Autothermal Cyclic Reforming Based Hydrogen Generating System

Ravi Kumar, Court Moorefield, Parag Kulkarni, Gregg Deluga & Greg Gillette
GE Global Research
Mike Manning & Andrew Rosinski
Praxair

May 2006

PDP 1

This presentation does not contain any proprietary or confidential information

imagination at work

Overview

Timeline

- Start - Jan 2002
- Finish - Mar 2006
- 100% Complete

Budget

- Total project funding
  - DOE - $2,382K
  - Contractor - $1,812K
- Funding received in FY05
  - $490K
- Funding for FY06
  - $160K

Barriers

- Barriers
  - > A. Fuel Processor Capital Costs
  - > B. Fuel Processor Manufacturing
  - > C. Operation & Maintenance
- Targets - production & dispensing

	2005	2010	2015
Production Efficiency (LHV)	69	70	80

Partners

- Praxair - Purifier
- University of California at Irvine - Site

imagination at work

Objectives

Overall	• Design a generating & refueling systems that can meet the DOE efficiency target of > 69% (LHV) basis • Fabricate & operate an integrated 60 kg of H_2/day generating system to generate > 99.99% hydrogen with < 1 ppm CO
Last Year	• High pressure reformer & pressure swing adsorber – Fabrication & Installation – Integration & Operation • Update economic analysis

imagination at work

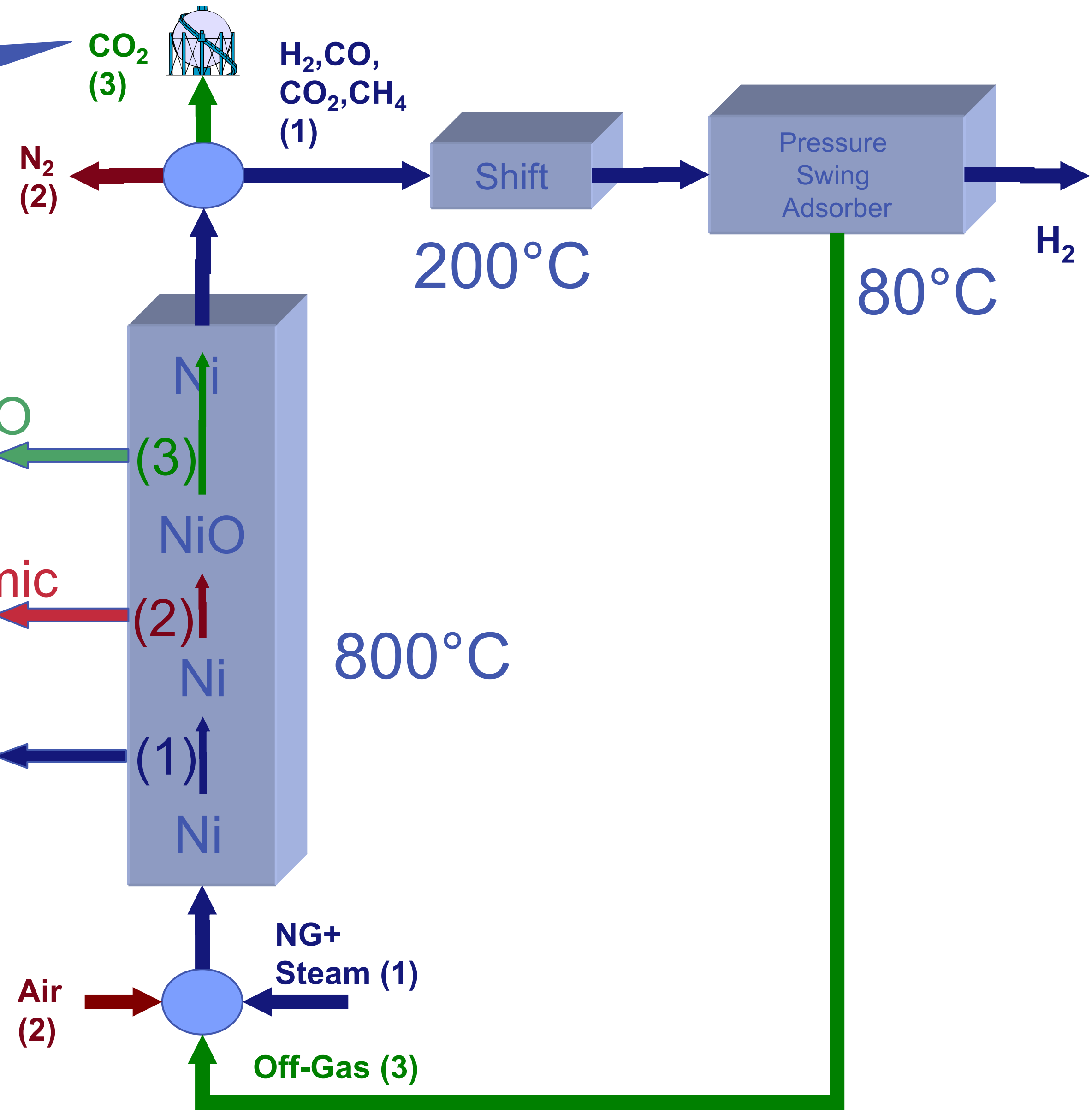
Technical Approach

Reformer	• Minimize capital cost • Design for 1000s of cold start cycles • Modeling of advanced control systems for stabilizing temperature and flows • Catalyst durability – thermal/RedOx cycles • Increase methane conversion
Shift	• Increase CO conversion
Pressure Swing Adsorber	• Impurities – CO, Sulfur • >75% recovery of Hydrogen
Safety & Permitting	• Gas Sensors – Lower Explosive Limit (LEL) • Seismic zone 4 classifications • Class I Div II explosion proof electrical

imagination at work

Autothermal Cyclic Reforming Process

Separation potential for large scales



Fuel Reduction – Mildly Endothermic

$4NiO+CH_4 \rightarrow 4Ni+CO_2+2H_2O$

$NiO+H_2 \rightarrow Ni+H_2O$

Air Regeneration - Exothermic

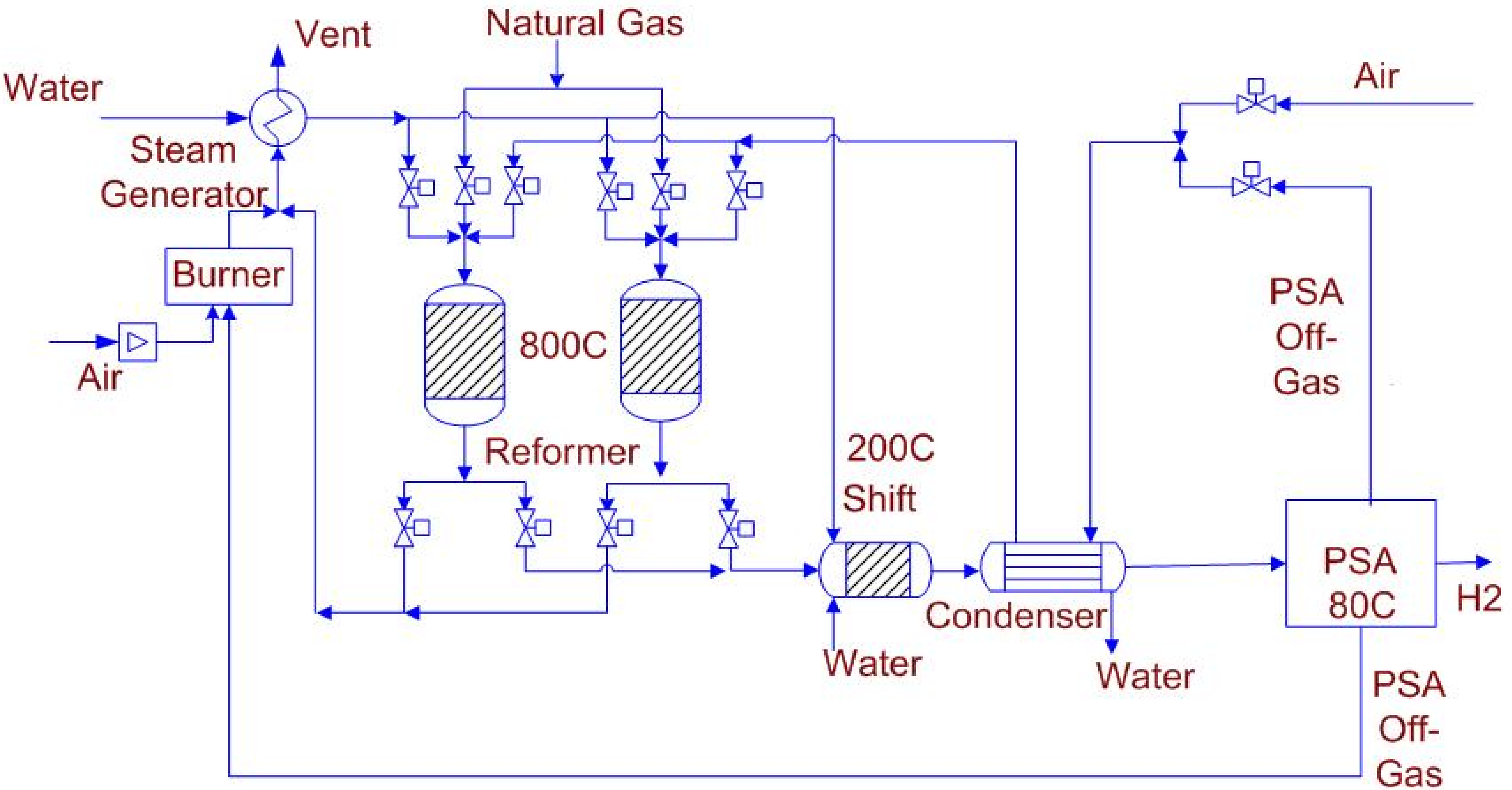
$Ni + 1/2\ O_2 \rightarrow NiO$

Reforming - Endothermic

$CH_4+H_2O \rightarrow CO + 3H_2$

$CO+H_2O \rightarrow CO_2 + H_2$

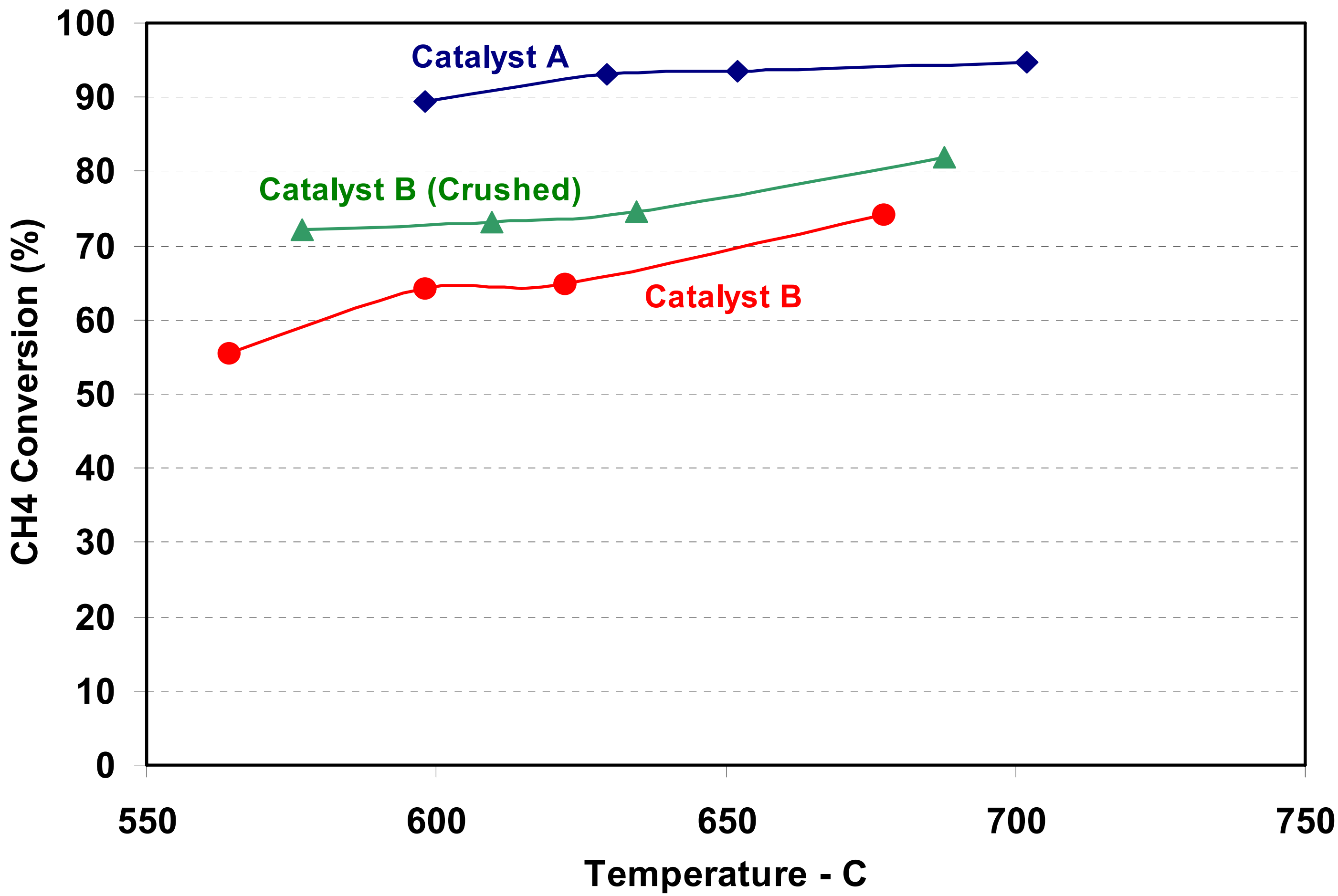
Projected Efficiency is 71% (LHV)



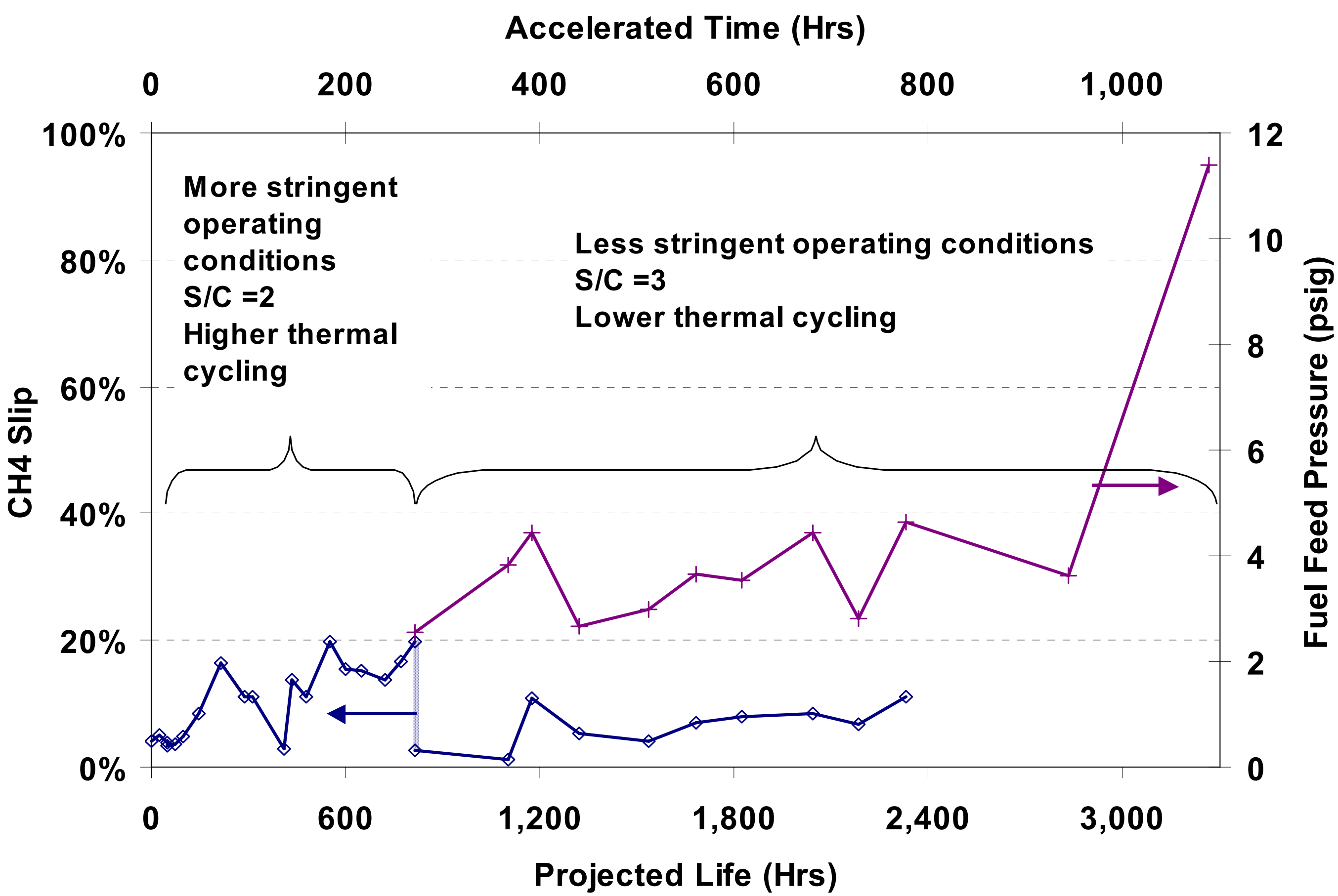
$$\text{Efficiency} = \frac{\text{LHV of H2 produced (kW) *100}}{\text{LHV of CH4 fed (kW) + electricity required (kW)}} = 71\%$$

imagination at work

Reformer Catalyst "A" Performed better than Catalyst "B"



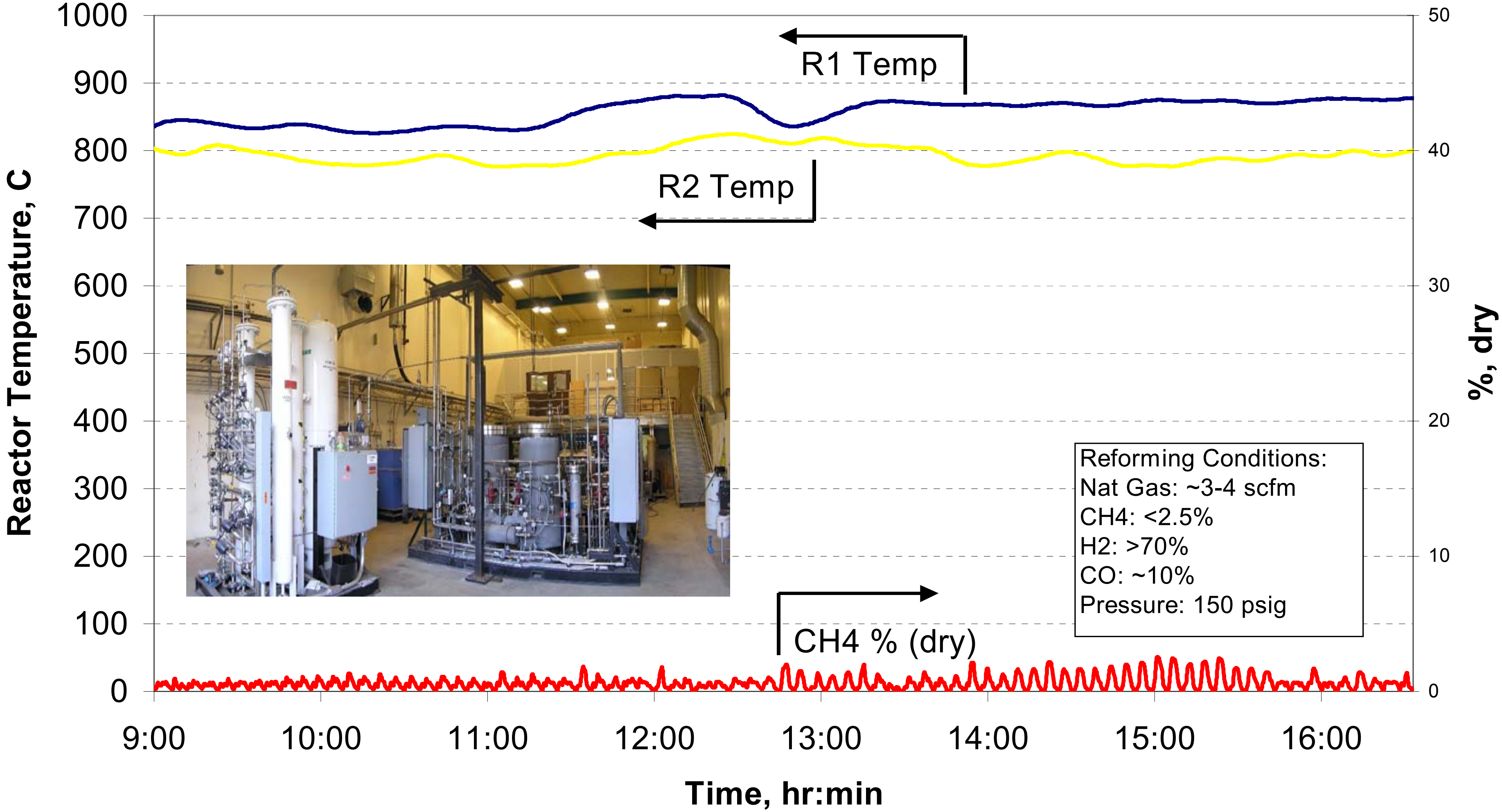
Lab-Scale Reformer Catalyst Testing Projects Lifetime > 2,300 hrs



T = 800C

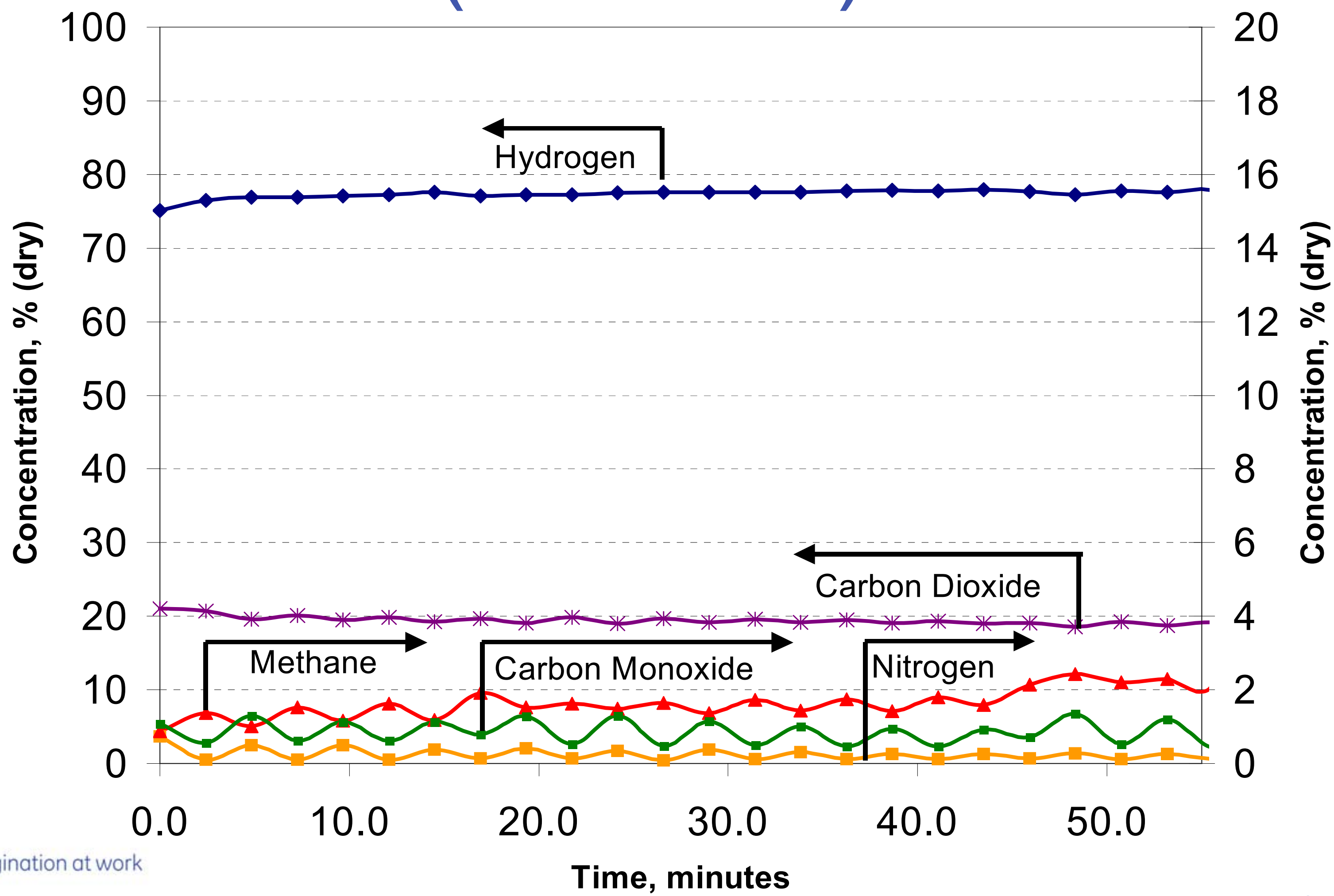
imagination at work

Both Reformer Reactors were Stable for Extended Periods



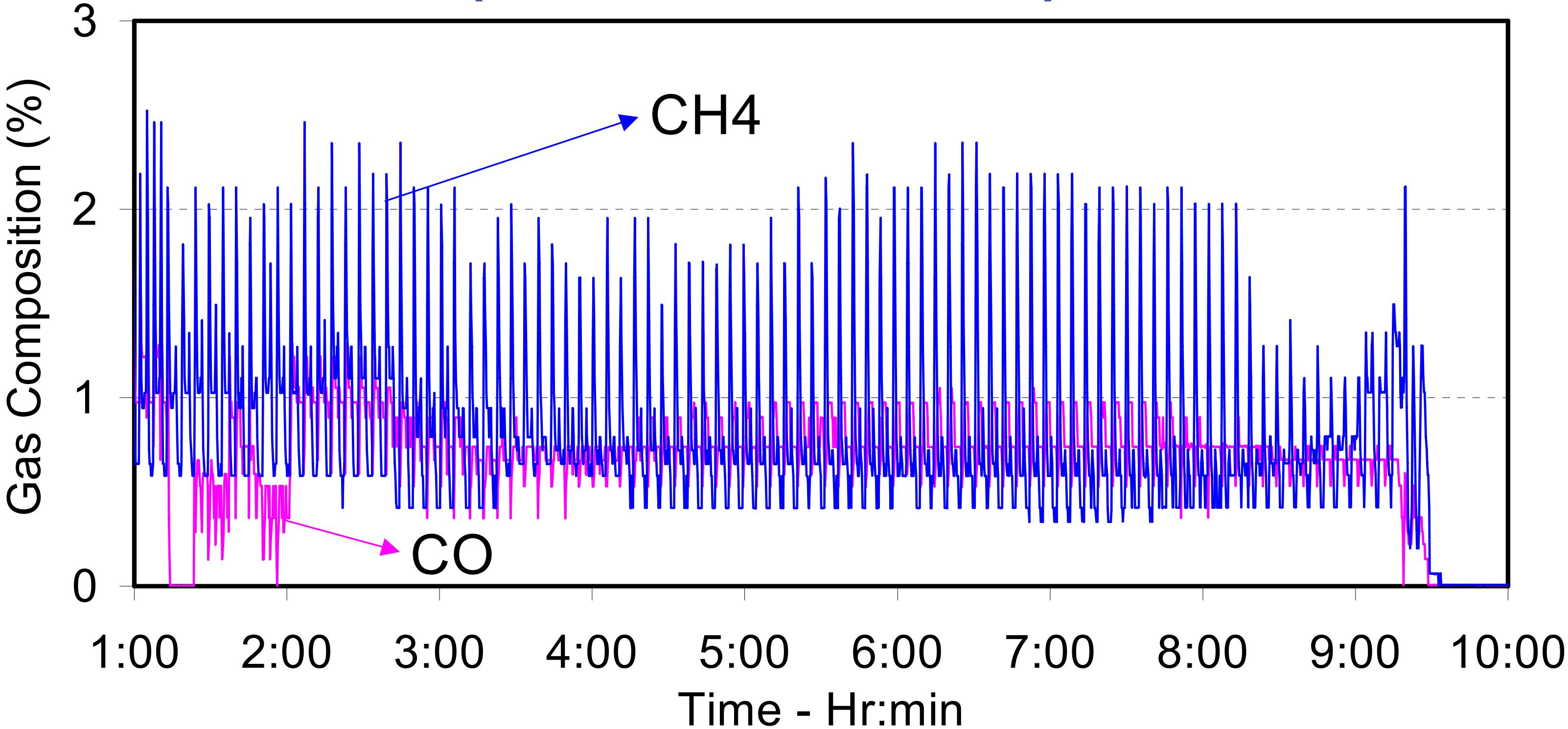
imagination at work

Pilot-Scale Reformer+Shift Met Targets of <10% CH_4 and > 70% H_2 (GC Data)



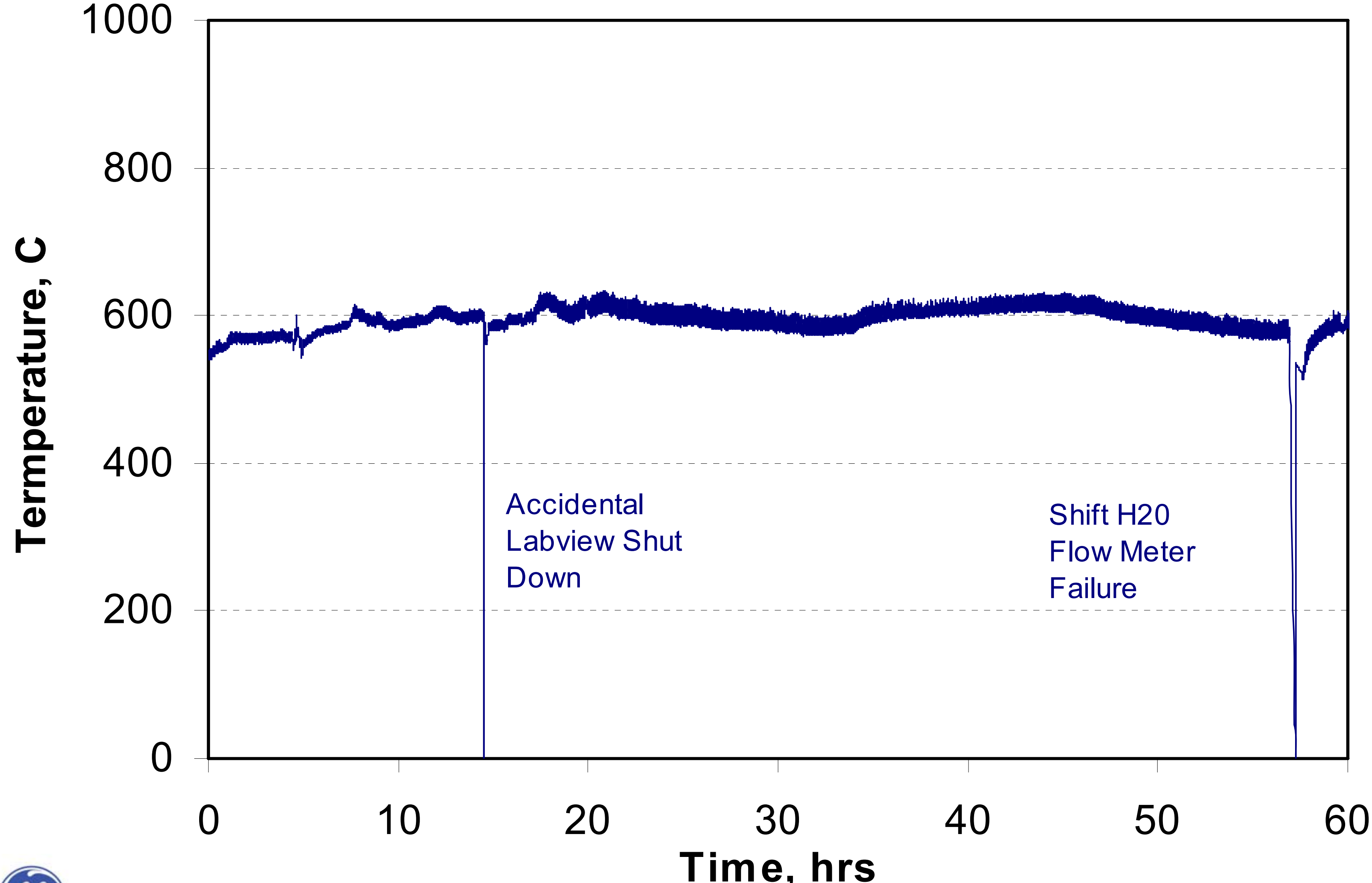
imagination at work

Pilot-Scale Reformer+Shift Met Targets of <10% CH_4 and > 70% H_2 (CEMS Data)

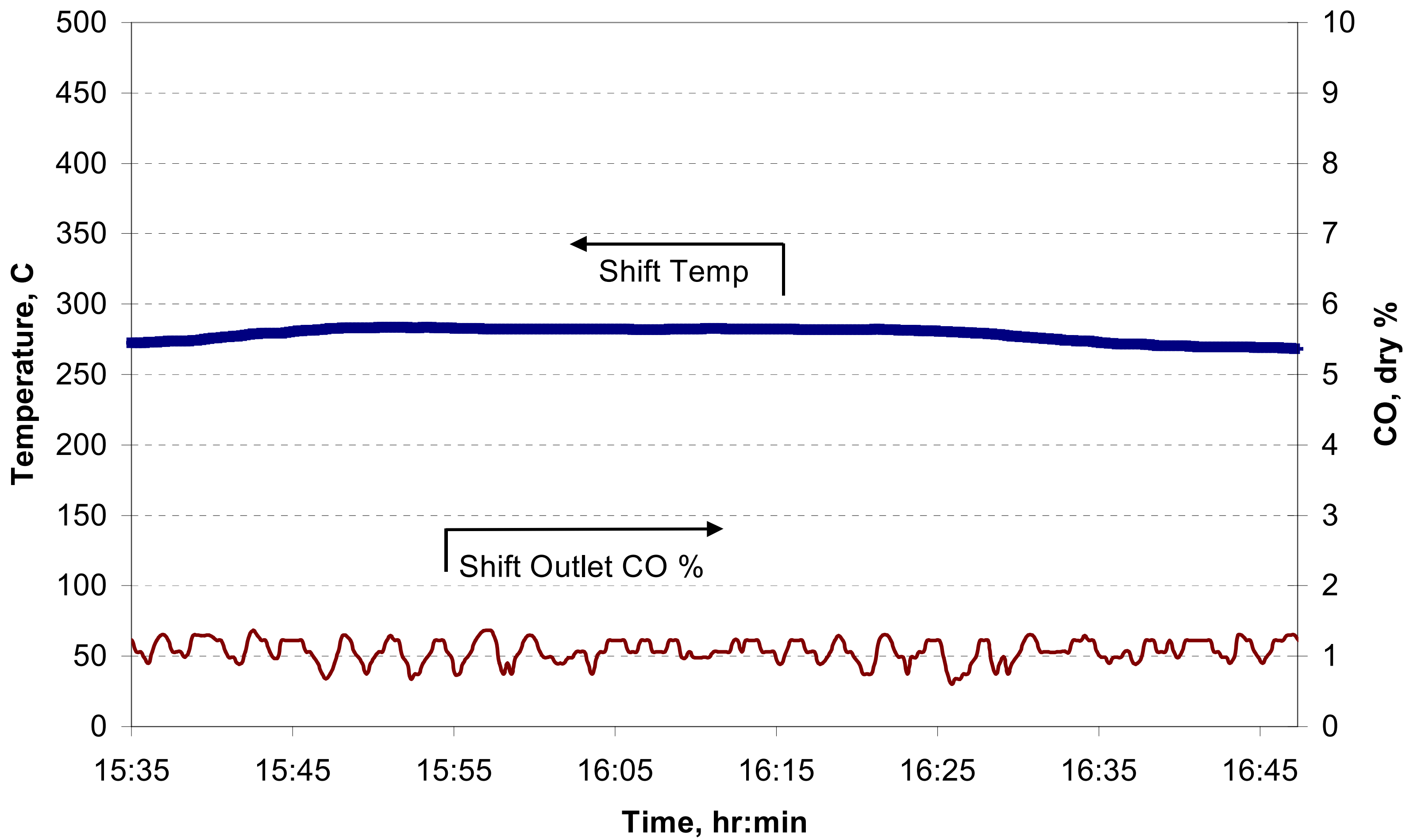


~ 20% CO_2
> 74% H_2

Pilot-Scale Reformer was Operated Successfully for 60 hrs

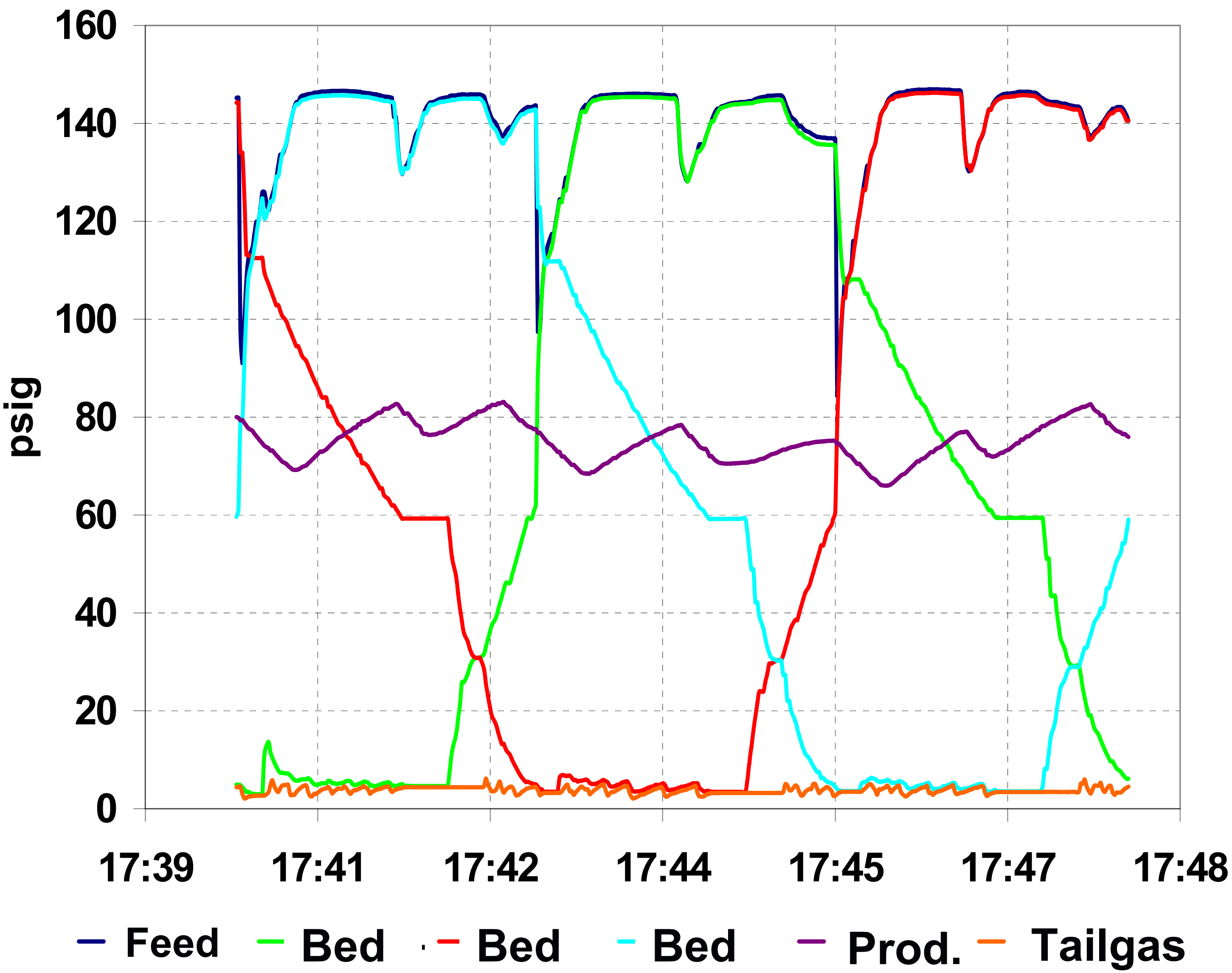


Shift Reactor met target of < 1.5% CO



imagination at work

Praxair Pressure Swing Adsorber Pressures



PSA Product Impurities < 11 ppm

Pilot & Prototype PSA Generated > 99.999% H_2

			pilot	pilot	proto*
			3-bed	3-bed	3-bed
Feed data	flow	cfh	**127.3**	**158.4**	**1556.4**
	temperature	F	86.8	95.9	103.1
	H_2	%	77.5	71.5	77.4
	CO_2	%	19.2	25.1	19.4
	CO	%	0.7	0.7	0.8
	N_2	%	0.7	0.7	0.2
	CH_4	%	2.0	1.9	1.7
bed pressure	low	psig	4.7	5.3	3.3
	high	psig	120.8	151.0	145.8
	ratio		7.0	8.3	8.9
product data	flow	cfh	74.9	70.9	692.6
	recovery	%	**75.9**	**77.2**	**57.5***
	bsf (total)	lb/tpd	5746	4947	8411
	purity	% H_2	**99.996**	**99.988**	**99.999**
	CO_2	ppm	nd	nd	nd
	CO	ppm	nd	nd	nd
	N_2	ppm	44.4	122.7	nd
	CH_4	ppm	nd	nd	nd
Cycle	Total cycle time	sec	480	480	423

- Reformer was supplying of 75% of feed flowrate required by PSA which, by the nature of the theoretical PSA process, results in a lower hydrogen recovery than at design (100%) feed flowrate
- ND – Non Detectable

imagination at work

Simulation Projects >72% Recovery of H2 in PSA at Full Load

	Exptl Results @ 75% Load	Model Results @ 100% Load
PSA Cycle Time – Secs	423	423
Feed Flow Rate – scfh	1,521	2,029
Product Flow Rate	695	1130
H2 Purity	> 99.999%	> 99.999%
H2 Recovery	> 59%	> 72%
Total Bed Size Factor – lb/ TPD H2	8,425	5,179

imagination at work

Publications and Presentations

- Patent # 6,878,362 - Issued to GE
- Patent # 6,792,981 - Issued to Praxair

Summary

- Pilot-Scale Reformer Experiments
  - 60 hr extended overnight run
  - Syngas Concentrations
    - » CH_4 0.5 –3%
    - » H_2 74%
- Prototype Pressure Swing Adsorber Experiments
  - Product Gas > 99.999% H2
  - Impurities (Mostly N_2) < 11 ppm
- Lab-scale catalyst durability testing projects reformer catalyst lifetime > 2,300 hrs

imagination at work