Sandia National Laboratories' Power Sources Technology Group Overview

SAND2006-6103C

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Presented at the 2006 Lockheed Martin Energy Storage Conference
Sunnyvale, CA Oct. 3-5 2006

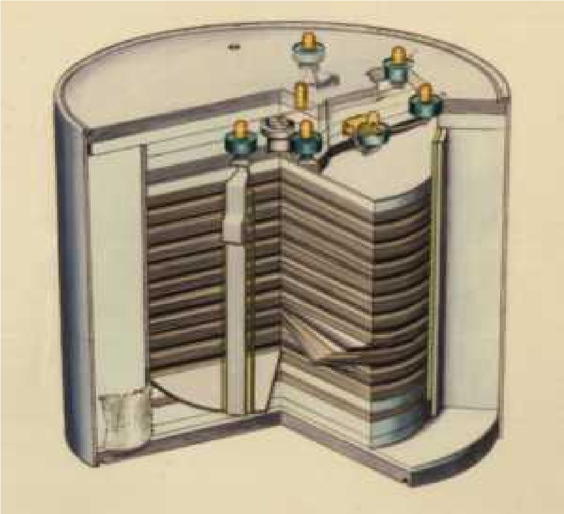
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Sandia National Laboratories

The Energy Components Realization Center 2500 Includes Four Technology Groups

Power Sources

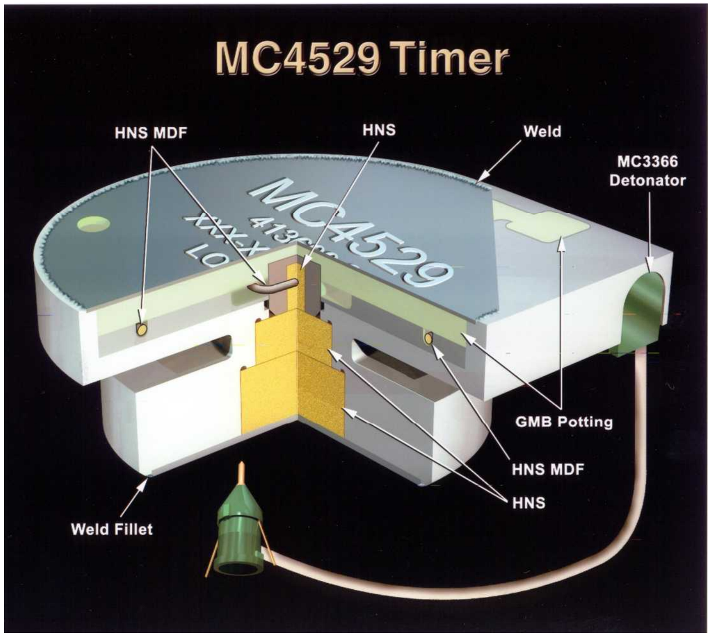
Provides batteries and other energy storage devices for both military and civilian applications



Thermal Batteries

Explosives

Energetic components are an essential part of weapons systems with long stockpile life and assured performance on command

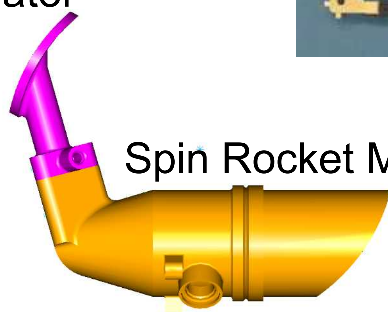


The Energy Components Realization Center 2500 Includes Four Technology Groups

Concurrent Design and Manufacturing (CDM) Program

Actuator

ASIC

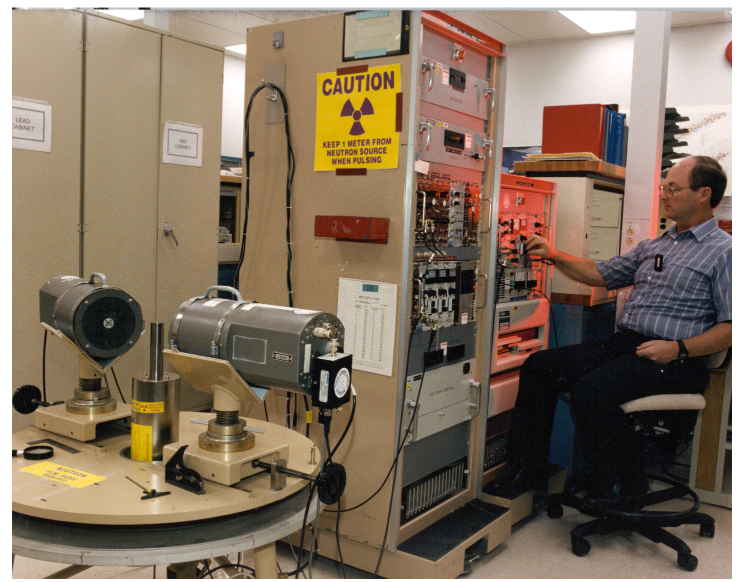


Spin Rocket Motor

Responsible for the development, qualification, supply chain management, and delivery of high reliability/complex components per the NWC Directive Schedule

Metrology

The mission of the Primary Standards Laboratory is to ensure weapon data integrity for the Nuclear Weapon Complex



Power Source Technology Group (PSTG)

We provide scientific and engineering solutions to meet national needs for power sources in nuclear weapons, advanced conventional weapons, and for energy, security, and environmental quality applications.

Our primary customers are the Nuclear Weapons Complex, other branches of the Department of Energy, the Department of Defense, other government agencies, and industry.

Electrochemical Capacitors

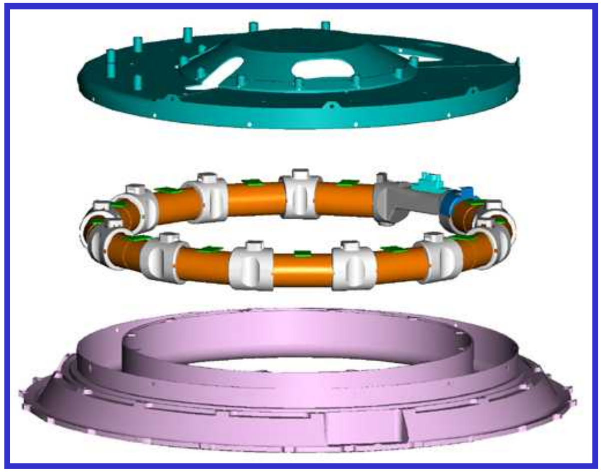
DOE Accepted Batteries

WFO Rechargeable Battery

Cell Prototyping

Sandia PSTG NW Mission

- **Cradle-to-Grave responsibility for power sources on all nuclear weapon systems**
  - **Technology Stewards for power sources for NW**
  - **Design and Development of stockpile and JTA power sources**
  - **Production Agent for all NNSA power source products**
    - **Mostly vendor supplied**
    - **Some in-house production**
- **Leverage existing investments and skills to benefit other non-DOE defense missions**

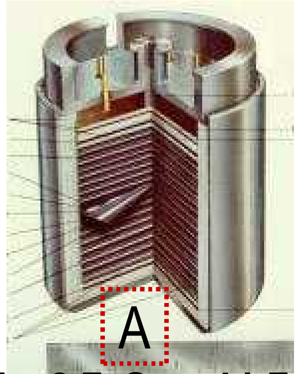


H

$$4Li + 2\ SOCl_2 \rightarrow 4LiCl + SO_2 + S$$

A

$$3\ Li + 2\ FeS_2 \rightarrow Li_3Fe_2S_4$$



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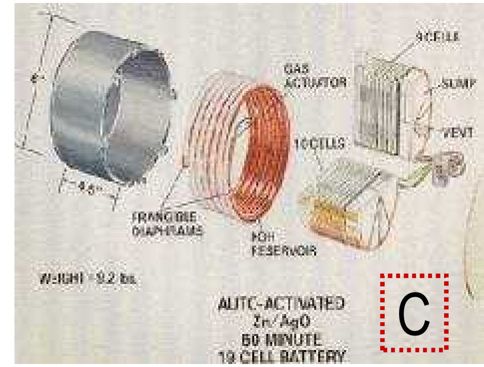


C

G

Basic Battery Types

Primary: not rechargeable

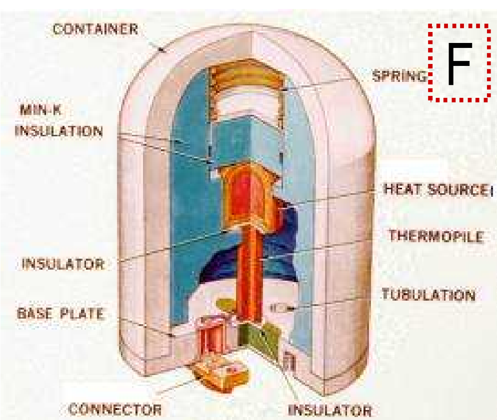
- ***Active:*** **power immediately available**
- ***Reserve:*** **must be activated**

Secondary: rechargeable

Nearly all weapon batteries are primary batteries.

Most weapon batteries are reserve batteries, interest in active systems is increasing.

A	**Thermal batteries**
B	**Lithium-primary batteries**
C	**Silver/zinc batteries**
D	**Electrochemical capacitors**
E	**Nickel/cadmium batteries**
F	**Radioisotopic thermo-electric generators (RTGs)**
G	**Advanced Rechargeable Batteries – Li Ion**
H	**Testers**



F

E

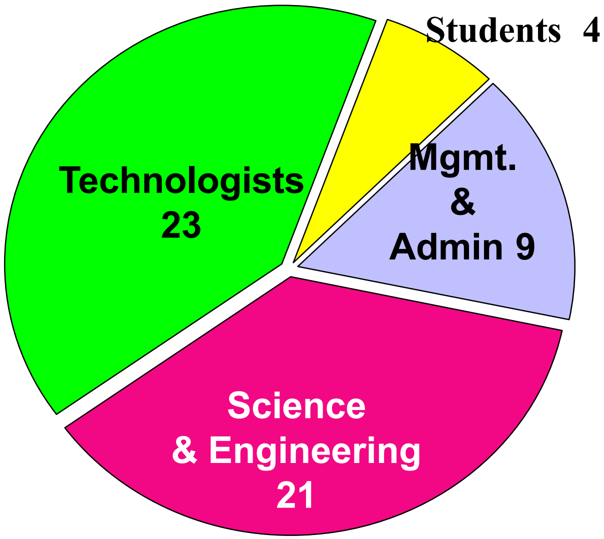
D

Power Sources Technology Group

2520 - Power Sources Technology Group
Mike Prairie

2521	2522	2523
Advanced Power Sources Technology	Power Sources Component Development	Power Sources Production
Dan Doughty	Terry Aselage	Rudy Jungst

Staff

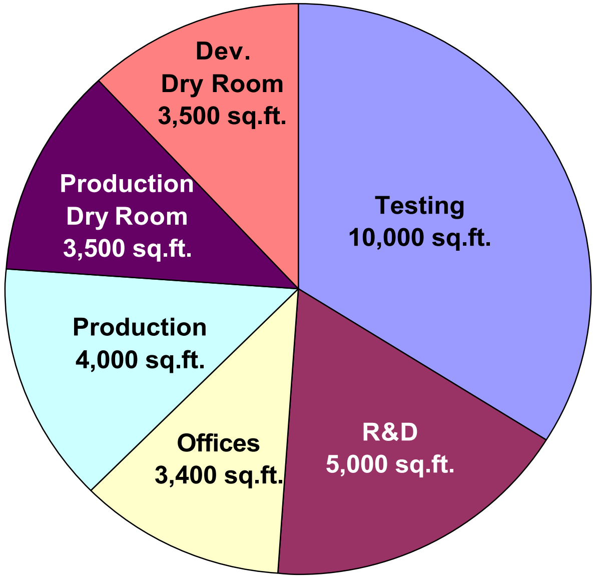


Total of 57 People

PSTG Research, Development, Test and Production Facilities

Two distinct work environments:

- **Building 894**
  - Three Dry Rooms
    - Production
    - Development
    - Research
  - Chemistry Labs
  - Battery/Cell performance testing
  - Production
    - Header assembly
    - Inspection
  - Machine Shop
  - Records Room
  - Offices
- **Building 905**
  - Battery Abuse Testing Laboratory



29,400 sq.ft.

Illustrative Photos

Wrapping a Thermal Battery

Putting a Closure Weld on a Thermal Battery

Testers/Testing

Cell Test Lab

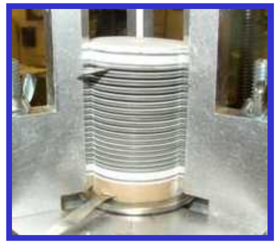
Electrochemistry R&D

Material Property Analysis

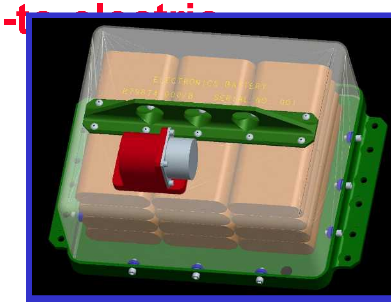
Power Source Characterization

Major Activities in FY06

- Nuclear Weapons
  - Power Sources Production
    - CDM
    - In-house
    - Testers (J. Garni talk)
    - Process Development
  - New Power Sources Development
    - Thermal battery
    - Li primary batteries
  - New Concepts
    - Thin-film thermal batteries
    - Li/CFx
- DOE Energy Programs
  - Energy Storage Program
    - Project management
    - Testing
    - Materials analysis
  - Abuse Testing
    - FreedomCar
    - Mechanisms



- Others
  - STARS Li ion battery
  - GaN Production R&D
  - Harsh environment thermals
  - Applied electrochemistry
  - Thermal-t



Thermal Battery Production

Thermal Battery Supply Strategy

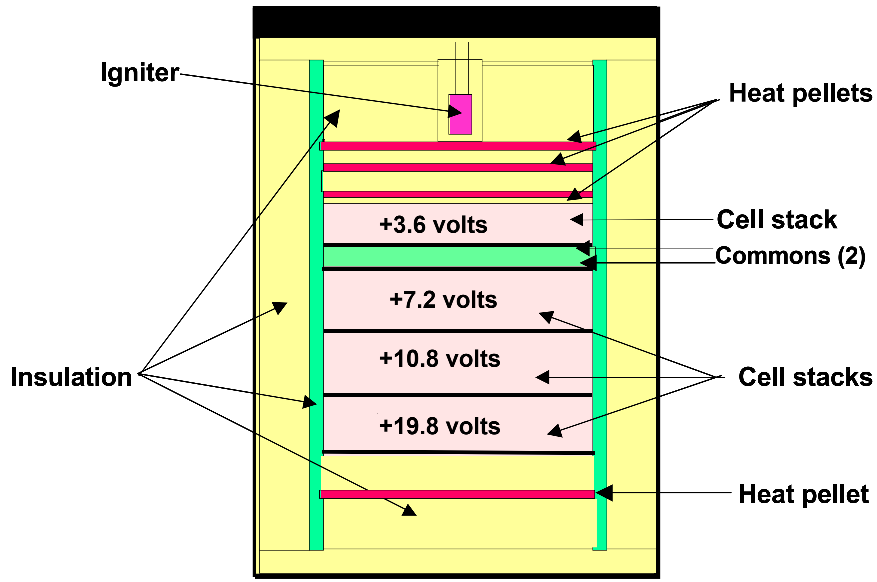
- **Thermal Battery Supply Chain Is Fragile**
- **Thermal Battery Risk Mitigation Plan Implemented**
  - **Maximize performance (quality, cost, schedule) of EPT**
    - SNL production engineer in residence at EPT for 2+ years
    - Contract for full time production engineer, technologist, and quality engineer
    - Consolidate most of our battery production at EPT
  - **Establish complete back-up production capabilities at SNL**
    - One War Reserve lot manufactured every two years at SNL
    - Sized to handle large lots (500 units) of W76-1 batteries
  - **Steady involvement of SNL staff and management at EPT**
    - Regular Coordination meetings
    - Dedicated Quality Engineering Support
  - **Joint R&D to solve problems of mutual interest**
    - **Modeling and Simulation**
    - **Ruggedized LTC keeper cells**
    - **Other topics being negotiated**
    - **CoS_2**
- **Provide TB design/manufacturing support to US industry when requested**
    - We do not compete with US Industry

EaglePicher

New CoS_2 Battery Design Eliminates The Need for a Two-Battery System

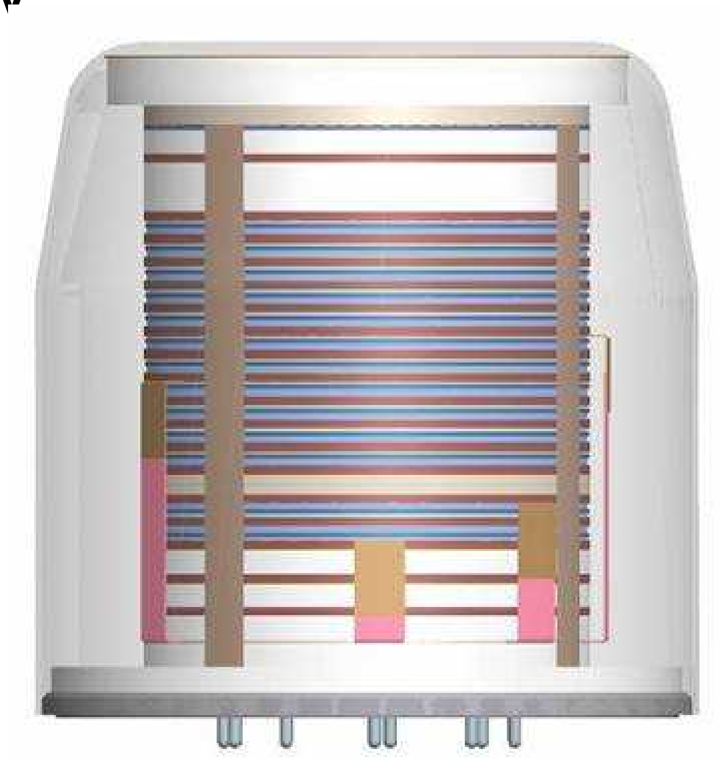
A previous approach was to use a long-life, single-tap battery coupled with a short-life multi-tap battery

Our new approach is to combine requirements in a single long-life, multi-tap battery



Sandia Baseline Design is being Built at EaglePicher Technologies

- 11 electrochemical cells for +7.2, +10.8, +19.8V
  - 6A pulse loads
  - 2A sustained loads
- 2 electrochemical cells for +3.6V tap
  - 0.2A sustained load
- CoS_2 cathodes
- Li(Si) alloy anodes
- Low melting-point ternary electrolyte
- 88/12 heat powder
- New igniter (blend of two existing designs)
- 500-650 lb battery stack closing force
- Tapered end on battery can
- Tapered Min-K sleeve insulation
- Eight terminals in battery header
- Configured for 1-hour operation



EaglePicher

CoS_2 Thermal Battery – First Lot Acceptance

Lot 1 was accepted by DOE July 26, 2006.

In-House Thermal Battery Production at Sandia

- First lot from in-house production, 85 WR thermal batteries, was produced and delivered in June 2005.

- Second lot from in-house production, of a different WR thermal battery, was produced and delivered in the summer of 2006.

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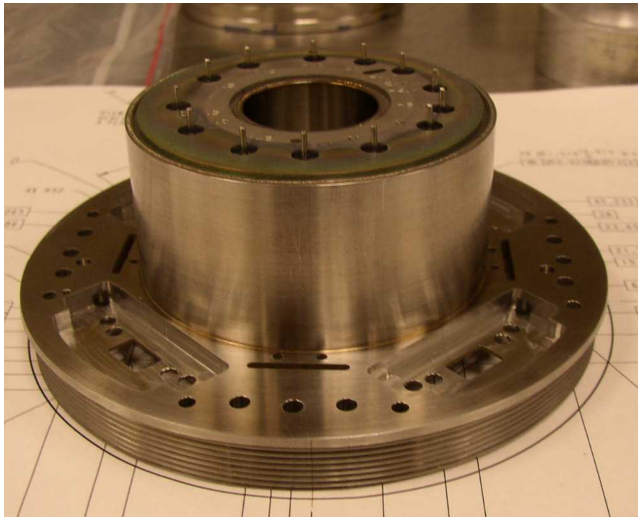
Specialty Thermal Battery Development and Prototyping

- **Prototype design, production, and testing**
  - **ATK MRM multi-tap annular thermal battery (CoS_2 cathode) for artillery application (high shock)**



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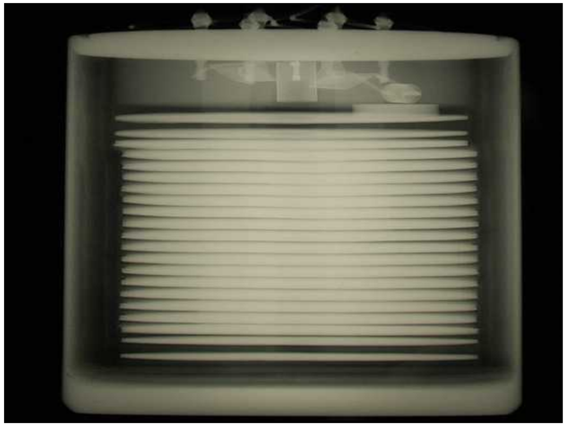
Thermal Battery R&D

- SNL/EPT thermal battery modeling project
  - SNL fabrication and testing of highly instrumented test batteries for model validation

- High-shock response of thermal batteries
  - Attempt to correlate electrical behavior (voltage drop outs) with mechanical displacements
  - Mechanical modeling of shock response



- Early (rise-time) electrical behavior of thermal batteries

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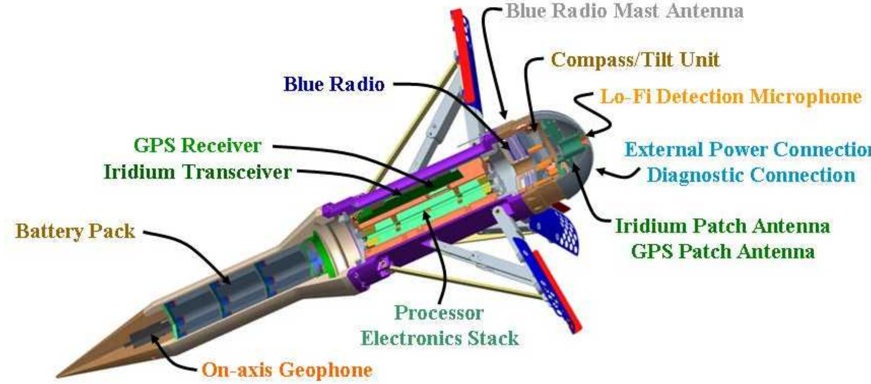
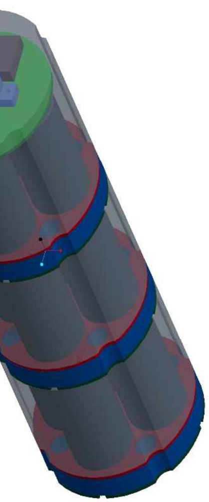
Additional WFO Projects

- **DARPA Dart**





- SAFT Lithium Sulphur Dioxide G54/6 Series
- 12, 3-V cells
- Derated Capacity: 171.5 WH
- Manufacture: Eagle-Picher

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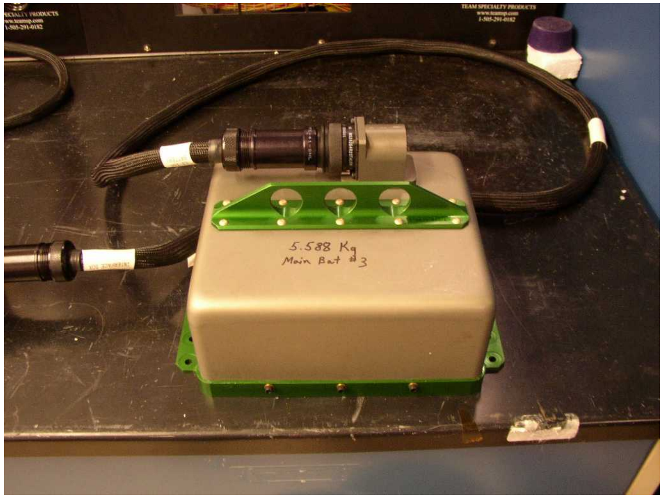
Additional WFO Projects

- STARS Rocket Program
  - Replace Ag/Zn launch, FTS, and ACS batteries with Li-ion
  - Main launch battery
    - SAFT MP176065 cells (5.5A-h)
    - 3 parallel strings, 8ea.



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R&D Activities

Thin-Film Thermal Battery

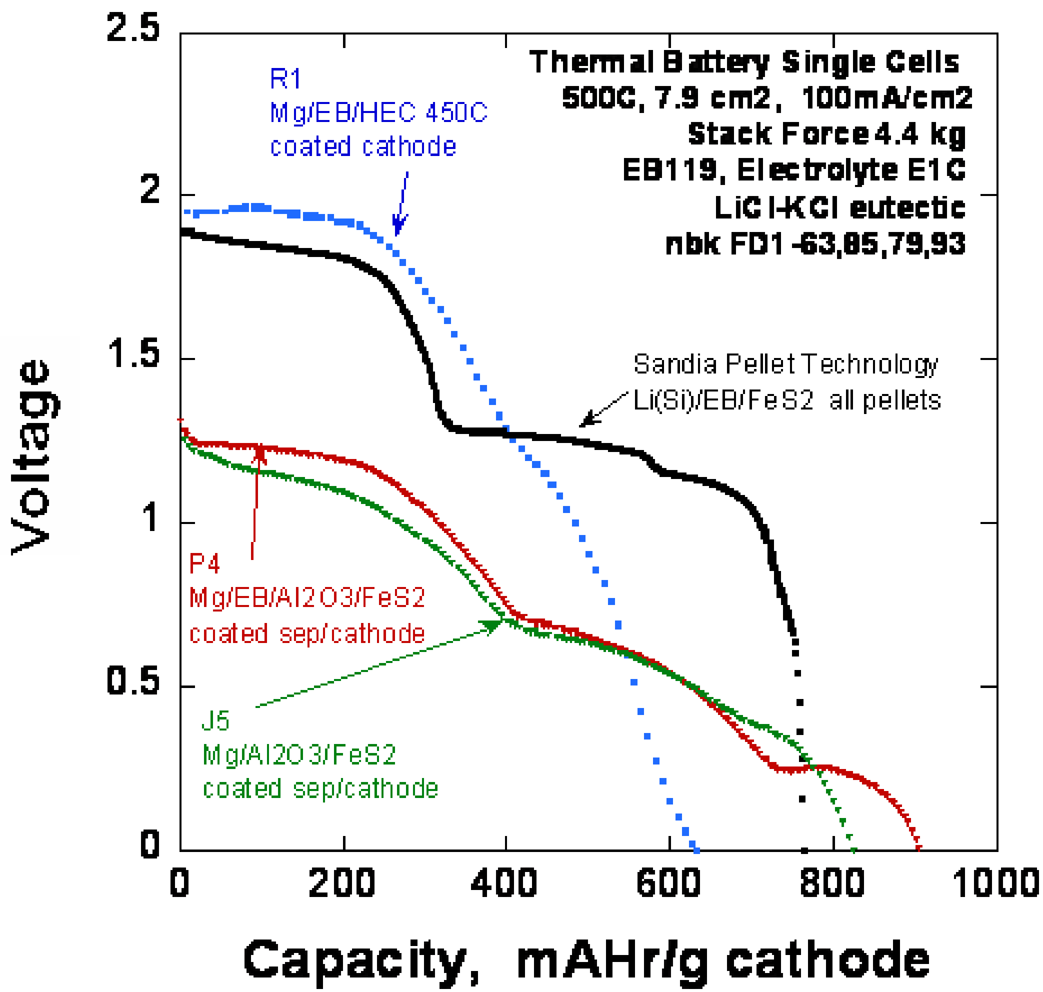
Advanced Thermal Battery Architecture: Thin-Film Thermal Battery Research

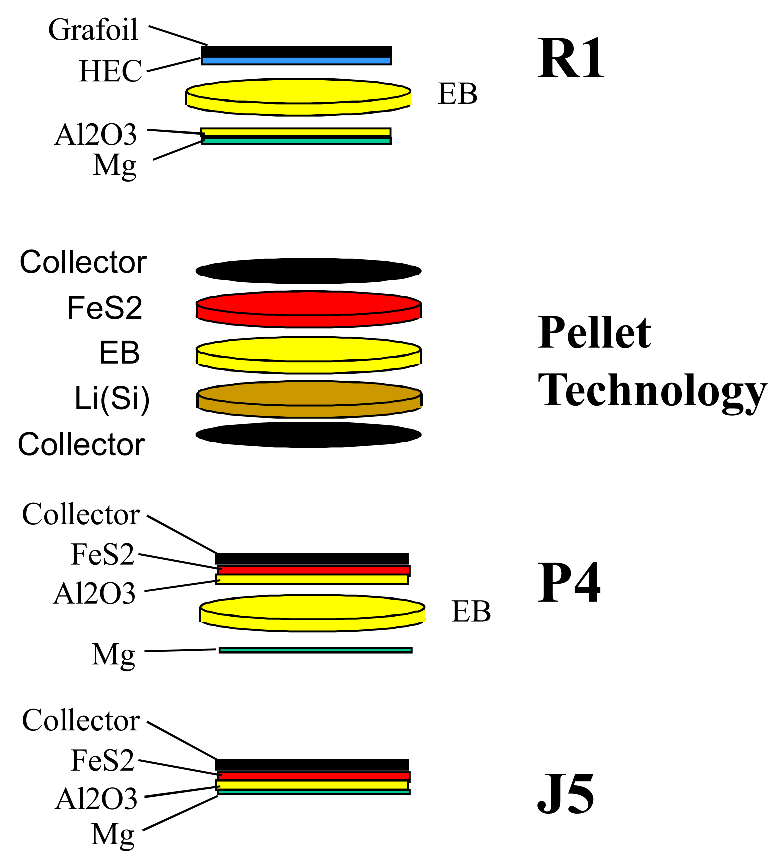
Develop an advanced thin-film thermal battery architecture based on coating/printing technology.

- Utilize current battery active materials and electrolytes.
- Develop chemically and thermally stable polymeric binders for cathode and separator components.
- Develop rheology for high speed coating of multi layers.
- Produce anode, separator and cathode components using common, commercial, industrial processes and commercial industrial suppliers.
- Bond cathode to current collector and bond separator to the cathode/anode.
- Develop new ignition heat source and continuous heat source for improved thermal management.
- Demonstrate technology with prototype.

Progression of Thin Film Thermal Battery Technology

Sandia binders are unstable against Li(Si). Thin film thermal battery must use Mg anode.





Thin Film Thermal Battery Achievements To Date

- Developed a chemically and thermally stable polymeric binders for cathode and separator components.
- Developed rheology for high speed coating of the cathode.
- Produced separator and cathode components using common, commercial, industrial processes and commercial industrial suppliers.
- Bonded cathode to current collector and bonded separator to the cathode/anode.
- Demonstrated proof of concept for new thin film heat source.
- Demonstrated thin film technology with prototype single cell.

R&D Activities

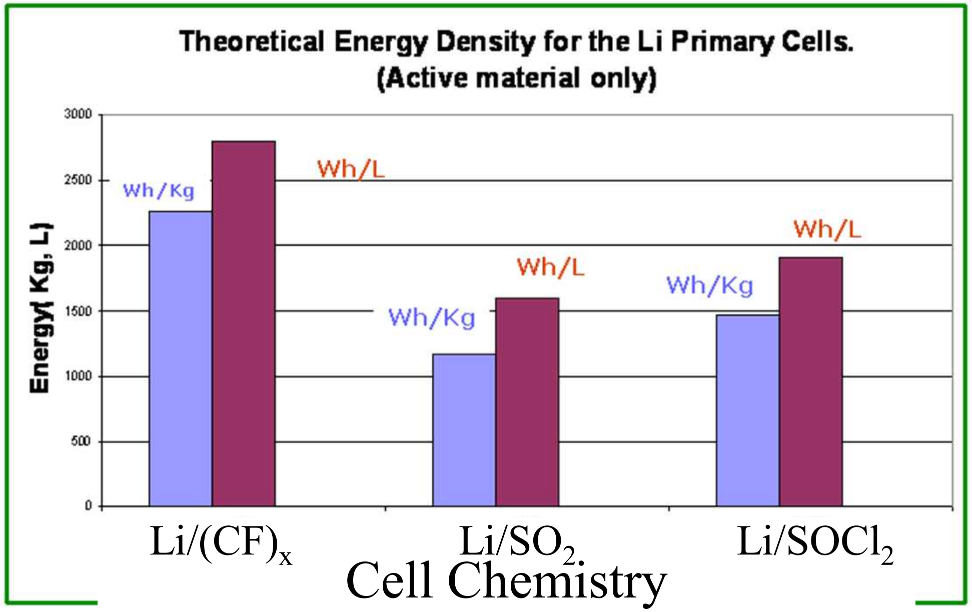
Enhanced Li/CFx Performance

Substantial Improvements In Primary Batteries Are Possible

- **Gains in Usable Energy Would Pay Big Dividends**
  - **Higher Specific Energy Will Provide Longer Life in All Applications**
  - **Lifetime in the application is directly governed by the deliverable capacity that can be obtained from a specific volume.**

$Li/(CF)_x$ has the Highest Theoretical Energy Density of Any Practical Lithium Cells but the utilization is poor at moderate rate.

- The major limitation arises from a dramatic increase in cell resistance during discharge.
- Anion Binding Agents solubilize reaction products and decrease cell resistance.

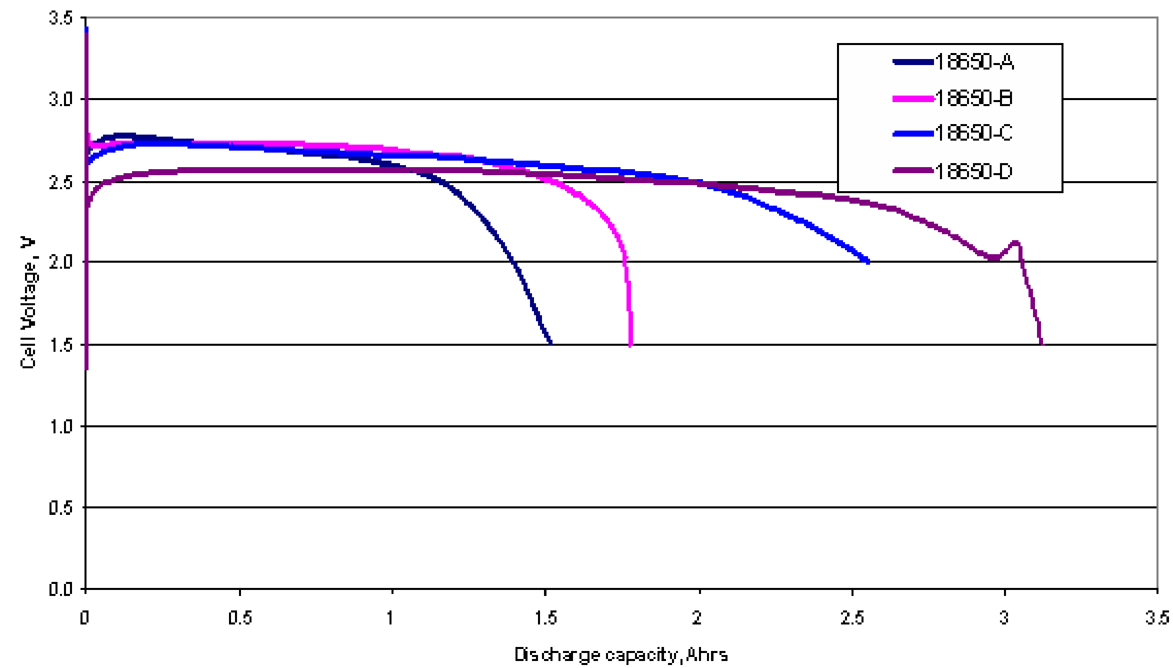


- CFx has the highest theoretical energy/capacity density of the three Li primary chemistries.

- CFx = 865 mAh/g; $SOCl_2$ = 451 mAh/g; SO_2 = 419 mAh/g

Improved Cell Design And Additives Increase The Usable Capacity

- We are making cells in-house to control the electrode fabrication and electrolyte composition.
- We have evaluated improved cathode materials that give better capacity at low temperature.
- Goal is to achieve 860 Wh/kg which doubles the capacity of today's best I primary cells.



We have increased the capacity and electrode uniformity of 18650-size cells made at SNL.

Improved Low Temperature Performance was Achieved with New Cathode Material.

Coin Cell with EC:PC:EMC-$LiBF_4$ electrolyte

Percentage delivered capacity of different $(CF_x)_n$ materials at sub-ambient temperatures				
Temperature, °C	$(CF_x)_n$ #1	$(CF_x)_n$ #2	$(CF_x)_n$ #3	$(CF_x)_n$ #4
-20	82	82	90	95
-40	16	39	82	88
-51	6	25	67	62

We have selected material # 4 which shows good performance at -51°C and all temperatures for a C/200 rate (42 microA rate)

Accomplishments & Future Work

- **Identified new source of $(CF_x)_n$ which performs well at low temperatures.**
  - Obtained close to 65% of the room temperature capacity at -51C
- **We have evaluated two Anion Binding Agents, which allow electrolyte formulations that have better stability at elevated temperatures.**
- **Developed two electrolytes**
  - EC:PC:EMC-$LiBF_4$
  - EC:PC:EMC-ABA-LiF
- **Funded University of South Carolina (USC) to develop an electrochemical model for the Li/$(CF_x)_n$ cell chemistry.**
  - This model will be validated with our 18650 cell data.
- **Thermal abuse studies will be performed to gather safety characteristics of the cells.**

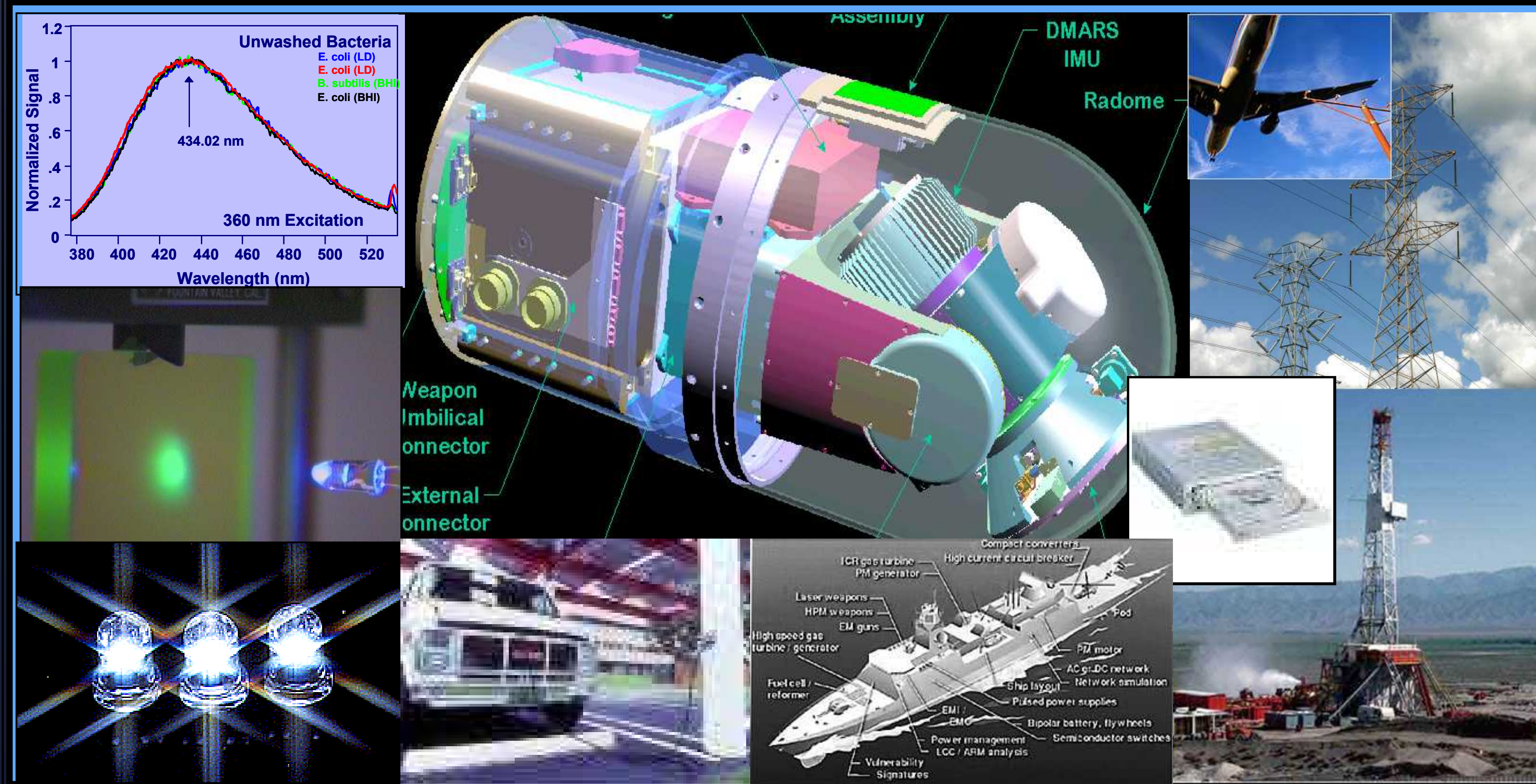
R&D Activities

Electrochemical Deposition of GaN

Gallium Nitride Has Many Important Applications for Energy and National Security

Synthetic Aperture Radar · Biological Agent Detection · Chemical Detection · Solid-State Lighting · MEMS

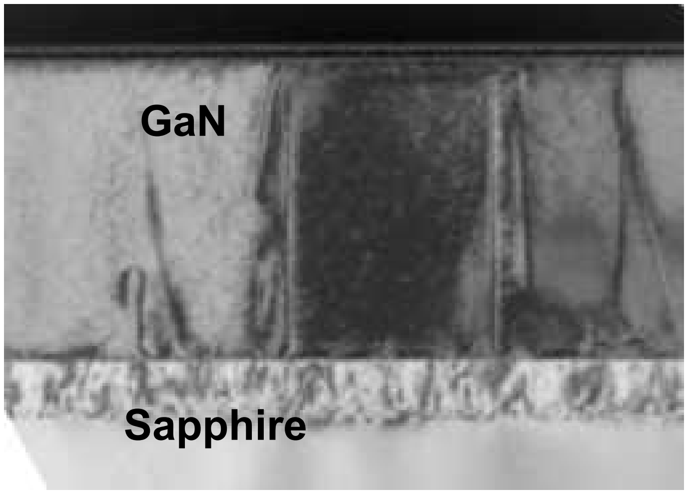
Data Storage · Water Purification · Down-hole Sensing



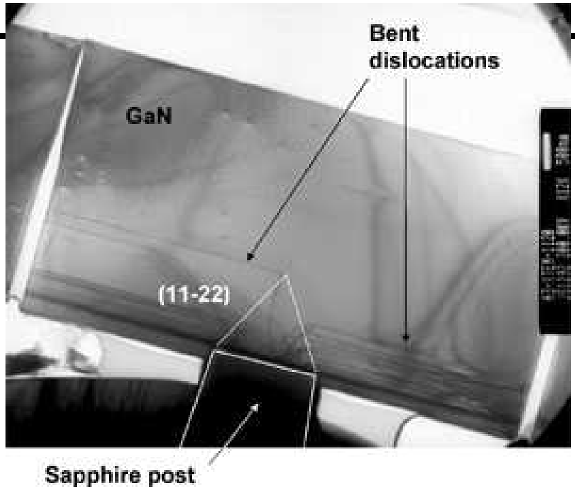
Hybrid & Electric Vehicles · Utility Grid Switching

Electric Ship & Aircraft · Non-Line-Of-Sight Communications · Missile Plume Detection · Polymer Curing

GaN Lacks a Native Substrate; GaN is grown heteroepitaxially on Sapphire and SiC substrates

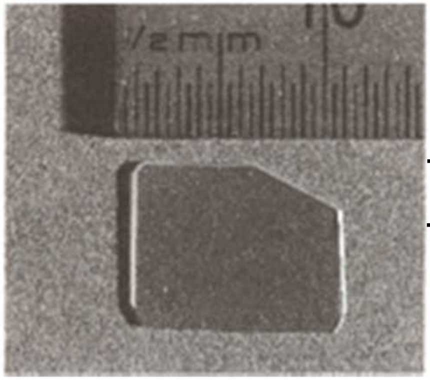


Planar growth: Dislocation Densities 10^9-10^{-11} cm^{-2}



Cantilever Epitaxy: 10^7cm^{-2}

Aggressive applications such as Solid State Lighting* and High Temperature Electronics are likely to require dislocation densities < 10^5/cm^2



HVPE thick-films: 10^5cm^{-2}

*Sony just announced it is having to cut back on production of the next generation Playstation 3 due to lack of volume of 405 nm lasers– a problem with yield, due to the high defect densities arising from the lack of native substrates.

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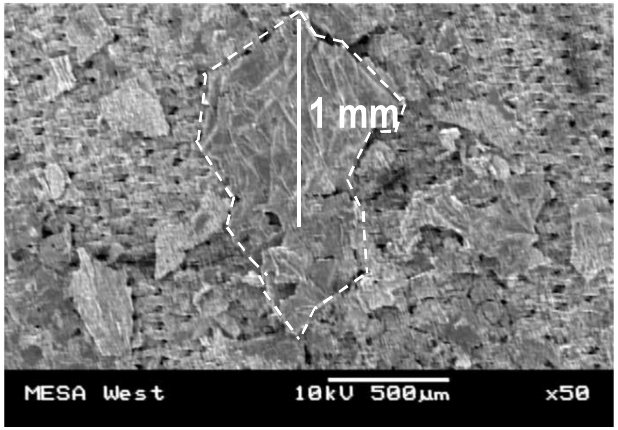
Atmospheric Pressure Growth of Bulk Gallium Nitride for Substrates

K.E. Waldrip, J.Y. Tsao, T.M. Kerley, W.G. Breiland, R.M. Biefeld, D.H. Doughty

Growth of Bulk GaN is problematic because:

- Molten GaN thermodynamics are extreme (60,000 atmospheres, 2500C)
  - Crystal growth by melting and freezing is impractical
- Kinetics of nitrogen reaction or dissolution is also very slow (cm/month)
- GaN is insoluble in almost everything, even at high pressures (4,000+ atm.)

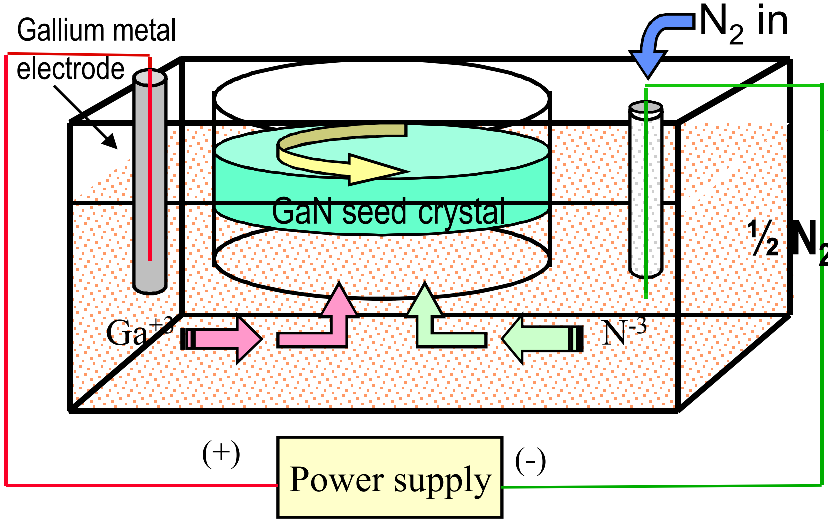


► ***Synthesize GaN from electrochemically-created ionic precursors that <u>are</u> soluble at atmospheric pressure***

Solvent is molten halide salts; temperature range 450-1100C

Advantages: scalable, flexible, favorable kinetics, non-hazardous process, low-cost, applicable to other metal nitrides

$Ga^0 \rightarrow Ga^{+3} + 3e^-$



$\frac{1}{2} N_2 + 3e^- \rightarrow N^{-3}$

Stir solution to prevent premature reaction and deliver reactants to seed crystal surface

Current status:

- 1mm crystal in 2 hrs by electroplating
- Hardware for rotation experiment under development

Sponsored by: LDRD & NETL

R&D Activities

Thermal – to – Electric Conversion

Miniature Radioisotopic Thermoelectric Generator - SNL

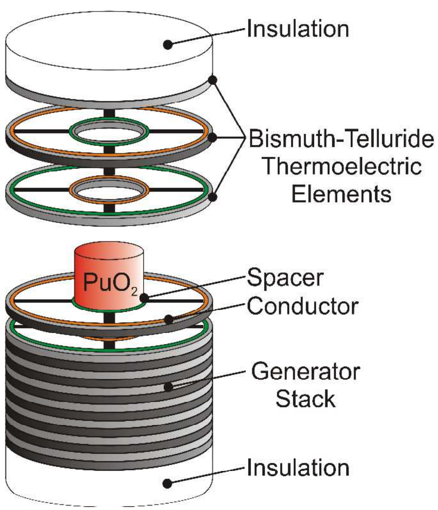
Goal:

Miniaturize RTG architecture to generate ~ 1mW for 10yrs

Approach:

- Maximize power density/efficiency
- Radial design optimizes heat flow without relying on vacuum
- Thin bismuth-telluride elements machined using EDM

Mini RTG Concept

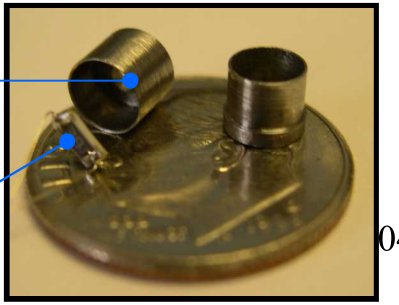


Working Prototype

Prototype Performance

- Surrogate heat source provides 150mW thermal
- 431μW electrical output in 4.35cm^3
- 100μW/cm^3
- Rev2 under construction 1.1mW in 4.35cm^3
- 250 μW/cm^3

Simulated Heat Source



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Spacers / Conductors / TE Elements

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Miniature Thermophotovoltaic Generator – DARPA / LM Heat into Power

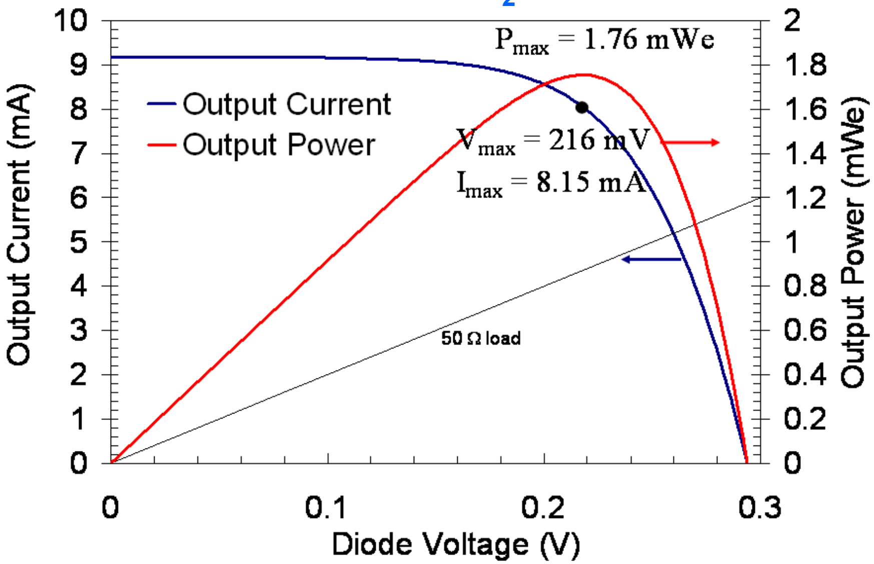
Goal:

Develop a miniature TPV ~ 30mW in 4cm^3 for 10yrs

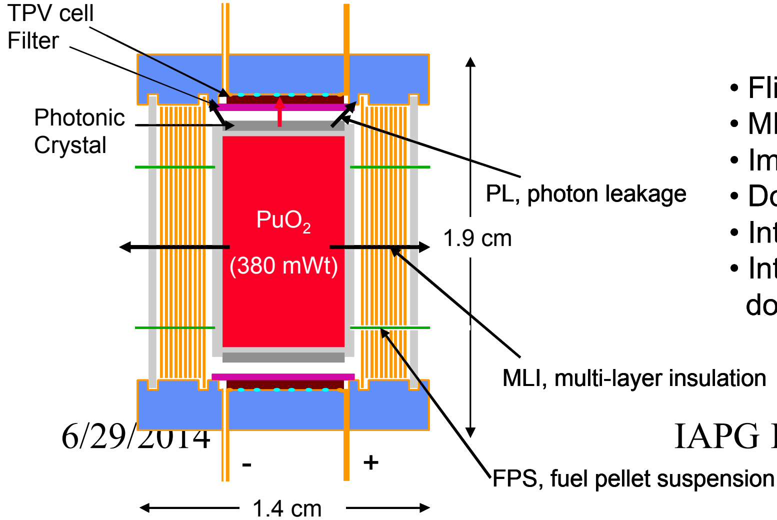
Approach:

- **Harvest photons emitted from heat source surface**
- **Insulate heat source using MEMS**
- **Use photonic crystal to improve efficiency**

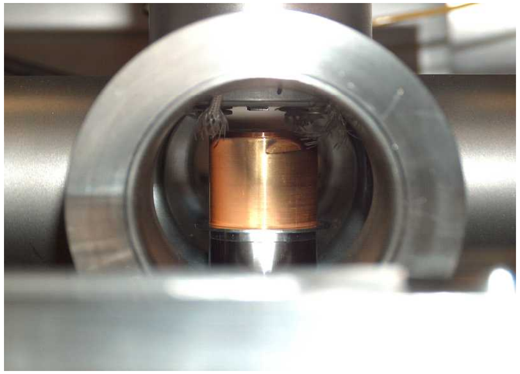
Prototype Performance – 380mW CmO_2 Pellet



Mini TPV Concept



- Flip-chip TPV Cell
- MEM multi-foil insulation
- Improved cavity photonics
- Double ended conversion
- Integrated photonic crystal
- Integrated shield to reduce dose



Test set-up at ORNL

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Other Activities

- Miniature Thermoacoustic Engine
  - SNL, LANL, LM Shared Vision
  - Heat to acoustic, Acoustic to electricity
  - Explore design space
  - Fabricate prototype operating off low ΔT
- TE Harvesting - SNL
  - Developing novel manufacturing techniques
    - Harvest low ΔT
    - High-aspect ratio thermoelectric elements
    - Manufacturability
    - Mechanically robust

DOE Energy Storage Program

Mission:

Develop advanced electricity storage and PE technologies, in partnership with industry, for modernizing and expanding the electric supply. This will improve the quality, reliability, flexibility and cost effectiveness of the existing system.

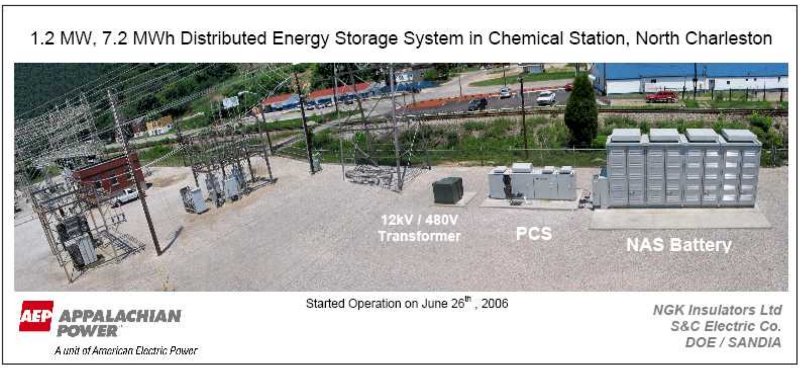
Program is led by Sandia National Laboratories

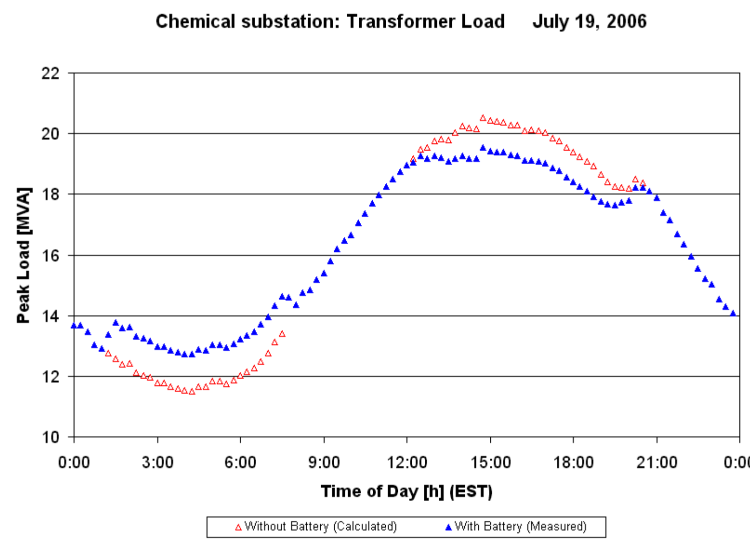
7 Major Technology Field Tests are underway.

3 R&D Awards have been received

Partner	Contract	System	Size	Location	Comm	Monit. Comp.
CEC	Beacon	Flywheel	100 kW	PG&E DUIT	Mar. 06	Dec. 06
CEC	Palmdale	Supercap	450 kW	Palmdale, CA	Feb. 07	Feb. 08
CEC	ZBB	ZnBr	1 MW / 4hr	PG&E DUIT	?	?
NYSERDA	Gaia	Lead-Acid	11 kW / 3hr	Delaware Coop	Nov. 05	Jan. 07
NYSERDA	Beacon	Flywheel	100 kW	Amsterdam, NY	June 06	Aug. 07
NYSERDA	NYPA	NaS	1 MW / 6hr	Long Island	Oct. 06	March 08
AEP	App.Power	NaS	1.2 MW / 6 hr	Charleston, WV	July 06	Sept. 07

NaS Battery for Substation Support





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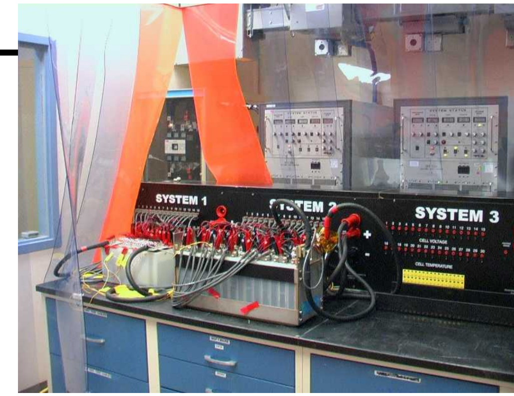
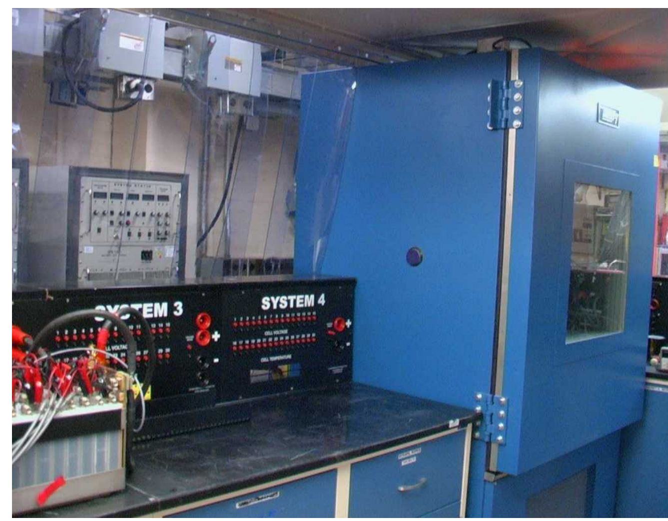
1.2 MW / 6hr NaS Battery for Substation Support:

- First Commercial Application in US.
- Provides Backup during Peak Load
- Defers Upgrade by 5 to 6 Years
- Reduces Transformer Heat up
- Potential Arbitrage Benefits 10K/month
- Commissioned July 20, 2006

SNL In-House Test Activities



- EC Supercap testing
  - Asymmetric Ni/Carbon Aqueous Electrolyte
  - Symmetric Carbon/Carbon Acetonitrile Electrolyte
  - Symmetric Carbon/Carbon PC Electrolyte
- Battery Testing
  - VRLA (NorthStar, Enersys)
  - NiMH (EEI - Bipolar)
  - Li-Ion (Saft)
- Abuse Testing
  - Symmetric Carbon/Carbon Acetonitrile Electrolyte



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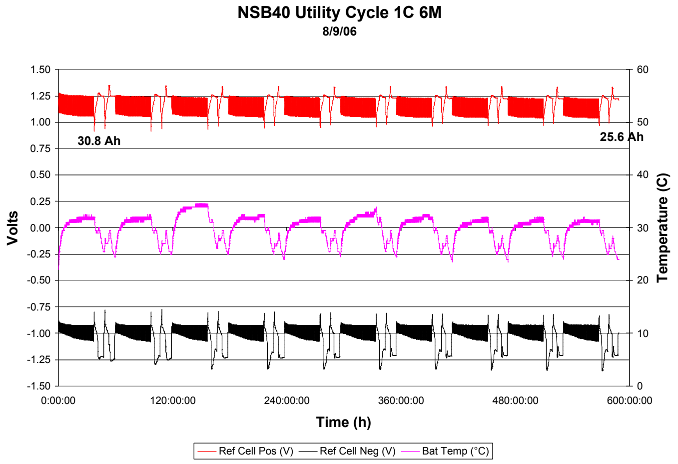
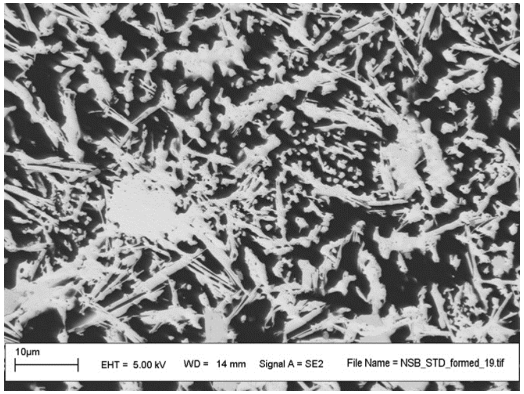
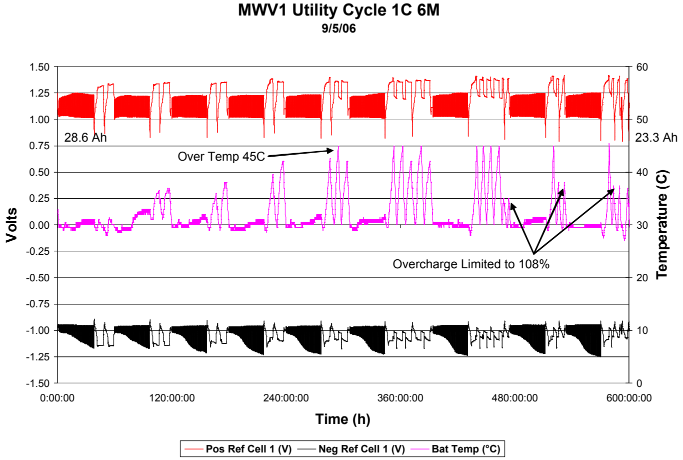
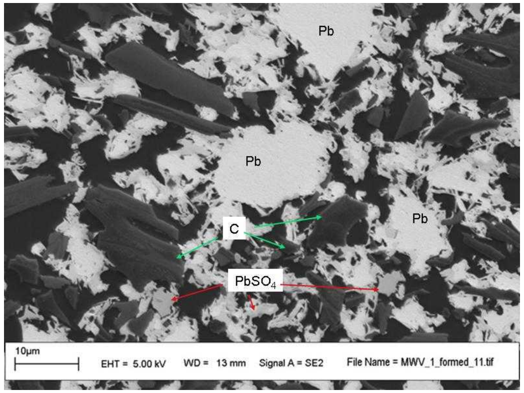
MeadWestvaco/NorthStar VRLA Battery Testing and Analysis









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Summary

- **PSTG has extensive capabilities in PS Technology**
  - **Fundamentals**
  - **Design/Development**
    - **For severe environments**
  - **Production**
    - **Small quantity/high reliability**
    - **Well connected to supply chain**
  - **Performance/Environmental Testing**
  - **Abuse testing and mechanisms**
  - **Program Management**
- **We team with SNL's Science and Technology Community to solve tough problems**
  - **Material Science**
  - **Modeling and Simulation**
  - **Environmental Testing**