COMSOL CONFERENCE BOSTON 2012

University of Central Florida

Parametric Study of Electrolyte-Supported Planar Button Solid Oxide Fuel Cell

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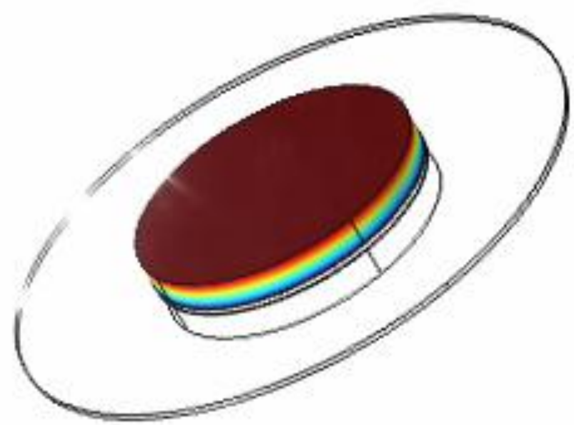
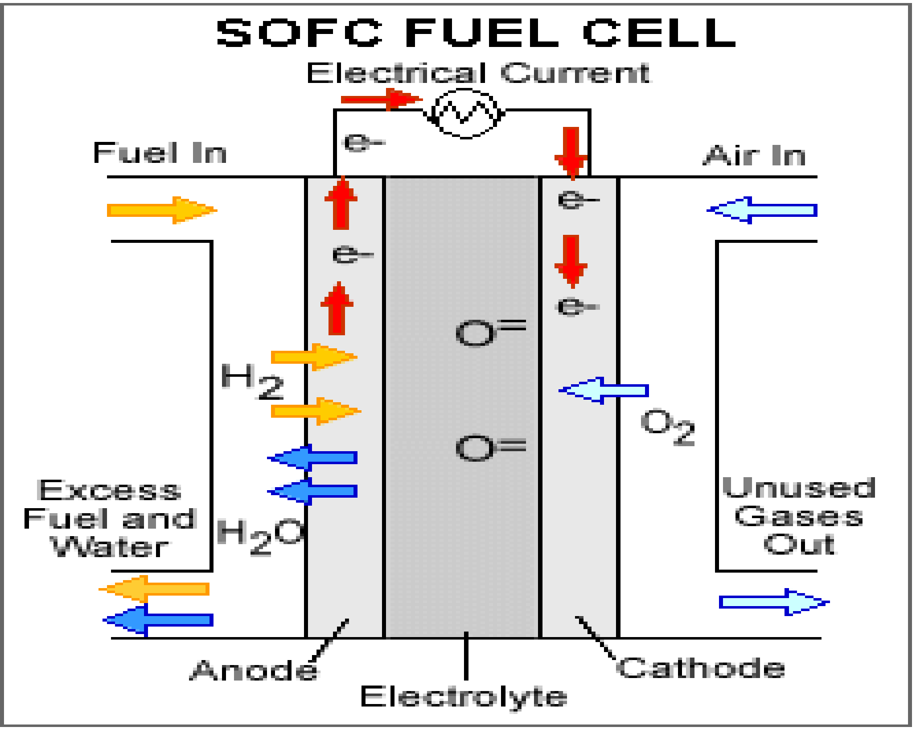


Solid Oxide Fuel Cell (SOFC)

SOFC
✓ Solid electrolyte - Ceramics
✓ Operating temperatures (400ºC – 1000ºC)



Picture Source: U.S. Department of Energy website

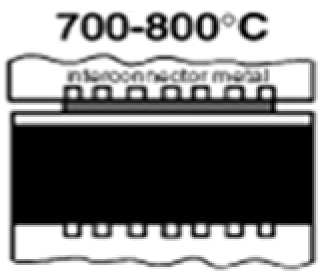
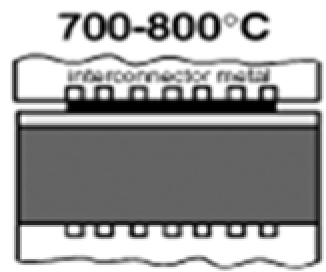
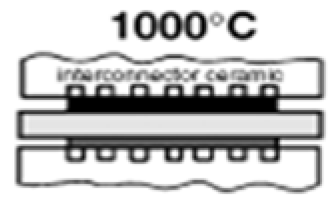
Advantages of SOFC
✓ High efficiency (>50%, >80% CHP)*
✓ Fuel flexibility (H_2, natural gas, biogases, etc.)
✓ Combined Heat & Power generation
✓ Compatible with gas & steam turbines
✓ Power output (W to MW)
✓ Relatively higher power density
✓ No water flooding issues, unlike PEMFC

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

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

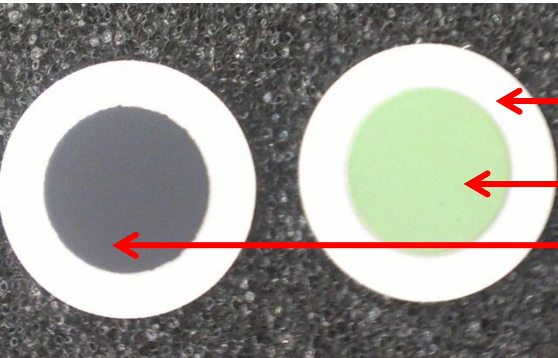
*Ryan O'Hayre, Suk-Won Cha, Whitney Colella, and Fritz B. Prinz, Fuel Cell Fundamentals, *Wiley*; 2nd edition, 2009.

Types of Planar SOFC

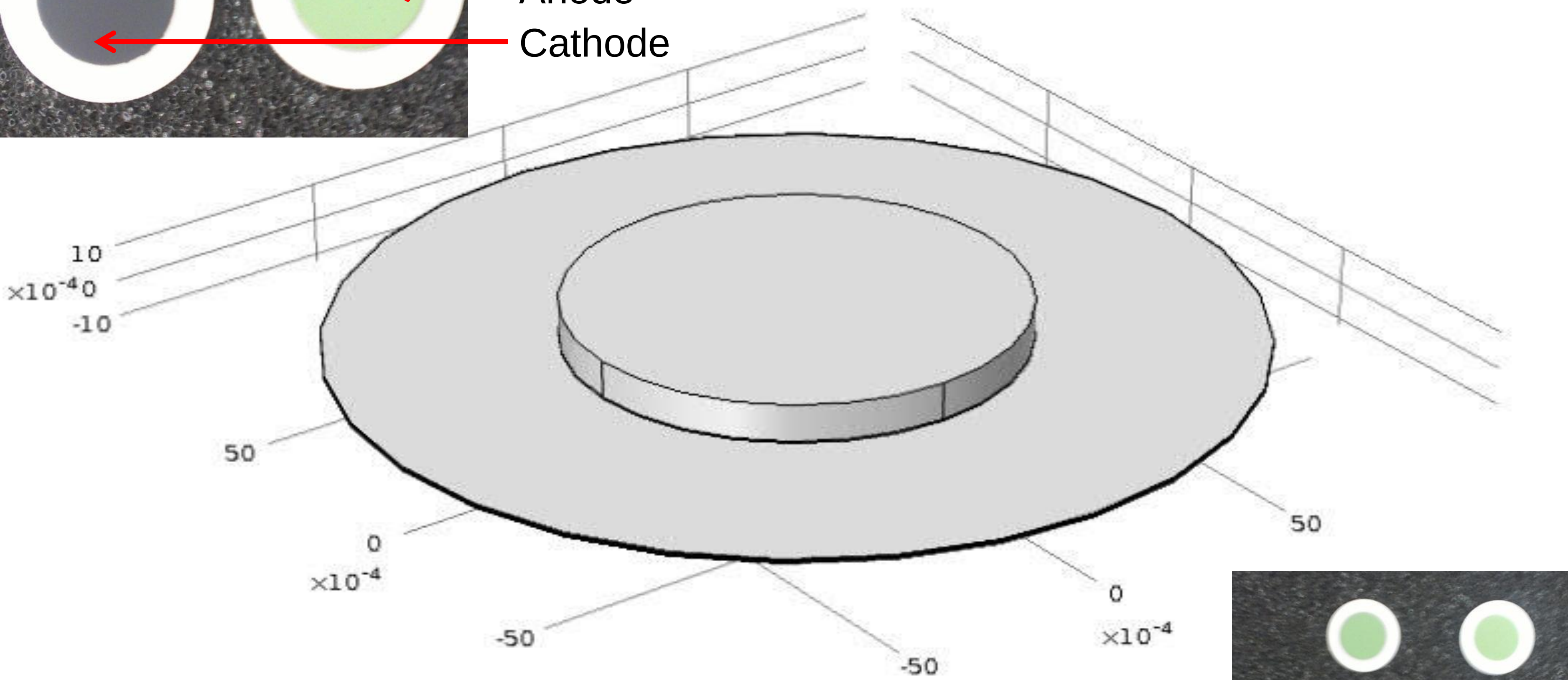
Cathode-supported	*Anode-supported*	*Electrolyte-supported*
		
Cathode: 300 - 1000 μm	**Cathode: 50 μm**	**Cathode: 50 μm**
Electrolyte: < 20 μm	**Electrolyte: < 20 μm**	**Electrolyte: > 100 μm**
Anode: 300 – 1000 μm	**Anode: 500 - 1500 μm**	**Anode: 50 μm**
Activation losses higher than Anode-supported	**Higher Activation losses**	**Higher Ohmic losses**

Source: Mark C. Williams, Joseph P. Strakey and Wayne A. Surdoval, U.S. Department of Energy's Solid Oxide Fuel Cells: Technical Advances, Int. J. Appl. Ceram. Technol., 2 (4) 295–300 (2005)

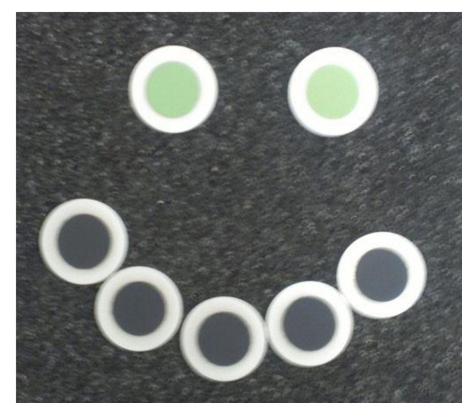
SOFC Geometry: Top View



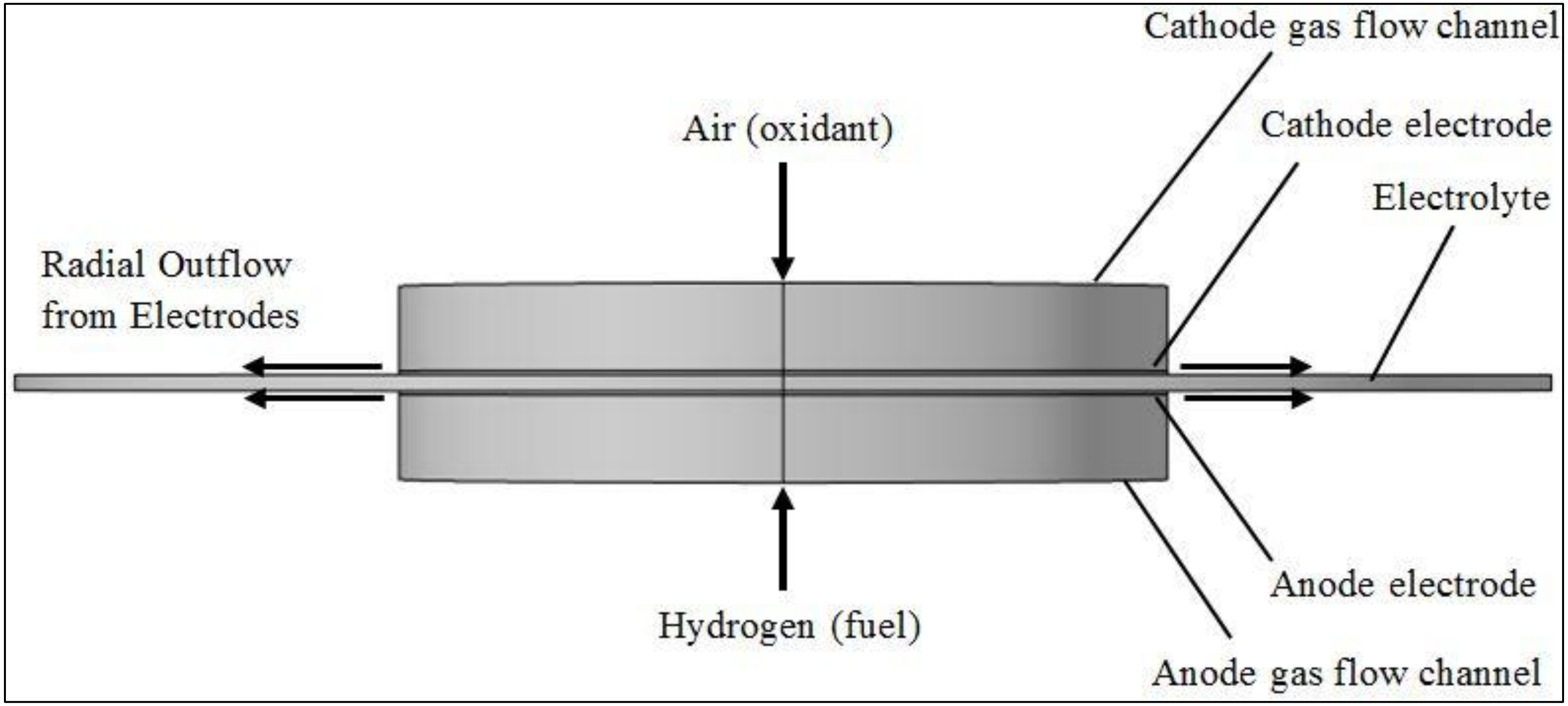
Electrolyte
Anode
Cathode



all units in m



SOFC Geometry



Anode & Cathode thickness	50 μm
Electrolyte layer thickness	30 μm
Anode & Cathode diameter	10 mm
Electrolyte diameter	20 mm
Gas flow channel height (Anode & Cathode)	1 mm
Gas flow channel diameter (Anode & Cathode)	10 mm

Parametric Study

• SOFC modeling involves a large number of parameters that affect the cell performance.

• These parameters affect different aspects of the cell's performance and hence it is important to study them individually.

• By this process, the parameters can be narrowed down to a few that have a significant impact and influence on the cell's behavior.

j_0 (A/m^2), exchange current density

SSA (m^2/m^3), specific surface area

σ (S/m), electrolyte conductivity

ε, electrode porosity

k, electrode permeability

t (μm), electrode thickness

Exchange Current Density (ECD) and Specific Surface Area

Butler-Volmer equation:

$$j = j_o \left[\left(\frac{c}{c_0}\right)_R exp\left\{\frac{n\alpha F}{RT}\eta\right\} - \left(\frac{c}{c_0}\right)_P exp\left\{\frac{-n(1-\alpha)F}{RT}\eta\right\} \right]$$

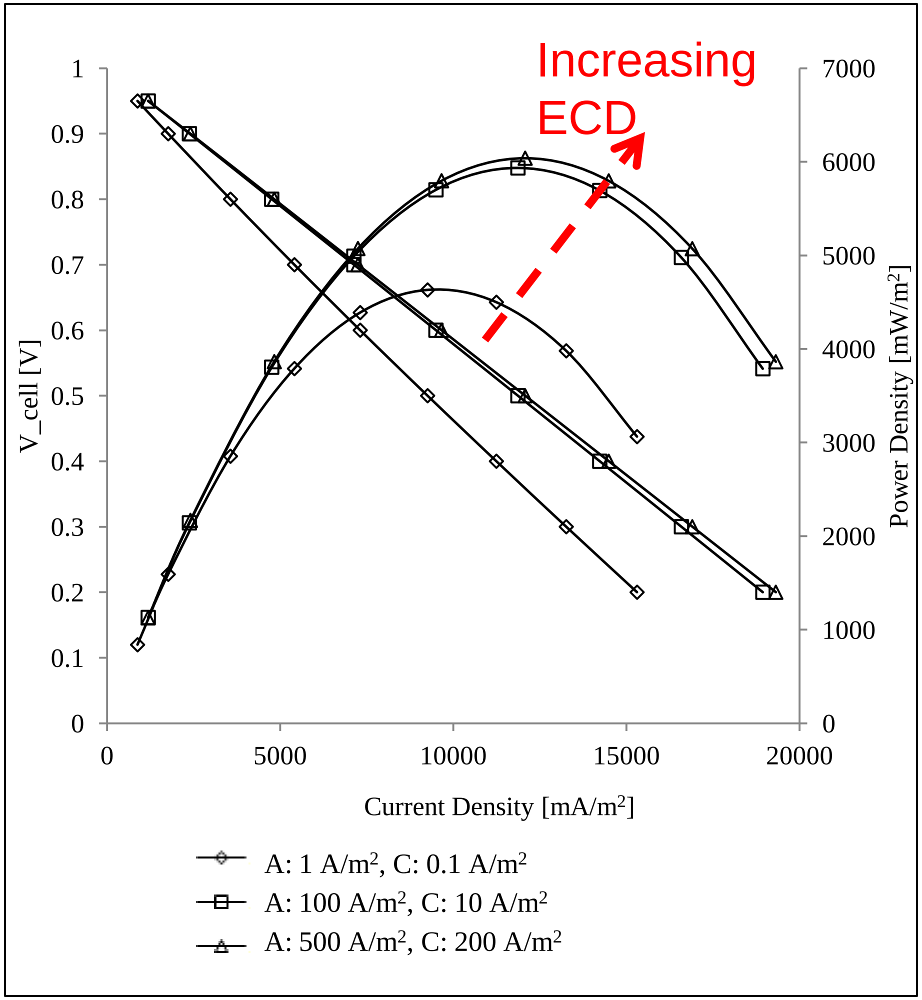
n = 2, anode
n = 4, cathode

$$j_o = A_v \cdot j_{local}$$

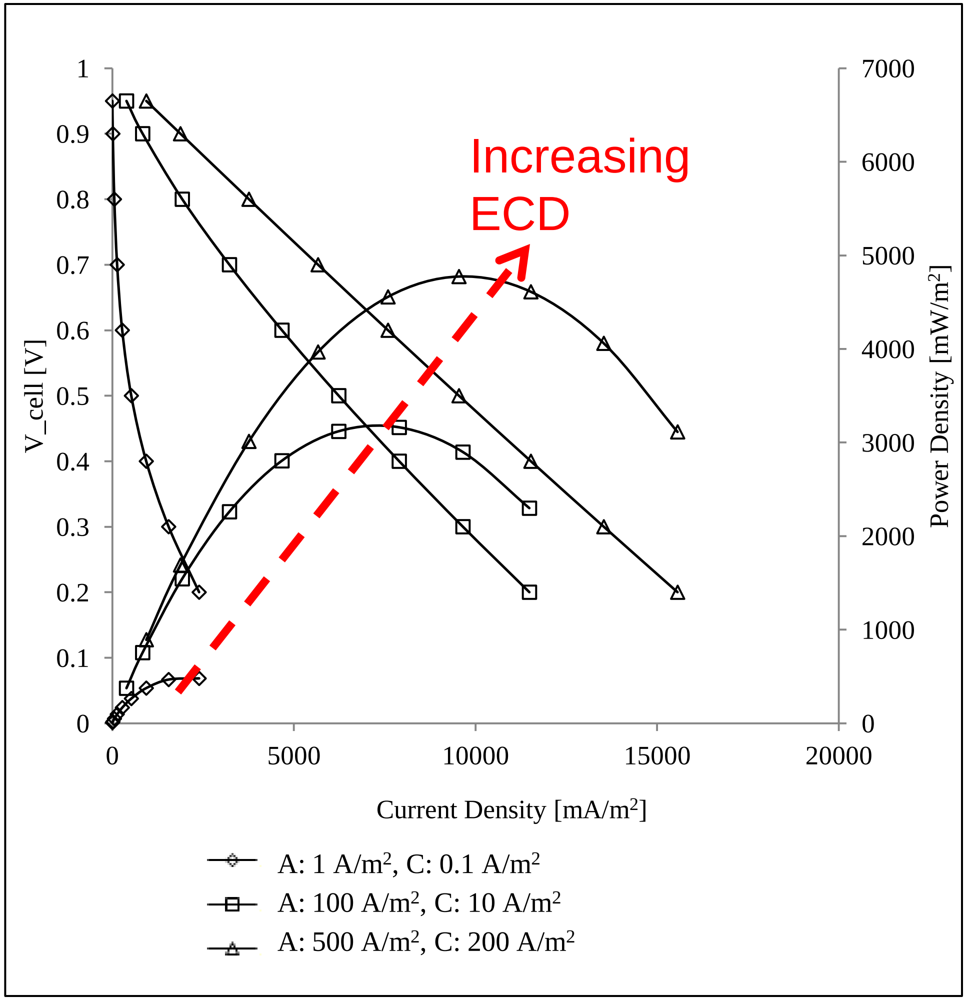
j = current/area [A/m^2], current density vector
j_0 – exchange current density
A_v – specific Surface Area [m^2/m^3]
η – activation overpotential [V]
c_R,c_P – concentration of reactants & products respectfully
n: number of charges transferred
α : transfer coefficient
T: temperature (K)

Exchange Current Density

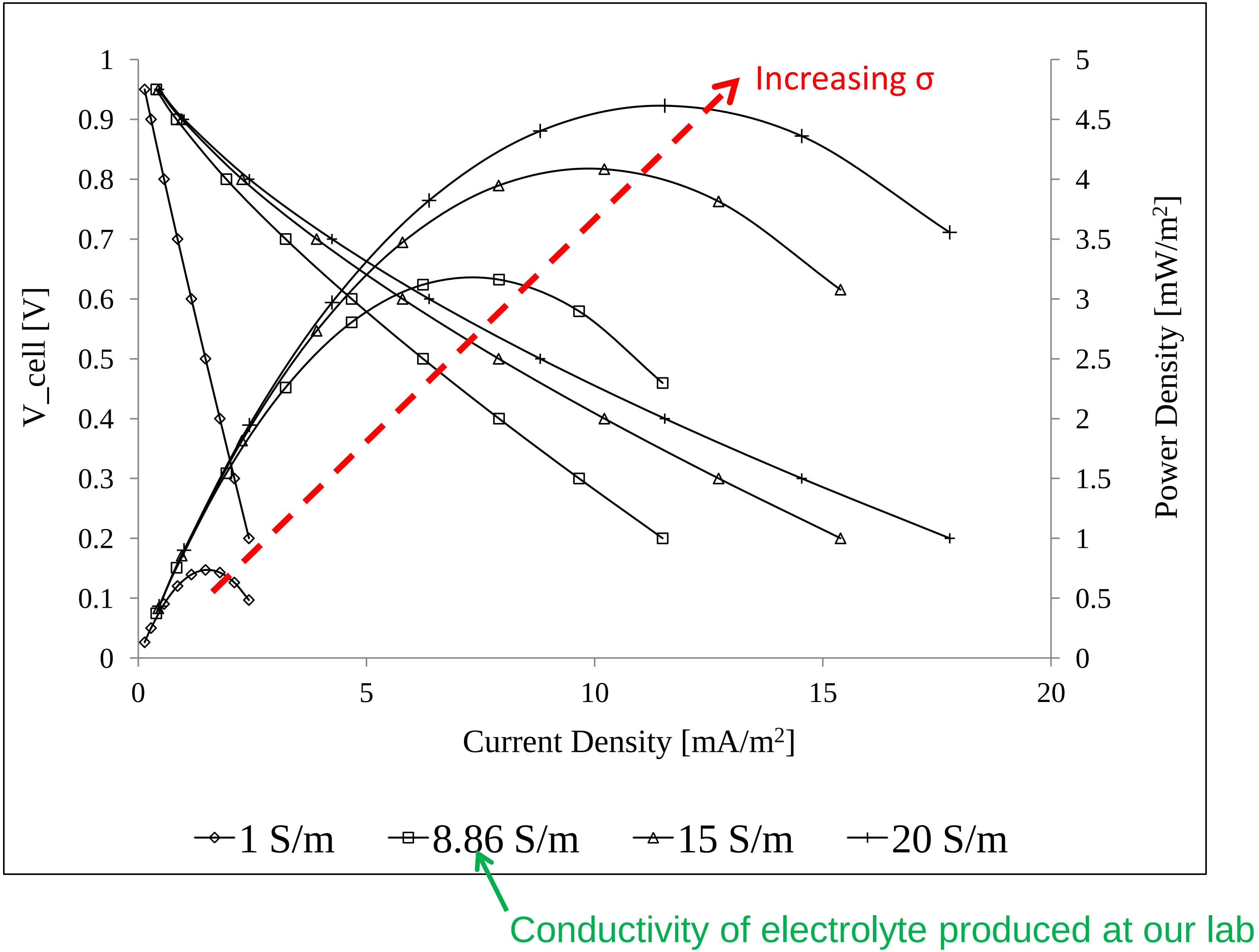
SSA: 1x10^{9} [m^{2}/m^{3}]



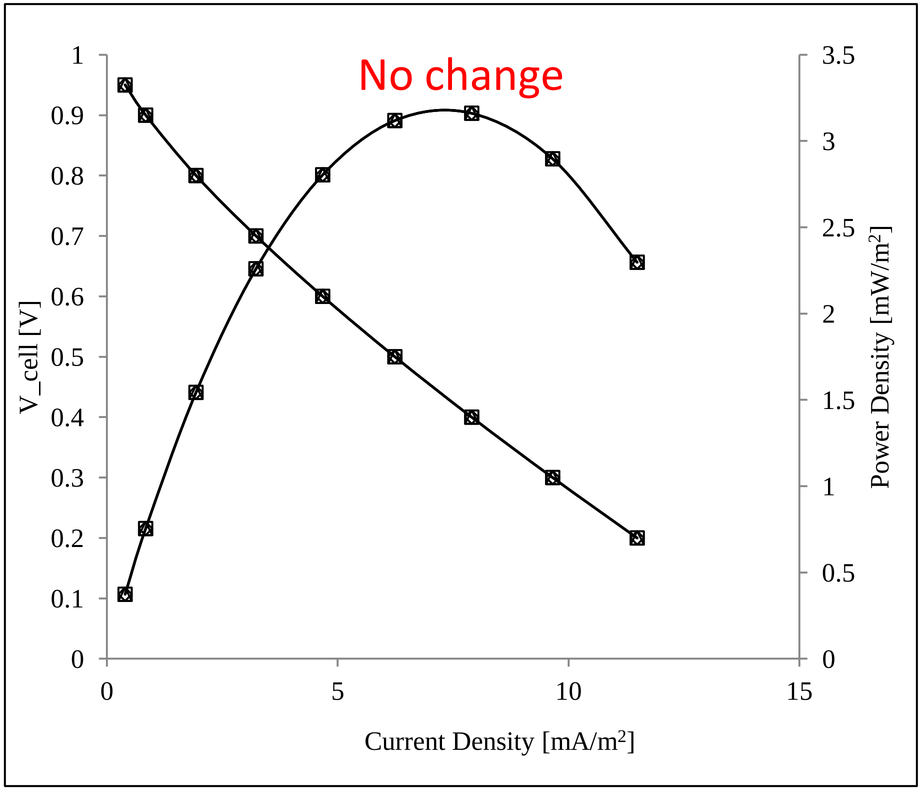
SSA: 1x10^{6} [m^{2}/m^{3}]

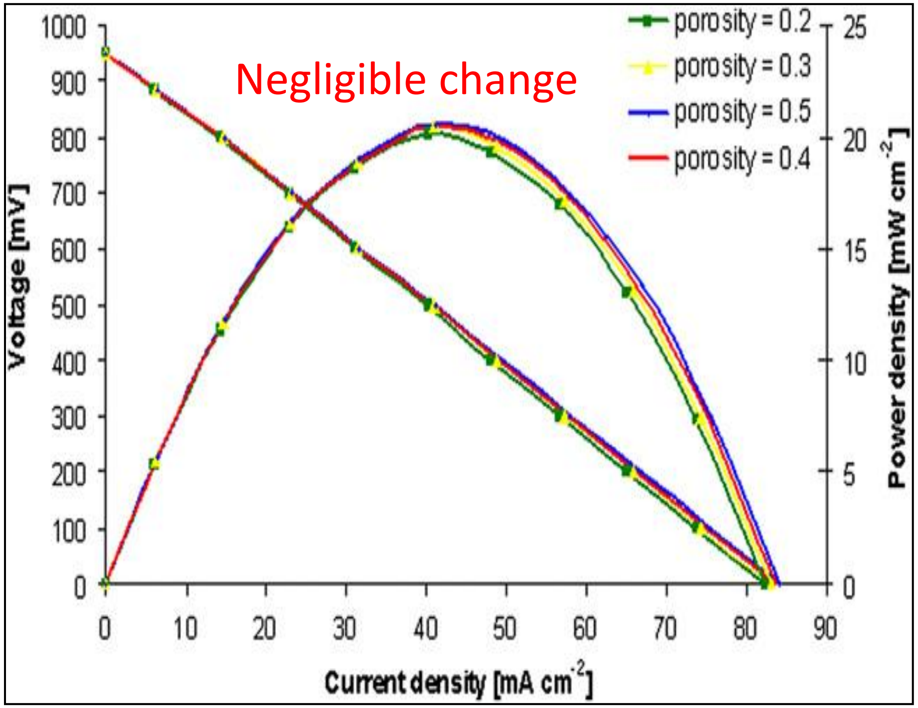


Electrolyte Conductivity



Electrode Porosity – Comparison with Published Results



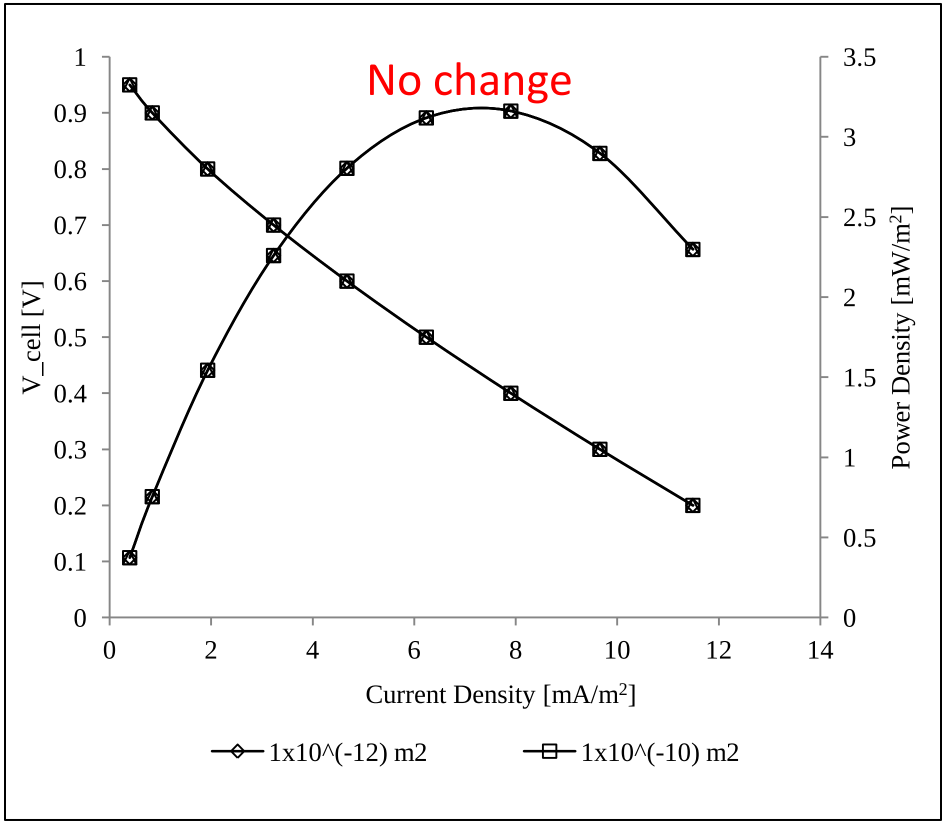


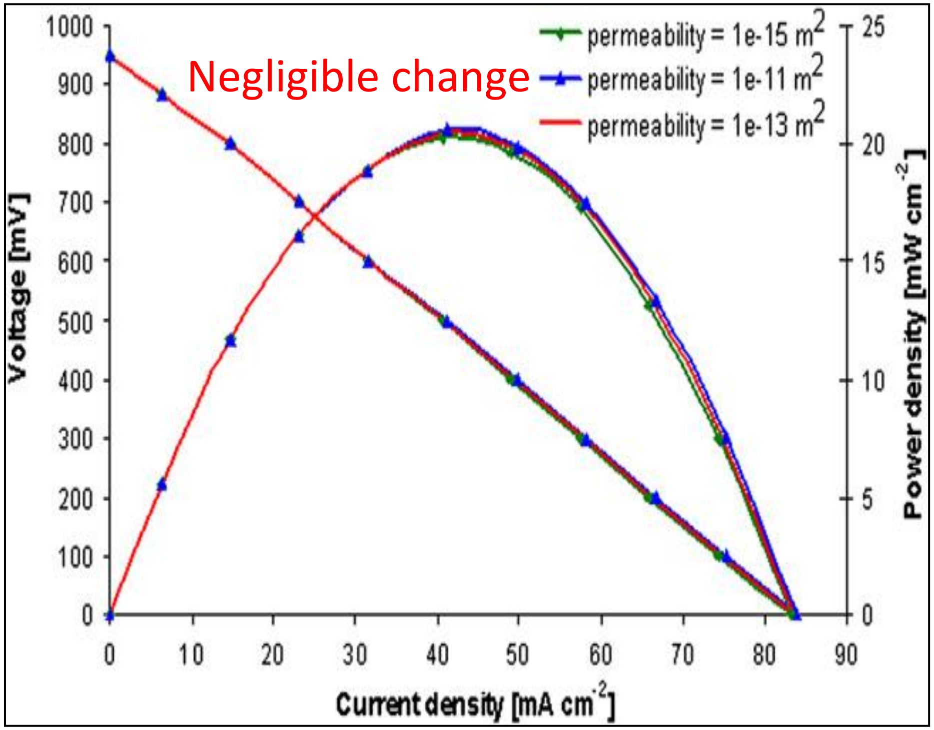
Akhtar et al., *International Journal of Hydrogen Energy*, 2011

$$\frac{\rho}{\varepsilon_p}\left(\frac{\partial u}{\partial t} + (u \cdot \nabla)\frac{u}{\varepsilon_p}\right) = -\nabla p + \nabla \cdot \left[\frac{1}{\varepsilon_p}\left\{\mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla \cdot u)I\right\}\right] - \left(\frac{\mu}{k} + Q_{br}\right)u + F$$

ε_p : porosity

Permeability – Comparison with Published Results





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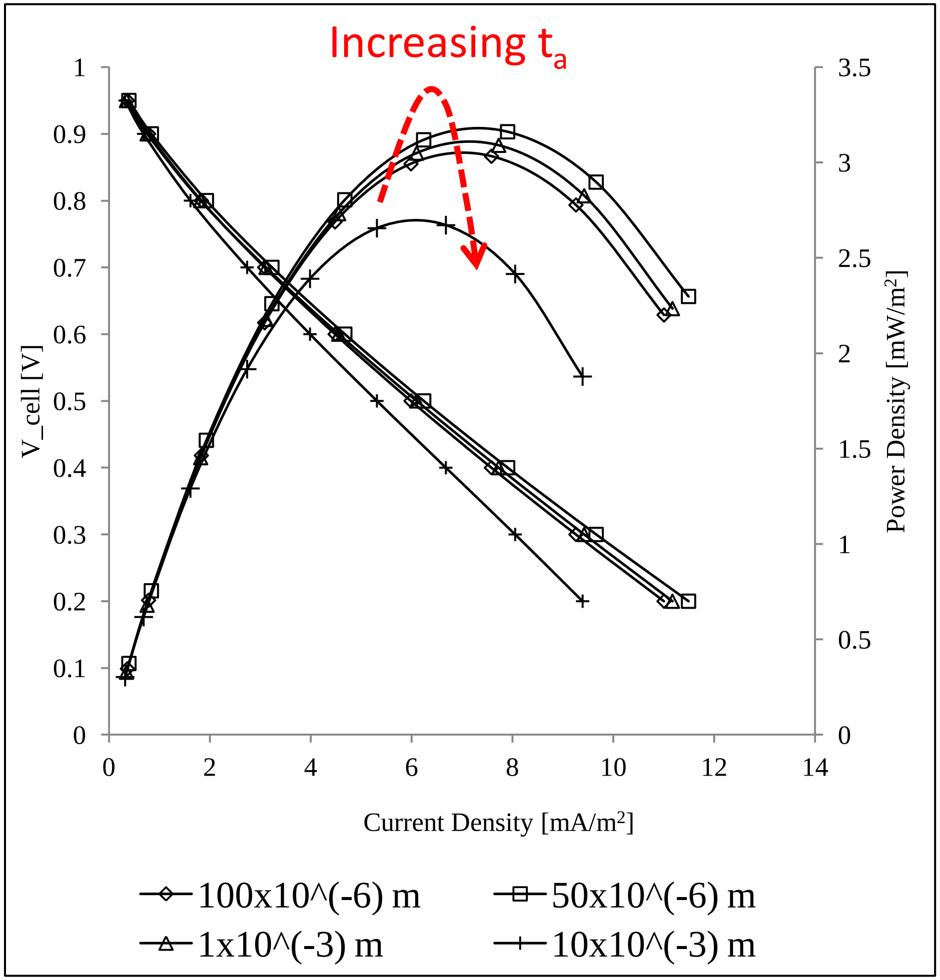
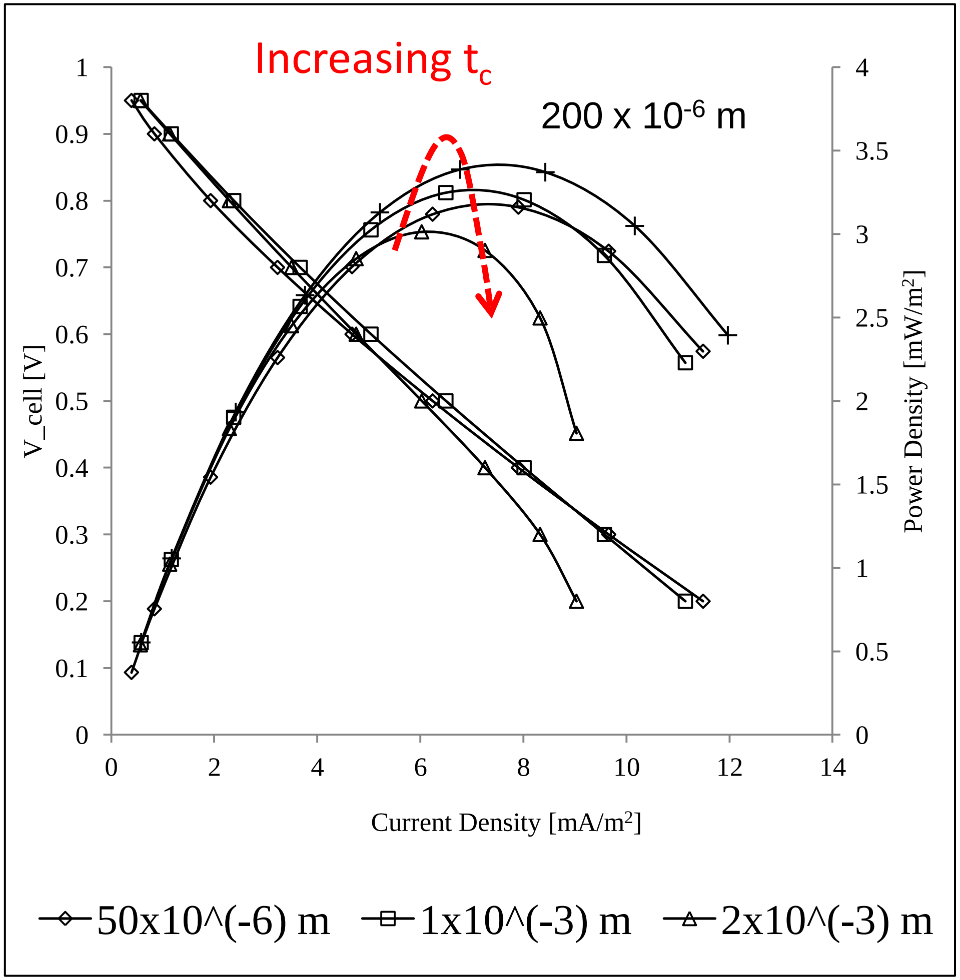
k : permeability of porous medium (m^2)

Anode & Cathode Thickness



Anode thickness



Cathode thickness

Summary

#	*Parameter*	*Range*	*Max % variation in Current or Power density*
1	Viscosity - Anode	1×10^{-6} - 1 Pa*s	< 1%
2	Viscosity - Cathode	3×10^{-7}- 10 Pa*s	4.83%
3	Exchange current - Anode	0.01 - 100 A/m^2	42.80%
4	Exchange current - Cathode	0.001 - 0.1 A/m^2	253.60%
5	Specific Surface Area - Anode	1×10^{6}- 1×10^{12} m^{-1}	98.90%
6	Specific Surface Area - Cathode	1×10^{6} - 1×10^{12} m^{-1}	327.22%
7	Permeability - Anode	1×10^{-13} - 1 m^2	0
8	Permeability - Cathode	1×10^{-13} - 1 m^2	0
9	Electrolyte Conductivity	1 - 15 S/m	63.35%

Conclusion & Future Work

- **A parametric study was conducted to identify key parameters that affect cell performance**
- **Exchange current density, specific surface area and electrolyte conductivity affect the performance significantly**
- **The affect of electrode thickness is not fully understood**
- **It is not clearly understood why performance is not affected by porosity and permeability of electrodes**
- **Future work will include incorporating emperical data or theoretical relationships**

Questions?
Thank you!