Honeywell

Solid Oxide Fuel Cell System Development and R&D Needs

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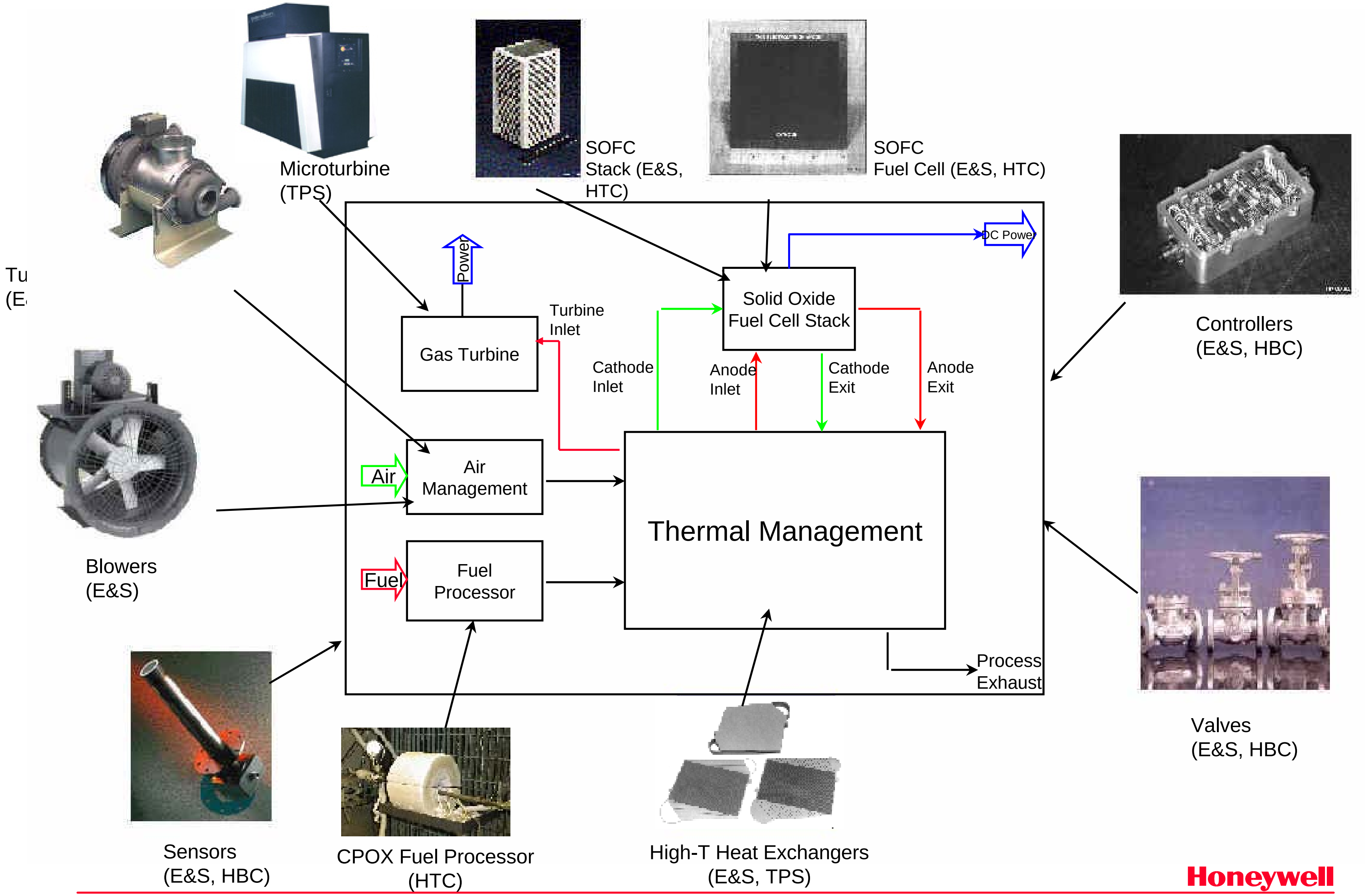
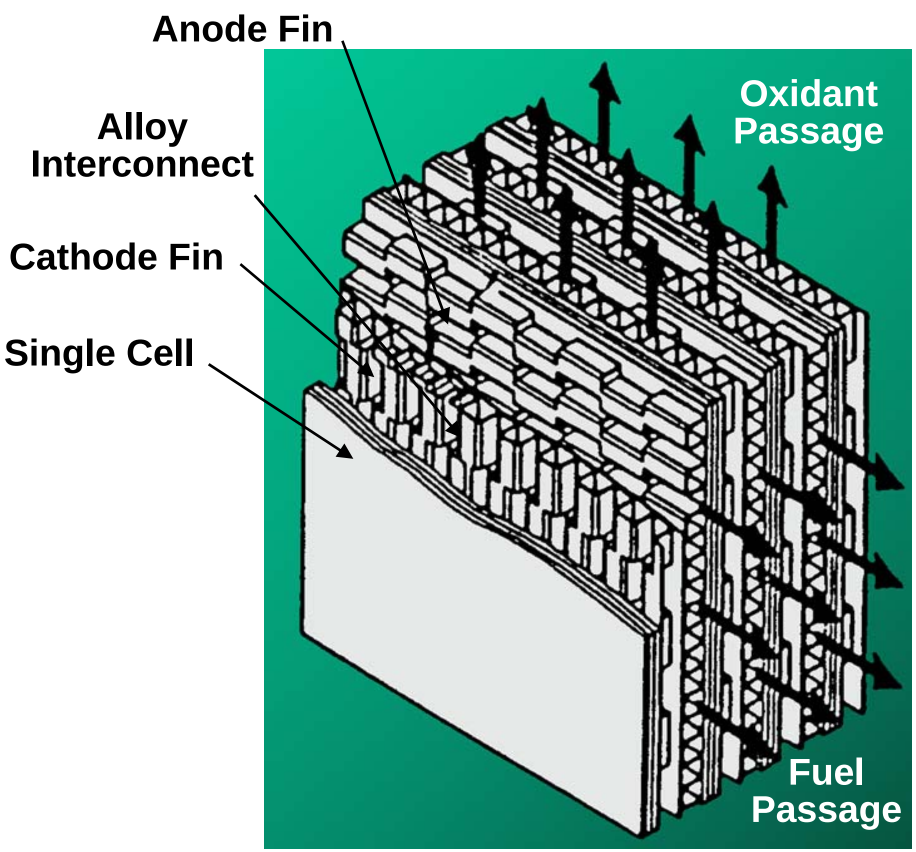
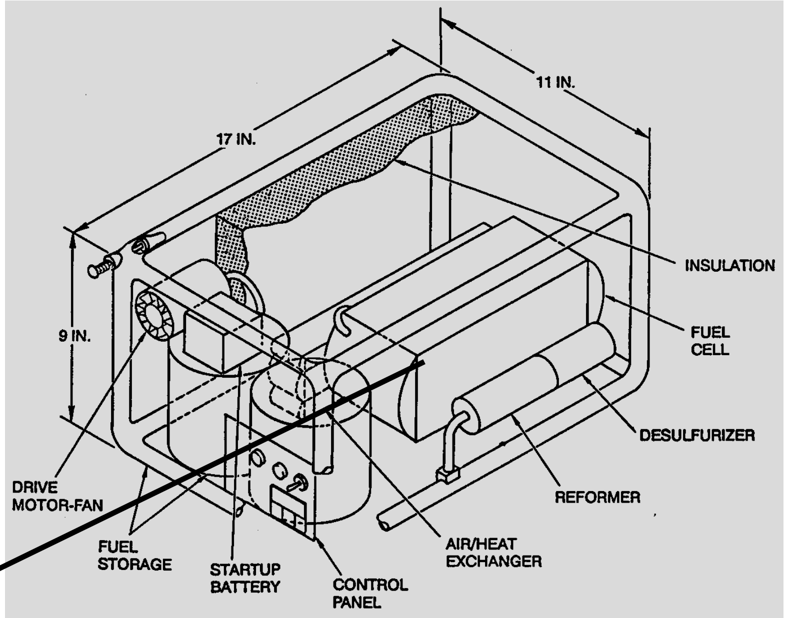
SECA Core Technology Program Planning Workshop
February 14-15, 2001
Atlanta, GA

Simplified SOFC System & Components



Solid Oxide Fuel Cell Battery Charger



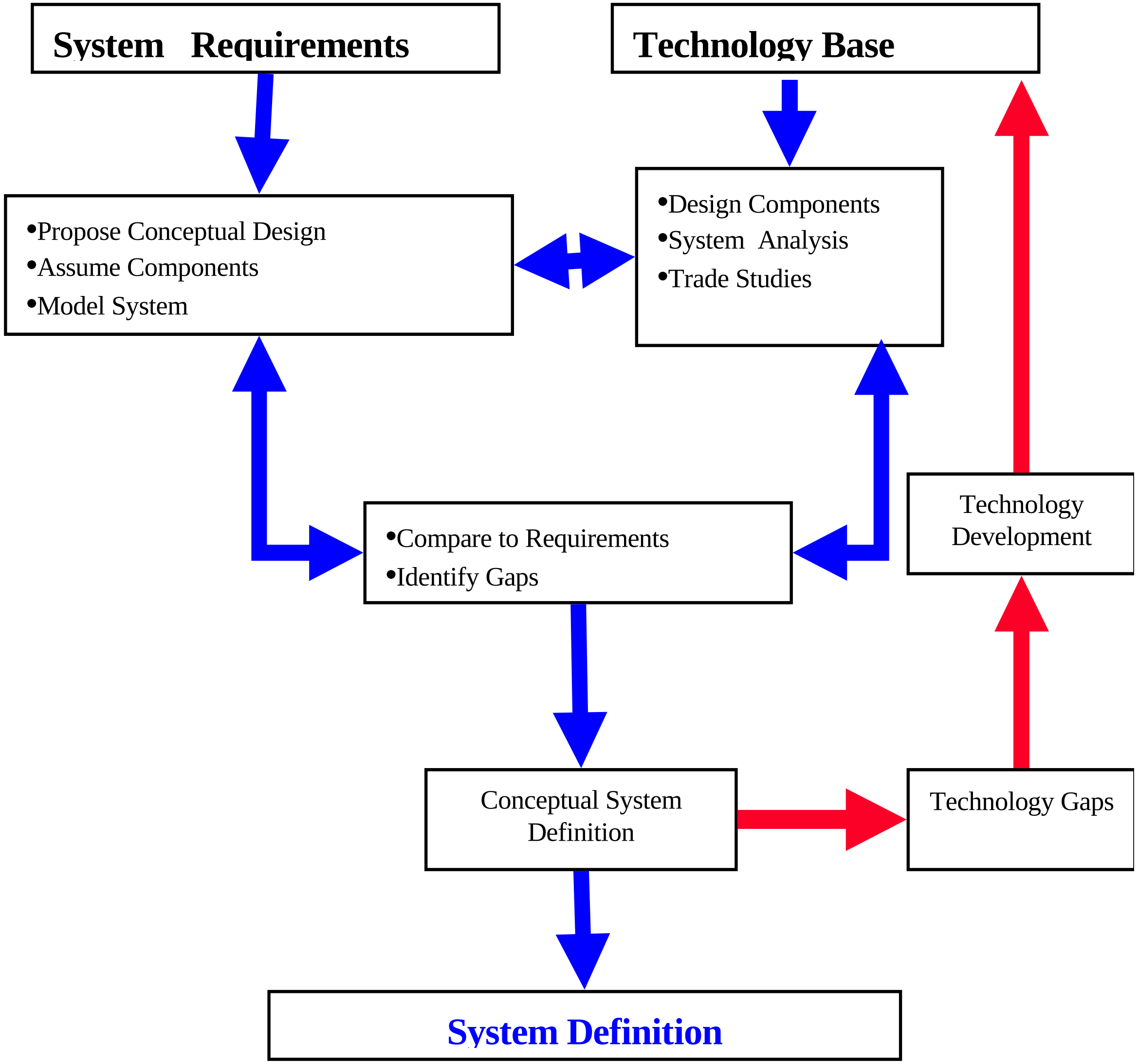


500-W SOFC Battery Charger - Characteristics

- **Targets**
  - Weight = 7 kg
  - Voltage = 28 VDC
  - Operation on logistic fuels (JP and diesel)
  - Portable

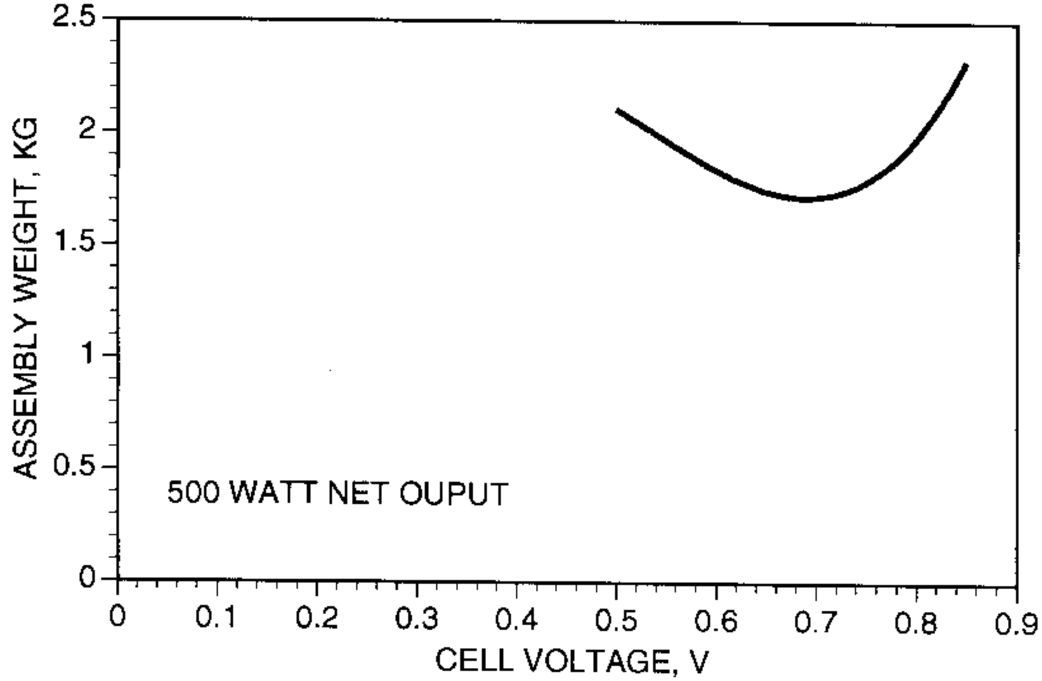
- **Key technologies**
  - Reduced-temperature solid oxide fuel cell (SOFC) for power generation
  - Catalytic partial oxidation (CPOX) for processing logistic fuels

System Design Methodology



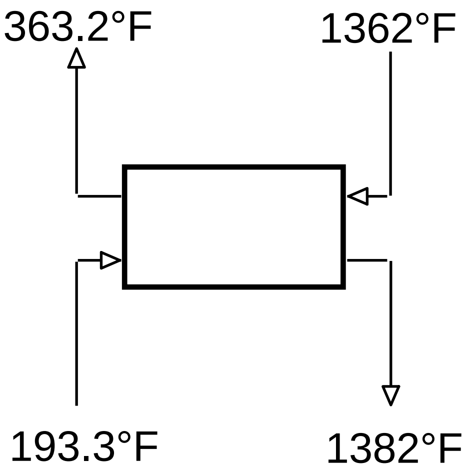
Fuel Cell Assembly Weight Optimization

- 500 Watt; 28 Vdc Output
- Hydrogen Utilization: 0.8
- Inclusion of Manifolds
- Inclusion of Insulation of Exposed Surface Areas (Tsurface 140°F)

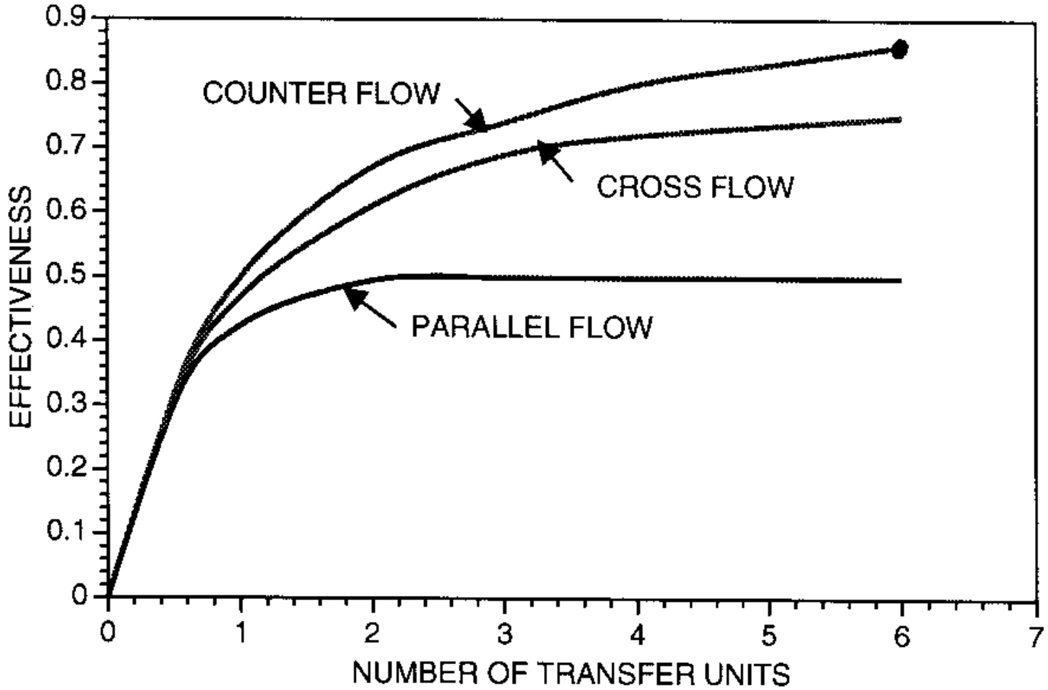


Air-to-Air Heat Exchanger Requirements

- **High Temperature Effectiveness Impose Counter Flow Design**

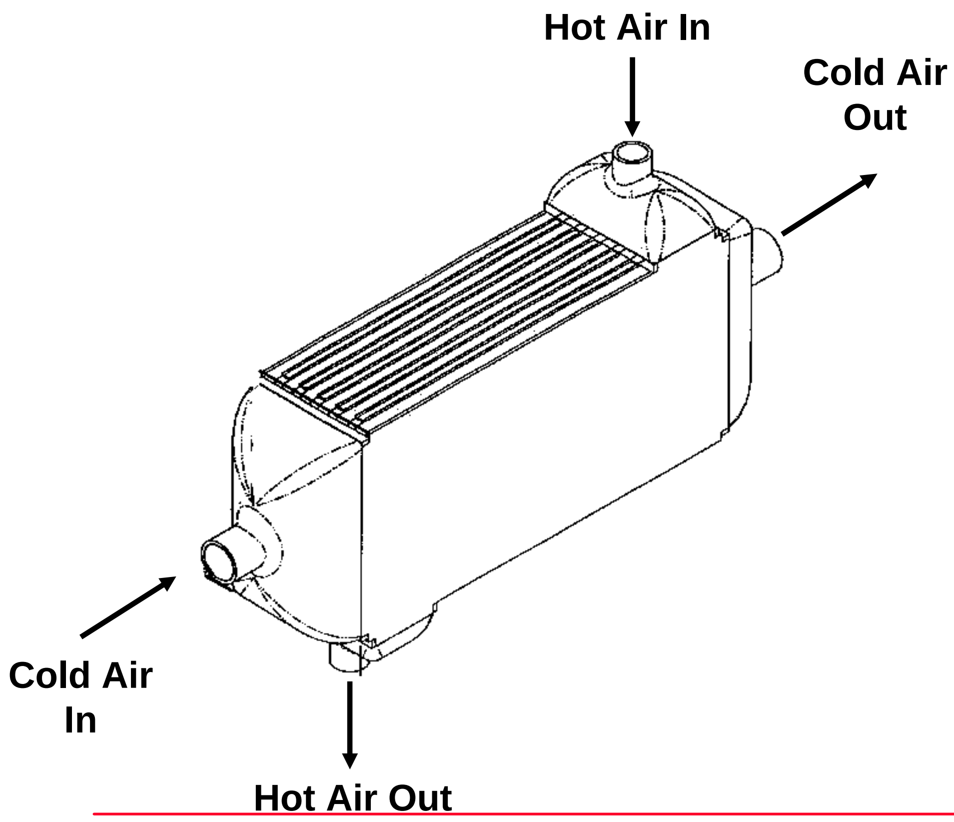


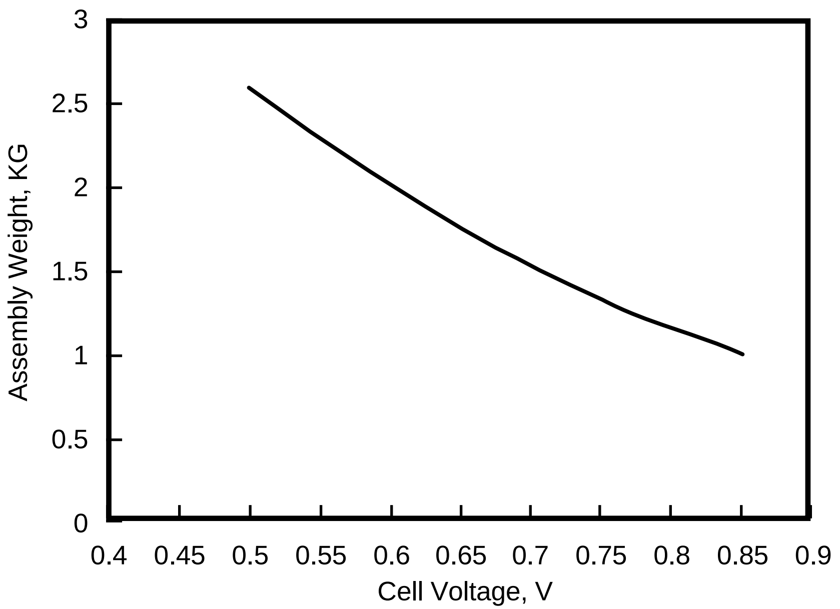
$$\varepsilon_{HOT} = \frac{1562 - 363.2}{1562 - 193.3} = .875$$



Air to Air Heat Exchanger Performance

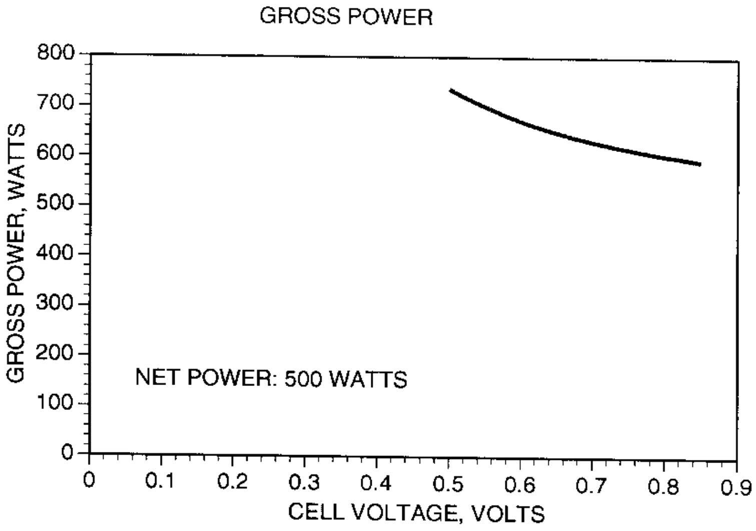
- **Alloy Construction**
- **Fin: 16R-.125-1/8 (0)-.004**

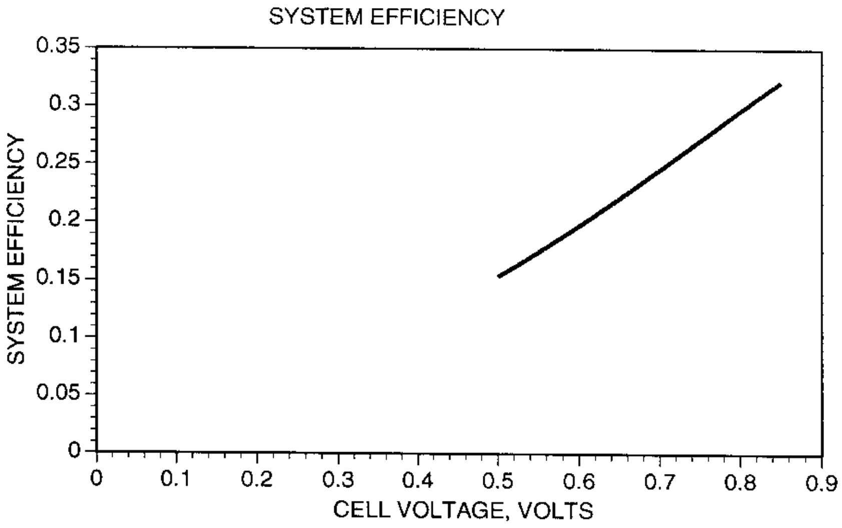




System Performance Characteristics

- **Hydrogen Utilization: 0.8**

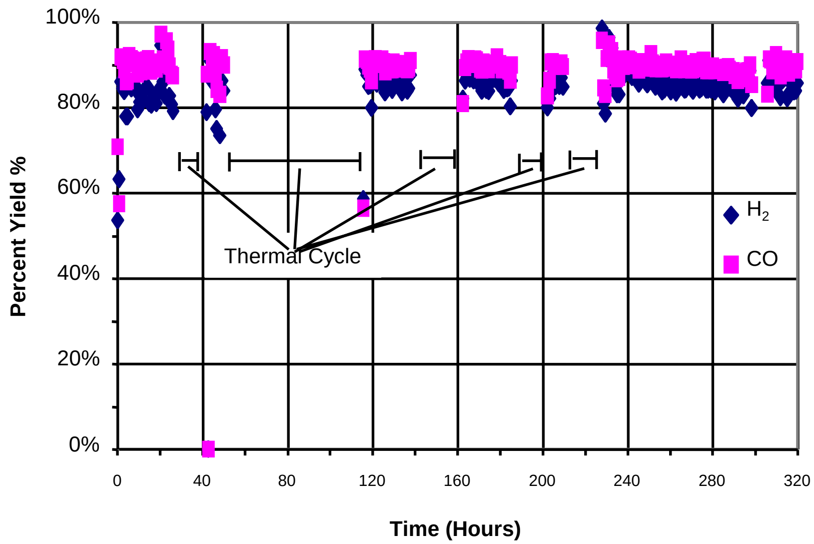




Fuel Cell Performance Characteristics

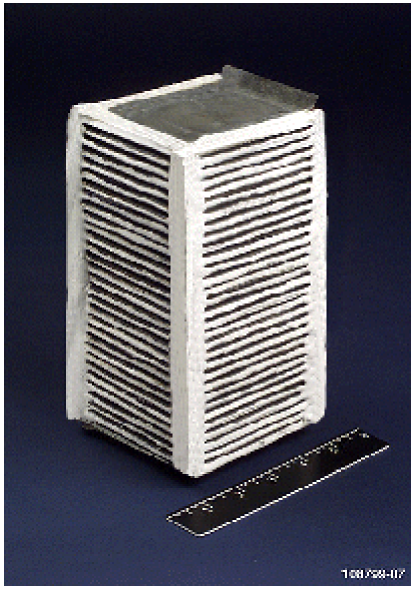
	Cross Flow	Radial Flow
• Cell Voltage	0.65	0.65
• Hydrogen Utilization	0.84	0.84
• Fuel Flow, lb/hr	0.361	0.361
• Air Flow, lb/hr	40.7	43.3
• Gross Power, W	584.9	587.3
• System Efficiency, %	25.07	24.91

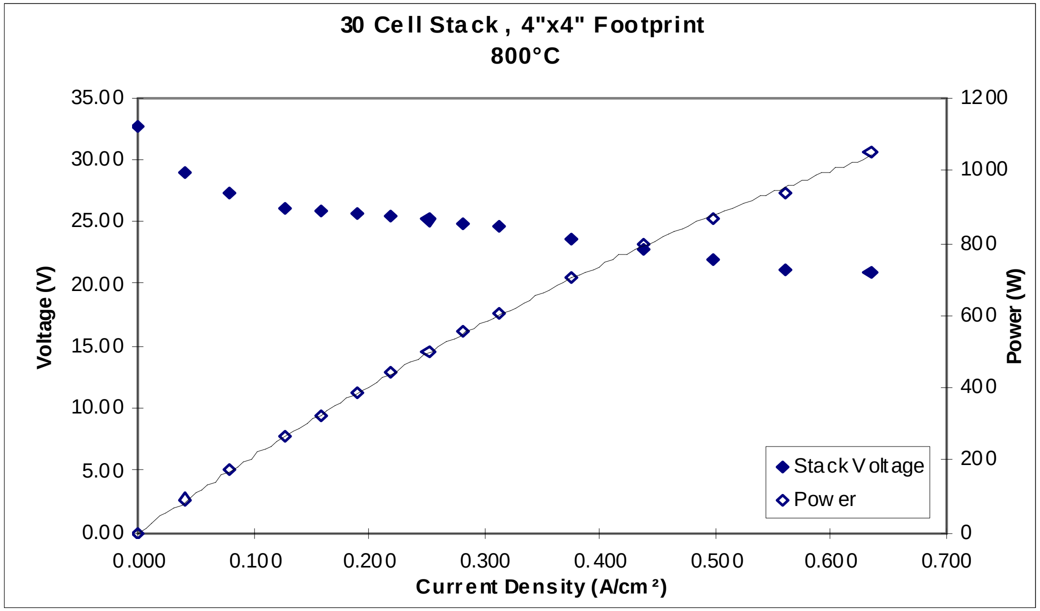
CPOX Performance Metrics



- **Duration: 700 hours to date**
- **Thermal Cycles: 10**
- **Sulfur Tolerance: 1000 ppm dibenzothiophene in JP-8**
- **Yield: 70-80% of LHV in JP-8**

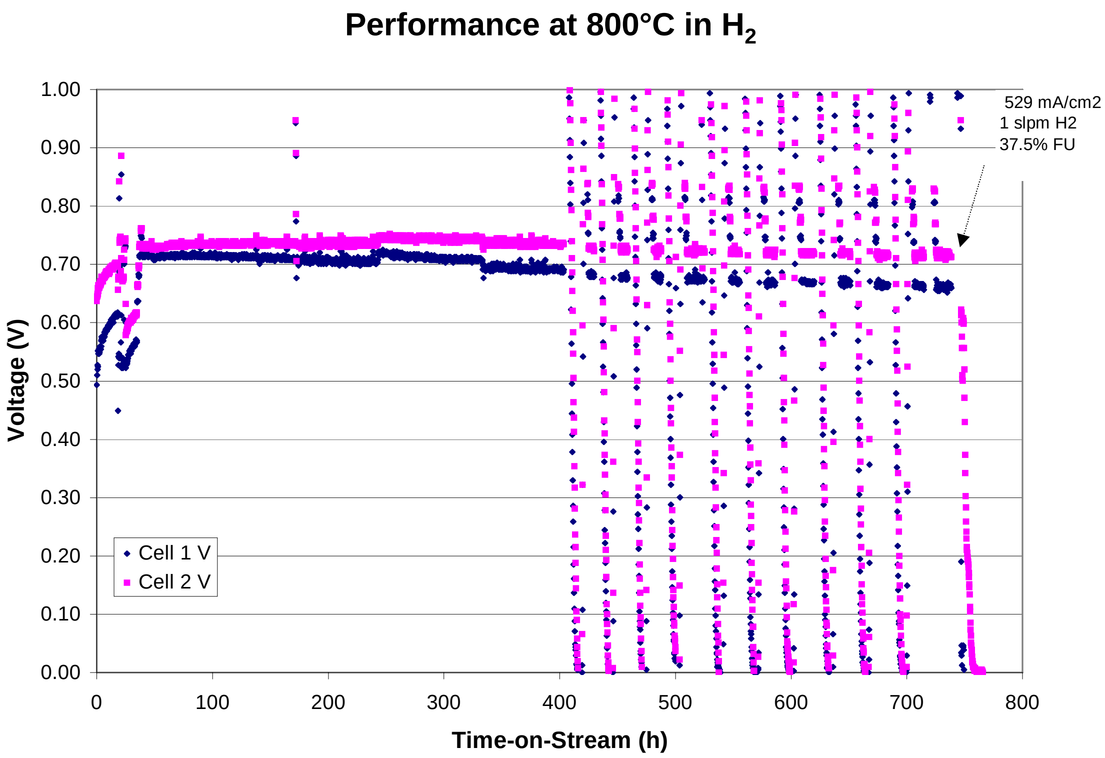
SOFC Stack Metrics





- **10 cm x 10 cm footprint**
- **800°C operation in hydrogen and air at ambient pressure**
- **Power:**
  - **1.1 kW at 0.7 V / cell**
  - **1.4 kW at peak power**
- **Power density:**
  - **0.42 W/cm2 at 0.7 V/cell**
  - **0.6 W / cm² at peak power**
  - **0.7 kW / kg, 0.7 kW / L at peak power**
  - **0.53 kW / kg, 0.53 kW / L at 0.7 V/cell**

Thermal Cycling



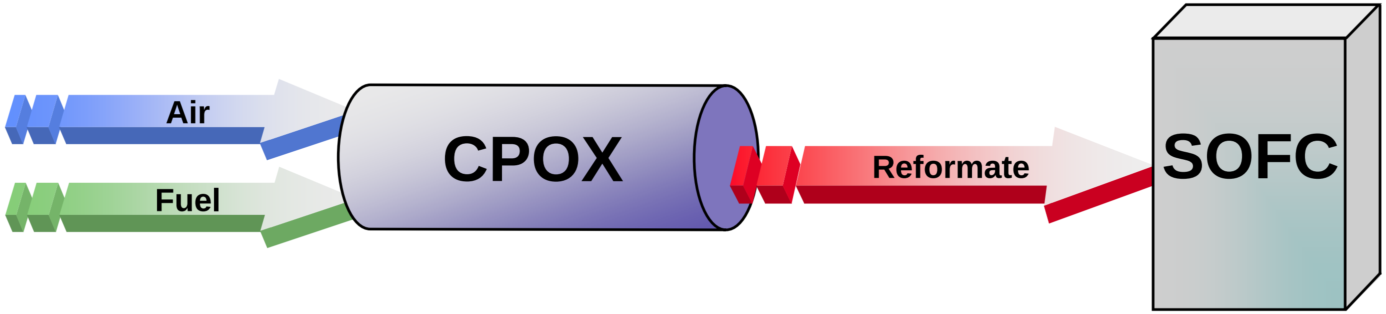
- **Multiple thermal cycles without significant performance degradation**
- **Minimal change in open circuit voltage and voltage under load between cycles**

SOFC stacks are being engineered for thermal cycling capability

CPOX/SOFC Integration - Key Parameters

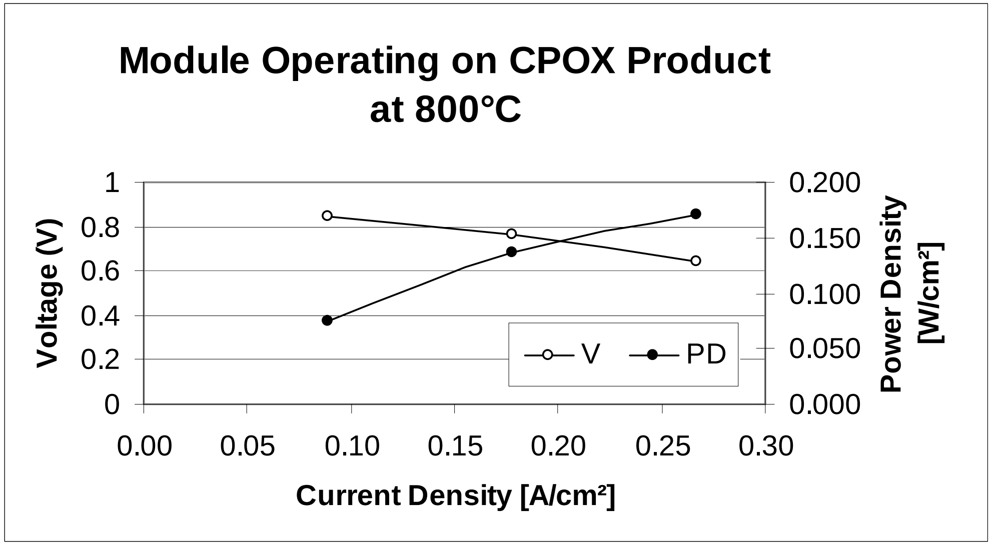
- **Start-up and shut-down procedures**
- **Range of operating parameters**
- **Pressure drop**
- **Thermal management**
- **Transient characteristics**

Integrated CPOX-SOFC Operation



CPOX

Input	Output
JP-8	17.3% H_2
Air	21.0% CO
	0.7% CO_2
	11.0% H_2O
	50.0% N_2



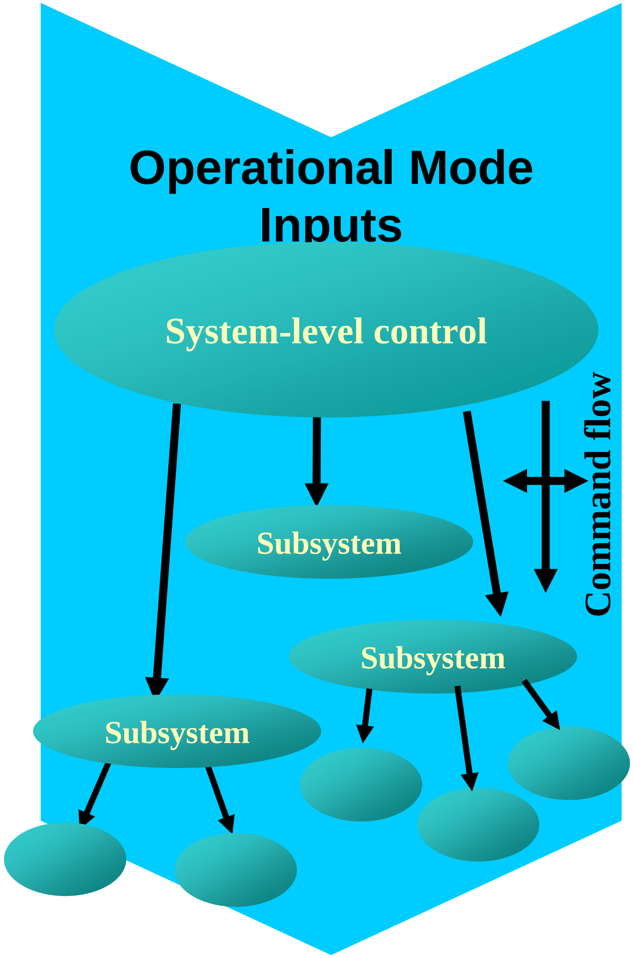
Demonstration of multicell SOFC operation on JP-8 syngas

50 W Demonstration Unit

- **Demonstration of key component integration**
  - **Integration of system components, especially CPOX fuel processor and SOFC stack**
- **Self contained operation**
  - **Startup**
  - **Thermal integration**
  - **Propane fuel**

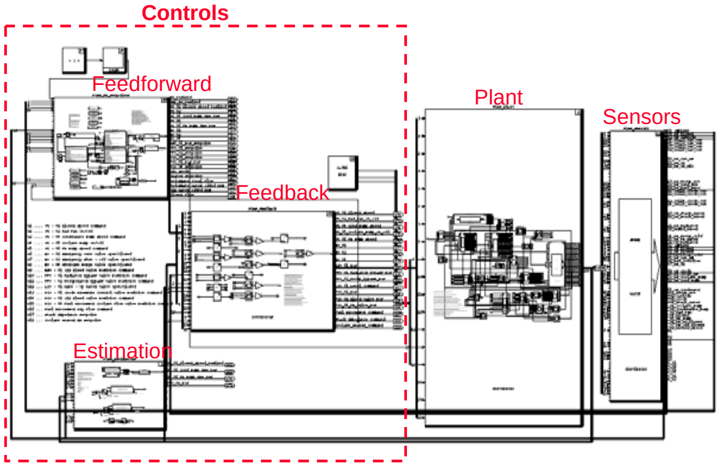
Control System Functions - drives integration

- **Coordinate subsystems for shared resources and efficient operation**
- **Regulate yet be responsive over a wide operating range**
  - **Flow / Composition**
  - **Temperature**
  - **Pressure**
  - **Power**
- **Provide safe system operation through built-in test**
- **Perform process and component health monitoring for improved life cycle**
- **Provides user interface and automated system operation**
  - **Startup/ Shutdown**
  - **Scheduled operation**
  - **Status indicators/alarms**

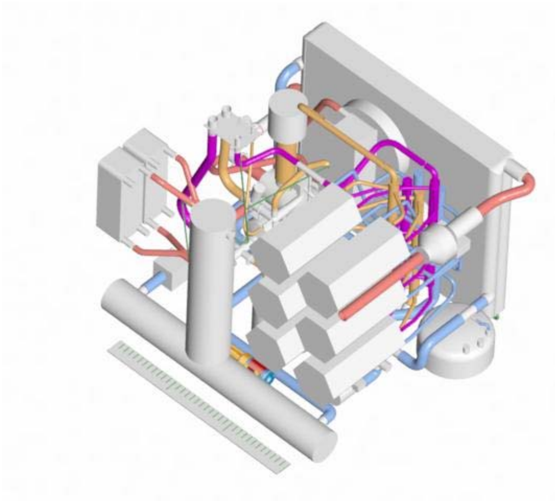


Control Development Approach

- **Develop dynamic system models and design control through simulation.**
- **Rapid prototyping capabilities allows quick evaluation of controls designed in simulation.**
- **Advanced control and sensing techniques can be investigated through simulation trade studies and prototyping. The most promising approaches implemented in product.**



Rapid Prototyping



SOFC System - R&D Needs

- System Analysis and Modeling
- System Thermal Management including
  - Thermal cycling
  - Startup
- Fuels and Fuel Impurities
- Controls/Sensors
- Power Electronics

System Analysis and Modeling R&D Needs

- **System Steady-State Models**
  - Component models
  - System performance
- **Dynamic System Models**
  - Component models
  - Transient performance
- **SOFC Design and Performance Analysis**
  - Thermal
  - Stress
  - Performance

Thermal Management R&D Needs

- **Heat Exchanger and Insulation**
  - Low-cost high-temperature alloys/composites
  - Oxidation resistant coating for low grade metals
  - Low-cost insulation materials/methods

- **Thermal Cycling**
  - Models to predict thermal cyclability of SOFC stacks
  - Modifications of material coefficient of thermal expansion

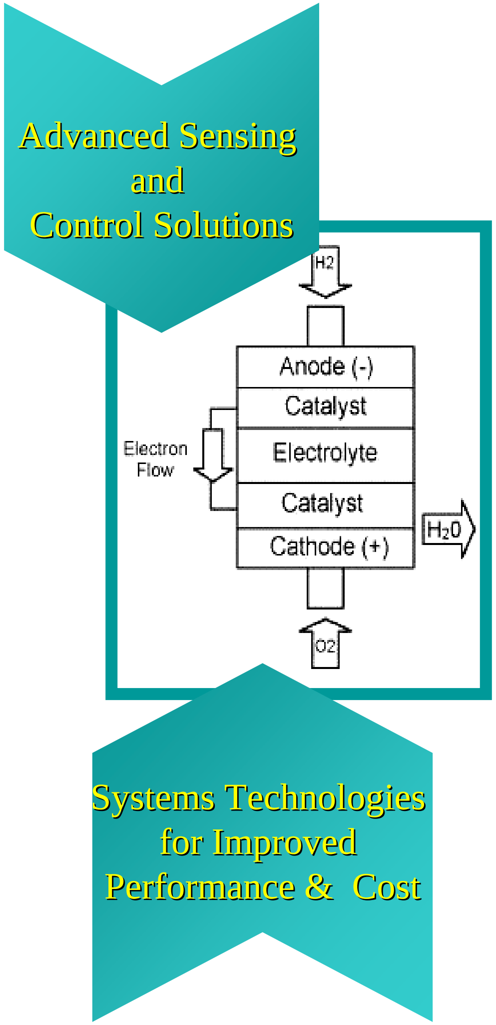
- **Startup**
  - Methods to minimize startup times
  - Thermal shock resistant materials/components

Fuels and Fuel Impurities R&D Needs

- **Influence of Fuels on SOFC and Fuel Processor Operation**
  - Performance
  - Fuel flexibility
- **Impurity Effects**
  - Performance degradation
  - Tolerance level
  - Life
- **Methods to Remove Sulfur from Hot Gases**

Control & Sensing R&D Needs

- **Advanced sensing and control technology - improved performance/cost**
  - **Advanced control and optimization technologies**
  - **Integrated embedded system implementations**
  - **Fuel composition and carbon monoxide (CO) sensors**
- **Advanced modeling for control development and information processing - address critical control challenges at component and system levels**
  - **System-subsystem-component dynamic modeling for control development**
  - **Bridging sensing and control: information-from-data technologies for control, safety, & system health**
- **Advance sensor development - address critical sensing challenges**
  - **Advanced sensing technologies for high temperature, flow and composition sensing**



Power Electronics R&D Needs

- **Fuel Cell/Power Inverter Interface**
  - Interface impedance calculation method for maximizing efficiency of fuel cell systems
- **Power Conversion Architecture**
  - Modeling and analysis of various architectures of power conversion systems (PCS)
  - Optimization of PCS architectures for various applications