National Aeronautics and
Space Administration

NASA Battery Research & Development Overview

Sandia Power Sources Technology
Group University Seminar
November 15, 2021

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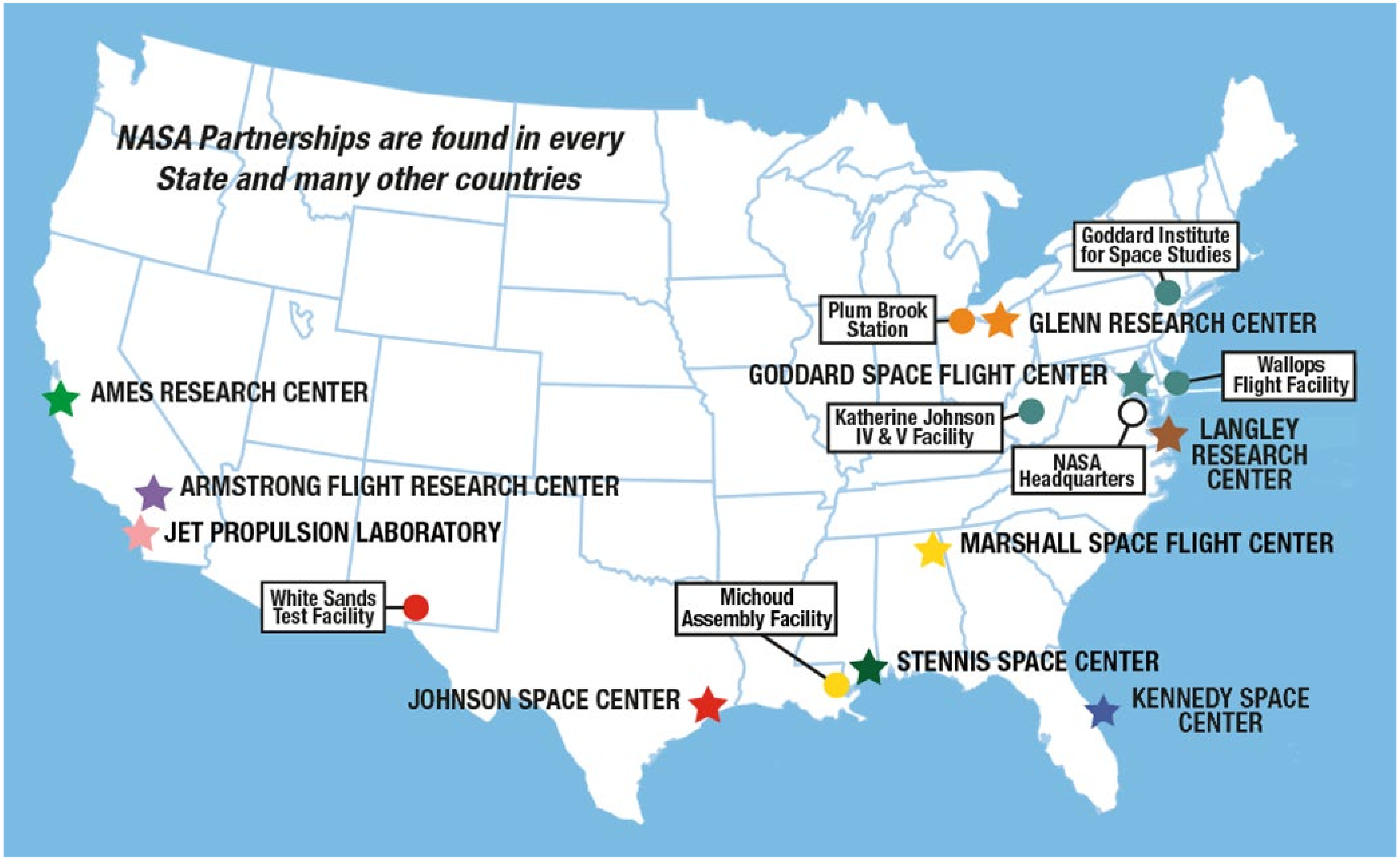
in collaboration with NASA JPL and ARC

Outline

- **NASA Centers**
- **NASA's Unique Requirements**
- **Battery Research & Development Efforts**
  - Space development
  - SBIR/STTR efforts
  - Aeronautics development

NASA Centers

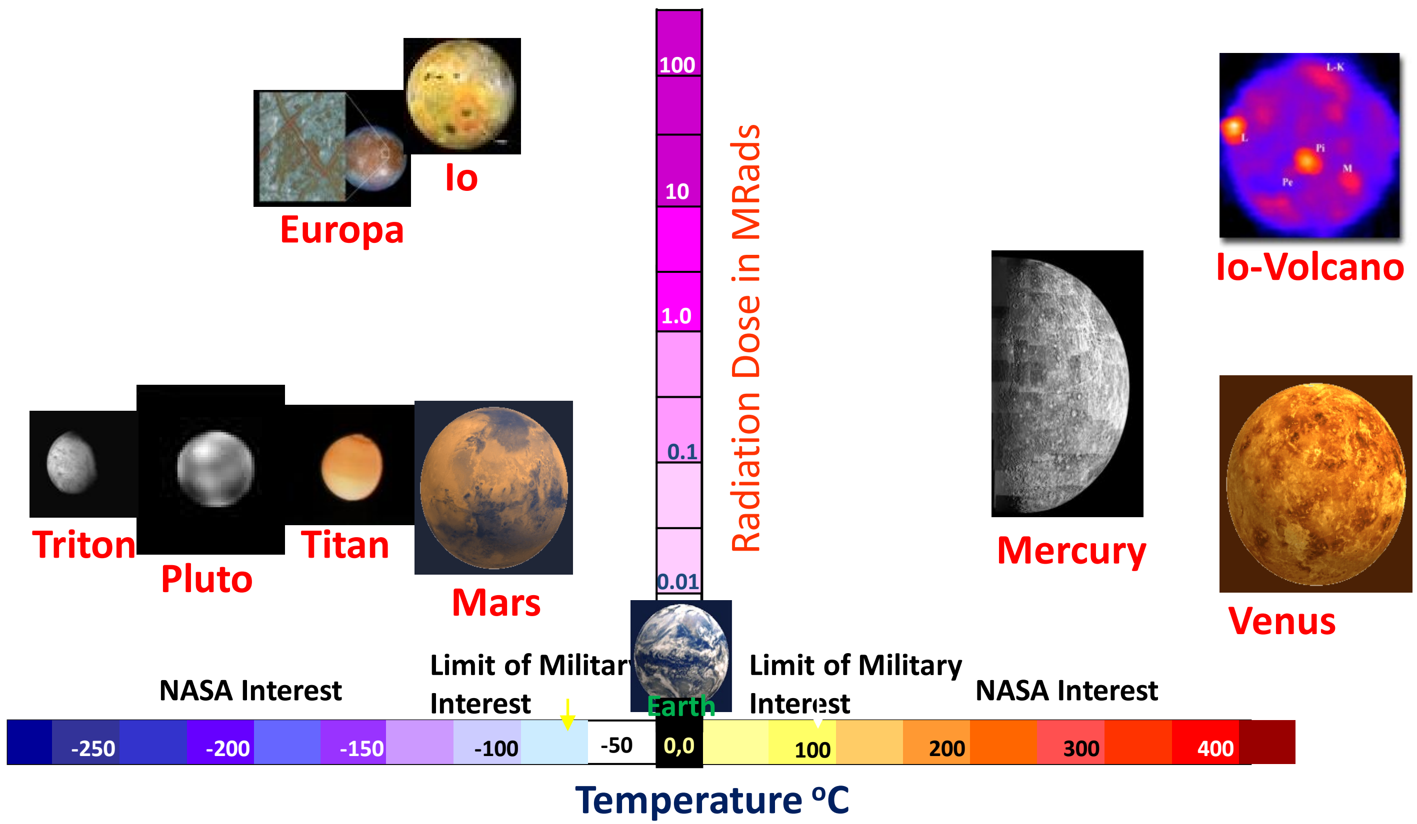
NASA Centers for Battery R&D



NASA's Unique Requirements

Extreme Environments for Planetary Missions

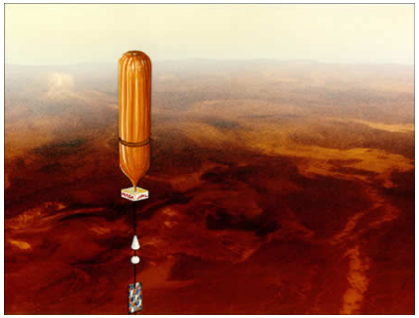
- NASA missions have unique requirements that span from terrestrial to outer planets
  - Some missions require high radiation resistant power systems
  - Inner planetary missions require operation at very high temperatures
  - Outer planetary surface missions require low temperature operation, some in dense or tenuous atmospheres



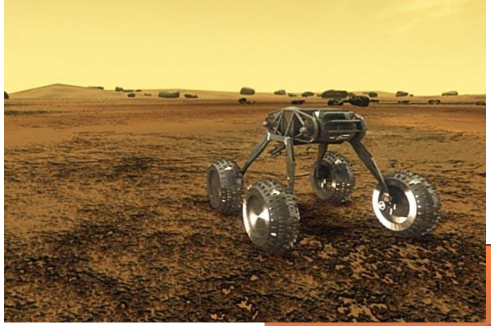
Space Power Requirements

Energy Storage System Needs for Inner Planetary Missions

- **Primary Batteries/Fuel Cells for Surface Probes**
  - High Temperature Operation (> 465^{0}C)
  - High Specific Energy (>400 Wh/kg)
  - Operation in Corrosive Environments



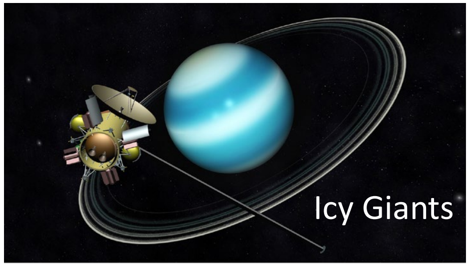
- **Rechargeable Batteries for Aerial Platforms**
  - High Temperature Operation (300-465^{0}C)
  - Operation in Corrosive Environments
  - Low-Medium Cycle Life
  - High Specific Energy (>200 Wh/kg)
  - Operation in High Pressures



Energy Storage System Needs for Outer Planetary Missions

- **Primary Batteries/Fuel cells for planetary landers/probes**
  - High Specific Energy (> 500 Wh/kg)
  - Long Life (> 15 years)
  - Radiation Tolerance & Sterilizable by heat or radiation

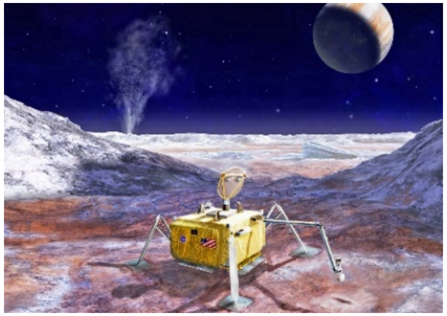
- **Rechargeable Batteries for flyby/orbital missions**
  - High Specific Energy (> 250 Wh/kg)
  - Long Life (> 15 years)
  - Radiation Tolerance & Sterilizable by heat or radiation



Uranus/Neptune missions

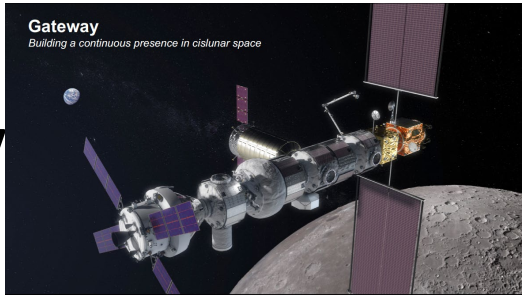
- **Low temperature Batteries for Probes and Landers**
  - Low Temperature Primary batteries (< -80^0C)
  - Low Temperature Rechargeable Batteries (< -60^0C)

Europa Lander (artist's concept)



Energy Storage System Needs for Lunar Applications

- **14-day eclipse Lunar Night survivability and operability beyond -40° C, increased reliability & decreased system complexity**
- **Cislunar Space**
  - Lunar Gateway Power & Propulsion Element
    - 15 year on-orbit operational life
    - 50 kW class spacecraft with 40 kW EP system
- **Lunar Surface**
  - Landers
  - Rovers (> 500 Wh/kg)
  - Permanent habitat power
  - Permanently Shadowed Regions (PSR)
- **EVA suits (> 400 Wh/kg, > 100 cycles)**



Lunar Gateway


Lunar Landers


Lunar Rovers

Aeronautics Power Requirements

Battery Needs for Electric Aircraft Propulsion

- > 400 Wh/kg required at the system level
- 1000's of cycles
- Extremely high power requirements (C-rates) during takeoff and landing
- Cruise power for long range flights
- High reliability, limited maintenance
- Improved safety for thermal runaway events

Representative Examples of Aeronautics Mission Requirements

Mission	Number of Passengers	Typical Range	Power Level	Specific Energy	EAP Configurations
Urban Mobility	<=4	<50 miles	200-500kW	250 – 400 Wh/kg	• All electric • Hybrid Electric
Thin Haul	<=9	<600 miles	200-500kW	300 – 600 Wh/kg	• Hybrid Electric
Short Haul Aircraft	40-80	<600 miles	500-1500kW	300 – 600 Wh/kg	• Hybrid Electric
Single Aisle	150-190	900 mile typical mission, 3500 mile maximum range	1000-5000kW	750 – 1000 Wh/kg minimum	• Hybrid Electric • Turbo Electric

Battery Research & Development Efforts

Battery R&D:
Space

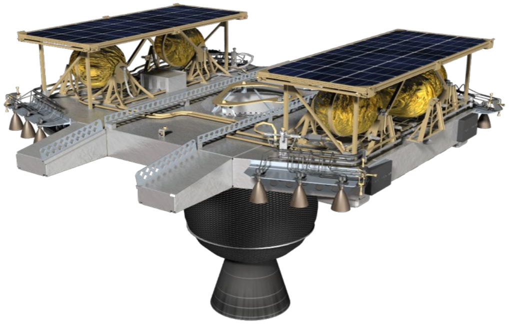
Lunar Lander Systems

POC: Robert Cataldo, NASA GRC

NASA GRC role as lead center for power system definition and design in support of lunar landers for science and human missions

- **Cargo Transportation and Landing By Soft Touchdown (CATALYST)**
  - LG MJ1 cell performance characterizations for Astrobotic's Peregrine lander
    - Demonstrated performance/mass benefits for high-energy LG MJ1 cells vs. obsolete Sony HCM cell
  - Identified and tested military Li-ion battery option (BB-2590) for Masten Space Systems for use in the XL-1T tethered flight demonstration
- **Volatiles Investigation Polar Exploration Reconnaissance (VIPER)**
  - Power profile screening of MJ1 cells
- **Advanced Cislunar and Surface Capabilities (ACSC) Human Landing System (HLS) project**
  - Surviving lunar night experiments planned for 18650 cells
  - Supporting power systems trade analysis

Astrobotic Peregrine Lander



VIPER Lander

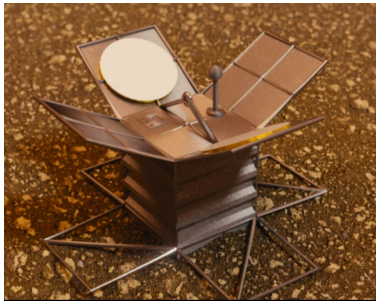
High-Temperature Tolerant Batteries
Long-Life In-situ Solar System Explorer (LLISSE)

POC: Tom Miller, NASA GRC

Primary & rechargeable batteries for high temperature (>400°C)

Venus surface missions

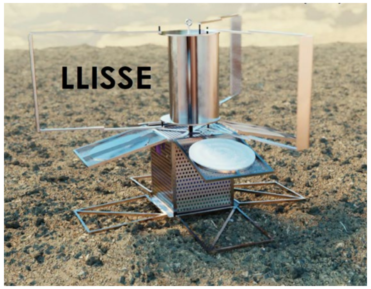
- 60 Earth day mission to provide scientific data (primary battery)
- 120 Earth day mission with wind turbine for recharge capability to battery



LLISSE-B probe powered only by charged battery

LLISSE In-house GRC Testing

- Primary battery testing in the Glenn Extreme Environments Rig (GEER) under simulated Venus conditions and nitrogen purged furnace facility
- Secondary battery cycling under simulated Venus temperatures



LLISSE-W probe with wind turbine for recharging the battery

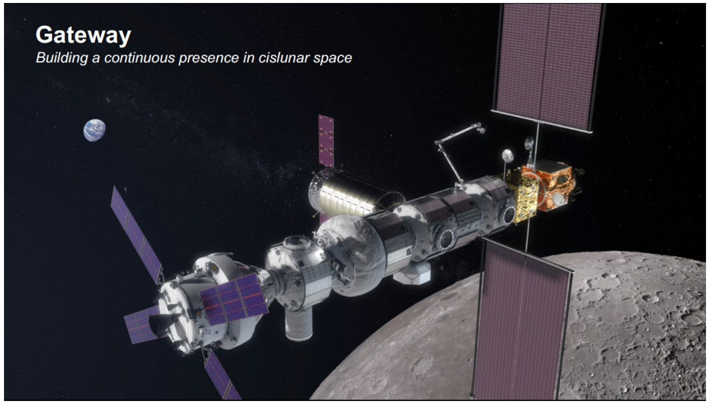
High Operating Temperature Technology (HOTTech)

- Rechargeable molten Li-S battery for Venus (U of Dayton Research Institute)
  - 3 year effort – demonstrate 300 Wh/kg prototype capable of 100-150 cycles
  - Identified a coating technique for high ionic conductivity, thermally stable, Li^+ selective solid electrolyte to operate at molten lithium conditions
  - Developed a custom cell for electrochemical characterization of a molten Li-S full cell
- High Temperature Long-Life (HiTALL) Primary Batteries – (JPL/Eagle Picher)
  - 2-year effort – validate 150 Wh/kg, 500oC prototype battery capable of 30+ day mission
  - Demonstrated 26 Earth days of operation in single cell at 4750C in a glovebox
  - Demonstrated 50+ days of discharge operations at C/1440 with C/10 pulses after recharging when voltage drops below minimum

Gateway Power and Propulsion Element (PPE)

POC: Pat Loyselle, NASA GRC

First element of Lunar Gateway
- Contract awarded to Maxar Technologies in May 2019
- NASA role to provide insight



Core functions for Gateway:
- Power transfer to other Gateway elements
- Transport of Gateway to multiple cislunar orbits
- Attitude control and orbit maintenance for Gateway stack
- Communications with Earth, visiting vehicles, and initial communications support for lunar surface systems

PPE Battery Requirements:
- 8 kW for 1.5 hr (12 kWh)
- Capable of 12 kW peak power
- 100 V nominal bus

Key Characteristics:
- 2022 launch on partner-provided commercial launch vehicle
- Up to one year joint commercial/NASA on-orbit flight demo
- 15 year on-orbit operational life
- 50 kW class spacecraft with 40 kW EP system

Saffire: Spacecraft Fire Experiment

POC: Rosa Padilla, NASA GRC

Assess the risks of fire and understand prevention, detection, and mitigation to protect the crew and vehicle

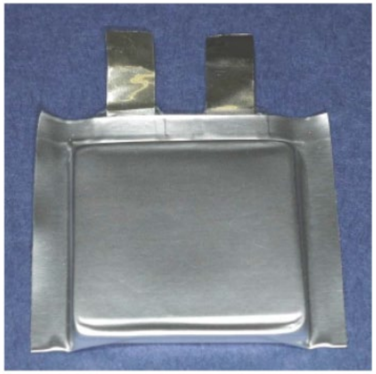
Objective #1: Determine the onset of thermal runaway and ignitability in pouch cells

Objective #2: Determine the flame structure, energy release, combustion products and particulates from Li-Ion battery units - pouch cells

Objective #3: Assess the flame structure, energy release, combustion products and particulates from Li-Ion battery units - tablets battery pack

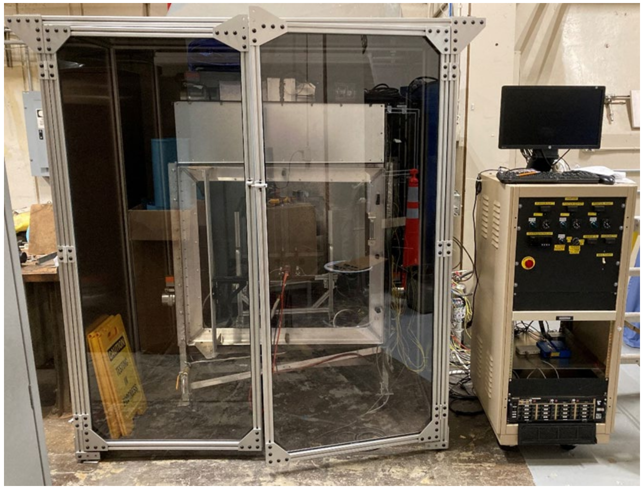
Objective #4: Determine the physical, thermal and chemical mechanisms and effectiveness of water suppression on primary fires

Objective #5: Quantify the energy release, combustion products, such as, CO_2, CO, H_2, organic compounds, and particulates by varying the environmental conditions



Typical Li-ion pouch cell

Tablet with patch heater



SAFFIRE Experimental Hardware

Sensors: high speed video, load cells, gas sensors, radiometers, aerosol measurements, thermocouples, obscuration meter (visibility), and relative humidity

Overview of JPL Battery Activities

POC: Will West, NASA JPL

- **Flight battery development, delivery, and operation of Li-ion, Li-primary, and thermal batteries:**
  - e.g. Mars Perseverance rover, Mars Ingenuity helicopter, Europa Clipper, MarCO, MSL, SMAP, MER, etc.
- **Cell chemistry research:**
  - Wide operating temperature Li-ion electrolytes
  - High specific energy Li-CF_x primary cells
  - High temperature (465^{o}C) rechargeable cells for Venus surface missions
  - Interface engineering (e.g. atomic layer deposition of protective films, electrolyte additives for tailoring solid electrolyte interphase, etc.)
  - Advanced cell chemistries:
    - ➢ Ultra-low temperature (-130^{o}C) primary cells
    - ➢ Li-S, Mg-ion, solid-state, dual intercalating, F-ion, etc. cell chemistries

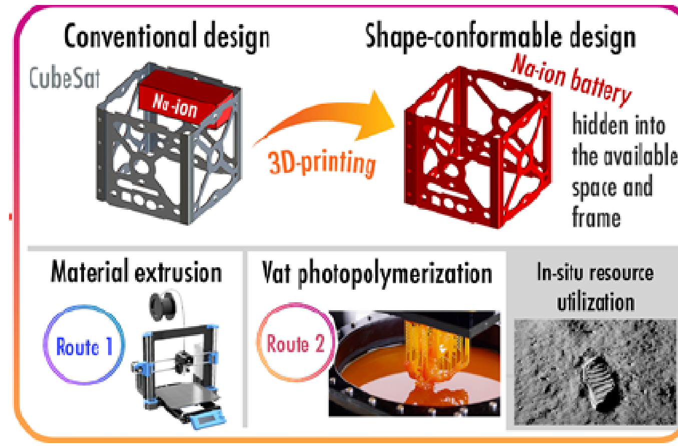
In-Space/On-Surface Manufacturing of Sodium Ion Batteries Using In-Situ Resource Utilization Materials

POC: Cameroun Sherrard, NASA MSFC

Overview

- Early Career Initiative effort – promotes early career-led efforts with engagement across centers
- Sodium-ion batteries components are abundant in Lunar and Martial regolith, making ISRU ideal
- Na-ion could enable improved safety, faster charge and higher performance compared to Li-ion

Concept Summary



Goals:

- Produce shape-conformable sodium-ion batteries via 3D printing processes
- Combine additive manufacturing for electronics and ceramics in a compact, conformal, smart battery

Execution:

- 2-year effort to demonstrate disruptive technology for 3D printing and ISRU extraction methods

Partners

The University of Texas at El Paso
A leader in advanced manufacturing with strong experience in 3D printing of energy storage devices including lithium-ion batteries.

Youngstown State University
A renowned additive manufacturing research institution. Team has strong experience in thermal post-processing.

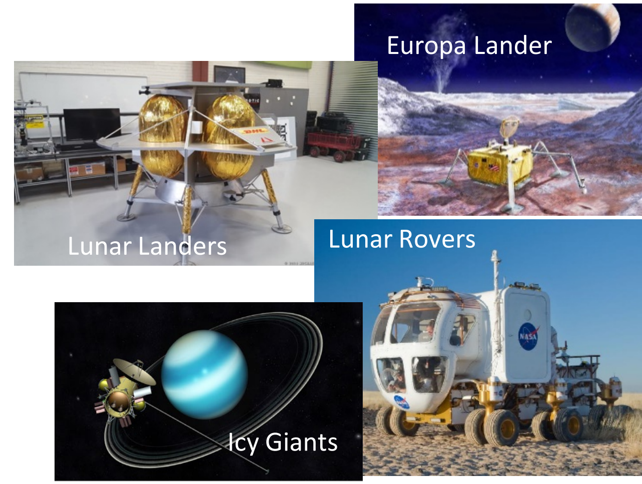
Formlabs
One of the top consumer 3D printer companies Formlabs will aid with resin formulation and parameter definition during printing.

ICON
The leading additive manufacturing company of residential homes in the world. ICON will advise the direction of the project and technology demonstration.

Batteries for Extreme Cold Environments Early Career Faculty Awards

POC: Pat Loyselle, NASA GRC

- **3-year grants awarded to outstanding early career faculty researchers at accredited U.S. universities**
- **FY18 solicitation for Batteries for Extreme Cold Environments – efforts extended into FY22**
- **Key Performance Targets**
  - Operation between -40°C to -180°C
  - >300 Wh/kg at C/720 rate (primary) and >150 Wh/kg at C/5 rate (rechargeable)
  - 100 charge/discharge cycles with <5% capacity loss



Principal Investigator	University	Project Title
Zheng Chen	University of California, San Diego	"Liquefying Gas Electrolyte by Capillary Condensation at Ambient Pressure for Extreme Low-Temperature Batteries"
Weiyang (Fiona) Li	Dartmouth College	"Development of High Energy and Low-Cost Semi-Solid Sodium Batteries Operating at Extreme Cold Temperatures"
Seung Woo Lee	Georgia Institute of Technology	"Improving Low-Temperature Performance of Battery Anodes on Surface-Controlled Charge Storage Mechanism"
Matthew McDowell	Georgia Institute of Technology	"Overcoming Kinetics Limitations in Materials and at Interfaces for Low-temperature, High-energy Batteries"

Lunar Surface Technology Research (LuSTR)

POCs: Pat Loyselle, NASA GRC

University-led efforts to improve critical systems and components or to catalyze development of new technologies that address high priority lunar surface challenges

Technical Characteristics:

- Unique, disruptive or transformational lunar surface technologies: autonomous excavation and construction, mitigation of lunar dust hazards, in-situ resource utilization, surface power, and accessing and surviving the extreme lunar environment.
- Low to mid Technology Readiness Level (TRL): TRL 2-5
- Post-award infusion opportunities

Topic 5 – Low-Temperature Batteries

- Reliable, high-performing primary and secondary batteries for harsh low-temperature Lunar conditions
  - Need for better operation with less mass/parasitic power for thermal management
- Operation from -40°C down to -120°C
- >400 Wh/kg (system-level primary battery)
- >250 Wh/kg (system-level secondary battery), 100 cycles
- Battery-level goals to focus on need to show a path towards a realizable product in 5 years

Award Information

- Expected duration: **2 years**
- Anticipated awards (LuSTRO20): **10-15 awards** valued at up to **$1-2M** each
- Oversight: Annual reviews by NASA/APL team and semi-annual briefings at LSIC meetings
- Award instrument: Grants
- Release Date: **Early summer 2020**

Small Business Innovation Research (SBIR)

POC: Pat Loyselle, NASA GRC

Phase I - Funding up to $125K for 6/13 months (SBIR/STTR)

2021

- Talos Tech, LLC – S3.03-3308 - High Temperature All Solid-State LiAl-CO2 Batteries for Venus Missions
- Structured Ions -

Phase II - Funding up to $750K for 24 months

2019

- ADA Technologies, Inc - Z1.04-2824- High Energy Density Long Cycle Life Li-S Batteries for Space Applications
- Giner, Inc – A1.04-3055 – High Energy Density and High Cycle Life Lithium-Sulfur Battery for Electrified Aircraft Propulsion
- Chemtronergy, LLC - T15.03-4336 - Solid State Li-S Battery Based on Novel Polymer/Mineral Composite (STTR)

Phase III

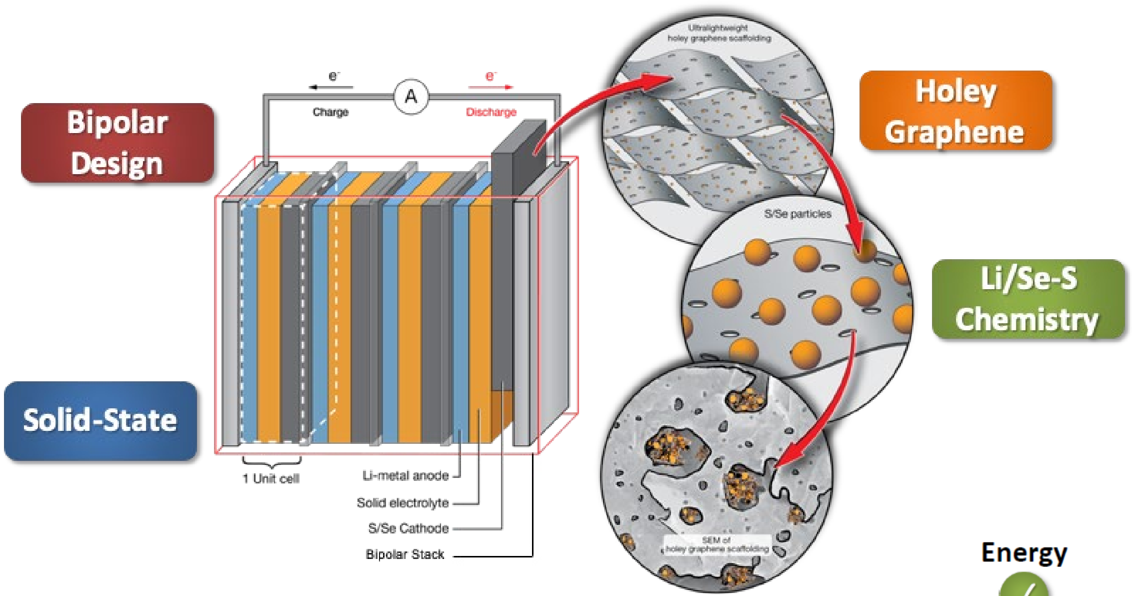
- Cornerstone Research Group, Inc. - H8.04-8147 – Advanced Lithium Sulfur Battery

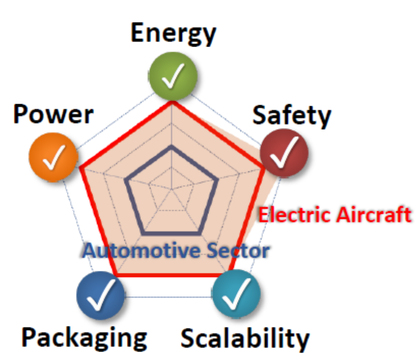
Battery R&D: Aeronautics

Solid-state Architecture Batteries for Enhanced Rechargeability and Safety (SABERS)

POC: Rocco Viggiano, NASA GRC

Can we enable energy intensive Urban Air Mobility (UAM) and all electric aero-vehicle designs through new battery technology that intrinsically meets rigorous aerospace safety and performance criteria?





SABERS Team

NASA Centers
- Glenn (lead)
- Langley
- Ames

DOE Labs
- ANL
- PNNL

Industry
- Aurora Flight Systems
- Ionic Materials
- Eagle Picher Technologies

Sensor-based Prognostics to Avoid Runaway Reactions and Catastrophic Ignition (SPARRCI)

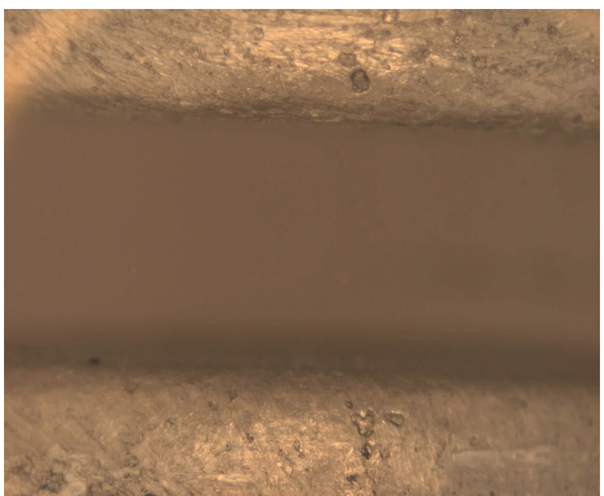
POC: Bri DeMattia, NASA GRC

Can catastrophic battery failures be avoided to enable safe next-generation ultra-high energy batteries for propulsive aircraft power?

Existing solutions reduce severity but NOT likelihood of battery failure

PROJECT GOALS

- **Eliminate catastrophic battery failures with early fault detection**
- **Improve safety of existing batteries + accelerate adoption of next-generation batteries**



TECHNOLOGY DEVELOPMENT

Battery Failure	Sensor Development	Nondestructive Evaluation	Modeling & Failure Prognostics
• Reproducible techniques to induce failure • Failure precursor identification	• Micro-sensors for real-time monitoring within cells • Multi-funtional parameter measurement	• In-situ and off-line techniques • Battery health data without damage • Advanced NDE data analysis	• Multiphysics modeling • Fault algorithm + failure prognostics • "Smart" battery management

SYSTEM-LEVEL IMPACT

✓ **Detect** failure mechanisms and **avoid** fires
  - Early warning from **within** cell

✓ Improved aircraft performance
  - Better state-of-health resolution
  - Enhanced reliability

✓ Accelerated introduction of next-generation chemistries

✓ Weight reduction

Partners: NASA Glenn (lead), Langley and Ames; Collaborations with Cornerstone Research Group

Electrified Powertrain Flight Demonstration (EPFD)

POC: Rosa Padilla, NASA GRC

- Electrified Aircraft Propulsion (EAP) concepts can reduce energy use, carbon and nitrogen oxide emissions.
- EAP concepts enable favorable direct operating costs (total energy and maintenance) resulting in benefits for both the public and the airline operators.
- EAP opens up the design space and adds flexibility
  - Distributed architectures
  - Reduced turbofan core sizes
- EAP coupled with advanced airframe architectures
  - May enable functionally silent and ultra-low emission flight
- EAP is synergistic with low emission airport infrastructure changes.

GE Aviation

magniX

Demonstrate **practical vehicle-level integration of MW-class electrified aircraft propulsion** systems, leveraging advanced airframe systems to **reinvigorate the regional and emerging small aircraft markets and strengthen the single-aisle aircraft market**

Subsonic Single Aft Engine Electrofan (SUSAN)

POC: Ralph Jansen, NASA GRC

- **SUSAN is a concept for a single aisle aircraft towards the future of electrified regional transport aircraft (to be built in 2040 timeframe)**
- **Both primary (i.e. single-use/non-rechargeable) and secondary (i.e. rechargeable) battery technologies required in the design of SUSAN**

Goals:

- **Advanced primary battery for backup (in case electrofan failure)**
- **Advanced secondary battery for hybrid/electric propulsion**

Key requirements/characteristics:

- **Primary Batteries**
  - Ultra high energy density: > 1500 Wh/kg
  - Long shelf life: 30 years
  - Discharge rate: 2C
  - Low cost
- **Secondary Batteries**
  - >500 Wh/kg
  - Safety – non-flammable
  - High rate capability

X-57 Distributed Electric Propulsion Demonstration

POC: Sean Clarke, NASA AFRC

Overview

- X-57 is NASA's Flight Demonstrator for Distributed Electric Propulsion (DEP) technology
  - Highly modified Tecnam P2006T

NASA X-57 Electrified Aircraft

Goals:

- Cruise goal: show 5x less energy consumption than baseline aircraft at high-speed cruise (150 knots true/8,000 ft MSL)
- Low Speed Goal: Make complex DEP airworthy and demonstrate end-to-end airframe-propulsion-mission benefit

Battery Development:

- **No commercial solutions to provide meaningful aircraft flight duration**
  - High power requirements within a "flight-weight" limitation
  - Industry target of 30% packaging overhead aligns with X-57 mass budget
  - Thermal management is a critical design driver and key X-57 design trade-off
  - Battery management software and control system had to be developed
  - No large, high density COTS battery packs prevent thermal runaway propagation
    - Original X-57 battery design failed to contain a failure propagation test & redesign was required

http://go.nasa.gov/2iZ5lYi

Battery Optimization Research. INterdiscplinary, Gradient-based (BORING)

POC: Dustin Hall, NASA GRC

Motivation

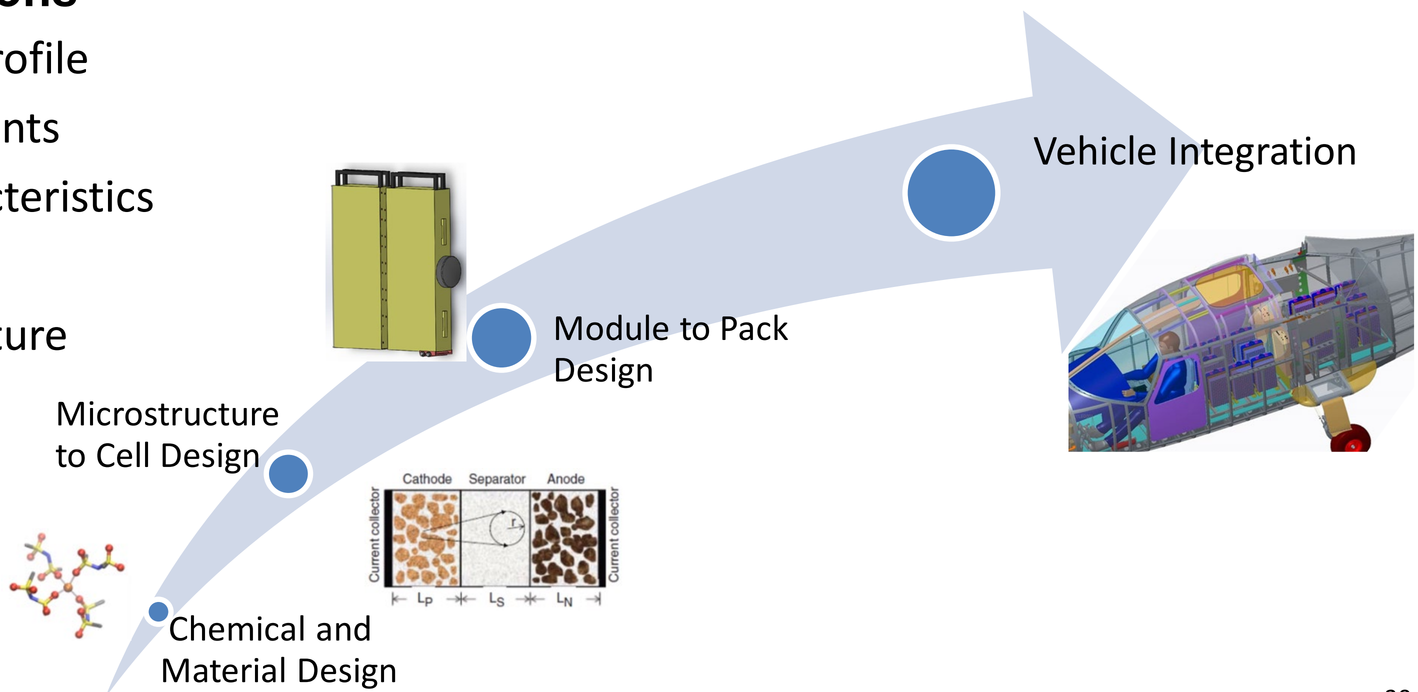
- Aircraft performance is sensitive to battery packaging penalty
- Advancements must be made to realize next-gen cell improvements at the battery pack level

Efforts

- Packaging & thermal management optimization trade-offs
- Next-generation high energy pouch cell testing
- New pack designed with advanced thermal management techniques

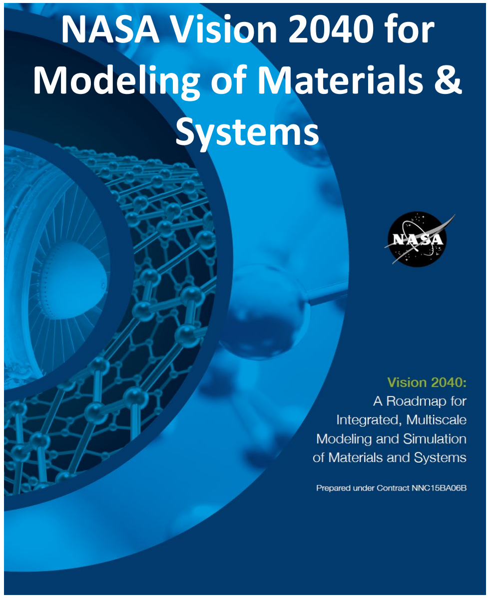
Pack Considerations

- Vehicle power profile
- Thermal constraints
- Discharge characteristics
- Cell packaging
- Cooling architecture

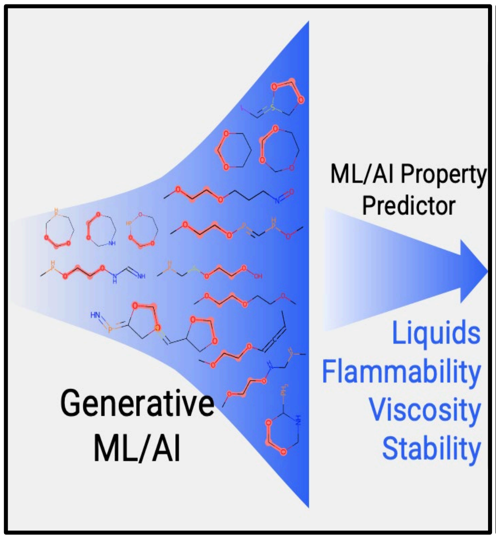
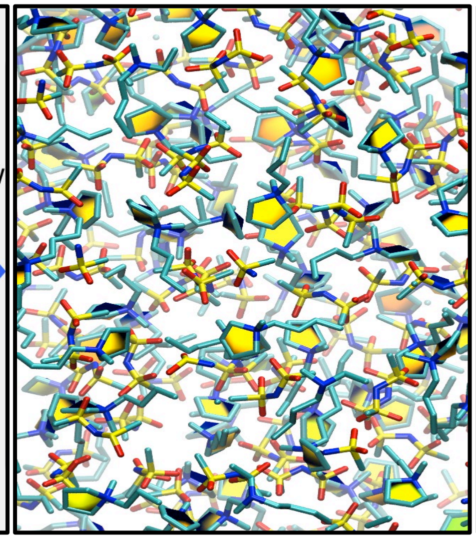
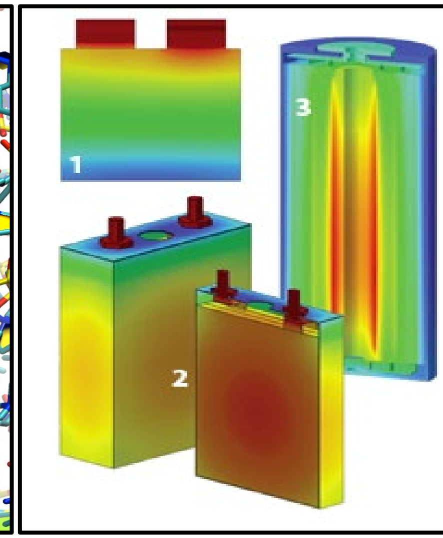


Computational Battery Materials and Systems Modeling

POC: John Lawson, NASA ARC



NASA Vision 2040 Goal: *Enable the <u>rapid</u>, <u>low cost</u> design, development, certification and deployment of application specific advanced aerospace materials*

I. Machine Learning	II. Materials simulations	III. Multiphysics analysis
		
Generate candidates	Understand mechanisms	Cell level integration

Battery research traditionally uses highly empirical "trial-and-error" approach
Predictive modeling at multiple scales can accelerate progress on advanced systems

Areas of Interest

Growing R&D Areas

- **Increase Wh/kg through system-level weight reduction**
  - Multifunctional thermal management/packaging
  - Reduced parasitic mass
  - Improved low-temperature cell operability & survivability
- **Multi-functionality & integration of energy storage within spacecraft/aircraft structures**
- **Integrated sensors for improved safety & enhanced operability**
- **Hybrid chemistry concepts to balance high power and high energy demands**
- **Hybrid battery/fuel cell/turbine engine concepts**
- **Increased efforts for safety/abuse for aeronautics batteries**

Thank you for your attention

NASA POCs

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MSFC Electrical Power Subsystems Lead: Jeff Brewer

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ARC Group Lead for Computational Materials Modeling: John Lawson

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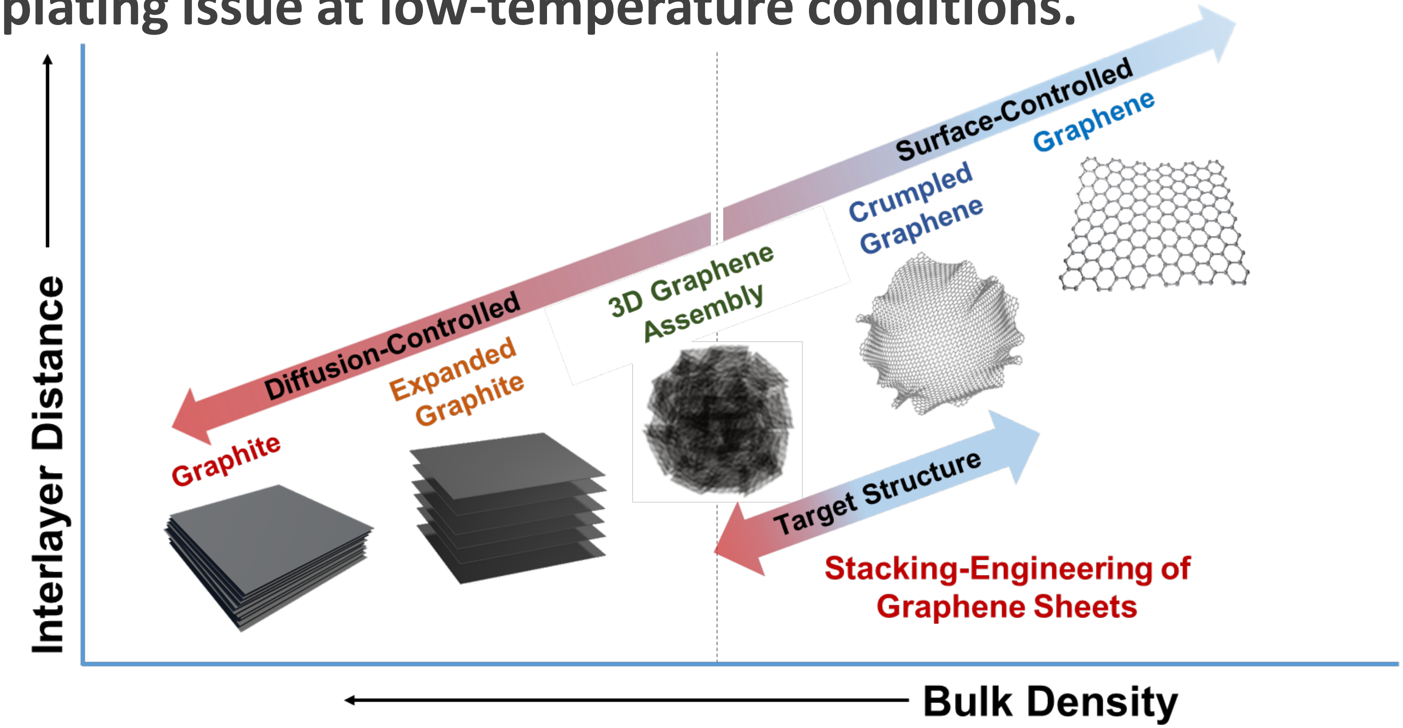
Back-up Slides

ECF - Improving Low-Temperature Performance of Battery Anodes Based on Surface-Controlled Charge Storage Mechanism

PI: Seung Woo Lee, Georgia Tech

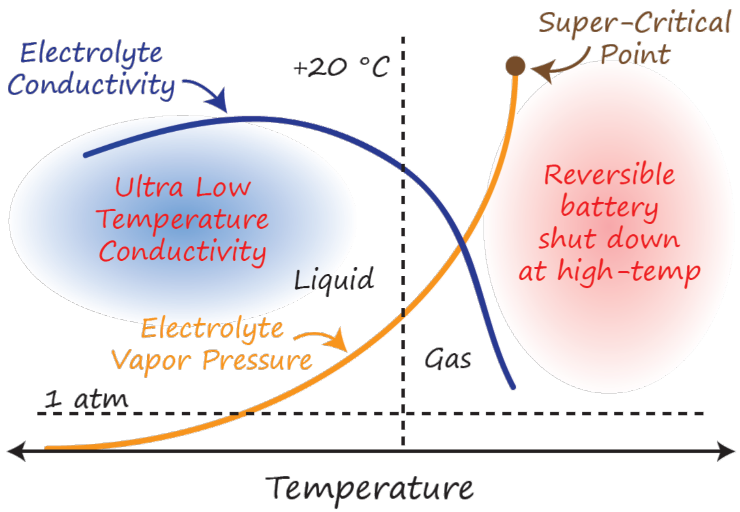
Central hypothesis: The effective utilization of the surface-controlled charge storage mechanism through the transition from layered graphite to graphene can dramatically improve the charge storage kinetics and overcome the metallic Li-plating issue at low-temperature conditions.

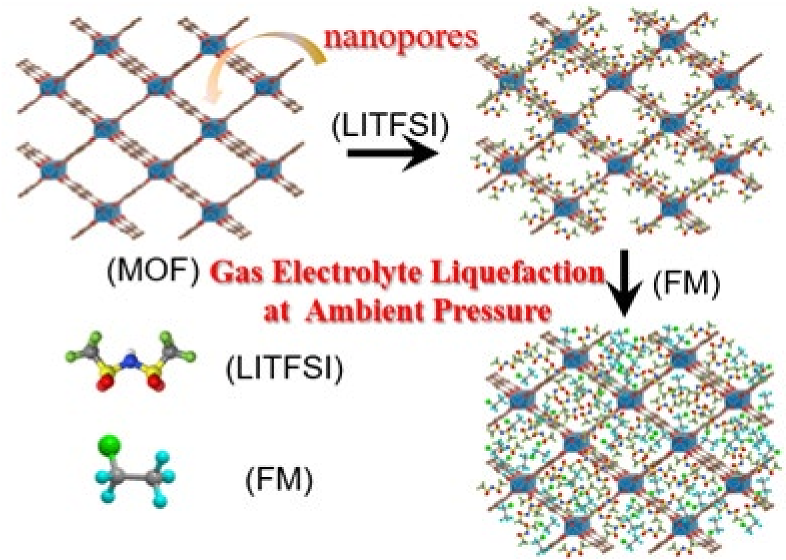


Goal: Designing a high-performance and stable anode based on the surface-controlled charge storage mechanism to enable battery operation in extreme cold conditions.

ECF - Liquefying Gas Electrolyte by Capillary Condensation at Ambient Pressure for Extreme Low-Temperature Batteries

PI: Dr. Zheng Chen, UC San Diego





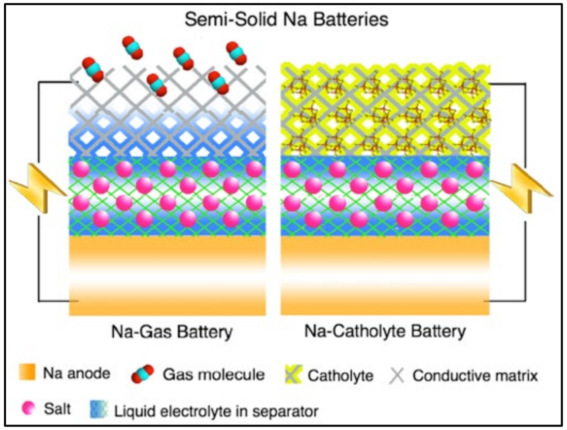
LIQUEFIED GAS ELECTROLYTES FOR ENERGY STORAGE DEVICES:

- Improve ***Low Temperature Performance*** from +20 °C to < -60 °C while Maintaining High Performance
- Increase ***Energy Density*** by Enabling High Voltage Cathodes and Lithium Metal Anodes
- Provide Excellent ***Inherent Safety Feature***: Reversible Battery Shut Down at High Temperature and Under Crushing Failure;
- Reduce ***"Shelf" Pressure***.

C. S. Rustomji, Y. Yang … Y. S. Meng. Science, 2017

ECF - Development of High-Energy and Low-Cost Semi-Solid Sodium Batteries Operating at Extreme Cold Temperatures

PI: Dr. Weiyang Li, Dartmouth College

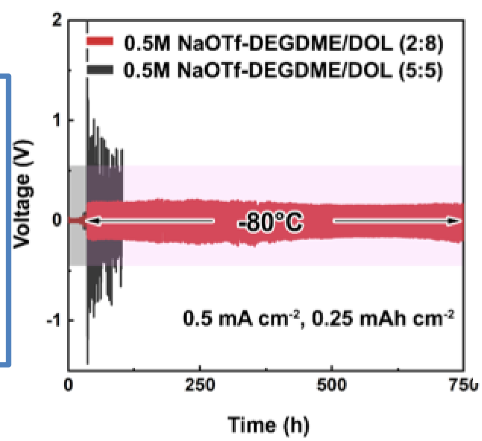


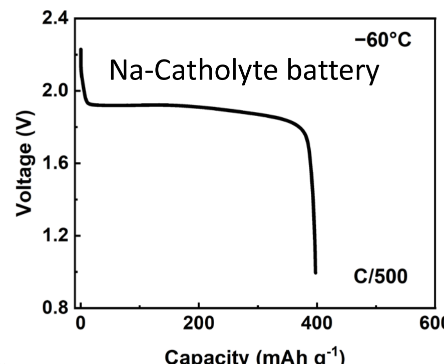
APPROACHES

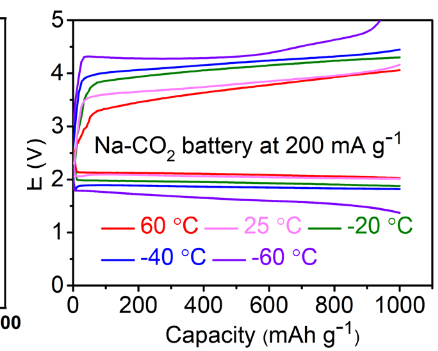
- Develop a rechargeable Na–catholyte battery composed of high-capacity and low-cost Na-phosphorus-sulfur complex (dissolved in organic solvent) as catholyte and Na metal as anode.
- Develop a primary/rechargeable Na–carbon dioxide (CO_2) $_{(gas)}$ battery composed of CO_2 gas as cathode and Na metal as anode.

Publication/patent:

- Li et al. Angewandte Chemie, https://doi.org/10.1002/anie.202014241
- Li et al. Nano Letters, 2020, 20, 3620-3626.
- Two manuscripts under review and one provisional patent filed.







PROGRESS HIGHLIGHTS

- Revealed the molecular structure & the complexation mechanism of novel Na-phosphorus-sulfur catholyte molecules.
- Identified the optimal electrolyte formulation to enable stable Na anode at temperature as low as -80˚C.
- Investigated the potential of Na-catholyte battery as a primary cell at low temperature down to -60˚C .
- Enabled Na-CO_2 battery using optimized electrolyte formulations for low-temperature operation down to -60˚C.

ECF - Overcoming Kinetics Limitations in Materials and at Interfaces for Low-Temperature, High-Energy Batteries

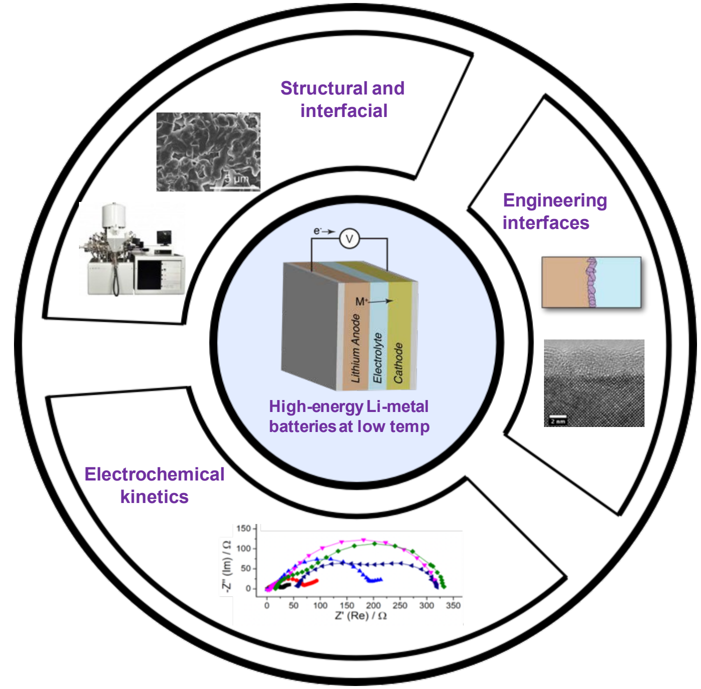
PI: Matthew T. McDowell, Georgia Tech

Objective

To understand and control the morphology and electrochemistry of lithium metal electrodes operating at low temperatures.

- Effects of temperatures on structural, chemical, and morphological changes in Li metal and its interfaces during charge and discharge.
- Understand electrochemical kinetics of lithium electrodes as a function of temperature
- Engineer interfaces for better stability and performance.

Relevance: Batteries with high energy (>150 Wh/kg, >300 Wh/L) that can operate at -80 °C could enable new mission possibilities for planetary exploration



Accomplishments

- *Understanding the link between morphology, temperature and electrolyte.*
- Formulating stable electrolyte blend with improved efficiency down to -60 C.
- Examined the effect of substrate chemistry and SEI growth on fundamental Li nucleation and growth behavior
- Found that the nature of the SEI at low temperature determines the Coulombic efficiency and longevity of the Li electrode.

Technical Approach

- *In situ* and cryo-based characterization techniques to understand structural/interfacial evolution
- Detailed electrochemical characterization of kinetics
- Modifying and engineering Li interfaces with thin films and alloying materials to enhance kinetics and Coulombic efficiency

S3.03-3308 - High Temperature All Solid-State LiAl-CO2 Batteries for Venus Missions

PI: Hansan Liu , Talos Tech LLC - New Castle, DE

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

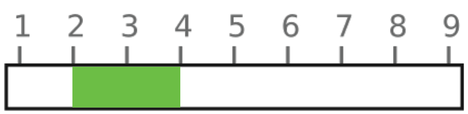
The planet Venus is an interesting target for scientific exploration. However, long-duration missions to the surface of Venus present a significant challenge to the power system due to its ambient temperature (390 to 485°C) and high average surface pressure of carbon dioxide (92 bar). Therefore, conventional power technologies including photovoltaic power systems and the conventional batteries could not meet the requirement for Venus surface application. TalosTech LLC and University of Delaware propose to develop a high temperature all solid-state LiAl-CO2 battery with superior specific energy by using a high performance cathode, an innovative tri-layer solid state electrolyte framework, LiAl metal anode, and ambient carbon dioxide at Venus surface as a reactant. During Phase I, the team will demonstrate the feasibility of the high temperature all-solid-state LiAl-CO2 battery with superior specific energy (948 Wh/kg). The successful development of this technology will provide a high energy battery operating 100- 600°C, which can be operated on the Venus surface for more than 60 days.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

The overarching goal of this project is to develop a new high temperature and high energy density all solid state LiAl-CO2 battery through combining LiAl alloy anode, a tri-layer solid state electrolyte, and a cathode with highly active CO2 reduction catalyst. The final LiAl-CO2 battery will have the following features: 1) high specific energy > 900 Wh/kg; 2) wide operation temperature range from 100 to 600°C; 3) low self-discharge rate; 4) operational lifetime >60 days under Venus circumstance.
At the end of Phase I, a final technical report and a Phase II proposal will be submitted to NASA.

TRL

Estimated



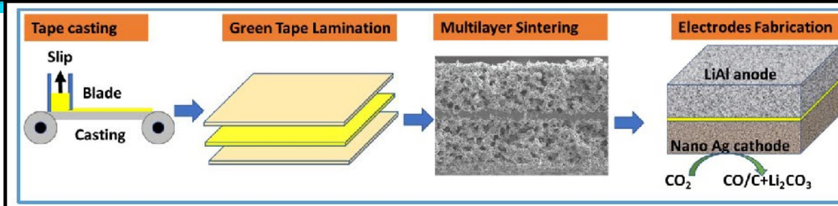


Figure 1. The schematic preparation process of a high temperature all solid-state LiAl-CO_2 battery.

NASA APPLICATIONS

Because of the benefits of the proposed battery system in terms of superior high energy, low cost, simple system, high stability, long life, wide operation temperature, and low self-discharging rate, it can be used on the Venus surface for both short and long durations. This low-cost and simple system also can be used for other planetary exploration missions where there is enough CO2 in ambient atmosphere.

NON-NASA APPLICATIONS

This proposed LiAl-CO2 battery system can efficiently convert CO2 into solid carbon or CO with generating electricity efficiently. The LiAl-CO2 primary battery can be redesigned to Na/K-CO2 battery which could provide 1) a cost-effective and eco-friendly CO2 fixation strategy 2) high efficiency renewable energy storage method.

FIRM CONTACTS

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SBIR
STTR

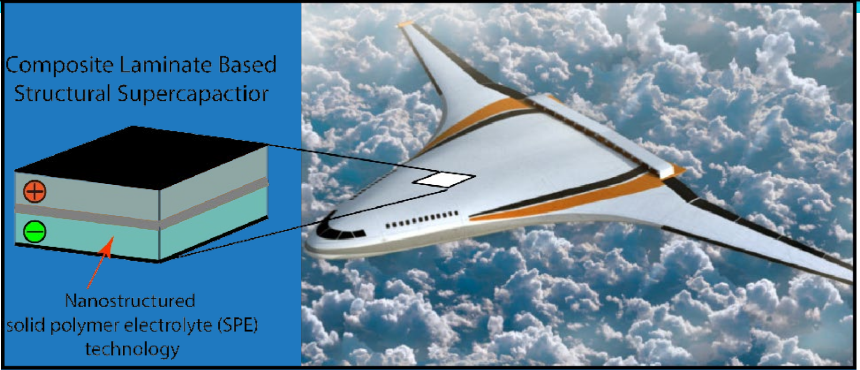
A1.04-2891 - Structural Supercapacitors for Energy Storage in Airframe Components

PI: Parvaneh Rouhani, Structured Ions, LLC - Tulsa, OK

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

- Structured Ions' technology is based on multi-functional composite laminates that can store electrical energy while simultaneously providing load bearing capabilities.
- These structural supercapacitors enable high-efficiency distributed energy storage systems while providing rapid charging and discharging capabilities.
- By distributing energy storage within airframe components, our approach overcomes the issues of parasitic weight of added batteries in conventional electrical energy storage solutions.
- Supercapacitors are inherently safer, as compared to lithium-ion batteries.
- The use of decentralized energy storage enhances durability.
- This technology will lead to higher payloads and longer flight duration for electrified aircraft while contributing to safety and reliability in flight-based systems.



TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Primary Objectives

- In Phase I develop and demonstrate composite laminate based structural supercapacitors.
- The materials will be developed by hierarchical nano-scale modifications to develop solid polymer electrolytes that can also function as a polymer matrix in reinforced composites.
- Tasks include material fabrication, mechanical and electrical characterization, and development of lab-scale prototype.

Proposed Deliverables

- All test data and material design parameters.
- Two multifunctional composite laminates that demonstrate structural supercapacitor capabilities.

TRL

Estimated

1 2 3 4 5 6 7 8 9

NASA APPLICATIONS

NASA applications included manned and unmanned aerial systems powered by electrical propulsion. This includes cargo and passenger transport electric airplanes, and UAVs for payload delivery, surveillance, data gathering, and weather monitoring applications

NON-NASA APPLICATIONS

Non-NASA applications include power storage for portable electronics, automotive panels for electric vehicles, UAVs for payload delivery and recreation, UAVs for law enforcement, DoD, and other security applications, and electric aircraft for urban air transport.

FIRM CONTACTS

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H8.04-8147 - Advanced Lithium Sulfur Battery

PI: Brian Henslee, Cornerstone Research Group, Inc. – Miamisburg, OH

NON-PROPRIETARY DATA

Identification and Significance of Innovation

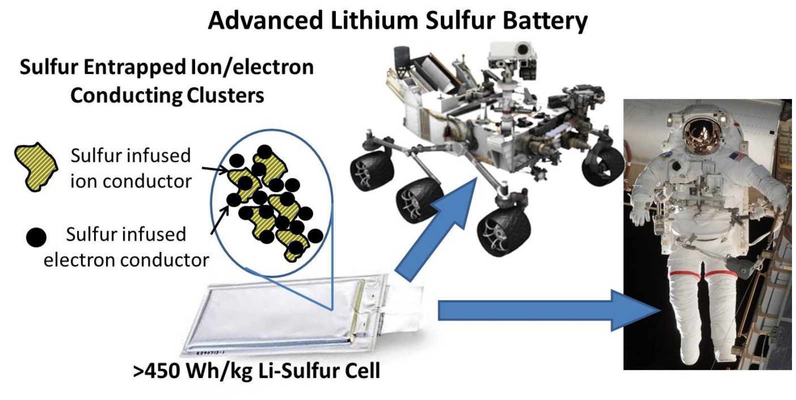
CRG proposes to develop an Advanced Lithium Sulfur Battery combining a super ion conducting ceramic electrolyte, entrapped sulfur cathode, and lithium metal anode. This project directly addresses high energy density space battery needs for NASA's Human Exploration and Operations directorate systems including:

- Extravehicular activities
- Rovers and landers
- Ascent vehicle space craft

This project's technologies address NASAs needs for:

- High energy density (>450 Whr/kg)
- Long operational life batteries (300+ cycles)
- -40 to 50 °C operational temperature range
- Long storage life (5-15 yr.)

These advancements will reduce power supply weight by 50% or more.



Estimated TRL at beginning and end of contract: (Begin: 1 End: 3)

Technical Objectives and Work Plan

Technical Objectives

1. To optimize and scale cell materials
2. To increase cathode loading
3. To optimize polysulfide blocking separator and use of liquid electrolyte
4. To optimize anode integration
5. To fabricate a large format prototype cell
6. To prepare for Phase III

Work Plan

Task 1: Optimize cathode formulation
Task 2: Optimize cathode coating
Task 3: Optimize separator and use of liquid electrolyte
Task 4: Optimization and integration of anode
Task 5: Scale-up
Task 6: Cell testing
Task 7: Assess Results, commercialization, and prepare for Phase III

NASA Applications

- Extravehicular applications power supply
- Space suit power
- Rovers
- Landers
- Ascent vehicles
- Cube Satellites
- Safe Li battery technology
- High energy density battery technology

Non-NASA Applications

- Portable electronics
- Cordless tool systems
- Electric vehicles
- Unmanned air vehicles
- Surveillance systems

Firm Contacts

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NON-PROPRIETARY DATA

S3.03-6816 - Advanced High Energy Density Lithium-Sulfur Battery for Low Temperature Operation

PI: Castro S.T. Laicer , Giner, Inc. - Newton, MA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

Future NASA missions require batteries that operate at low temperatures. Mars and small body surface mission concepts require batteries capable of operating at -40°C. Current lithium-ion batteries (LIBs) have been adapted for low temperatures, but their performance is still limited below -20°C. Additionally, the gravimetric energy density of NASA LIBs is low. Low temperature performance is limited by a reduction in electrolyte conductivity and an increase in Li-ion transport resistance through the solid electrolyte interface and the electrode/electrolyte interface. Giner, Inc., will develop an electrolyte that enables reliable operation of Li-S batteries down to -40°C. The Li-S battery is one of the most promising technologies for future NASA missions because of its high theoretical gravimetric energy density of 2500 Wh/kg, which is up to 5 times higher than the theoretical value of SOA commercial LIB cells. A successfully developed Li-S battery capable of low temperature operation would offer a significant advantage over current LIBs in NASA mission applications.

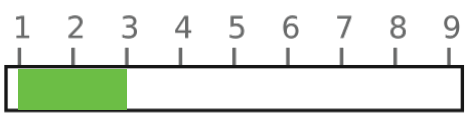
TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

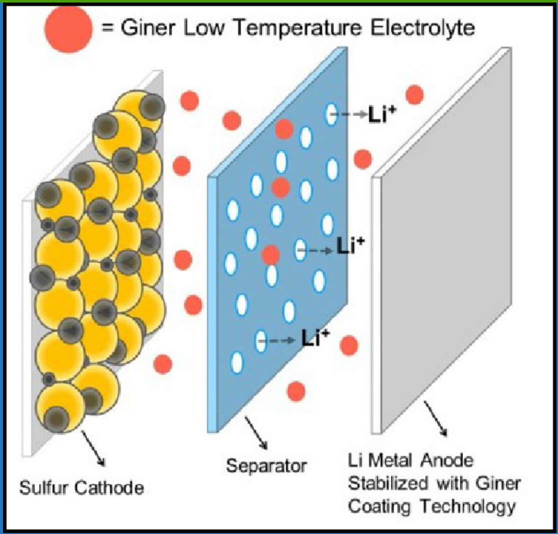
The Phase I deliverables are:

- Develop a low temperature (-40°C) electrolyte that demonstrates high ionic conductivity, good electrochemical compatibility with sulfur and lithium electrodes, low viscosity, and decreased flammability.
- Demonstrate use of electrolyte in Li-S cells capable of achieving ≥200 cycles to 80% capacity retention at 100% DOD.
- Demonstrate use of electrolyte in Li-S cells that retain ≥50% of their room temperature capacity at -40°C and 100% DOD cycling test conditions.

TRL

Estimated





NASA APPLICATIONS

The technology will enable use of a high energy density Li-S battery that can operate at low temperatures down to -40°C for various NASA programs including robotic landers, rovers, aerial vehicles for exploring Mars, the Moon, and the outer planets. Other NASA applications include batteries for extravehicular activities (e.g., power for life support, communications, power tools, glove heaters, lights and other devices), satellites and electrified vehicle propulsion (EAP) (e.g., power for urban air mobility, thin haul and short haul aircraft).

NON-NASA APPLICATIONS

This technology will enable commercialization of high energy density and low temperature tolerant Li-S batteries for electric vehicles, unmanned aerial and underwater vehicles, military aircraft and satellites, large-scale grid energy storage, and consumer electronics.

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SBIR STTR

T15.03-5033 - Enabling High Energy Density Li-ion Battery Using Solid Electrolytes

PI: Hui Xu , Giner, Inc. - Newton, MA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

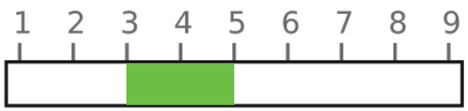
This proposed project aims to develop high energy density and low cost solid electrolyte batteries with extended cycle life. This project is very innovative first because novel garnet and plastic crystal electrolytes (PCE) with superior Li-ion conductivity and chemical stability will be adapted, which may enhance their energy density and cycle life. Second, the solid electrolyte will be integrated with high voltage cathode and Li metal anode to further improve the battery energy density.

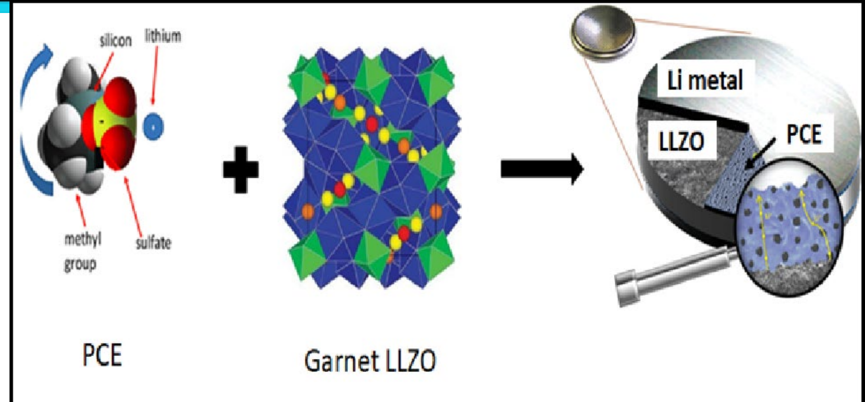
TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

-Prepare solid electrolyte powders with high Li-ion conductivity (> 1 mS/cm) -Fabricate and evaluate hydride solid electrolyte separators with high Li-ion conductivity and good mechanical resilience -Construct and test all solid-state high–voltage Li-ion button cells to attain capacity > 300 mAh/g cathode after 300 cycles -Fabricate and test all solid-state high–voltage Li-ion pouch cells to achieve energy density >350 Wh/kg after 200 cycles

TRL

Estimated





NASA APPLICATIONS

If successful, the proposed battery technology can be used as energy storage solutions for NASA's Electrified Aircraft Propulsion (EAP), with much higher energy density and longer cycle life than conventional Li-ion batteries. More specifically, this battery storage technology can be used for landers, construction equipment, crew rovers, and science platforms and many other NASA applications.

NON-NASA APPLICATIONS

The proposed battery technology can also be used for electrical vehicles. It may directly facilitate the commercialization of electrical vehicles as two major barriers of cost and energy density will be addressed. They may also be applicable in the consumer market to portable electronics and communication devices.

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SBIR STTR

S3.03-5527 - High temperature rechargeable Li/Se batteries for Venus missions

PI: Mahesh Waje, Lynntech, Inc. - College Station, TX

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

Space energy storage systems are required to enable/enhance the capabilities of future planetary science missions. Venus aerial and surface missions pose challenges for energy storage systems where the temperature and pressure can be up to 460 °C and 92 bar, respectively. Rugged, high temperature batteries with high capacity are needed for future long duration Venus missions.

Lynntech proposes to develop an innovative cell design that enables the operation of rechargeable molten lithium batteries under harsh Venus conditions. The design uses a solid-state electrolyte to separate the molten anode and cathode while compensating for electrode volume changes during charge-discharge cycles. Lynntech's molten battery design is compatible with several cell chemistries including lithium-bismuth and lithium-selenium with excellent rechargeability and operate at high discharge rates. The estimated specific energy of a Li/Se battery using the novel volume compensating design is >760 Wh/kg which far exceeds NASA's target of 200 Wh/kg.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Technical Objectives

- Achieve high ionic conductivity >0.1 S/cm for the solidstate electrolyte at temperatures up to 460 °C
- Demonstrate chemical compatibility and corrosion resistance of cell components including electrodes, electrolyte, current collectors, and seals
- Validate Li/Bi and Li/Se cell performance at 460°C
- Fabricate and test an initial prototype of the volume compensating cell design
- Develop a Phase II design which meets NASA's targets for Venus missions (operation at 460 °C and 92 bar, >200 Wh/kg, and continuous operation up to 60 days)

Work Plan

- Task 1: Lithium solid state electrolyte characterization at 460°C
- Task 2: Chemical compatibility testing of cell components
- Task 3: Li/Bi and Li/Se planar cell testing up to 460 °C
- Task 4: Fabrication and testing of volume compensating cell design
- Task 5: Develop a preliminary Phase II design for a fullscale battery
- Task 6: Reporting and project management
- Deliverables: Timely Reports and Documentation

TRL

Estimated

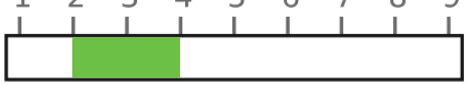
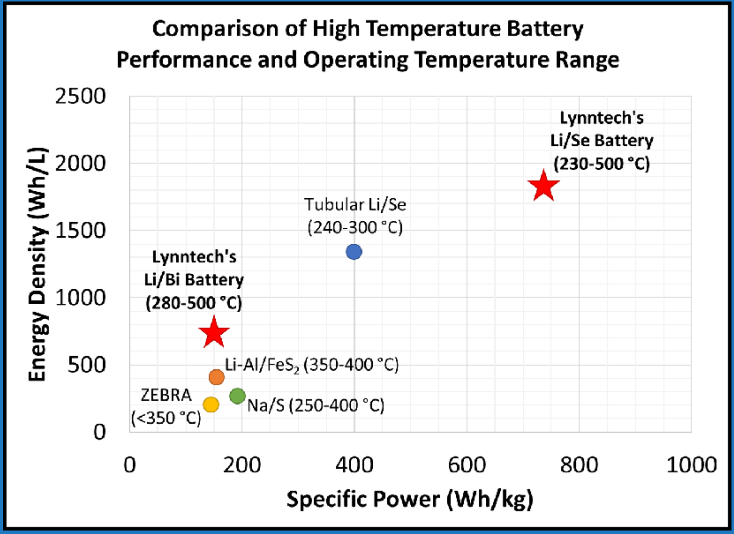


IMAGE TITLE: Venus Battery Comparison



NASA APPLICATIONS

Lynntech's innovative volume compensating cell design has the potential to provide rugged, high energy density batteries. These batteries will be beneficial for NASA applications at high operation temperatures for inner terrestrial surface and low altitude and other systems. Additional NASA applications would include satellites, remote power equipment, telecommunications systems, remote sensors, detection devices where solar concentration heating can be harnessed.

NON-NASA APPLICATIONS

The batteries proposed here can provide improved energy density, cycle life, and rate capability of energy storage systems for both commercial and military applications where operation temperatures can be elevated. Commercial applications include hybrid electric vehicles. Military applications include aircraft, military ground vehicles, and grid power systems.

FIRM CONTACTS

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SBIR STTR

S3.03-6272 - High Energy Density Lithium-Sulfur Battery with Improved Cycle Life

PI: Castro S.T. Laicer , Giner, Inc. - Newton, MA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

A high cycle life and high energy density rechargeable battery would address an important need for a reliable power source that offers significant weight reductions, as well as improved mission range and longevity in several NASA program applications including energy storage devices for extravehicular activities (EVA), satellites, robots, and spacecraft vehicles. The Li-S battery is promising as a next-generation energy storage device because of its high theoretical gravimetric energy density of 2500 Wh/kg, which is up to 5 times higher than today's commercial lithium-ion battery cells. However, Li-S cells are limited by poor cycle life caused by shuttling of dissolved polysulfide (LiPS) species during cell operation. In Phase II, Giner will build on the successful Phase I feasibility demonstration to scale up its novel, polysulfide-blocking coating technology in prototype Li-S pouch cells that will be validated under test conditions important for NASA planetary mission applications.

TECHNICAL OBJECTIVES AND WORK PLAN

Technical Objectives, Work Plan and Deliverables

The Phase I Technical Objectives and Work Plan are:

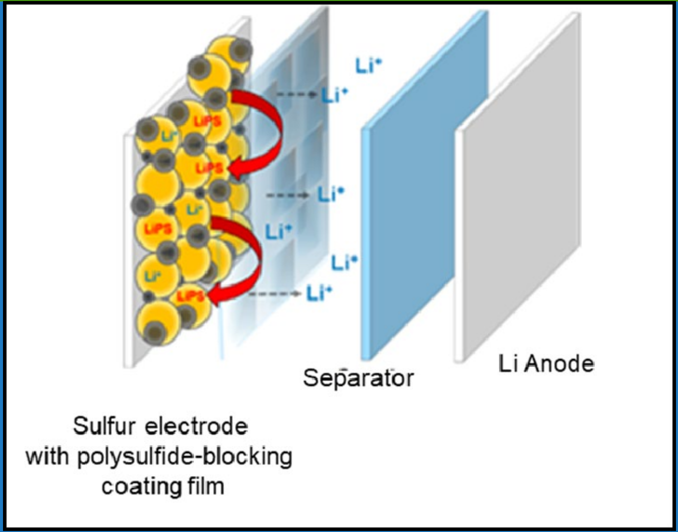
Objective 1. Scale Up Synthesis of LiPS Blocking Materials
Objective 2. Scale Up LiPS-blocking Coating Process
Objective 3. Fabricate Prototype Prismatic Li-S Pouch Cells
Objective 4. Evaluate Electrochemical Performance of Pouch Cells
Objective 5. Evaluate Abuse Testing of Pouch Cells
Objective 6. Perform Post Mortem Analysis of Pouch Cells

Deliverables: Deliver up to four (4) optimized Li-S pouch cells (0.50 to 1.0 Ah) to NASA for external test validation.

TRL

Estimated

1 2 3 4 5 6 7 8 9 (estimated range: 3–5)



NASA APPLICATIONS

The developed technology will enable the use of high energy density Li-S batteries with increased cycle life for various NASA missions and programs such as: EVA applications (including life support, communications, power tools, glove heaters, lights and other devices); orbital satellites; and other spacecraft and robotic surface lander/rover vehicles such as JUNO and the planned new Mars rover.

NON-NASA APPLICATIONS

Additional markets include power for: electric vehicles; persistent unmanned aerial vehicles; unmanned undersea vehicles; aerospace vehicles; satellites for military communication applications; large-scale grid energy storage; and consumer portable electronics and communication devices.

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SBIR STTR

A1.04-3055 - High Energy Density and High Cycle Life Lithium-Sulfur Battery For Electrified Aircraft Propulsion

PI: Castro S.T. Laicer , Giner, Inc. - Newton, MA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

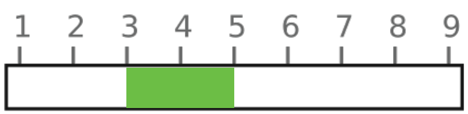
A high cycle life and high energy density rechargeable battery will address important growing demands for safe, efficient, low-cost, environmentally sustainable air transportation. These advances will enable "thin-haul" aircraft with low-carbon propulsion systems that provide low-cost passenger, package transportation. Advances in electrified aircraft propulsion (EAP) will also introduce a new class of small aircraft with vertical take-off and landing capability for on-demand, urban air taxi and regional commuter service applications. Lithium-sulfur (Li-S) batteries are promising next-generation energy storage devices for NASA EAP applications due to their high theoretical gravimetric energy density of 2500 Wh/kg, which is up to 5x higher than today's commercial lithium-ion batteries. However, their use is limited by poor stability of Li metal anodes during cycling. In Phase II Giner will build on its successful Phase I feasibility demonstration to scale up development of a novel coating technology for stabilizing Li metal anodes in Li-S pouch cells.

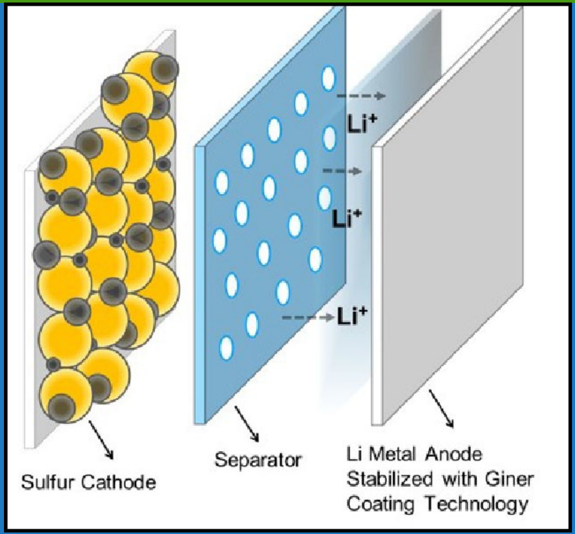
TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Technical Objectives, Work Plan and Deliverables The Phase I Technical Objectives and Work Plan are:
Objective 1. Scale Up Synthesis of Li Stabilization Materials Objective 2. Scale Up Coating Process
Objective 3. Fabricate Prototype Pouch Cells
Objective 4. Evaluate Electrochemical Performance of Pouch Cells Objective 5. Evaluate Abuse Testing of Pouch Cells
Objective 6. Perform Post Mortem Analysis of Pouch Cells
Deliverables: Deliver up to four optimized Li-S pouch cells to NASA for external test validation.

TRL

Estimated





NASA APPLICATIONS

The developed technology will enable the use of high energy density Li-S batteries with increased cycle life for various NASA missions and programs such as: EAP applications (urban air mobility, thin haul, and short haul aircraft), EVA applications (life support, communications, power tools, glove heaters, lights and other devices), satellites, and other spacecraft and vehicles such as JUNO and the planned new Mars rover.

NON-NASA APPLICATIONS

This technology will enable commercialization of high energy density Li-S batteries with increased cycle life. This improvement will make Li-S batteries more practical for electric vehicle applications. Additional markets include power for unmanned aerial vehicles, aerospace vehicles, military satellites, large-scale grid energy storage, and consumer electronics.

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T15.03-5735 - Solid-State Lithium-ion Batteries for Electrified Aircraft Propulsion Energy Storage

PI: Chuck Tan , Aegis Technology, Inc. - Santa Ana, CA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

High performance all-solid-state Li-ion rechargeable batteries (ASSLiBs) are one of the most promising enabling energy storage technologies for new generation Electrified Aircraft Propulsion and electric vehicles. One key technology for the ASSLiBs is the development of a more advanced solid electrolyte and the associated new battery design which will exhibit high ionic conductivity, high electrochemical stability, long cycle life, and low costs.

In this project, Aegis Technology teaming up with Cornell University and Bioenno Tech proposes to develop a novel class of ASSLiBs based on a proprietary solid electrolyte and a novel cell structure design. The resultant ASSLiBs will exhibit substantially enhanced performance compared to conventional products.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

The ultimate objective of this project is to develop, demonstrate, and produce a novel class of high energy density, ultrahigh safety, and long cycle life ASSLiBs for electrified aircraft propulsion energy storage.

Phase I will focus on the feasibility demonstration, which will include: 1) Demonstration of a high performance solid electrolyte based on a proprietary composite; 2) Development and demonstration of the proposed ASSLiBs using the obtained solid electrolyte and electrodes and a well established prototyping method; 3) Establishment of cost-effective and scalable processes for both materials preparation and ASSLiB fabrication that are suitable for future mass production.

In Phase I, the resultant ASSLiBs will be expected to provide energy densities >250 Wh/kg (~>300-400 Wh/kg in Phase II), cyclability across ~2000 cycles with a capacity retention >80%.

TRL

Estimated

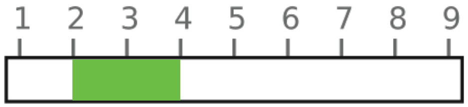
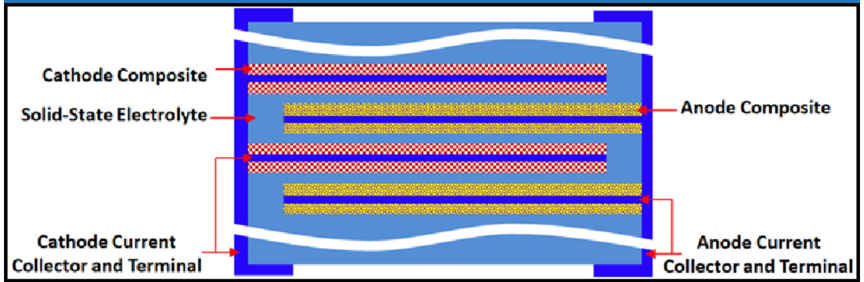


IMAGE TITLE: Schematics of SSLiBs



NASA APPLICATIONS

High performance, long cycling life, and low costs ASSLiBs, once successfully developed, will find wide applications in NASA systems. EAP is an area of strong and growing interest in NASA's Aeronautics Research Mission Directorate (ARMD). High performance ASSLiBs are required for aircraft to have sufficient range, safety, and operational economics for regular service. It will fulfill the markets needs for span Urban Air Mobility (UAM), thin/short haul aviation, and commercial air transport vehicles which use electrified aircraft propulsion.

NON-NASA APPLICATIONS

Potential non-nasa applications include both military systems (such as silent watch applications, electric vehicle and spacecraft) and commercial systems (hybrid electric, all electric power generation as well as distributed propulsive power).

FIRM CONTACTS

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Z1.04-2824 – High Energy Density, Long Cycle Life Li-S Batteries for Space Applications

PI: Jeff Nelson , ADA Technologies, Inc. – Littleton, CO

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

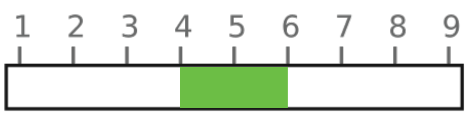
ADA has successfully demonstrated an advanced Li-S battery technology through material engineering of battery cell components with the following main achievements. (1) Successfully developed sulfur composite electrodes with high S content, high electrode loading and excellent electrochemical performance in the resultant Li-S cells. (2) Successfully developed Li metal anode protection/coating methodologies with demonstrated superior electrochemical performance to the uncoated Li anode. (3) Demonstrated highly stable cycle life performance showing a great promise of achieving NASA cycle life goal. (4) Successfully demonstrated a Li-S pouch cell. The successful Phase I program laid a solid foundation for a continued Phase II development effort where a technical readiness level (TRL) of 6 is anticipated at the end of the Phase II program. ADA will further develop/mature the Li-S battery technology via material engineering to achieve multiple performance goals and demonstrate in large format prototype cells.

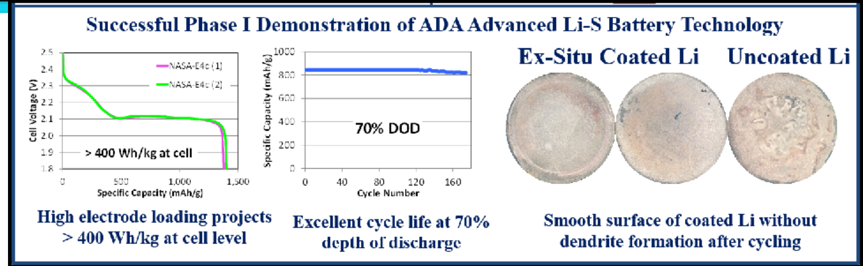
TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

The overarching objective in Phase II is Further develop the advanced Li-S battery and demonstrate in large format prototype cells to achieve TRL 6 for NASA space applications. Phase II optimization efforts will achieve some major NASA performance goas. At the end of Phase II, ADA will provide a Final Report containing key demonstrations, empirical data, a detailed cell design and a delivery of test articles.

TRL

Estimated





NASA APPLICATIONS

An immediate potential application for the ADA Li-S chemistry is thrust vector control (TVC) systems used in flight control systems of launchers and space vehicles. These systems demand high energy and power to control the flight surfaces of high value vehicles. The technology would also play very well in interplanetary spacecraft. This Li-S chemistry would provide high energy density for the modest number of battery cycles these missions require. Another potential application for this chemistry is planetary rovers.

NON-NASA APPLICATIONS

Mission-critical battery back-up systems are a potential application for this technology. Remotely located back-up energy storage for critical government communications and mobile lightweight UPS power to back-up rocket launch computing and communications equipment can also be addressed with this Li-S technology. DOD spacecraft have similar energy storage needs as NASA and are in play.

FIRM CONTACTS

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SBIR STTR

S3.03-5173 – Extreme Environment Battery

PI: Brian Henslee, Cornerstone Research Group, Inc – Miamisburg, OH

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

* Future lunar missions must operate in extreme temperature environment
* Batteries capable of operation at – 230 °C to +120 °C are needed
* High specific energy and energy density are needed
* Safety improvements are needed
* "Electrolyte-in solvent" superelectrolyte technology extends operational temperature
* Advanced battery materials extends operational temperature
* Non-flammable electrolyte improves safety

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Technical Objectives

1. To define Extreme Environment Battery requirements
2. To prepare materials for cell assembly
3. To integrate and test pouch cells
4. To assess maturity of Phase I technology

Work Plan

Task 1: Establish Requirements and Cell Design

Task 2: Cell Component Selection and Fabrication

Task 3: Assemble and Test Prototype Cells

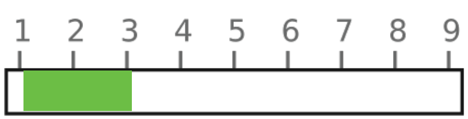
Task4: Phase I maturity analysis

Proposed Deliverables

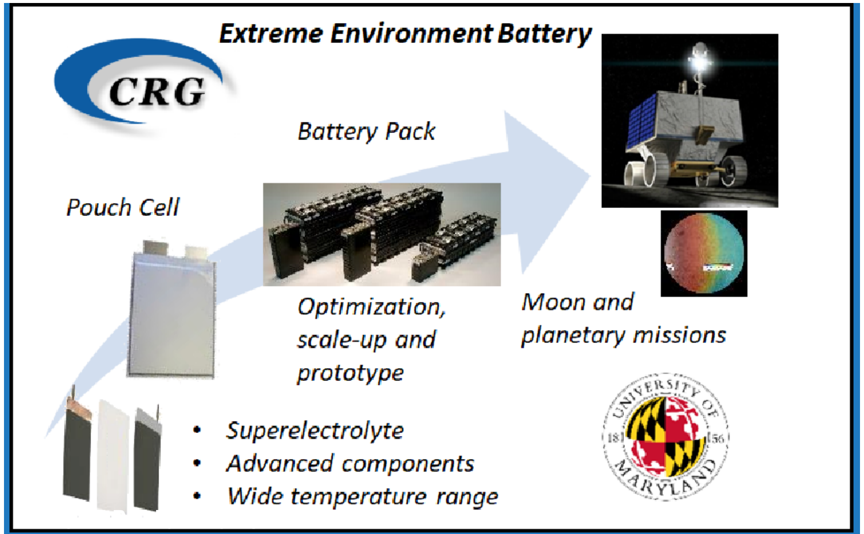
1. Kick-off meeting
2. Progress reports
3. Final report
4. Representative prototype cells devices

TRL

Estimated



S3.03-5173 - Extreme Environment Battery



- Power for CLPS Moon payloads
- Power for planetary missions
- Rovers

NON-NASA APPLICATIONS

- Power for electric vehicles in extreme climates
- Power for geological research, petrochemical exploration and extraction in extreme climates
- Pseudosatellites

FIRM CONTACTS

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T2.05-5203 - Pressure and Low Temperature Tolerant, High Current Density Solid Electrolyte for Propellant Grade Reactants

PI: Subir Roychoudhury, Precision Combustion, Inc. - North Haven, CT

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

Precision Combustion, Inc. (PCI) proposes to develop a new fuel cell design utilizing a solid electrolyte technology that will meet NASA's target specifications of (i) cycling through very low temperatures (<150K) to survive storage during lunar night or cis-lunar travel; (ii) recovery of >98% of its performance post cycling; (iii) capability to process propellants and tolerate contaminants without performance loss; (iv) capability to sustain high fluid pressures and vibration loads; and (v) achieving current density of >300 mA/cm2 (for >500 hrs), transient currents of >750 mA/cm2 for 30 sec and slew rates of >50 A/cm2/s. The fuel cell will consist of a solid electrolyte in an innovative design and internal reforming catalysts for meeting objectives, while allowing fuel cell operation with propellants. The innovative design and integration of reforming elements will allow for effective fuel cell operation with tolerance to extreme temperature swings, thermal cycling, and other operational requirements. A faster system start-up is also possible with this approach.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Technical Objectives:

1. Design and fabrication of fuel cell and stack configuration.
2. Design of hermetic test environment for fuel cell testing.
3. Design of thermal cycle testing environment and fuel cell evaluation.
4. Evaluation of the fuel cell performance to meet topic requirements.
5. Design of the stack structure for modular SOFC system.

Work Plan:

1. Identify and confirm key requirements to meet NASA specifications.
2. Fuel cell materials design, including electrolyte, and fabrication.
3. Design and evaluation of fuel cell configuration for testing and thermal cycling.
4. Fuel cell operational validation.
5. Stack design development and optimization.
6. Reporting and program management.

Phase I Deliverables:

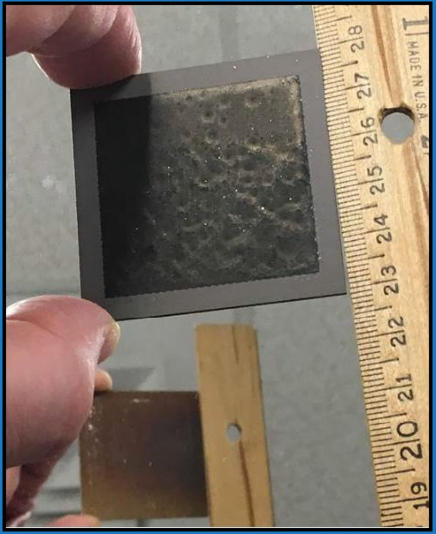
1. Periodic reporting.
2.Final report that will include detailed analysis of the scientific, technical, and commercial merit and feasibility of the proposed innovation as well as detailed recommendations for the Phase II activities. It will also comprise recommendations on the integrated design and assessment of system performance under preferred operating conditions.

TRL

Estimated

1 2 3 4 5 6 7 8 9

IMAGE TITLE: Fuel Cell Component



NASA APPLICATIONS

Potential NASA applications include future power generation systems from propellants and LOX initially for lunar bases and supporting upcoming Commercial Lunar Payload Services (CLPS). The systems have applicability over a broad range of mobile and stationary lunar surface systems, including landers, rovers, robotic rovers, and various science platforms. Key potential customers include NASA Glenn Research Center, NASA Johnson Space Center, and private sector customers.

NON-NASA APPLICATIONS

Targeted non-NASA applications will be for automotive, defense, and distributed power generation opportunities which rely on fast start, vibration tolerance, and high efficiency. It will also be applicable to SOFC-based military generators/vehicle APU's, commercial vehicle APU's and stationary fuel cell CHP applications seeking a more cost-effective, lightweight, and power dense fuel cell stack.

FIRM CONTACTS

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SBIR STTR

T15.03-4336 - Solid State Li-S Battery Based on Novel Polymer/Mineral Composite

PI: Greg Tao , Chemtronergy, LLC - Salt Lake City, UT

SBIR·STTR America's Seed Fund™ POWERED BY NASA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

Li-S battery technology faces the main challenge – "rapid capacity fade on cycling" due to shuttling effects and volumetric change, which has to be resolved. In phase I, collaborating with the University of Utah, Chemtronergy developed a unique all solid-state Li-S battery (ASSLSB) consisting a novel conductive polymer composite electrolyte and an advanced sulfur cathode, potentially capable of integrating with an industrial roll-to-roll battery manufacturing process. The composite SPE showed a conductivity as high as 2.2x10-4 S/cm and electrochemical window > 6.26 V at 25ºC. Coin cells constructed with the novel SPE and unique sulfur cathode showed initial discharge specific capacity of 1500 mAh/g. In Phase II, a prototype Li-S battery pouch cell will be constructed, followed by proof-of-concept demonstration. Successful development of the SPE and high-performance sulfur cathode could eliminate the use of flammable organic substances in the electrolyte while suppressing the polysulfide dissolution and lithium dendrite formation, thus making the Li-S batteries safer and durable.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Technical Objectives:

The principal objective of this STTR Phase II project is to develop an all solid-state Li-S battery (ASSLSB) by integrating a novel highly conductive solid polymer composite electrolytes and a novel sulfur cathode with an industrial scale manufacturing process. The proposed ASSLSB technology features with high energy density (>600 Wh/kg based on cell level), high power density (>1000 W/kg), high chemical and electrochemical stability (> 5000 cycles), low self-discharge rate (<5% per month), high safety, excellent low temperature performance, and good thermal stability (up to 85ºC).

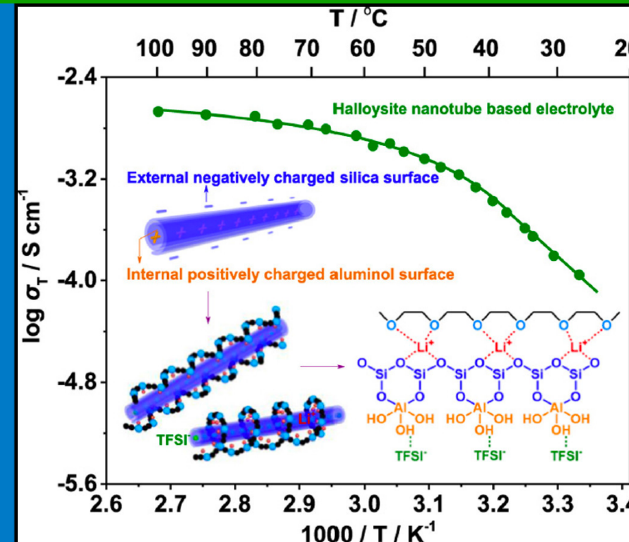
Work Plan:

Five major tasks will be performed over the two years of the proposed Phase II development. In the first year, efforts will be made to fine-tune the Li-S battery chemistry and optimize the SPE and composite cathode compositions, followed by the refinement of a prototype pouch cell design. The second-year efforts will focus on scaling-up the ASSLSB technology and proof-of-concept demonstrations, followed by the techno-economic analysis and comparison to the state-of-the-art Li-S battery technology.

TRL

Estimated

1 2 3 4 5 6 7 8 9



NASA APPLICATIONS

Through improving cycle life and safety, the proposed all solid state Li-S battery will address the key limitation for space applications. With high safety and long cycle life, ASSLSB would meet multi-use or cross platform space energy storage applications, and result in significant mass and volume savings and operational flexibility, including Electrical Aircraft propulsion (EAP), EVA space suits and tools, human example, lunar and martian landers, science platforms and surface solar arrays.

NON-NASA APPLICATIONS

The proposed ASSLSB can be widely used in consumer electronic, electric vehicles and charging stations, tourist coaches, yachts, wind and solar energy storage power, traffic signals, solar hybrid street lighting, UPS power supply, home energy storage, coal miner, disaster relief emergency, communication base stations, telecommunications, etc.

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