U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – C5ISR CENTER

Aluminum Hydride Title III Project

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The BUZZ About ALANE

WHY ALANE ?

Different materials available for energy storage

Technology	EDAB	NH3 Borane	Na Silicide	Na Borohydride
Fuel Energy Density (Wh/kg)	3697	6722	3025	7058
Cartridge (Wh/kg)	490	800	133	587
Comments	Pentaborane byproduct	Ammonia byproduct	Low energy density	Difficult reaction control

Selected Alane (AlH_3) based on high energy density, high H_2 product purity and H_2 generation process

$$2AlH_3 \xrightarrow{\Delta} 2Al + 3H_2$$

$\Delta H = 6.6$ kJ/mol H_2

With commercial partner have developed AlH_3 systems that are promising

Technology	RMFC	DMFC	AlH3
Fuel Energy Density (Wh/kg)	2907	5538	3361
Cartridge Wh/kg	485	780	800
System Power Density (W/kg)	22	13	29
System Vol. Power Density (W/l)	23	11	32
TRL	TRL 8	TRL 8	TRL 6

T. Thampan, D. Shah, C. Cook, J. Novoa, S. Shah, J. Power Sources 259 (2014) 276-281

ALANE APPLICATIONS
Soldier

A LITTLE BIT OF HISTORY ………

DEVCOM CSISR CENTER

2010

Cartridge energy remaining

Power output

AlH_3 cartridge compartment

12.4 cm

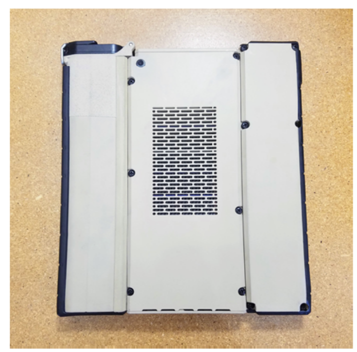
13.2 cm

Cartridge

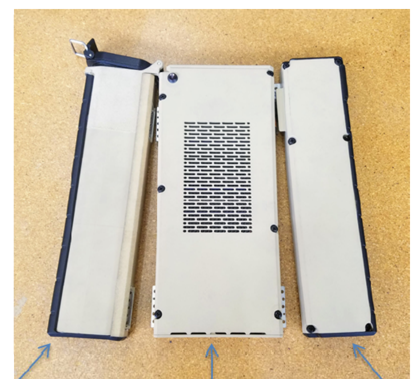
3.4 cm

7.0 cm

Volume: 62 cm^3
Weight: 68 g
ED: ~800Wh/kg



Fully integrated System
Dry Weight: 967 g



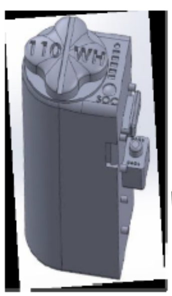
Reaction Chamber: 295 g

Fuel Cell System: 310 g (Fuel cell: 109 g)

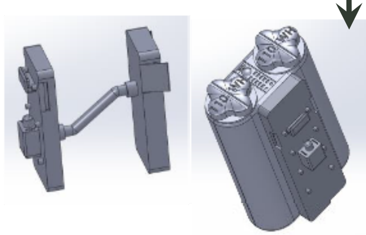
Battery Chamber

Fuel Cell System

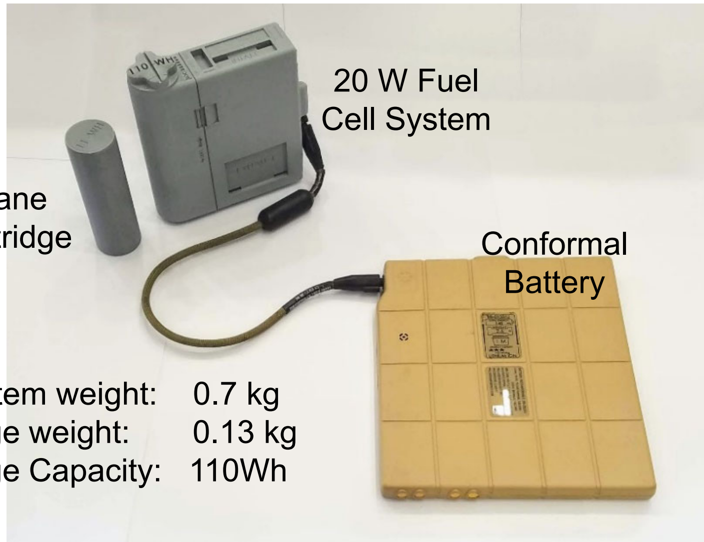
NOW



Cartridge Options



ARDICA 20 W RIF PROGRAM WEARABLE RANGE EXTENDER



FC System weight: 0.7 kg
Cartridge weight: 0.13 kg
Cartridge Capacity: 110Wh

Contribution to the Requirement

- Lightweight, wearable, fuel cell power generator, reduces Soldier Load compared to CWBs alone
- Works in conjunction with CWB to keep the CWB at high State of Charge (SOC) and extend battery runtime
- Designed to communicate with ISPDS, ISPDS-C, SPM, and NETT WARRIOR to augment Small Unit Power solutions
- Transition (Existing Military System, Program or Capability)
  - PM SWAR can field units to augment CWB, power hubs, and NETT WARRIOR
  - Alane Power Systems for Wearable, TARDEC Vehicle, and UAS power
- Anticipated TRL: 5/6

Technical Approach/Qualifications

Project Objectives and Scope:

- Operate as a battery charger for the CWB
- Maintain Conformal Wearable Battery (CWB) SOC while passing battery power through to the user
- Round form factor cartridges for decreased cost and increased capacity compared to Wearable Power System (WPS)

Key Personnel, Facilities / Equipment

- Dr. Tibor Fabian, Daniel Braithwaite: Ardica team leaders
- Ardica lab contains all equipment required for systems dev

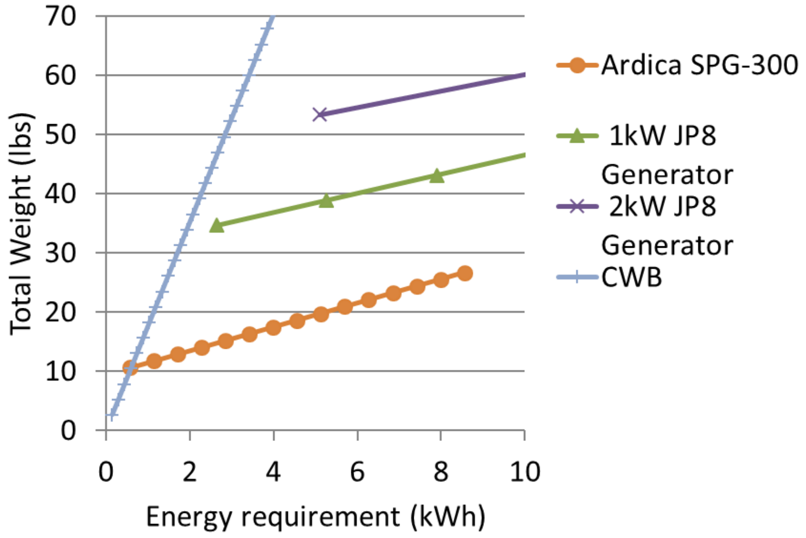
Related Prior or Current Work:

- Ardica Wearable Power System (WPS)
  - Field Testing at AEWE 2016
  - Revised prototypes delivered Dec 2018
- Ardica 300W Squad Power Generator

Potential Risks

- Unexpected delays due to integration into new form factor
- Compatibility with power hubs depends on all components compliance with Smart Battery charging specification
- Output power capabilities subject to limitations of combined CWB and Fuel Cell during start-up

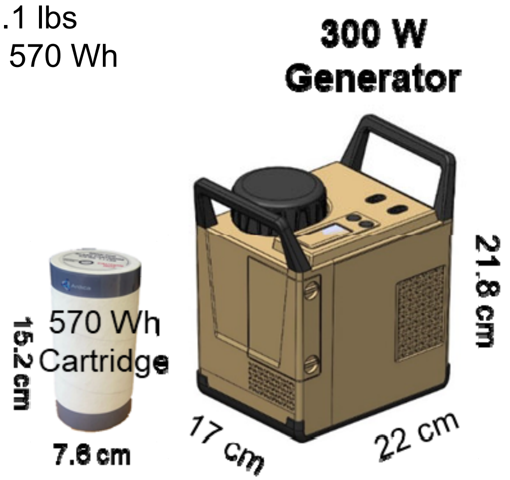
ARDICA 300 W GENERATOR – POWER TO RECHARGE ARMY MOBILE BATTERIES



Contribution to the Requirement

- Lightweight, nearly silent, no toxic emissions, fuel cell squad power generator, fulfills energy gap for Soldier missions compared to CWBs alone
- Works in conjunction with Universal Battery Charger (UBC) to charge CWBs using lightweight solid-state fuel cartridges
- Transition (Existing Military System, Program or Capability)
  - Squad/Platoon Power – Battery Charging requirement
  - Auxiliary power for silent watch capability on vehicles or other unmanned platforms
  - Alane Power Systems for Wearable, TARDEC Vehicle, and UAS power
- Anticipated TRL: 5

System weight: 9.6 lbs
Cartridge weight: 1.1 lbs
Cartridge capacity: 570 Wh



Technical Approach/Qualifications

Project Objectives and Scope:

- Design an Alane-fueled 300 W fuel cell power generator
- Assemble and test the operation of the 300 W generator when used in conjunction with a UBC to recharge mobile batteries
- Significant reduction in weight for soldier operations compared to other energy sources

Key Personnel, Facilities / Equipment

- Dr. Jeffrey Mishler, Daniel Braithwaite: Ardica team leaders
- Ardica lab contains all equipment required for systems dev
- Shailesh Shah/Tony Deanni/Kevin Chu

Related Prior or Current Work:

- Ardica Wearable Power System (WPS)
  - Field Testing at AEWE 2016
  - Revised prototypes delivered Dec 2018
- Alane Hydrogen Storage for an ATV (with TARDEC).
  - SBIR Phase I (2017-2018)
  - SBIR Phase II (2019-2021)

ALANE APPLICATIONS
Unmanned Ground Vehicles

Use Cases and Estimated Alane Demand

Platform	# Vehicles	H2/vehicle (kg)	Total kg AlH_3/day	MT AlH_3/year
SMET	100	10	10,204	3,724
GMV	300	15	45,918	16,760
RCV	100	60	61,224	22,347
Total			117,346	**42,832**

Squad Multi-pupose Equipment Transport

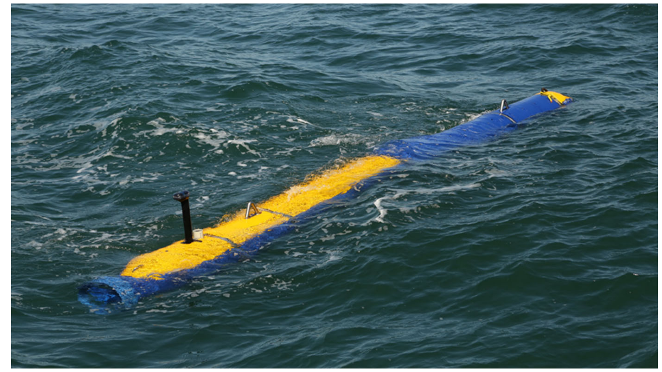
Ground Mobility Vehicle

Robotic Combat Vehicle

ALANE APPLICATIONS
Unmanned Underwater Vehicles

USE CASE – REMUS 600

Remus 600



Knifefish UUV

REMUS 600	Initial Prototyping	Prototype sea trials	Initial Ops	Deployed Ops	Total
Alane Demand	12 Kg	1.2 MT	56 MT	112 MT	169 MT/yr

POTENTIAL CUMULATIVE ALANE DEMAND

Platform	# Systems Planned	Alane/System/yr	Total Annual Alane
20 W Wearable	26, 000	20 kg	520 MT
15 kW - SMET	100	37,240 kg	3,724 MT
250 W - REMUS 600	50	2, 232 kg	112 MT
TOTAL POTENTIAL DEMAND			> 4000 MT

MIND BOGGLING - DEMAND

ALANE MANUFACTURING PROCESS

CHEMISTRY

Brower Petrie Process

Reactor

$$3\ LiAlH_4 + AlCl_3 \xrightarrow[Et_2O]{} 4AlH_3\cdot Et_2O\ (Complex) + 3LiCl\downarrow + LiAlH_4$$

Recrystallization Reactor

$$AlH_3\cdot Et_2O\ (Complex) \xrightarrow[Toluene]{Et_2O\ (g)\uparrow} AlH_3\ (polymeric\ crystalline\ product)$$

(transferred from reactor)

SRI Process

$$NaAlH_4 + LiCl \xrightarrow{THF} LiAlH_4\ (LAH) + NaCl(s)$$

$$4LAH + AlCl_3 + 4Et_2O \longrightarrow 4AlH_3 \bullet Et_2O + LiAlH_4(s) + 3LiCl(s)$$

$$AlH_3 \bullet Et_2O \xrightarrow[Heat]{LAH,\ toluene} \alpha\text{-}AlH_3 + Et_2O(g)$$

PLANT PROCESS STEPS

SRI Process

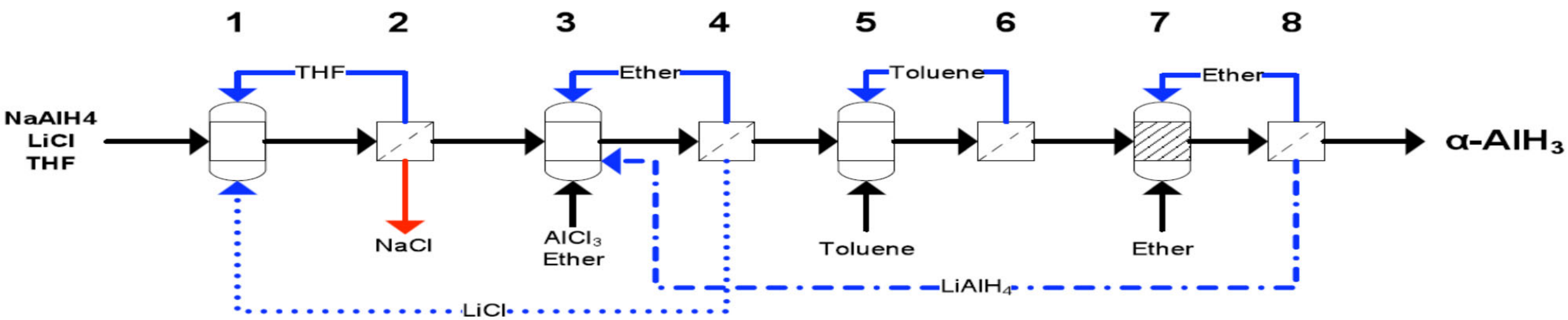
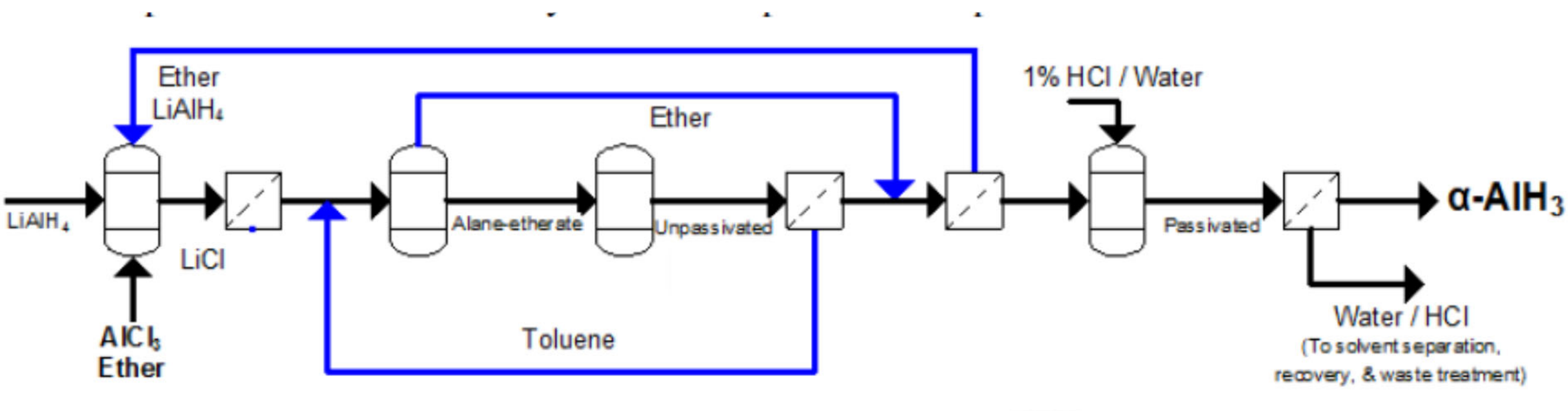


Figure 1. α-AlH$_3$ process diagram

Brower Petrie Process



COST MODELLING

- Highly dependent on Raw Material Costs – potentially > 50% of total manufacturing cost could be raw materials – $LiAlH_4$ cost is key

- High Labor content for small lab scale manufacturing can be addressed by large scale batch or continuous processes

- Target cost must be competitive with rechargeable battery costs which are < $ 0.10/cycle/watt-hour

- $ 1000/kg cost for alane translates to ~ $ 1.00/Wh for portable applications

THE STORY ON ALANE

- There is no current manufacturer of Alane in the US
- Fuel Cell grade Alane process has been demonstrated at a laboratory scale of ~ 200 g/batch
- Data is needed to determine accurate Capital, Raw Material, Energy and Labor costs estimates for a multi MT/year Alane plant
- There is a significant market potential for Alane for Military Applications
- Steady initial quantity supply of Alane is required to stimulate military market demand