Low Temperature Solid Oxide Fuel Cells;
A Transformational Energy Conversion Technology

Eric D. Wachsman

University of Maryland Energy Research Center

University of Maryland
College Park, MD 20742

ewach@umd.edu

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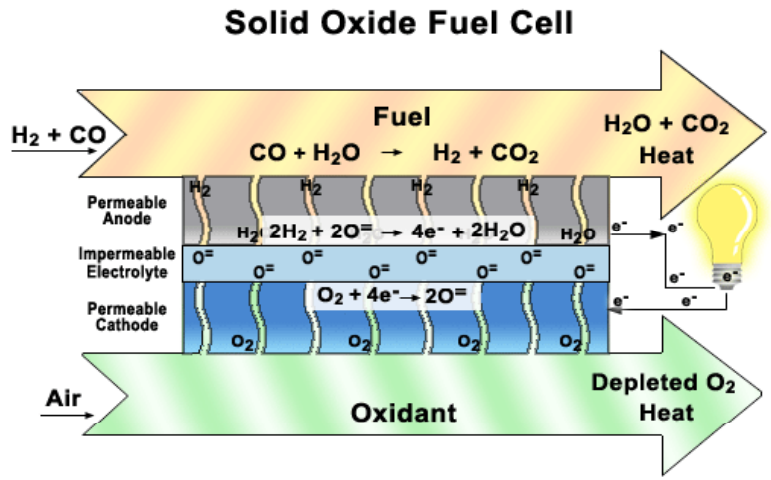
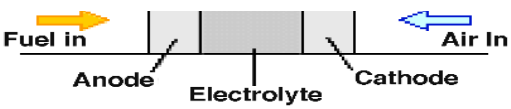
REDOX

Solid State Fuel Cell Technologies





Temperature

~80°C 200°C ⟷ 600°C ~800°C

Fuel C/H Ratio

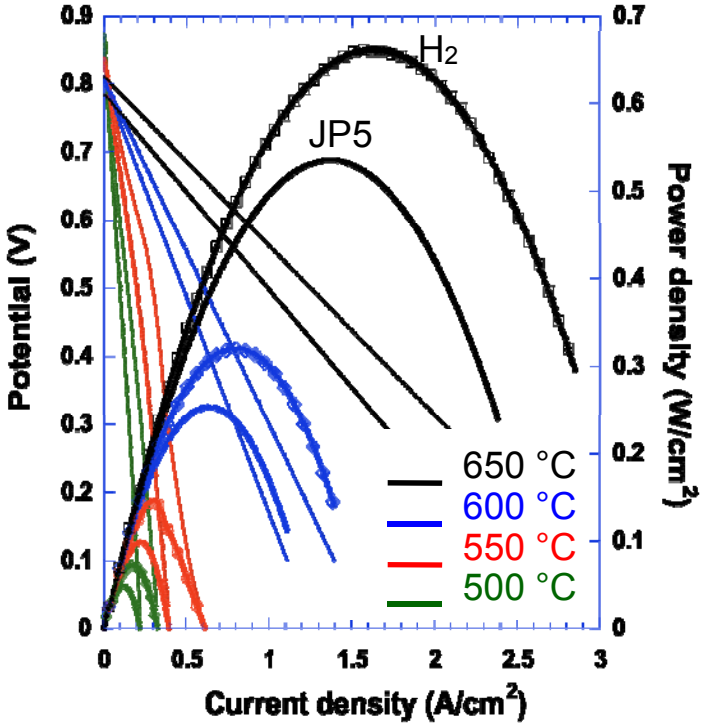
H_2 Natural Gas Biofuel Gasoline Diesel Coal Gas

DOE – EERE's
H_2 & Fuel Cell Program

?

DOE – FE's
SECA Program

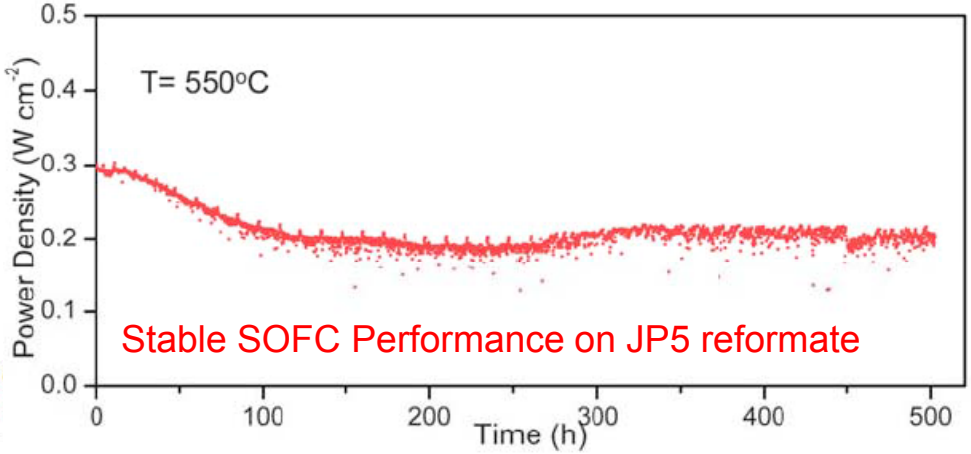
SOFC Fuel Flexibility



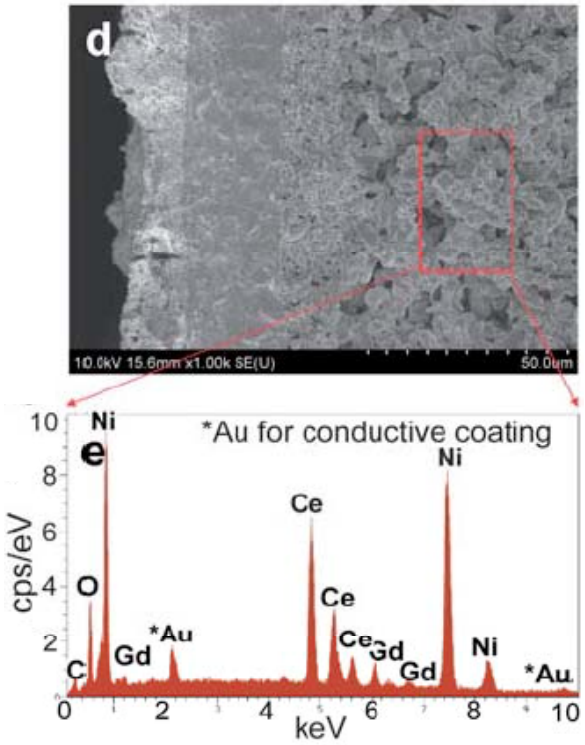
SOFC with H_2 and JP5 reformate

(H_2 0.306, H_2O 0.244, CH_4 0.008, CO 0.093, CO_2 0.093, N_2 0.255)

Only ~20% drop in power with JP5



Stable SOFC Performance on JP5 reformate



No Carbon deposition at 550°C

Journal of Materials Chemistry

Cite this: DOI: 10.1039/c2jm35590f

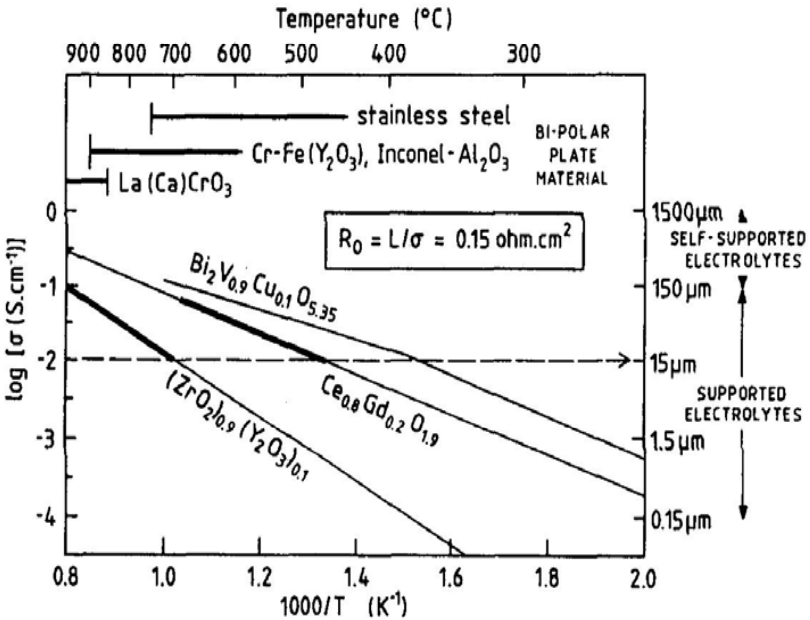
www.rsc.org/materials

COMMUNICATION

Feasibility of low temperature solid oxide fuel cells operating on reformed hydrocarbon fuels

Kang Taek Lee, Colin M. Gore and Eric D. Wachsman*

Why Lower Temperature SOFCs (≤ 600 ºC)?



Metallic Interconnects

Lower cost and greater reliability

Easier Sealing

Lower cost and greater reliability

Smaller Thermal Mismatch

Greater reliability

Less Insulation

Lower cost

Rapid Startup with Less Energy Consumption

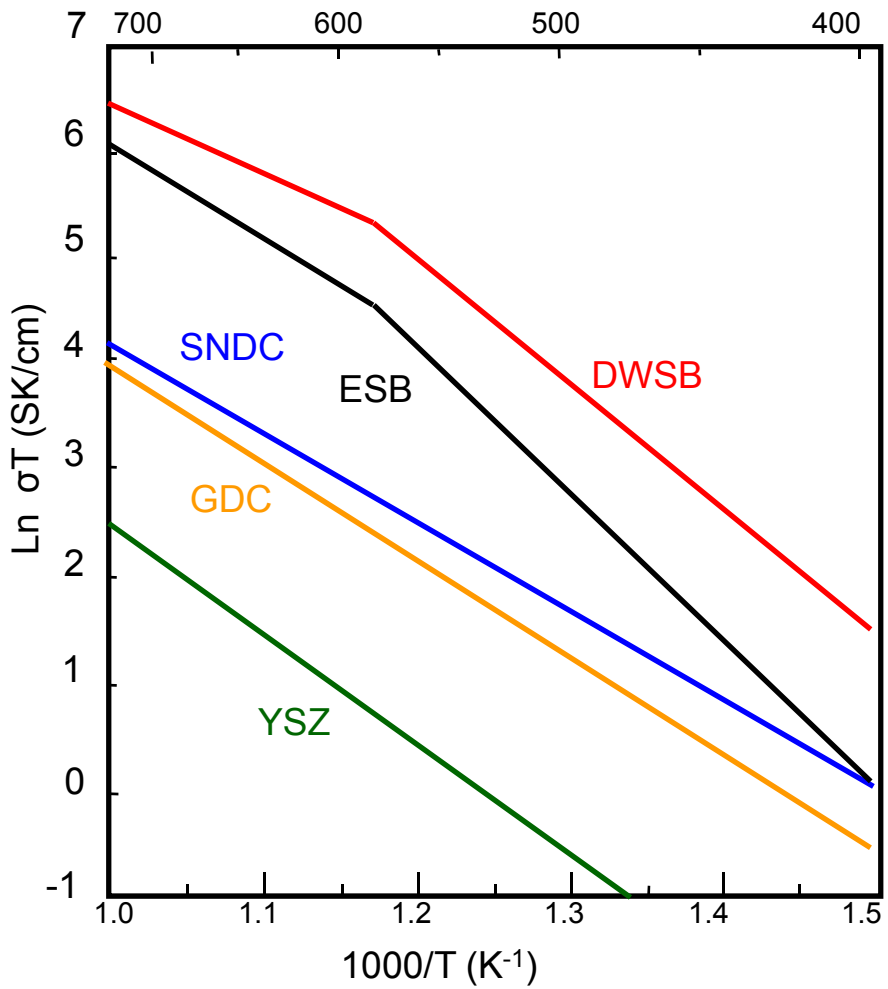
Lower cost and better performance

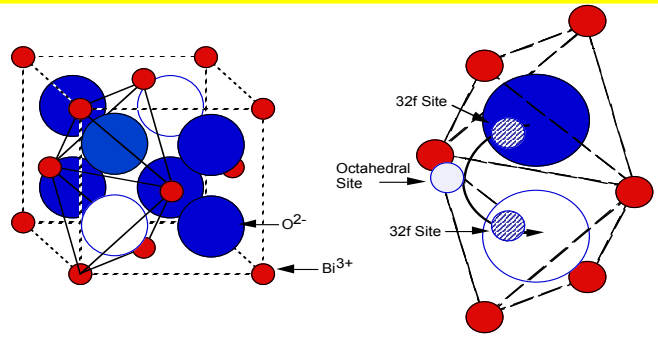
Portable/Transport applications

Transient Operation

Need higher conductivity electrolytes

Higher Conductivity Electrolytes





- Fundamentals of oxide transport
- Conductivity of 8Dy4WSB is
  - 0.57 S/cm at 700°C
  - 0.10 S/cm at 500°C
- Highest conductivity of any stabilized Fluorite oxide
  - 3X that of ESB
  - 10X that of GDC
  - 100X that of YSZ
- Optimizing composition for operation down to ~300°C
- Demonstrated co-doping enhancement of conductivity with SNDC

Stability of High Conductivity Electrolytes in Reducing Conditions

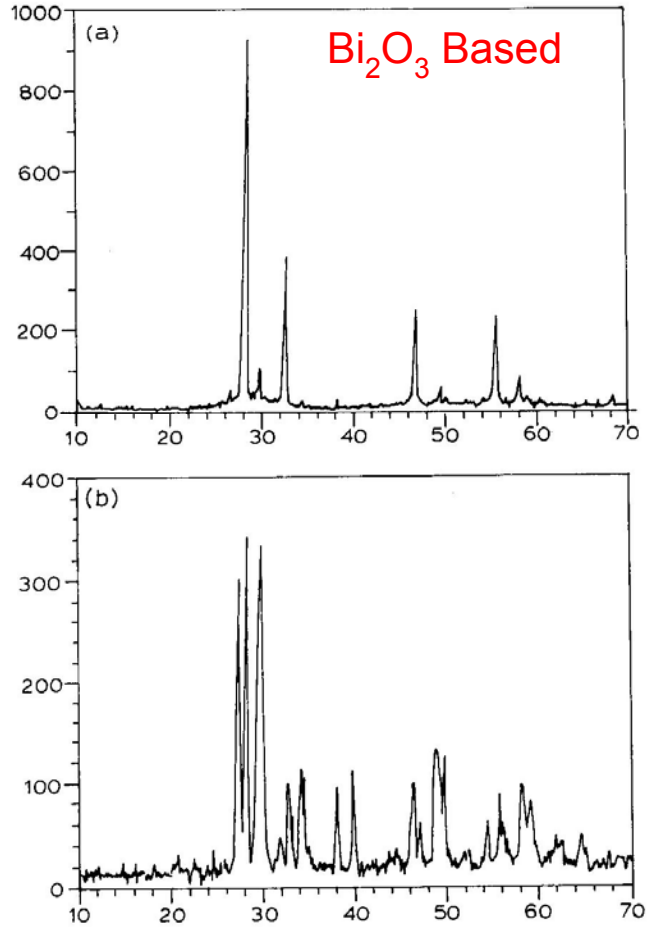


Fig. 4. X-ray diffraction of 20 mol% ESB: (a) as received; (b) annealed 4 h at 700 °C in H_2/H_2O $P_{O_2} = 10^{-21}$ atm).

Wachsman, et al., *Solid State Ionics,* **52**, 216 (1992)

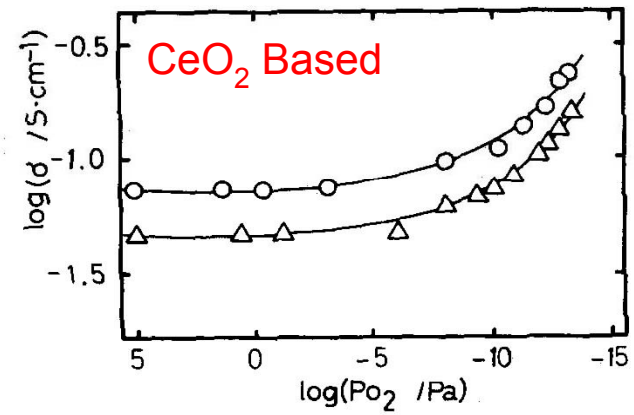
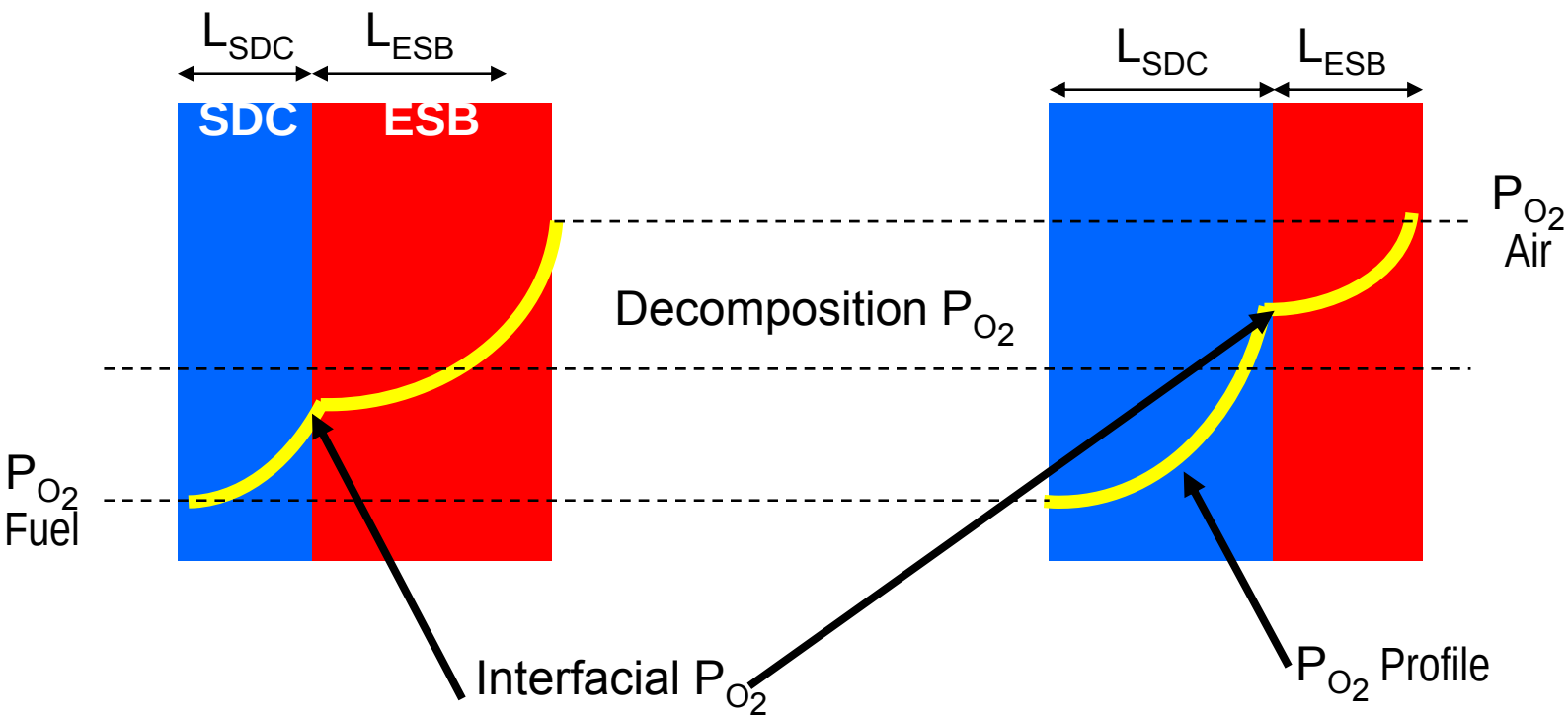


Fig. 6. Electrical conductivities as a function of oxygen partial pressure at 800°C: (○) $(CeO_2)_{0.8}(SmO_{1.5})_{0.2}$; (△) $(CeO_2)_{0.8}(GdO_{1.5})_{0.2}$.

Eguchi, et al., *Solid State Ionics,* **52**, 168 (1992)

Weak M-O bonds lead to high conductivity but also low thermodynamic stability

Bilayer Electrolyte



$L_{SDC} / L_{ESB} < l_{optimal}$

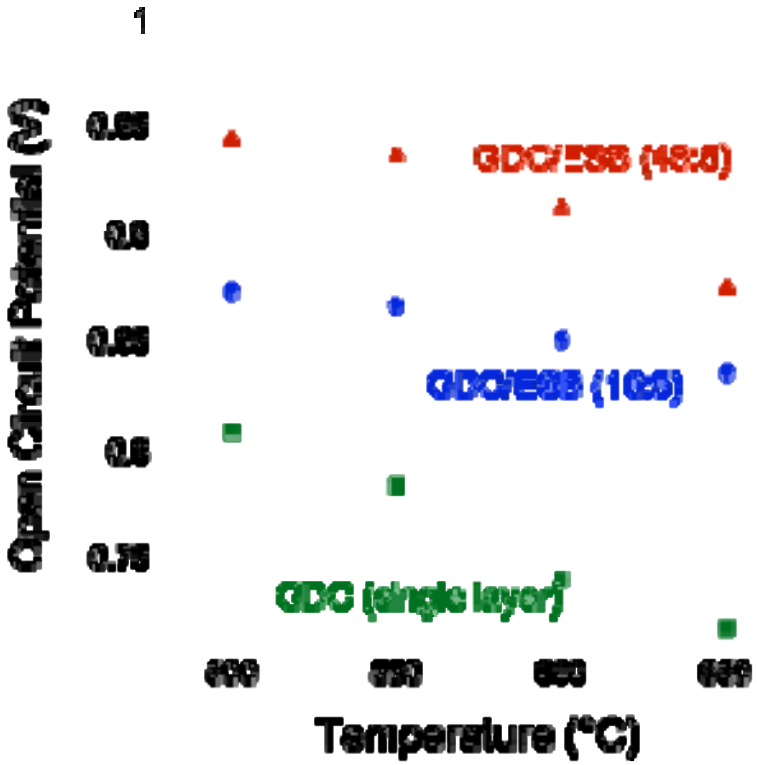
ESB decomposes

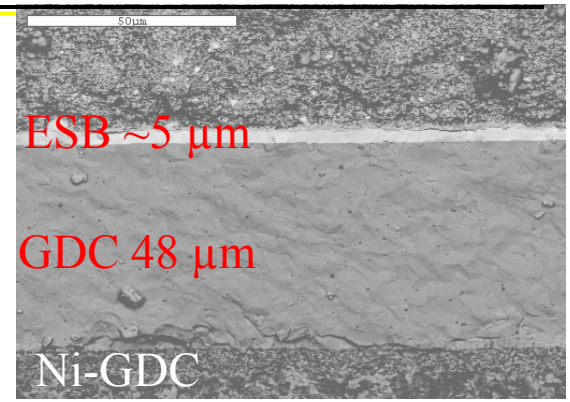
$L_{SDC} / L_{ESB} > l_{optimal}$

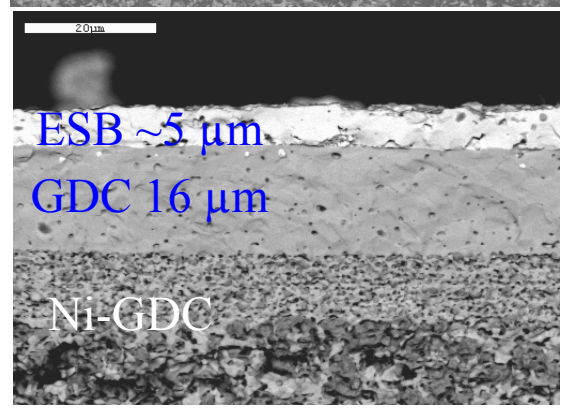
ESB is stable

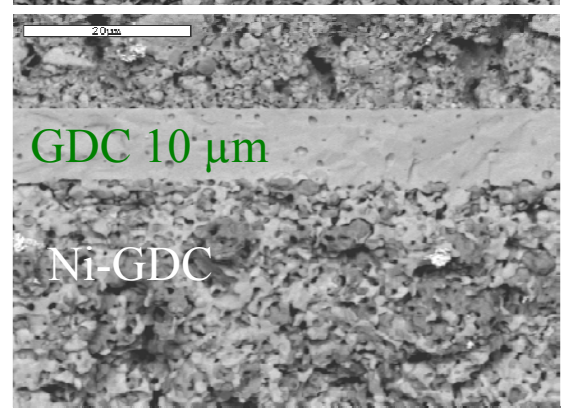
E. D. Wachsman, P. Jayaweera, N. Jiang, D. M. Lowe, and B.G. Pound, *J. Electrochem. Soci.*, **144**, 233 (1997).

Thin Bilayer Electrolyte OCP



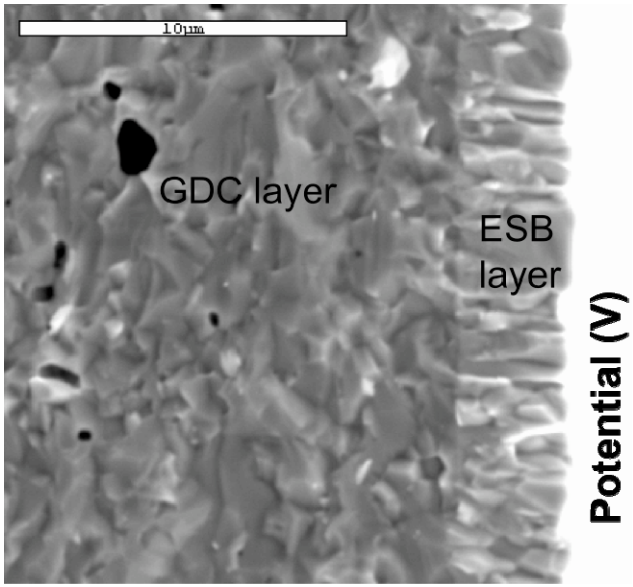


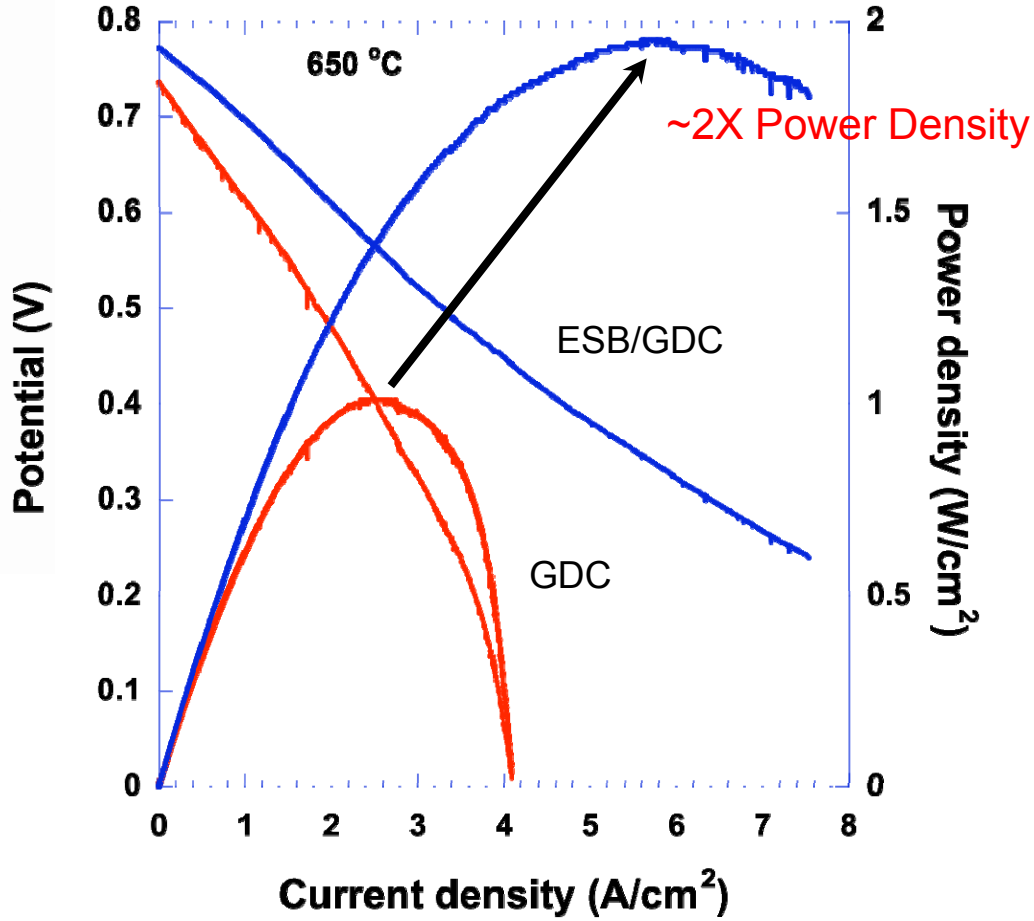




- Near theoretical OCP achieved with anode supported thin bilayer electrolytes
- Need to optimize *both* GDC and ESB thicknesses

Bilayer Electrolytes for LT-SOFC





Integrating new materials and microstructures to achieve world record performance

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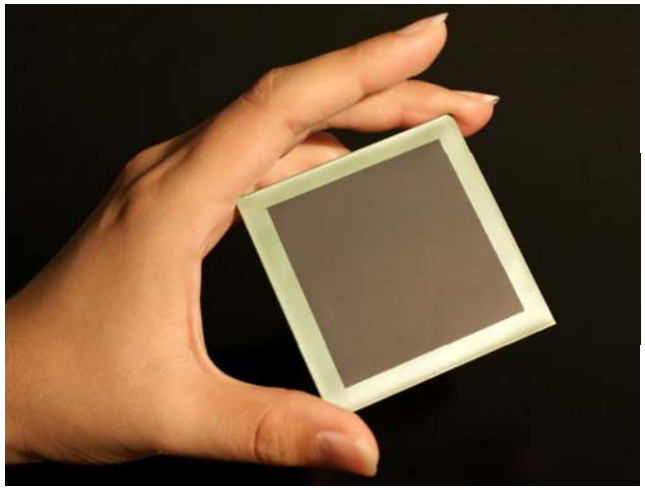
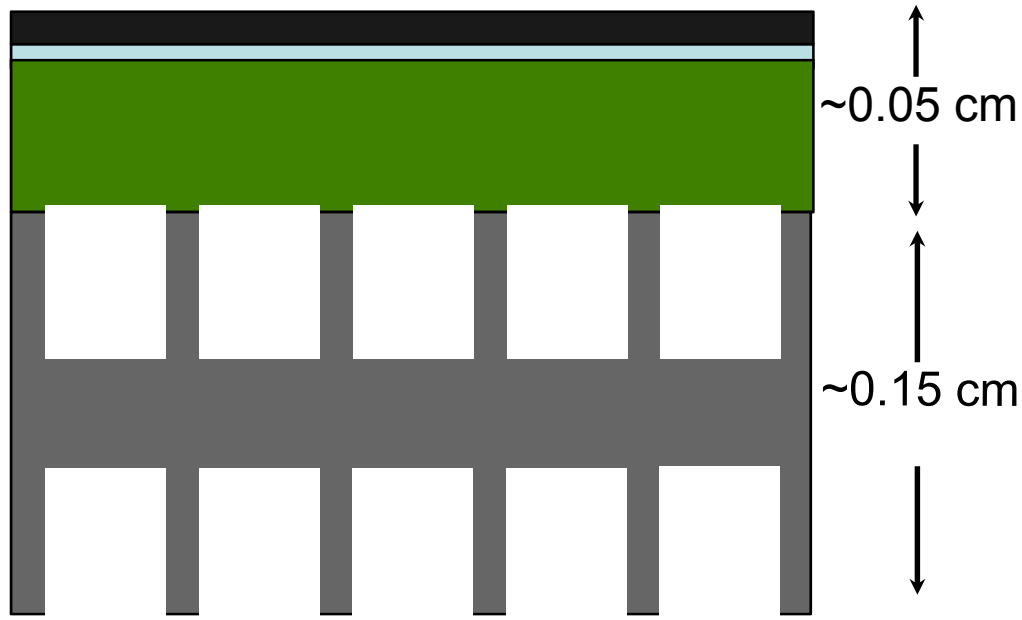
J. S. Ahn, D. Pergolesi, M. A. Camaratta, H. Yoon, B. W. Lee, E. Traversa and E. D. Wachsman, *Electrochem. Comm.*, **11**, 1504 (2009).

Volumetric Power Density

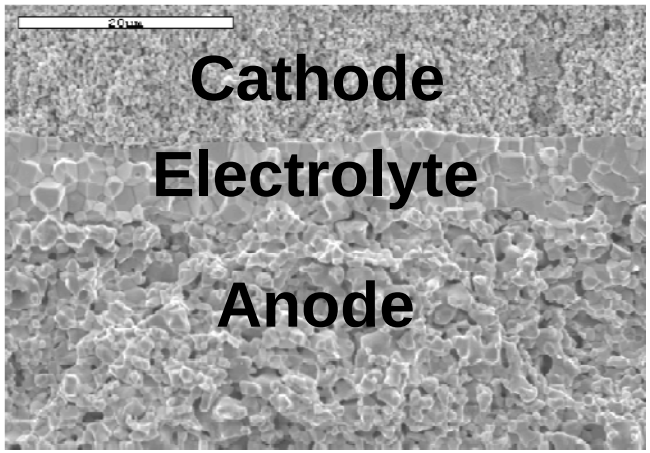


$2\ W/cm^2 = 10\ W/cm^3$

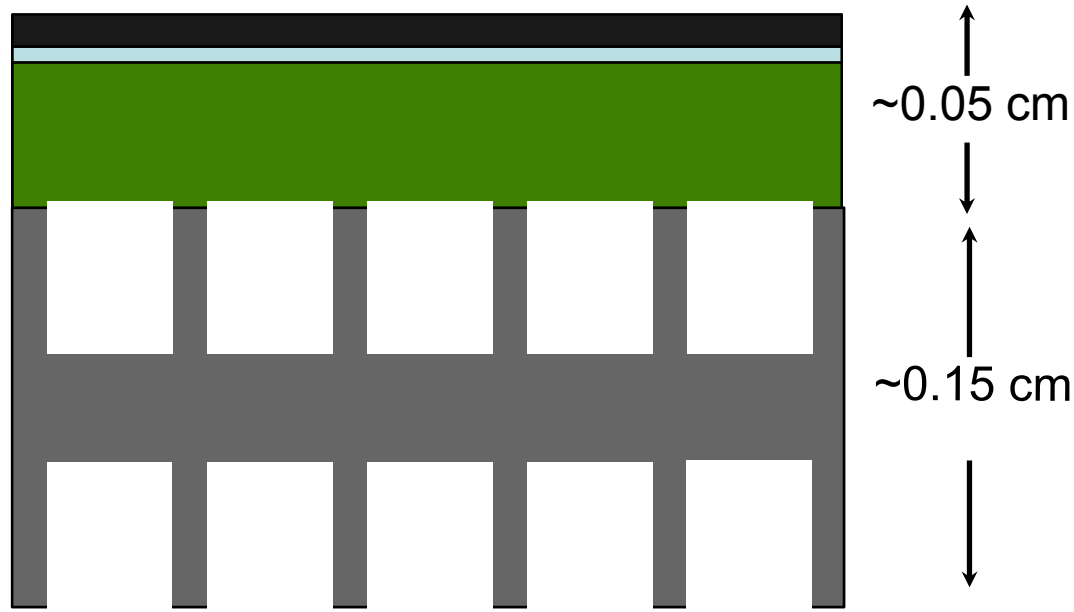


Steel Interconnect/gas channels

Gravimetric Power Density



Electrodes ~30% porous



Steel Interconnect/gas channels ~70% porous

0.7 X 7g/cc X 0.05cm + 0.3 X 8g/cc X 0.15cm = ~0.6 g/cm^2

~2 W/cm^2 / 0.6 g/cm^2 = **~3 kW/kg**

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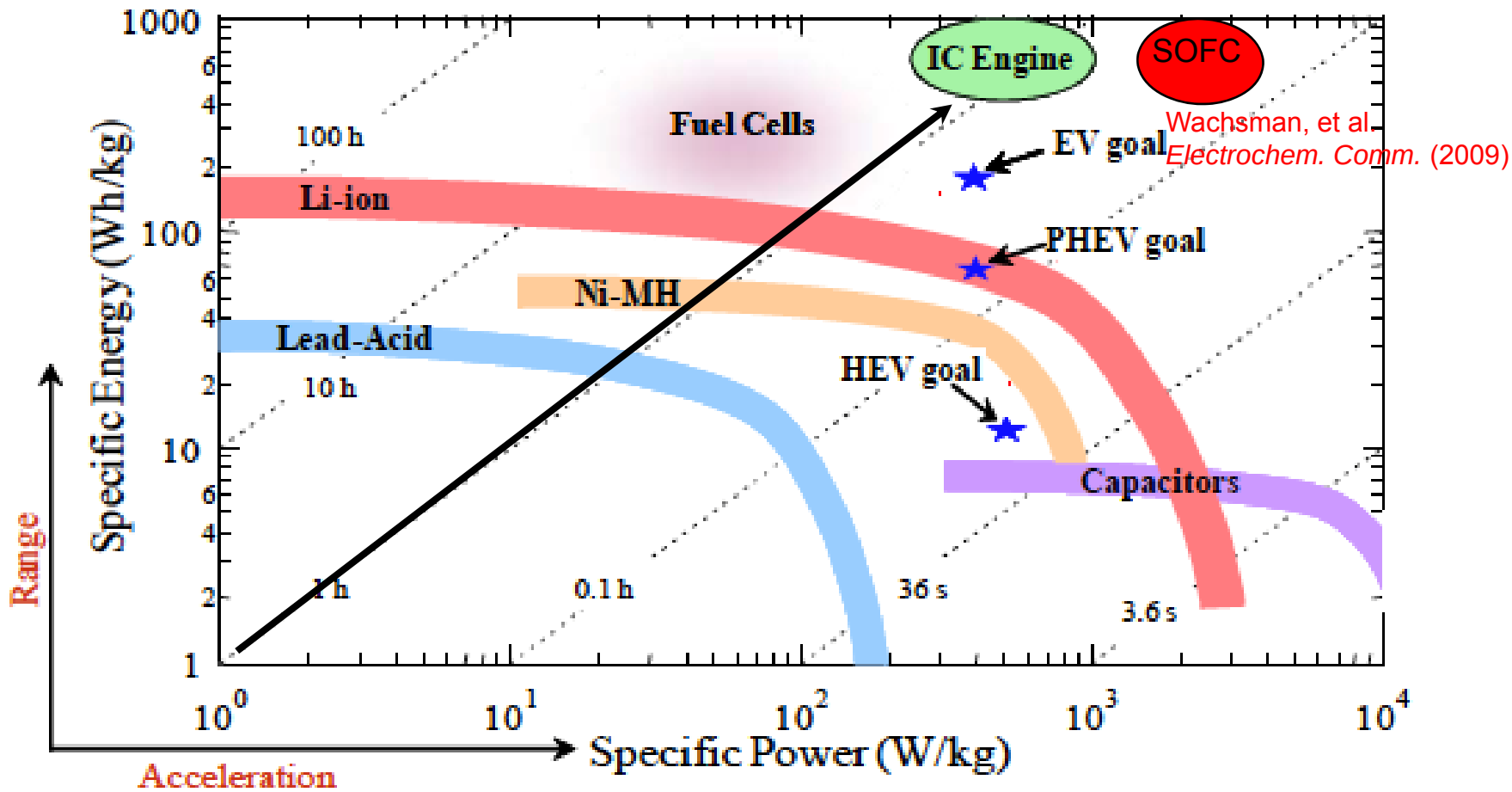
Energy Storage Figure of Merit



Wachsman, et al. *Electrochem. Comm.* (2009)

V. Srinivasan, Batteries for Vehicular Applications, http://berc.lbl.gov/venkat/files/batteries-for-vehicles.pdf

Next Generation Solid Oxide Fuel Cells

SCIENTIFIC AMERICAN™

Permanent Address: http://www.scientificamerican.com/article.cfm?id=next-generation-flex-fuel-cells-ready

Next-Generation Flex-Fuel Cells Ready to Hit the Market

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By Steven Ashley | Friday, November 18, 2011 | 2 comments

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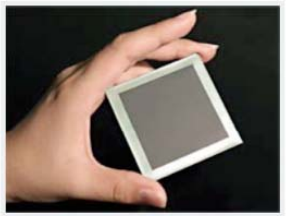

Gas guzzler: The fuel cell developed at the University of Maryland.
University of Maryland

ENERGY

Gasoline Fuel Cell Would Boost Electric Car Range

The advanced fuel cell could eliminate range anxiety and make electric cars more practical, while keeping carbon-dioxide emissions low.

FRIDAY, DECEMBER 2, 2011 | BY KEVIN BULLIS

Audio »

If you want to take an electric car on a long drive, you need a gas-powered generator, like the one in the Chevrolet Volt, to extend its range. The problem is that when it's running on the generator, it's no more efficient than a conventional car. In fact, it's even less efficient, because it has a heavy battery pack to lug around.

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technology review
Published by MIT

Tuesday, December 27, 2011

The Year in Energy

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power.
By Kevin Bullis

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