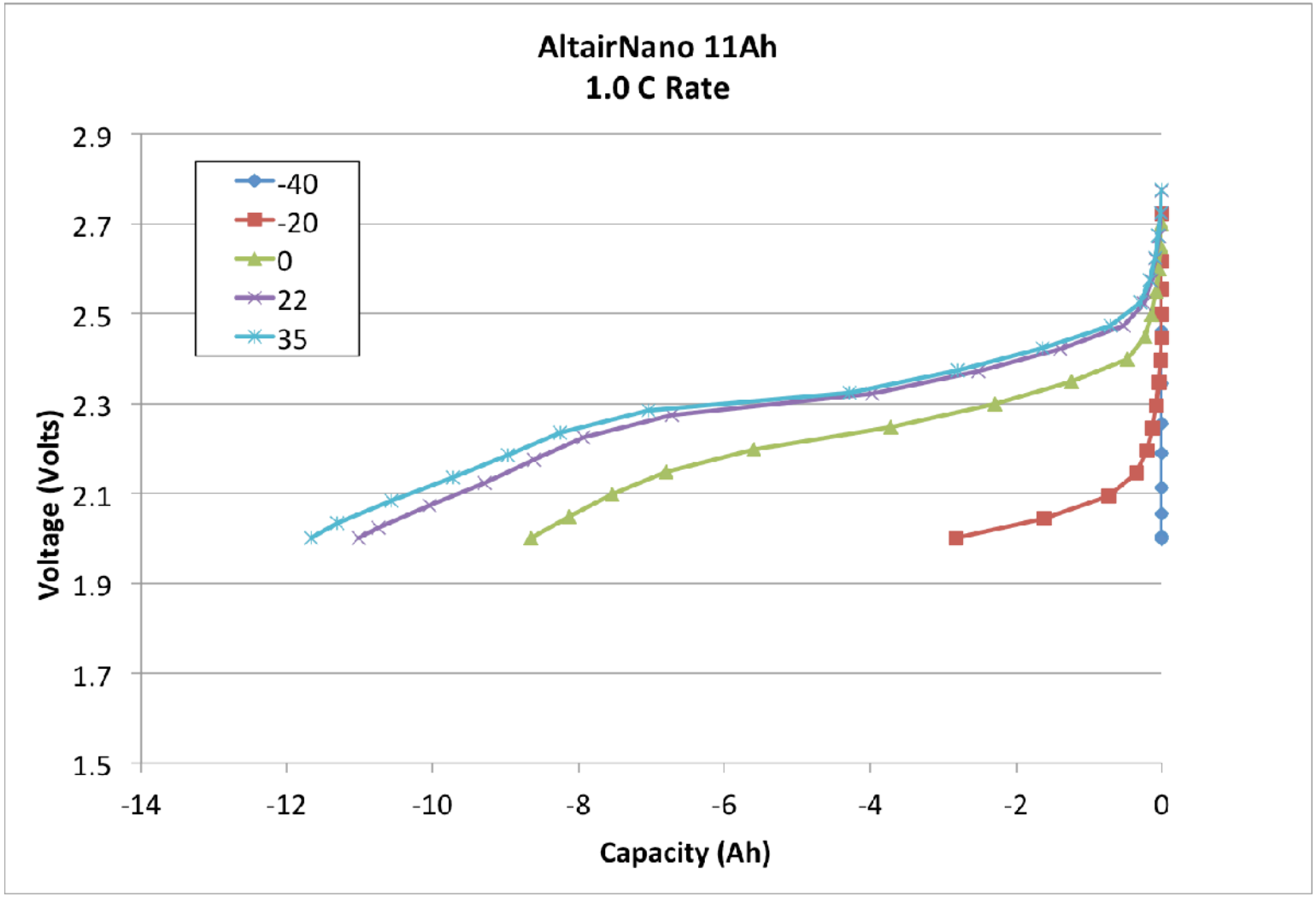
Fraction of Full Charge

Coulombic efficiency may be used to understand how cell chemistry affects performance, and even predict cycle life after minimal cycling.

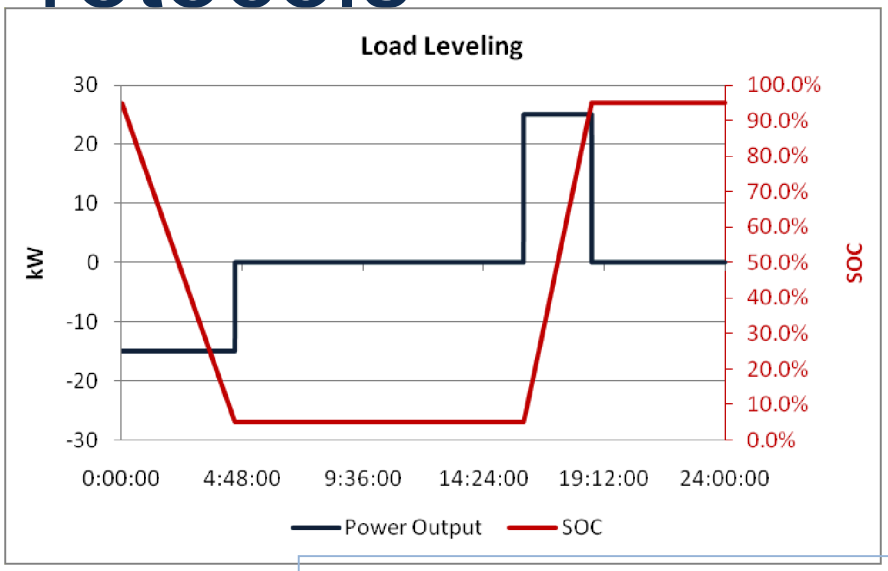
Altairnano Characterization

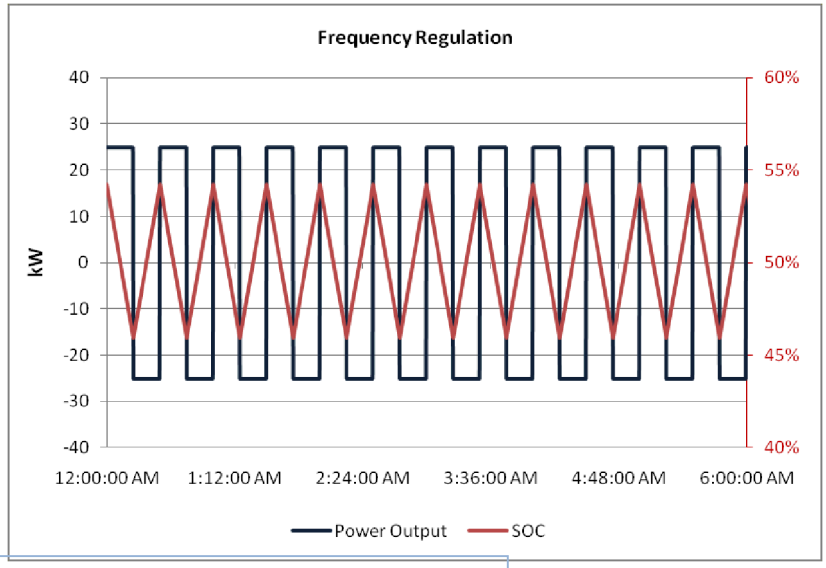


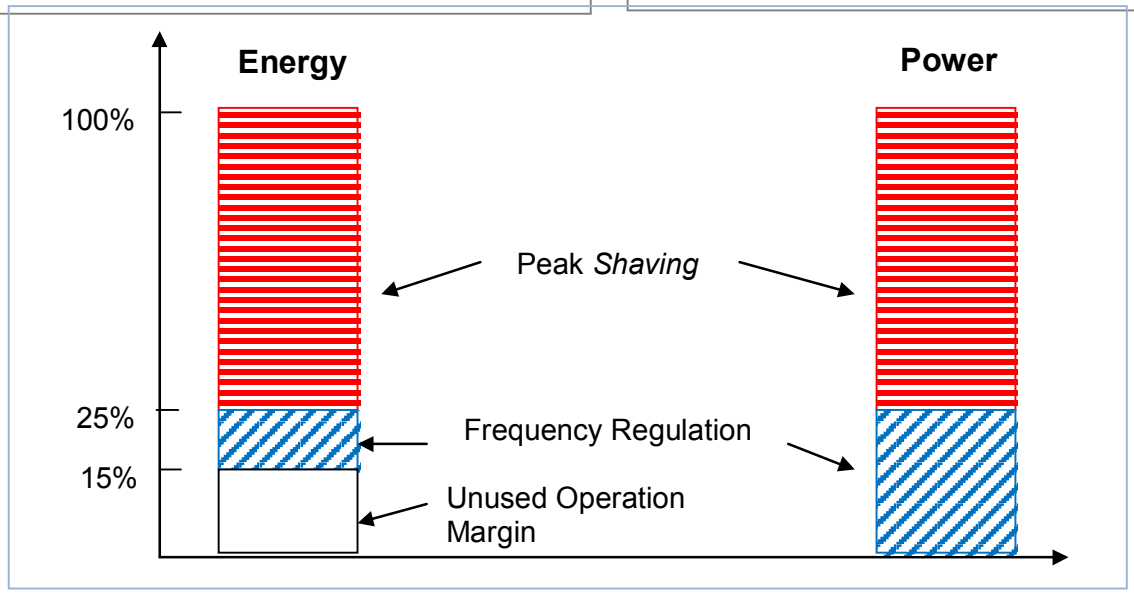
Altairnano Characterization



Individual Application Test Protocols







Stacked Waveform Testing: