Contract No:

This document was prepared in conjunction with work accomplished under Contract No. 89303321CEM000080 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

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Savannah River National Laboratory

We put science to work.™

SRNL-STI-2022-00084

BSRA Collaboration Exchange on Advanced Manufacturing

Dr. Ralph James
Interim ALD for Science, Engineering Energy

February 22, 2022

Vision: Create high-impact manufacturing solutions serving EM, NNSA and energy security

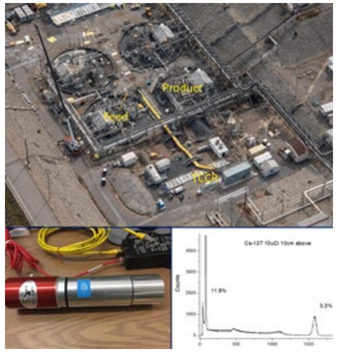
Advanced Manufacturing Collaborative (AMC)

- 60,000 square feet facility
- Located at University of South Carolina, Aiken

SRNL's Sponsored R&D Priorities

- Sensors
- Robotics
- Human machine interface
- Bioenergy
- Additive manufacturing
- Wasteform development
- Crystal growth
- Metrology
- Process heating
- Hydrogen processing
- Simulations/modeling & AI/ML
- Hydrogen economy
- Industrial power and grid test bed
- Energy systems scaling
- Cyber/wireless
- Circular economy
- Maker Space
- Collaborative Spaces
- Faculty, Guest Scientist, Post-doc and Student offices

Assuring production & safety with robotics

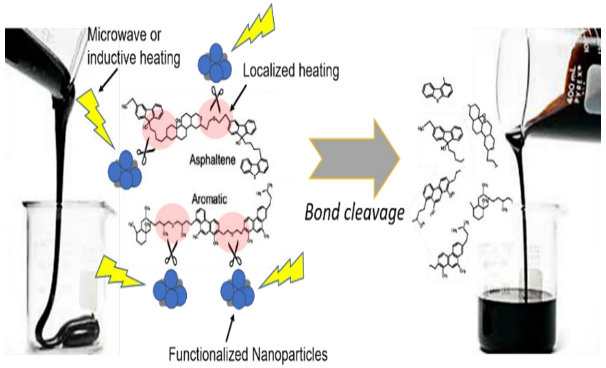


On-Line Monitoring for nuclear chemical processing

ICS: Internet of Things in Production

Additive manufacturing

Production of strategic materials



Catalysis: Heavy Crude Upgrading

SRNL's Journey

Technology Center
Focused Federal Resource

A National Leader
Solving National Problems

Approach:

- Transition from technical support arm of Savannah River Site to nationally recognized **science and technology thought and solutions leader** in targeted areas of advanced manufacturing
- Demonstrate success in transferring manufacturing technologies as an **intellectual asset**
- Build the Advanced Manufacturing Collaborative (AMC) as a dedicated Federal resource designed to grow local and regional R&D partnerships supporting and facilitating both **academic and economic leadership**

University and industrial collaborations are vital to SRNL's ability to create high-impact manufacturing solutions

Planned Attributes for AMC

- Facility that Supports the DOE EM Mission
- Open / Accessible
- Ample Formal and Informal Collaboration Space
- Highly Functional and Flexible Laboratories
- Integrates Strong Data-Infrastructure
- Coordinates with Adjacent Dream Port on Cyber
- Includes Demonstration Spaces for Pilots and Scaleup
- Attracts Academia and Industry in Public-Private Partnerships
- Encourages Student Participation and Enhances Education
- Attracts Talent for Student Recruitment
- Enhances SRNL's R&D reputation
- Inspires Future Scientists in STEM
- Encourages SRNL Culture Change

Advanced Manufacturing Collaborative – R&D Themes

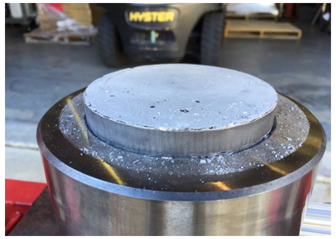
60,000 sq. ft. of conditioned space located at USC Aiken
Occupancy expected in January 2024

Renderings of External Design

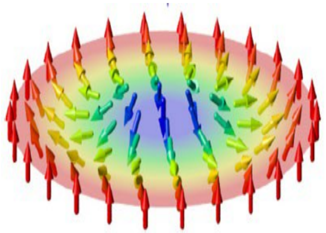
- 35% Design Plan Approved
- 65% Design Plan in March 2022
- Groundbreaking ~April 2022

Advanced Manufacturing Applies Across DOE Missions

AMC: Key R&D Themes
Intelligent Autonomous Systems
Human Machine Interface (VR/AR) & Smart Manufacturing (AI/ML)
Sensors (Chemical, Physical and Biological) and Sensor Networks
Cybersecurity Technologies to address cyber threats and hazards in manufacturing
Biomanufacturing
Additive Manufacturing & 4D Printing
Materials Synthesis and Crystal Growth
Multiscale Dynamic Modeling and Simulation

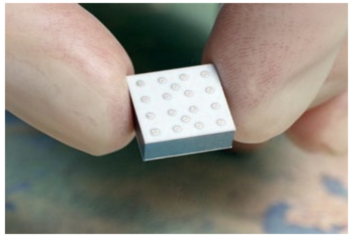


Materials Development



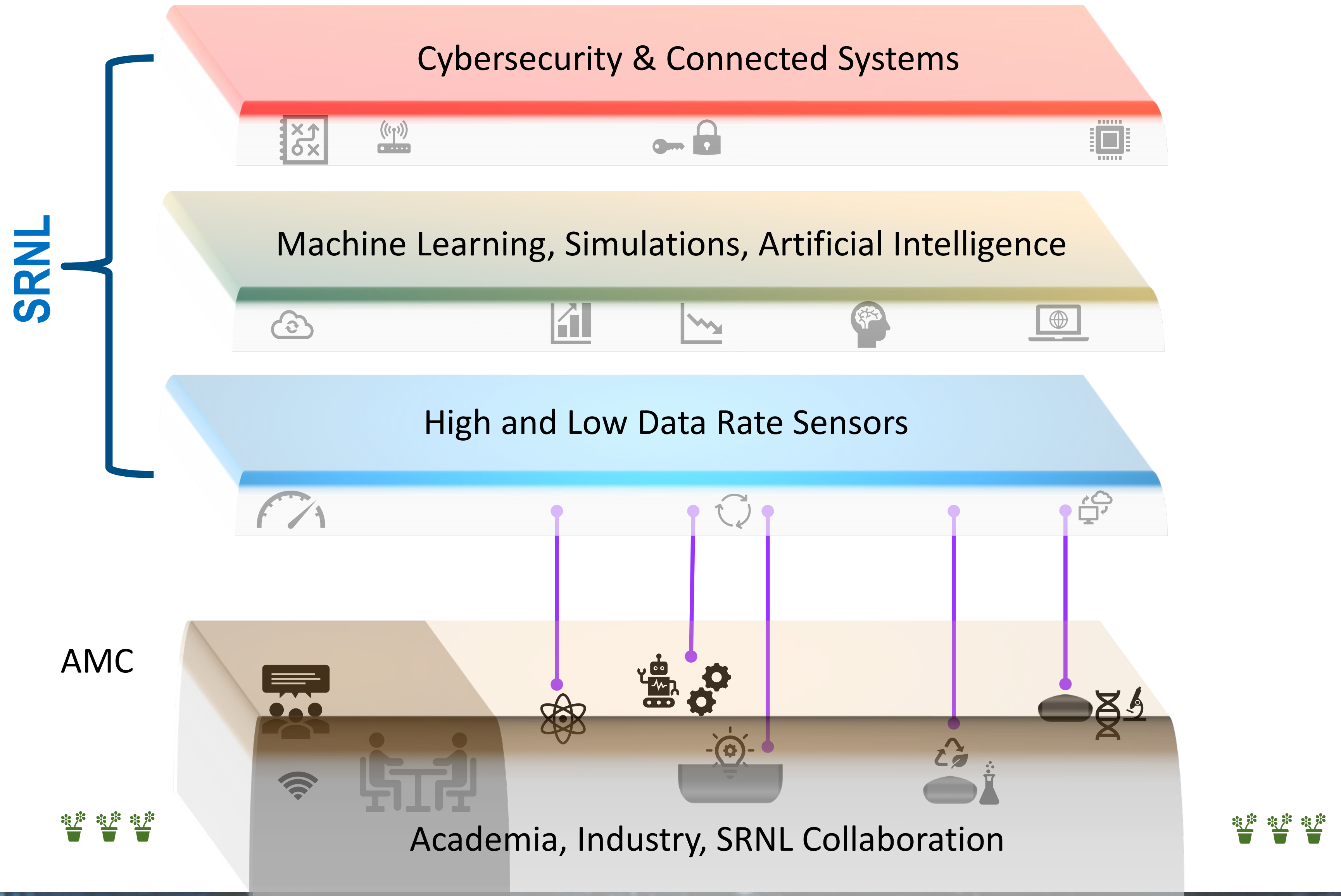
Scientific computing

Robotics



Sensors and Networks

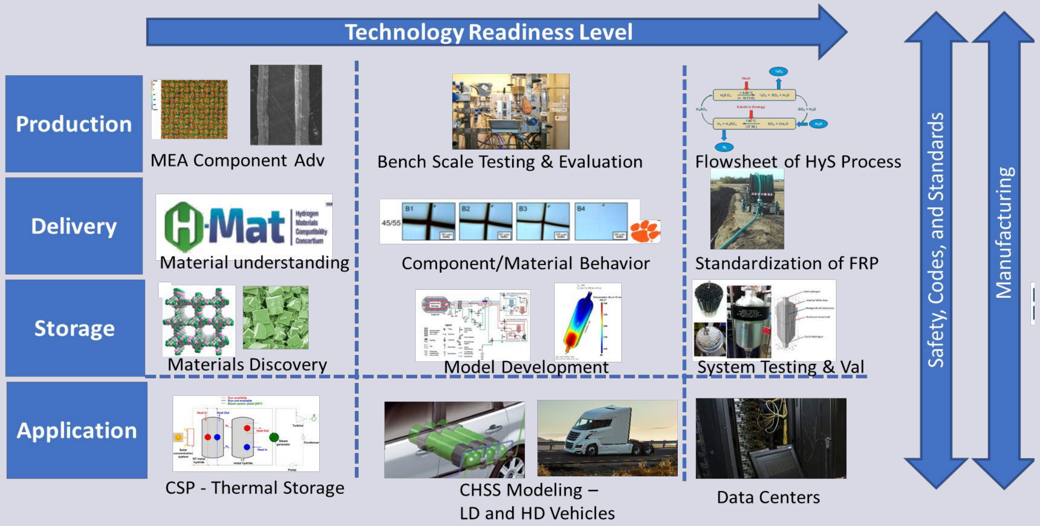
Savannah River National Laboratory (SRNL)



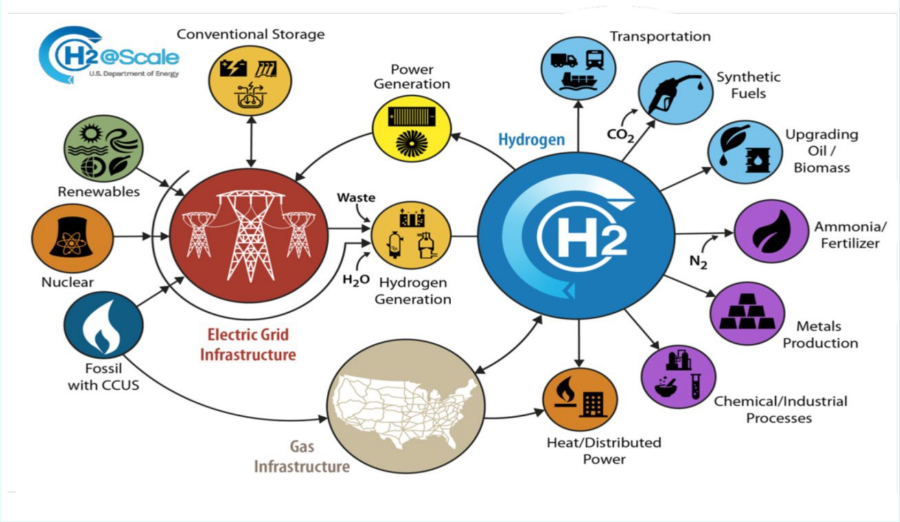
Appendix: Selected Project Descriptions and Points of Contact

Establishing a Hydrogen Ecosystem

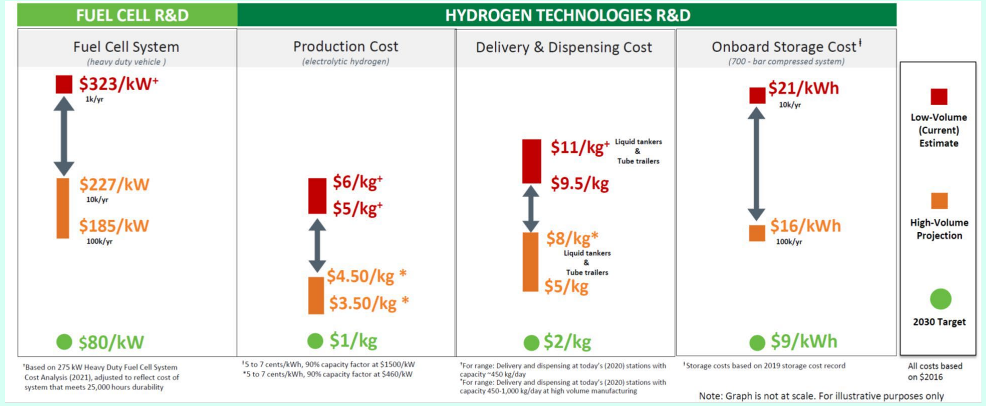
R&D CONCEPT



OBJECTIVES/IMPACTS



CHALLENGES



Satyapal, Hydrogen and Fuel Cell Day Remarks, Hydrogen Online Conference 2021

TEAM & COLLABORATORS

- **SRNL: Will James** (charles.james@srnl.doe.gov), **Hector Colon-Mercado** (hector.colon-mercado@srnl.doe.gov)
- **Partners:**
  - **Nikola Motors**
  - **National Laboratories (ANL, SNL, NREL, ORNL)**
  - **Clemson University**
  - **University of South Carolina**
  - **University of Virginia**

AMC Computation and Modeling

R&D Concept

- SRNL experts in physics and computational modeling, data analytics and AI/ML will share space with the experimental manufacturing teams at the AMC facility
- AMC will leverage these subject matter experts to help drive cutting edge manufacturing research
- Encourage coordination and collaboration between multi-disciplinary teams using multi-scale dynamic modeling and AI/ML techniques to achieve:
  - Rapid simulation of new ideas and concepts
  - Improved predictions, visualizations and diagnostics of design and production changes

Objectives/Impact

- Support the AMC's mission of developing advanced manufacturing capabilities by fully leveraging modeling and simulation and developing a core team of manufacturing and mod/sim experts co-located at the AMC. Key areas of interest:
  - Expand understanding of Additive Manufacturing techniques
  - Develop innovative solutions for SRNL's biotechnology efforts
  - Develop in-situ diagnostic capabilities for process monitoring and environmental efforts at SRS
- Development of a GPU focused HPC cluster at AMC to bring the necessary computing capabilities to AMC staff for faster processing

Context/Challenges/Risks

- Avoid the traditional pitfalls of failing to successfully integrate the experimental science/engineering with theoretical mod/sim and AI/ML in all aspects of the manufacturing process (silo-ing)
- Physics based modeling and data science are integral in advanced manufacturing and engineering. However, leveraging these tools and capabilities into real-time manufacturing process development is a challenge
- Incorporating insights gained from AI/ML into design and process improvement or changes is relatively new and not well understood

Team

- Point of Contact(s): Marc Taylor, SRNL (Marc.Taylor@srnl.doe.gov), Jonathon Baker, SRNL (Jonathon.Baker@srnl.doe.gov)

Additive Manufacturing

R&D Concept

1. Conducting cutting-edge research to develop **advanced deposition processes** and **alternative materials**.
2. Incorporating **in-situ** probes to advance real-time AM operations, data collection and analysis.
3. Utilizing a more complete range of post-growth tools to **characterize** the structural, mechanical, chemical, electrical and optical properties of AM-produced materials.
4. **Integrating AM** into the SRNL research community by providing unique, expedited, critical component development of AM-specific parts not available by traditional subtractive manufacturing.
5. Pursuing new product development applications and delivering **state-of-the-art** custom-built components to sponsors.
6. Creating and **growing a facility** that can be used by researchers across the lab for extramural (external sponsors) and intramural (LDRD and PDRD) research and development.

Context/Challenges/Risks

Commercial equipment is locked down with limited if any parameter adjustment

AM technology is rapidly advancing – technology gets out of date fast

Objectives/Impact

Industry is working on the mainstream applications – SRNL is focused on the fringes

- Harsh environments
  - Temperature, chemical, radiological
- High consequence applications
  - Part qualification
  - Better process monitoring and control
  - NDE techniques
- SRNL is using AM to enable better non-AM research

Team

- **Aaron Washington** – Thermosets
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- **Tim Krentz** – Hydrogen compatibility
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- **Guru Dinda** – High entropy alloys
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- **Hector Colon-Mercado** – AM Surfaces
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- **Donny Benza** – Polymer processes
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- **Yuefeng Luo** – Metal processes
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- **John Bobbitt** – Engineering Lead
  john.bobbitt@srnl.doe.gov
- **Jay Gaillard** – Thermoplastics, continuous carbon fiber & ink jet
  Jay.gaillard@srnl.doe.gov

Laser Directed Energy Deposition (DED) System

- Custom printer under development for high entropy alloy development
  - Fully controllable parameter set
  - 3kW laser, spot size 2-4mm
  - 2 powder feeders
  - 6 Axis robotic arm
  - Through beam measurements
  - Build volume – 600x600x600 mm
  - Layer thickness – 0.2-1.0 mm
  - Build rate – 25-125 cm^3 / hr
  - Inert build chamber (Ar or He)
  - Materials
    - Steel – 316, 304, H13, 4340
    - Titanium – Ti-6Al-4V
    - Nickel – Inconel 625, 718
    - Custom alloys
    - MMC

Advanced Biomanufacturing

R&D Concept

Strategic Goal:
- Develop industrial-scale biocatalytic processes to support the synthesis of chemical compounds and architectures for which current processes are prohibitively expensive, environmentally harmful, or difficult to reproduce

Approaches:
- Whole cell recombinant systems
- In vitro “cell free” processes
- Isolated enzymes
- Combined biochemical/nanotechnology processes

Topical Areas:
- Production of sensor substrates
- Production of uniquely-biocompatible buffering systems
- Alternative architectures for collection
- Biosynthesis of DoD-centric materials and precursors

Objectives/Impact

- **Technical**
  - Allow production of a range of industrially important biomolecules/processes for use in the environmental, agricultural, food, energy, material, medical, pharmaceutical industries and defense
- **Educational**
  - Training the next generation of scientists/engineers from generation of concept to production of product
- **National Security**
  - Provide a test bed for cybersecurity advancements in identifying threats, vulnerabilities and consequences to our nation’s biomanufacturing infrastructure related to synthetic biology applications
- **Collaborative**
  - Provide environment/facility for interactive instruction of graduate and undergraduate students through interaction with SRNL, universities and industrial partners

Context/Challenges/Risks

Context:
- Biocatalysis can enable development of complex and highly specific materials where:
  - Variability in material properties is difficult to control using traditional chemical synthesis methods
  - Novel material functionalities are desirable
  - Competitive products are based on non-renewable resources
  - Enzyme-based production is more resource efficient

Challenges/Risks:
- Renewable energy/chemical production is saturated research area

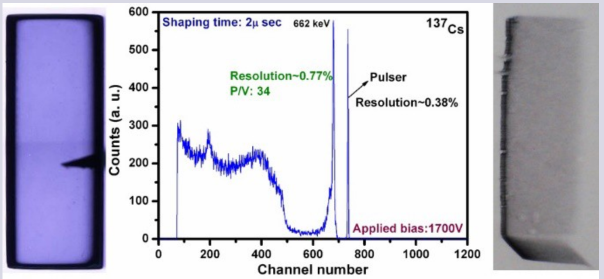
Team

- Program Lead: Dr. Brady Lee, Director – Earth and Biological Systems Division
- Technical Leads: Dr. Chris Bannochie, R&D Manager Biotechnology Group; Dr. Wendy Kuhne, Biological Sciences SME
- Email: Brady.Lee@srnl.doe.gov, Phone (803) 989-6087

Crystal Growth and Processing Laboratory

R&D Concept

- Develop efficient detector material to combat nuclear proliferation threats at substantial lower cost.
- Focus is to develop high resolution detector, operating at room temperature to ease the field operation.
- Defect free crystals are the key to achieve manufacturing of high-resolution detectors at lower cost of production.
- The new material CdZnTeSe (CZTS) evolved as promising candidate with substantially lower defect concentrations.



pulse height spectrum of 137Cs source of the Frisch-grid detector of length ~9mm, fabricated from as-grown Cd0.9Zn0.1Te0.98Se0.02 THM-grown ingot.

Objectives/Impact

- Develop ultra high-resolution nuclear detector and knowledge-based future workforce.
- Strengthening collaboration with industry and academia involving graduate students.
- The new material proven to be far more superior to the widely used material CZT. The new quaternary material (CZTS) has only one noted disadvantage of having high content of external impurities. Straight forward techniques will be implemented to tackle this problem and enable production.
- The success of the proposed work will have direct impact on industries that manufacture proliferation detector equipment as well as medical imaging industries for producing the advanced products at lower cost.
- Projected TRLs: Initially 1-2, after 3 years: 3-4.

Context/Challenges/Risks

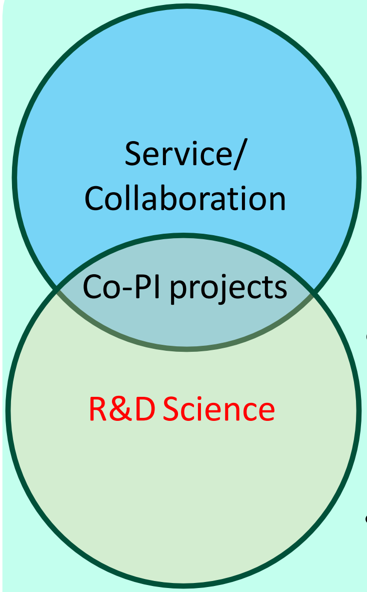
- Traveling Heater Method (THM) is widely accepted method to grow detector grade CdTe/CdZnTe (CZT) industrially. THM technique will be adopted to grow detector-grade CZTS.
- Academia getting involved in developing CZTS globally.
- Considering interested in manufacturing low-cost detectors and imaging arrays. General Electric is also focused on product development.
- Brookhaven National Laboratory is another active collaborator.
- Purification of the raw material is envisaged to be the key challenge for further advances.

Team

- Principal Investigator(s): Utpal N Roy, Sensing & Metrology
- Collaborators: Prof. K. C. Mandal, Univ. of South Carolina, Prof. S. Egarievwe, Alabama A&M University, Dr. Y. Cui and G. S. Camarda, Brookhaven National Laboratory. Prof. J. Franc, Prof. R. Grill, Charles University, Czech Republic.
- Open to other institutions
- Email: utpal.roy@srnl.doe.gov
- Phone #: 803 989 3301

AMC Materials Characterization Lab

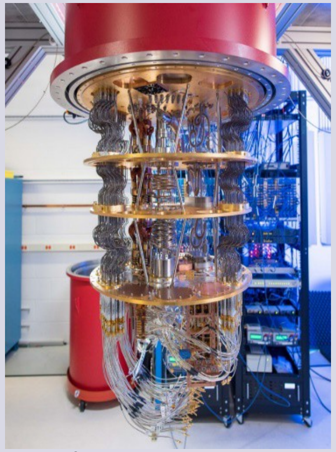
Objectives/Impact



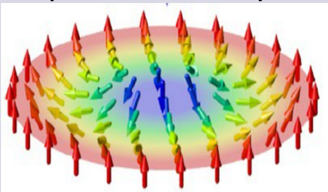
- Provide service to research teams at SRNL through scientific collaboration and help realize their success on the projects.
- Conduct topological quantum materials and additive manufacturing magnets research.
  - Quantum information science, Clean Energy, and critical materials
  - Understand the fundamental science behind these technologies
- Achieve the end goal using the state-of-the-art techniques available at SRNL, other national labs and universities through collaboration.
- Support colleagues at SRNL and collaborate with external entities.
- Support research teams through collaboration and conduct basic science research that will be the foundation for quantum and manufacturing technologies during a 3-year lifecycle.

R&D Concept

Computing power = 2^N



Google quantum computer, N ~ 53 qubits



Topological spin textures (skyrmion)

- Discover exotic quantum phases and topological features like skyrmions in lanthanide- and actinide-based crystalline materials.
- Create and control nanometer-size skyrmions, which allow higher energy information density.
- Achieve the end goal due to PI's experience, excellent team members at SRNL and collaborators at national labs and universities.

Additive Manufacturing Magnets

NdFeB AM magnets (Above left) could be used in motors

https://researchfeatures.com/additive-manufacturing-future-permanent-magnets-production

Context/Challenges/Risks

- Has potential to be used in the future technology.
- Experience in conducting magnetic materials research for more than 11 years and published > 34 peer-reviewed articles.
- Rely on user facility measurement techniques due to the unavailability of physical and magnetic property measurement systems at SRNL, which could delay the research progress.
- Need cutting edge techniques to conduct cutting edge science.

Team

- Principal Investigator: Binod K Rai (Sensing and Metrology, SRNL)
- SRNL Co-Investigators: Patrick O'Rourke, Catherine Housley, Henry Ajo, Utpal Roy (Sensing and Metrology), Lindsay Roy (Advanced Modeling, Simulations)
- Ext. Collaborators: Idaho National Laboratory and Buffalo State College
- Email: binod.rai@srnl.doe.gov/Phone: 8394650020

AMC Robotics / Automation Lab

R&D Concept

- Remote operation of complex tasks typically executed by a person to reduce overall dose
- Leveraging COTS equipment through integration with custom developed equipment for unique remote operations
- Perform tasks with robotic equipment in areas that have dose rates too high for any human interaction

Objectives/Impact

- Develop robotic / remote systems to reduce the hazard to the worker
- Reduce dose to worker through advanced technology
- Extend the life of aging facilities through remote inspection / characterization
- Develop a means to safely execute tasks that would otherwise not be possible
- Reduce worker fatigue and augment capability
- Typical project advances technology from TRL 3 or 4 to 8

Context/Challenges/Risks

- Robotic development can be capitalized for manufacturing scenarios that are dull, dirty, or dangerous
- Complementary work is taking place at other National Labs
- Acceptance of automation for tasks traditionally performed by a human (safeguards & security)
- Cybersecurity requirements of control systems
- Approval to use wireless technology in security areas
- Current procedures are written for manual execution

Team

- Rick Minichan, 803-725-2271, richard.minichan@srnl.doe.gov
- Alan Busby, 803-725-8504, alan.busby@srnl.doe.gov
  - MK-18
- Mike Dalmaso, 803-725-2348, michael.dalmaso@srnl.doe.gov
  - Nuclear Material Package automation
- Kevin Hera, 803-725-6469, kevin.hera@srnl.doe.gov
  - H-Canyon Inspection Crawler
- Dan Krementz, 803-725-2410, Daniel.krementz@srnl.doe.gov
  - Glovebox Automation
- Nick Spivey, 803-725-2427, nicholas.spivey@srnl.doe.gov
  - Wearables

Human Machine Interfacing

R&D Concept

The purpose of this lab is to develop new methods of passing information and controls between a computer system and humans. Multiple novel approaches have been proposed that include developing new methods of utilizing existing hardware, new hardware development, and design of novel human interfacing methodology.

Objectives/Impact

The objective of this lab is to develop cutting edge hardware, software, and methods for interfacing with computer systems. This will be achieved by demonstrating the value of these systems to end users as well as writing proposals for the proper calls. Increasing the speed and efficiency of interfacing with a machine will dramatically improve the speed at which equipment and discovery can progress.

Context/Challenges/Risks

This lab builds on years of previous work with virtual and augmented reality. The manufacturing applications include product development, training, work execution, and robotics.

Challenges:
- Industry acceptance
    - Under applied
    - Over applied
- Conveying results

Team

- Team Lead: Matthew Folsom, Instrumentation and Wireless Systems
- Co-lead: Caleb Scott, , Instrumentation and Wireless Systems

Matthew Folsom
matthew.Folsom@srnl.doe.gov
(803) 761-2326

Example of Using Modeling/Simulation to Predict Semiconductor Manufacturing

Exploring doping and processing strategies in semiconductors:

- State of the art DFT calcs yield quantum mechanical information on defects
- Statistical mechanical simulations allow exploration of collective behavior under experimentally relevant quantities

Input Data

100s-1000s of DFT point defect calculations

Generate quantum mechanical information

Independent Variables

Thermochemical Model of Processing

Dopant and Impurity Concentrations

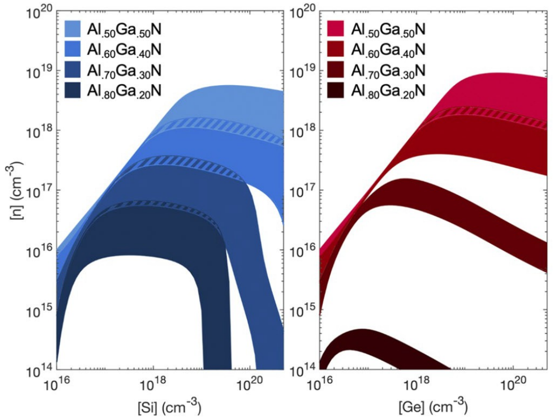
Statistical Mechanical Simulation

Predicted Outcomes

Electronic properties of material

Optical properties of material

Gas solubilities



Electron conc. for Si doped (left) and Ge doped (right) AlGaN versus alloy composition and growth conditions.. Mirrielees *et al*, J. Chem. Phys. (2021), 154, 094705

Additional Talking Points

- **Avoiding silo-ing: the Materials Genome initiative**
  - Materials discovery timeline spans 1-2 decades
  - MGI was meant to coordinate theory and experiment to accelerate stages 1-4 with modeling and sim
  - However, due to silo-ing and organizational pressures, many theoretical efforts went towards stage 1

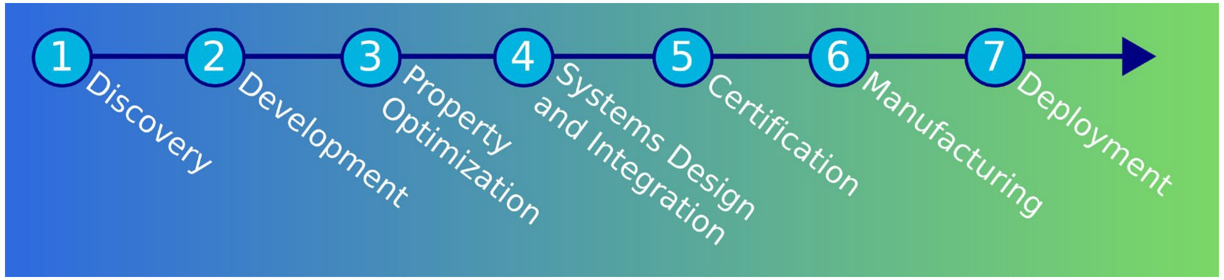


Image reproduced from Baker *et al*, MRS Comm (2019), 9, 839–845

- **Why a GPU focused cluster?**
  - SRNL's existing HPC is meant to support CPU-heavy applications, and has very limited GPU computing available
  - AMC will need data storage capabilities on site anyway to support the large volumes of data that the other labs are planning to collect
  - Developing complementary, linked capabilities means that we get all of the co-location scaling benefits of our existing CPU-based system while putting the GPU-based system close to the large amounts of data required for AI models

AMC - Critical Infrastructure, ICS, and Cybersecurity Lab

R&D Concept

- **Identifying and remediating cyber risks are key to 21st century security of U.S. Critical Infrastructure and the Industrial Base.**
- **SRNL has an expanding cybersecurity R&D program with experts in diverse disciplines** who will focus AMC cybersecurity R&D efforts on challenges of securing the U.S. Critical Infrastructure and the Industrial Base.
- **Cyber landscape is ever changing.** The team will continually evaluate, discover, & remediate vulnerabilities, inform industry, and roll out solutions to mitigate the vulnerabilities.

Objectives/Impact

- **Objective: Perform Cybersecurity R&D** focused on Critical Infrastructure, Electrical Grid, and Industrial Base to *develop and field solutions to increase U.S. cybersecurity preparedness* for, defense against, and response to cyber attacks.
- **Impact: Securing America.** Protect C/I and the Industrial Base from cyber attacks to ensure sustainable energy, products, data flow, etc. to ensure a robust civil and expanding society.
- **Metrics: Solutions Deployed** to Industrial Base and C/I installations, vulnerabilities discovered, collaborative projects, and publications and reports issued.

Context/Challenges/Risks

- **Cyber vulnerabilities are abundant in much U.S. C/I and Industrial Base control systems.** These control systems are comprised of legacy equipment designed before a "real" cyber threat existed, therefore cyber vulnerabilities are abundant.
- **Solutions must be practical**, implementable, sustainable, and cost effective for all Critical Infrastructure (C/I) installations and the entire Industrial Base.
- **SRNL is currently developing cybersecurity solutions** which can be leveraged for this research.

Team

- Principal Investigator(s):
  - **Rick Poland** (Team Lead, Lab Design)
  - **Jon Dollan** (Cyber Strategy Director)
  - **Klaehn Burkes** (Elec. Grid)
  - **Harrison Howell** (Software)
  - **Ajay Tiwari** (ICS)
  - **Nick DeRoller** (Electronics)
- Potential Co-Investigators:
  - **Dr. Jeffrey Morris** (AU-Quantum Encryption)
  - **Dr. Kristen Booth** (USC-uGrid)

Additional Information the A-CIIC Lab

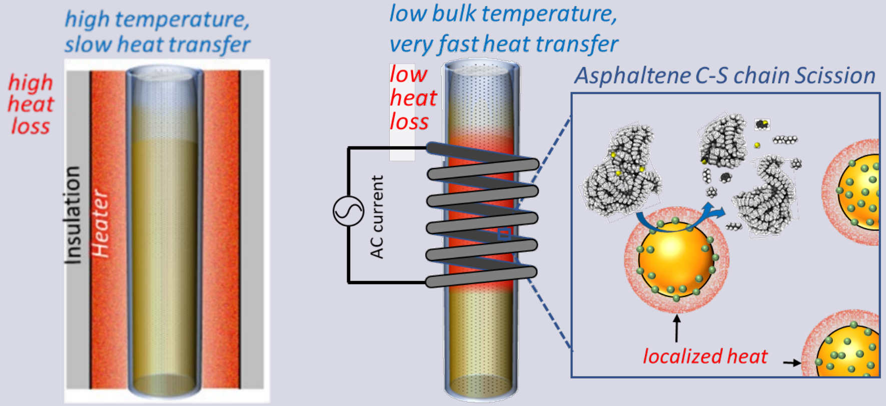
- **SRNL has Ongoing Cybersecurity Relationships** with other National Labs (LANL, SNL, LLNL, PNNL), US Army Cyber Command (CPB, CCoE, CyS), SC Army National Guard, etc.
- **SRNL CIIC Infrastructure** includes the S-CIIC at the SRNL campus and the G-CIIC at the Georgia Cyber Center in Augusta, GA
- **SRNL CIIC Expertise** includes multiple disciplines (Cybersecurity, ICS, Electrical Grid, Electronics, Computer Science & Engineering, & Intelligence). The team holds nearly 30 SANS certifications.
- **The AMC will include a Cyber Security Operation Center (CSOC)** for monitoring the operational/research network and testing cybersecurity solutions & SCADA/DCS systems.
- **AMC CIIC includes 5G/Wireless Research** for implementation to manufacturing environments and the cybersecurity related implications and solutions.

Thermal Process Intensification

R&D Concept

Decrease energy intensity of thermal processes using electromagnetic and non-thermal technologies to reduce environmental impact of manufacturing.

- Tailor control over molecular-level phenomena that govern chemical reactivity at the catalyst surface
- Increase reaction selectivity through elimination of thermal gradients
- Increase chemical process throughput rate
- Direct MW and RF energy for low bulk temperature conversion



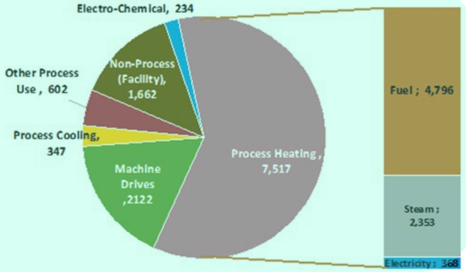
Manufacturing Challenges

Reduce manufacturing energy and GHG footprint

- Manufacturing accounts for **32%** of US energy use
- Thermal processes account for **74%** of total manufacturing energy use and **42%** GHGs

→ large driver to **electrotechnologies**

- microwave
- ultrasonic
- RF induction
- plasma
- IR
- hybrid



Objectives/Impact

Benefits to the process heating industry

- Reducing barriers to process scale-up, improved uniformity of reaction temperatures, better control of conversion and product distribution
- Precise and selective heating, applying heat directly to the susceptor for better energy efficiency and improved selectivity
- Volumetric heating
- Rapid heating rates compared to conventional heating methods
- Reduced process footprint, enabling modular systems through process intensification

Portfolio/Team

1) **EM Catalysts Low Temp. Heavy Crude Upgrading**
2) **EM-Enhanced Thermocatalytic Depolymerization of Mixed Plastic**
3) **Directed EM Thermocatalysis for Selective Conversion of Waste Plastic to High Value Intermediates**
4) **Soft Smart Tools Using Additive Manufacturing**
5) **EM-Enhanced HyPOR Loop for Fast Fusion Cycles**
6) **Thermocatalytic Ethylene Production using Targeted RF Induction Heating**
7) **Integrated RF and US with Conventional Processes for Efficient Water Removal**

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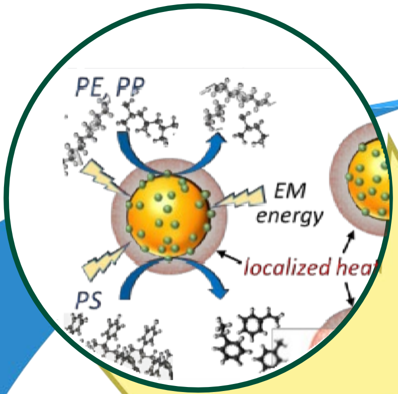
- **Mark Elvington** – mark.Elvington@srnl.doe.gov
- **George Larson**– george.larson@srnl.doe.gov

- Prabhu Ganesan
- Joseph Meany
- Tyler Guin
- Aaron Lando
- Matthew Craps
- Kori MacDonald
- Taylor Adams

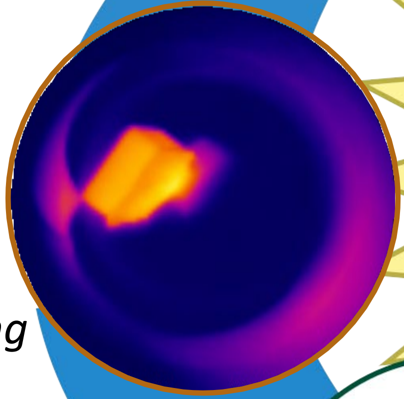
Programs Leveraging Thermal Process Intensification

AMO Seedling
- *Directed Electromagnetic Thermocatalysis for Selective Conversion of Waste Plastic to High Value Intermediates*



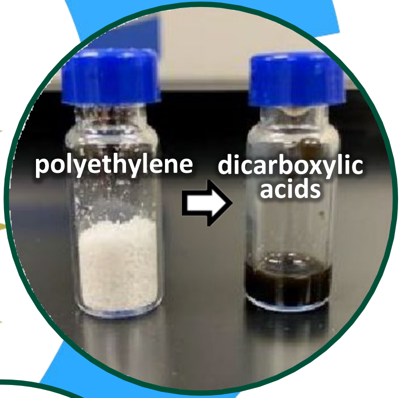
CREATE
Center for Research in Electromagnetic and Thermal Engineering

VTO
- *Soft Smart Tools Using Additive Manufacturing*

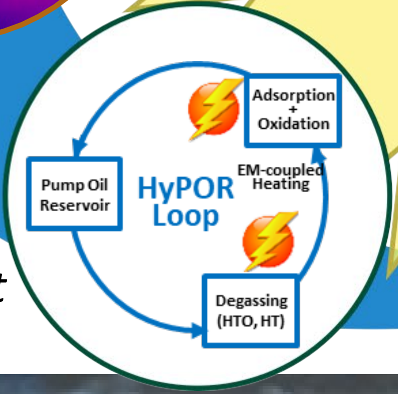


Thermal Process Intensification at SRNL

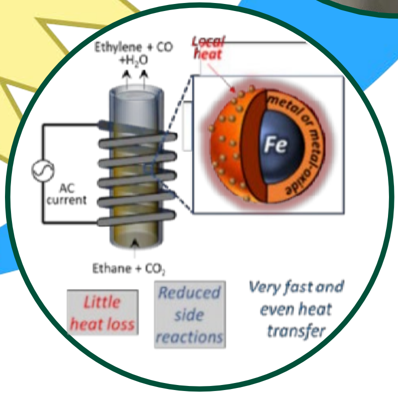
DARPA ReSource
- *EM-Enhanced Thermocatalytic Depolymerization of Mixed Plastic*



ARPA-E
- *EM-Enhanced HyPOR Loop For Fast Fusion Fuel Cycles*



EERE AMO
- *Thermocatalytic Ethylene Production Using Targeted RF Induction Heating*



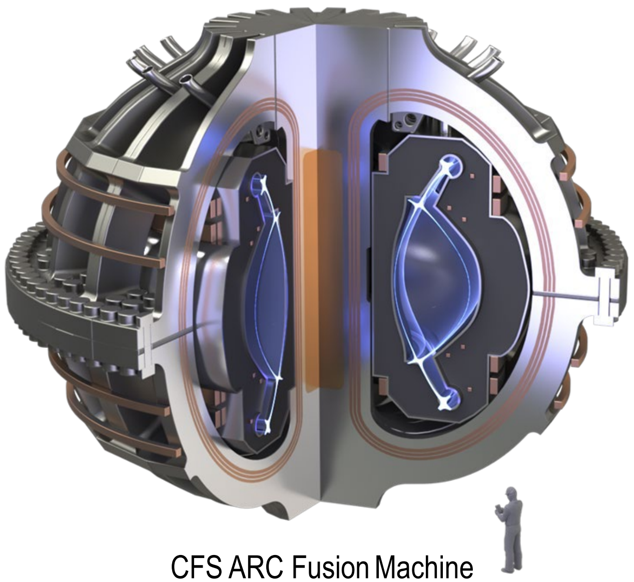
Fusion Energy and Hydrogen Processing

R&D Concept

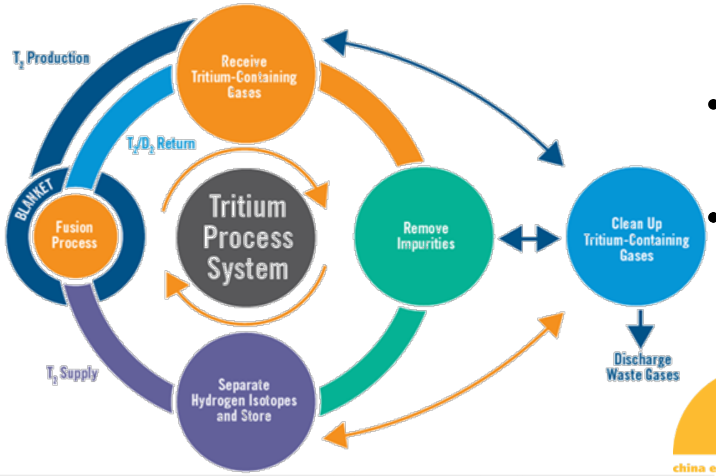
- **Goal: Enable Affordable Decarbonization of Energy Production**
- Fusion technologies have developed to the point where they are near commercial viability
- The most viable short term fuel cycle for fusion energy is a deuterium/tritium fuel cycle
- SRNL is working with DOE and commercial partners to develop fusion fuel cycle technologies
- Utilities considering fusion to meet targets in 2050's

Context/Challenges/Risks

- Research on tritium fuel cycles have applicability to both fusion energy and national security applications
- Technical challenges (e.g., maintaining hydrogen isotope purity and preventing release of tritium to the environment) are similar and the significant difference is the high throughput (10-100x) for fusion
- Tritium breeding and tritium extraction infusion is an additional challenge and many concepts are at low TRL
- SRNL both works with companies on their technologies and develops its own solutions



CFS ARC Fusion Machine



SRNL has in-depth capabilities in each of the tritium process systems required for fusion success

Objectives/Impact

- Develop fuel cycle technologies and materials that can meet the processing rates in a fusion plant and have high durability in the fusion environment
- Improve processing throughput, reduce the concentration of impurities, improve tritium confinement methods
- Prepare technologies for a TRL 7 level fuel cycle demonstration at SRS or other facility
- Companies planning to operate pilot facilities in 2030's and are planning pre-pilots in the mid-2020's

Team

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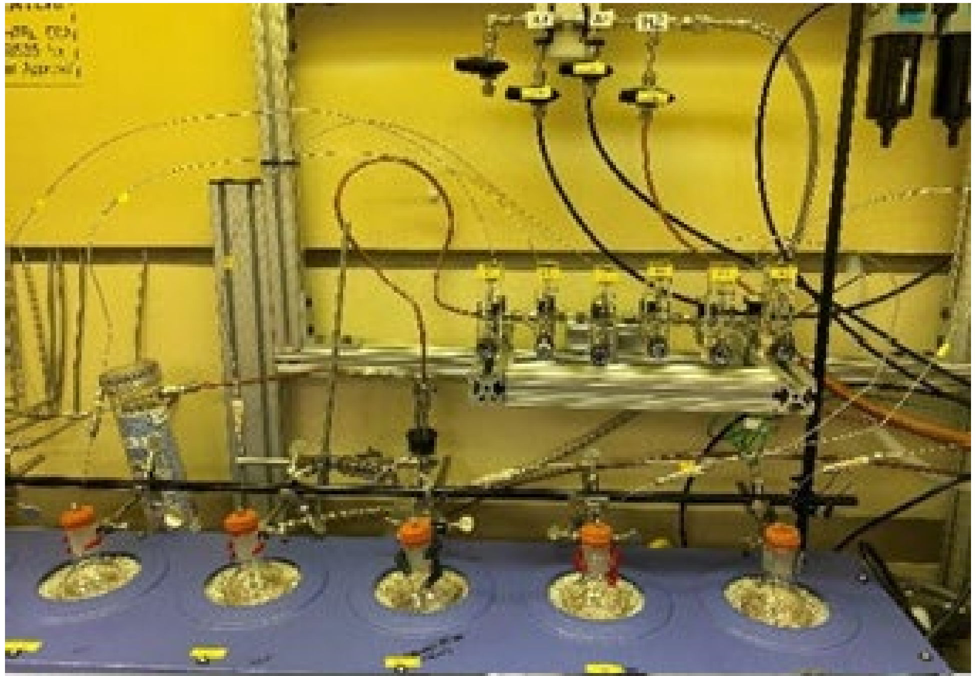
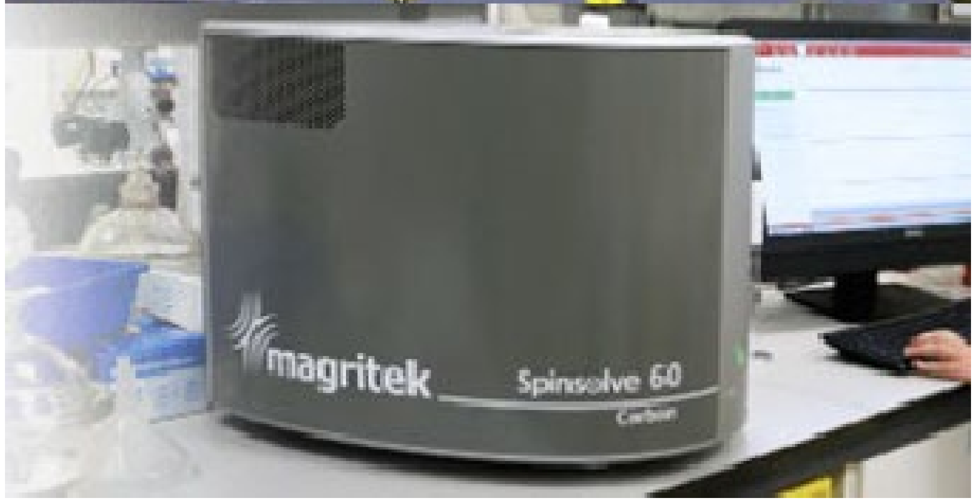
- PIs / Co-PIs: George Larsen, Jay Gaillard, Lucas Angelette, Tim Krentz, Dale Hitchcock, Holly Flynn, Chris Dandeneau

iter — china eu india japan korea russia usa
Oak Ridge National Laboratory
Renaissance Fusion
University of South Carolina
Commonwealth Fusion Systems
Clemson University

HyPOR Loop – Technology Development with ARPA-e GAMOW and FES





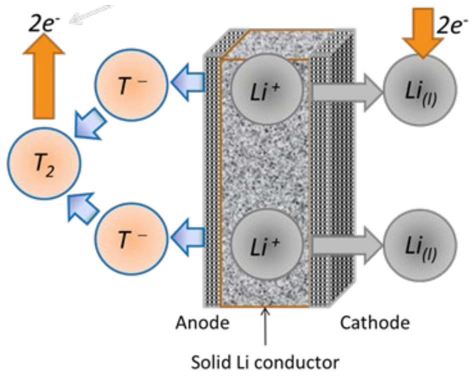
- **Hydrocarbon Pump Oil Recycling (HyPOR) Loop**
- **<u>Goal:</u> Selectively remove heavier H_2 isotopes from pump oil while also purifying the oil of radiation-induced damage**
  - >4x reduction in tritium inventory
  - >10x reduction in pump electrical consumption
  - >50x reduction in costs
- **Selecting Oils and Performing Initial Catalyst Synthesis and Characterization**
  - The project team has successfully identified oil compositions of interest that should be able to withstand the projected radiation damage and processing conditions
  - Experimental testing facilities have been set up and initial testing on catalyst synthesis have been conducted in conjunction with partners at Clemson and the University of South Carolina
  - Currently working to characterize oil functional group impacts
  - Identifying commercial partners for project
  - Working to patenting the process

Direct LiT Electrolysis – Technology Development with ARPA-e GAMOW and FES

- **<u>Goal:</u> Develop method to electrochemically extract tritium directly from a PbLi blanket for reduction of tritium concentrations below vacuum extraction**
  - >50% reduction in capital cost
  - Develop durable electrolytes and electrodes
  - Scale-up demonstration to 1 kg/hr processing rate
- **Improving cell design, experimental setup, and electrolyte materials**
  - Fabricated multiple iterations of experimental cell to improve electrode integration and reduce introduction of impurities into the cell
  - Improved electrode and electrolyte synthesis methods
  - Working to scale electrolyte synthesis methods and test durability
  - Achieved initial current efficiency targets for the process and are working to test electrode fabrication with new electrolytes

Lithium Conducting Electrolyte

$2LiT \rightarrow 2Li^{+} + T_2\uparrow + 2e^{-}$ $\quad Li^{+} + e^{-} \rightarrow Li$



$E^0_{400°C} = -2.82V$ $\quad E^0_{400°C} = -3.22V$