Regenerative Fuel Cells for Space Power and Energy Conversion ($NaBH_4/H_2O_2$ Fuel Cell Development)

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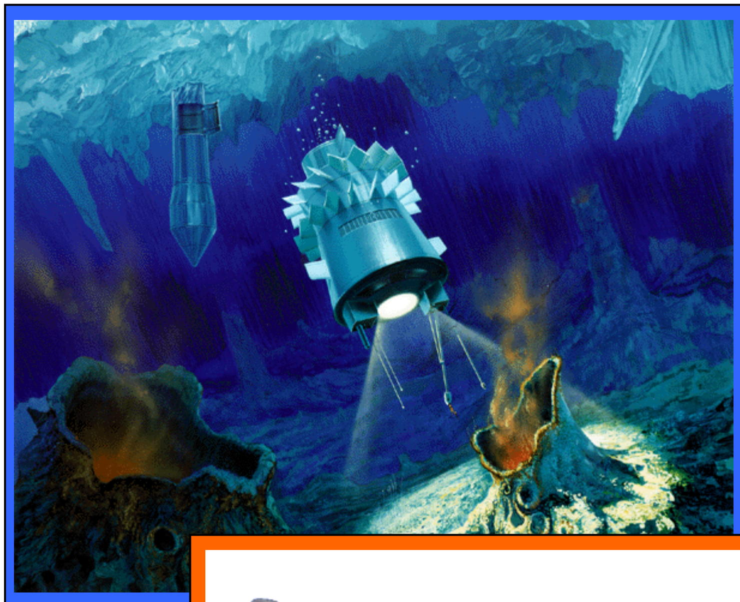
Presentation Outline

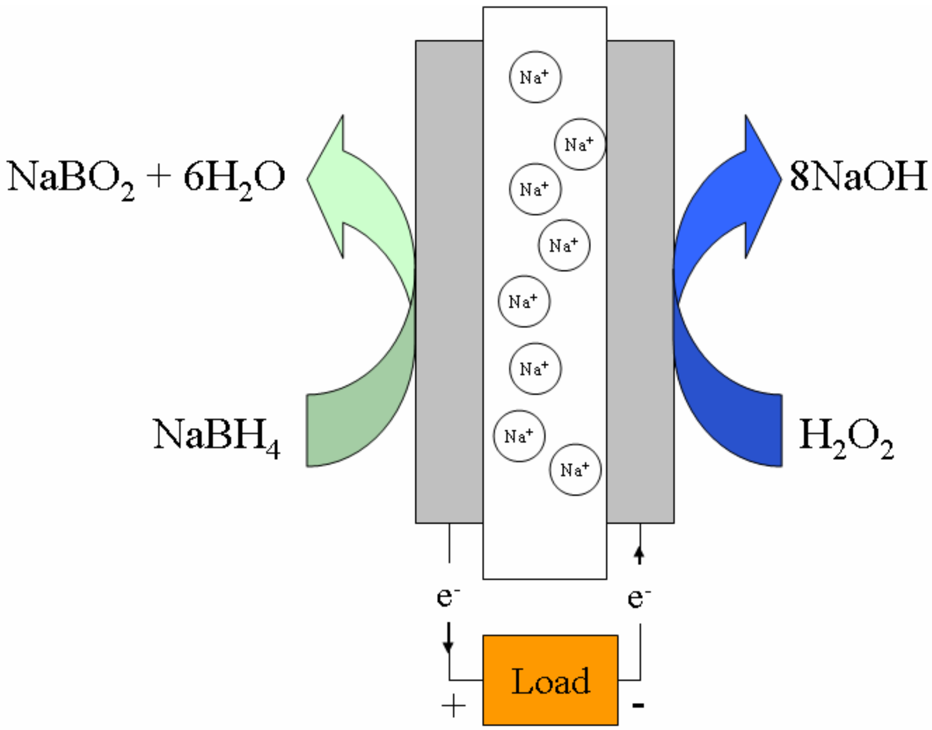
- Motivation
- The Sodium Borohydride Fuel Cell
- Fuel Cell Comparisons
- MEA Optimization
- 500-Watt Stack Testing
- System Modeling: Fuel Cell Power Source for Lunar Rovers
- Conclusions

Hydrogen Peroxide Fuel Cell Systems



- Hydrogen peroxide can be used as an alternative oxidant for PEM based fuel cells in any application which can see a limited amount of free convection air.
- NPL Associates, Inc. (NPL) pioneered the direct sodium borohydride/ hydrogen peroxide fuel cell technology in a DARPA SBIR. They have collaborated with a UIUC lead team to further develop this technology under NASA support.
- The sodium borohydride/hydrogen peroxide fuel cell offers distinct advantages:
  - System Energy Density: 1000 W-hr/kg
  - Very high efficiency, over 75% experimental - due to the fast kinetics of the peroxide cathode

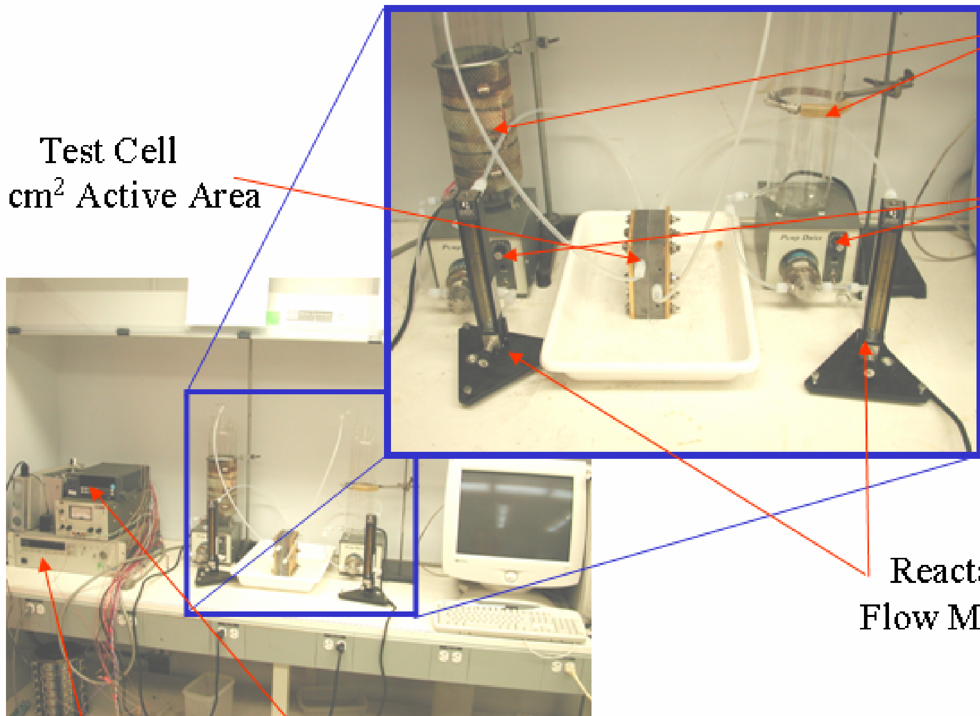
The Sodium Borohydride/Hydrogen Peroxide Fuel Cell

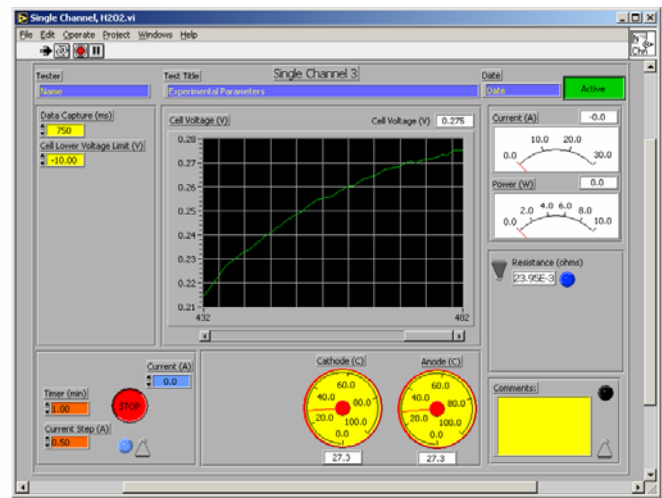


- Benefits of hydrogen peroxide as an oxidant
  - Higher current density from larger oxidizer mass density
  - Single-phase transport on the cathode side of FC increases reaction rate
- Benefits of sodium borohydride as a fuel
  - Sodium and Borate do not react electrochemically: neither pass through the PEM and both stay at anode side
  - NaBH4 is 30-40% soluble in water: can be used as a liquid directly at the anode, promising higher current density and efficiency
- Waste heat removed by oxidizer and fuel both in liquid form, giving better cooling

Anode:	$NaBH_4 + 8Na^+ + 8OH^- \Rightarrow NaBO_2 + 6H2O + 8Na^+ + 8e^-$	$E^o = -1.24$ V[1]
Cathode:	$8Na^+ + 8e^- + 4H_2O_2 \Rightarrow 8Na^+ + 8OH^-$	$E^o = 0.95$ V
Cell:	$NaBH_4 + 4H_2O_2 \Rightarrow NaBO_2 + 6H2O$	$V_{cell} = 2.19$ V

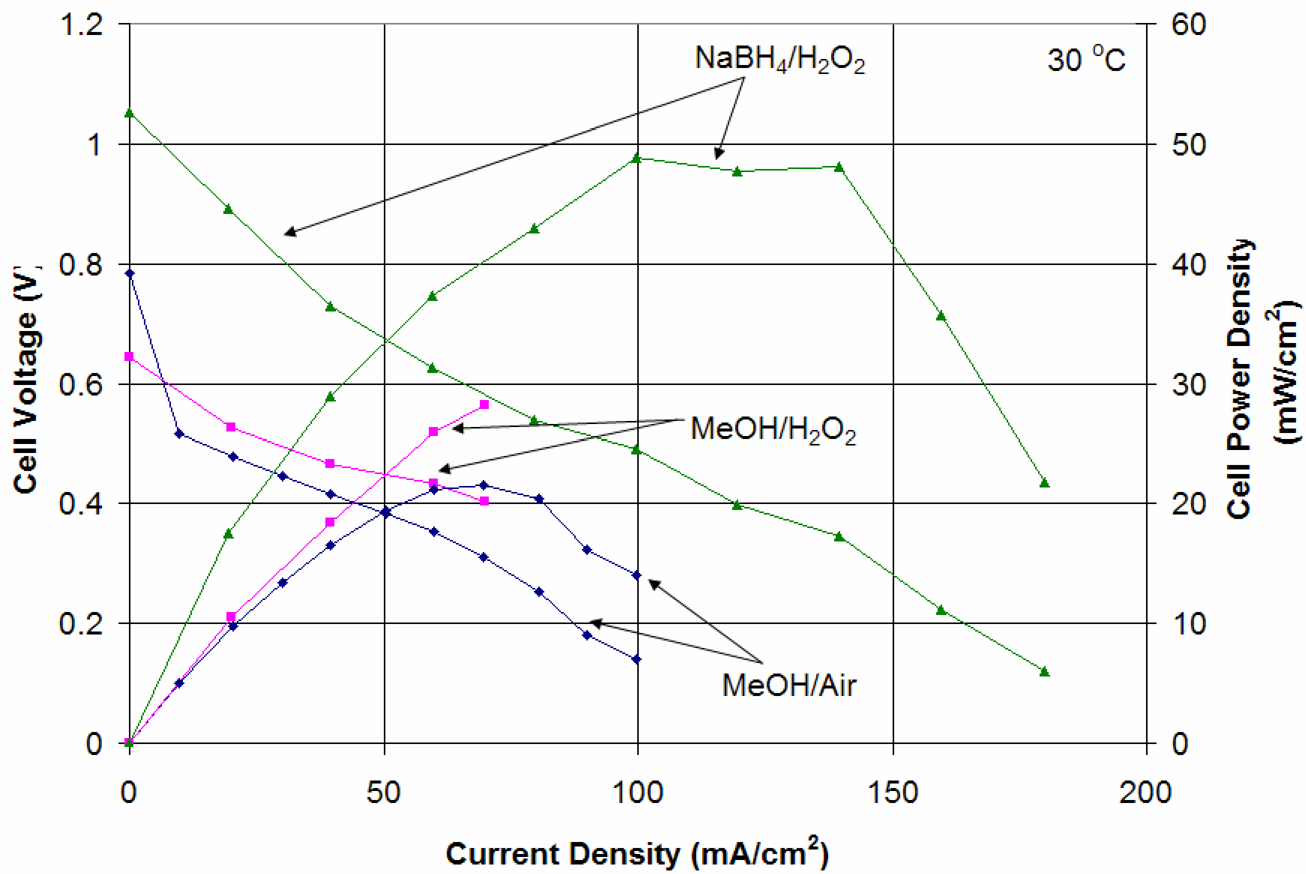
$NaBH_4/H_2O_2$ Fuel Cell Test Stand





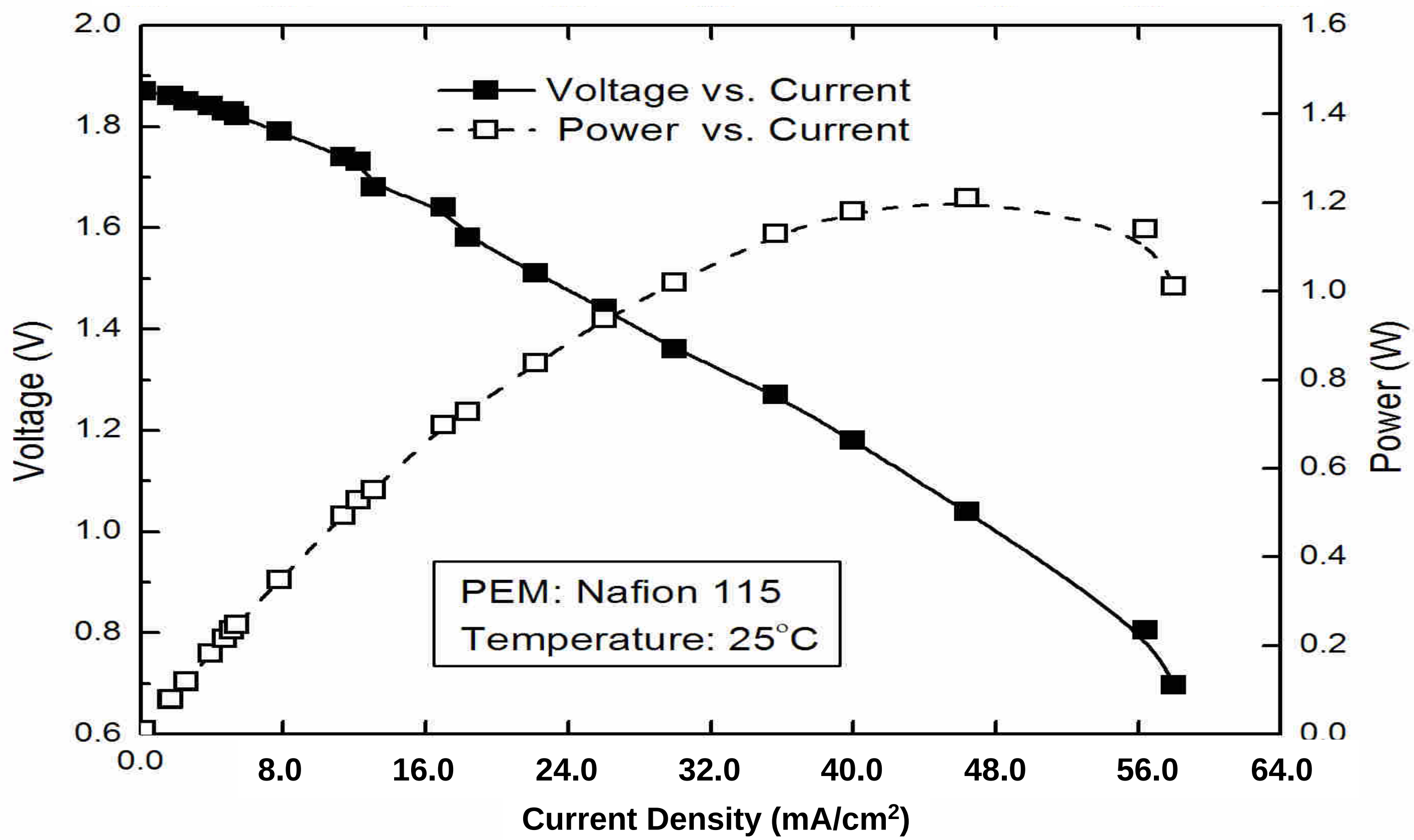
Test Stand GUI

Methanol-Based Fuel Cell Performance Comparison



- Comparison of liquid-feed direct oxidation fuel cells at room temperature and ambient pressure operation.
- The maximum power density measured for the sodium borohydride/hydrogen peroxide system, at 30 °C, is 48 mW/cm^2. These values are higher (>2x) than that of a methanol/hydrogen peroxide system operated under similar conditions.

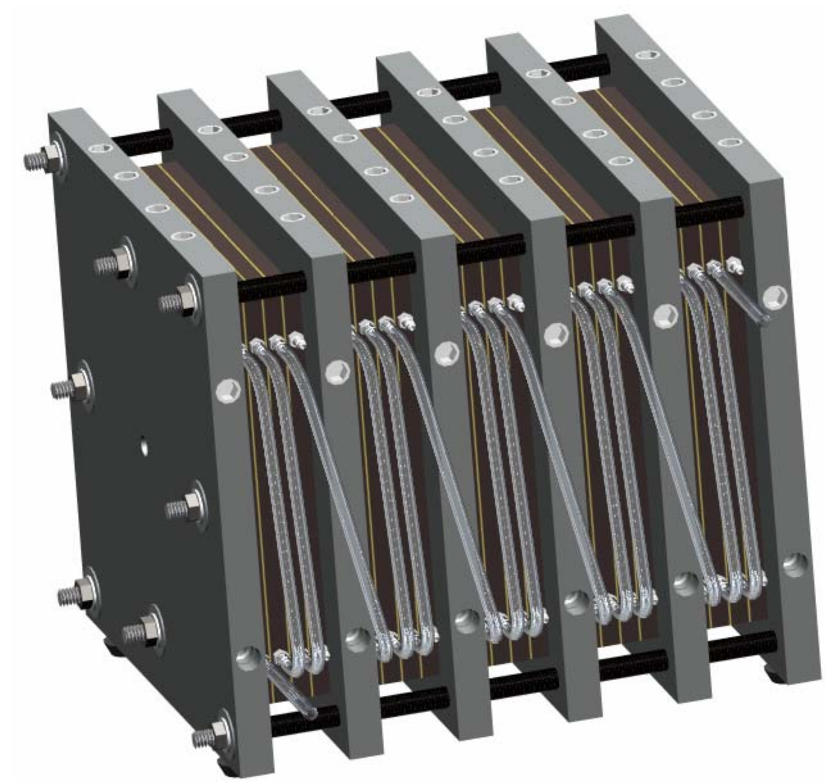
Efficiency Optimized $NaBH_4/H_2O_2$ MEA



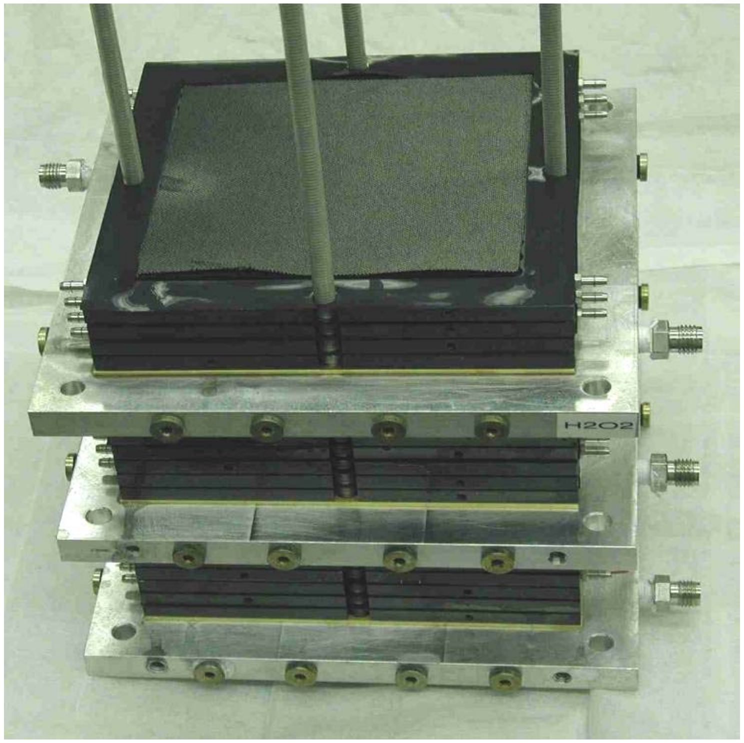
- Cell performance at room temperature and ambient pressure
- Optimized MEAs can operate at a very high conversion efficiency and much reduced reactant decomposition

$NaBH_4/H_2O_2$ 500-Watt Stack Testing at UIUC

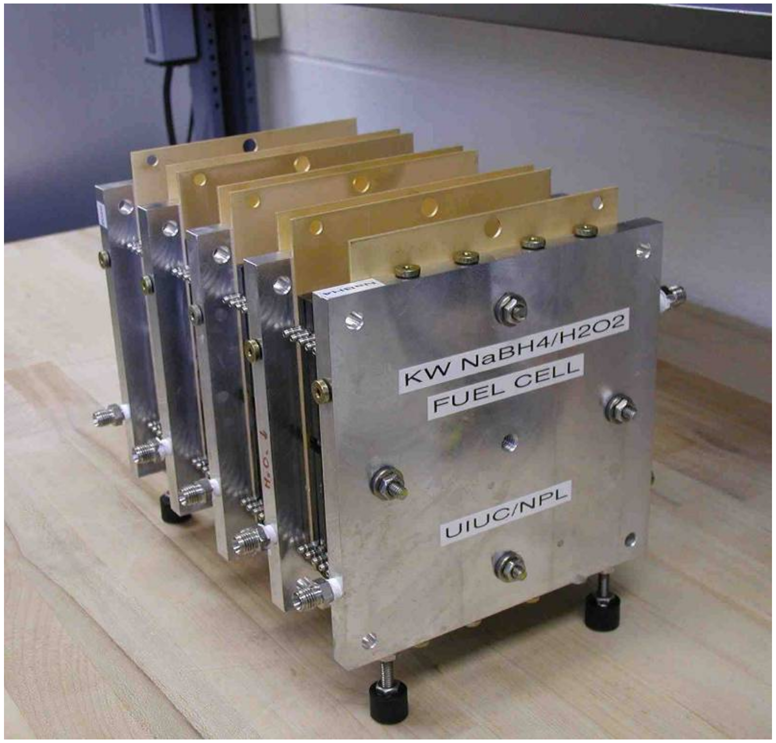
- MEA Fabrication
  - Nafion based electrolyte
  - Anode Catalyst: Palladium
  - Cathode Catalyst: Gold
- Bipolar Plate Design
  - 144 cm^2 active area
  - Serpentine design
  - External Inlets and Outlets
- Testing Parameters
  - Operation from room temperature
  - Reactant flow rate of approximately 200 cm^3/min



The 500-Watt UIUC/NPL $NaBH_4/H_2O_2$ Fuel Cell Stack

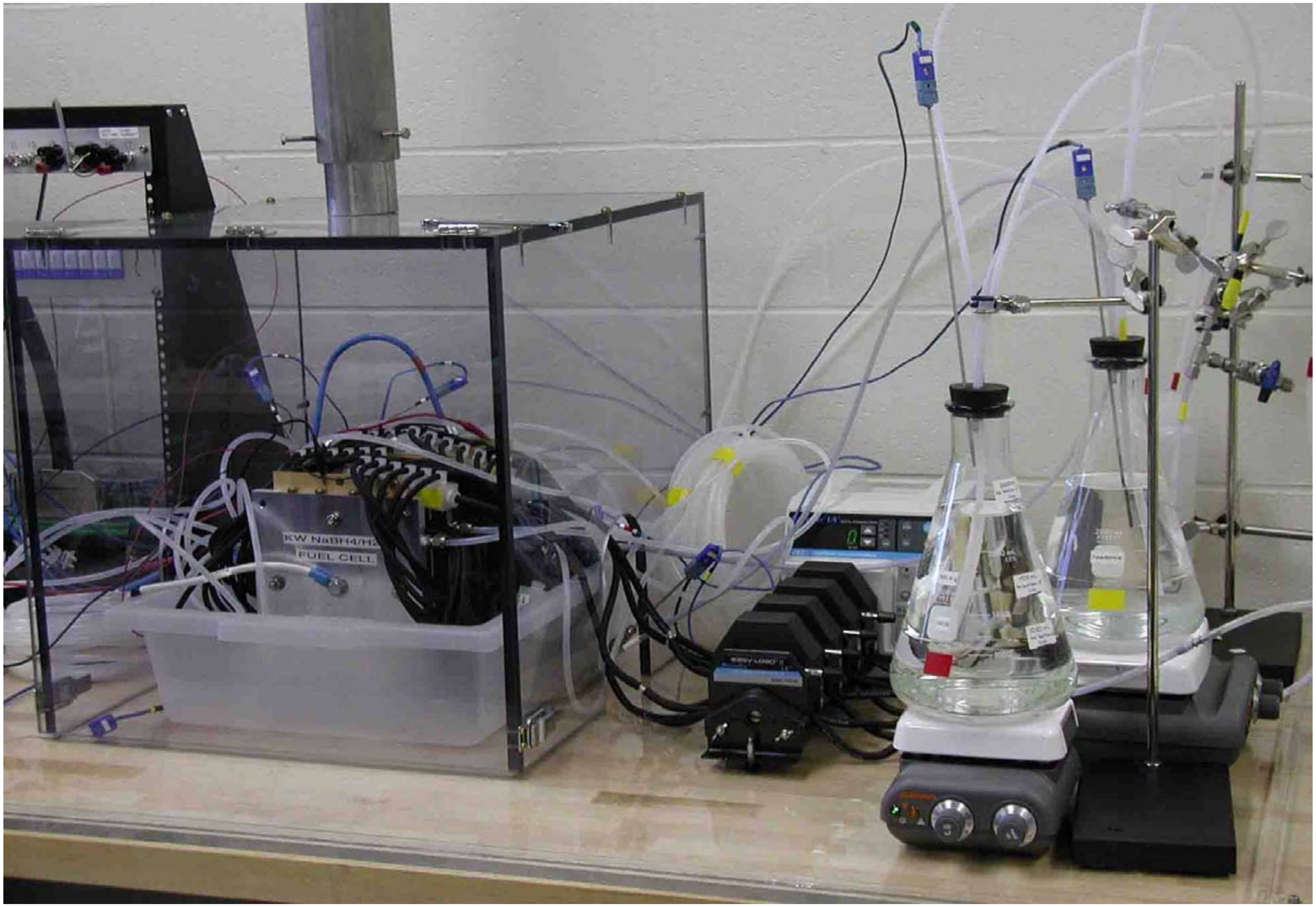


Stack Assembly

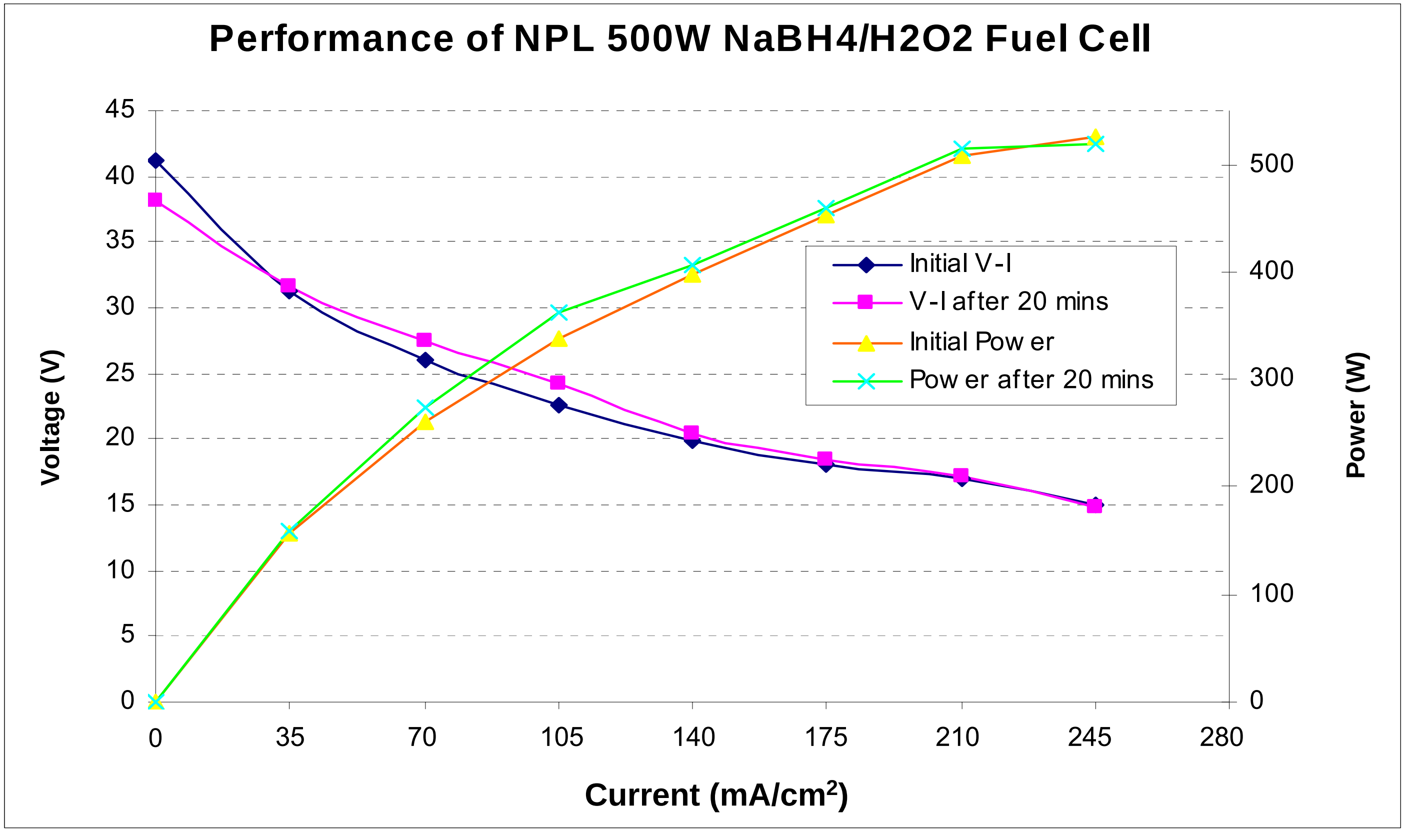


Preparation for Testing

$NaBH_4/H_2O_2$ Fuel Cell Stack Test Stand

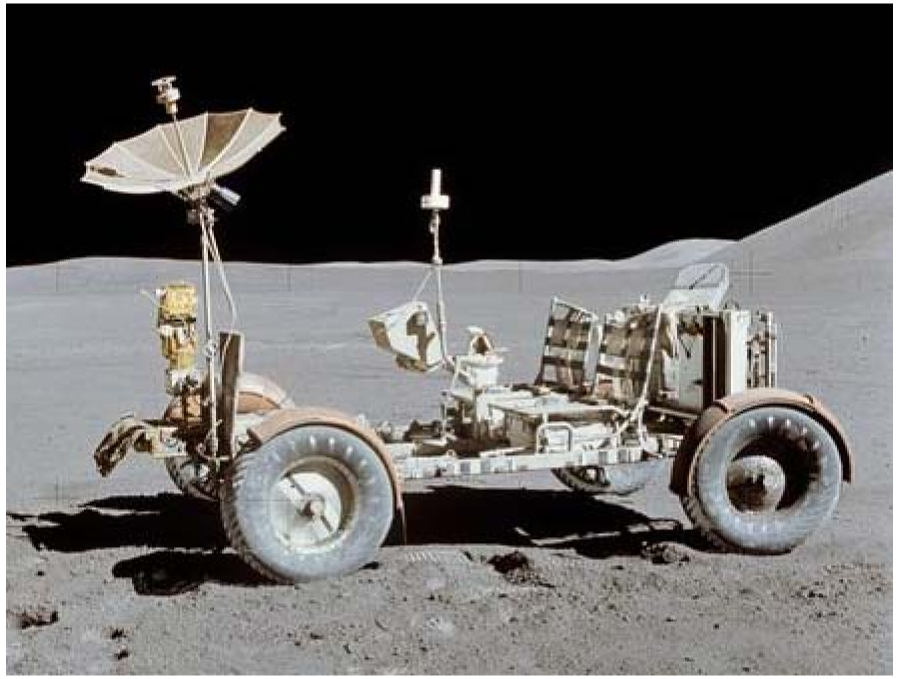


$NaBH_4/H_2O_2$ Fuel Cell Stack Testing



- V-I and P-I performance of the 500-Watt UIUC/NPL/CUA NaBH4/H2O2 Fuel Cell Stack.
- Stack voltage at 17 V at ~ 29A (~0.7V/cell at 210 mA/cm^2)
- ~60% Efficiency @ 35 mA/cm^2
- ~30% Efficiency @ 200 mA/cm^2

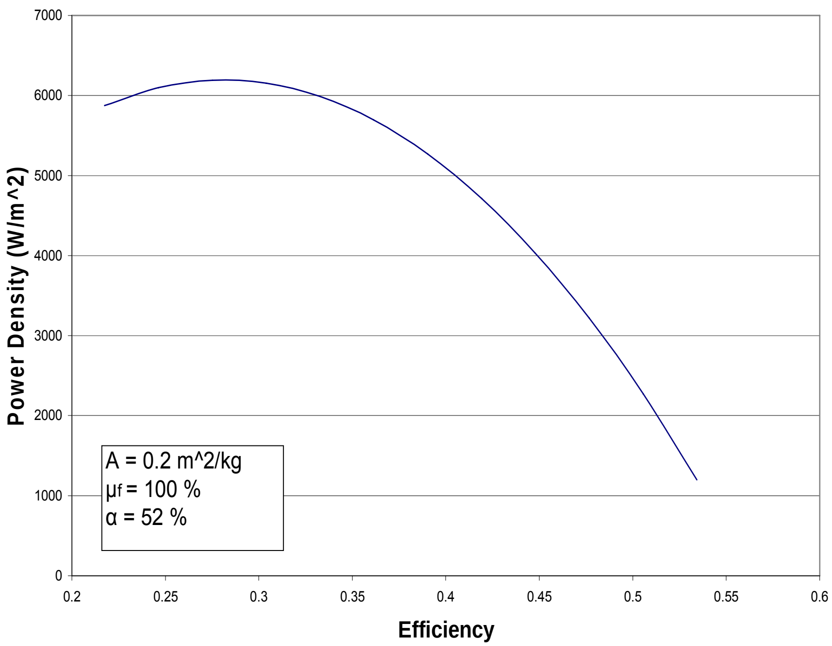
$NaBH_4/H_2O_2$ fuel cell system for Lunar rovers



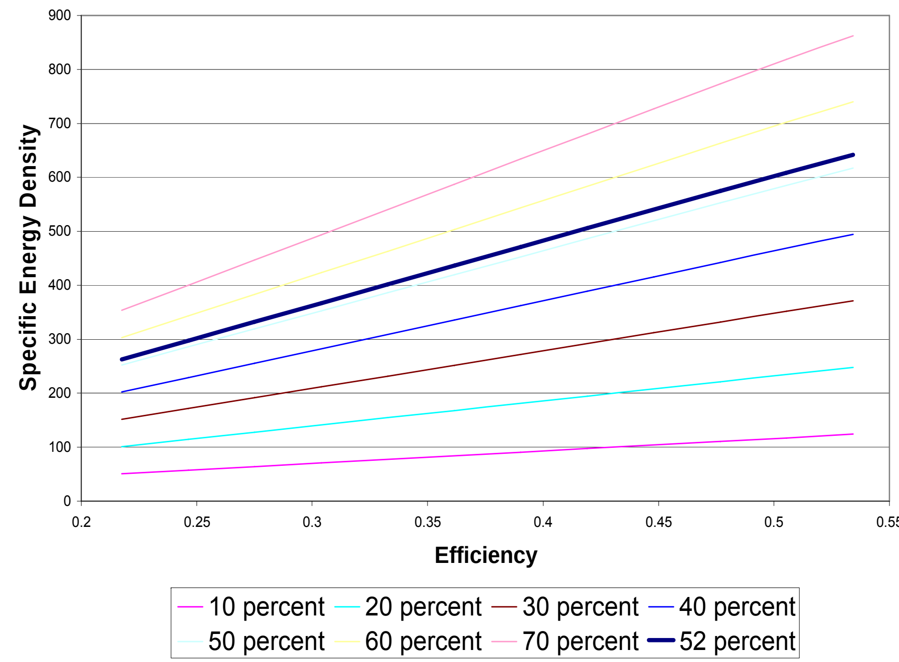
- The Apollo type rovers required about 1 kW of power.
- Power was provided by two 36-volt silver-zinc potassium hydroxide non-rechargeable batteries with a capacity of 121 Ahr. The typical energy density for such batteries is on the order of 100 Whr/kg.
- Apollo rovers operated for less than 5 hours total
- A 500-Watt $NaBH_4/H_2O_2$-50 Ahr Li-Ion hybrid fuel cell system could readily extend the rover mission range by a factor of 5

Parametric Performance Studies for the $NaBH_4/H_2O_2$ fuel cell system

Peroxide FC efficiency vs. power density

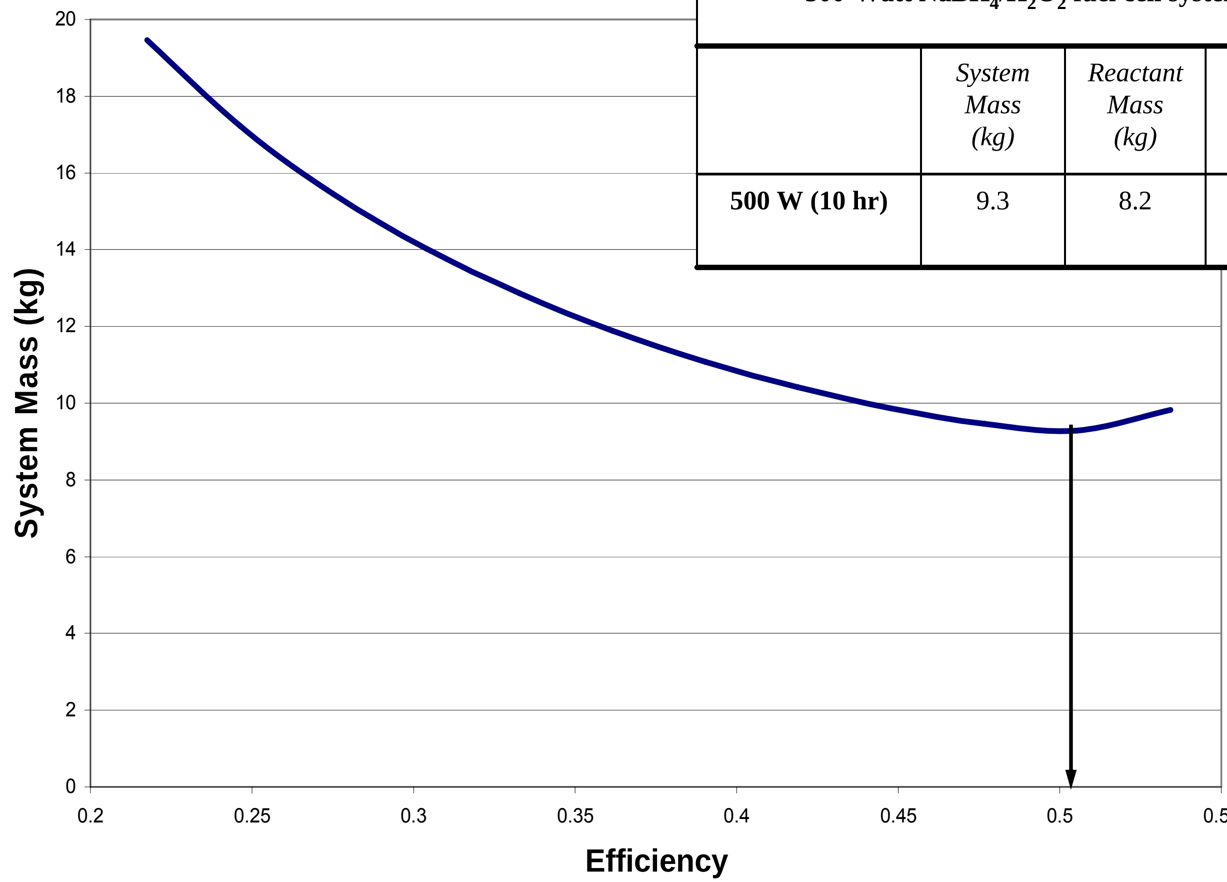


Efficiency vs. specific energy density for varying concentration



- The maximum power density of the FC stack occurs at approximately 28% efficiency.
- The higher the reactant concentrations are, the better the cell's specific performance.

System mass vs. efficiency for 500-W, 10-hr mission



500-Watt $NaBH_4/H_2O_2$ fuel cell system specifications

	System Mass (kg)	*Reactant Mass (kg)*	*Stack Mass (kg)*	*Stored Energy (kWhr)*
500 W (10 hr)	9.3	8.2	1.1	5.02

- The optimal system mass to obtain the required power output and mission life is 9.3 kg; corresponding to 51 % efficiency.

Conclusions

- Optimized $NaBH_4/H_2O_2$ MEAs can operate at a very high conversion efficiency and much reduced reactant decomposition
  - Open Circuit Voltage (OCV) > 1.75 V
  - Conversion Efficiency > 75%
- A 500-Watt $NaBH_4/H_2O_2$ fuel cell stack fabricated and demonstrated
  - Stack voltage at 17 V at ~ 29 A
  - ~60% Efficiency @ 35 mA/cm^2
  - ~30% Efficiency @ 200 mA/cm^2
- The $NaBH_4/H_2O_2$ fuel cell is particularly attractive for a variety of demanding space applications due to its superior operational performance
  - Very high energy density (over 1000 W·hr/kg based on optimized stack performance and system calculations) greater than five times higher than current state-of-the-art batteries used for space applications
  - Very high volume power density because of the direct utilization of aqueous solutions of $NaBH_4/H_2O_2$ at the anode and cathode, respectively

Acknowledgement

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