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

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Solid State Fuel Cell Technologies

Solid Oxide Fuel Cell

Temperature

~80°C  200°C  →  600°C  ~800°C

Fuel C/H Ratio

H₂  Natural Gas  Biofuel  Gasoline Diesel  Coal Gas

DOE – EERE’s  H₂ & Fuel Cell Program

DOE – FE’s  SECA Program

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SOFC Fuel Flexibility

SOFC with H₂ and JP5 reformate

(H₂ 0.306, H₂O 0.244, CH₄ 0.008, CO 0.093, CO₂ 0.093, N₂ 0.255)

Only ~20% drop in power with JP5

No Carbon deposition at 550°C

Stable SOFC Performance on JP5 reformate

Journal of Materials Chemistry

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

Kang Tack 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

**Bi₂O₃ Based**

**CeO₂ Based**


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

Bilayer Electrolyte

L_{SDC} / L_{ESB} < I_{optimal}
ESB decomposes

L_{SDC} / L_{ESB} > I_{optimal}
ESB is stable

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

~2X Power Density

Volumetric Power Density

2 W/cm² = 10 W/cm³

Steel Interconnect/gas channels

~0.05 cm

~0.15 cm
Gravimetric Power Density

Electrodes ~30% porous

Steel Interconnect/gas channels ~70% porous

\[
0.7 \times 7 \text{g/cc} \times 0.05\text{cm} + 0.3 \times 8 \text{g/cc} \times 0.15\text{cm} = \sim 0.6 \text{ g/cm}^2
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\[
\sim 2 \text{ W/cm}^2 / 0.6 \text{ g/cm}^2 = \sim 3 \text{ kW/kg}
\]
Energy Storage Figure of Merit

V. Srinivasan, Batteries for Vehicular Applications,
Next Generation Solid Oxide Fuel Cells

**Next-Generation Flex-Fuel Cells Ready to Hit the Market**
Solid oxide fuel cells that can use conventional fossil fuels as well as hydrogen are set to take a larger role in the energy game.

**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.

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.

**The Year in Energy**
Surprising successes helped offset disappointing failures in solar, biofuel power.

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**Fuel Cell Seminar & Energy Expo Award**

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**Scientific American**
Published by MIT

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**Technology Review**
Published by MIT

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