Catalytica ENERGY SYSTEMS

2003 DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program Review Meeting

Plate Based Fuel Processing System

DOE ID# DE-FC04-01AL67605

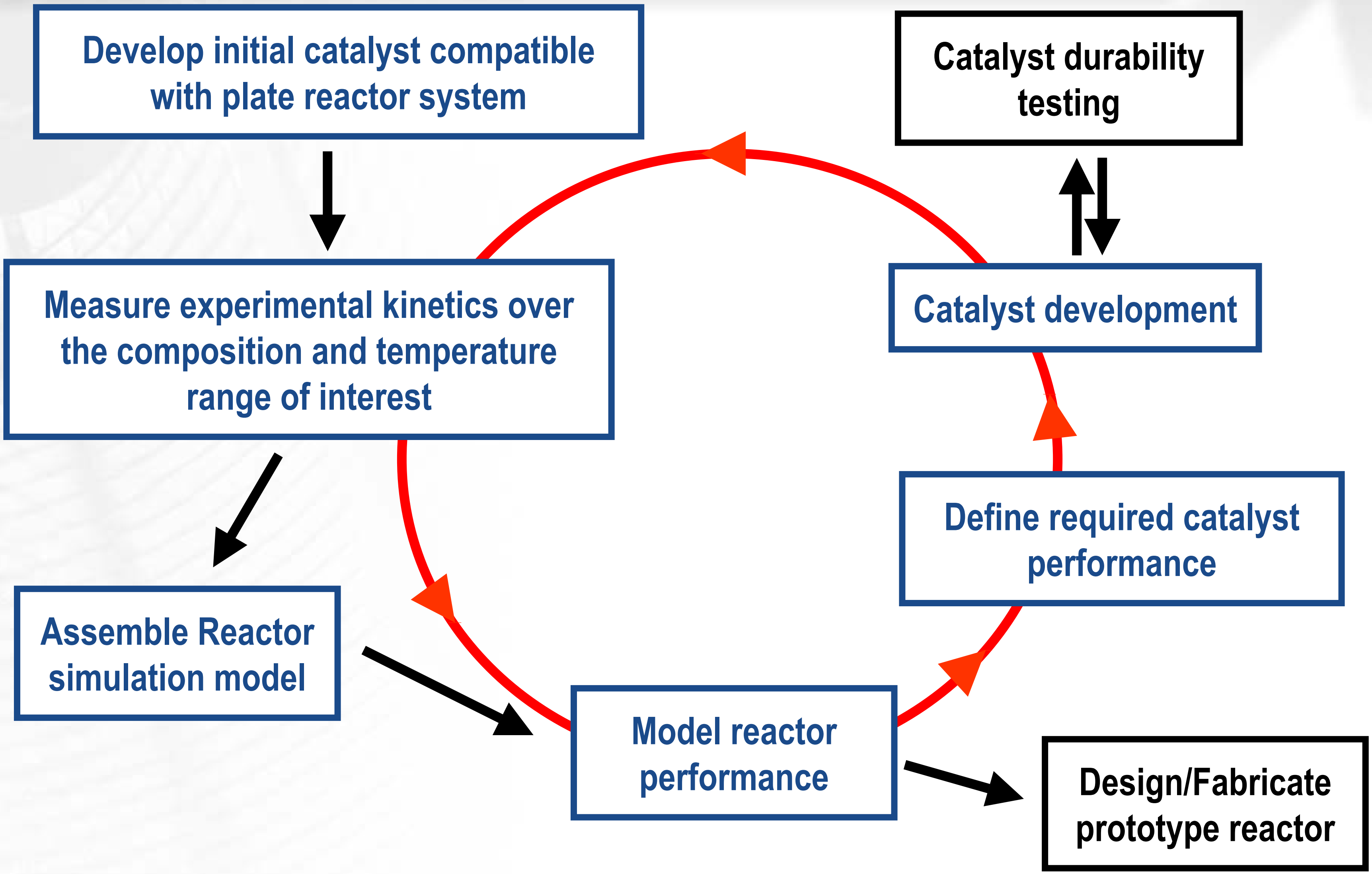
May 19-22, 2003

DEDICATED TO INNOVATIVE SOLUTIONS FOR CLEAN ENERGY PRODUCTION

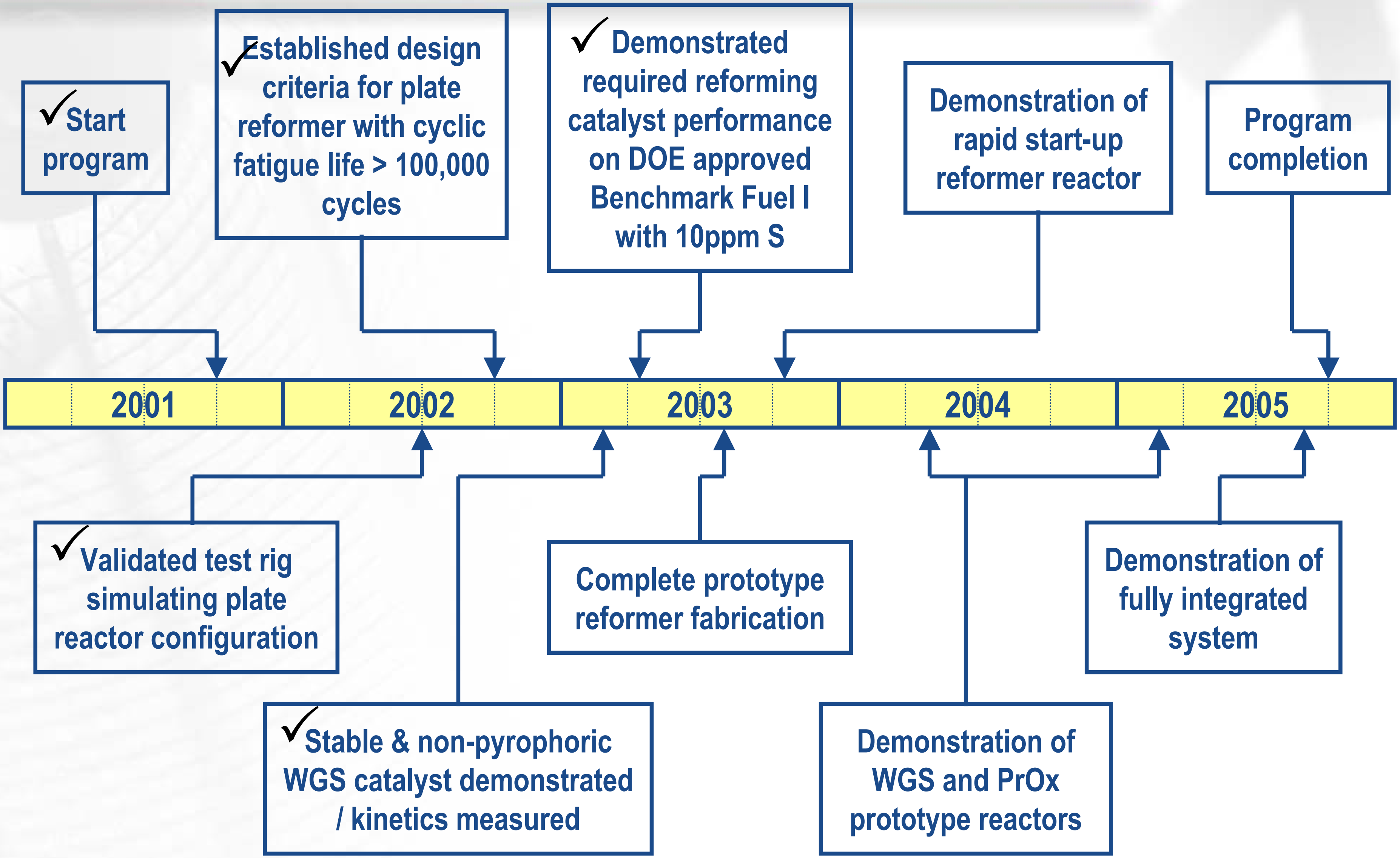
Project Objectives

- Develop new catalytic reactor designs and reactor technology for processing gasoline to PEM quality H_2
  - Develop improved catalyst materials compatible with these reactor systems
- Design and fabricate prototype units for each reactor at the 2 to 10kW(e) scale
  - Demonstrate steady state and transient performance
  - Evaluate rapid start up performance
- Integrate component reactors in a fuel processor system taking gasoline to PEM quality H_2 (specific objective being refined)

Approach


Develop initial catalyst compatible with plate reactor system
Measure experimental kinetics over the composition and temperature range of interest
Assemble Reactor simulation model
Model reactor performance
Define required catalyst performance
Catalyst development
Catalyst durability testing
Design/Fabricate prototype reactor

Project Timeline



12 month milestones: Success Criteria

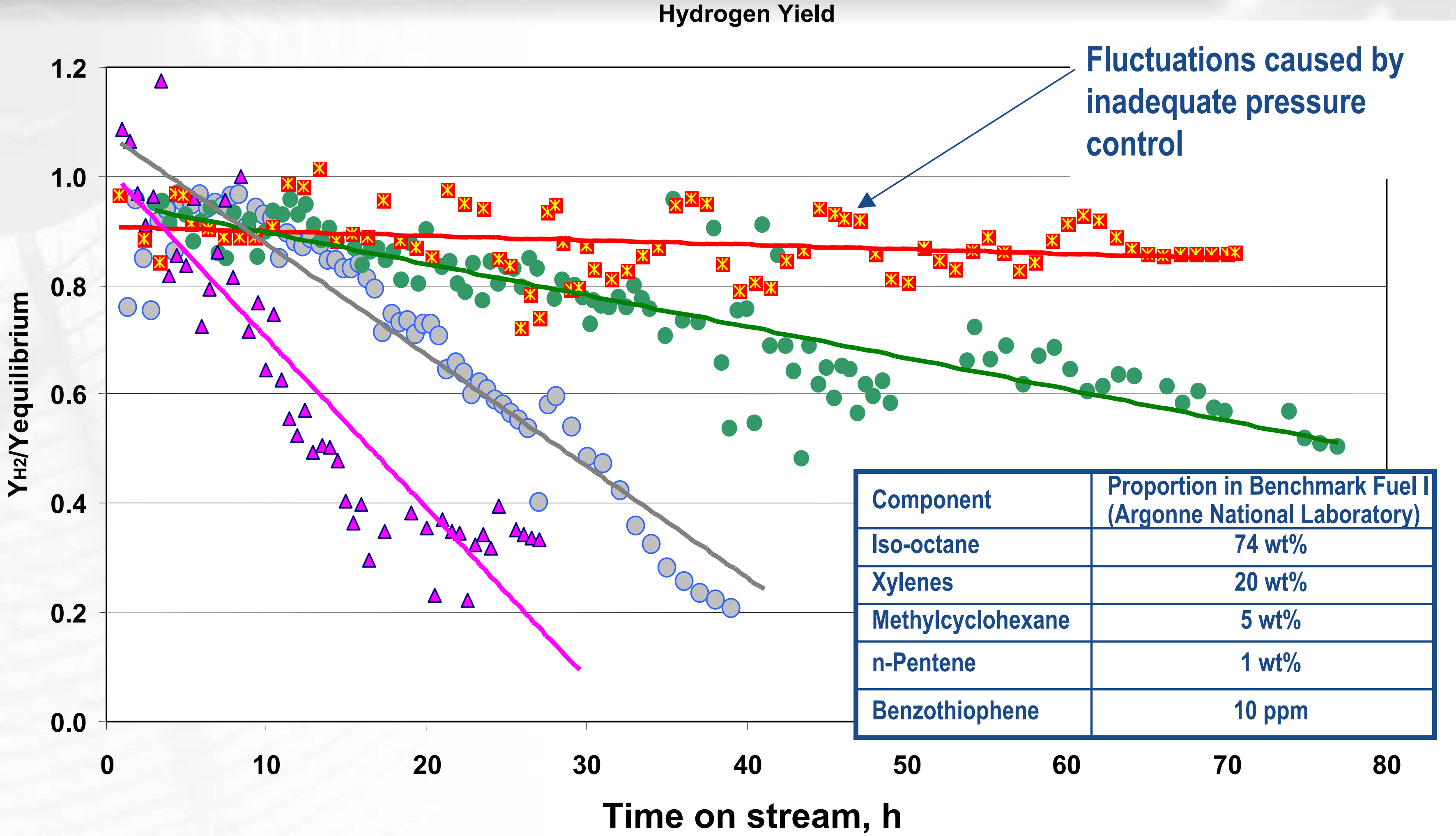
- Demonstration of rapid startup prototype reformer
  - 2 to 5 kW(e) prototype reformer “brass board” unit designed to required critical performance aspects
  - Rapid start up and rapid cycling tests run under realistic conditions
  - Start up to full reformer output in < 30s

  Technical Barriers: Reduced thermal mass, low light-off catalysts, rapid heat/start strategy

- Demonstration of WGS and/or PrOx prototype reactors
  - 2 to 5 kW(e) prototype reactor “brass board” unit
  - Steady state and rapid cycle testing

  Technical Barriers: Reactor design strategy that reduces WGS reactor weight and volume
  Establish durability of PrOx catalyst and integrate into plate configuration

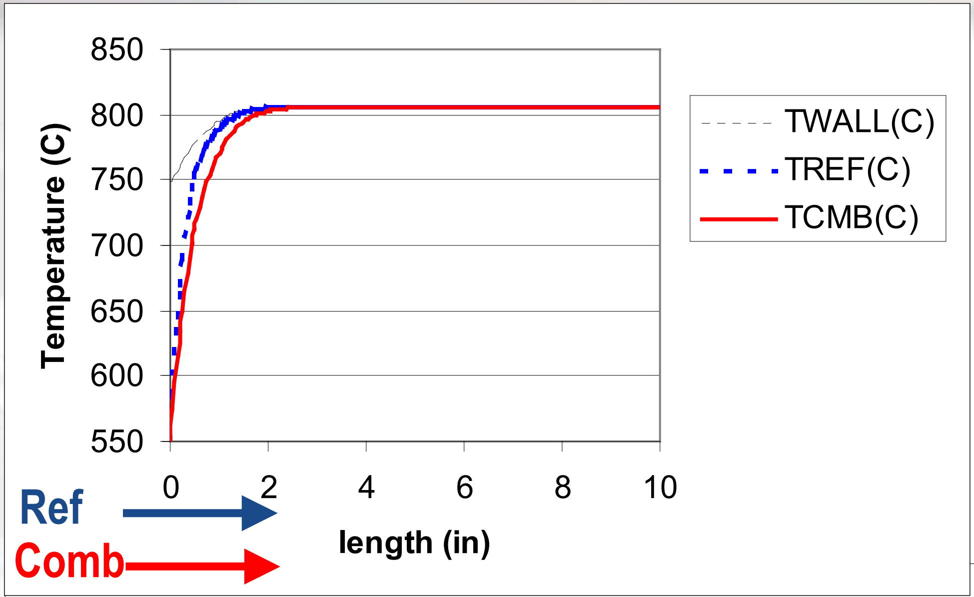
Improved Reformer Stability

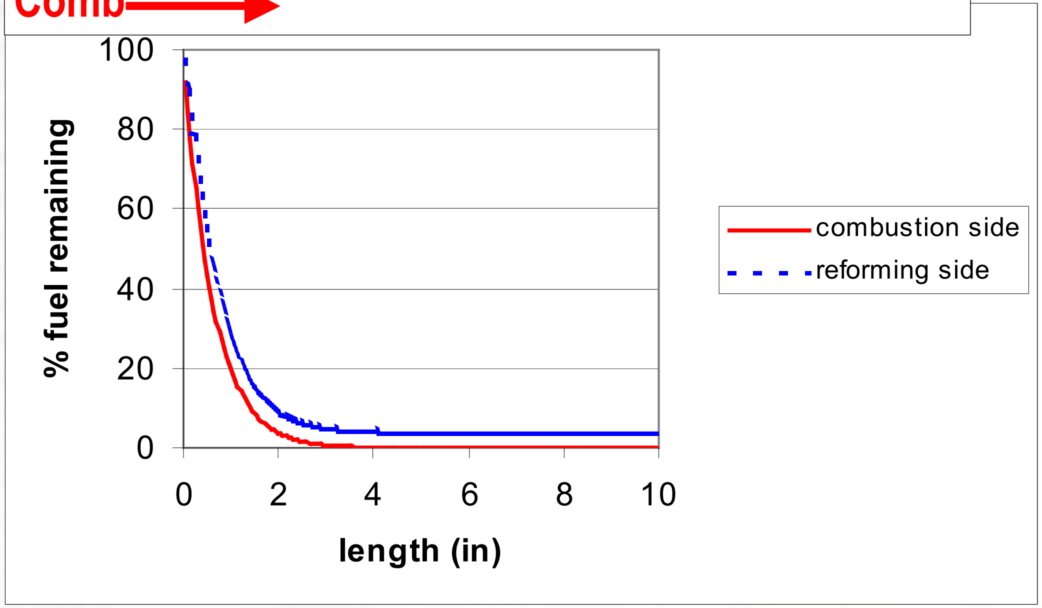


Component	Proportion in Benchmark Fuel I (Argonne National Laboratory)
Iso-octane	74 wt%
Xylenes	20 wt%
Methylcyclohexane	5 wt%
n-Pentene	1 wt%
Benzothiophene	10 ppm

High stability achieved with Benchmark Fuel I with 10ppm S

Co-Current Reformer Design



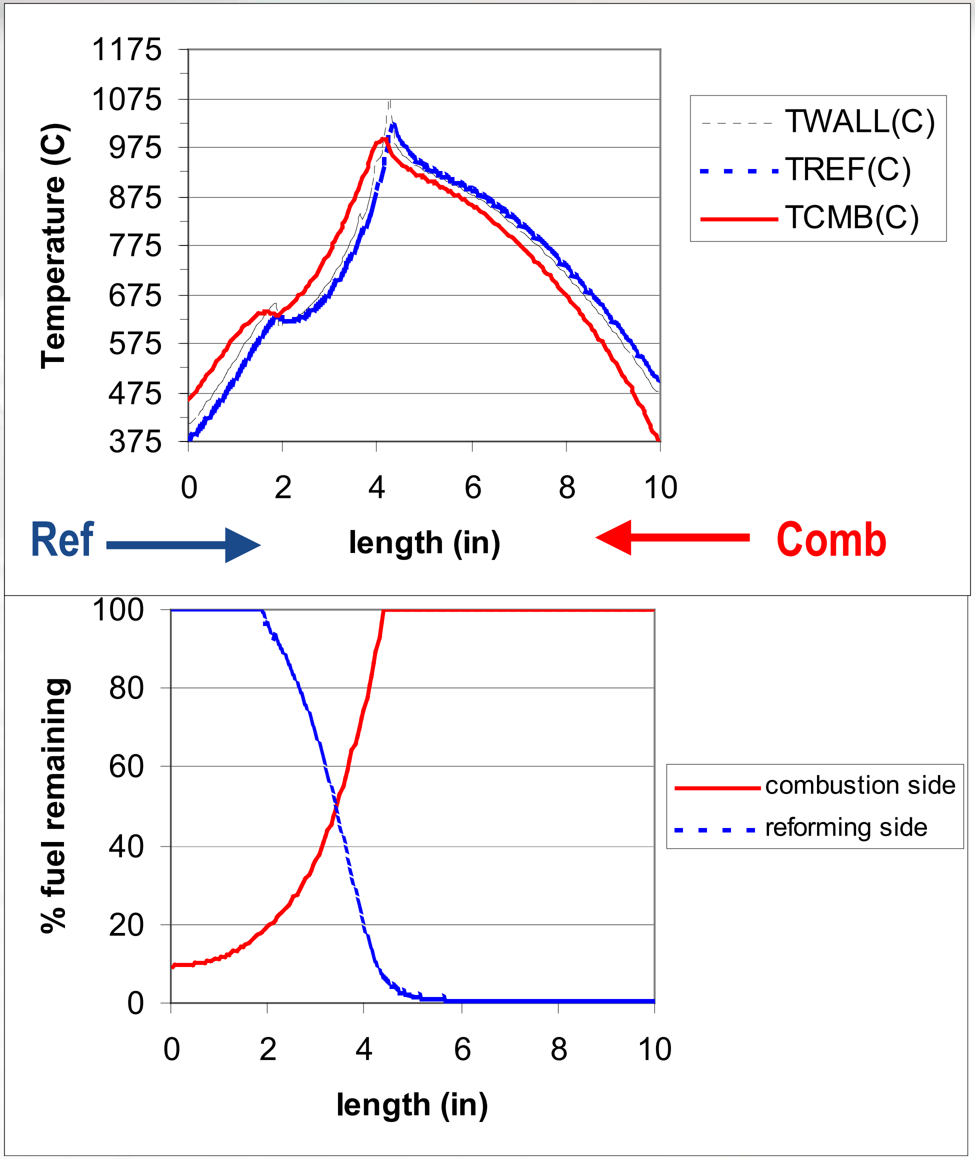


Reactor model of plate reformer using hypothetical kinetics

Conclusions:

- Exothermic and endothermic reaction well matched for this test case
- Reactor volume requirements and space velocities are reasonable
- Robustness studies (load from 25% to 100%, deactivation, poisoning) show good performance

Counter-Current Reformer Design



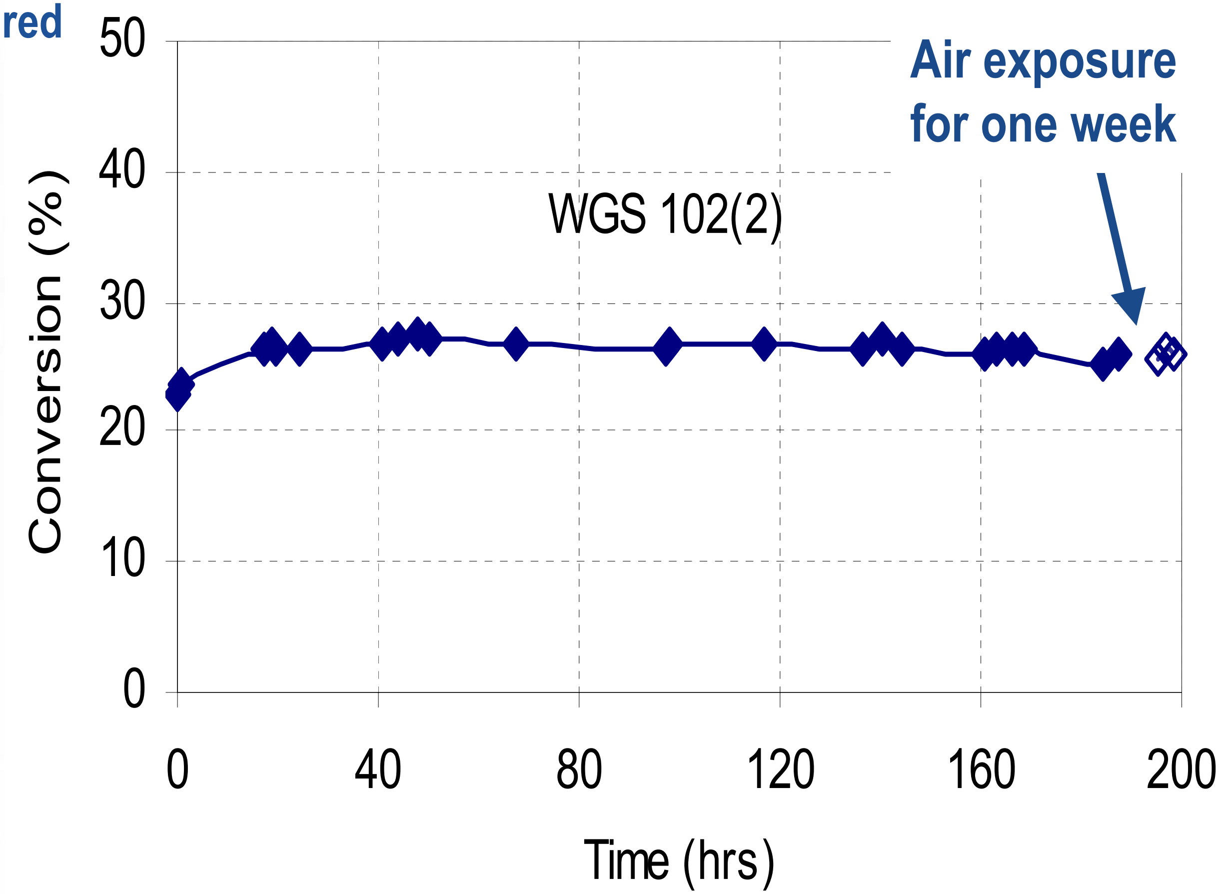
Reactor model of plate reformer using hypothetical kinetics

Conclusions

- Design of reactor and catalytic coating is very critical to performance
- Can achieve outlet temperatures that integrate well with upstream and downstream processes
- Robustness studies (load from 25% to 100%, deactivation, poisoning) show good performance

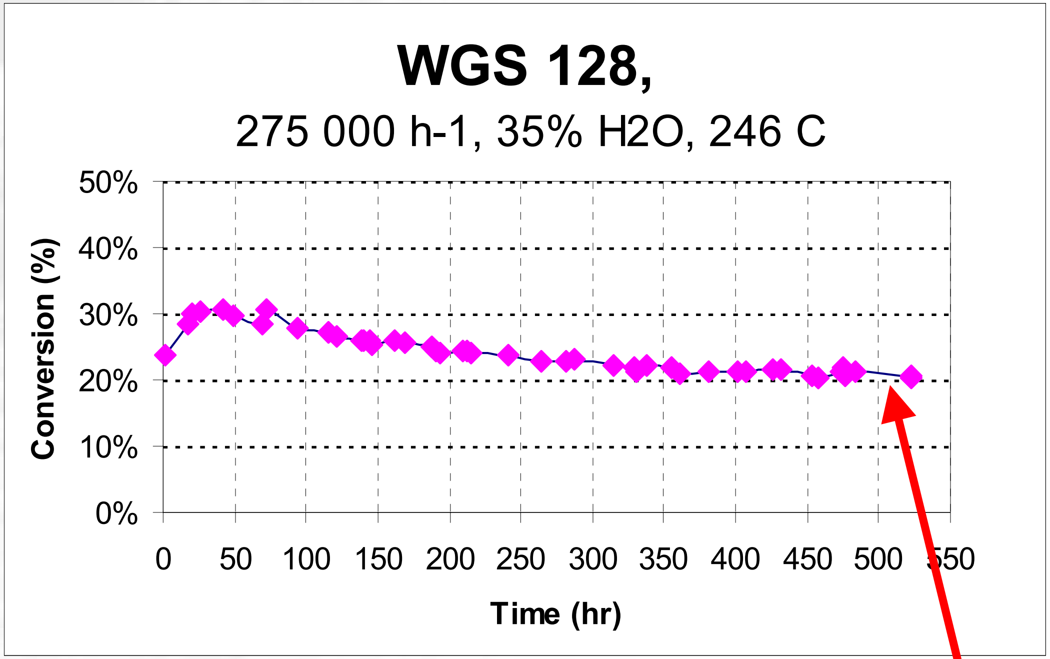
Effect of Air Exposure

- Water gas shift catalyst development
  - Base metal nano-particle structure
  - Non-pyrophoric
  - No pre-reduction required
  - Air stable



Catalyst Durability

Long term reactor runs show good durability



<u>To obtain 5000 hour durability data</u>

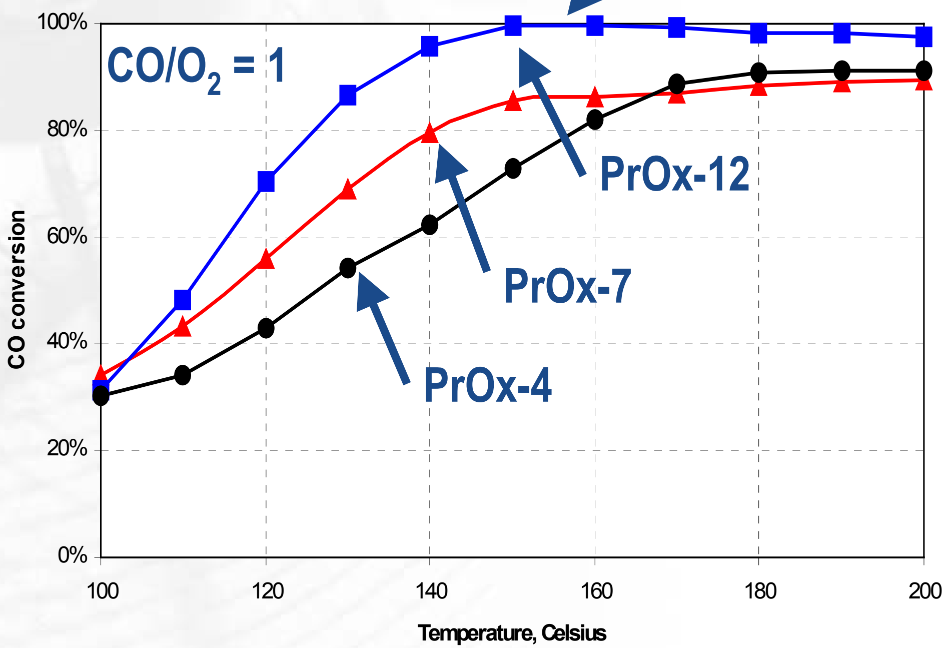
Have developed a static aging system

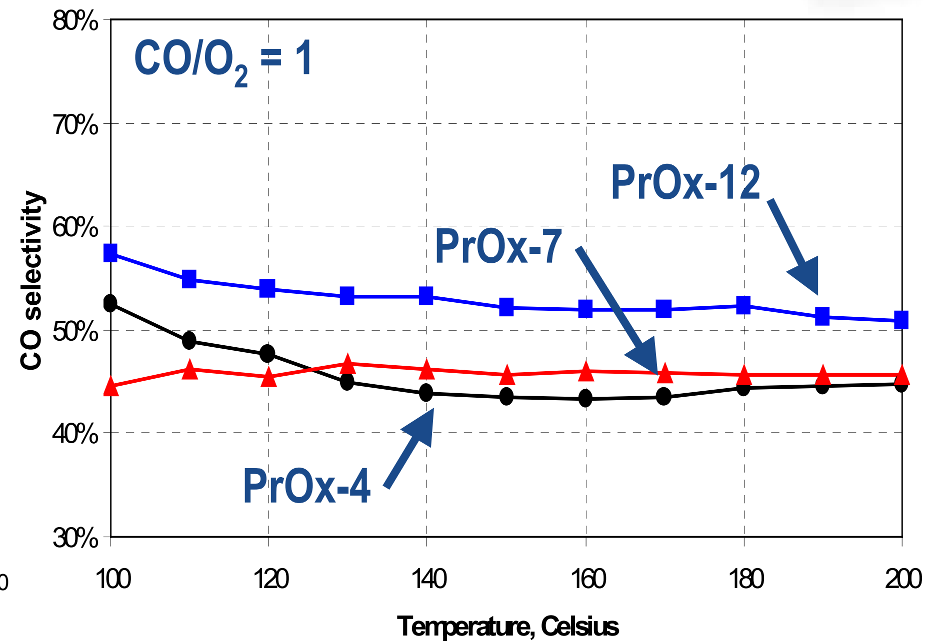
- Age multiple samples
- Low operating cost
- Can run to 5000+ hours
- Have demonstrated correlation with on-line reactor aging data

At this activity, 5 kg of catalyst required for 50kW(e) plate reformer
→ Meets DOE WGS catalyst performance target

Improved PrOx Performance

Conversion near target performance





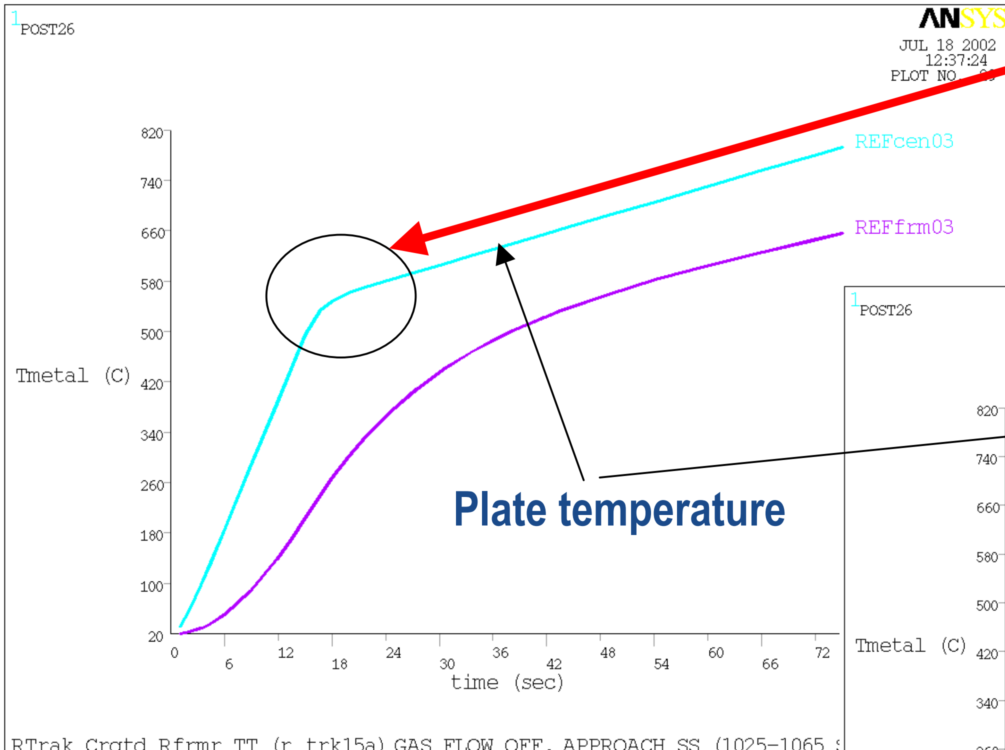
At this activity, 0.6 kg of catalyst required for 50kW(e) PrOx reactor in plate configuration

Transient Thermal Stress Analysis

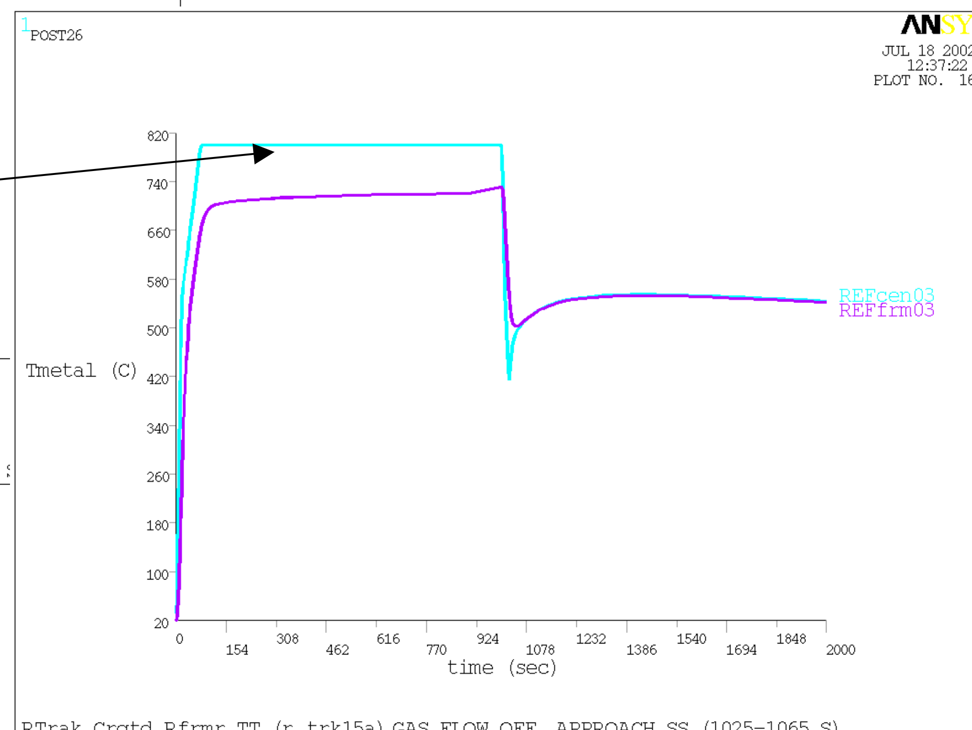
- Transient thermal stress
  - Expected to limit mechanical durability due to the spatial temperature variation throughout time.
- Low cycle fatigue life target
  - 100,000 to 250,000 start/load transient cycles
- Numerous configurations have been analyzed

Plate Temperature vs. Time

Close up of early time shows largest gradient between 15 and 20 seconds where limiting strain condition occurs.



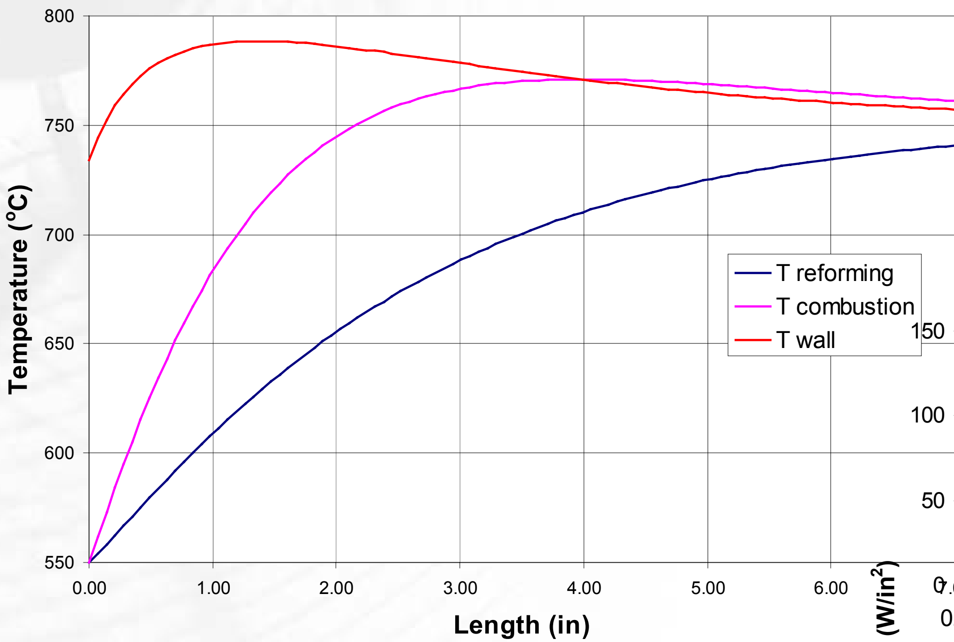
For most designs, the highest stress was in the 15 to 25 second period



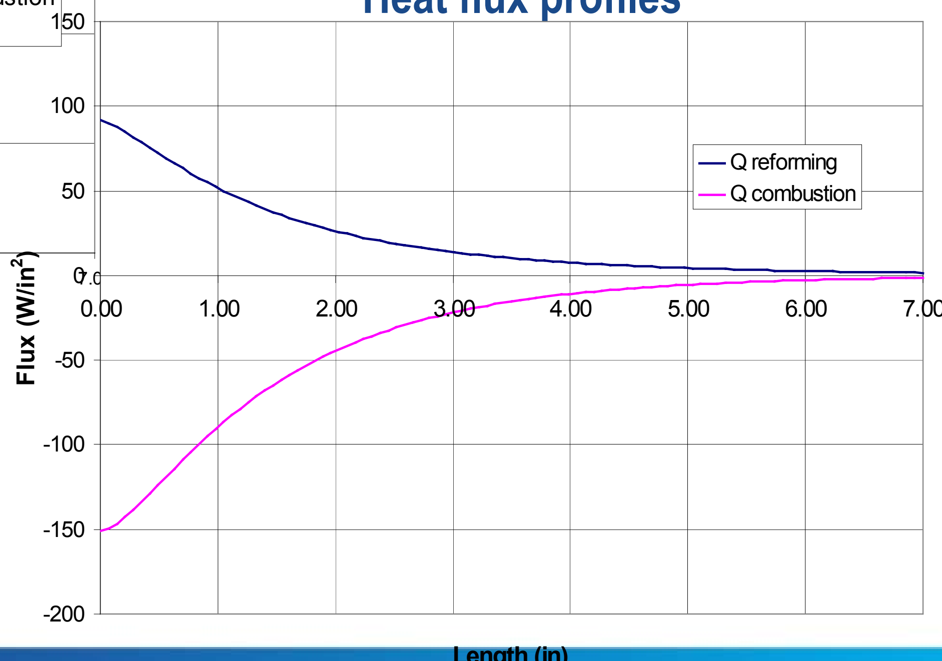
Boundary Conditions

Boundary conditions for reactor plate provided by reactor simulation model of the steam reformer

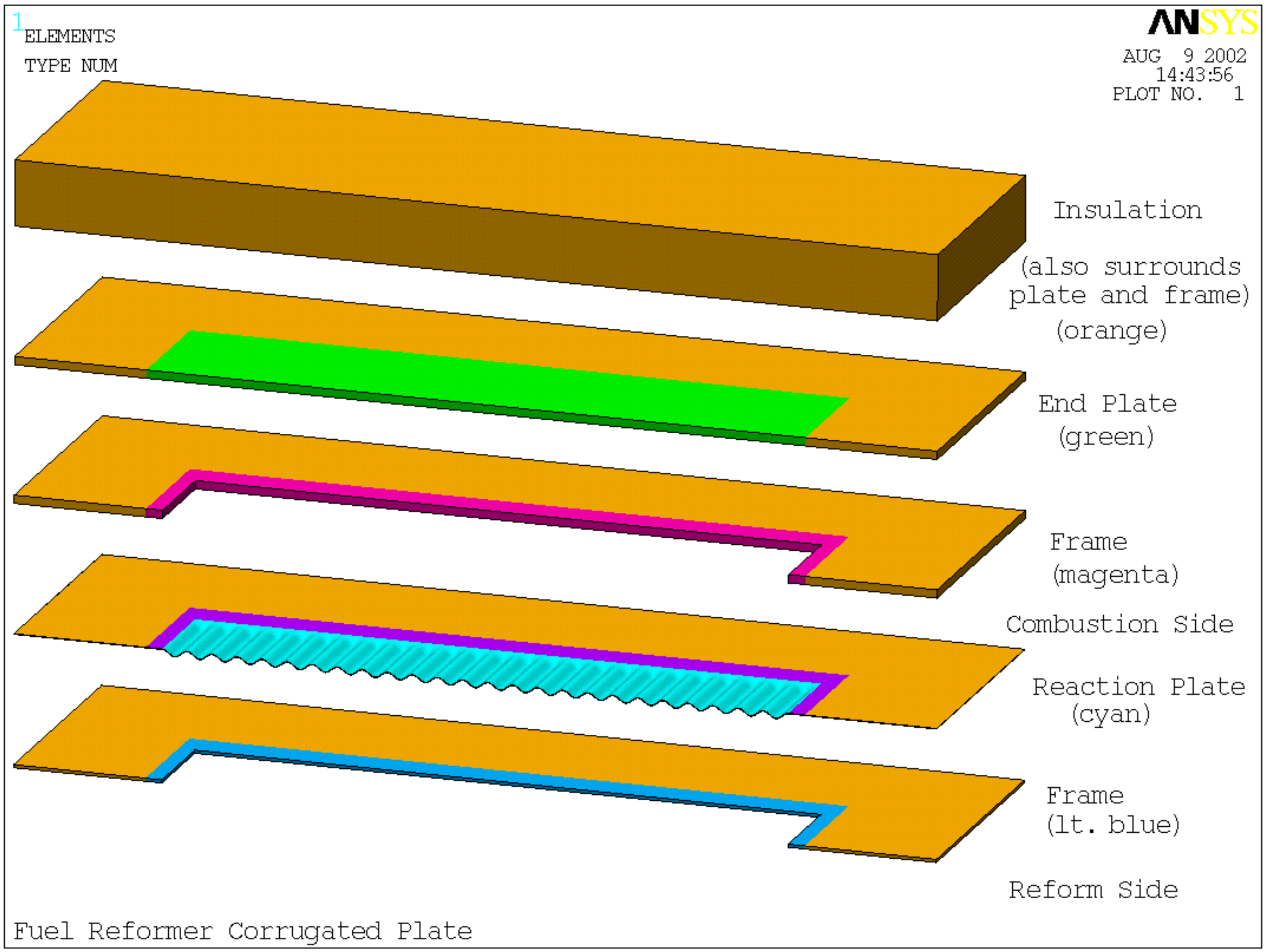
Gas temperature profiles



Heat flux profiles

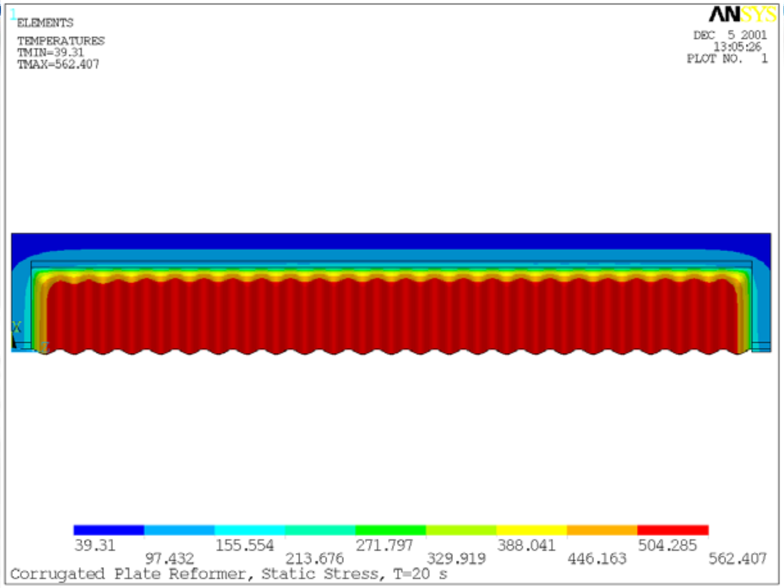


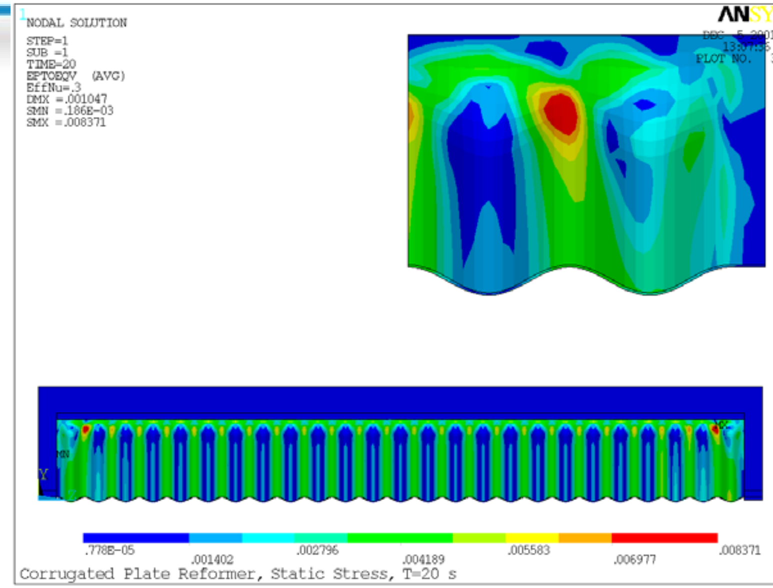
Finite Element Model

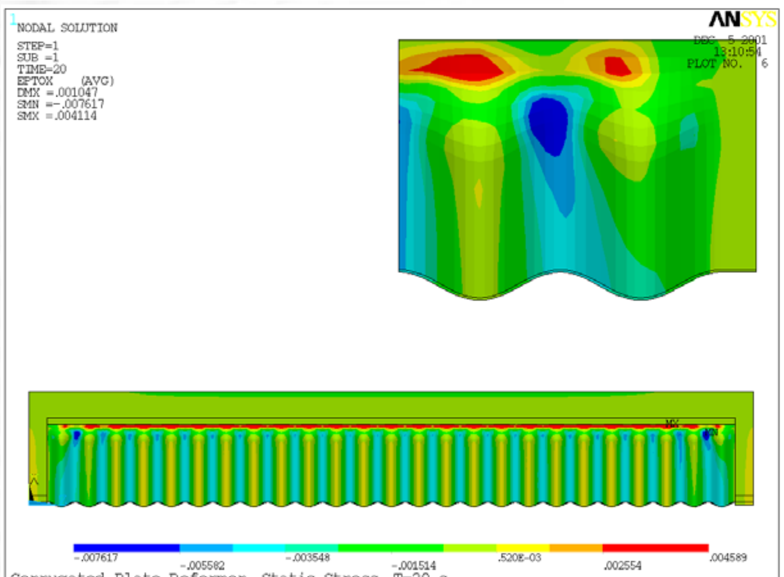


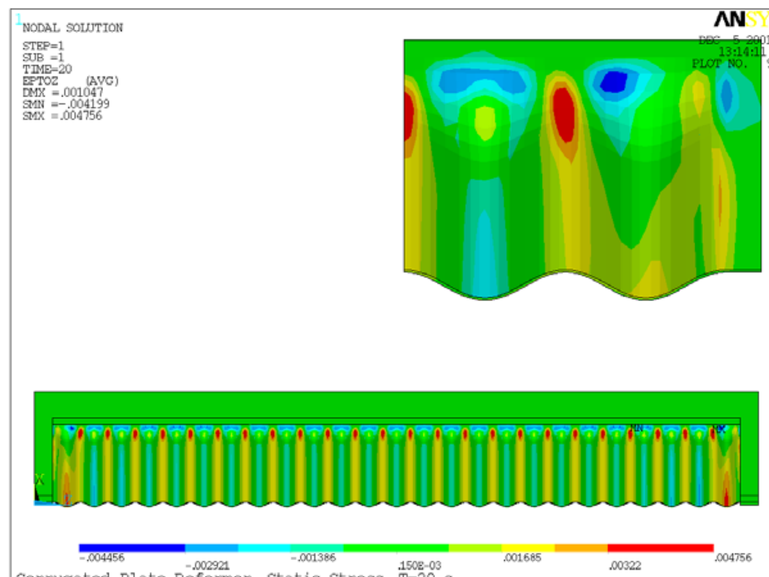
Prototype Plate Reactor Accomplishments

Finite Element Model









Prototype Design

- Have developed design strategy for plate reactor
  - Cyclic fatigue life > 150,000 cycles
  - Potential for very rapid startup
- Mechanical design in progress
  - Prototype unit for laboratory demonstration
  - 2 to 10 kW size with applicability to the reforming, WGS and PrOx reactors
  - Identifying vendors with required fabrication capability, initial fabrication in progress

Prototype Testing Plan

- Will fabricate several prototype reactors
  - Will contain > 10 layer segments for adequate simulation of full scale system
- Demonstration objectives
  - Basic gasoline reforming demonstration at required (high) temperature
  - Fast transient startup
  - Durability studies including cyclic durability (100s of cycles) and long term operation
- Laboratory facilities being upgraded to handle larger flow volume and rapid startup design
  - Gasoline feed system
  - Disposal of product reformate stream

Reactor Components Sizing—Status

Based on plate reactor design strategy

➔ Preliminary estimate of reactor size and volume
(not including system piping, heat exchangers or controls)

		Weight (kg)	Volume (liters)
Steam Reformer		3.7	4.0
WGS		25.3	30.6
PrOx		3.6	3.9
Total		**32.7**	**38.5**
DOE Targets	2005	71.4	71.4
	2010	62.6	62.5

➔ The WGS reactor offers best potential for weight and volume reduction

➔ Other components appear adequate—need confirmation of input data

Future Plans: next 12 months

Prototype plate reactor demonstration

- Design and fabricate prototype reactor
- Upgrade test rig to handle prototype reformer testing
  - Demonstrate steady state performance
  - Demonstrate rapid startup of the gasoline reformer

Reformer reactor

- Establish global kinetics for gasoline reforming
  - Best catalyst system
  - ANL Benchmark Fuel I with 10ppm S
- Complete design studies of plate reformer

Future Plans: next 12 months

WGS reactor

- Continue catalyst development – low level effort
  - Evaluate outside catalyst systems (vendors, Nat'l Labs)
  - Durability testing to 5000 hours – static test rig
- Reactor design/modeling studies to reduce weight and volume

PrOx reactor

- Establish kinetics over working range
- Model plate reactor systems to achieve <10ppm CO
- Initial durability studies