



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

Aluminum Hydride Title III Project

Shailesh Shah
Chemical Engineer
CP&I Directorate, Power Division

Distribution Statement A

Approved for Public Release,
Distribution is Unlimited



The BUZZ About ALANE

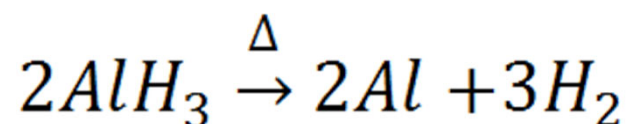


WHY ALANE ?



Different materials available for energy storage

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



$$\Delta H = 6.6 \text{ kJ/mol H}_2$$

With commercial partner have developed AlH_3 systems that are promising

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

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



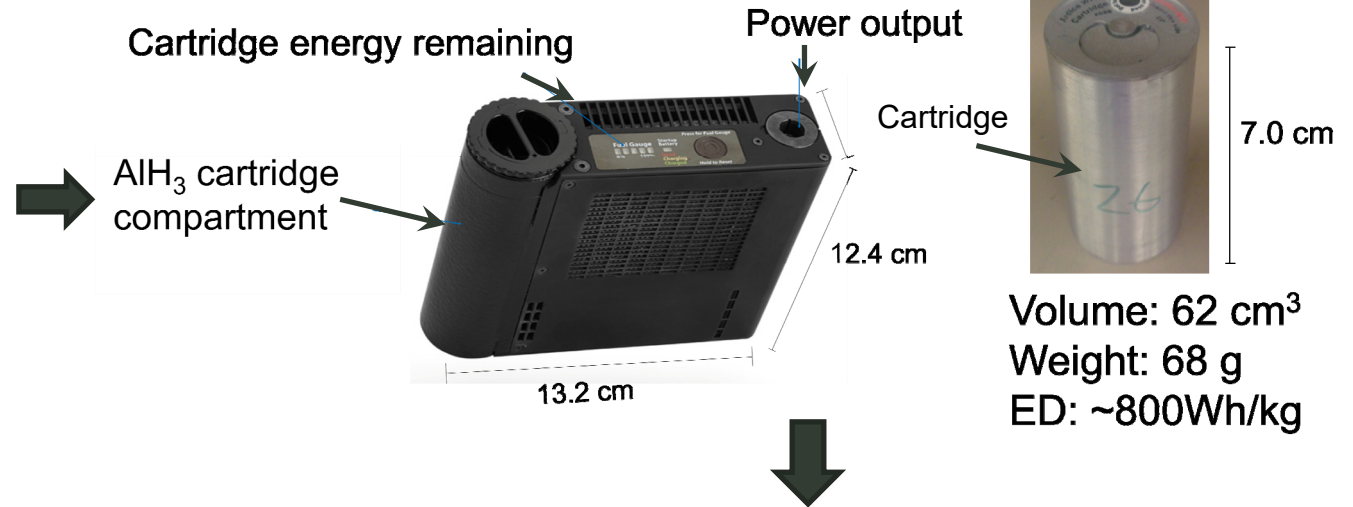
ALANE APPLICATIONS Soldier



A LITTLE BIT OF HISTORY

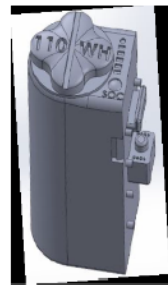


2010

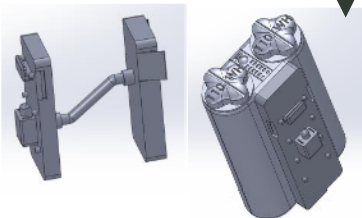


Fuel Cell System

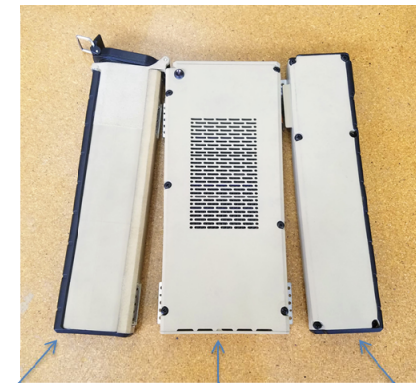
NOW



Cartridge Options



Fully integrated System
Dry Weight: 967 g



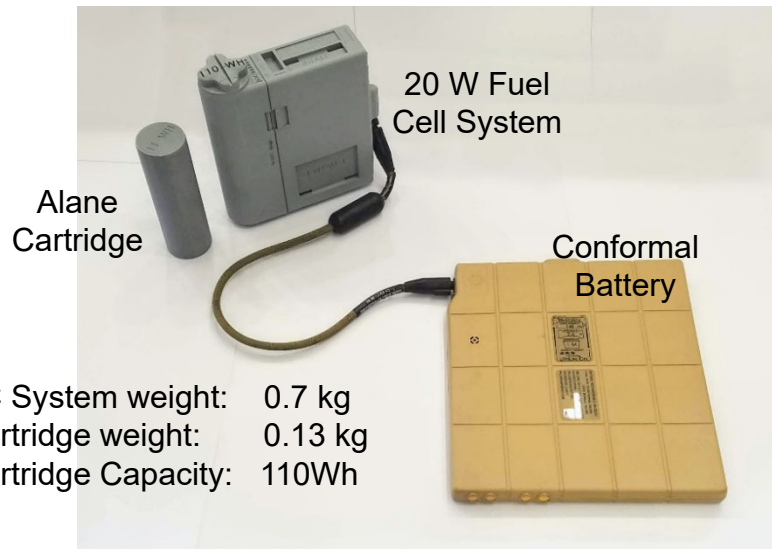
Reaction Chamber: 295 g

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

Battery Chamber



ARDICA 20 W RIF PROGRAM WEARABLE RANGE EXTENDER



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:

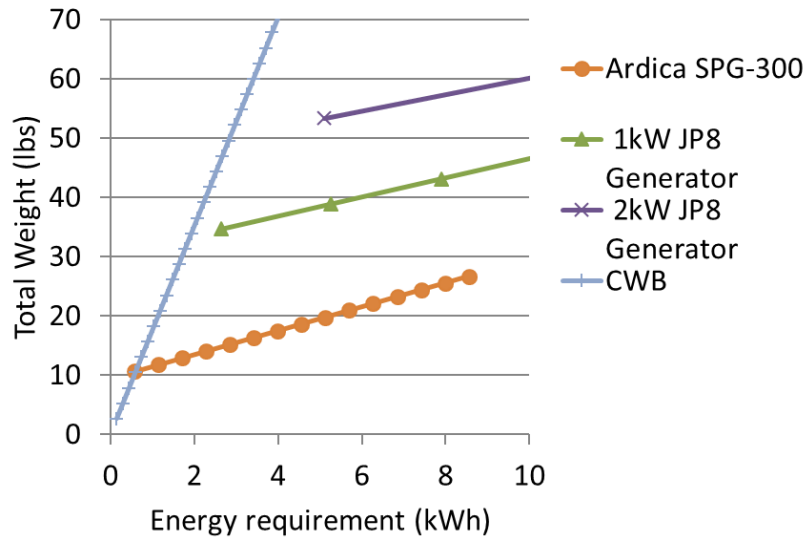
- Ardica Wearable Power System (WPS)
 - Field Testing at AEWE 2016
 - Revised prototypes delivered Dec 2018
- Ardica 300W Squad Power Generator

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



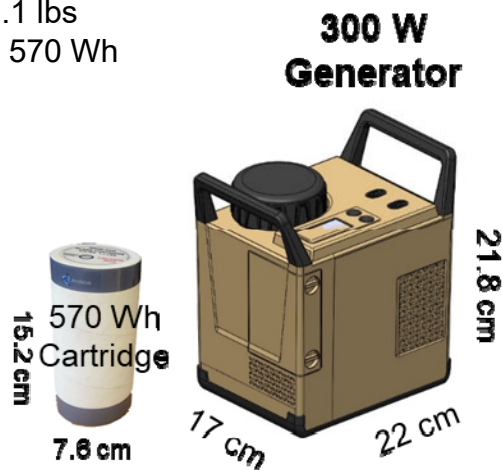
ARDICA 300 W GENERATOR – POWER TO RECHARGE ARMY MOBILE BATTERIES



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	H ₂ /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-purpose
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

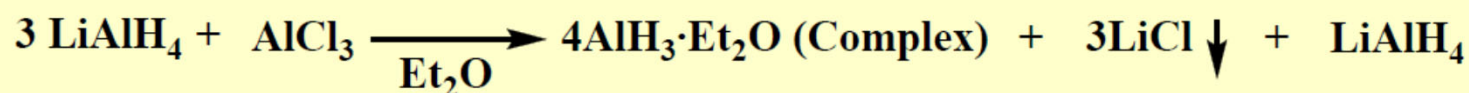


CHEMISTRY

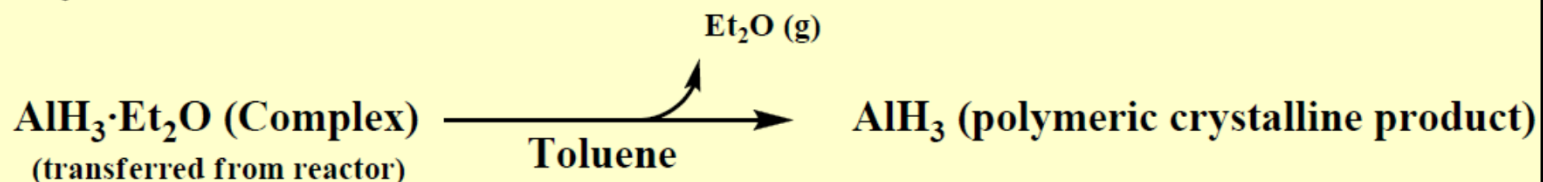


Brower Petrie Process

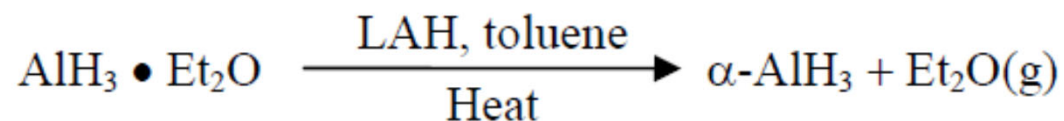
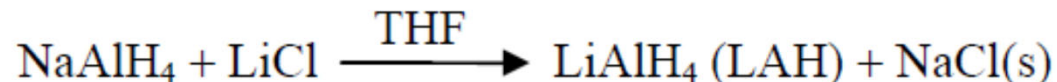
Reactor



Recrystallization Reactor



SRI Process





PLANT PROCESS STEPS



SRI Process

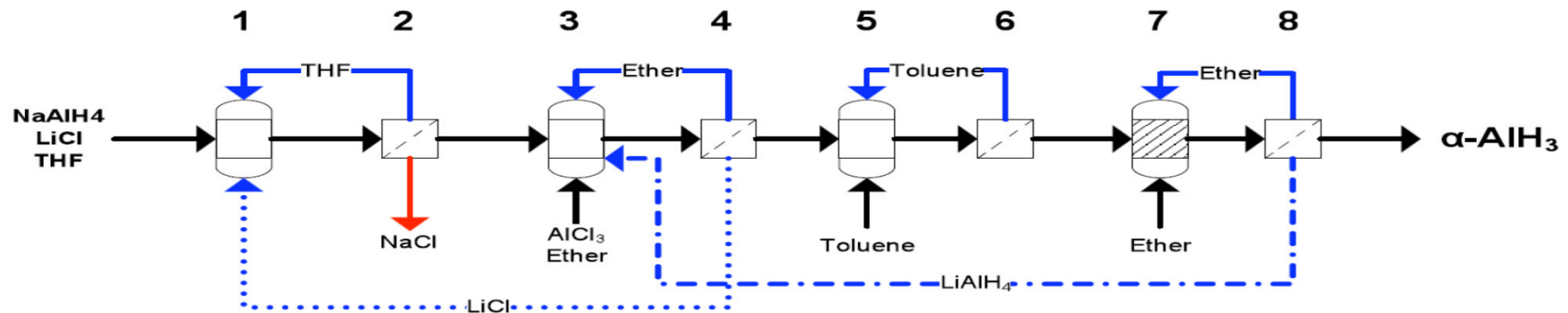
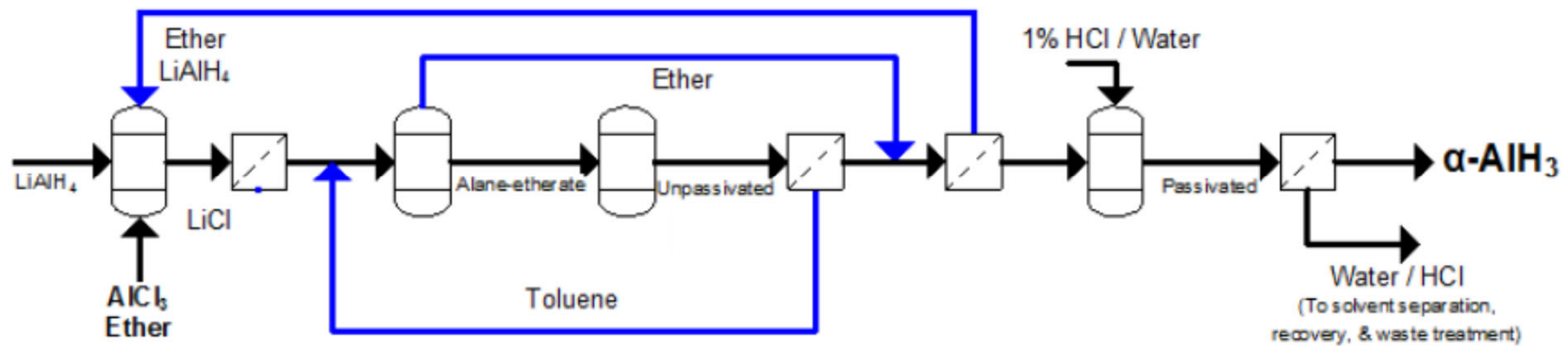


Figure 1. $\alpha\text{-AlH}_3$ process diagram

Brower Petrie Process





COST MODELLING



- **Highly dependent on Raw Material Costs – potentially > 50% of total manufacturing cost could be raw materials – LiAlH₄ 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