Fuel Cell Systems Analysis

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Objectives and Approach

- Objectives
  - ✓Identify key design parameters and operating efficiencies
  - ✓Assess design, part-load, and dynamic performance
  - ✓Support DOE/FreedomCAR development efforts
- Approach
  - ✓Develop, document, and make available an efficient, versatile system design and analysis code
  - ✓Develop models of different fidelity
  - ✓Apply models to issues of current interest

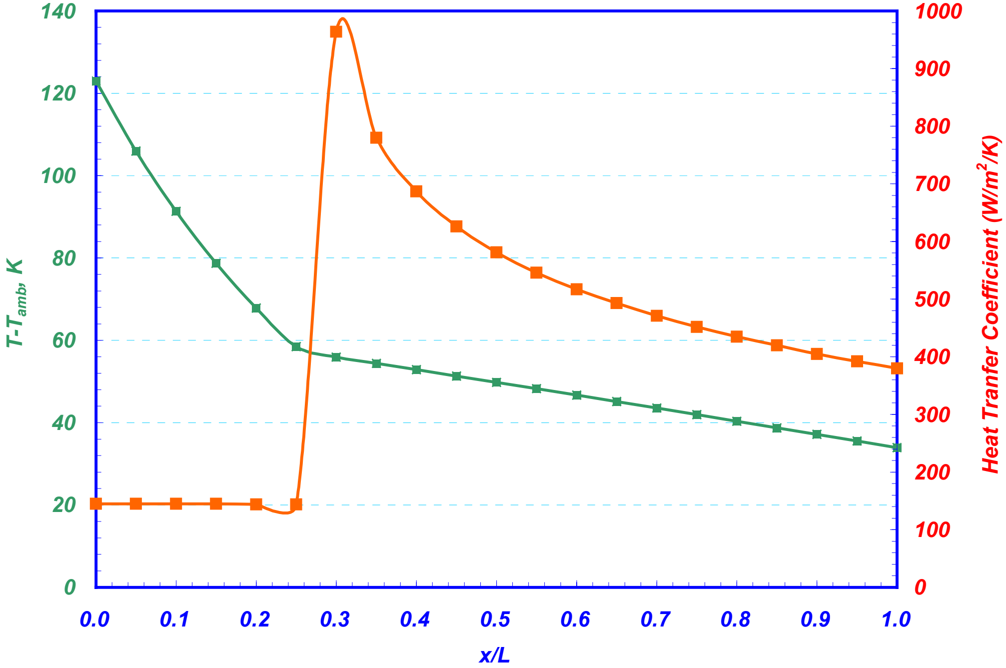
Reviewers' Comments

• Emphasize code development rather than code utilization	Developed several new component models
• Analyze cold start-up of fuel processors	Fast start fuel processor initiative
• Focus on transient modeling	Load following fuel processor
• Investigate effects of driving protocols on system performance	Pressurized direct H_2 system on FUDS and FHDS
• Conduct sensitivity and trade-off analyses	High temperature membrane systems
• Make model available at minimum cost	No cost to DOE contractors

Component Model Development in FY2002

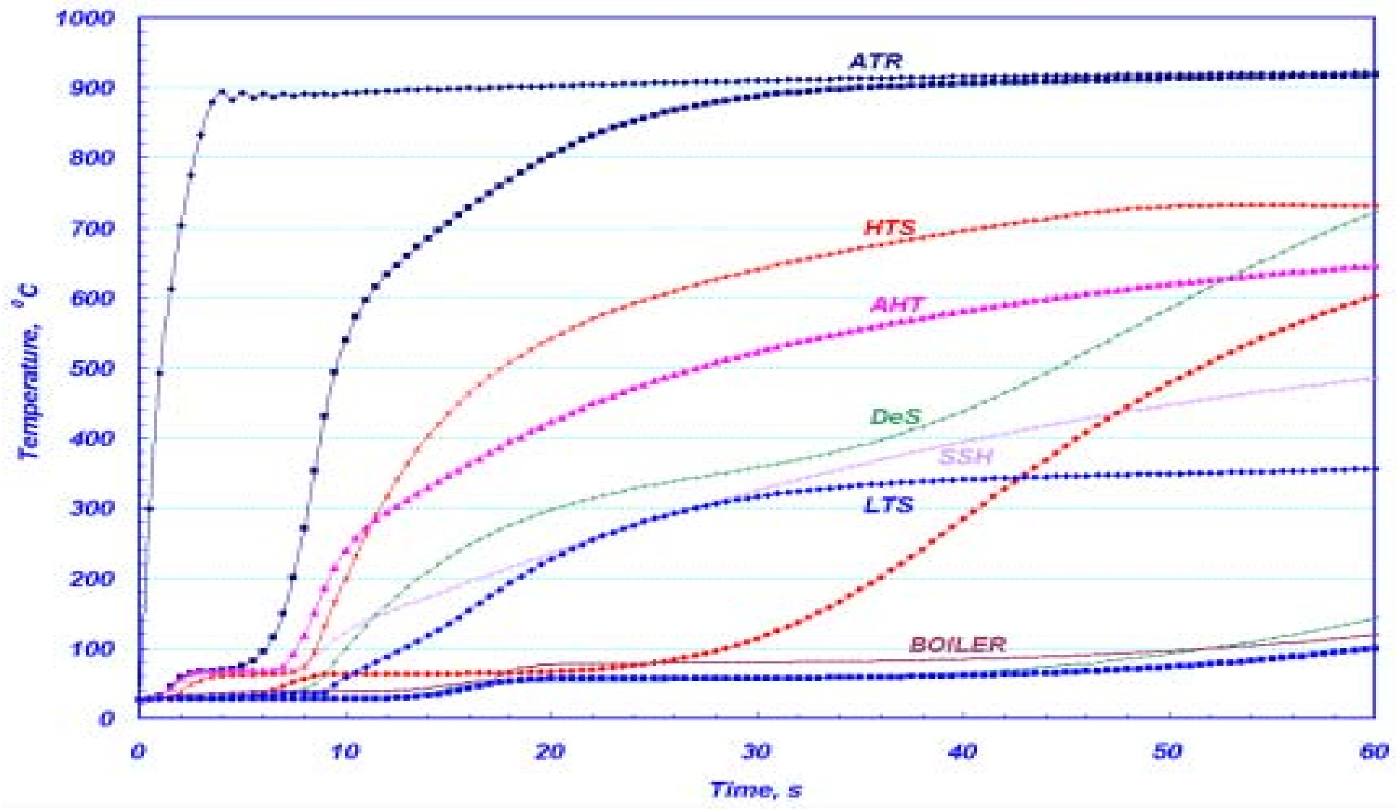
- New application package for analysis of data on catalytic reactions
- Generic model for metal hydrides: kinetics with heat transfer
- Desulfurization with ZnO sorbent
- Auto-thermal reforming of iso-octane with ANL catalyst

Heat transfer coefficients for desuperheating & condensing sections



GCtool Simulations for Rapid-Start Fuel Processors

- Our simulations showed that for rapid startup, the catalytic reactors must be heated in parallel rather than sequentially
- Analyzed effect of start-up energy on cycle efficiency



PSAT-GCtool Integration for Fuel Cell Vehicle Analysis

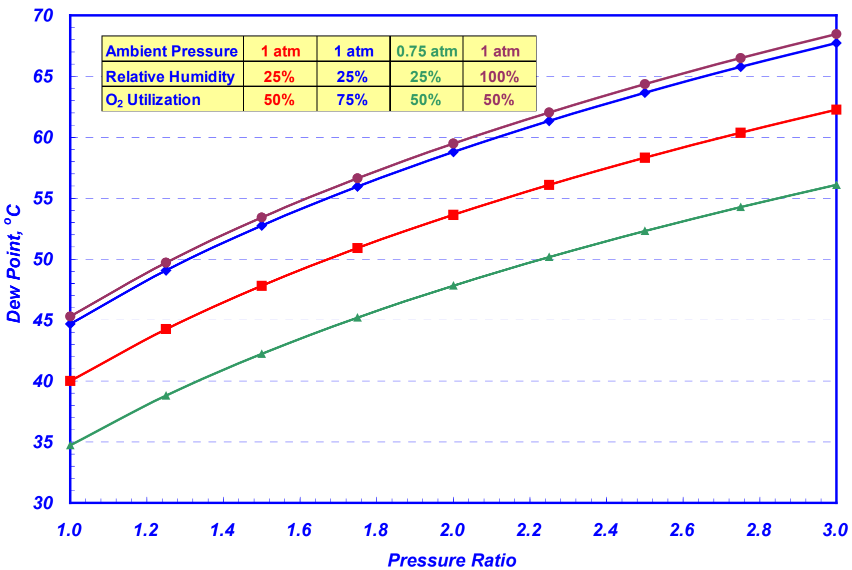
- PSAT and PSAT-Pro: Hybrid vehicle simulation codes (FreedomCAR and Vehicle Systems)
  - ✓"Forward" model: driver to wheel
  - ✓Consistent rapid control prototyping, hardware-in-the-loop and vehicle control system integration
- GCtool_ENG: Engineering models of FC systems based on GCtool architecture
  - ✓Speed and accuracy appropriate for fast transients
  - ✓Component maps from models in GCtool or test data
  - ✓Translator to port GCtool_ENG models to MATLAB
- Applications
  - ✓Multi-platform study
  - ✓Fuel Cell–Battery/Supercap hybridization

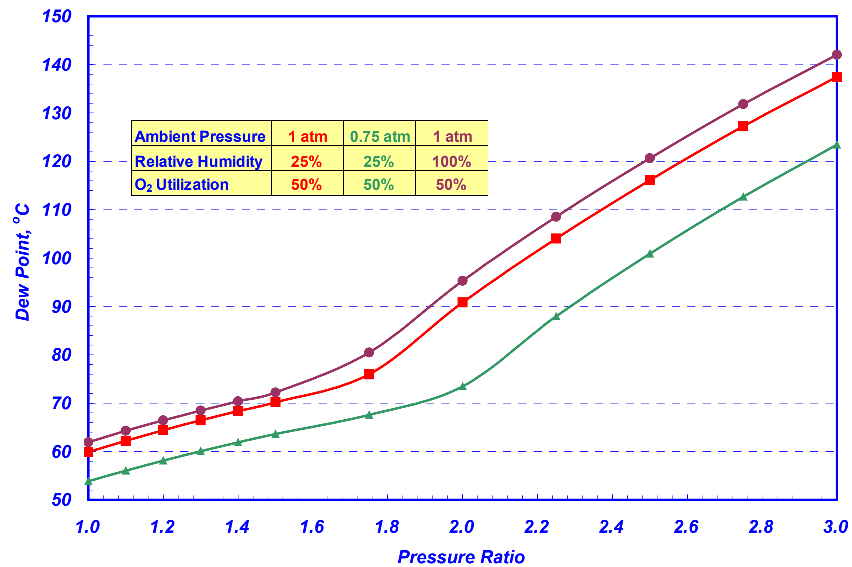
80-kW Direct Hydrogen System (for SUV Application)

- Compressed hydrogen fuel
- CEM performance data from DOE contract
- Pressurized stack at 3 atm, 80^{o}C, 0.7 cell potential at design point
  - ✓Stack polarization curve from LANL and GCtool
- Anode and cathode feeds heated/cooled to 70^{o}C, humidified to 90% RH at stack temperature
  - ✓Stack coolant used for controlling anode and cathode feed temperatures
- Fuel cell – battery hybrid on SUV platform

Water Management in Pressurized Fuel Cell Systems

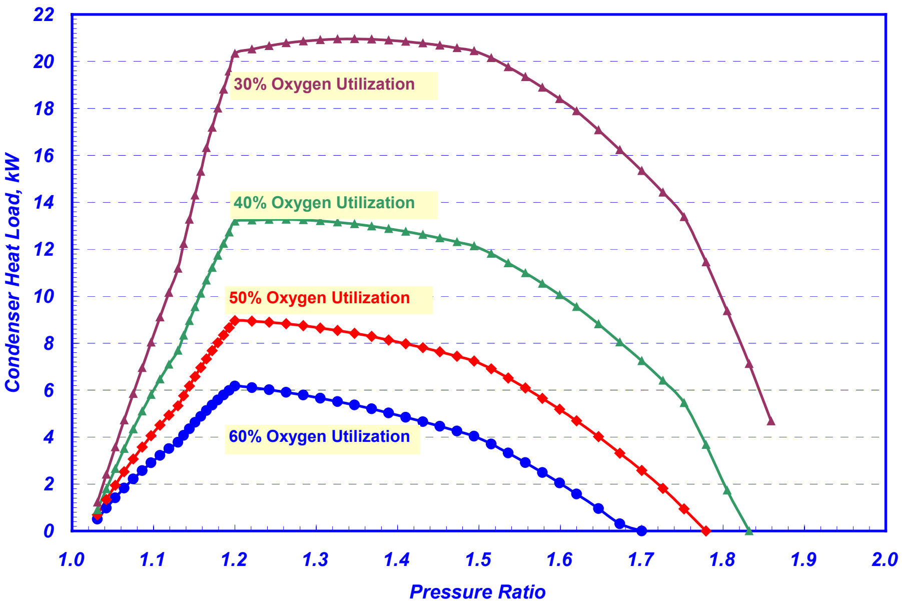
- Reformed gasoline systems:
  - ✓Condenser needed to recover process water at all conditions
  - ✓Dew point is a function of ambient pressure and O_2 stoichiometry
- Direct hydrogen systems:
  - ✓Condenser needed only at part load
  - ✓Water also recovered at stack and condenser exits

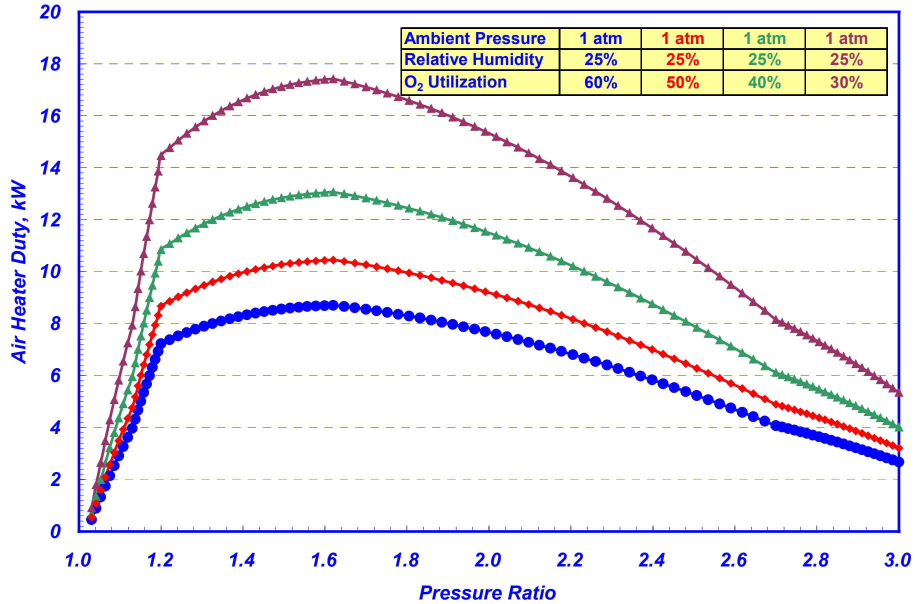




Condenser and Air Heater Duties in Pressurized Direct Hydrogen Systems

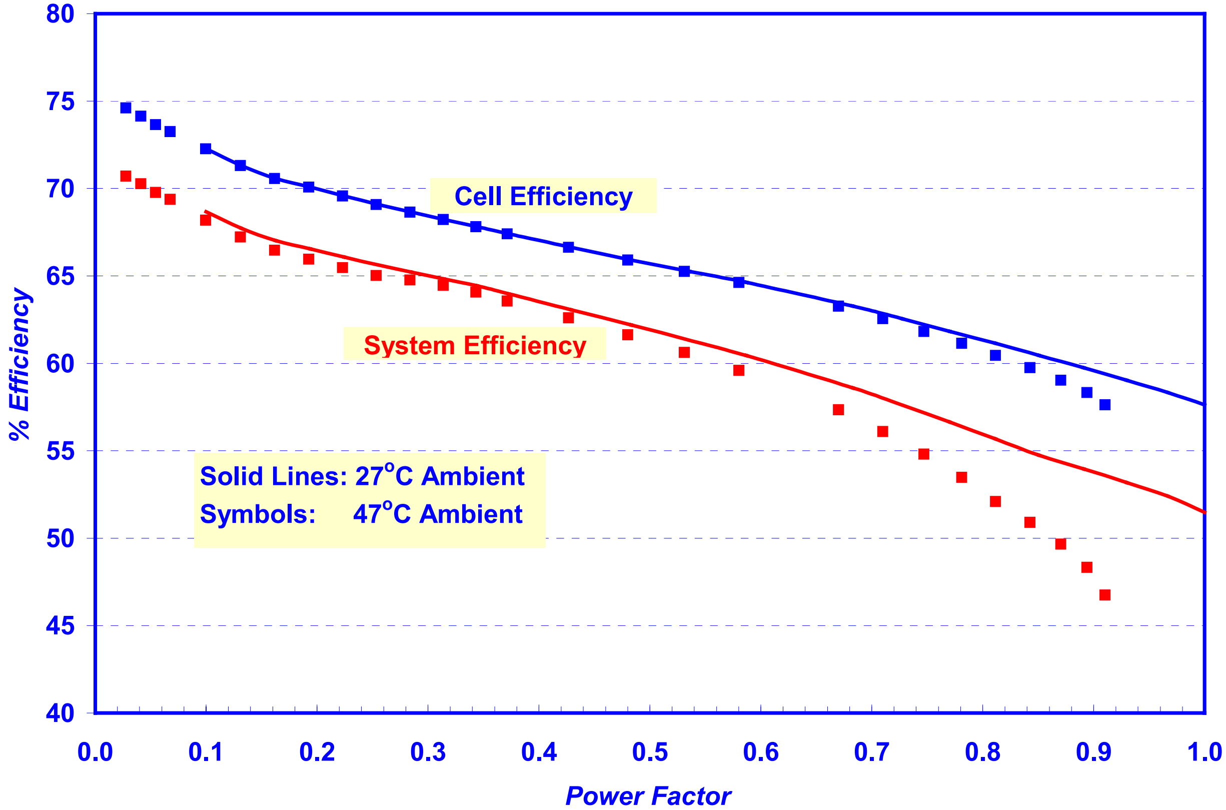
- For design pressure ratio of 3, condenser cooling load is highest at 20% of rated flow
- Condenser duty is a strong function of cathode stoichiometry
- Cathode air heater/humidifier duty is also highest at part load





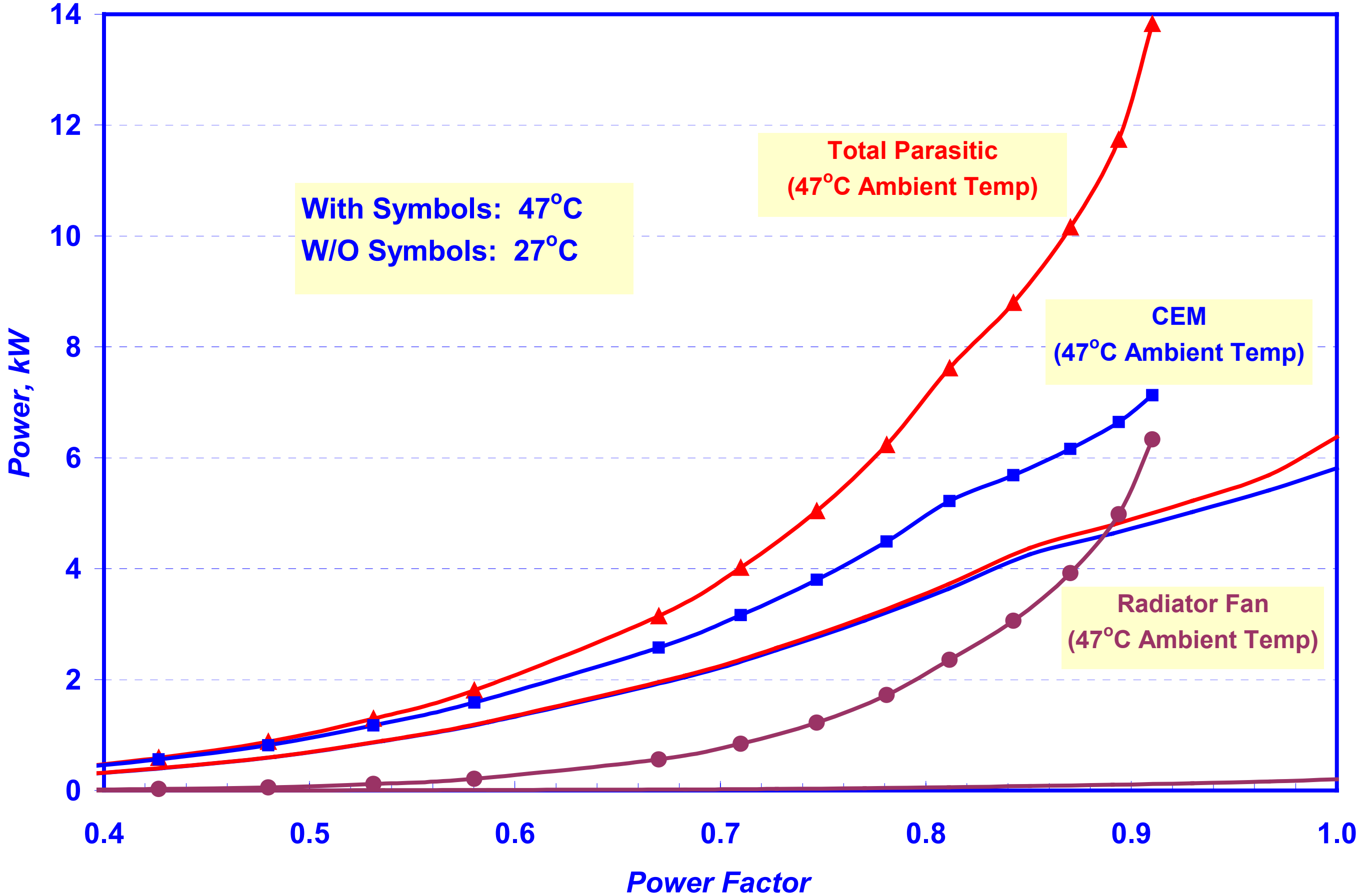
Performance of Pressurized Direct Hydrogen System

- DOE Phase I data for CEM: design pressure ratio of 3
- Stack at 80°C and 0.7 V cell potential at design point
- 70% efficiency for condenser and radiator fans



Parasitic Losses in 80-kW Pressurized Direct Hydrogen System

- CEM and radiator fan account for much of the parasitic power
- Auxiliary power is affected by the ambient temperature



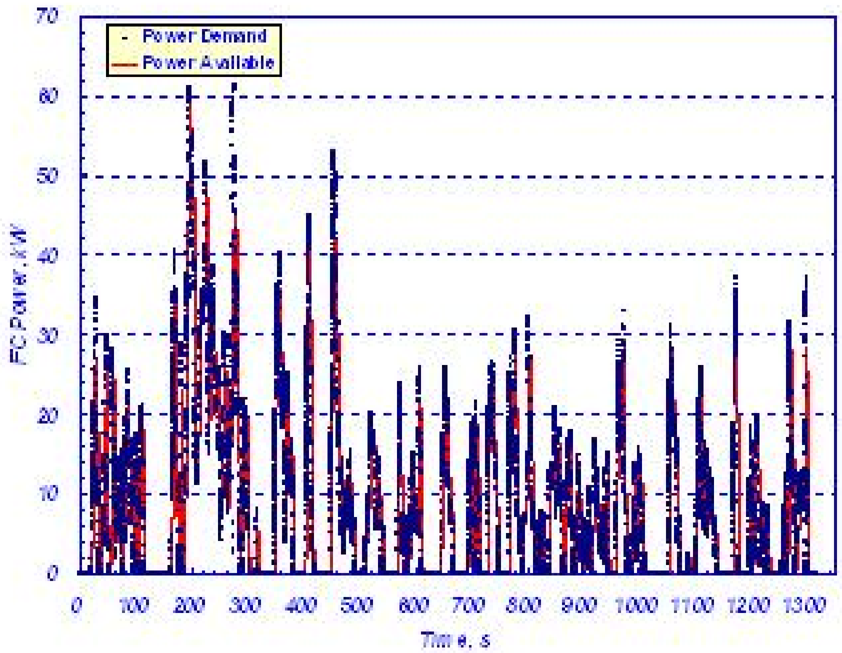
Efficiencies With and Without Expander for 80-kW Direct Hydrogen System

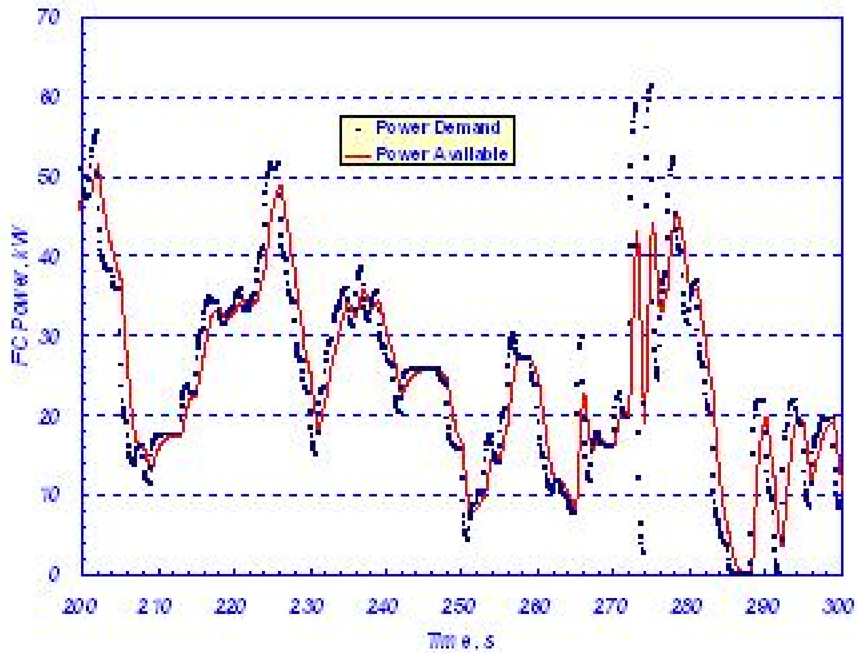
- Efficiencies and power at high ambient temperature (320 K)

	50% O_2 Utilization		40% O_2 Utilization		30% O_2 Utilization	
	With GT	W/O GT	With GT	W/O GT	With GT	W/O GT
Power to CEM	7.5 kW	21.2 kW	9.3 kW	28.3 kW	12.3 kW	42.4 kW
Efficiency at Rated Flows	45.6%	39.4%	44.8%	36.9%	43.5%	32.8%
Efficiency at 50% Flows	59.6%	56.3%	59.3%	54.4%	58.5%	51.7%
Stack Size	100 kg	116 kg	102 kg	123 kg	105 kg	139 kg
Condenser Heat Duty	9 kW		13 kW		21 kW	

Dynamic Response of the Pressurized Direct Hydrogen System

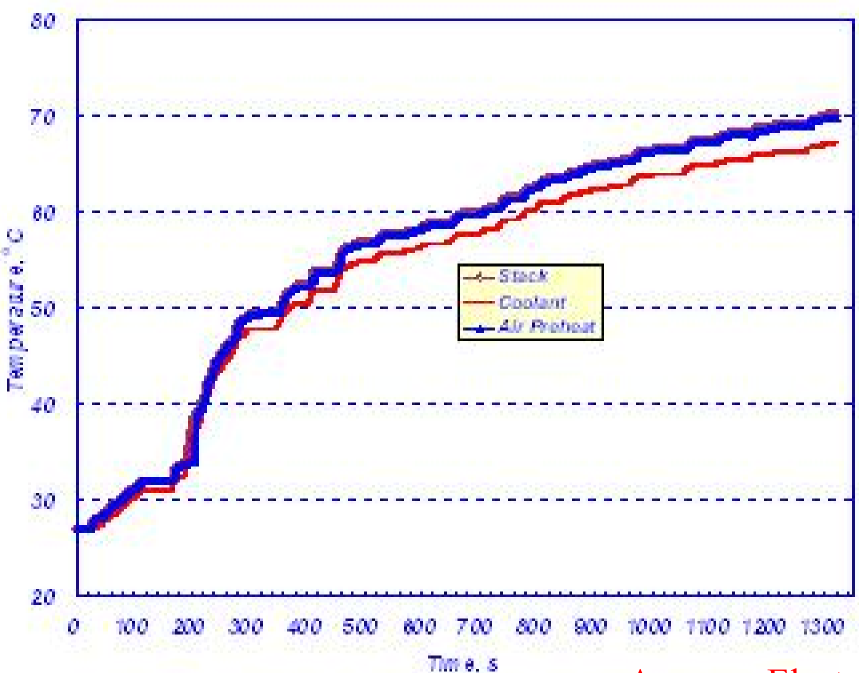
- In current simulations, dynamic response is determined by the CEM and the integral controller
- Extended period of stack operation at very low current densities over FUDS cycle

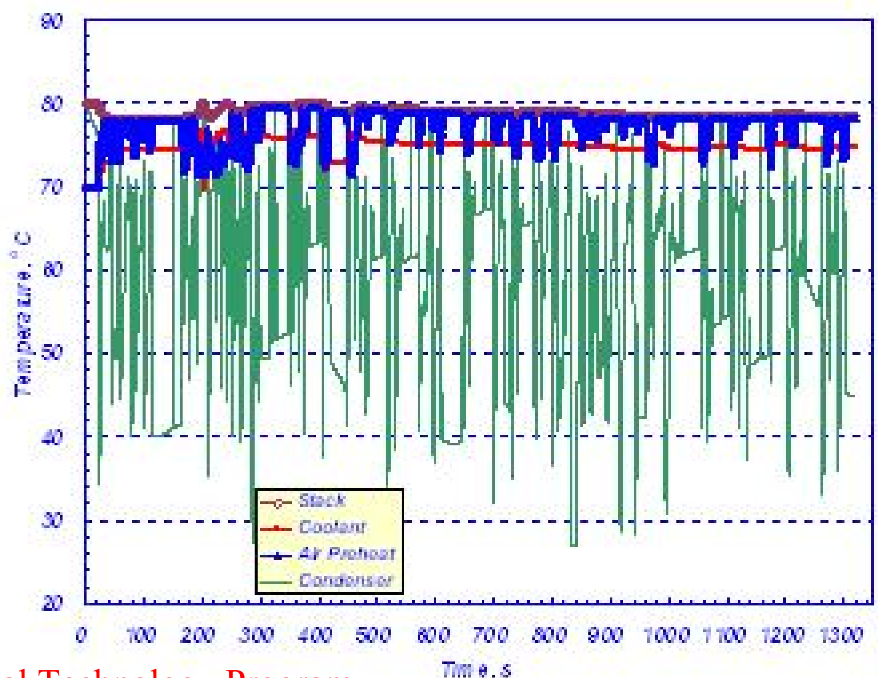




Temperature Response Over the FUDS Cycle

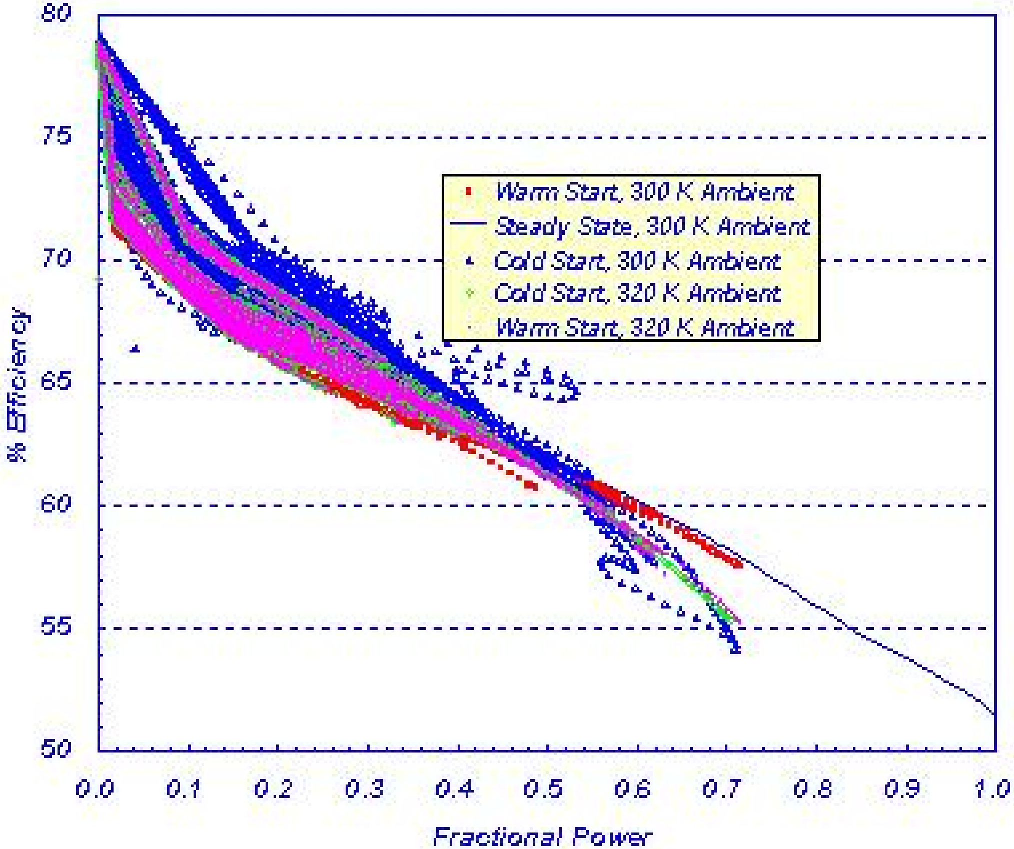
- Cold start at 300 K
  - ✓Condenser and radiator fans remain off over one FUDS cycle
- Warm start at 300 K
  - ✓Radiator fan remains off at low power
  - ✓Condenser fan cycles off and on





Dynamic Efficiency on FUDS Cycle

- Beside ambient temperature, pressure, and load, dynamic efficiency depends on the control algorithm and the state of the FC system



Current and Future Work

- Model validation with data from Nuvera system
- Ambient pressure direct hydrogen systems
- Direct hydrogen systems with physical / chemical hydride hydrogen storage
- Reformed liquid fuel systems on drive cycles
- Fast-start and load-following fuel processors
- High temperature membrane systems
- Alternative system configurations
- Detailed component models

- Interactions with A.D. Little, Nuvera, others