Thermal Management in Fuel Cells

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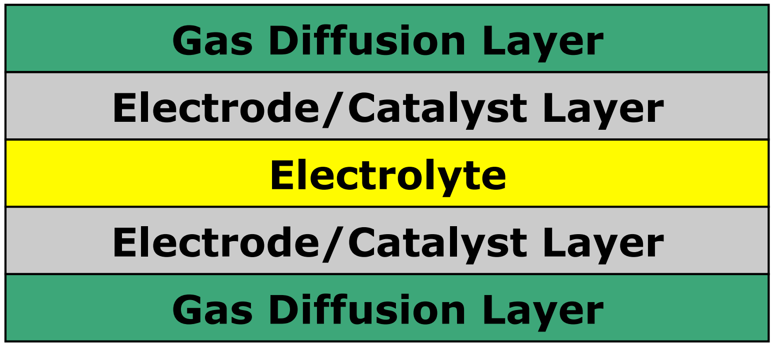
Agenda

- What is a Fuel Cell?
- Why Fuel Cells?
- Types of Fuel Cells and accompanying thermal management techniques
- Other Considerations
  - Stack size and power
  - Fuel supply
  - Start-up
  - System considerations
- About UltraCell
- Questions?

What is a Fuel Cell?

- A device that directly converts chemical energy to electrical energy
- Consists of an **M**embrane **E**lectrode **A**ssembly (MEA)
  1) Gas Diffusion Layer (GDL)
  2) Electrode and catalyst layer
  3) Electrolyte in a support material



- A **Bipolar Plate** is the current collector and flow field for reactant gas feed
- Fuel is supplied to the **Anode** side (**negative** terminal)
- Oxidant is provided to the **Cathode** side (**positive** terminal)

What is a Fuel Cell?

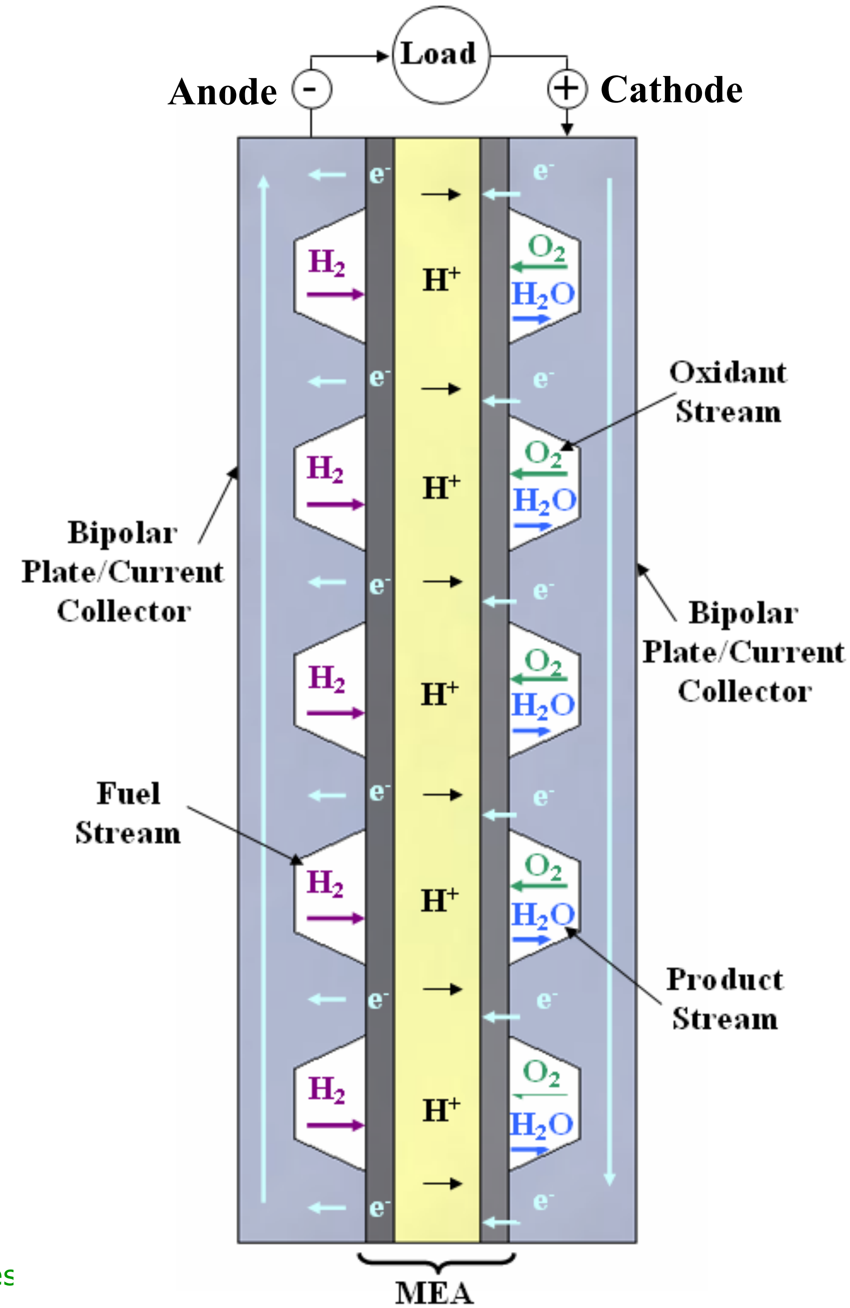
- Most common fuel is hydrogen, and the most common oxidant is oxygen (air)
- Most common half cell reactions include:
  - At the anode:

$$H_2 \rightarrow 2H^+ + 2e^-$$

  - At the cathode:

$$H^+ + e^- + \tfrac{1}{2}O_2 \rightarrow H_2O$$

- An electrical potential is generated
- The cells are stacked in series to increase the voltage



Why Fuel Cells?

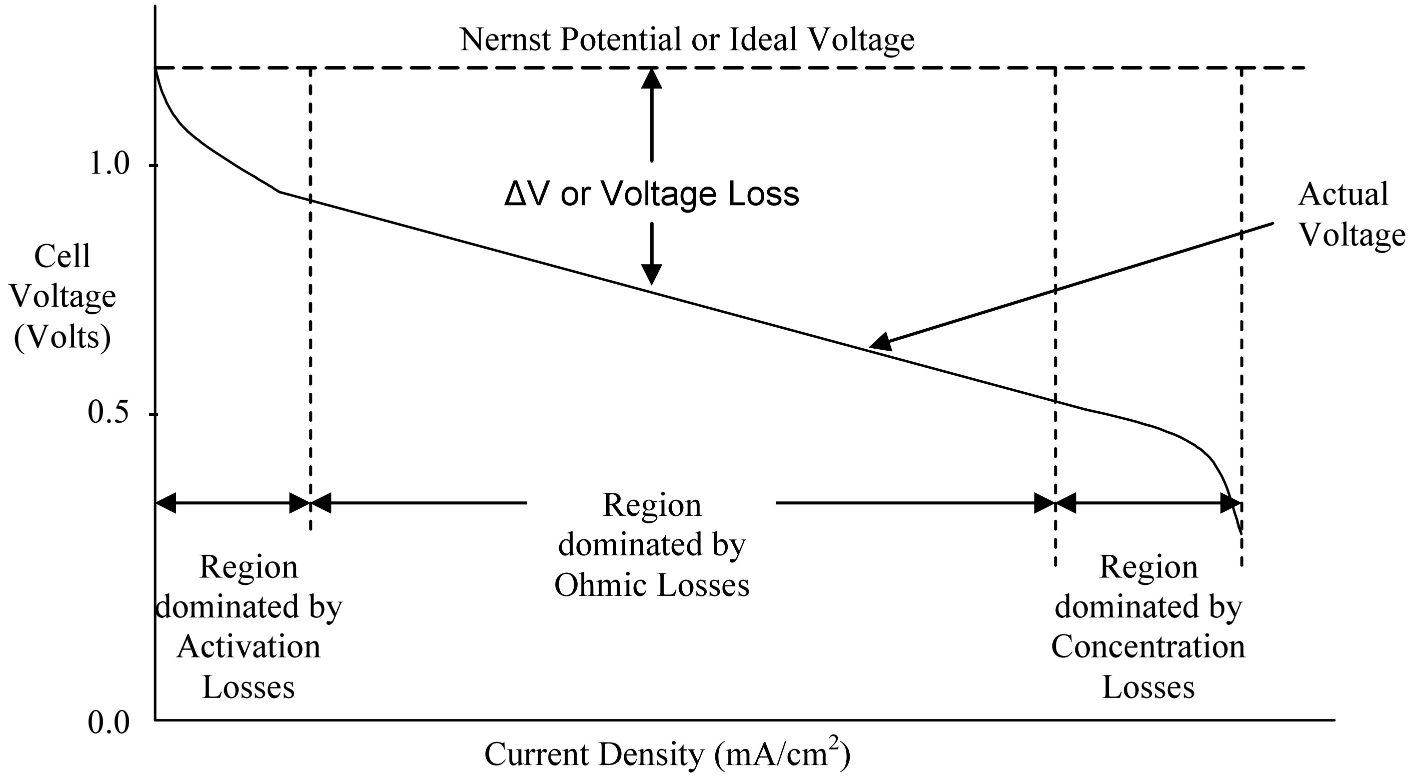
- Ideal First Law Efficiency is: $\Delta H / \Delta G$
  - First law efficiency for a typical fuel cell at 298K is 83%
  - The actual efficiency of a fuel cell is: $W_{out} / \Delta H$
  - A typical efficiency of a fuel cell is approximately 50%
- Most power generating devices have a maximum theoretical efficiency defined by the Carnot Efficiency:

$$1 - \frac{T_L}{T_H} = \frac{W_{out}}{Q_{in}}$$

  - A typical Carnot Efficiency for a Coal-Fired Power Plant is approximately 64%
  - The actual efficiency of this same power plant is 36%

Heat Generated in Fuel Cells

- Any inefficiency in a power generating devices will go to heat
- The heat generated is determined using: $W_{out}\left(\left(\frac{1}{\eta_{eff}}\right)-1\right)$
- Below is a Fuel Cell Performance Curve showing losses



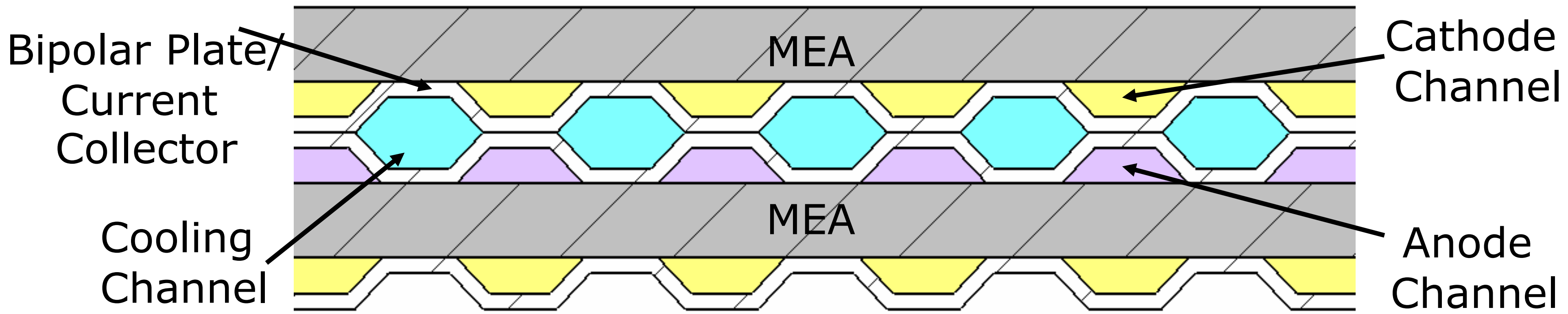
Thermal Management in Fuel Cells

- Thermal management techniques in fuel cells are determined by the power output/heat generated and the type of fuel cell
- Most fuel cells are classified according to the electrolyte employed
- Varies with respect to operating temperature, design, fuel use, etc.
- Some examples:

Type of Fuel Cell	**Operating Temp. (°C)**
Polymer Electrolyte Membrane (PEM)	80
Phosphoric Acid (PAFC)	150-200
Molten Carbonate (MCFC)	650
Solid Oxide (SOFC)	700-1000

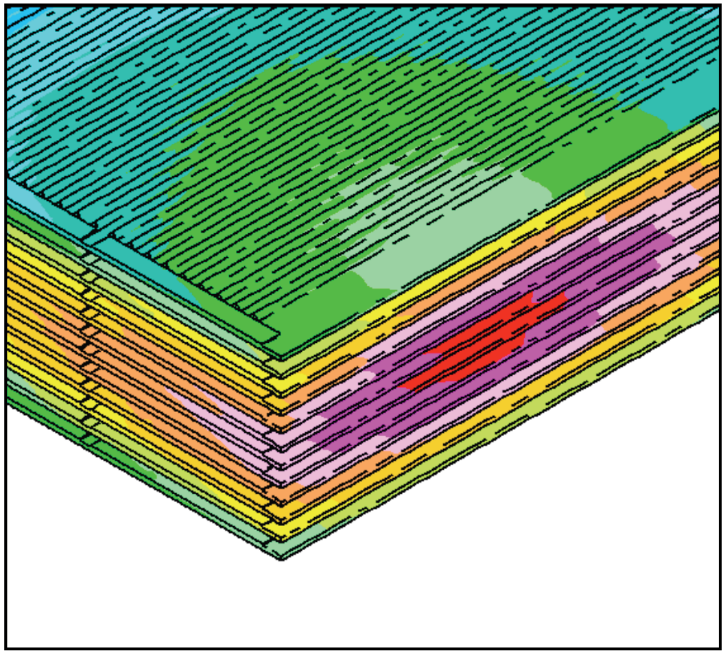
Polymer Electrolyte Membrane Fuel Cells

- Operating temperature approximately 80 deg. C
- Membrane consists of a perfluorosulfonic polymer where the water absorbed into the membrane ionizes the sulfonic acid groups and facilitates proton transport
- Thermal gradient at each cell and throughout the stack must be controlled to guarantee proper humidification of the membrane and overall performance
- Because the operating temperature is fairly low, typically, liquid cooling channels throughout the stack transfer heat from the fuel cell



Phosphoric Acid Fuel Cells

- Operating temperature between 150 and 200 deg. C
- Electrolyte is phosphoric acid which transfers H^+ ions
- The temperature difference between the fuel cell stack and the environment is high enough (100-150 deg. C) that the stack can be air-cooled
- The surface area for cooling on the stack is large enough that standard heat sinks, etc. can be utilized
- If high thermal conductivity materials are used for the stack construction, there will be a small thermal gradient



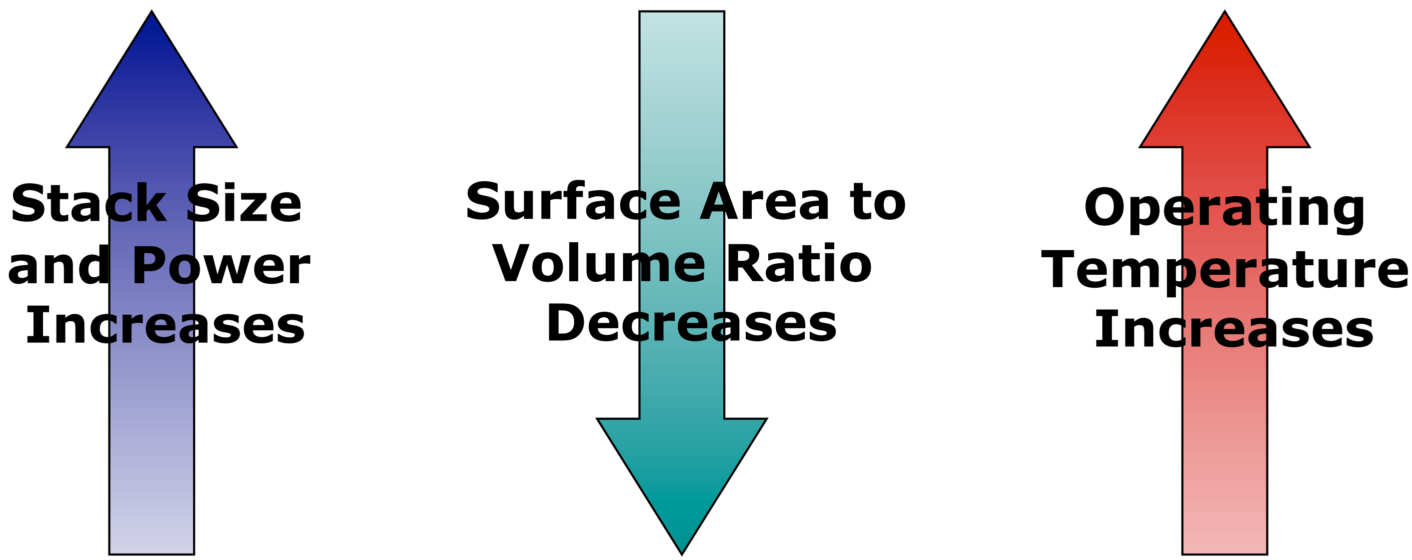
Temperature Gradient in a Phosphoric Acid Fuel Cell Stack

Solid Oxide Fuel Cells

- Operating temperature between 700 and 1000 deg. C
- Electrolyte is a solid ceramic consisting of Yttria-stabilized Zirconia which transfers oxygen ions ($O^{=}$)
- A key issue with the thermal management of SOFCs is minimizing heat losses
- Large thermal gradients and thermally cycling of stacks can introduce cracks in the membrane and cause leaks at sealing interfaces
- Because of high operating temperatures, feed gases into the stack are adequate for minimizing thermal gradients in the stack; flows are typically in a cross-flow or counter-flow orientation

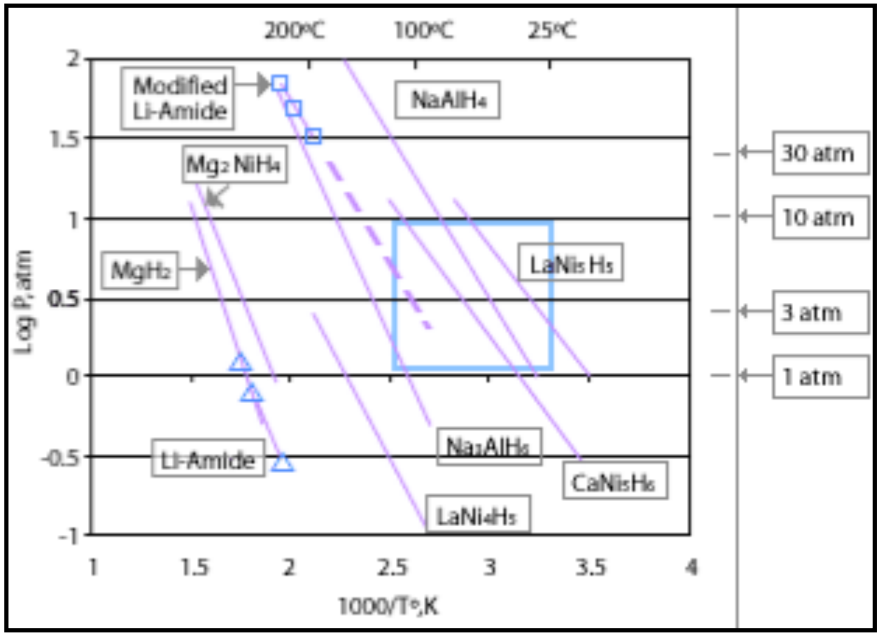
Other Considerations: Stack Size and Power

- Depending on the design, as the stack size and power increases, the outer surface area to volume ratio decreases
- Because of this factor, larger stacks use electrolyte chemistries that operate at higher temperatures, and smaller stacks use electrolyte chemistries that operate at lower temperatures



Other Considerations: Fuel Supply

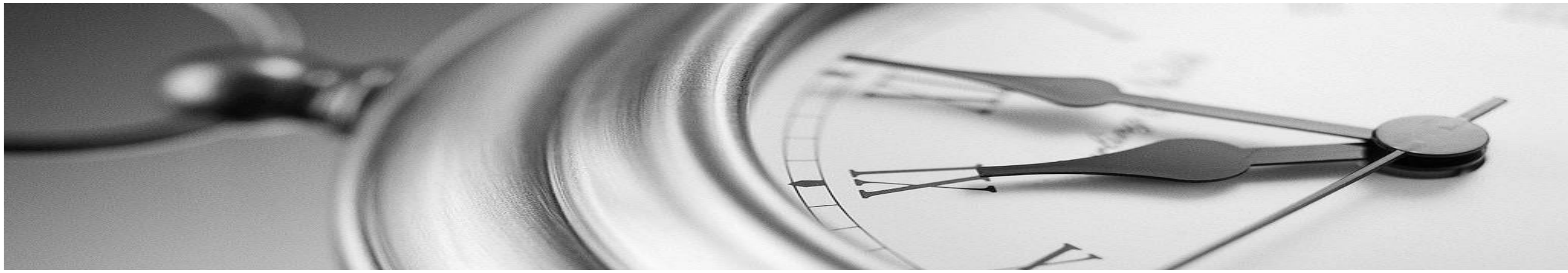
- Hydrogen can be supplied from Metal Hydrides
  - Heat is needed to release hydrogen from Metal Hydrides
- Hydrogen can be generated from other fuels through reforming
  - External Reforming – Occurs outside of the Fuel Cell and requires heat
  - Internal Reforming – Occurs inside the Fuel Cell and can help in the thermal management of the Fuel Cell
- Other fuels can be used directly at the fuel cell anode depending on the fuel and fuel cell type



http://www1.eere.energy.gov/hydrogenandfuelcells/storage/metal_hydrides.html

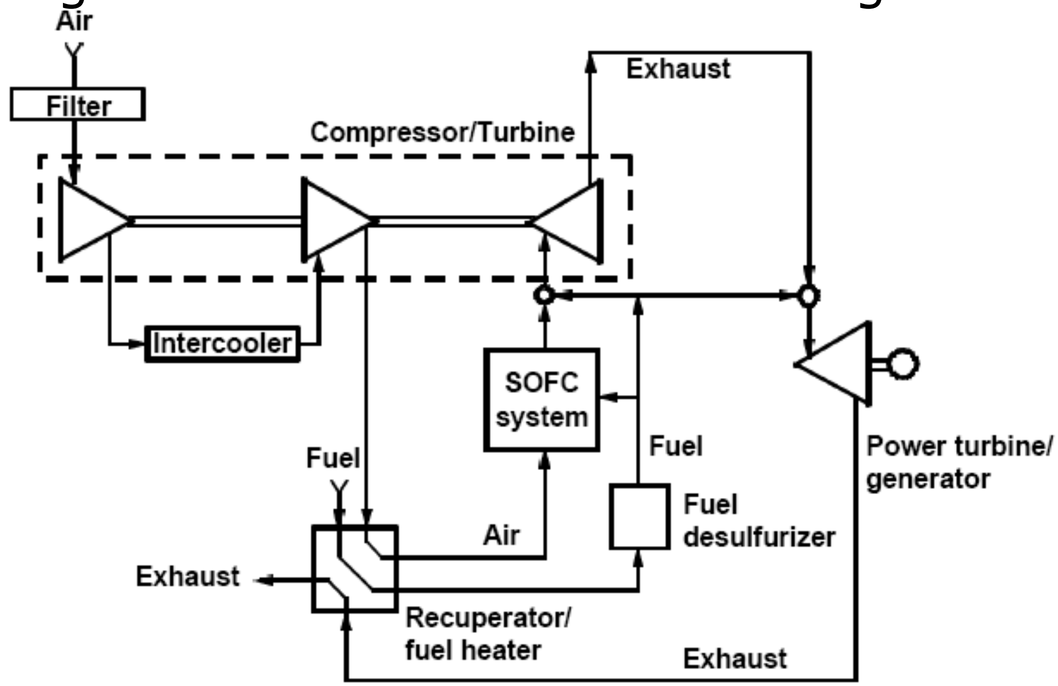
Other Considerations: Start-up Time

- Because each fuel cell type requires operating temperatures above ambient conditions, there is a period of time for heating before power generation begins
- Burning fuel interior or exterior of the fuel cell can be an effective way to increase the temperature of the stack
- Resistive heating in the stack
- Fast start-up times are key to public acceptance of fuel cells in most markets



Other Considerations: Fuel Cell Systems

- To improve system efficiency, waste heat from the fuel cell stacks can be used to pre-heat incoming air and fuel with heat exchangers
- With higher temperature fuel cell stacks, the exhaust gases from the stacks can be used inline with other power generating devices such as gas turbines
  - Hybrid systems like this can achieve system efficiencies above 60%
  - Waste heat can be used for domestic and industrial purposes; this is known as Cogeneration or Combined Heat and Power (CHP)



http://www.netl.doe.gov/publications/proceedings/96/96fc/fc96/96FC5-3.PDF

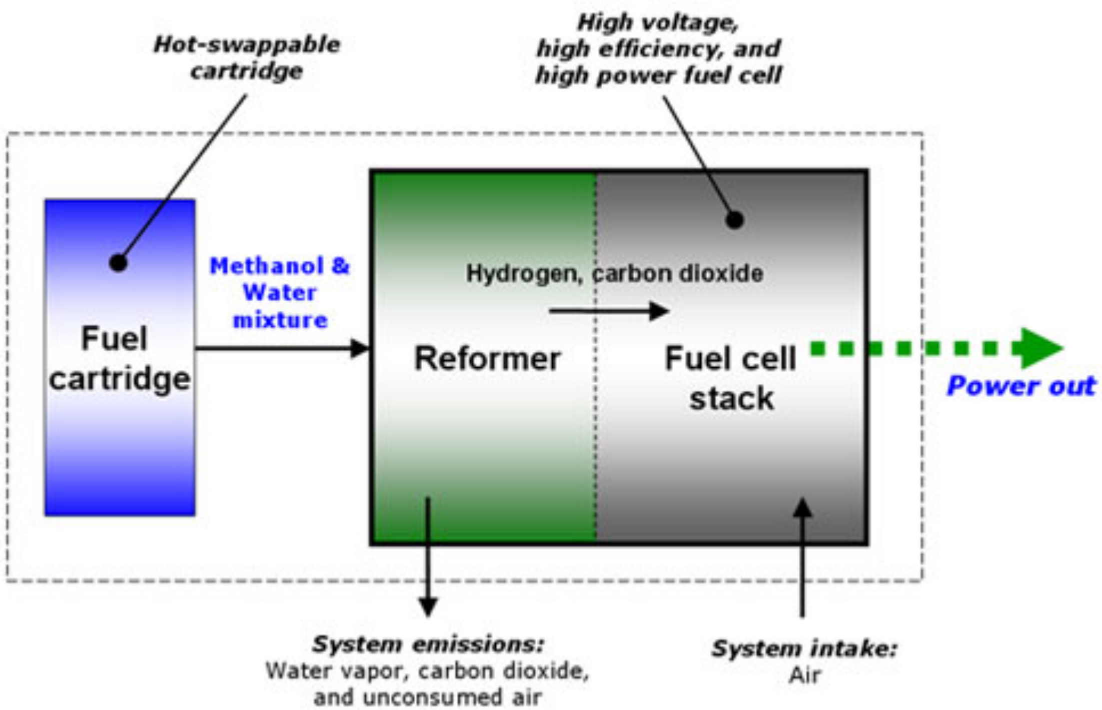
- Any unconsumed air or fuel from the fuel cell can be used in other processes to improve the system efficiency

UltraCell XX25™ Fuel Cell System

- Company founded in 2002
- Headquarters and R&D in Livermore, CA
- Manufacturing facility underway in Dayton, OH
- First commercially viable Reformed Methanol Fuel Cell (RMFC)
- Alpha tests complete: general performance and durability
- Beta tests underway: application specific performance
- Completed Mil. Spec. tests and achieved TRL7
- UltraCell XX25A (25W) system available for delivery

UltraCell XX25™ Fuel Cell System

- 25 Watts continuous power output (up to 2A at 12V)
- Like a small generator. Runs on fuel cartridges
- Weighs just 1.24kg and is the size of a hardback book
- Reformed Methanol Fuel Cell (RMFC) System

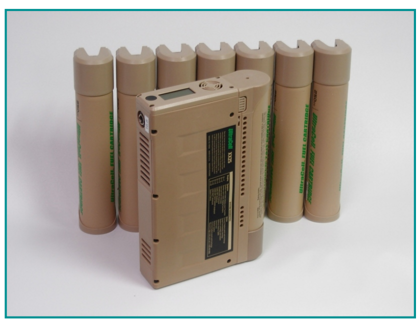


UltraCell XX25™ Fuel Cell System

- Markets include:
  - Portable Power for Military Applications
  - Communications
  - Sensors and Surveillance
  - Battery Charging
  - Ruggedized Laptops
  - Emergency disaster and response
  - Field research and exploration
- Will provide a 70% weight savings for a 72hr mission

XX25™ and eight cartridges

72 hr mission wt. = 4.0 kg (8.8 lb)

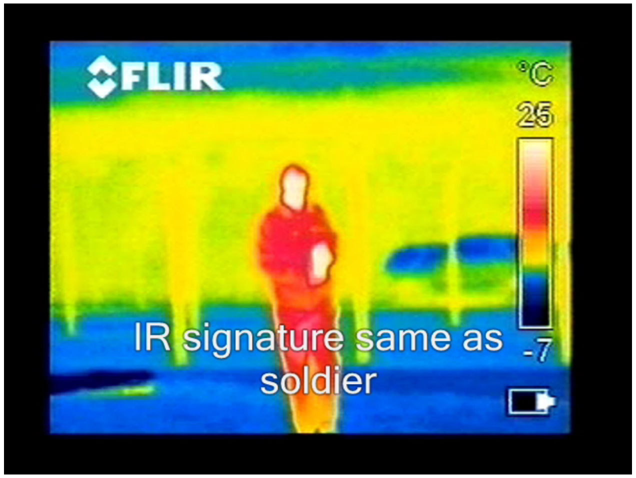


Nine BB-2590s (military Li-Ion rechargeable batteries)

72 hr mission wt. = 12.3 kg (27.0 lb)

UltraCell XX25™ Fuel Cell System

- XX25™ has passed a multitude of MIL-STD-810F Tests which include:
  - Altitude (810F, Method 500.4, II & IV)
  - Temperature Cycling (810F, Method 503.4, II)
  - Solar Radiation (810F, Method 505.4, I)
  - Humidity (810F, Method 507.4)
  - Dust (810F, Method 510.4, I)
  - Vibration (810F, Method 514.5)
  - Functional Shock (810F, Method 516.5, I)
  - Acidic Atmosphere (810F, Method 518, sev. "a")
  - Icing and Freezing Rain (810F, Method 521.1, II)
  - EMI/EMC (461E/462 - RE101, RS101)



Any Questions?

"*Best Soldier System Innovation & Technology*"
at the Soldier Technology USA 2008 Conference