Freedom from the Grid

Alane – Aluminum Hydride for Fuel Cell Power
NDIA Power Sources Committee Meeting June 21, 2017

Energy technology is failing our modern world

- The world is increasingly reliant on powered devices
- We expect ***energy continuity*** - our power to be there on-demand, without limitation or negative impact
- We *only* accept poor power options because the alternative is to self-limit our device usage
- What we really require are clean, efficient energy solutions that have truly outstanding performance
- Current power technologies are **heavy**, **toxic and unsuited** for maximizing use of most devices
- A substantial opportunity exists for ***lighter*** energy solutions with superior ***efficiency***, ***stability*** and ***sustainability***
- To accomplish this, a **superior** fuel must be employed

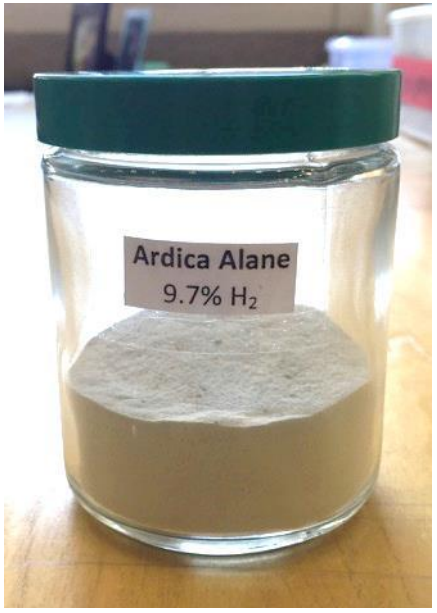
Ardica – Revolutionary energy to meet growing demands

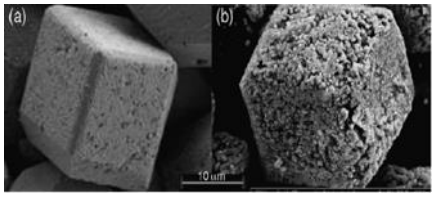
Ardica relentlessly focuses on building efficient, stable energy systems that greatly enhance the utility and range of all devices

- Built on **Alane** (aluminum hydride), produced through a patented Ardica process, and acknowledged by energy experts to be one of the most versatile **fuels** ever made
- Continued, growing U.S. government support (DoD, DoE)
- Strong team, board, and partner ecosystem
- Extensive expertise and IP portfolio around producing Alane at volume and at low cost
- Commercializing now

Alane – An ideal, *available* fuel for our energy needs

- **Alane**, or Aluminum hydride, is a well-studied solid-state hydrogen fuel
- Extremely **lightweight**
- **Superior** energy density: 2-5x better than other fuels
- **Reliable**
- **Non-explosive** during storage and use
- **Recyclable**
- **Non-toxic** (aluminum, water vapor by-products)
- **Easy to transport**
- **Long shelf life** - lasts for decades with minimal decline
- **Highly-regarded** by DoE, U.S. National Labs, and international energy experts

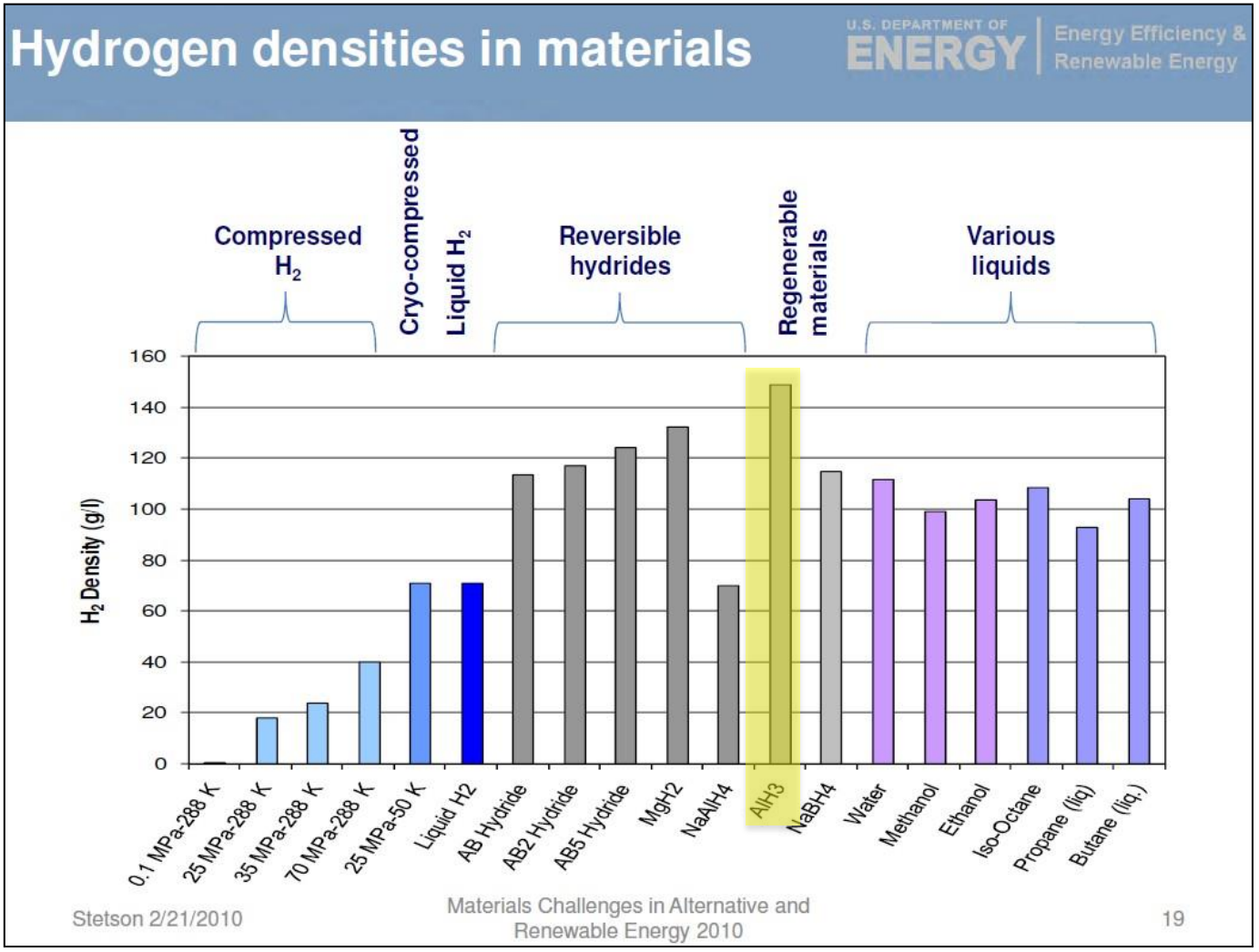




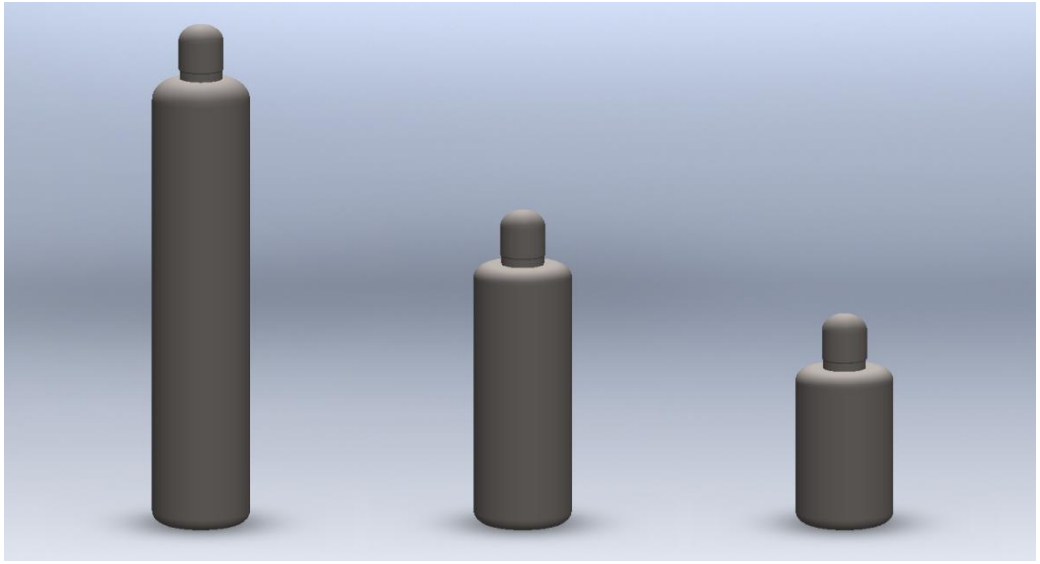
Alane Properties

Property	Value	Note
Crystalline polymorph	Alpha [α-AlH_3]	Most stable phase, practical applications
Decomposition Reaction	$\alpha\text{-}AlH_3 \xrightarrow{heat} Al + \frac{3}{2}H_2$	Single step
Heat of Reaction	-7 kJ/mol H_2	Mildly endothermic, inherent safety
Decomposition Temperature	140°C - 180°C	Typical for practical release rates
Density	1.477 g/cm^3	Crystalline basis
Volumetric Hydrogen Content	148 gH_2/L	Crystalline basis
Gravimetric Hydrogen Content	10.1% gH_2/g	Crystalline basis
Energy Density	2,763 Wh/L 1,867 Wh/kg	Assumes fuel cell conversion at 0.7 V

Alane Highly Rated by the Department of Energy



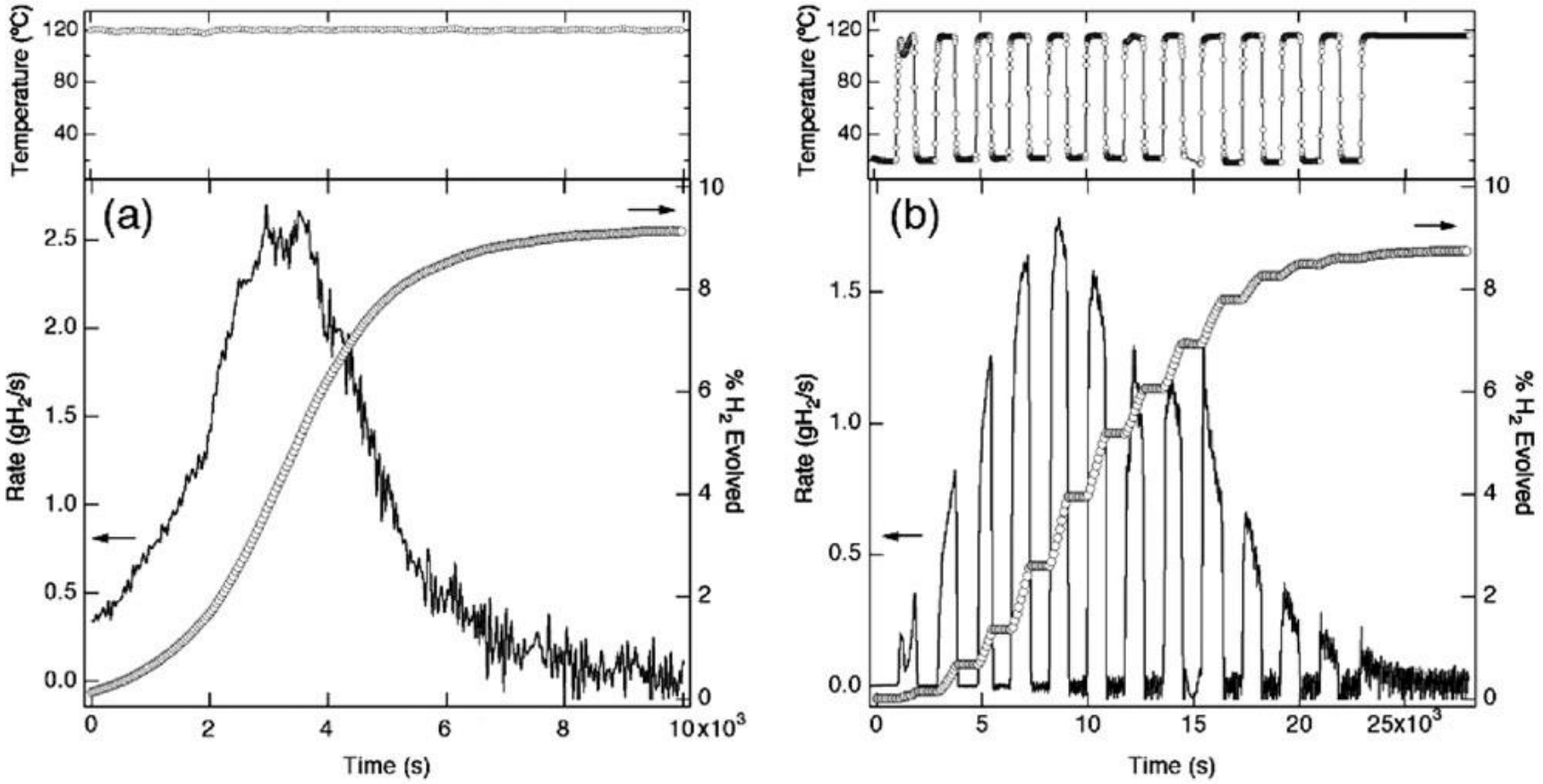
Alane vs. other hydrogen storage



Energy-rich, compact, lightweight, safe:

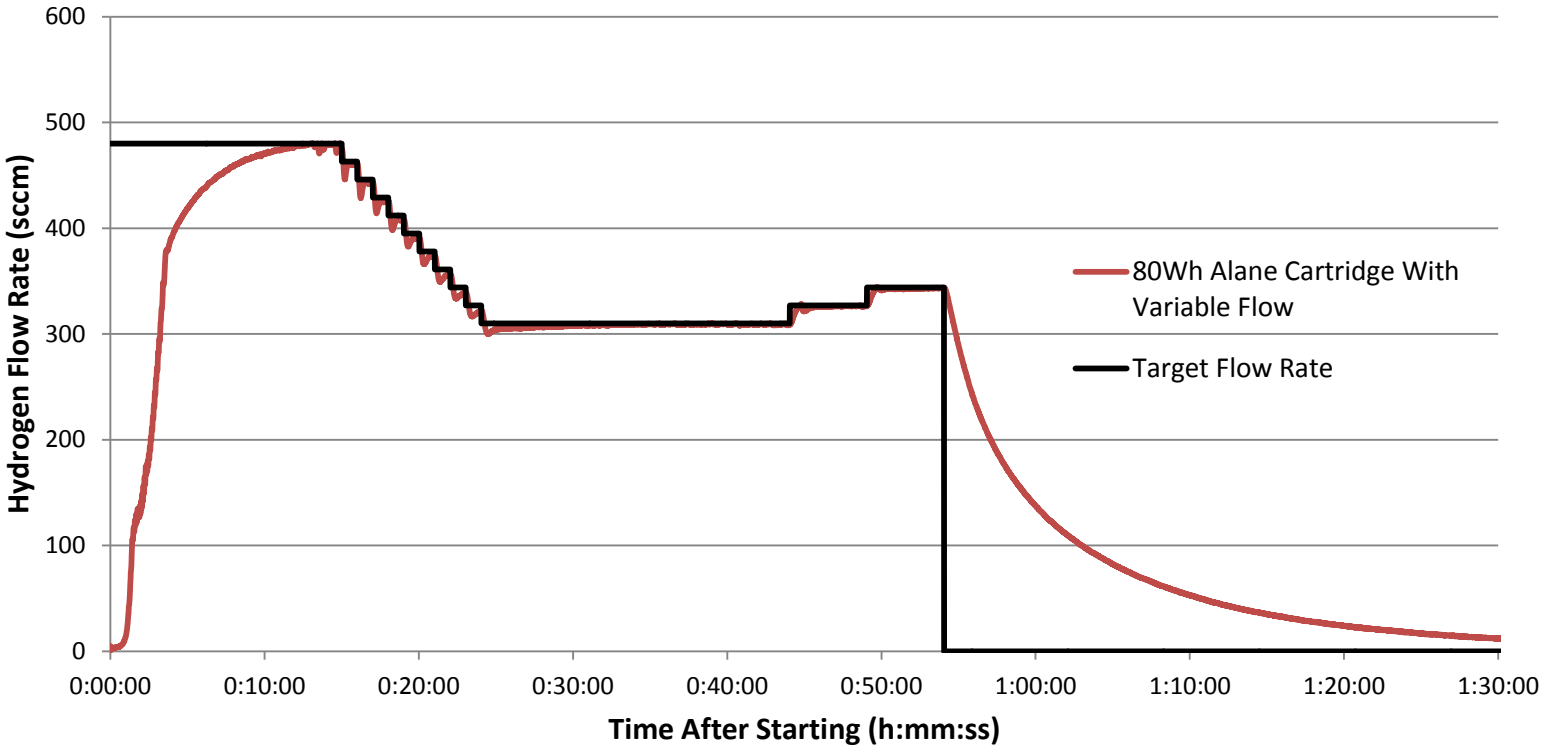
	Industrial Compressed Gas	Composite Tank Compressed Gas	Metal Hydride	Alane
Weight	**136 lbs**	33 lbs	**43 lbs**	**15 lbs**
Volume	**50 L**	37 L	19 L	**6 L**
Pressure	2400 psi	**4351 psi**	1450 psi	**0 psi**
Wt % H2	1.1%	4.5%	3.4%	**9.8%**
Total H2	670 g	670 g	670 g	670 g
Note	Heavy, Pressurized, Bulky and Flammable	Highest Pressure, and Flammable	Small, but Heavy for its size	No Pressure, Lightweight, Compact, and Safe

Alane Dehydrogenation in a Systems Context



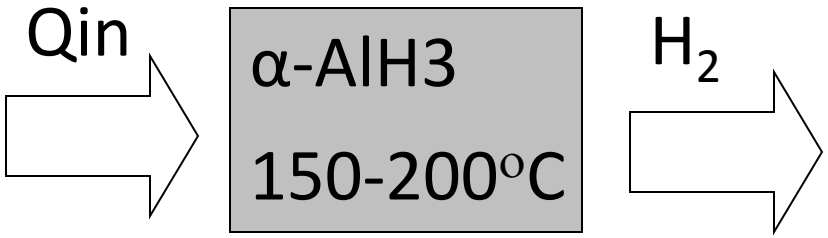
J. Graetz, "New approaches to hydrogen storage," Chem. Soc. Rev., vol. 38, no. 1, pp. 73–82, 2009

Fuel Cartridge Controllability



- On-demand H_2 generation with start-stop capability
- Orientation independent operation
- Simple, solid-state cartridge
- Highly controllable hydrogen release rate

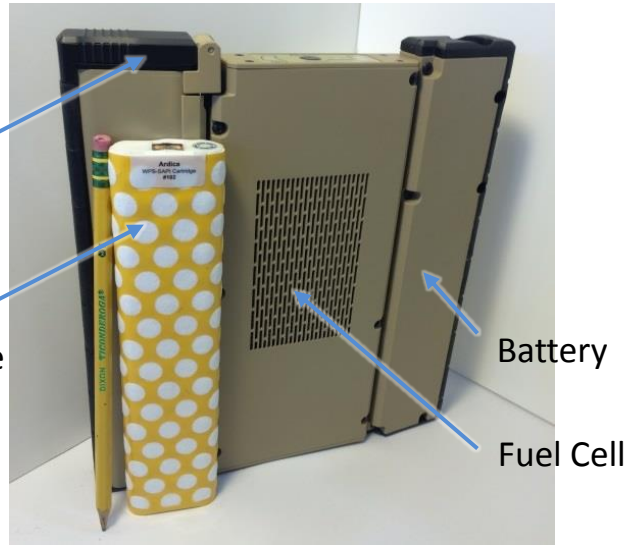
Alane Decomposition Energy

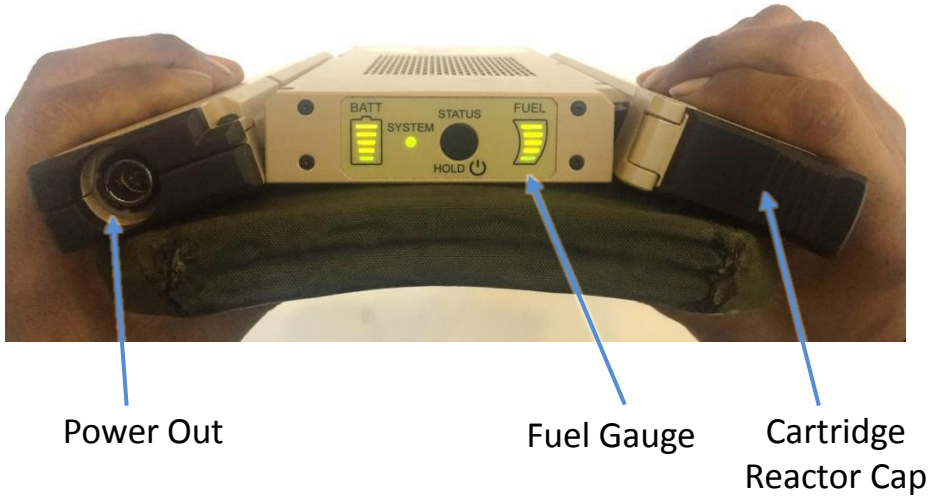


- Qin = Qsens + Qloss + Qreaction

- **Qsens** = m*Cp*dT – sensible heat required to heat AlH3 from ambient to release temperature = ~ 64 Wh/kg AlH3
- **Qreaction** = 7kJ/mol H2 or ~ 97Wh/kg AlH3
- **Qloss** = A*k*dT/z - heat loss to ambient required to maintain AlH3 at the release temperature – depends on geometry and insulation

Wearable Power System (WPS) for a dismounted soldier



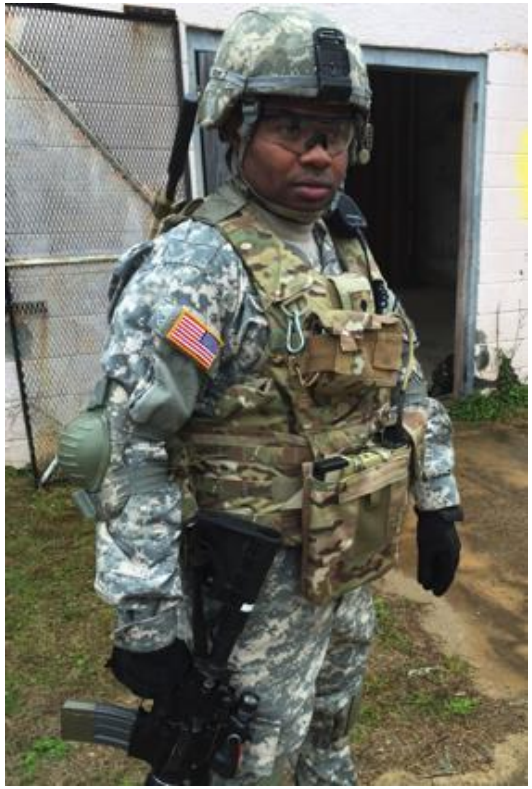


System Technical Specs	
Power	20 W (35 W peak)
Weight	2.5 lbs
Dimensions	7.9 x 8.7 x 0.9 in
Output Voltage	12 – 16.8 V DC

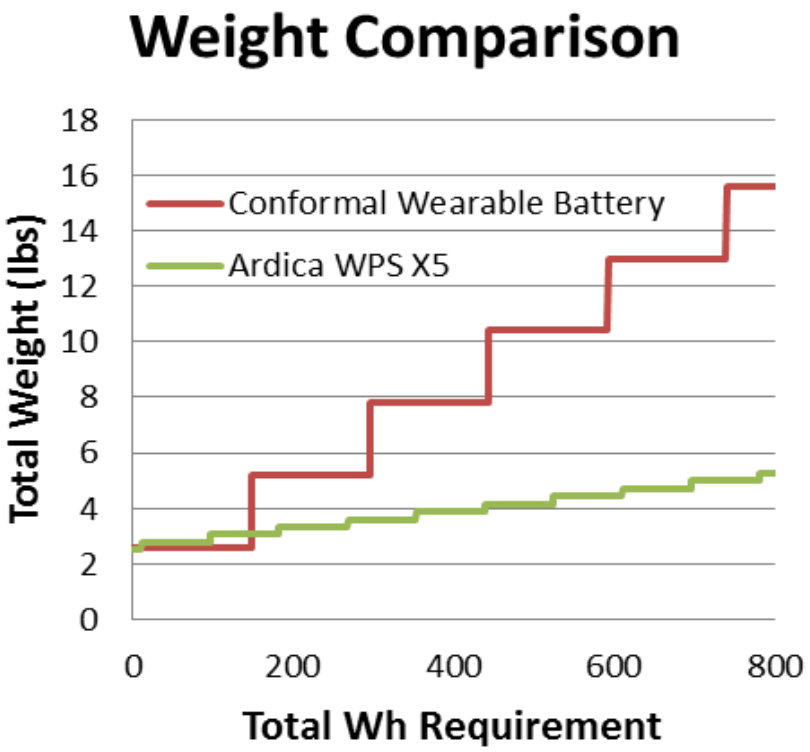
Fuel Cartridge Technical Specs	
Nominal Capacity	85 Wh
Weight	0.28 lbs
Volume	148 cc

Wearable Power System Features

- Developed with Army CERDEC Power Division.
- TRL 6 – Field Tested at Army Expeditionary Warrior Experiments (AEWE) 2016.
- Instant power on with hybrid battery.
- Hot swap capability with fuel cartridges. No need to stop and recharge.
- Waterproof 1m for 2 hours.
- Flexible design bends 2x 15 degrees to conform to soldier's body.
- Solid state hydrogen storage and quiet fuel cell system for near silent operation.



Soldier Weight Burden Reduction



- System Energy Density: 463 Wh/kg, 528 Wh/L (72h at 20W nominal)
- Over 55% weight reduction compared to standard batteries on 72 hour missions
- Energy continuity with hybrid fuel cell system and disposable fuel cartridges.

NUWC UUV Remus 600 Prototype

- UUV application for increased range over lithium ion batteries
- 12.75” OD form factor
- 250W continuous power draw
- Example mission bottom mapping
- On-board oxygen generation exists
- Initial modeling suggests > 2x improvement over current lithium ion battery system
- Christian Schumacher, NAVSEA NUWC Newport

ARMY TARDEC SBIR

- Phase 1 just started
- Alane powered Fuel Cell All Terrain Transport
- Build and demonstrate a reliable and controllable benchtop system
- Compare the alane system to compressed hydrogen, specifically volumetric hydrogen density, weight fraction, energy requirements, and operating conditions
- Cost, performance, and system architecture model for scale up

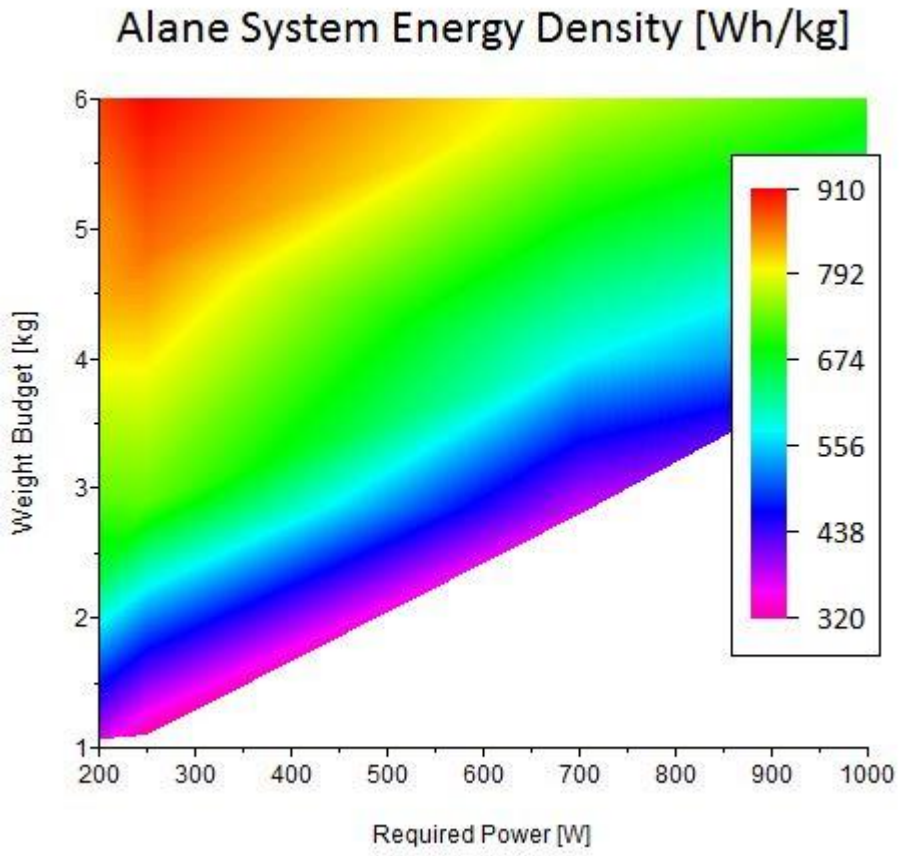
1kW Power Generator Concept

System Technical Specs	
Max Continuous Power	1,000 W
Weight	14.3 lbs
Volume	732 in^3
Output Voltage (nominal)	24V DC

Fuel Cartridge Technical Specs	
Nominal Capacity	1300 Wh
Weight	2.6 lbs
Volume	73 in^3

Alane-powered UAV

- Battery hybrid architecture for peak power and transients
- System model includes fuel cell, alane cartridge, cartridge reactor, hybrid battery, and control electronics (ground start assumed)
- High energy density translates into longer runtime, **2-5**x over batteries for small UAVs

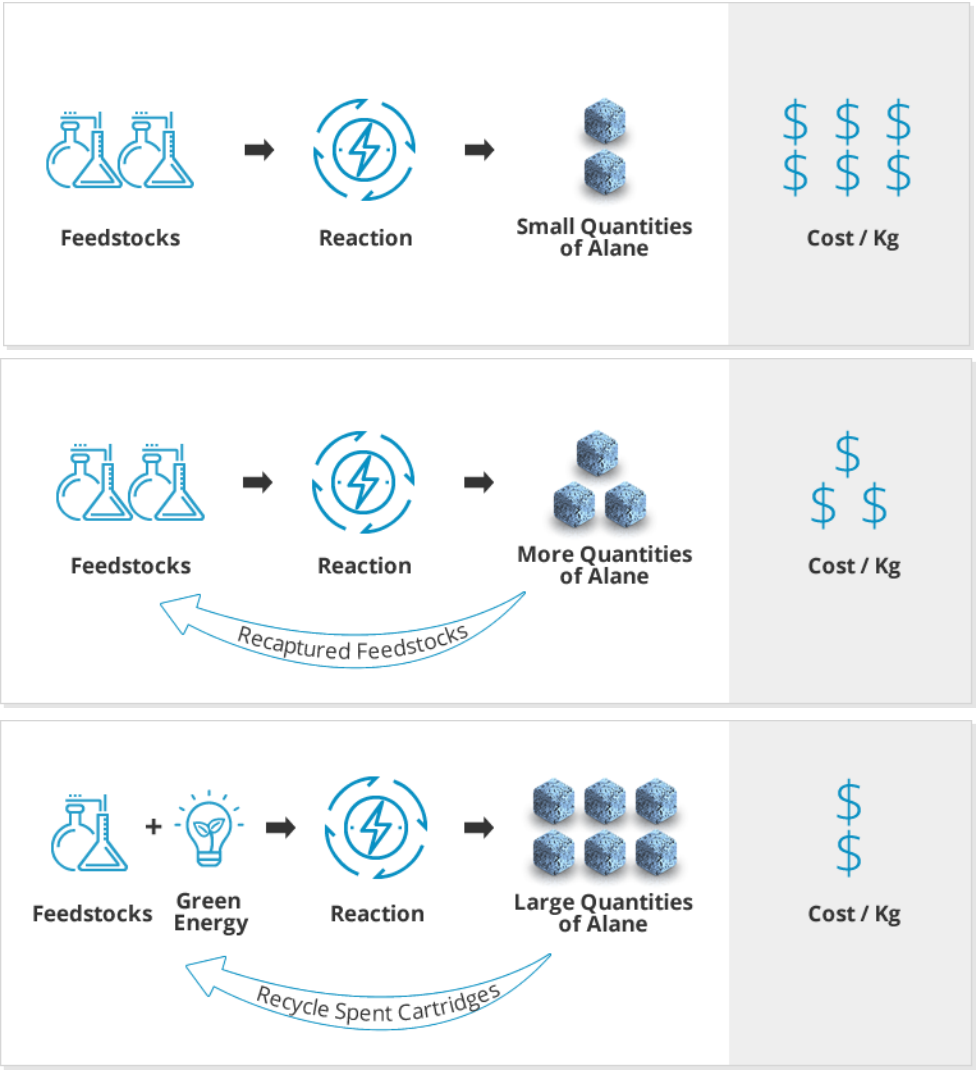


Ardica is executing a multi-step Alane production roadmap to unlock its enormous potential

Old Process: Large quantities of expensive inputs or "feedstocks" and energy produced small, high-cost yields, severely limiting the practical use of Alane.

Optimized Process: Cheaper feedstocks are employed, recaptured, and reused in a continuous process, cutting down labor requirements and leveraging economies of scale. This delivers far better yields at declining costs.

Breakthrough: A next generation process *eliminates certain feedstocks altogether*. Spent aluminum is also recycled back into this process. The result? Large quantities of stable, flexible energy-rich fuel at extremely low cost.



Ardica makes Hydrogen a compelling, *viable* fuel

Proven ability to develop innovative, functional new technologies

A track record of establishing strong partnerships and strategic alliances

IP and business model that captures multiple areas of the value chain

For more information:

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