Planar Intermediate Temperature Direct Ammonia Fuel Cell

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Ammonia – The Key to Energy Independence
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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

CH4 103 (1.5 H2)

$$NH_3 \rightarrow \frac{3}{2}H_2 + \frac{1}{2}N_2 \qquad \Delta H^o = 46\frac{kJ}{mol}$$

- Very mild enthalpy of reforming
- 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**

356 kWh nom
180 mi gas

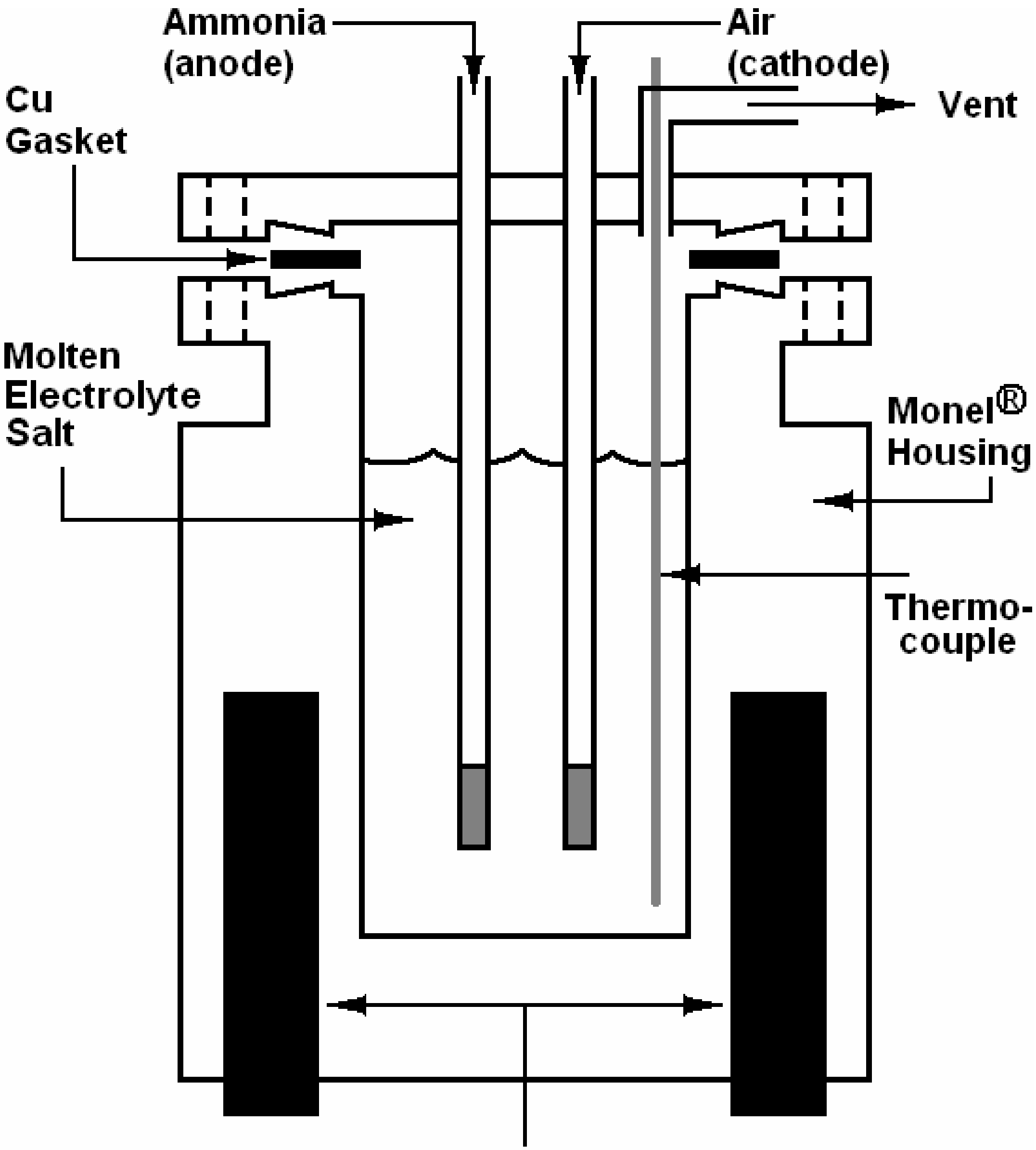
Step 2: Operate at the Right Temperature

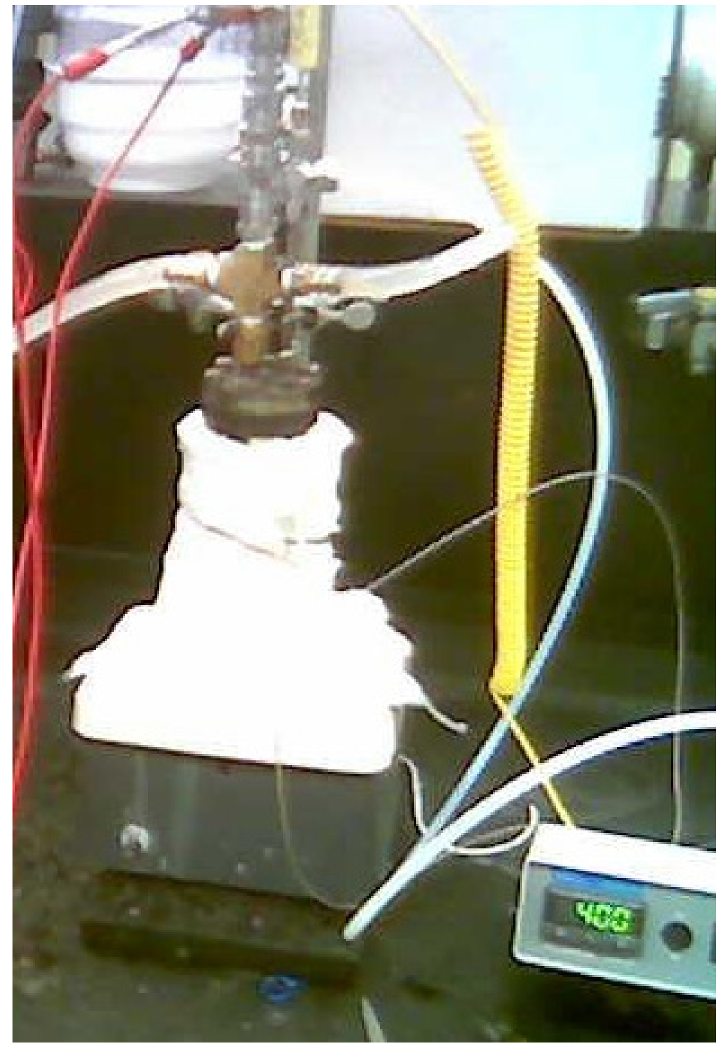
- **Low Temperature Fuel Cell Advantages**
  - Quick start-up to operating temperature (~100°C)
  - Wide range of cell construction materials
- **High Temperature Fuel Cell Advantages**
  - Fuel flexibility via internal fuel reforming
  - Inexpensive, base metal electrocatalysts
  - Easier heat recovery 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

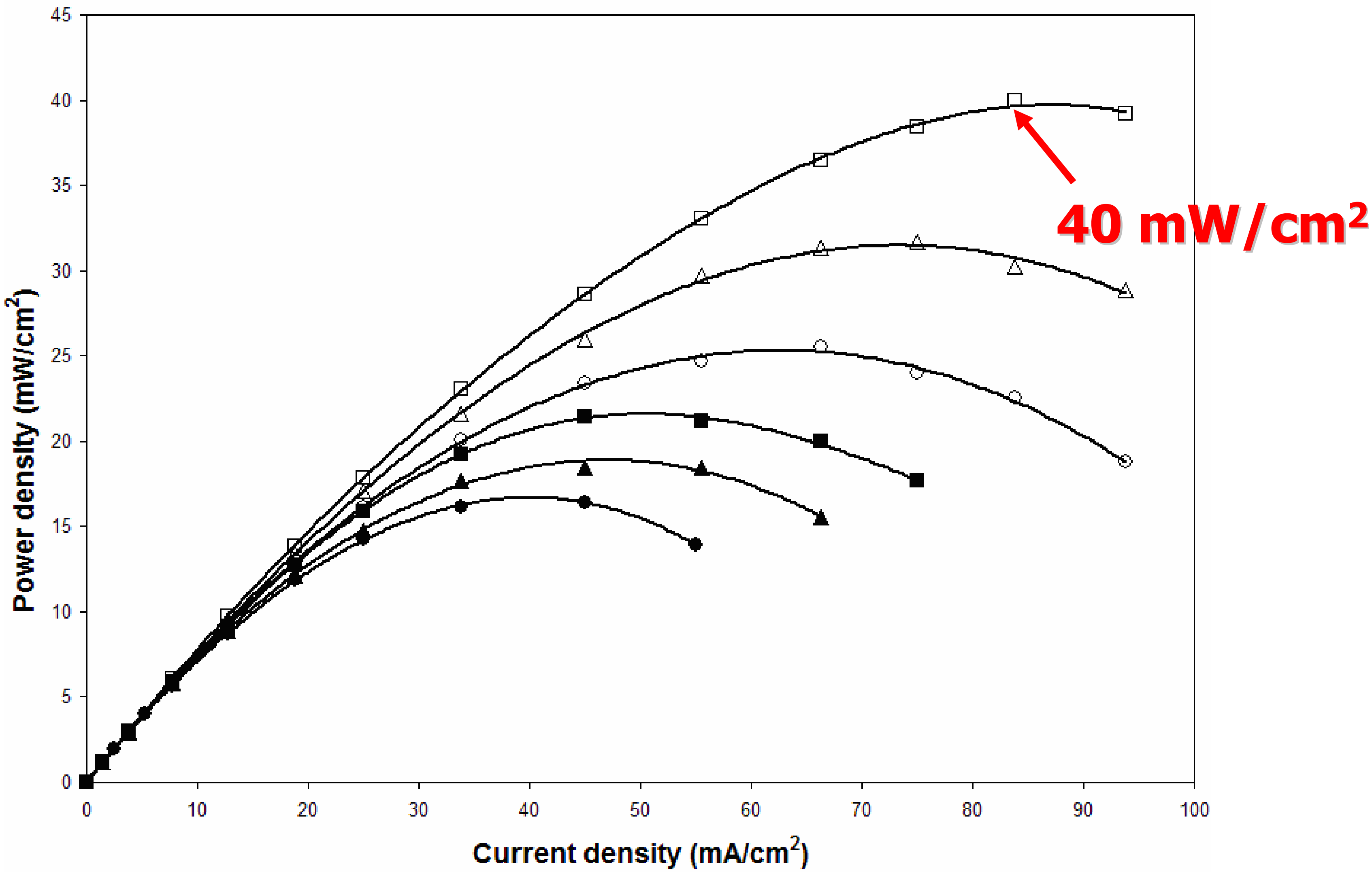
- **Polymer Electrolyte Membrane Fuel Cells (PEMFC) [80°C, H^+]**
- **Alkaline Fuel Cells (AFC) [80-150°C, OH^-]**
- **Phosphoric Acid Fuel Cells (PAFC) [220°C, H^+]**
- **[Intermediate Temp Fuel Cell, 300 - 500°C]**
- **Protonic Ceramic Fuel Cell (PCFC) [600°C, H^+]**
- **Molten Carbonate Fuel Cells (MCFC) [650°C, CO_3^{2-}]**
- **Solid Oxide Fuel Cells (SOFC) [800°C, O^{2-}]**

1st Generation IT-DAFC



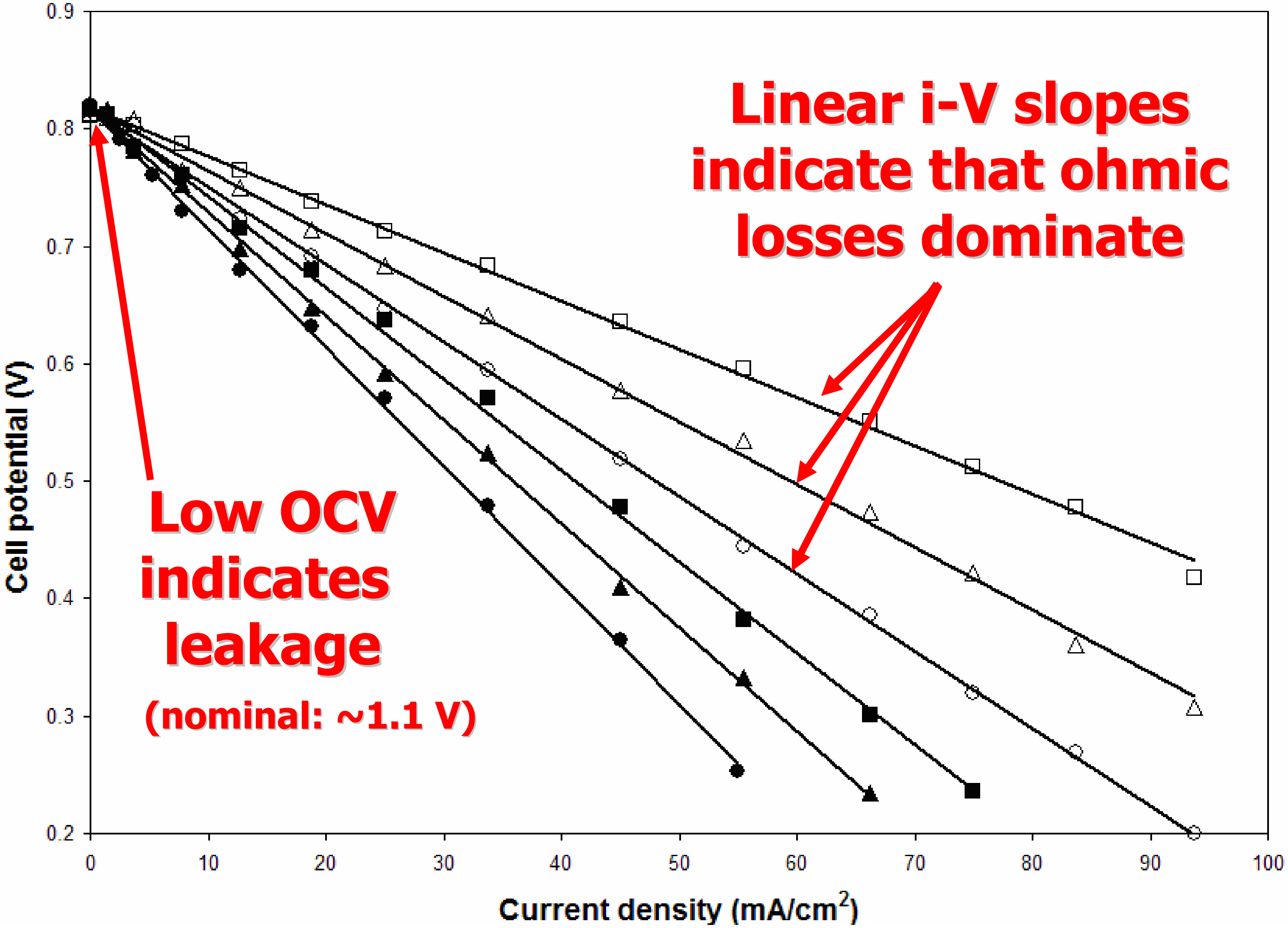


1st Generation Ammonia Cell Performance



Power production performance of the first generation direct ammonia fuel cell operating at (●) 200°C, (▲) 250°C, (■) 300°C, (○) 350°C, (△) 400°C, and (□) 450°C.

1st Generation Ammonia Cell Performance

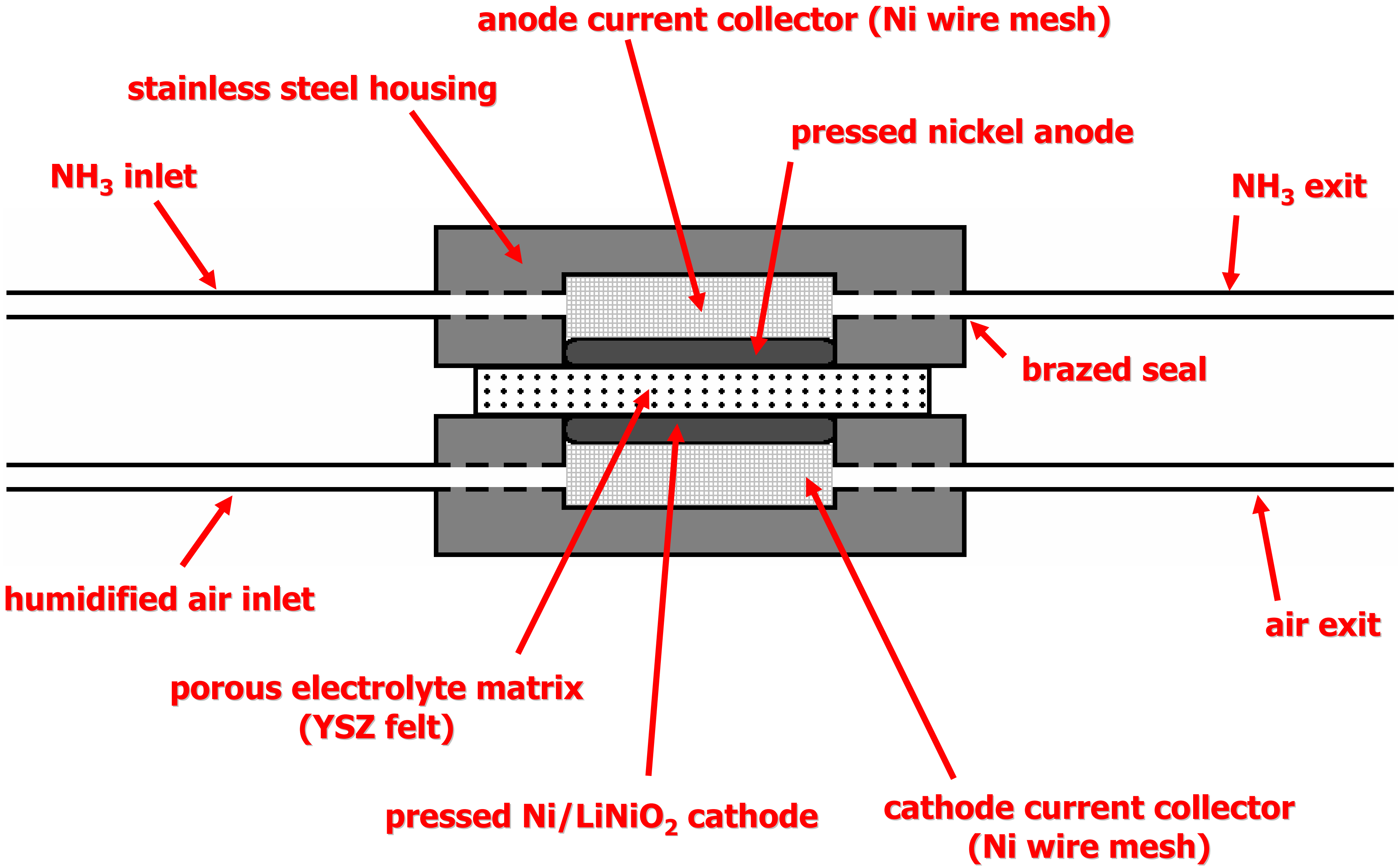


Polarization behavior of the first generation direct ammonia fuel cell operating at (●) 200°C, (▲) 250°C, (■) 300°C, (○) 350°C, (△) 400°C, and (□) 450°C.

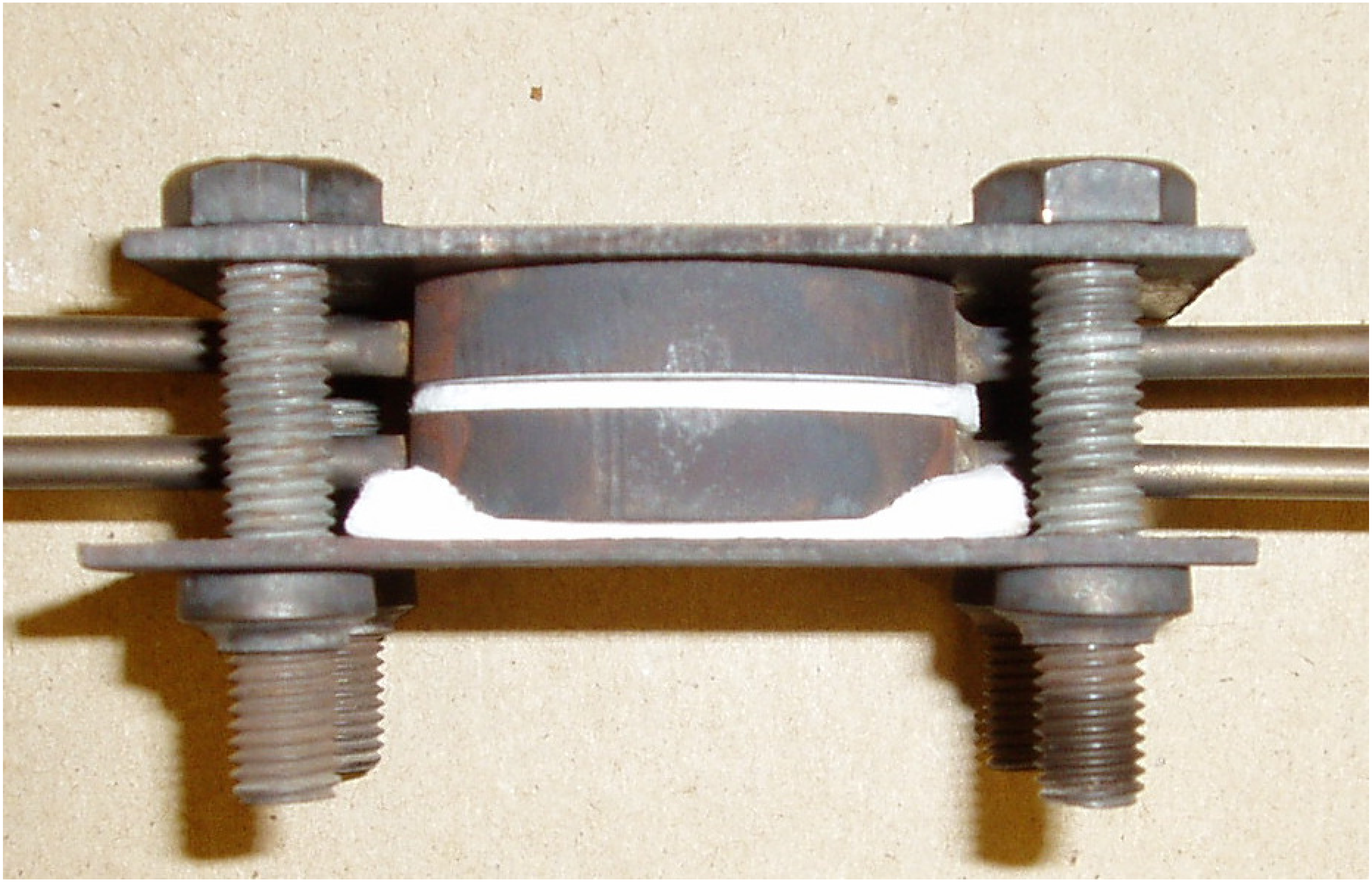
Conversion to Planar Geometry

- **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

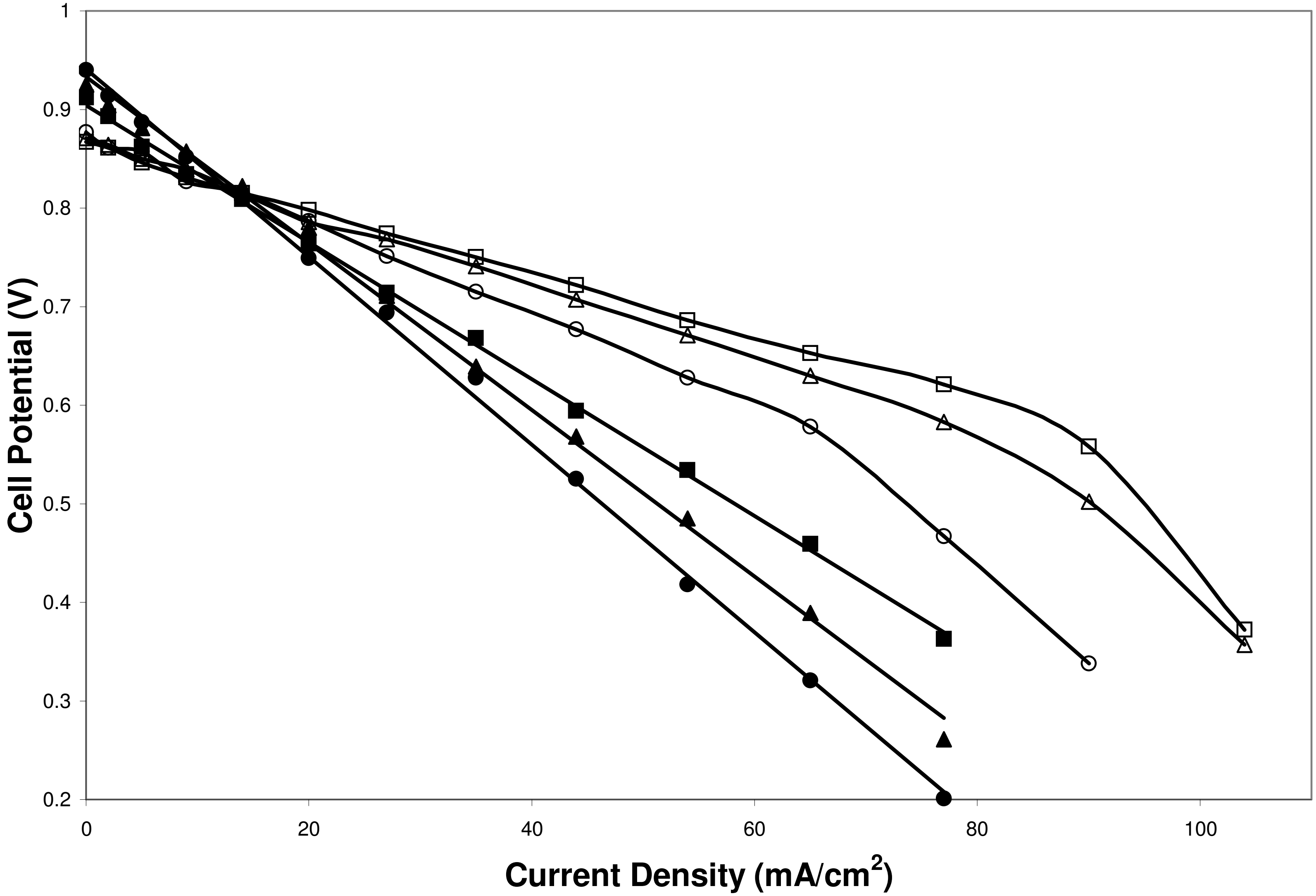
Planar Cell Design



Planar Cell Assembly



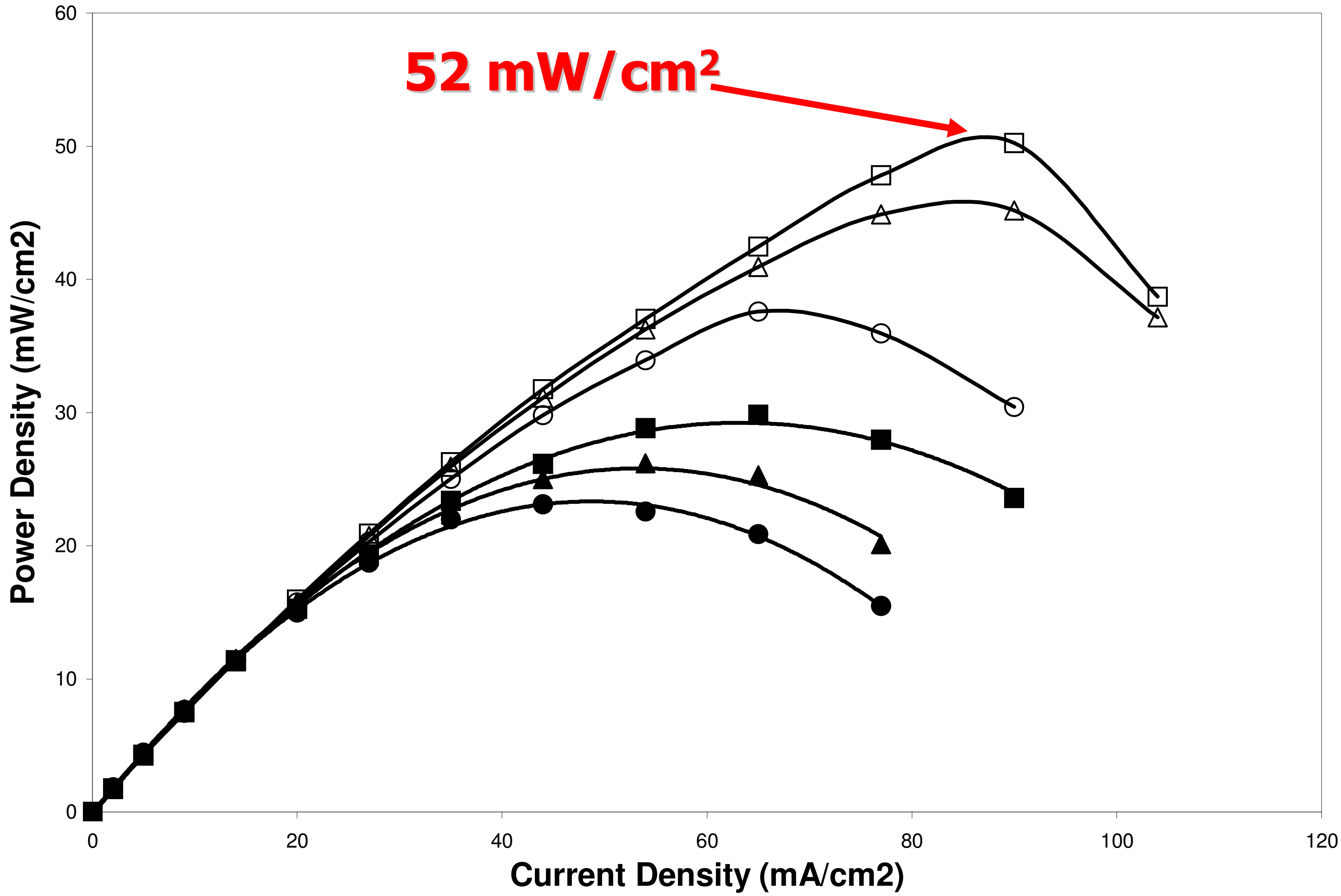
Planar Cell Performance



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, and (□) 450°C.

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**

Questions/Discussion