Planar Intermediate Temperature Direct Ammonia Fuel Cell

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Ammonia – The Key to Energy Independence
September 29, 2008
Why Fuel Cells?

- **Pros:**
  - High chemical-to-electric efficiency (45-80%)
  - No moving parts (quiet, low/no maintenance)
  - High energy density (limited only by size of fuel tank)
  - Cell is usually lightweight
  - Systems are inherently scalable

- **Cons:**
  - Expensive! (catalyst costs, housing costs, electrolyte costs)
  - Often limited by fuel type or purity of fuel & fuel byproducts
  - Limited power density (difficult to get energy delivered quickly)
  - Balance of plant may be costly/heavy/problematic

- **So, how do we maximize the “pros” and limit the impact of the “cons?”**
Focus Areas

- **Cons:**
  - Expensive! (catalyst costs, housing costs, electrolyte costs)
    - Catalysts and housing: impacted by operating temperature
    - Electrolyte: Fuel cell type (op. temperature, again)
  - Often limited by fuel type or purity of fuel & fuel byproducts
    - Compatibility with electrocatalysts: proper fuel choice
    - Direct fuel & avoiding catalyst poisoning: op. temperature
  - Limited power density (difficult to get energy delivered quickly)
  - Balance of plant may be costly/heavy/problematic
    - Reducing HX sizes: operating temperature
    - Fuel reservoir size or delivery of fuel: proper fuel choice
Step 1: Use the Right Fuel

\[ \text{CH}_4 \rightarrow 3H_2 + \frac{1}{2}N_2 \quad \Delta H^\circ = 46 \frac{kJ}{mol} \]

- Very mild enthalpy of reforming
- \( \text{NH}_3 \) is a liquid at room temperature and 10 bar
  - Power density is comparable to other liquid fuels
  - Vaporizes when throttled (no flash line required)
- Essentially non-flammable, non-explosive
- 171 kWh of motive power from 15 gallons ammonia (38 kg) with 48% efficient fuel cell system incl. motor
- Highway driving: 19 kW; yields 9 hours of cruising
- 65 miles per hour takes you 585 miles
- **Ammonia makes that possible**
Step 2: Operate at the Right Temperature

- **Low Temperature Fuel Cell Advantages**
  - Quick start-up to operating temperature (~100°C)
  - Wide range of cell construction materials

- **High Temperature Fuel Cell Advantages**
  - Fuel flexibility via internal fuel reforming
  - Inexpensive, base metal electrocatalysts
  - Easier heat recovery for increased efficiency

- **Intermediate Temperature Fuel Cells: The Best of Both Worlds?**
  - Precious metal catalysts not needed above ~300°C
  - Steel internals may be used below ~500°C
Contemporary Fuel Cell Options

- Polymer Electrolyte Membrane Fuel Cells (PEMFC) [80°C, H⁺]
- Alkaline Fuel Cells (AFC) [80-150°C, OH⁻]
- Phosphoric Acid Fuel Cells (PAFC) [220°C, H⁺]
- [Intermediate Temp Fuel Cell, 300 - 500°C]
- Protonic Ceramic Fuel Cell (PCFC) [600°C, H⁺]
- Molten Carbonate Fuel Cells (MCFC) [650°C, CO₃²⁻]
- Solid Oxide Fuel Cells (SOFC) [800°C, O²⁻]
1st Generation IT-DAFC

Diagram showing the components of the 1st Generation IT-DAFC:
- Ammonia (anode)
- Air (cathode)
- Vent
- Monel Housing
- Heating Cartridges
Power production performance of the first generation direct ammonia fuel cell operating at

- (●) 200°C
- (▲) 250°C
- (■) 300°C
- (○) 350°C
- (△) 400°C
- (□) 450°C
Polarization behavior of the first generation direct ammonia fuel cell operating at

- (●) 200°C
- (▲) 250°C
- (■) 300°C
- (○) 350°C
- (△) 400°C
- (□) 450°C

Low OCV indicates leakage (nominal: ~1.1 V)

Linear i-V slopes indicate that ohmic losses dominate
Conversion to Planar Geometry

- **Improvement of electrolyte conduction**
  - Thinner layer of electrolyte = less ohmic loss
  - Faster water transfer to/from/ across electrolyte

- **Reduction in cell size**
  - Better power/weight ratio
  - Higher electrode surface areas/volume

- **More convenient cell construction**
  - Techniques similar to MCFC construction
  - Electrolyte layer may double as gas seal

- **More efficient use of ammonia fuel**
  - No “bubbling” of gas onto electrode surface – better mass transfer
  - No ammonia into electrolyte means less crossover
Planar Cell Design

- Porous electrolyte matrix (YSZ felt)
- Stainless steel housing
- Anode current collector (Ni wire mesh)
- Brazed seal
- Pressed nickel anode
- NH₃ inlet
- NH₃ exit
- Humidified air inlet
- Air exit
- Porous electrolyte matrix (YSZ felt)
- Pressed Ni/LiNiO₂ cathode
- Cathode current collector (Ni wire mesh)
Planar Cell Assembly
Planar Cell Performance

Polarization behavior of the planar direct ammonia fuel cell operating at

(●) 200°C, (▲) 250°C, (■) 300°C, (○) 350°C, (△) 400°C, and (□) 450°C.
Planar Cell Performance

Power production performance of the planar direct ammonia fuel cell operating at

- (●) 200°C
- (▲) 250°C
- (■) 300°C
- (○) 350°C
- (△) 400°C
- (□) 450°C

The graph shows the power density (mW/cm²) as a function of current density (mA/cm²) with different temperatures as indicated by the markers. The peak power density at 350°C is 52 mW/cm².
Conclusions

- **Increased power density achieved**
  - 30% increase from 40 mW/cm$^2$ to 52 mW/cm$^2$
  - Higher open circuit potentials
  - Possible further increase possible with attention to mass transfer issues at high currents

- **Mass transfer limitation possibilities**
  - Electrode porosity insufficient?
  - Too much/too little electrolyte wicking into electrodes?

- **Reduced fuel/air leakage and/or crossover**
  - Higher OCV
  - Molten salt/matrix seal appears effective

- **Future work: electrode catalysts, electrolyte matrix**