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Investigation of Solid State Hydrides For Autonomous Fuel Cell Vehicles

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Savannah River National Laboratory

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Project #ST134

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Overview

Timeline and Budget

Project Start Date: 3/1/2015

FY 17 DOE Funding: $250k

Planned FY 18 DOE Funding: $250k*

Total DOE Funds to Date: $950k

* Project continuation and direction determined by DOE annually

Partners

- Naval Undersea Warfare Center (Newport)
- Office of Naval Research

Relevance

DOE Funded Activities

Objectives:

- Screen H_2 storage systems against DoD targets and requirements that are suitable for vehicle demonstration platforms
- Complete a detailed design of the hydrogen storage system for use in an integrated system design
- Demonstrate feasibility of hydrogen storage system to operate under given system constraints

ONR/NUWC Funded Activities

Objectives:

- Design, build, and test a small bench-scale, alane hydrogen storage vessel with appropriate heat transfer fluid and material volumes to simulate full system
- Demonstrate full hydrogen release with given heat transfer fluid quantities
- Provide a safe and reliable high energy density power system to extend operational time over existing systems

Impact:

- The experience gained from the HSECoE and the core capabilities of SRNL and DOE were leveraged to develop a unique hydrogen storage system for new fuel cell applications
- Extension of this program to other unmanned and manned platforms is likely
- *This project also provides the basis to extend a long-term partnership between DOE and the DOD in hydrogen and renewable energy systems*

Approach

The overall approach of this research is to develop a methodology that incorporates engineering modeling and analyses to efficiently screen, design and select storage materials and material systems against cost and performance targets leading to an initial system design for an Unmanned Underwater Vehicle (UUV) application.

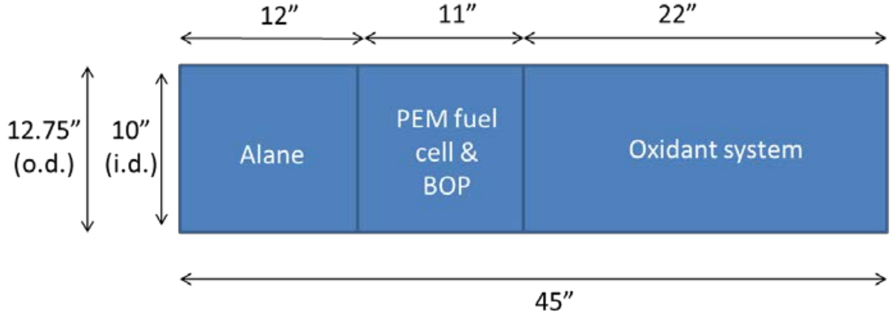
- This methodology, initially developed by SRNL and applied to light-duty vehicle in the Hydrogen Storage Engineering Center of Excellence (HSECoE), was adapted for other hydrogen and FC applications
- By leveraging previous experience with alane and system design, a power system capable of extending the operational time of UUV is being systematically developed and optimized
- Maintaining this capability for DOE will attract other opportunities and projects in other high energy density integrated power systems

Naval Undersea Warfare Center (NUWC) Division Newport

Christian Schumacher and Dr. Joseph Fontaine (Navy program partners)

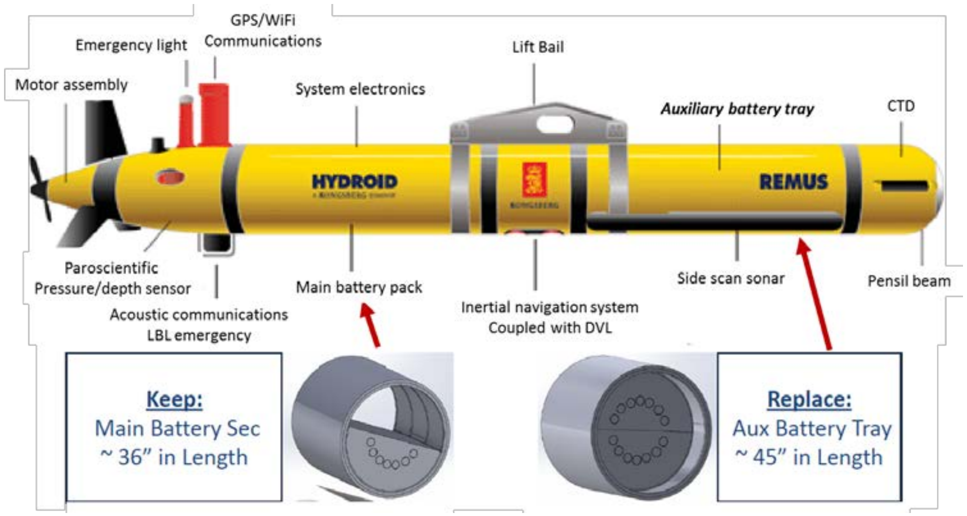
Naval Undersea Warfare Center, is the Navy's full-spectrum research, development, test and evaluation, engineering, and fleet support center for submarine warfare systems and many other systems associated with the undersea battlespace.

Space Allocation for System

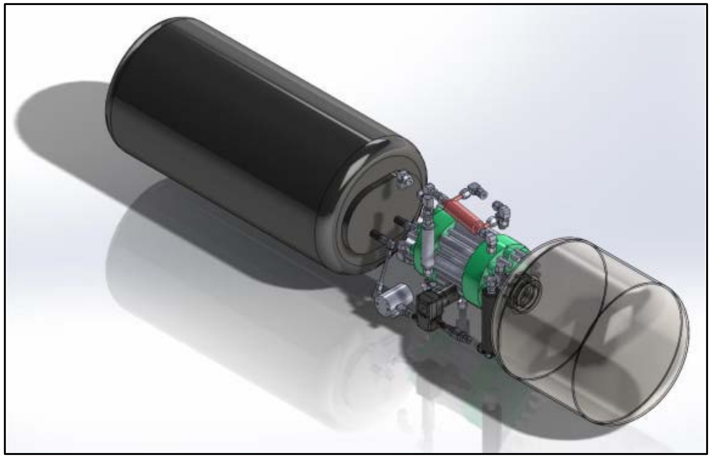


Space allocation for system

- Utilizing alane and the hydrogen storage material allows for **2x increase in vehicle operational range/time**
- This system will utilize heat from the oxidant system to drive the thermal desorption of hydrogen from alane to drive a fuel cell



Space allocation for batteries in current system



System integration configuration

Alane, oxidant system, and fuel cell interfaces

Alane
-7 kJ/mol of H_2
11.3 kg
3917.9 kJ (1.089 kW-hrs)

H_2 gas
559.7 mol
1.13 kg

PEM Stack
250W Avg.
96 hr, 24 kW-hrs
0.8V, Ɛ=0.6
100W waste heat

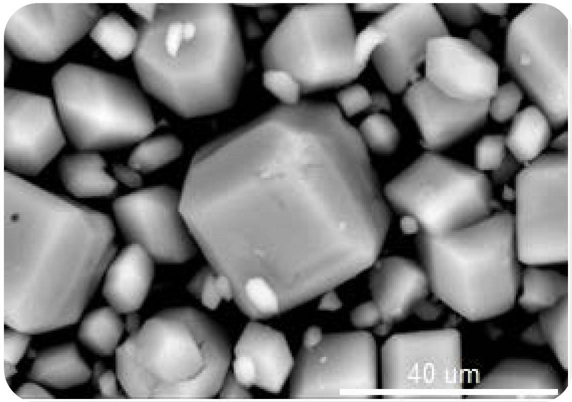
Cooling water
100W * 3600s/hr =
34,560 kJ (9.6 kW-hrs)
96 hr, 24 kW-hrs

Hydrogen peroxide
(60 wt%) 46.7 kJ/mol @
265 psia, 200°C
1264.2 mol
34.9 kg

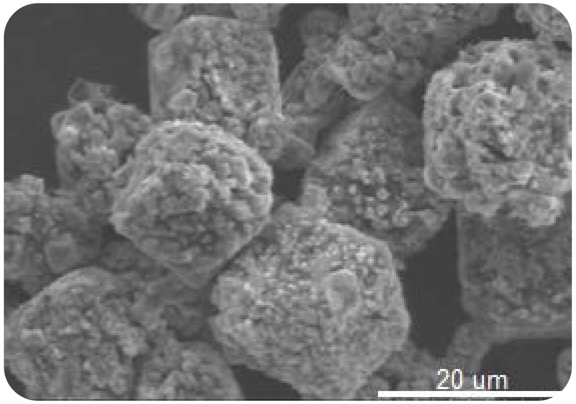
O_2 gas
279.8 mol
8.95 kg

By-product water ~200°C
1264.2 mol
22.78 kg
59038.1 kJ (16 kW-hrs)

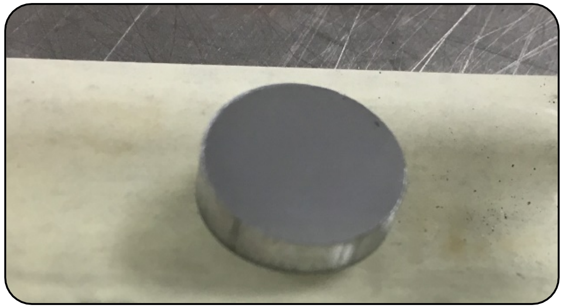
Accomplishments: Expansion/Contraction Effect for Alane



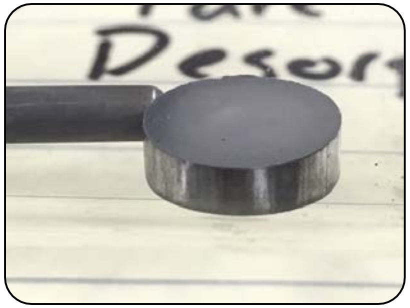
ATK alane before desorption



ATK alane after desorption



ATK alane pellet before desorption

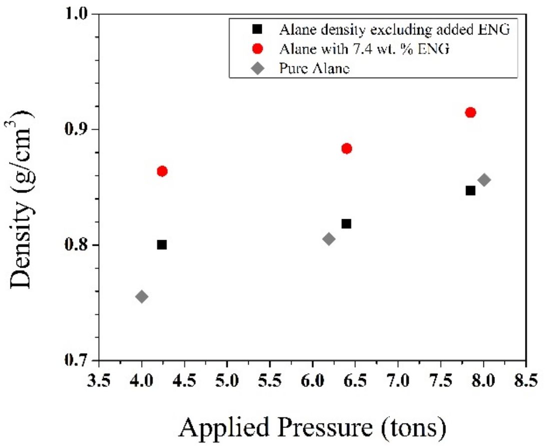


ATK alane pellet after desorption

- Decomposition of alane results in the formation of particles which retain original shape but consist of nanoparticles of aluminum
- The expansion of material during desorption was evaluated
- Expansion could cause excessive pressure on vessel wall whereas contraction could result in decreased thermal contact
- No observable expansion or contraction observed in pelletized ATK alane

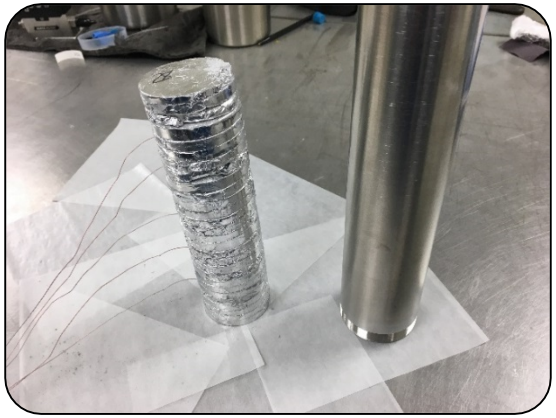
Accomplishments: Alane Thermal Conductivity Enhancements

- Enhanced thermal conductivity required to efficiently transport heat and improve system performance

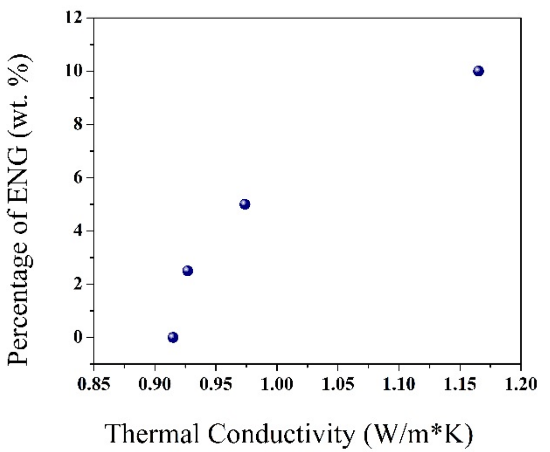


Density of 35 mm pellet of alane with and without ENG

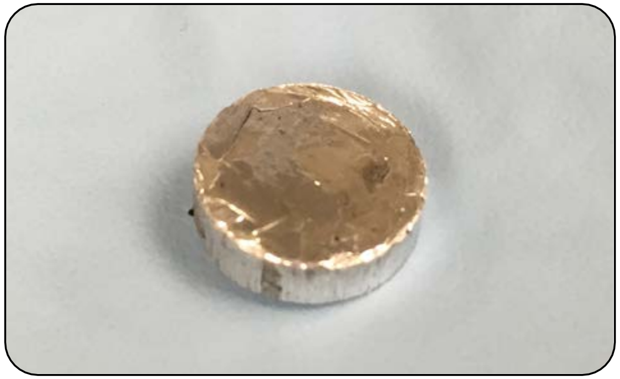
Aluminum foil coated 50 mm alane pellets



Aluminum foil coated 50 mm alane pellet stack with thermocouples



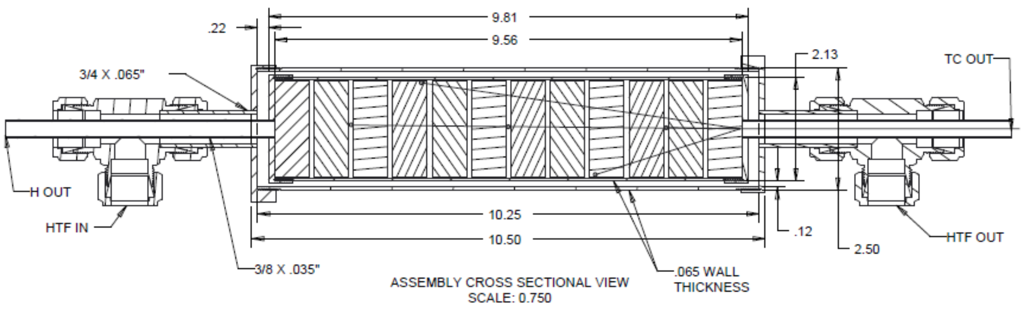
Thermal Conductivity of Alane with the addition of Expanded Natural Graphite (ENG)



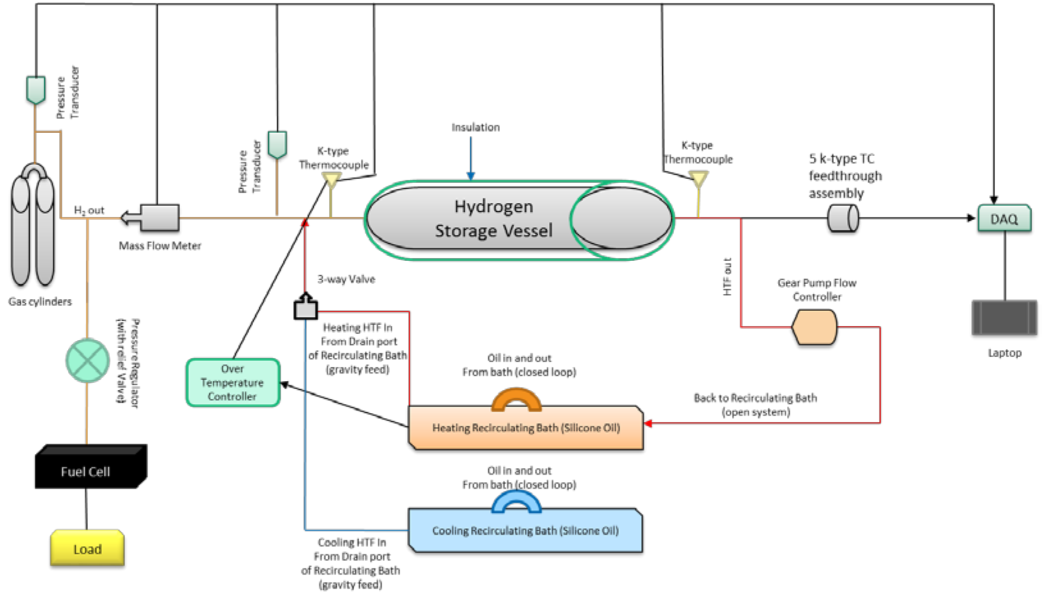
Aluminum foil coated 10 mm alane pellet after full hydrogen desorption

Aluminum foil coated 50 mm alane pellets after full hydrogen desorption from demonstration vessel

Accomplishments: Confined Alane Power System Design and Construction



Alane storage vessel utilized to illustrate practical conditions



System design for confined alane vessel demonstration

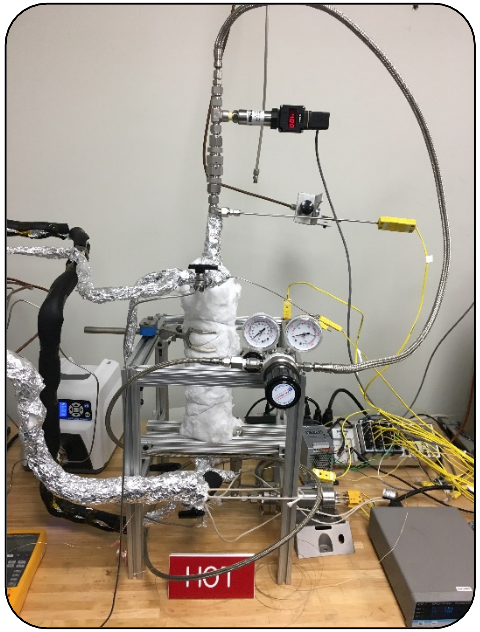
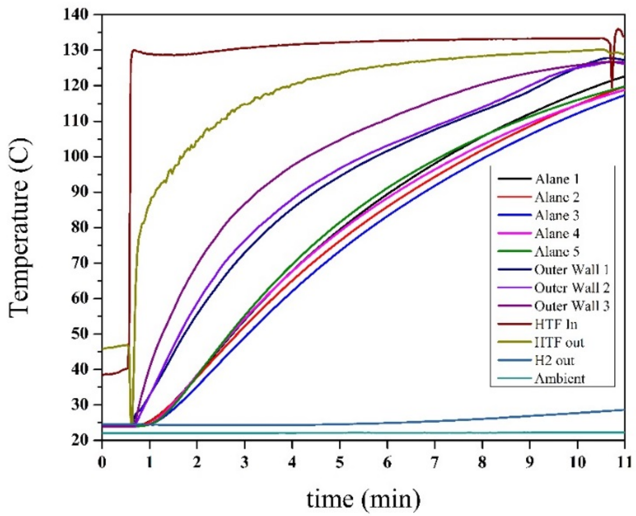


Image of alane vessel demonstration system

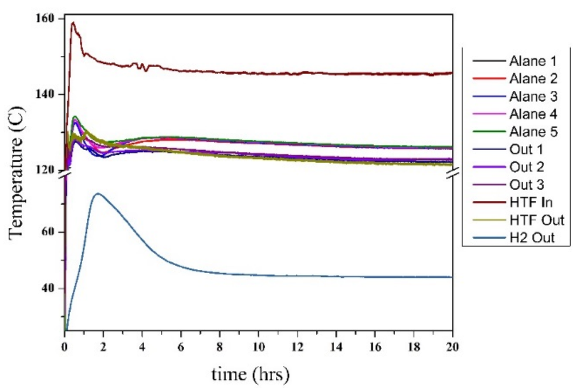
Gear pump used to simulate heat transfer fluid flow rates

Accomplishments: System Preheat Testing

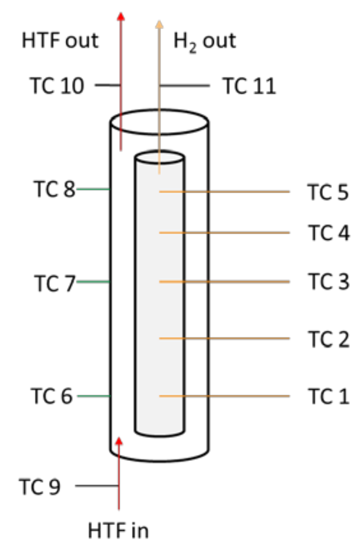
- Preheating of vessel "on board" was evaluated to increase efficiency of operation
- Simulated preheating experiment in confined alane vessel design determined to exceed desorption temperatures of alane (> 80 °C)
- Test confirms that "on board" preheating can be accomplished in the targeted 10 minute timeframe



10 minute simulated "on-board" system preheating



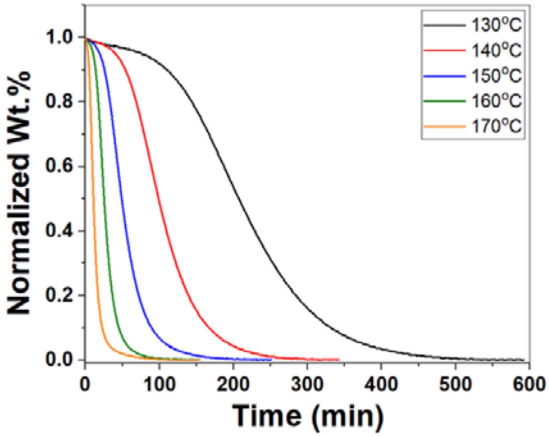
Temperature Profile over alane reaction vessel demonstration



TC 12 = ambient temperature

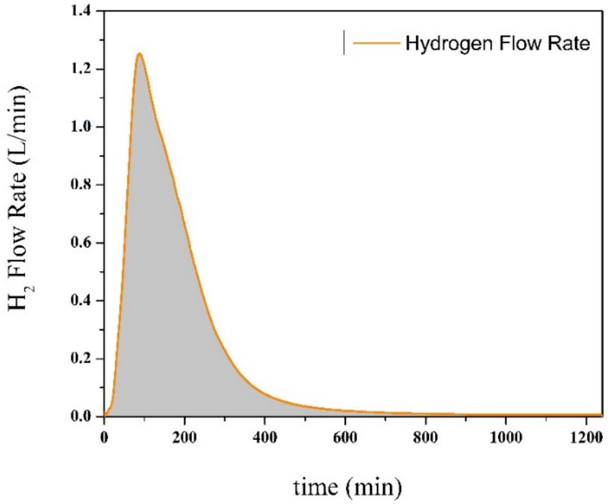
Thermocouple placement diagram

Accomplishments: Hydrogen Release Kinetics

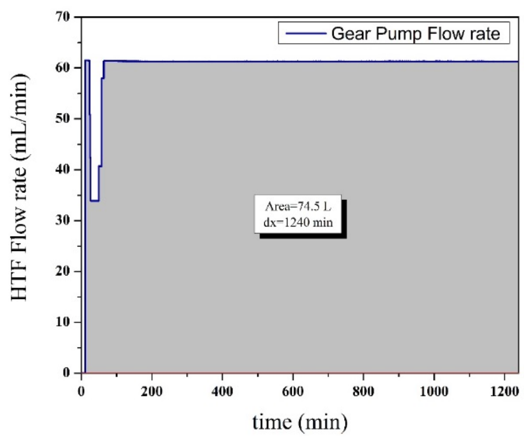


Isothermal desorption of alane at various temperature (TGA method)

Kinetics of SRNL alane were evaluated for system modeling and heat management



Hydrogen release profile during demonstration



Silicone HTF flow profile during operational conditions demonstration

- 74.5 L of P90 silicone oil used during the experiment to desorb hydrogen from 235 g of alane over 20.7 hours
- Assuming the same ΔT for H_2O, this would correspond to <u>12.9 L</u> of H_2O with no phase change.
- Assuming a 20 % (by mass) phase change of H_2O, this would correspond to <u>3.65 L</u> of H_2O
- This demonstration confirms lower than initially predicted operational temperatures can be utilized for 2x operational time and with appropriate insulation the quantity of heat transfer fluid is adequate

Summary

- Completed an engineering analysis to screen the most attractive solid-state hydrogen storage materials for UUV applications
- Alane (AlH_3) was selected as the most attractive candidate
- Demonstration unit developed with control over flow rate of heat transfer fluid and appropriate alane and heat exchanger volume ratios
- Experiments verified that alane expansion/contraction will not be a problem for the system design.
- Preliminary analyses indicate that alane can provide a feasible material which can utilize heat generated from the peroxide system to provide ***2 times the energy storage compared to battery systems***
- Greater control over alane particle size during crystallization can led to slight reductions in operational temperatures

Results confirm that an alane-based UUV power system is capable of increasing system performance over currently available systems in a safe and efficient manner

Collaborations and Presentations

Naval Undersea Warfare Center (Newport)

- UUV Energy System Integrator
- End-user and System Tester/Evaluator

Office of Naval Research

- Sponsor

Acknowledgments

Christian Schumacher (NUWC)
Dr. Joseph Fontaine (NUWC)
Craig Urian (NUWC)
Michael Brown (SRNL)
Dr. Joseph Teprovich (California State University Northridge)

Presentations:

Teprovich J. et al, “ONR Undersea Power and Energy Program Review,” Arlington, VA, March 28–30, 2017.
Teprovich J. et al, “Investigation of Solid State Hydrides For Autonomous Fuel Cell Vehicles,” Washington D.C. June, 2017.

Remaining Challenges and Barriers

- Capability of producing large scale quantities of alane for full scale system testing
- Make further weight reductions to the overall system design to maintain neutral buoyancy
- Provide insulation solutions which reduce heat loss to surroundings

UUV operations off the coast of Bahrain in 2013. Credit: Specialist 2nd Class Michael Scichilone/US Navy/Released

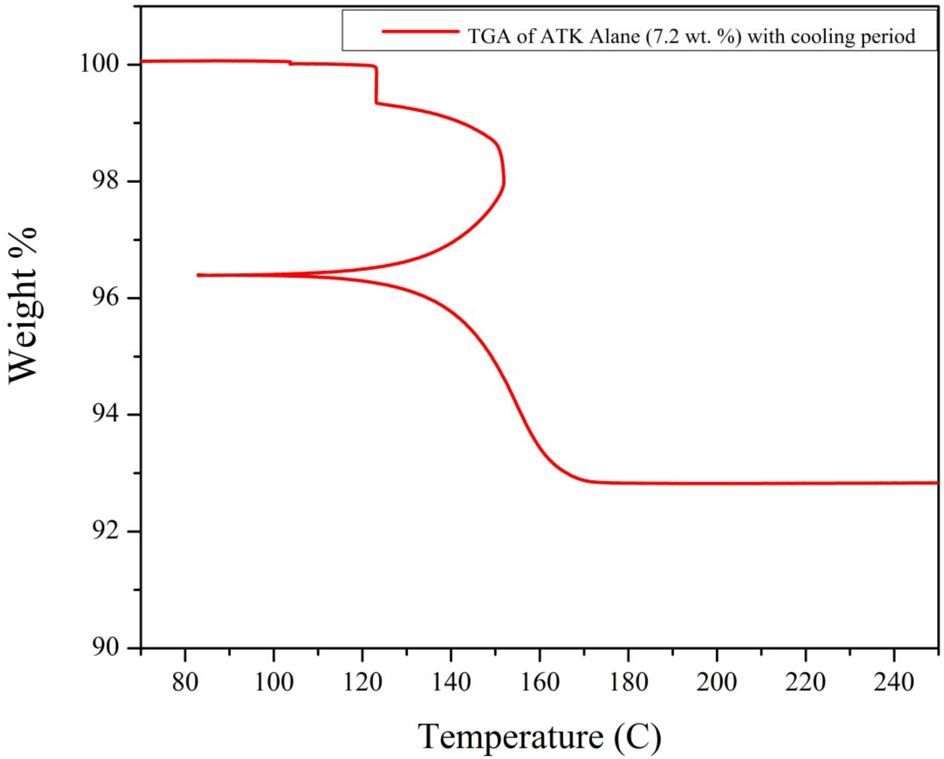
Proposed Future Work

- Efficiently integrating alane-based hydrogen storage vessel design with fuel cell, hydrogen generator (hydrogen peroxide) and BOP
- Meeting system volume and weight requirements to meet Navy UUV specifications and maintaining neutral buoyancy and achieving all performance objectives
- Supporting the Navy to provide a suitable cost supply of alane to meet future missions and applications
- Developing detailed system models to accurately describe heat transfer and hydrogen release kinetics under various operational conditions for a full scale system

Any proposed future work is subject to change based on funding levels.

Technical Backup Slides

Evaluation of Reaction Start/Stop Conditions



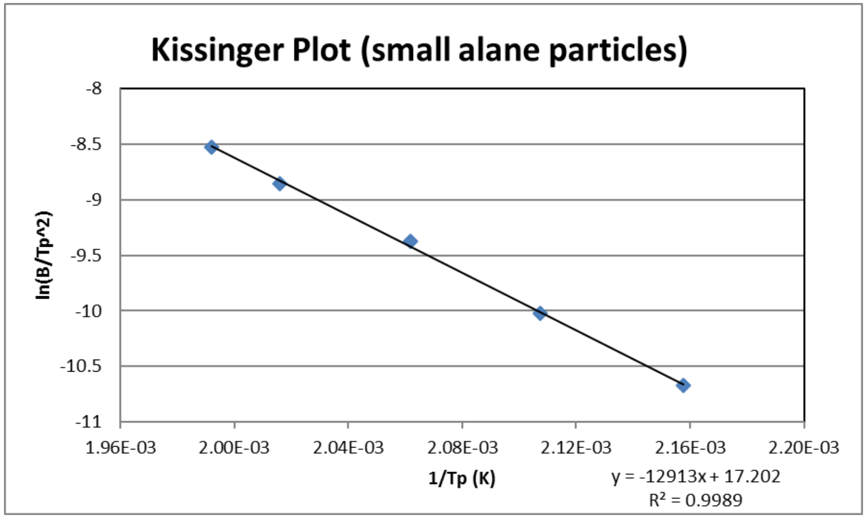
TGA of ATK α-Alane with 7.2 wt. % H_2 capacity

Heating Conditions:

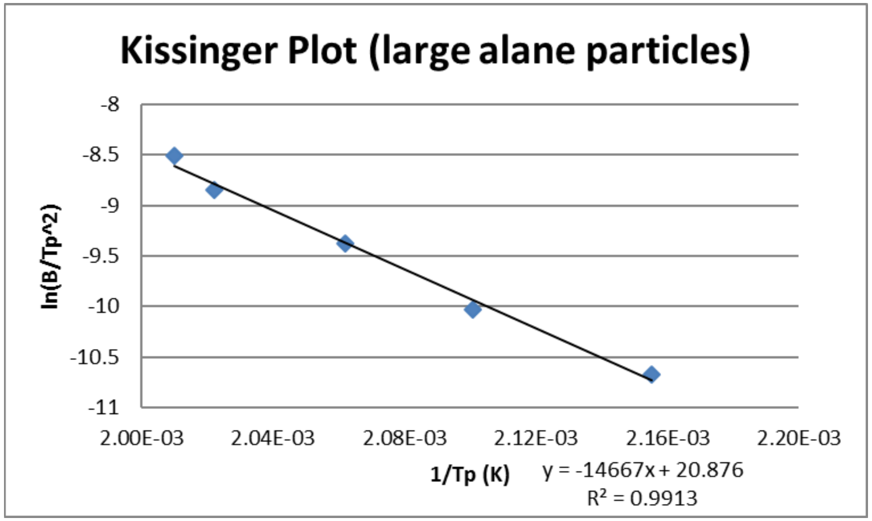
1) Heating Ramp 30°C to 100°C at 1°C/min
2) Isothermal at 100°C for 10 minutes
3) Heating Ramp 100°C to 120°C at 5 °C/min
4) Isothermal at 120 °C for 10 minutes
5) Heating Ramp 120°C to 150°C at 10°C/min
6) Isothermal at 150°C for 1 minute
7) Cooling Ramp 150°C to 80°C at 10°C/min
8) Isothermal at 80°C for 10 minutes
9) Heating Ramp 80°C to 300°C at 5°C/min

Perkin Elmer Pyris 1 Thermogravimetric Analyzer

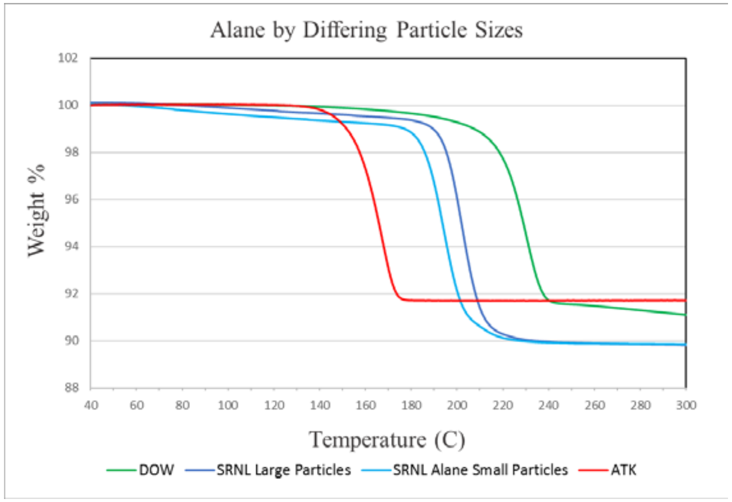
Evaluation of Particle Size Effects



Activation Energy (small) = 107 kJ/mol



Activation Energy (large) = 122 kJ/mol



Activation Energy (small) = 107 kJ/mol