Efficient Fuel Cell Systems

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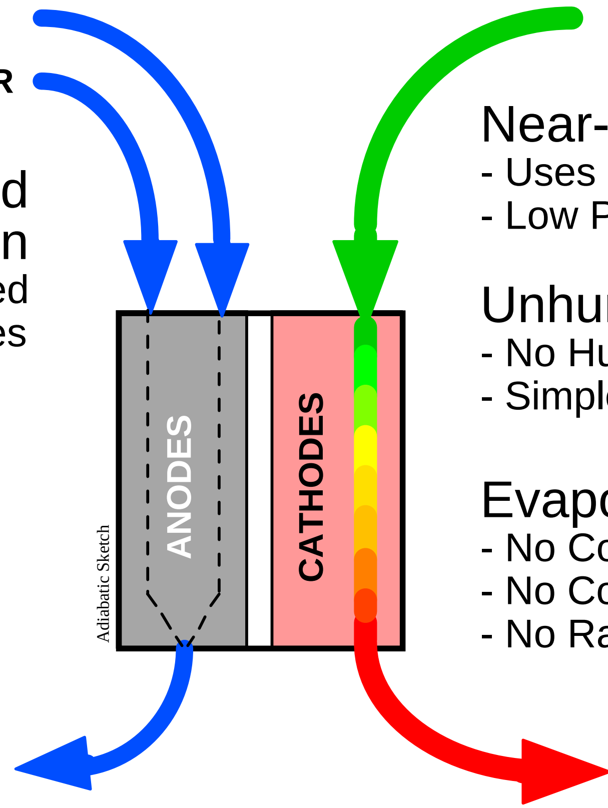
Efficient Fuel Cell Systems: Objectives

- **High System Efficiencies**
  - > 55% w/ Hydrogen Fuel
  - > 40% w/ Hydrocarbon Fuels (gasoline, etc.)
- **Simplicity**
  - For Fuel Cell Systems to be competitive for transportation, they will need to be:
    - » Inexpensive
    - » Reliable

Approach:
"Adiabatic" Stack Operation



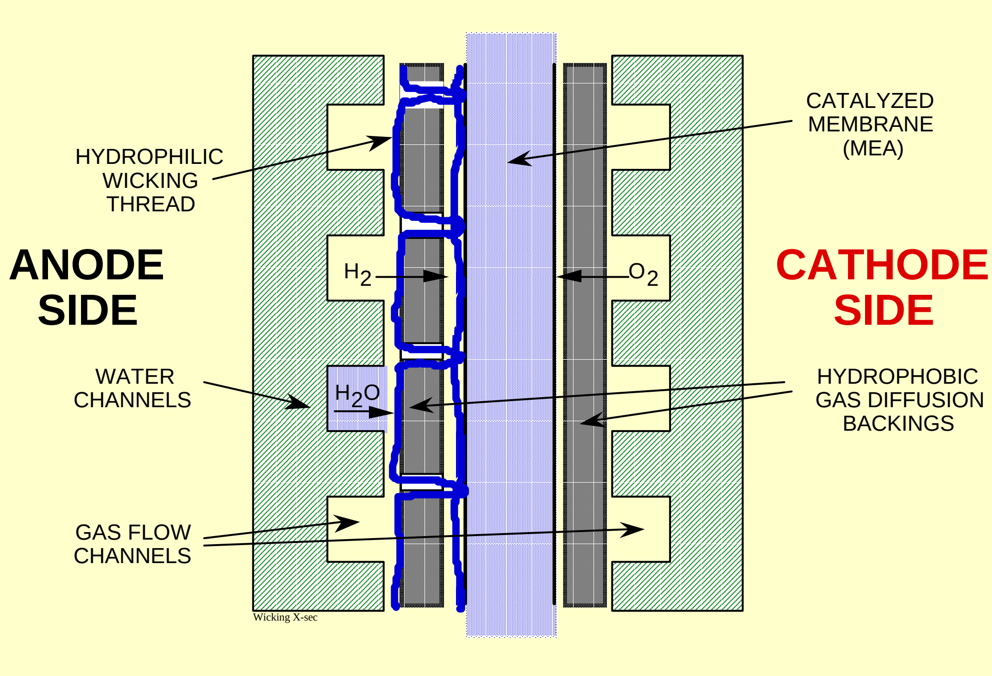
Direct Liquid Water Hydration
- Well Hydrated Membranes

Near-Ambient Pressure
- Uses Blower (No Compressor),
- Low Pressure Components

Unhumidified Air
- No Humidification Module,
- Simple Flow-Field

Evaporatively Cool
- No Cooling Plates,
- No Coolant Subsystem,
- No Radiators

Efficient Fuel Cell Systems: Key Aspects of the “Adiabatic” Approach

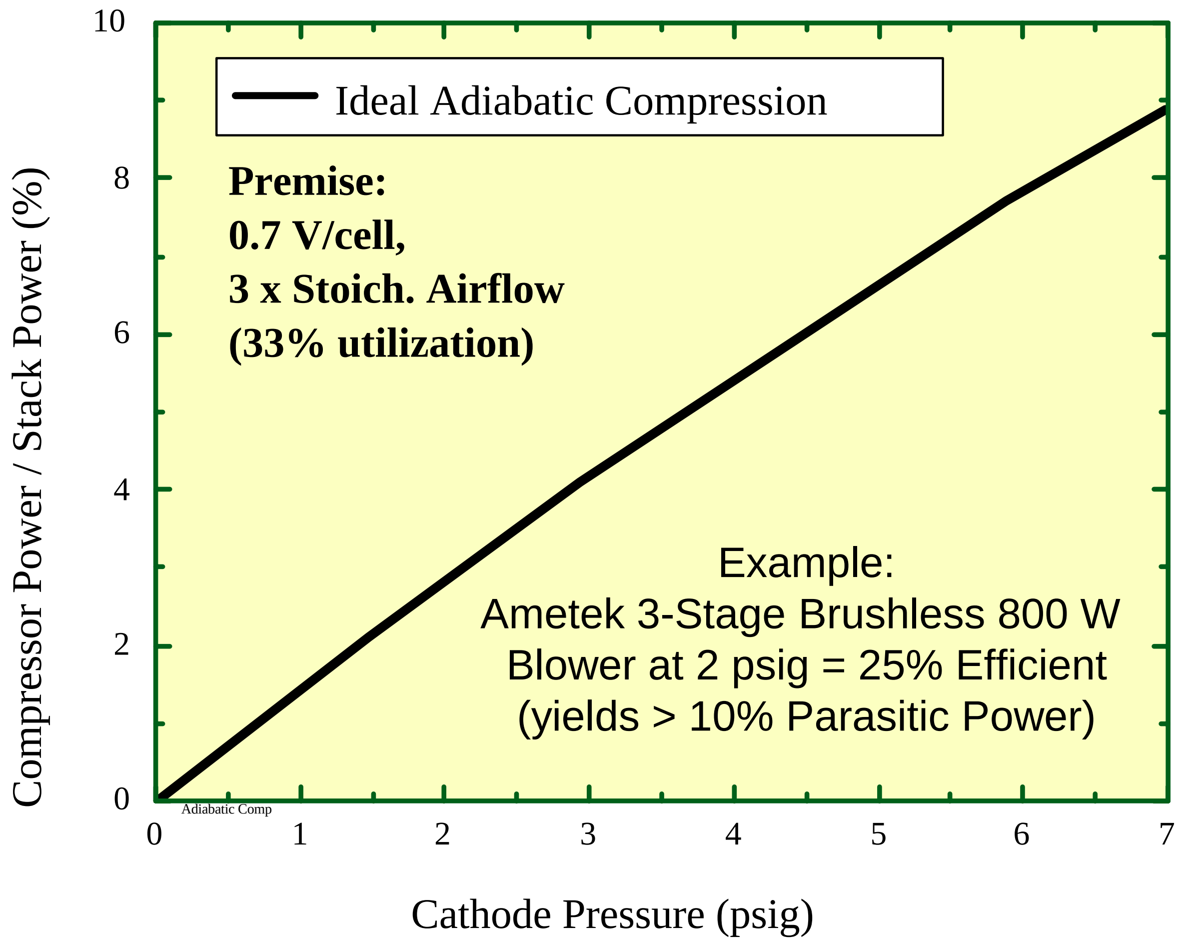


- **Direct liquid water hydration of the membranes needed to allow operation with a dry, ambient pressure cathode airstream.**
- **Utilizes an “Anode Wicking Backing” to transport the water to the membrane.**

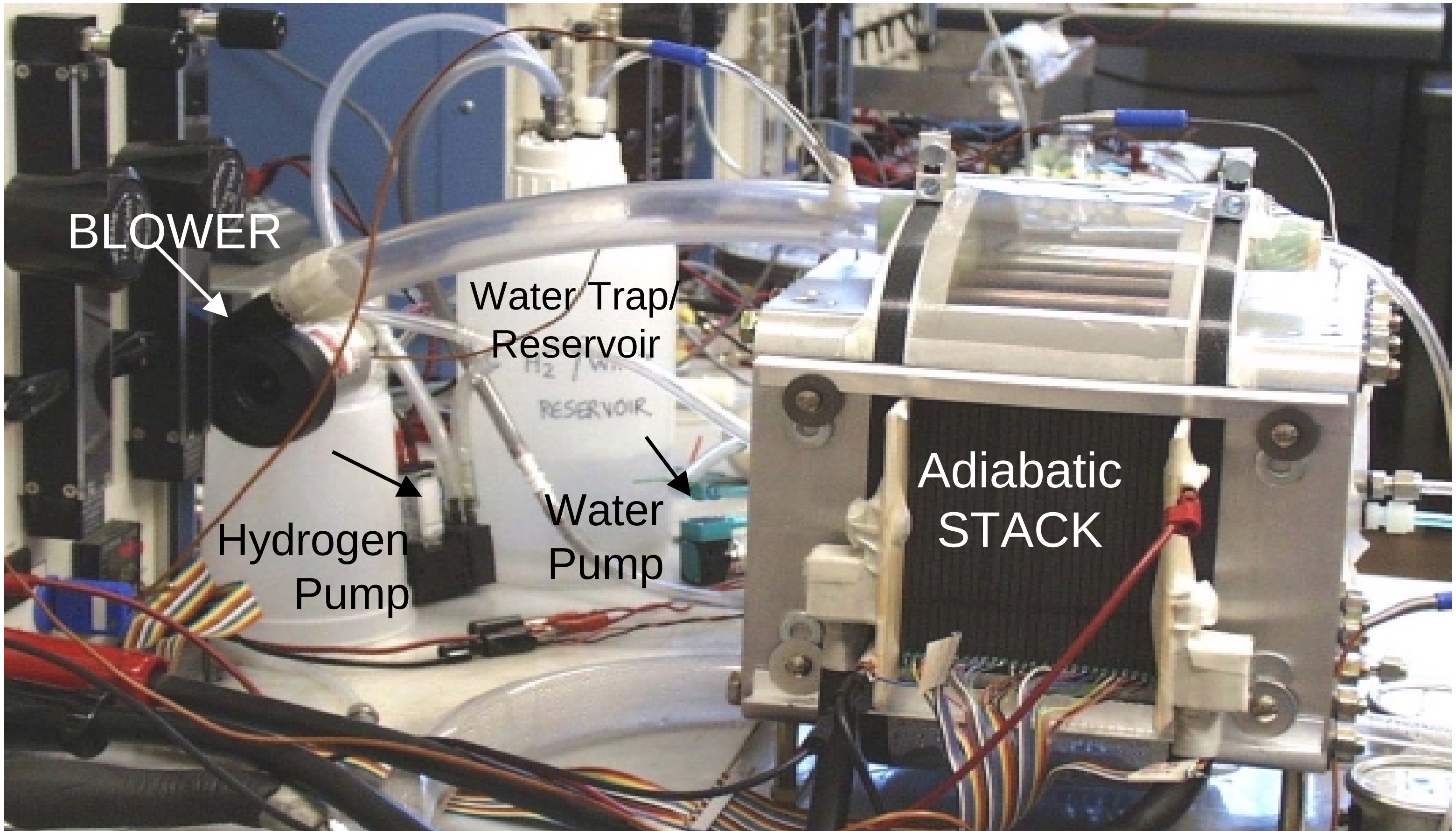
Efficient Fuel Cell Systems: System Benefits of “Adiabatic” Operation

- **Simplicity**
  - **“Inexpensive”**
    - Standard Bipolar Plate Technologies
    - Standard MEA Technologies
    - Blower (instead of Compressor)
    - Low-Pressure Components (manifolds, seals, tubing, etc.)
  - **Fewer Parts**
    - No Cooling Plates
    - No Cooling System / Radiators (replaced by Condenser)
    - No Humidification Modules
- **Minimal Liquid Water on the Air-Side**
  - **Low Pressure Drops Possible** (typically less than 6” H_2O)
    - Very low air compression power requirements.
  - **Simple flow-fields.**

Blowers & Low Parasitic Powers: Need For Very Low Pressures.



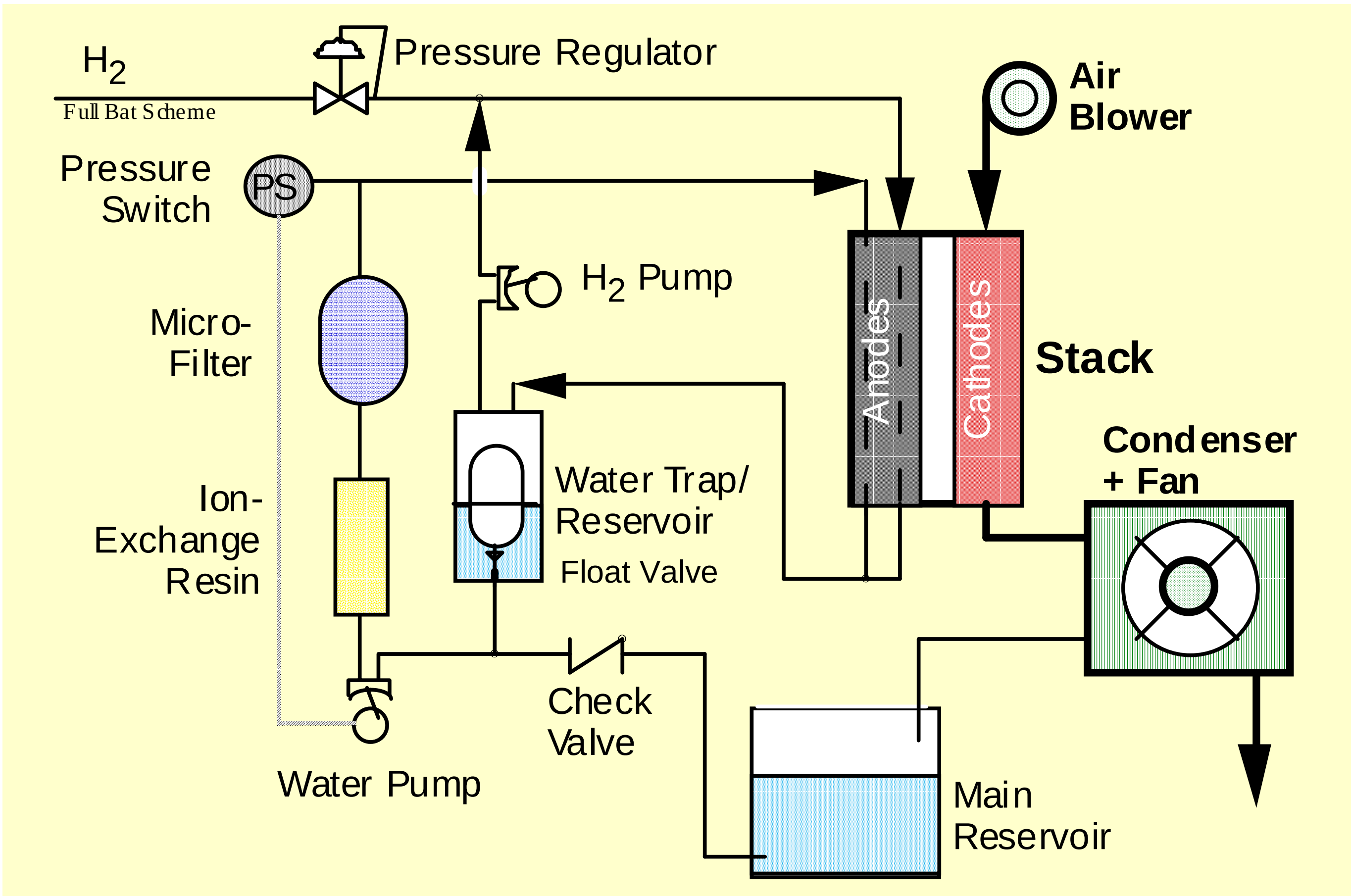
Efficient Fuel Cell Systems: 1.5 kW Adiabatic Stack



Accomplishments / Progress

- **Re-Optimized Single Cell Cathode Flow-fields**
- **Disassembled, Remachined & Rebuilt 26-cell Stack**
  - Desired air-side pressure drops now attained.
  - New gasket materials provide less leakage.
- **Further Simplified System**
  - Devised Simple Water Subsystem Scheme
    - » Uses a single pump and and pressure switch for both water recirculation and make-up.
- **Operated w/ Water Self-Sufficiency and Low Parasitic Power.**
  - Used ‘98 Flat-Plate Plastic Condenser
  - Off-the shelf aluminum “condensers” also tried.

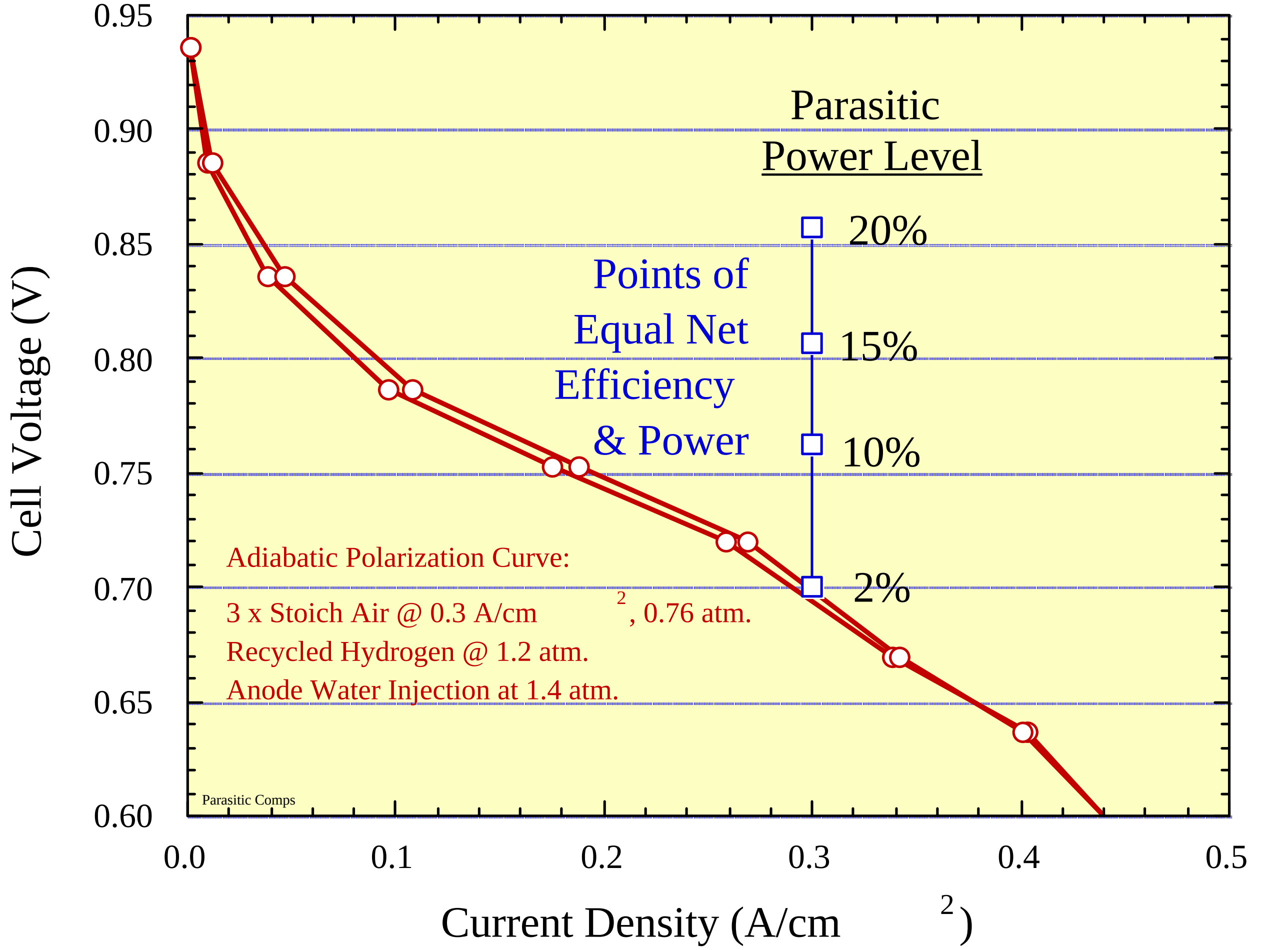
Efficient Fuel Cell Systems: Current Adiabatic System Schematic



System Performance Description with Water Self-Sufficiency

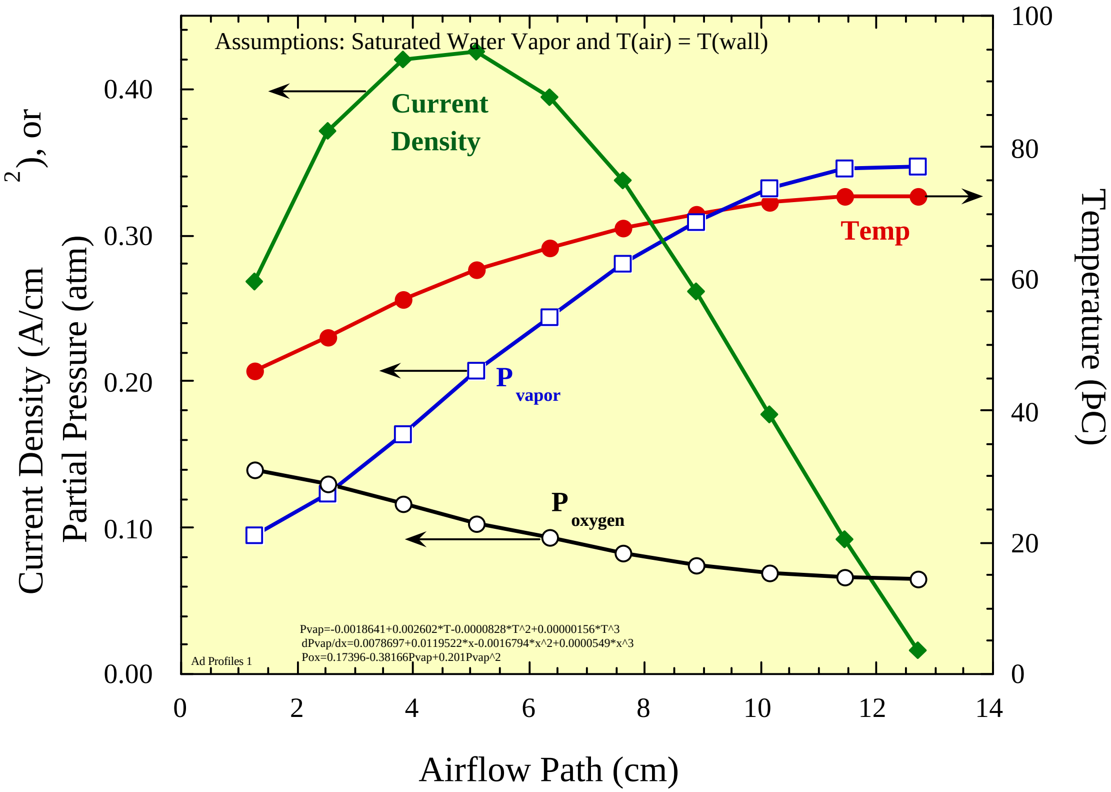
- **26 cell stack, 300 cm^2 active area, 17.5 V (0.673 V/cell) - 57% voltage efficiency), 83 A (1.45 kW gross power). Approx. 3x stoich airflow.** Endplates thermally isolated from cells and heated (to minimize passive cooling).
- **FY98 plastic, flat-plate homemade condenser used. Blocked off 2/3 of the condensate-side channels (leaving 1/3rd functional). 1/6 ft^3 exchange volume. 36 W total fan power. Recovered a surplus of 2.5 g/min of water.**
- **5.5" H_2O air manifold pressure at the stack. Total power draw for blower, (1/3) condenser fan, H_2 and water pumps is 26.1 W or 1.8 % stack power - net power is 1.43 kW or 56% overall efficiency.**
- **<u>Net</u> stack power density is 346 W/L** (bipolar plate basis).

Efficient Fuel Cell Systems: Relevance and Effect of Parasitic Power



Stack Design Issues: Characterizing/Understanding the Stack

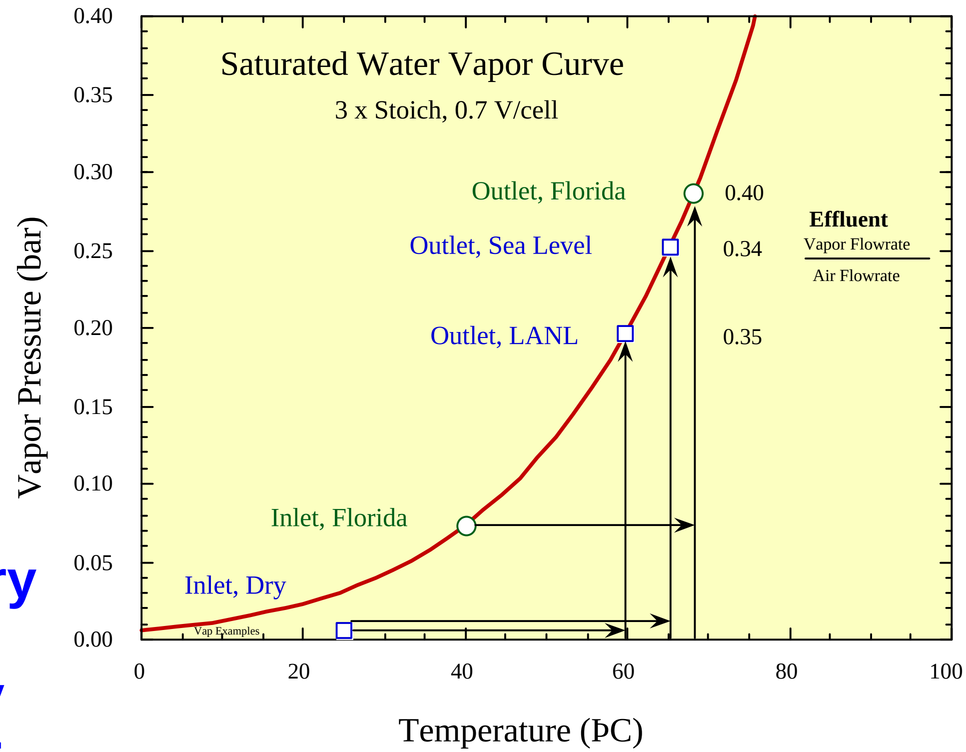
- Temperature gradient across the stack measured
  - Suggests tail end is relatively dead
- What is the optimal geometry?



  - e.g., Role of plate heat conduction?
  - Detailed Stack Modeling Needed

Efficient Fuel Cell Systems
Evaporative Cooling in Florida?

- **Is Evaporative Cooling (adiabatic operation) possible with high humidity and temp? (e.g., Florida)**
- **System is <u>not</u> an Evaporative <u>Cooler</u>**
  - **Easier water recovery at SL. - Effluent T dominates, humidity & inlet T have lesser effects.**



Efficient Fuel Cell Systems: Water Recovery at High Ambient T's

■ System Heat & Mass Balance Model

- **Used to anticipate condenser performance (e.g., water self-sufficiency) under various ambient temperatures and pressures.**
  - » Condenser inlet temperature increases with ambient P & T.
  - » Heat transfer coefficients proportional to ambient pressure.

■ Overall Sweeping Conclusion:

- **For similar condensers and coolant airflows (<u>s</u>cfm), operating with $T_{ambient}$= 25˚C at Los Alamos is roughly equivalent to $T_{ambient}$= 40˚C at sea level.**
  - » (Although same fan power level actually doubles the air-flow)
- **$T_{ambient}$= 40˚C at Los Alamos <u>halves</u> the water recovery.**

Is “Cooling” with Condensers Feasible?: Condensers vs. Radiators

- **For similar U_o’s, Adiabatic Heat X-change area is half pressurized’s** (due to higher LMTDs in ANL model).
  - **A_{press} = 36 m^2, $A_{adiabat}$ = 17 m^2** (a car radiator is about 2 m^2).
- **One heat X-change system replaces two.**
- **Radiators + coolant are heavy** (robust to hold H_2O. A 2 m^2, 2.8 kg car radiator holds 2.0 kg of water).
  Condensers mostly contain air - hence:
  - **lightweight and**
  - **freeze tolerant.**
- **Adiabatic condenser can conceivably be sized for average power, not max** (about half again smaller?).
  - **Water recovery** (condenser) **is not “critical” - cooling** (radiator) **is.**
    - **Can operate full power at 40°C in Los Alamos - until water runs out.**

Efficient Fuel Cell Systems: Milestones / Timeline

- June ‘00 - Demonstrate water self-sufficiency at 55% overall energy conversion efficiency for a 1-3 kW stack operating at ambient air pressure.
  - Achieved, but would also like to demonstrate with “evolved” condenser (while project is not for developing condensers, it is an important aspect).
- Sept. ‘00 - Attain power densities of 500 W/L (on a bipolar plate area basis) with 55% overall efficiency for a 1-3 kW stack operating at ambient air pressure.
  - Utilize thinner plates, more effective hydration in Vs. 2.0 (also sea level performance aspect).

Efficient Fuel Cell Systems: Activities Through Sept '00

- **Further Water Self-Sufficiency Development**
  - **Featuring Yet Another Condenser Design**
    - » **Off-the-shelf plastic components (**Lightweight, simple, cheap).
- **Version 2.0 Stack**
  - **Single cell optimization**
    - » **Internally Manifold Anode Side**
      - Now externally manifolded (not commercially desirable).
    - » **Increase power density (500 W/L).**
      - Further refine hydration scheme
      - Decrease bipolar plate thickness
  - **Stack fabrication, assembly, and testing.**
- **Sea-Level Performance**

Efficient Fuel Cell Systems: Interactions with Industry / Tech Transfer

- **Currently Transferring "Adiabatic"Stack System Technology to Two Companies**
  - **One company is emphasizing auxiliary power.**
  - **The other is primarily developing systems for stationary and propulsion applications (**but not automotive**).**

Efficient Fuel Cell Systems:
Summary / Conclusions

- **Demonstrated Adiabatic Stack / System with:**
  - **Water self-sufficiency,**
    - » Simple water system scheme,
    - » Relatively low stoichiometric air flows (3x).
  - **55% overall efficiency, and**
    - » Very low parasitic powers (1.8%),
  - **Reasonable <u>net</u> power densities.**
    - » 350 W/L (bipolar plate basis)
    - » 460 W/L (active area basis)
- **Adiabatic Stack / System provides:**
  - **Simple and "inexpensive" approach.**

Efficient Fuel Cell Systems: Future Plans

- **Progressing w/ System and Stack Design**
  - **Detailed Modeling of Stack Heat and Mass Transport**
  - **Radically Modify Stack Design - Version 3.0**
    - » Higher power densities.
    - » Improved stability and reliability.
    - » Near dead-end hydrogen feed.
      - Further System Simplification
- **Utilizing the Advantages of the Adiabatic System**
  - **Does not mesh well with POX approach.**
  - **Significant design advantages with neat H_2, using**
  - **Alternative Fuel Processor/FC Approaches**
    - » Steam reformer + membrane purifier + efficient FC system.
      - Overall efficiencies > 40%