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Developing & Transitioning Cutting-edge Technologies into Breakthrough Solutions for:

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Outline

• Problem Statement
• Bio-Battery Solution
• Adaptation for JP-8
• Scale-Up and System Design
• Conclusions
20+ lbs per soldier

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
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

• 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/AIDH, 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 CO₂ 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

![Image of Bio-Battery and SOFC comparison](image_url)
Enzymatic Conversion of Alkane to Alcohol

Octane + NADH + O₂ → Enzyme (AMO) → 1-Octanol + NAD⁺ + H₂O

UV-Vis Technique proves that Octane in converted to Octanol

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

Solution Assay Shows High Activity

Potential (mV) vs. sat. Ag/AgCl

Current Density (mA/cm²)
No Inhibition at 1,000 and 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/AIDH – multi-step oxidation of alcohol to carboxylic acid.
JP-8 Fuel Cell Studies

- Power Density: \( \sim 3\text{mW/cm}^2 \)
- Max current: \( \sim 15\text{mA/cm}^2 \)
- On Par with Glucose Tech.

JP-8 straight from Army motor pool produces power without desulfurization.
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 where >1,000 Wh of Energy are required the Bio-Battery offers advantages in total mission weight.
Use Scenarios: “Silent Watch” – TQG replacement

- 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

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*
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
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Thank you

Questions?

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