SOFC Seal Meeting
SECA Core Technology Program

SOFC Overview

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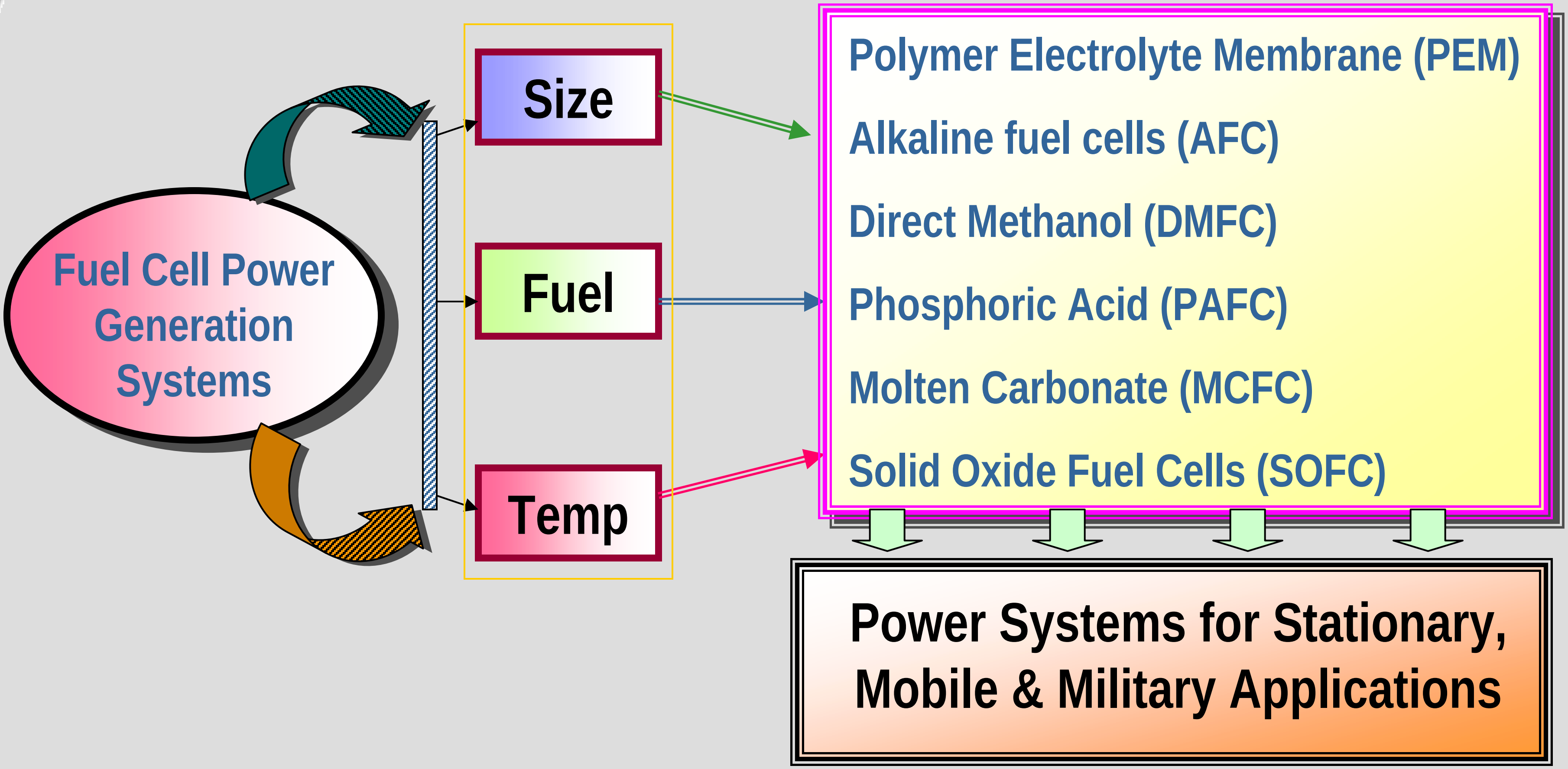
Presentation Scope

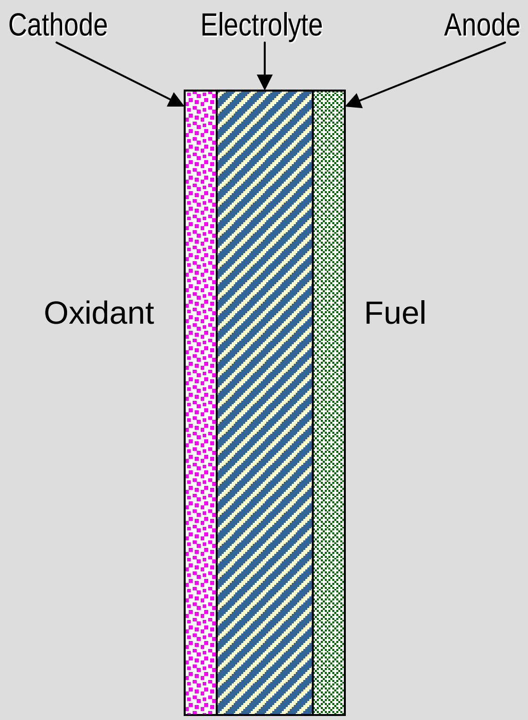
- **SOFC Operation**
- **Cell and Stack Designs**
- **Seal Concepts**
- **Path Forward**

Fuel Cell Technologies



Fuel Cell Technologies

Fuel cell	Electrolyte	Charge carrier
PEMFC	Polymeric	H^+
AFC	KOH	OH^-
PAFC	Phos. Acid	H^+
MCFC	(Li,K..)Carbonate	$CO_3^=$
SOFC	Stab. ZrO_2	$O^=$



SOFC Advantages

High efficiency **- >60% achievable**

Multi Fuel Capability **- PNG to propane to methanol to gasoline & diesel**

Environmentally Friendly **- No / Negligible NOx, SOx, VOC, particulates**

Ease of Siting **- Modular construction, noiseless operation**

Multiple Market **- Stationary, transportation and military**

- **High Power density operation**
- **Tolerance to Gas Phase Poisons**
- **Non noble / Non Strategic materials**
- **Less Demanding Fuel Processing**
- **Solid State Construction and Stability**
- **Simpler BOP**

CTP Objectives

- Identify technology gaps and development needs
- Prioritize development needs
- Develop and execute technology programs
- Disseminate results through meetings/ publications

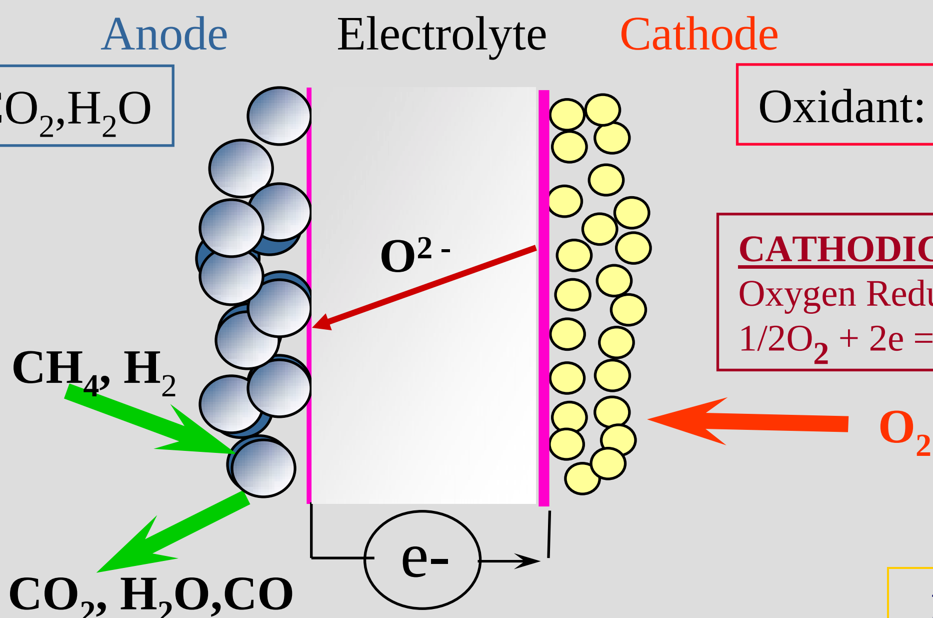
- Meet SECA Modular SOFC Cost Targets
- Meet SECA Performance Targets
- Meet SECA Development Schedule

Solid Oxide Fuel Cell Operation

Electrochemical and Reformation Processes

Fuel: $CH_4, H_2, CO, CO_2, H_2O$

Oxidant: Air, O_2



ANODIC REACTION

Electrochemical Oxidation:

H_2+O2- =H_2O+ 2e

CO+O2- = CO_2 + 2e

Steam reforming:

CH4+H_2O = CO+ 3H_2

Shift Reaction:

CO+H_2O = CO_2+ H_2

CATHODIC REACTION

Oxygen Reduction

1/2O_2 + 2e = O2-

OVERALL CELL REACTION

H_2+1/2O_2 = H_2O

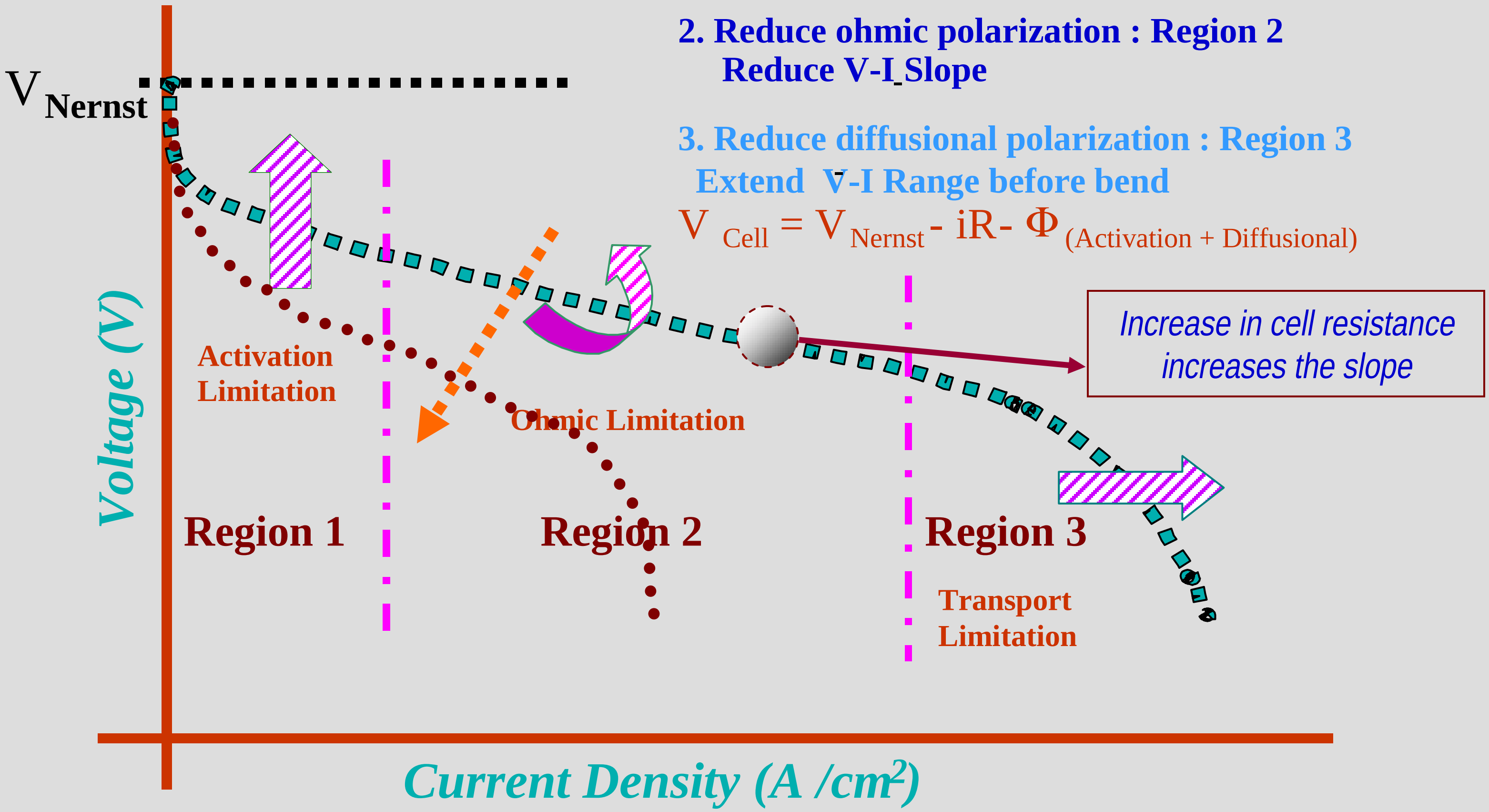
CO+1/2O_2 = CO_2

Internal short and combustion of fuel reduces cell performance

Cell Electrical Performance

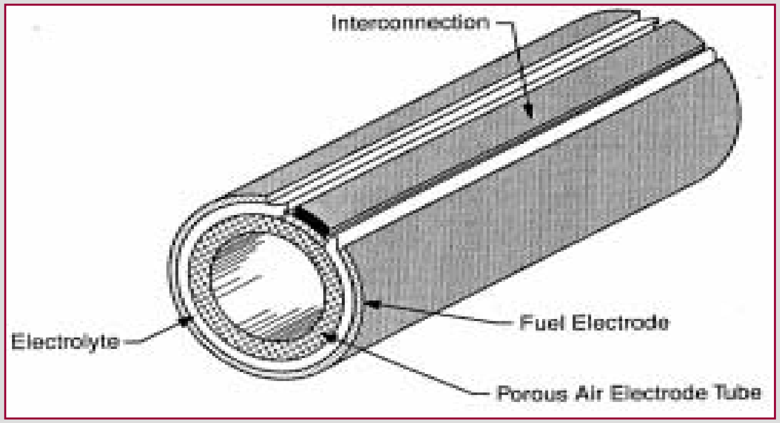
1. Reduce activation polarization : Region 1
   Move V-I Curve upward
2. Reduce ohmic polarization : Region 2
   Reduce V-I Slope
3. Reduce diffusional polarization : Region 3
   Extend V-I Range before bend

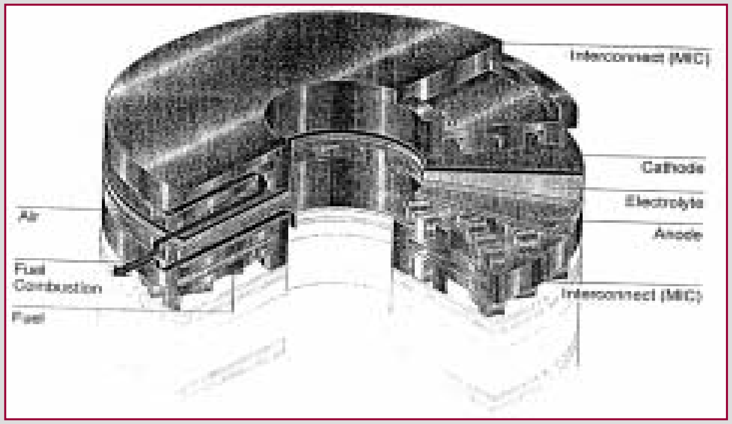
$V_{Cell} = V_{Nernst} - iR - \Phi_{(Activation + Diffusional)}$

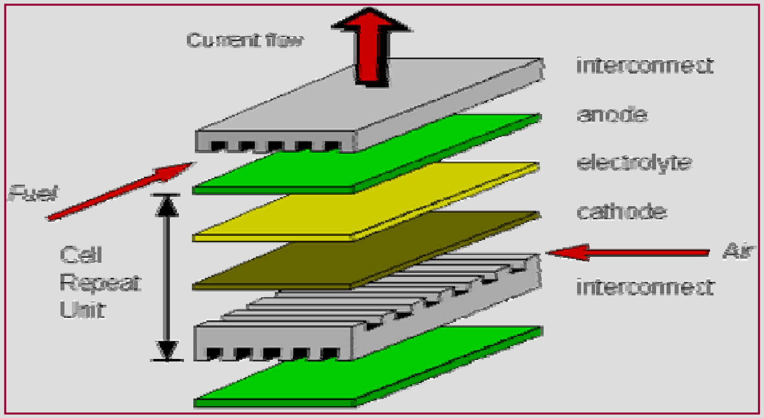


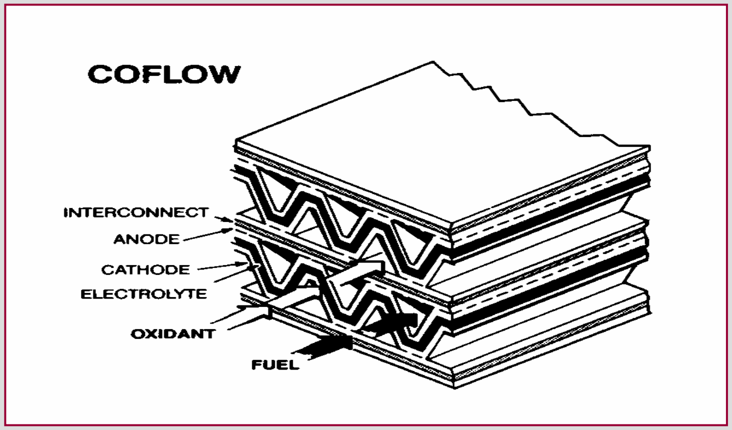
Localized combustion of fuel can lead to lower V_{Nernst} and increased cell resistance- both contributing to performance reduction pg- 20

SOFC Configurations



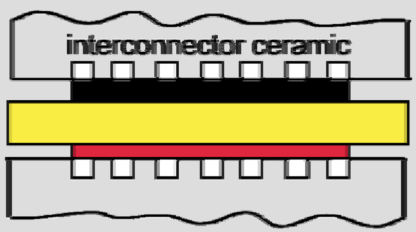






Cell Architectures

1000° C



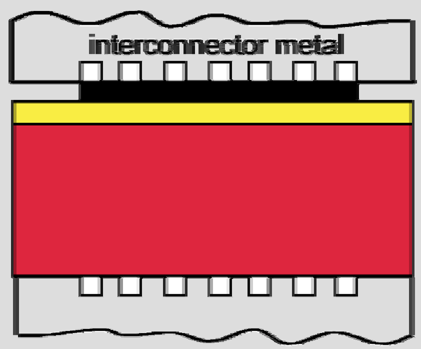
Electrolyte-supported

Cathode: 50 µm

Electrolyte: >150 µm

Anode: 50µm

700-800° C



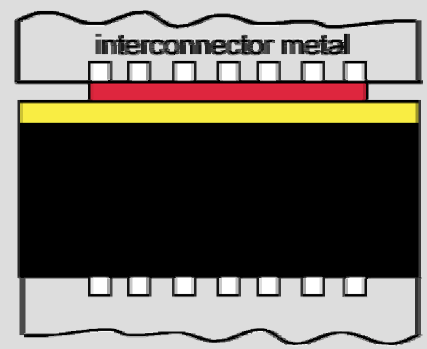
Anode-supported

Cathode: 50 µm

Electrolyte: <20 µm

Anode: 500 –1500 µm

700-800° C



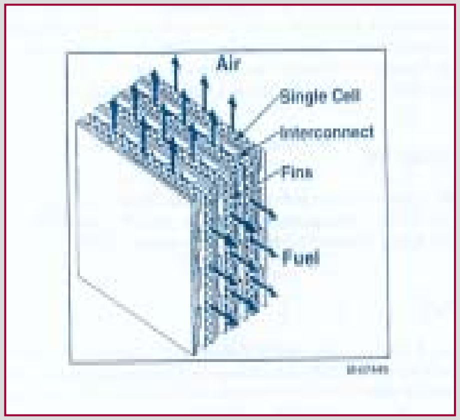
Cathode-supported

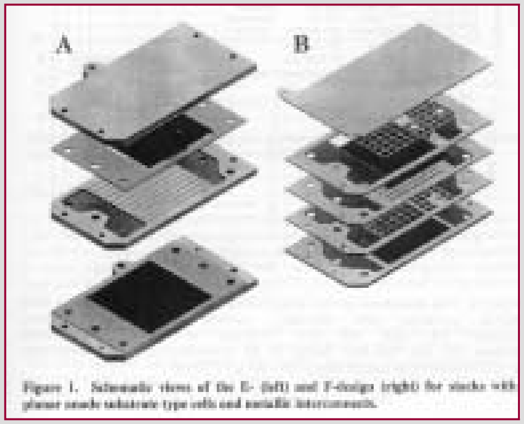
Cathode: 500 - 2000 µm

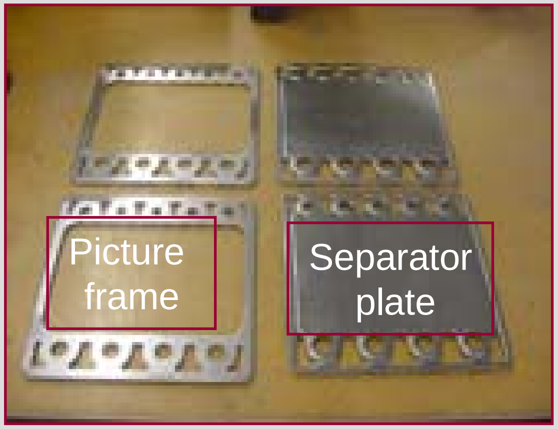
Electrolyte: <20 µm

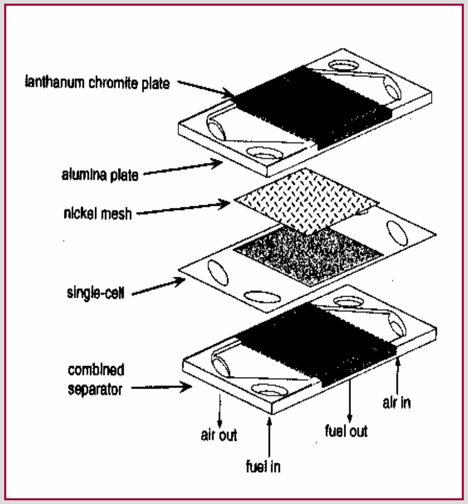
Anode: 20 - 50 µm

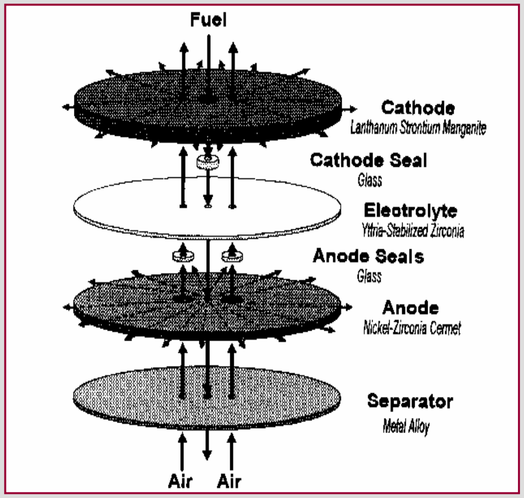
SOFC Designs: Flow Paths



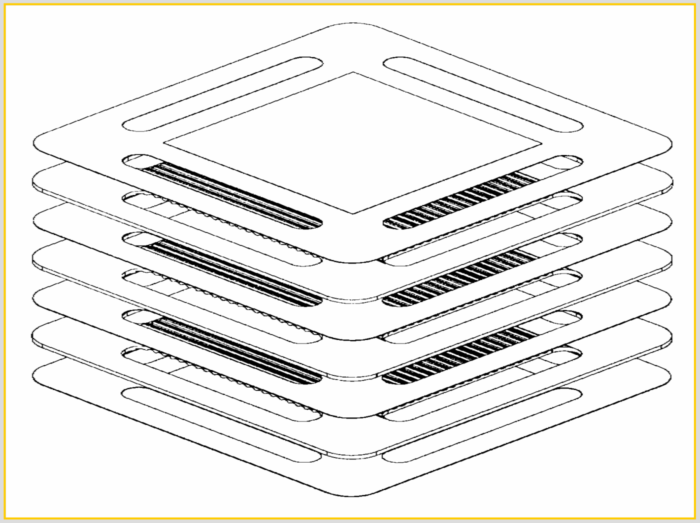


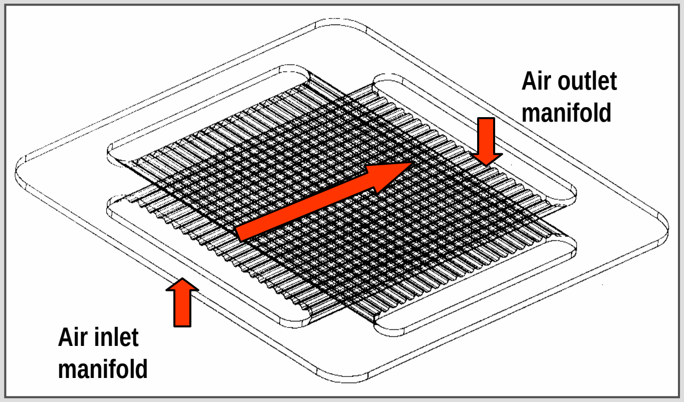


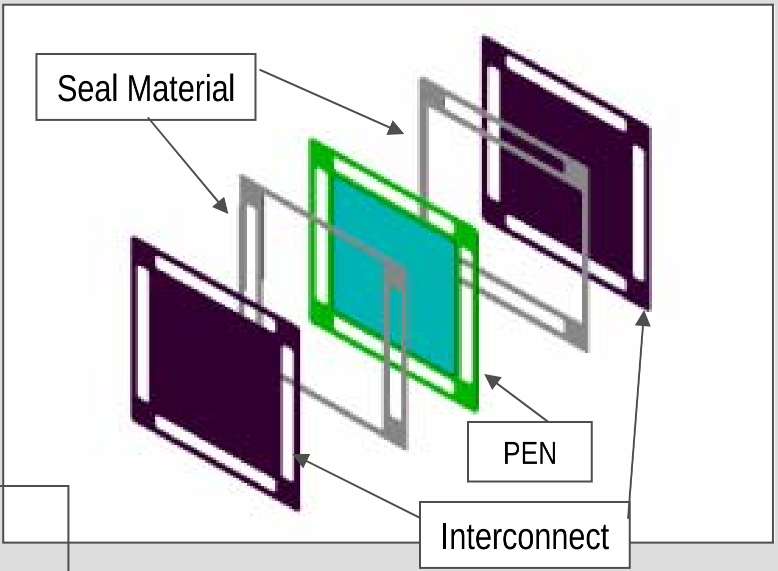




Basic Planar Seal Design







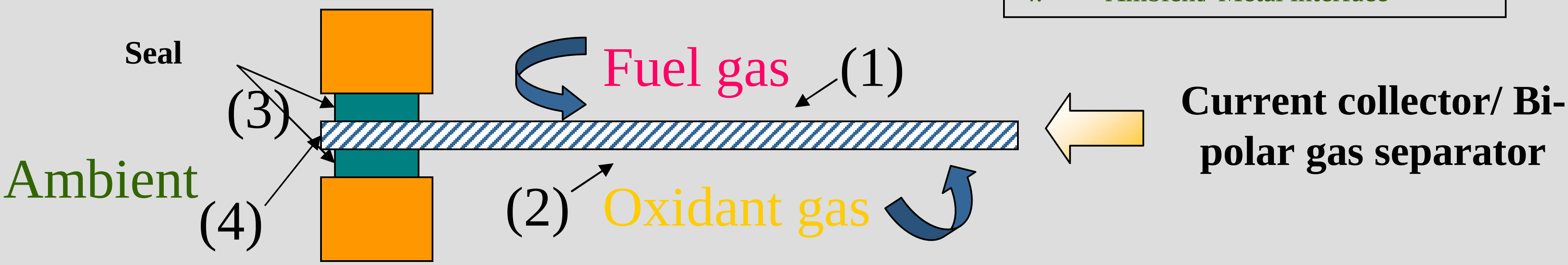
<u>Design Variables</u>
- Gas flow distribution channel dimensions/types
- Ceramic or metallic interconnect
- Material thickness and PEN strength
- Rigid or compression seals
- Manifold dimensions and Flow configuration

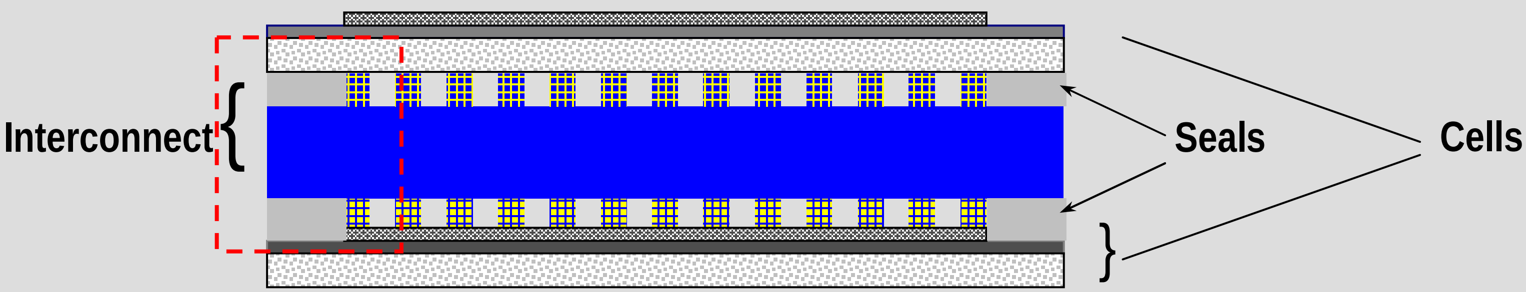
<u>Operational Variables</u>
- 600-800C or higher
- Air as oxidant
- Hydrocarbon or reformed fuel
- 60-85% fuel utilization

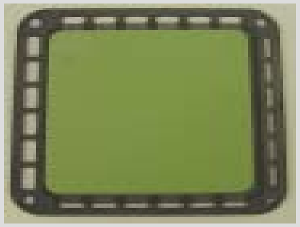
- Design Constraints
  - Thickness
  - Sealing temperature
  - Operating temperature
  - Scalability
  - Insulation

Seal exposure conditions

1. Fuel gas / Metal interface
2. Oxidant gas/ Metal interface
3. Compliant seal/ Metal interface
4. Ambient/ Metal interface







SECA CTP Workshop Findings

Topical area	Top 3 development Needs
Cell/Stack Materials & Manufacturing	1. Stable Interconnect 2. Fuel/ Oxidant Seals 3. Internal Reforming/ Direct oxidation
Fuel processing	1. Sulfur Tolerant Anode 2. Catalyst Kinetics, Parameters & Deactivation 3. On anode Fuel Utilization
Stack/ Systems Performance & Modeling	1. Fast start up and Thermal Cycles 2. Cell & Stack Performance Model 3. Low Cost HX, Insulation, Blowers & sensors
Power electronics	1. Fuel cell /PE Interface 2. Materials & Fabrication Processes 3. Modeling: Electrical Interfaces

SOFC SEALS

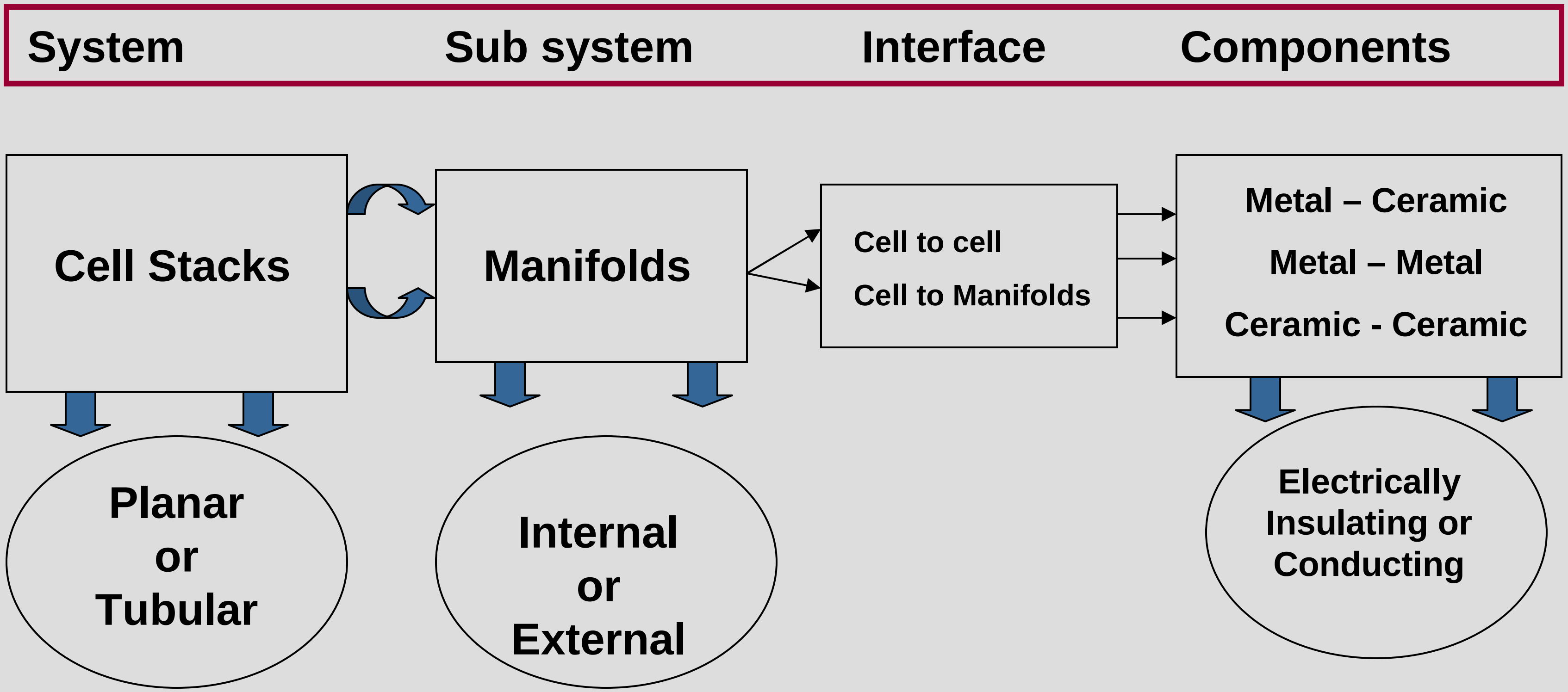
Functions

- SOFC seals prevent mixing of fuels and oxidant.
- SOFC seals may provide mechanical bonding of components.
- SOFC seals electrically isolate cells in stack
- SOFC manifold seals prevent mixing of reactants and ambient

Requirements:

While fulfilling the above functions, seal materials must remain structurally stable and chemically compatible with other cell components

SOFC Seals



Seal designs and materials will largely depend on the cell and stack configurations and contacting surfaces/ materials

Requirements for seals in SOFC

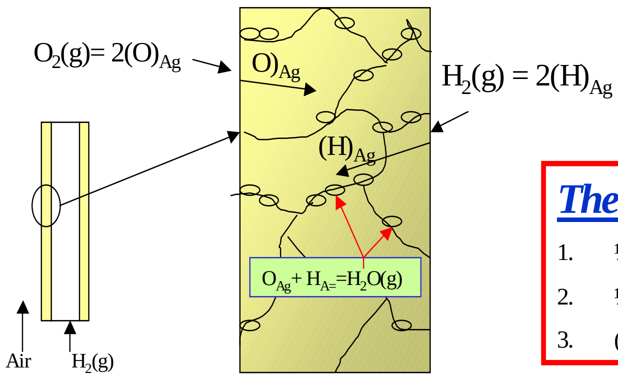
- **Hermetic seal – Prevent mixing of fuel/oxidant**
- **Electrical insulation – Isolate cells electrically**
- **Chemical stability – Tolerant to fuel/oxidant environment**
  - **Long-term stability**
  - **Thermal cycle stability**
  - **Vibration stability for vehicles**
  - **Thermal shock resistance**
- **Interfacial stability – Resistance to corrosion**
- **Low cost materials and fabrication**

SOFC Seal Options

- **Rigid seals (i.e., glass-ceramic)**
  - **Close TEC matching of all stack components to minimize stresses.**
  - **Compact cell/ stack designs**
- **Compressive seals**
  - **Relaxed TEC matching by providing compliance in “x-y” plane.**
  - **External load frame structure required**
  - **Bulky design**

Accelerated Corrosion in Dual Environment

Mechanistic undersatnding of corrosion processes are being developed for addressing long term performance of materials



Reaction Steps

1. $(H_2)_g = 2(H)_{Ag}$ — Ag/Fuel interface
2. $(O_2)_g = 2(O)_{Ag}$ — Ag/ Air Interface
3. $2(H)_{Ag} + (O)_{Ag} = (H_2O)_g$ Bulk Ag

Thermochemical Data

1. $\frac{1}{2}(H_2)_g = (H)_{Ag}$, $-G$
2. $\frac{1}{2}(O_2)_g = (O)_{Ag}$, $-G$
3. $(H_2)_g + \frac{1}{2}(O_2)_g = (H_2O)_g$, $-G$

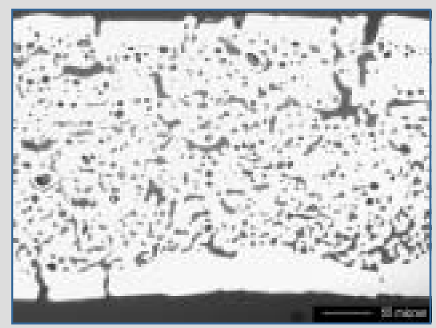
Bulk Degradation Related to :

1.Dissociation and dissolution of H and O in the bulk metal

2. Interaction between dissolved H & O to form High pressure H_2O gas

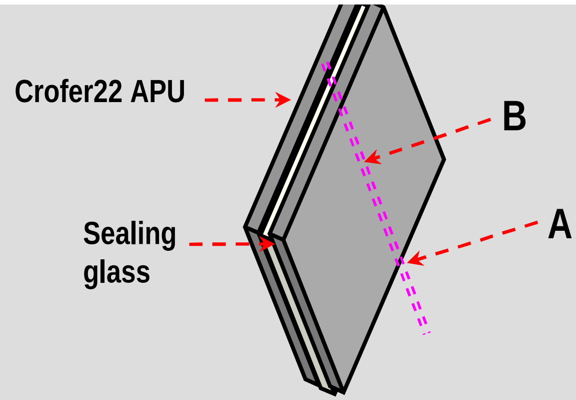
3. Nucleation and growth of steam bubbles/voids at GB/defects

Air/ Air



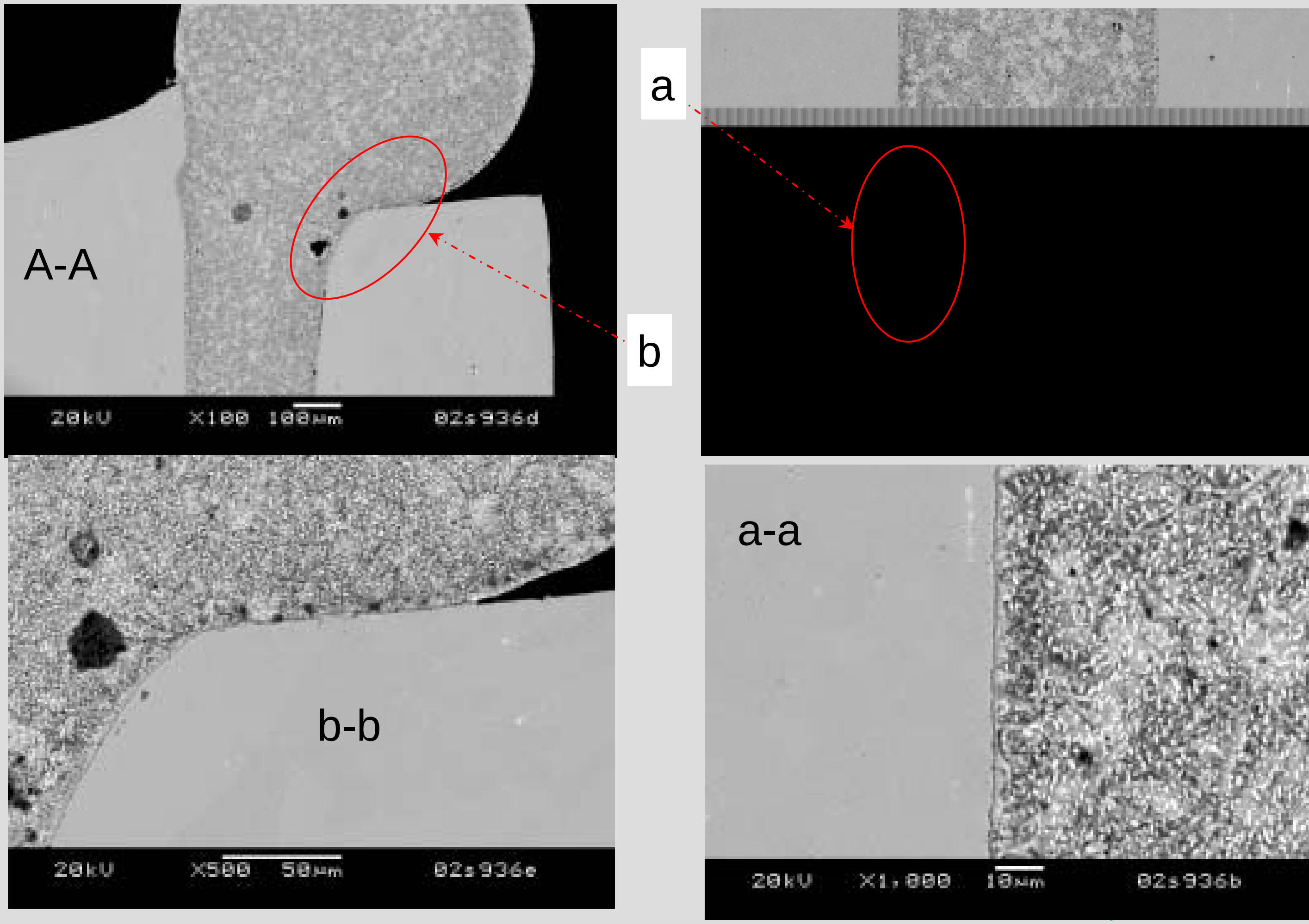
Air/ Fuel

Interface of Crofer22 APU/sealing glass (G18)

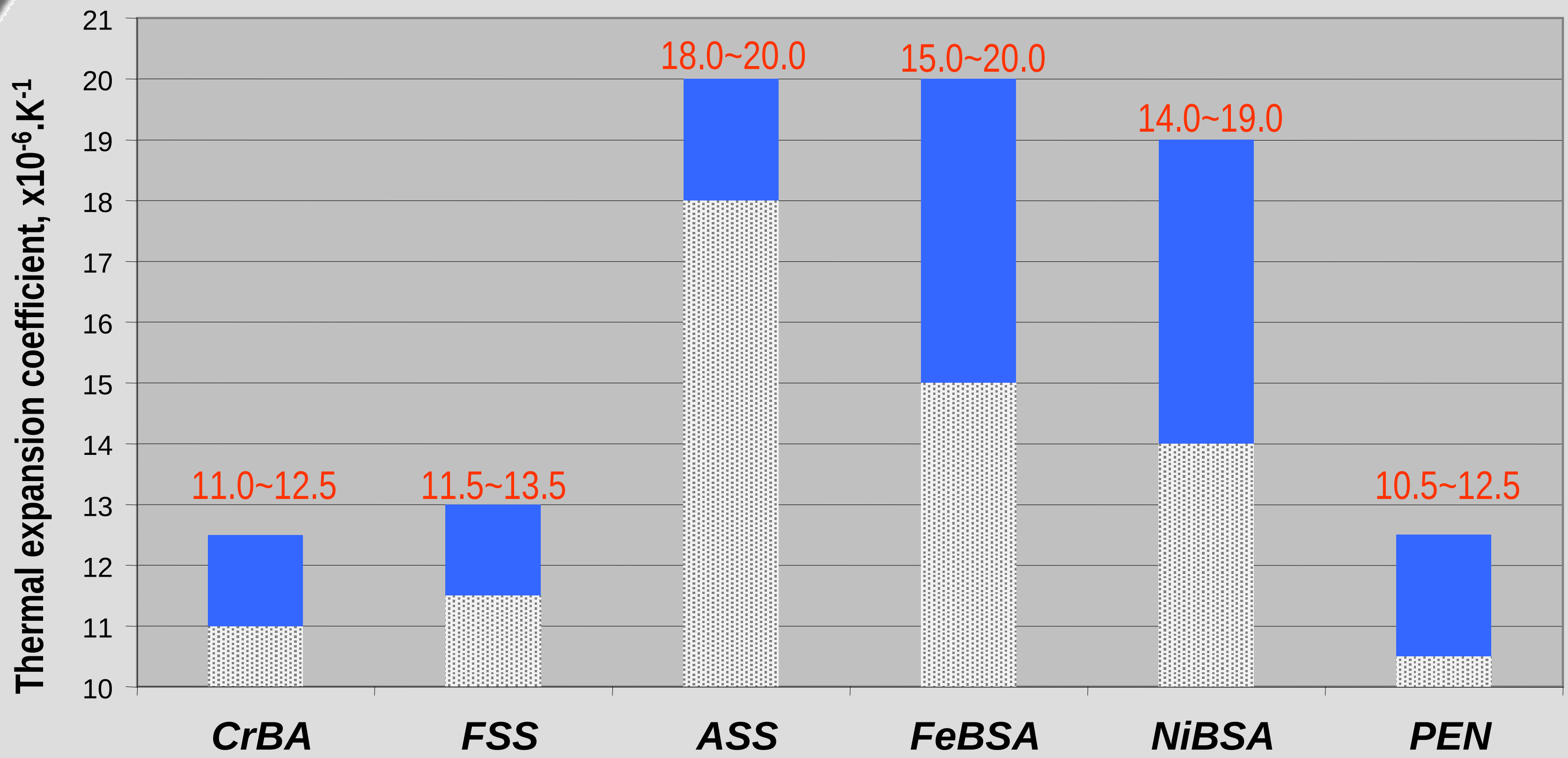


850ºC for 1 h, followed by 750ºC for 4 h.

Formation of barium chromate hindered due to lower Cr volatilization?

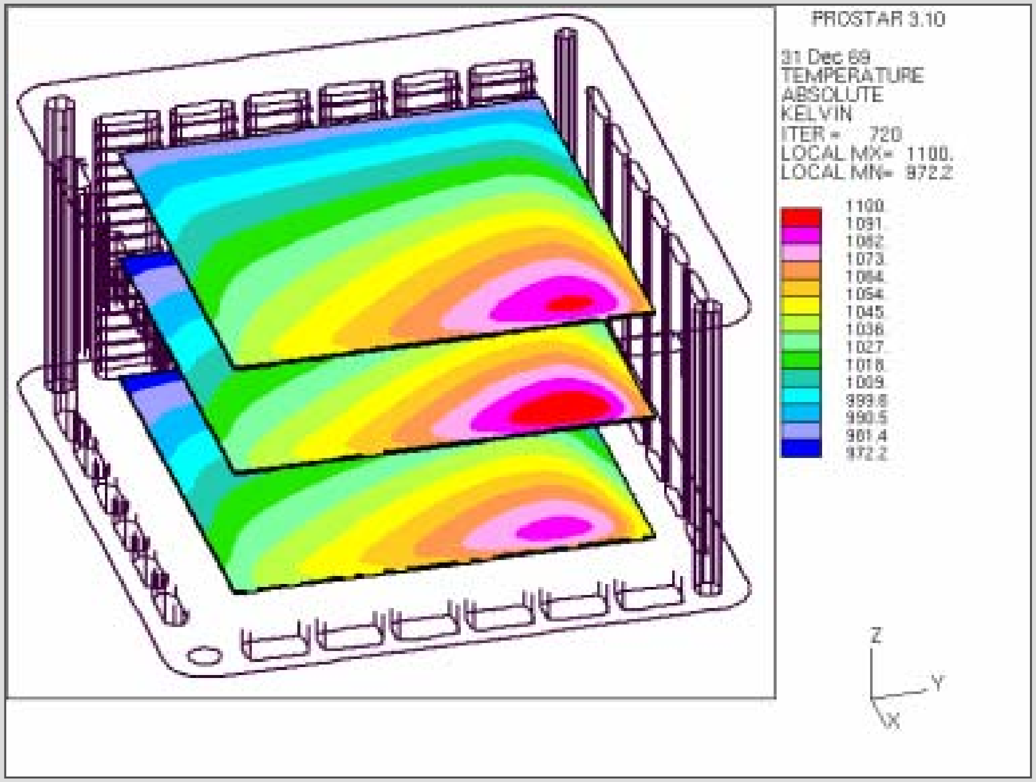


CTE of Different Alloy Groups



- *BCC matrix alloys (CrBA, FSS) have a lower CTE that FCC matrix alloys (ASS, FeBSA, NiBSA);*
- *FSS, including Fecralloy offer better CTE match to PEN.*

Steady State: 16-Cell Stack Model



Fuel Delivery: 8E-6 kg/s/cell @ 944K
Air Delivery: 0.25 kg/s/cell @ 944K

Output:
245 mW/cm^2
Tcell (ave) = 751C

Full 3-D Temperature dataset available for computing thermal stress

SOFC seal designs must accommodate chemical, mechanical and structural changes due to changes in temperature, gas environment, interface structure and reactions

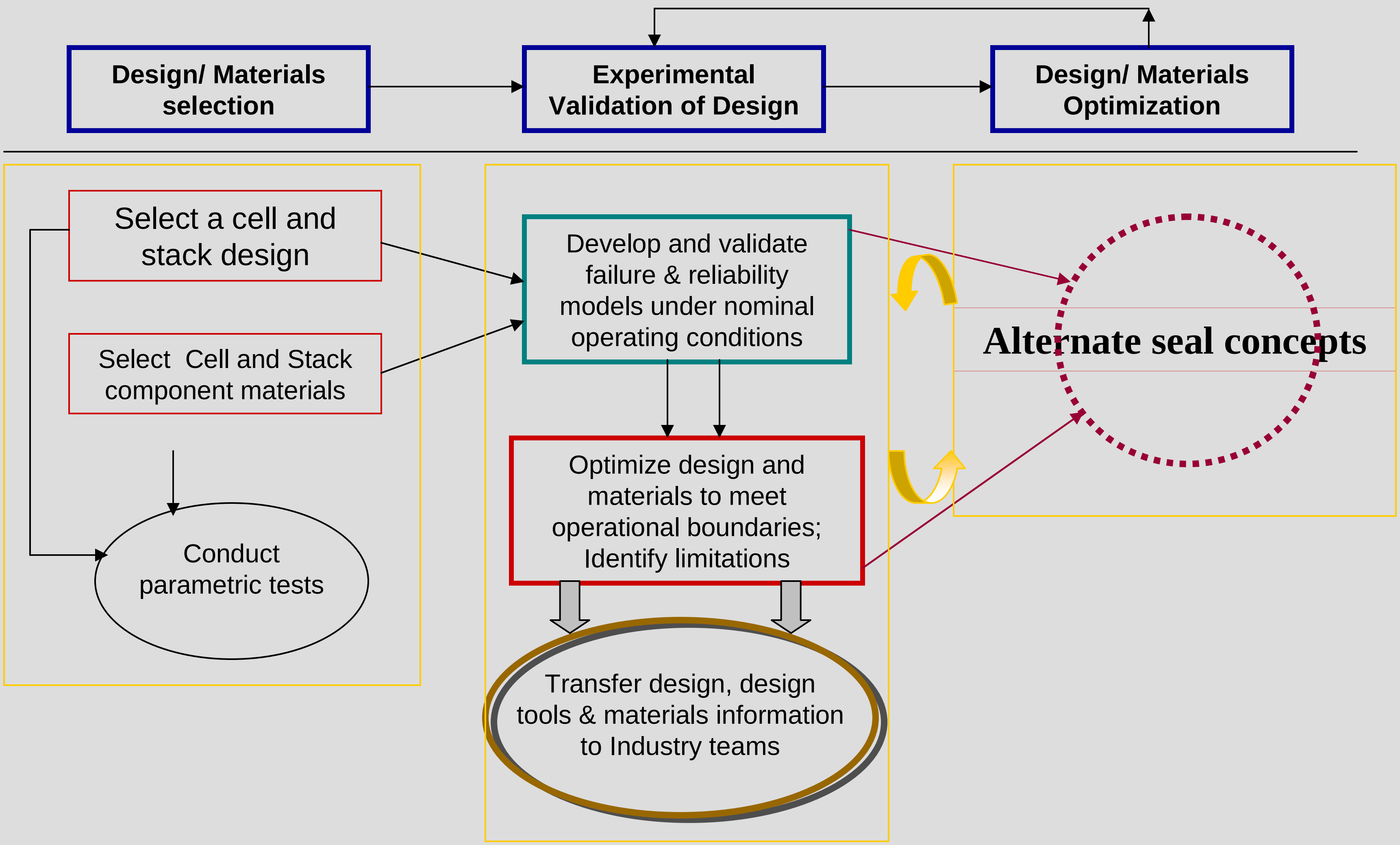
Task Force Objectives:

Develop SOFC Seal technology Road Map:

- Address SOFC seal technology requirements and status
- Identify technology gaps and development needs
- Present advanced seal technologies and concepts
- Develop technology evaluation and validation procedure
- Implement in SECA SOFC system

A technology Road Map will be formulated and implemented for the development, testing and deployment of sealing technologies that meet the SECA cost and performance targets.

Seal Development Approach



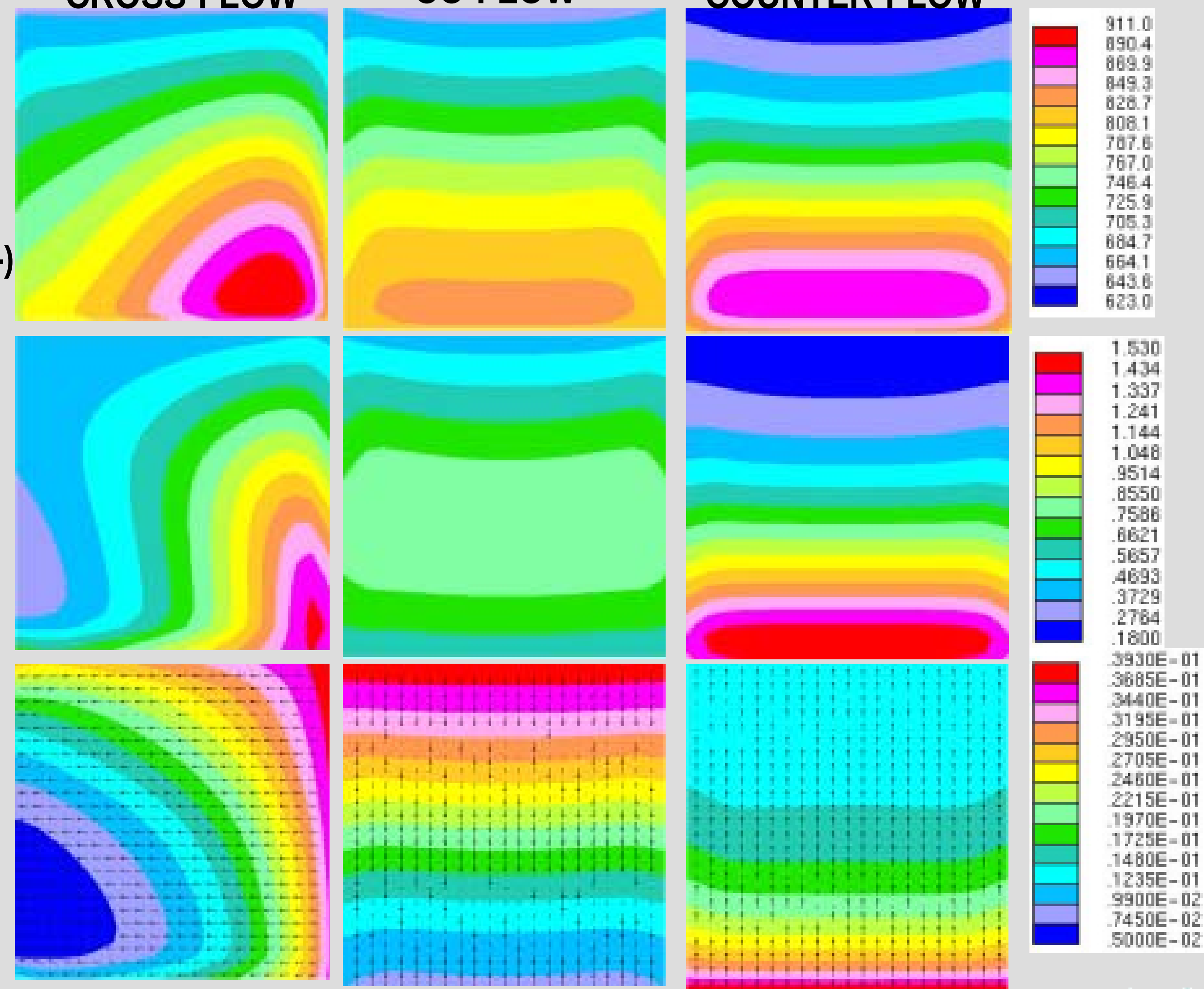
Alternate Flow Configurations – Steady State

CROSS-FLOW | CO-FLOW | COUNTER-FLOW | 04/09/02

Temperature, Degrees C (ΔT=180 co- ΔT=270 cross-)

Current Density, A/cm2

H2 Mass Conc., kg/kg



Anode-Supported Cell Development

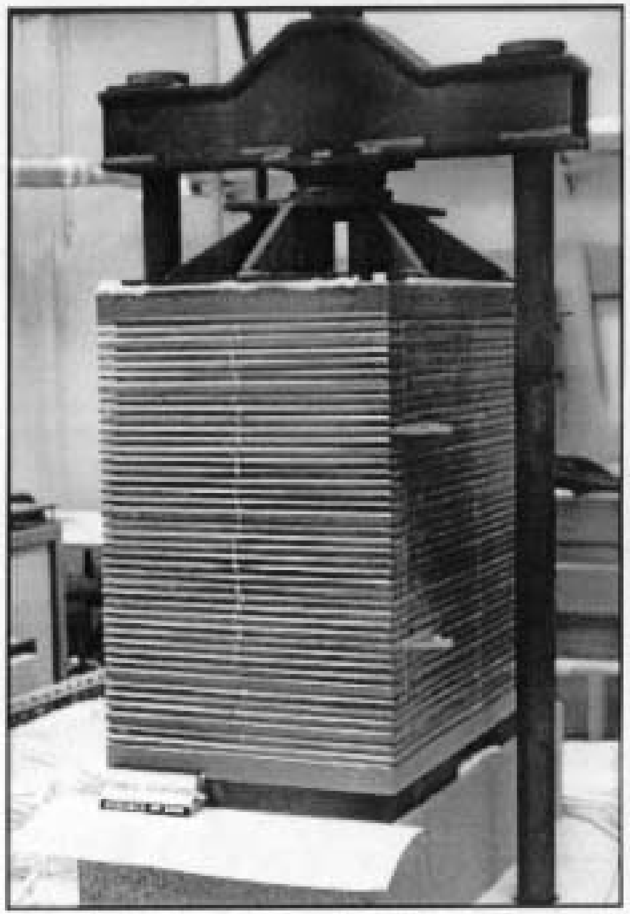
- **Anode-supported SOFCs (<10 μm YSZ)**
  - **Allows for operation at 800ºC or below; advantageous for interconnect, balance of plant, thermal management and cycling**
- **Fabrication by tape casting/screen printing**
  - **Proven, low-cost method of manufacturing planar ceramic structures**
- **Co-sintering of anode and electrolyte in air**
  - **Reduces number of heat treatments**

Research Center Juelich - Germany

Technical details:
40 cell stack based on Jülich substrate cells
cell size 20 cm x 20 cm
361 cm^2 active surface
ferritic steel interconnects

Operation I:
mean stack temperature 800°C
fuel humidified hydrogen
($90\%H_2/10\%H_2O$)
oxidant air
fuel utilisation 76 %
air stoichiometry 2
stack voltage 30.2 @ 300 A
(0.755V/cell @ 0.83 A/cm^2)
power output 9.2 kW

Operation II:
mean stack temperature 800°C
fuel pre-reformed methane
($7\%H_2:31\%CH_4:62\%H_2O$)
oxidant air
fuel utilisation 59 %
air stoichiometry 3,5
stack voltage 30.2 V @ 180 A
(0.755V/cell @ 0.50 A/cm^2)
power output 5.4 kW



- 40 cell stack
- 9.2 kW (hydrogen)
- 627 mW/cm^2
- 76% fuel utilization