Delivering Breakthrough Solutions

Bio-Battery: Alternative Power Source for Extracting Energy from JP-8 without Fuel Processing

2015 Joint Services Power Expo

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Outline

- Problem Statement
- Bio-Battery Solution
- Adaptation for JP-8
- Scale-Up and System Design
- Conclusions


DELL
DELL
DELL


SAMSUNG
SAMSUNG

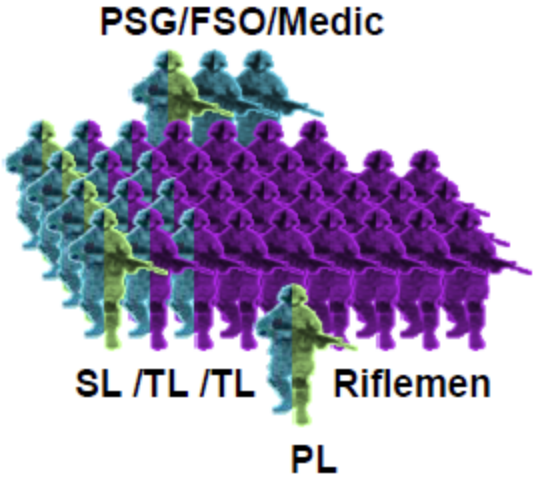

27
7


LG
Lithium Ion
Battery 3.7V
LG
Lithium


DELTA

2010 Infantry Rifle Platoon
72 Mission Hour Requirement

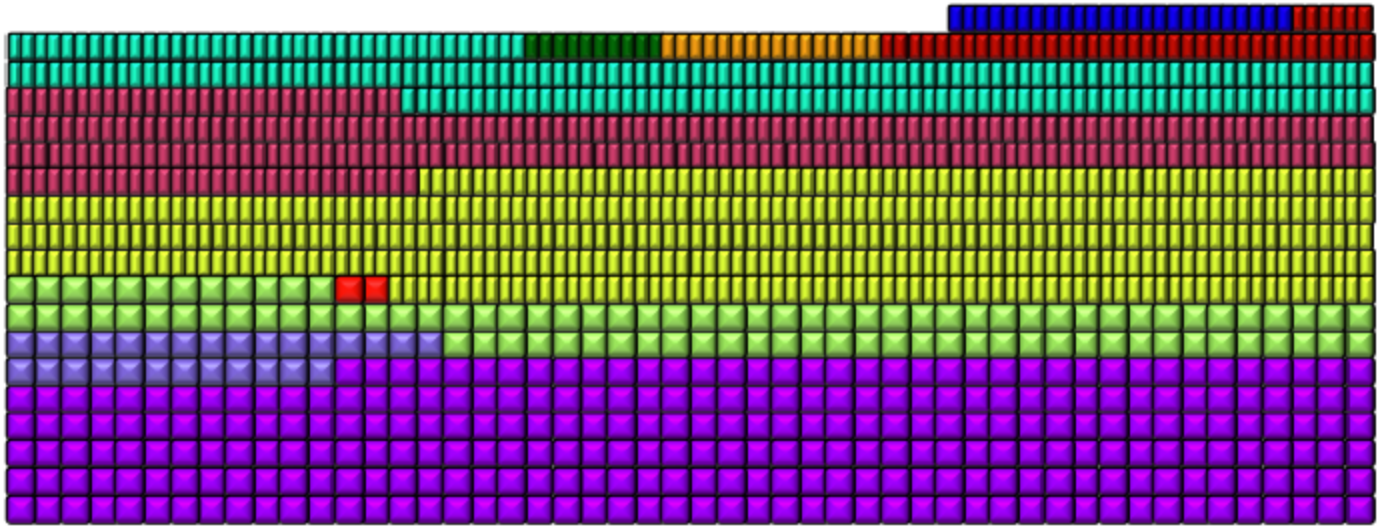
11 Battery Types,
1418 Batteries,
Per Platoon,
412-436 LBS for a 72 Hour Mission



20+ lbs per soldier

Basis of issue (BOI)

- DL1/3N
- 9V
- 9V Lithium
- ½ AA
- DL123A
- AA Alkaline
- AA Lithium
- MARK VII
- MBITR Radio
- BA5590/BB2590
- LMR



Based on 2010 CERDEC/MCOE analysis; assumes BOI systems are carried/worn

Current Recharging Solutions

Traditional Solutions (Generators, HUMVEEs)

Not Portable
Large Signature
(noise and thermal)

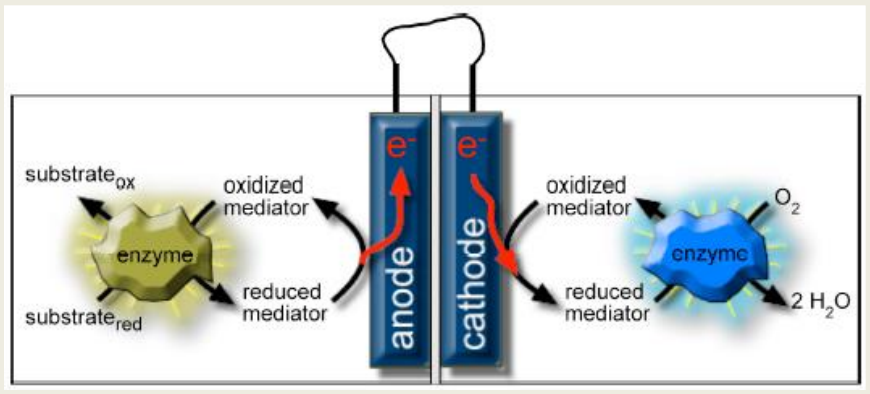
Renewable Solutions (Flexible Solar Panels)

Limited Availability (<20%)

Bio-Battery Introduction

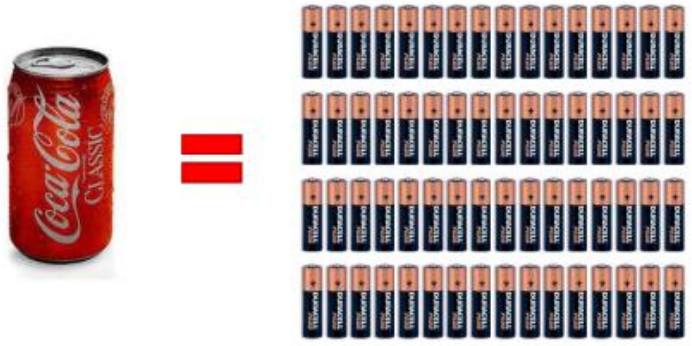
Renewable, Low-Cost Bio-Catalysts

Uses enzymes to convert fuel directly into electrical energy as opposed to rare earth metals



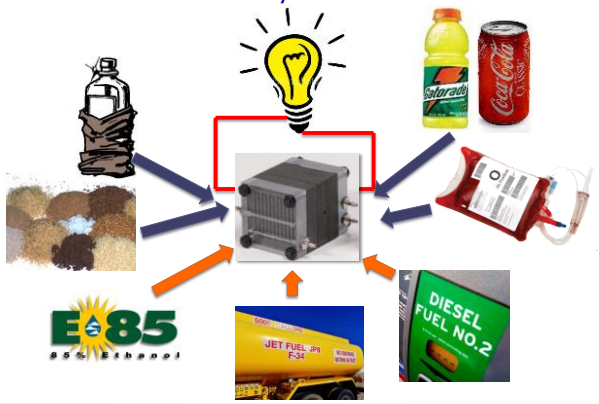
High Energy Density

Sugar in 1 can of soda is equal to 72 AA batteries



Fuel Flexibility

Runs on multiple fuel sources such as sugar, alcohol, and diesel



Signature Free Operations

Runs at room temperature and neutral pH
No thermal or acoustic signature

Bio-Battery Background

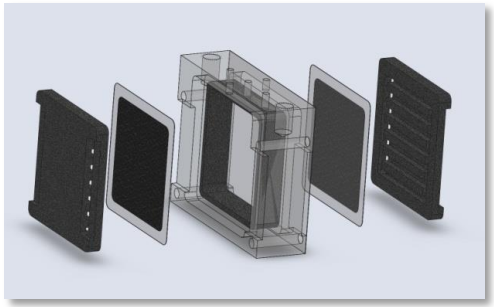
Multiple Prototypes created and tested

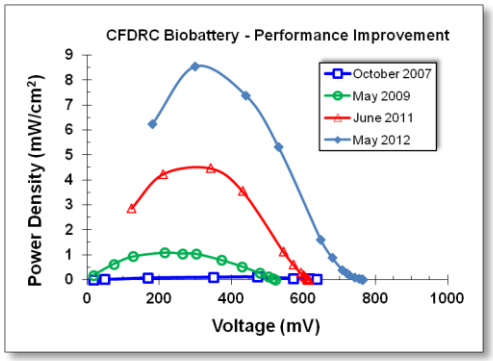
Performance increased 100 X to over 10 $mWcm^{-2}$

6 months of shelf-life demonstrated from -30°C to +55°C

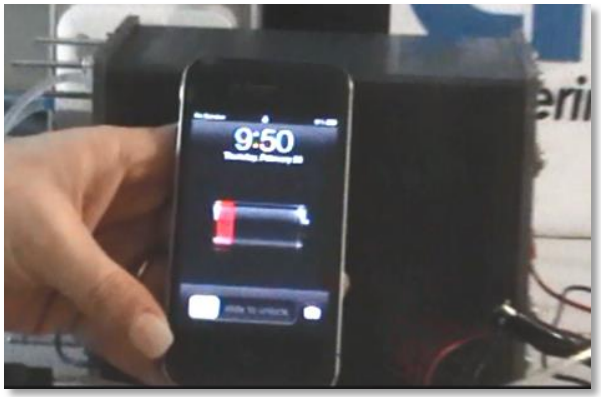
Demonstrations performed at customers and conferences:

- 0.25 W prototype running on Gatorade and powering microprocessors, LCD displays and wireless transmitters
- 5.0 W prototype powering an iPhone
- Implantable prototype running on sugar in insect hemolymph





5mL of Gatorade >100 hrs runtime



5W prototype for powering iPhone

Implanted in beetle

Modification for JP-8

Work sponsored by:
NORTHROP GRUMMAN

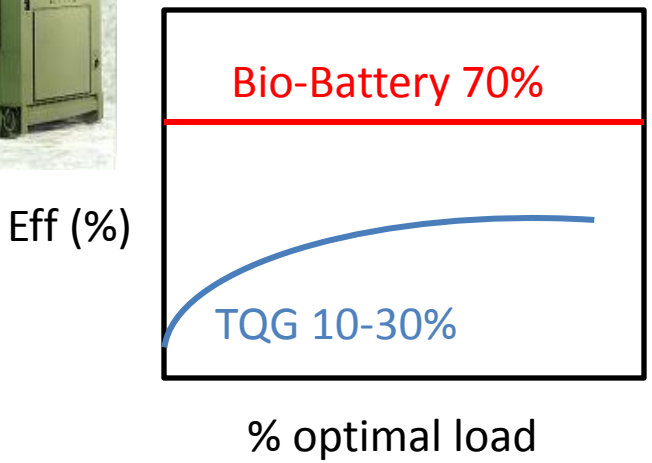
- Modify anode side of device
- JP-8 is made of long chain alkanes (C6-C16)
- Use proprietary first enzyme to convert alkanes into alcohol
  - Hexane → Hexanol, Octane → Octanol, Dodecane → Dodeconol, etc
- Secondary enzyme(s), AOx or PQQ-ADH/AlDH, to covert the alcohol into energy
  - Hexanol → release to 2e- and an aldehyde by-product
  - Hexanol → release to 2e- and an aldehyde by-product → release to 2e- and a carboxylic acid by-product
- Additional enzyme – Lyase, to take aldehyde by-product and regenerate alkane to be re-introduced into the enzymatic cascade.
- Eventually multiple enzymes can release all electrons in JP-8 and only have CO_2 as by-product

Advantages

- Sulfur tolerance – enzymes allow JP-8 to be used without pre-processing.
- Fuel flexibility - include enzymes for sugar, alcohol, and JP-8
- No thermal or acoustic signature
- High efficiency (50%) independent of load

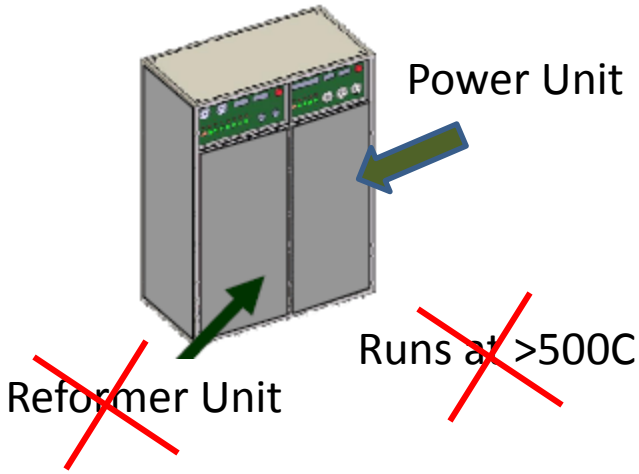
JP-8 Bio-Battery Value Proposition

vs Generators



- Higher Efficiencies (goal of 70%) vs 30% peak for generators and 10% under typical operation
  - Bio-Battery efficiency is load independent
- No noise or thermal signature

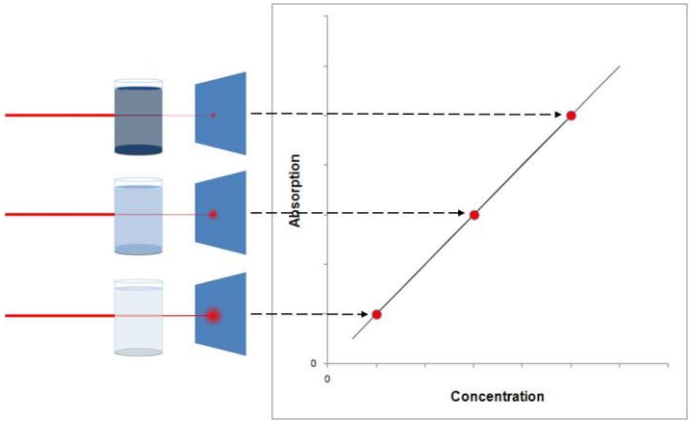
vs SOFCs

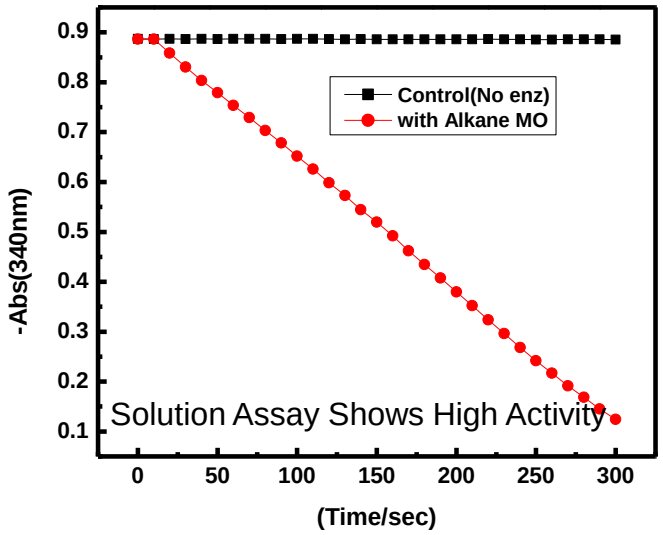


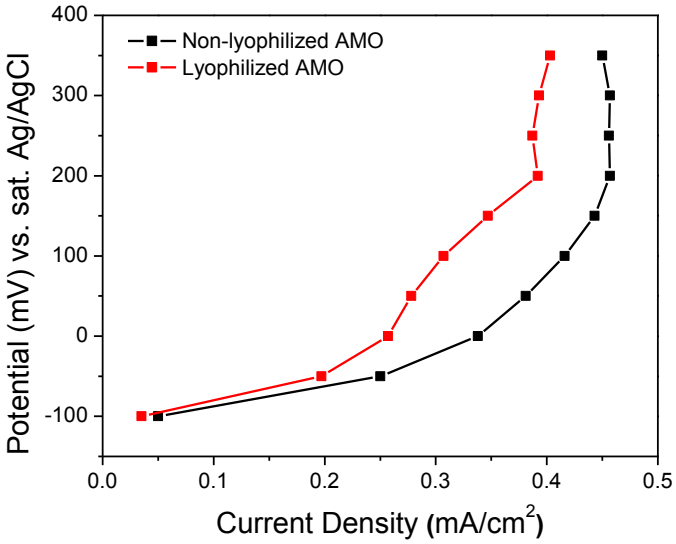
- SOFCs need de-sulfurization
  - Increases system size 2X, increase complexity, reduces system level eff.
- Enzymes are sulfur tolerant – no need for reforming.
- Lower noise and thermal profile

Enzymatic Conversion of Alkane to Alcohol

$$\text{Octane} + \text{NADH} + O_2 \xrightarrow{\textit{Enzyme (AMO)}} \text{1-Octanol} + NAD^+ + H_2O$$



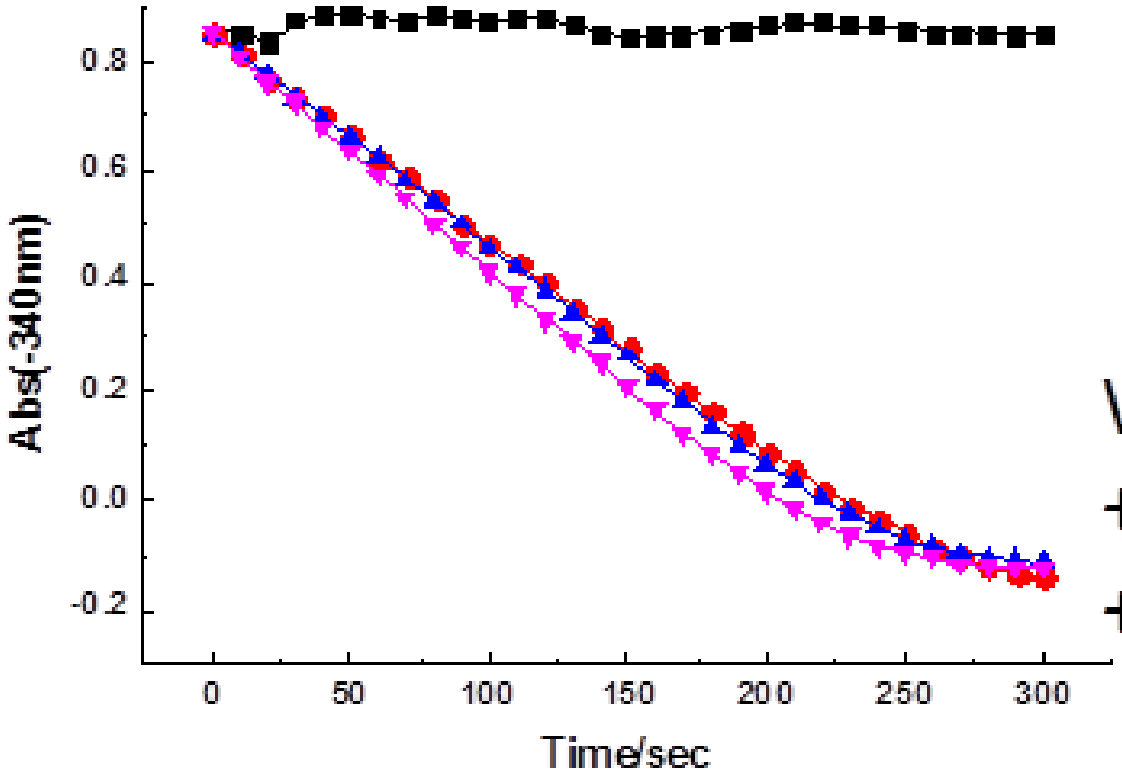




UV-Vis Technique proves that Octane in converted to Octanol

Ability to lyophilize the enzyme allows for further improvements to the system.

No Inhibition at 1,000 and 2,0000ppm Sulfur

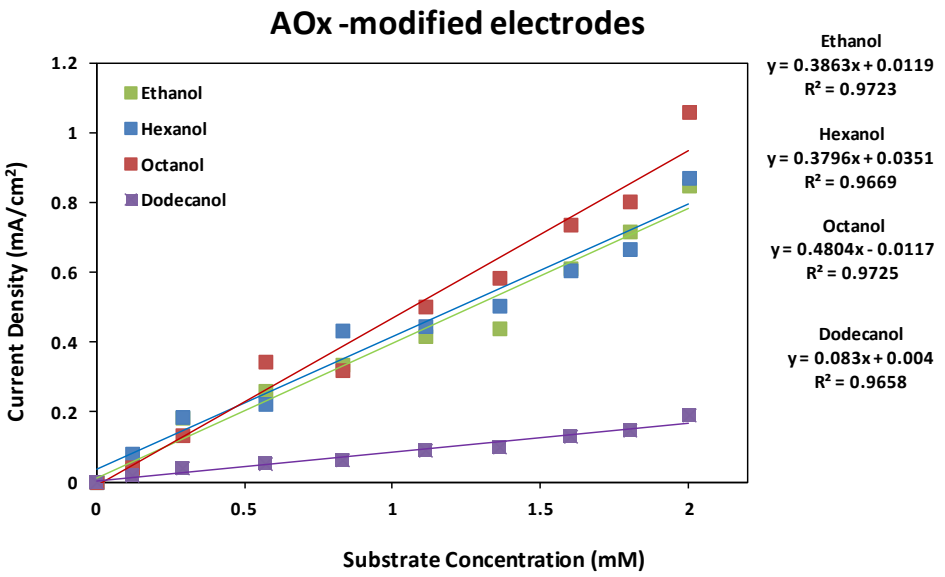


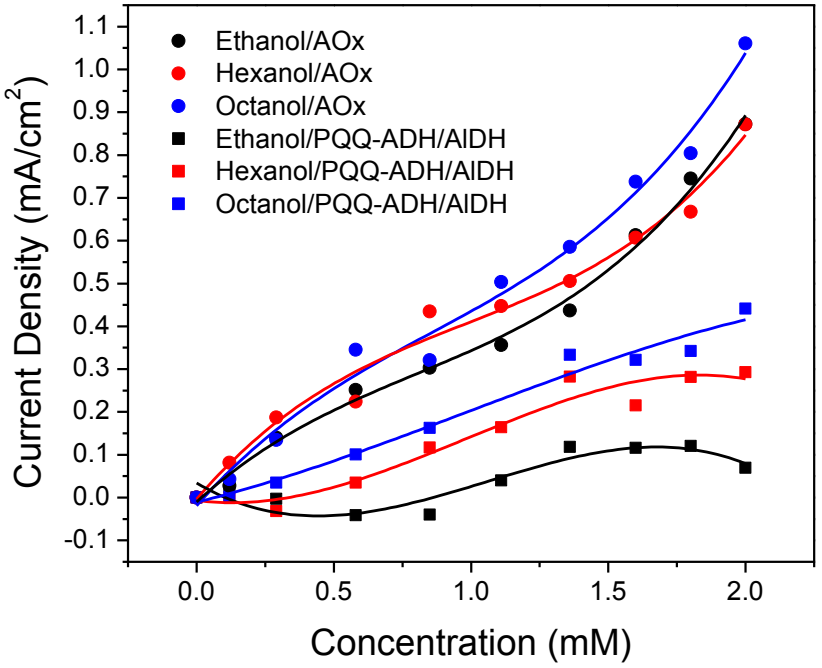
Control

With Enzyme
+ 1,000 ppm Sulfur
+2,000 ppm Sulfur

No inhibition with sulfur

Oxidative Enzyme Studies

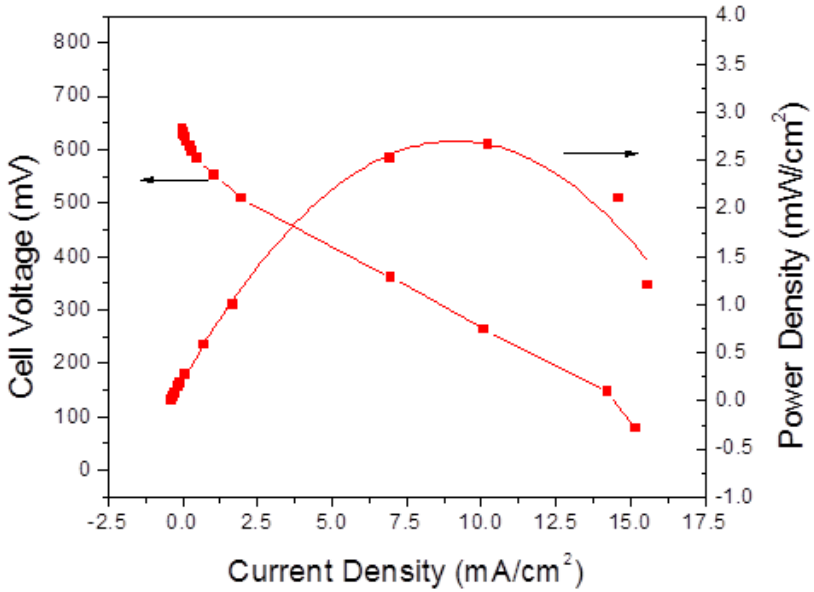


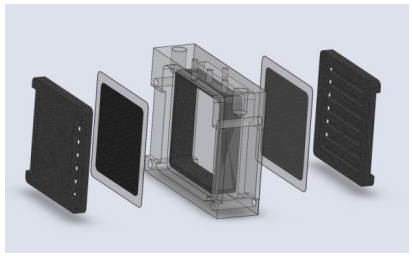


AOx converts C2, C6, C8, and C12 alcohols to energy.
Lower eff. for C12 process.

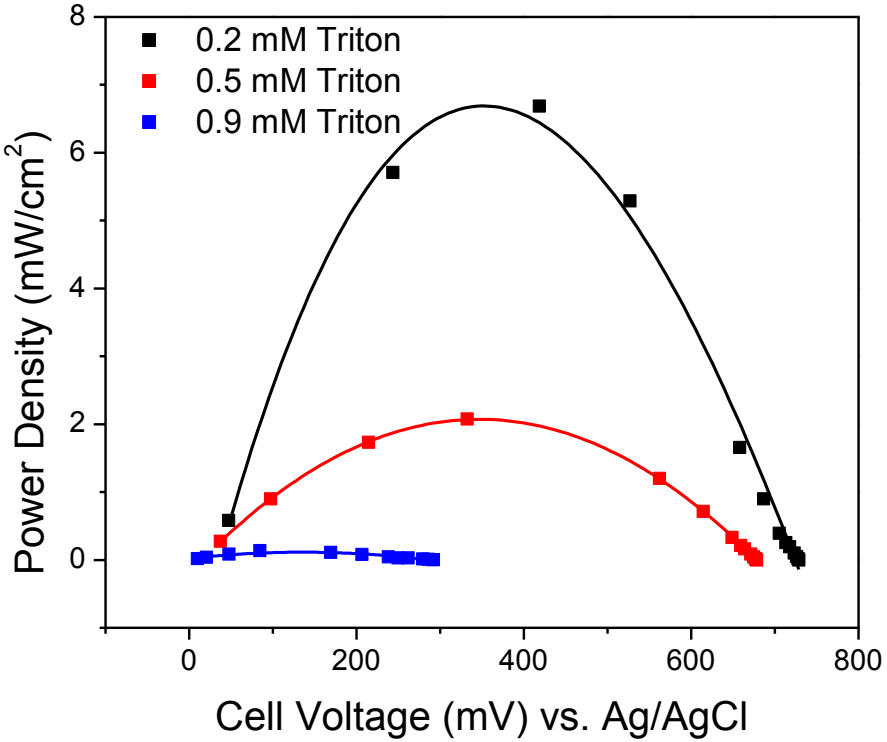
AOx – single step oxidation of alcohol to aldehyde.
PQQ-ADH/AlDH – multi-step oxidation of alcohol to carboxylic acid.

JP-8 Fuel Cell Studies



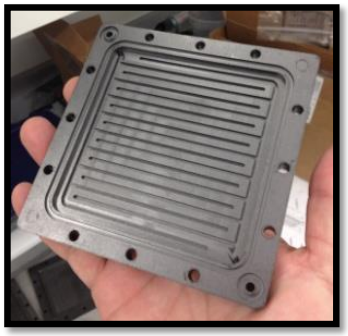


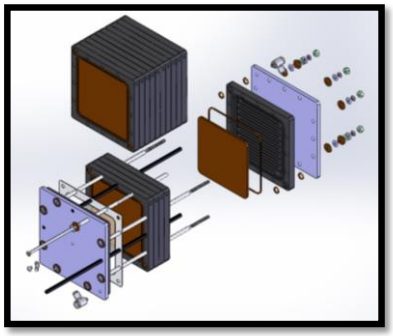
- Power Density: ~3mW/cm^2
- Max current: ~15mA/cm^2
- On Par with Glucose Tech.

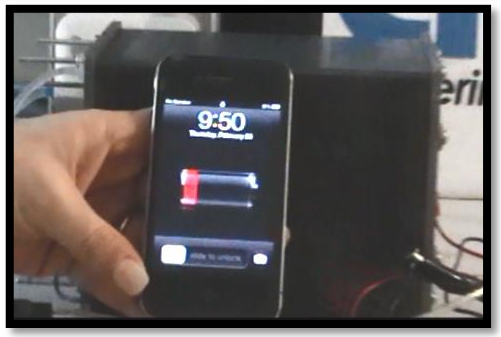


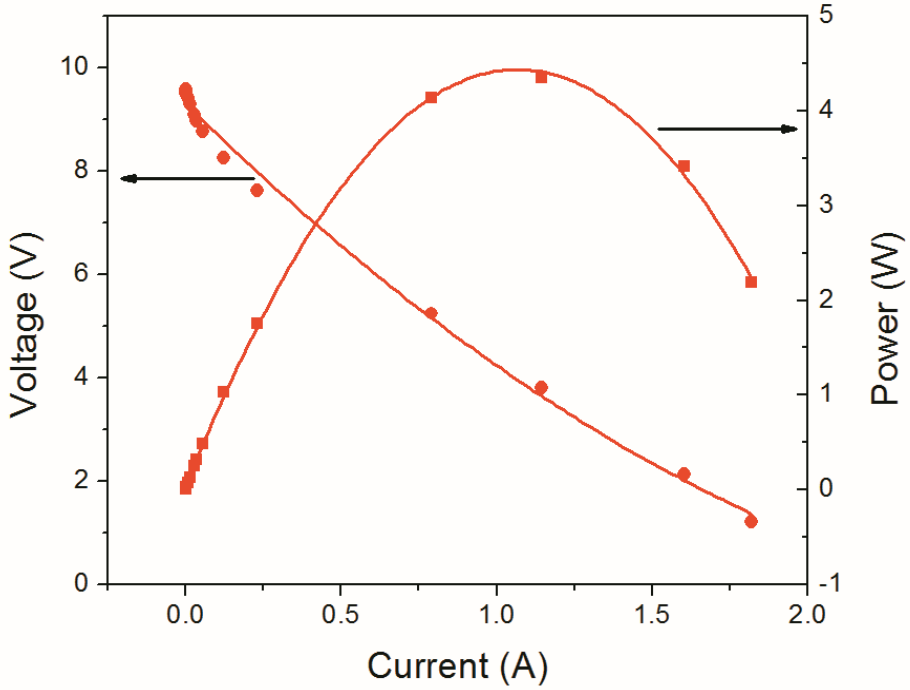
JP-8 straight from Army motor pool produces power without de-sulfurization

5W Prototype – 15-cell graphite stack



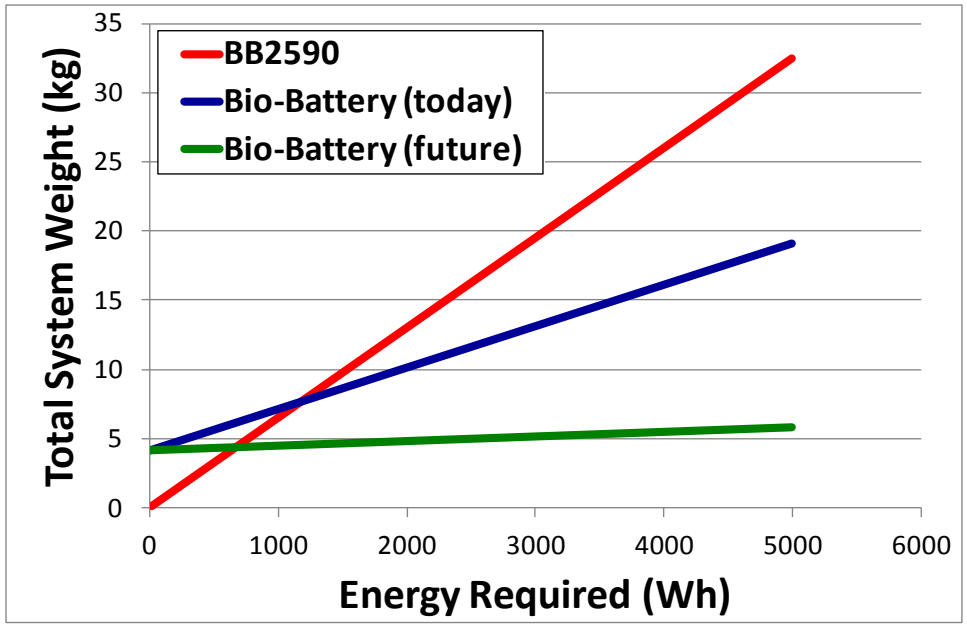






- Designed and fabricated graphite bipolar plate configuration
- ***Stack provides 5V at 1A (5W) with glucose fuel***
- Fitted with USB connector and demonstrated powering electronic devices and recharging an iPhone

Use Scenarios: Soldier Portable Power



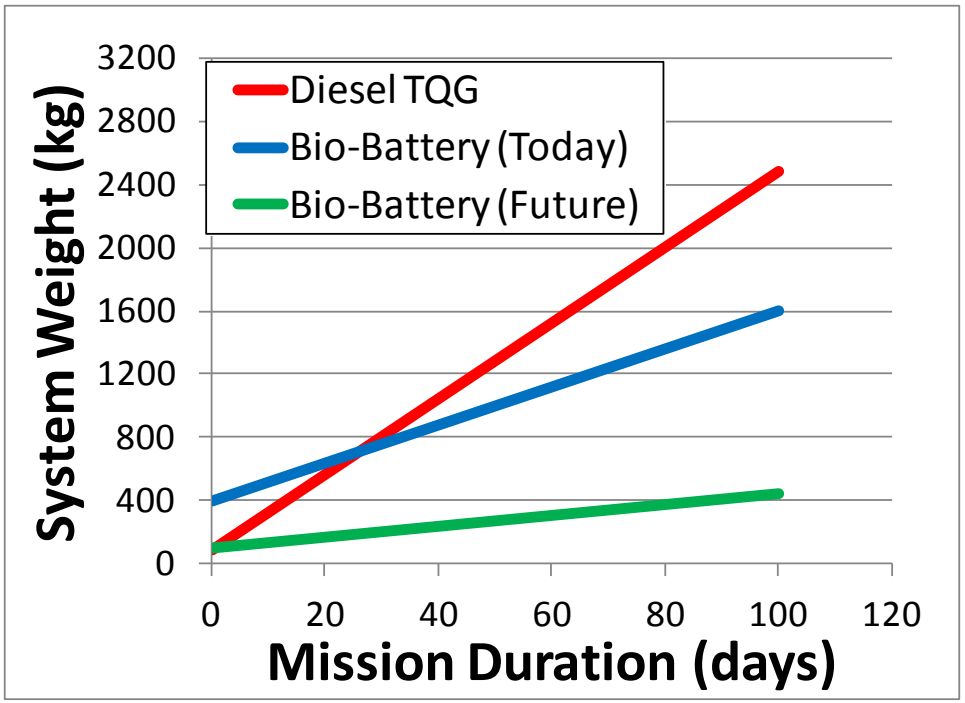
Example 100hr Mission:

SINCARS Radio	– 1,600 Wh
DAGR GPS	– 400 Wh
Misc devices	– 1,000 Wh
TOTAL	– 3,000 Wh

Bio-Battery provides >15kg of weight savings

- For mission were >1,000 Wh of Energy are required the Bio-Battery offers advantages in total mission weight.

Use Scenarios: "Silent Watch" – TQG replacement



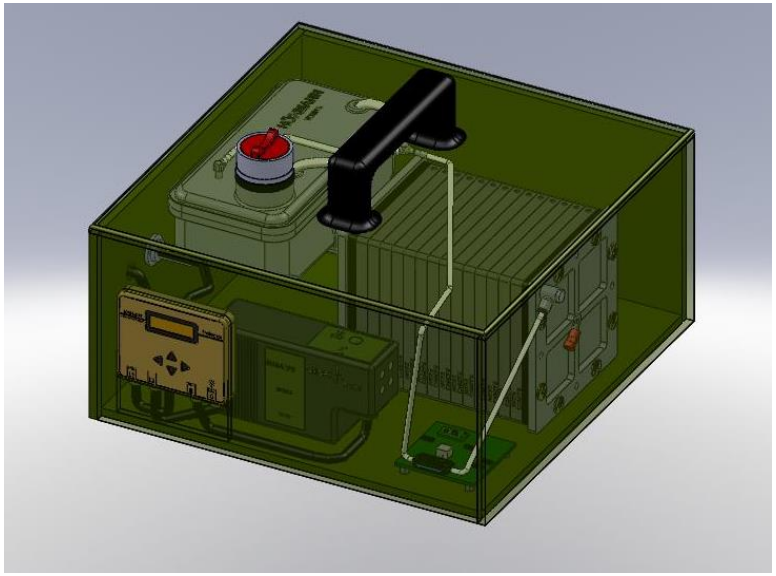
Example 100 day Mission:

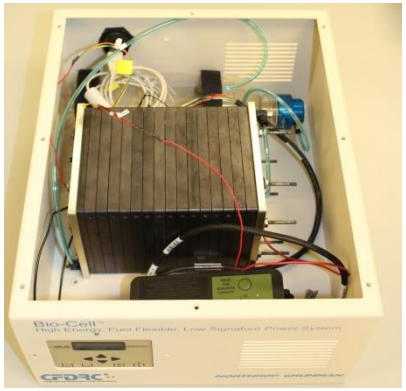
2kW TQG	– 81kg
Average Eff.	– 20%
2kW for 12hrs	– 24kWh/day
TOTAL	– 2400kWh

Bio-Battery can provide 80% savings in JP-8 fuel consumption

- After just 10 days the Bio-Battery system can save 150kg of total weight (system + fuel) and 250L of JP-8
- For 100 day mission the weight saving is almost 2,000kg
- Advantages in low signature exist from day 1

System Design





- Rev0 version of fully-integrated unit (Rev1 will be ready for field trails).
- Components:
  - 5V/5W Bio-Cell
  - 1L Fuel Tank
  - Low power pump (mp-6)
  - Power Manager (VPM)
  - Buffer Battery (Li-80)
- Size:
  - 30cm x 30cm x 15cm (13.5L)
  - 6.5kg
- Performance:
  - Total Energy in 1L of 1M glucose: 55 Ah
    - Recharge smart phone 20 times
    - With complete enzyme cascade energy increases 10X → 200 smart phone charges

Conclusions

- High performing, stable, and reproducible Bio-Battery technology developed.
  - ADVANTAGES: energy density, fuel flexibility, catalyst, and signature.
- Scaled-up demonstrations performed at multiple conferences and customer sites.
- Adapted to run from JP-8 fuels without pre-processing.
- Case studies show advantages for both soldier portable power as well as TQG replacement.
- Fully-integrated Bio-Battery charging prototype developed.

Future Direction: Fully-integrated demonstrations, executed in close collaboration with customer, for relevant applications

Acknowledgements

- The core Bio-Battery technology has been developed through SBIR programs from the Army and Air Force.

- The adaptation for JP-8 described in this paper was supported by Northrop Grumman Corporation

- Advice and support from colleagues at CFDRC and University of Utah.

Thank you

Questions ?

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