

2007 DOE Hydrogen Program

Hydrogen Generation from Biomass-Derived Carbohydrates via Aqueous-Phase Reforming Process

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This presentation does not contain any proprietary or confidential information

Project ID #
PDP8

Overview

Timeline

- Start – Sept 2005
- Finish – Aug 2008 (Tentative)
- 20 % complete

Budget

- Total project funding
 - DOE share -1,942 K
 - Contractor share - 679 K
- Funding received to date
 - 369 K DOE
- Funding Reduction in FY06 resulted in limiting work to catalyst development

Barriers

- Feedstock Cost, Reformer Capital Cost, Operations Cost, and GHG emissions
- Feedstock Cost Reduction
 - 2012 Feedstock Cost Contribution \$2.10/gge
 - 2017 Feedstock Cost Contribution \$1.55/gge
- By 2012, reduce H₂ costs to \$3.80/gge
 - Overall Efficiency 72%
- By 2017, reduce H₂ cost to <\$3.00/gge

Partners

- ADM
- University of Wisconsin

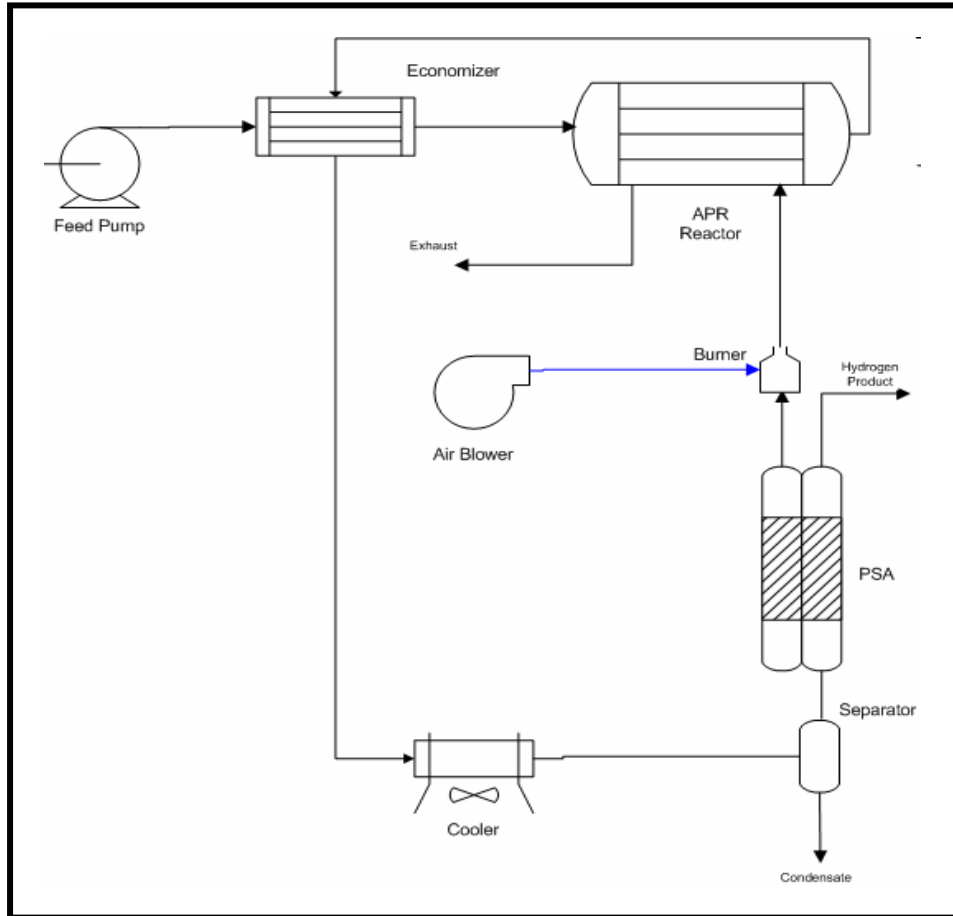
Objectives

Overall	<ul style="list-style-type: none">• Design a generating system that uses low cost sugars or sugar alcohols that can meet the DOE H₂ cost target of \$2 to 3/gge for 2017.• Fabricate and operate an integrated 10 kg of H₂/day generating system.
2006	<ul style="list-style-type: none">• Limited scope of work for 2006 due to funding cutbacks.• Develop APR catalyst, reaction conditions, and reactor suitable for converting glucose to hydrogen.

Objectives (cont)

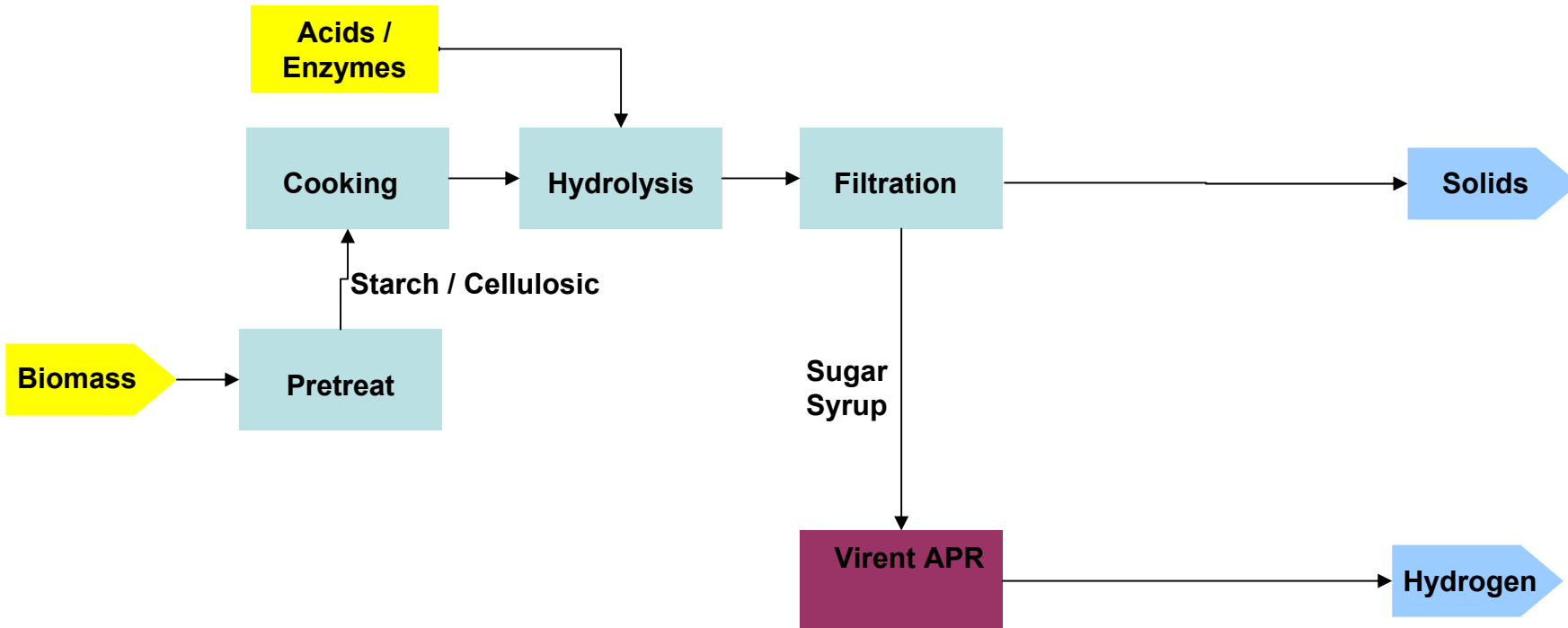
2007	<ul style="list-style-type: none">• Virent will continue to investigate catalyst, reaction conditions, and reactor suitable for converting low cost sugars to hydrogen• Calculate the thermal efficiency and economics of the APR system utilizing different feedstocks (low cost sugars, glucose, sugar alcohols)• Compare results of techno-economic analysis with DOE Hydrogen Programs Goals• Make a Go No-Go decision on moving forward to the design and construction of a 10 kg H₂/day demonstration system with the preferred feedstock.• Design of 10 kg H₂/day demonstration system
2008	<ul style="list-style-type: none">• Fabrication of 10 kg H₂/day system• Startup and operation of 10 kg H₂/day system• Analysis of 10 kg H₂/day system

Hydrogen Production using the APR Process



- Simple Catalytic Process
 - No Water Gas Shift
 - No Steam System
 - No Gas Compressor
 - No Desulphurizer
- Energy Efficient
- Scalable
- Feedstock Flexible

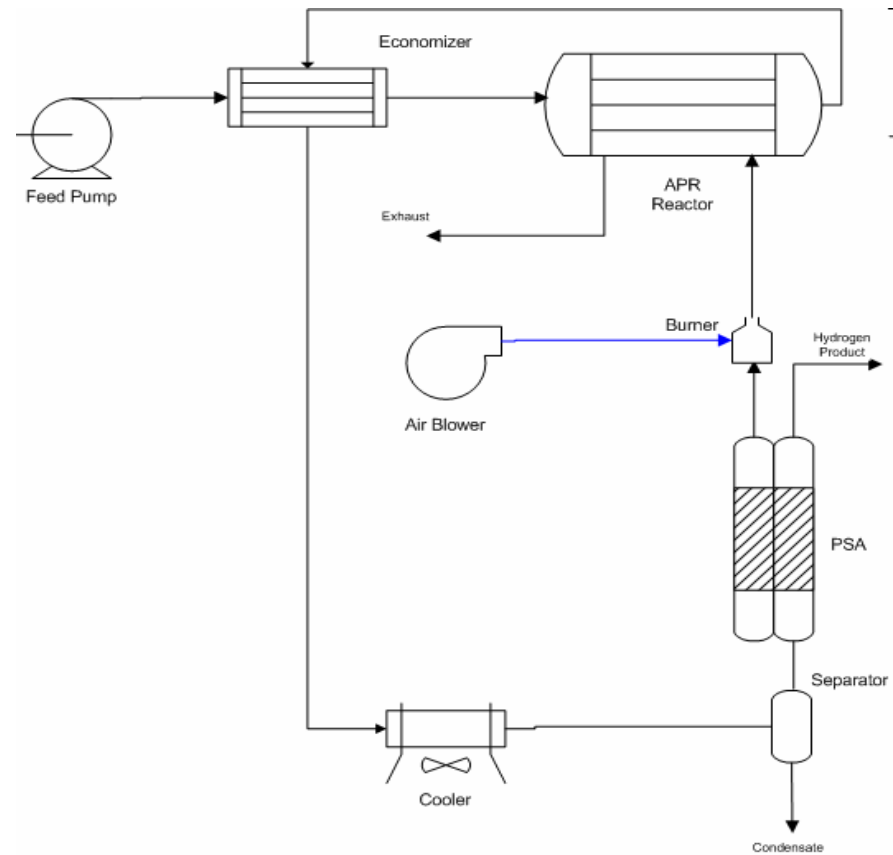
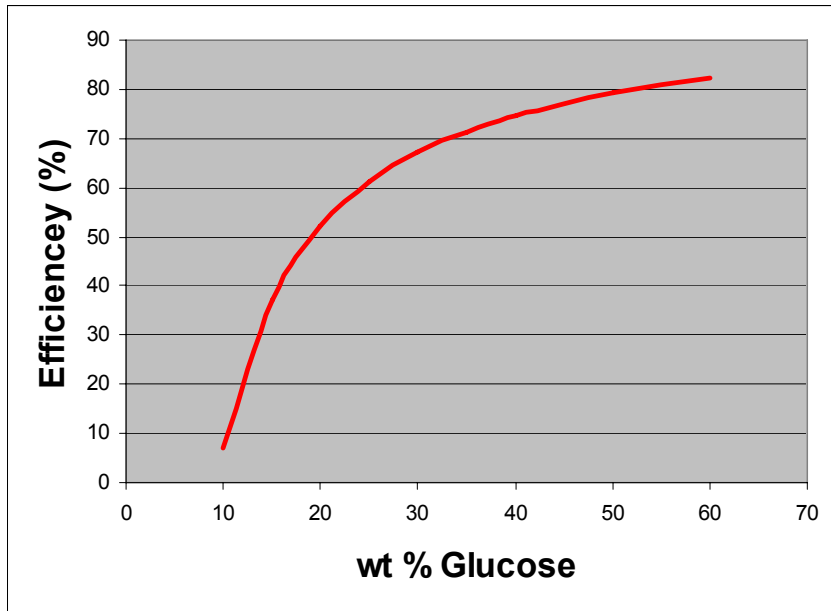
Biomass to Hydrogen via the APR Process



Technical Accomplishments/ Progress/Results

- Initiated project in September 2005
- ADM provided glucose samples for processing.
- Investigating catalyst and conditions for operations with high concentrations of sorbitol
- Investigating catalyst and conditions for operation with high concentrations of glucose
- Virent funded project to convert glycerol to hydrogen
 - Proved Catalyst Lifetime of greater than a year
 - Tested First Generation Reactor System
 - Designed and Constructed Second Generation Reactor System

Effects of Feed Concentration



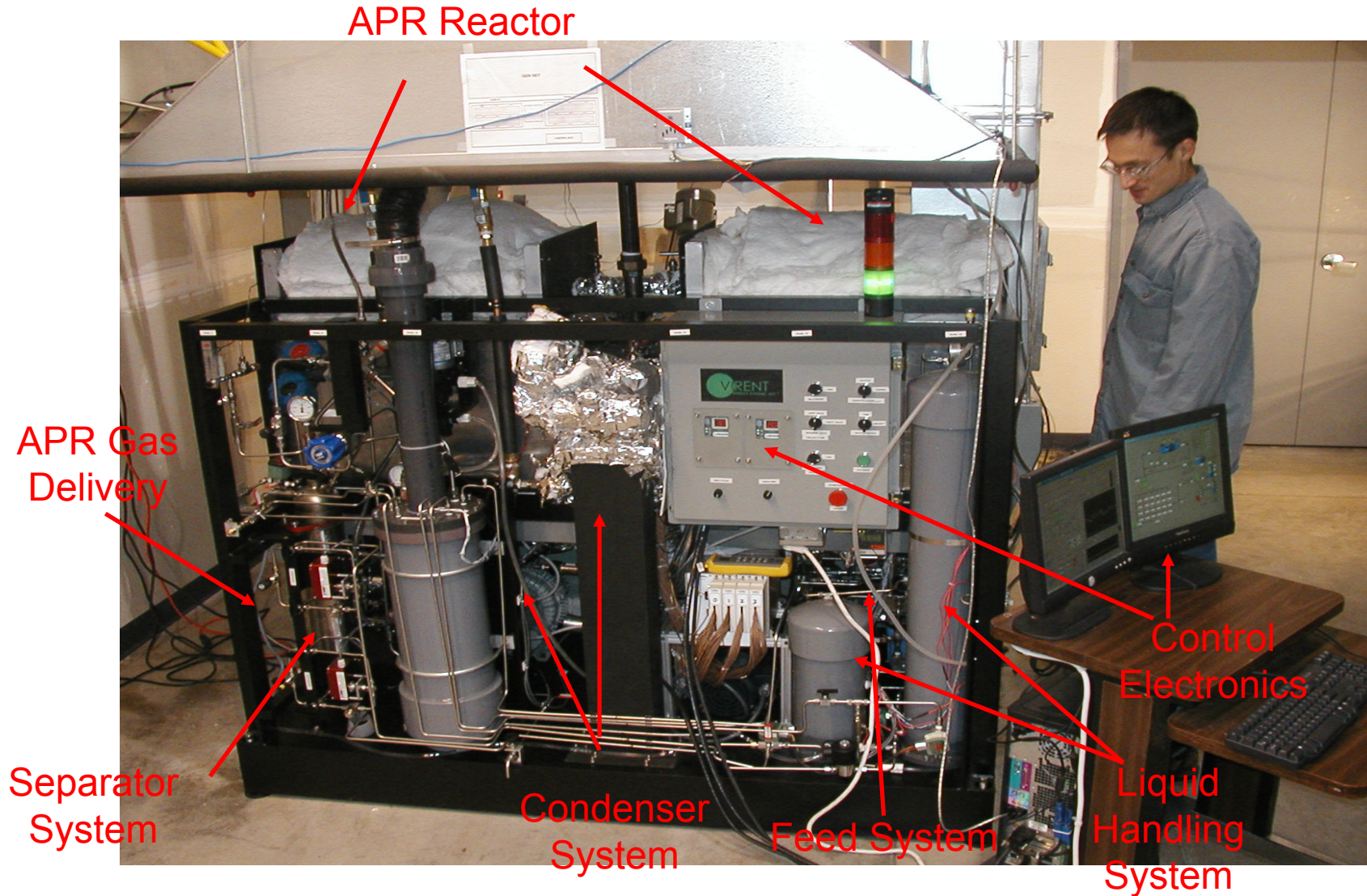
- System Efficiency
 - Combustion of Hydrogen for Process Energy Required
 - Higher Feedstock Concentrations Reduce Heating Requirements

Reforming of Glucose

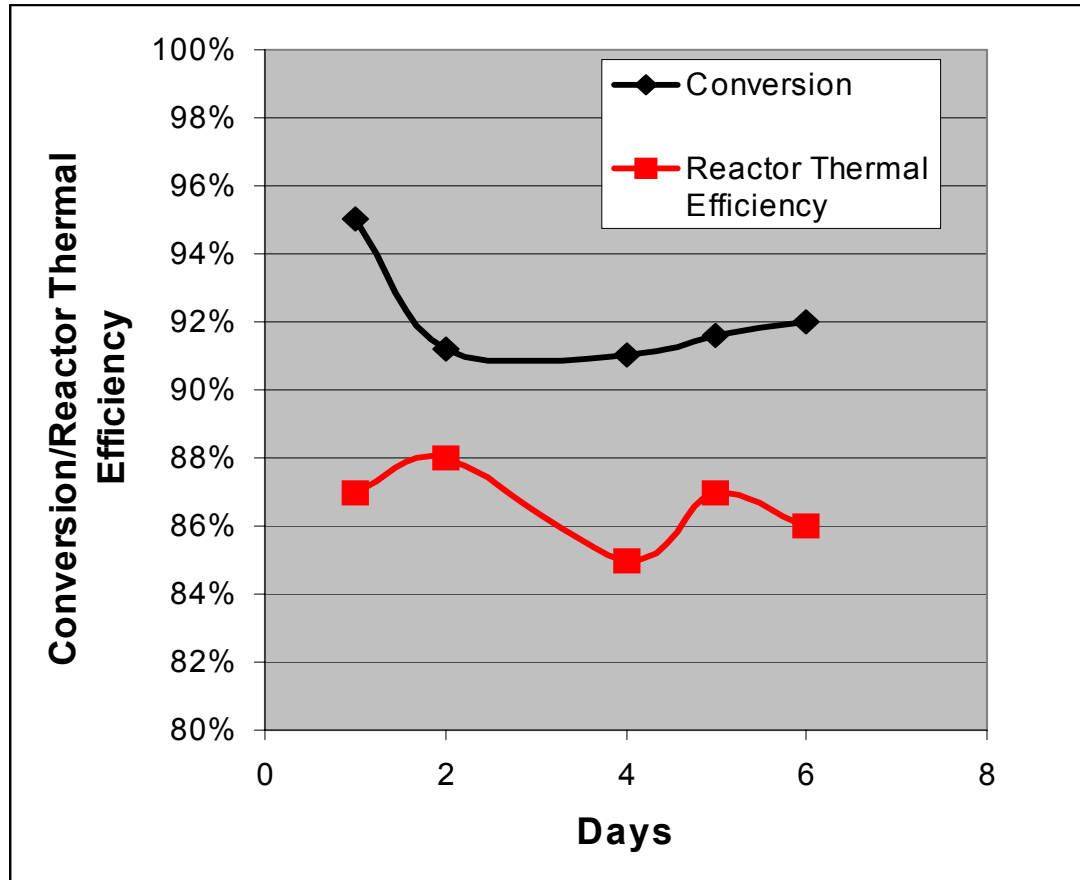
Date		Apr-04	Sep-05	Jan-06
Feedstock	30% Sorbitol	3% Glucose	30% Glucose	30% Glucose
WHSV	2.0 /h	0.897 /h	0.996 /h	2.1 /h
Reactor				
Temperature	240 °C	230 °C	240 °C	240 °C
Pressure	500 psig	430 psig	500 psig	600 psig
Conversion	100%	73%	100%	100%
Conversion to Gas	75%	14%	58%	36%
H2 Selectivity	72%	33%	23%	58%
Watt H2/gram	4.2	0.12	0.39	0.91
Watt Alkane/Gram	2.1	0.03	1.26	0.73

WHSV – gram of oxygenated compound per gram of catalyst
per h

Green Energy Machine (GEM)



APR Reactor Performance



Single Pass Conversion

1.8 WHSV
based on Glycerol

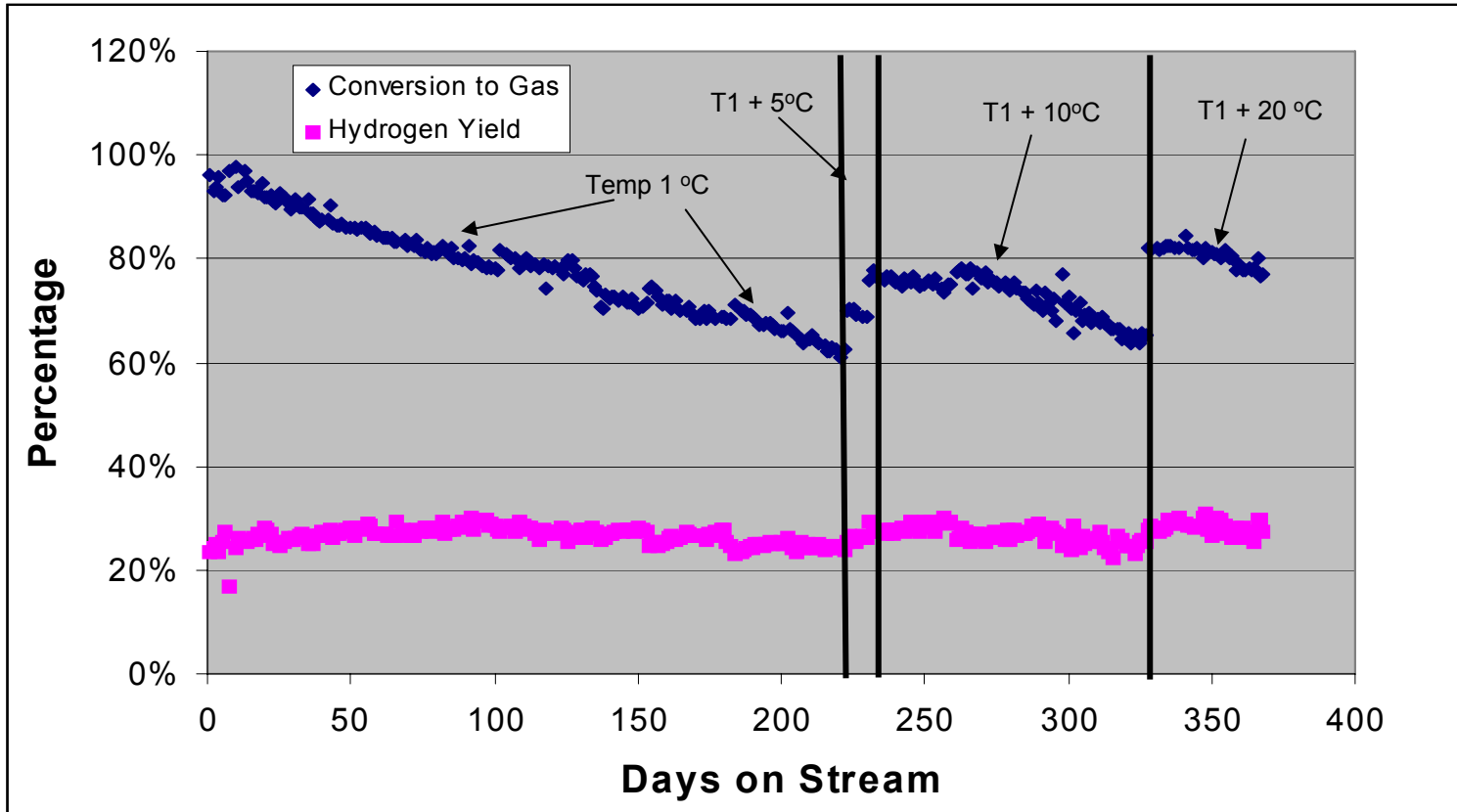
Reactor Thermal
Efficiency

$$100 \times \left(1.0 - \frac{\text{Process Energy}}{\text{Generated Energy}} \right)$$

Process Thermal Efficiency
78.5 % of LHV of Feed

GEM Catalyst Lifetime Testing

13 months of Continuous operation



- 50 wt% Glycerol In water
- First Generation Catalyst
- One pass operation
- Very stable H₂ production
- Temperature can be raised to keep conversion high

APR Outlet Gas Composition

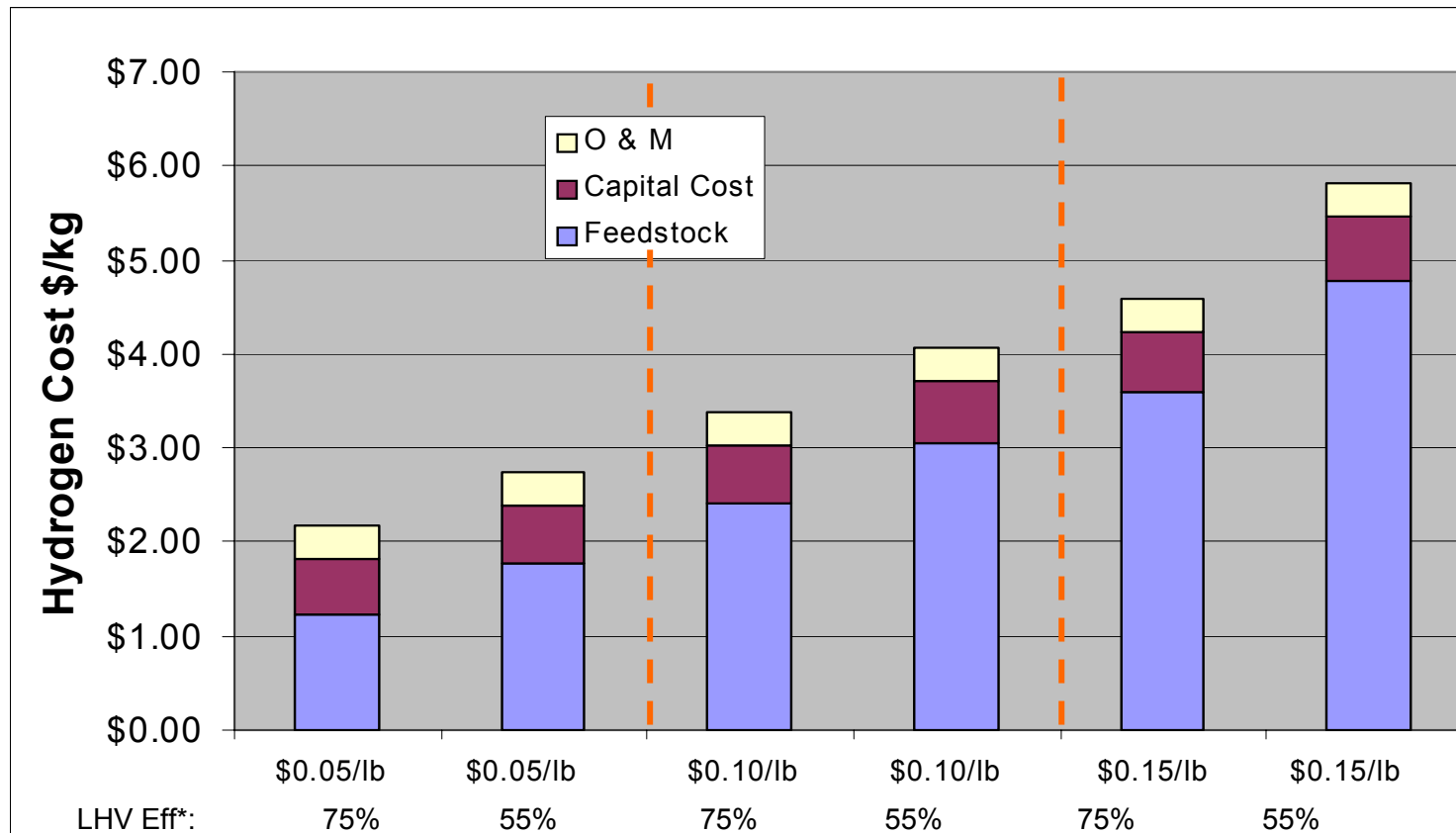
Glycerol Feedstock

	SNG Catalyst Vol. %, Dry	H2 Catalyst Vol. %, Dry
Hydrogen	35%	60%
Methane	8%	7.5%
Ethane	12%	1.5%
Propane	5%	0.5%
CO2	40%	30.5%

Hydrogen Pilot Plant



Projected Cost of Hydrogen Using the BioForming Process



Capital Cost
Includes
APR
PSA

Current
Performance
55% LHV*

Projected
Performance
75% LHV*

1500 Kg/day H₂, 10% ROI, 10 Year Project Life, Glycerol Feed

*LHV Eff: LHV of hydrogen exit PSA / LHV of Feed Glycerol

Future Work

- Worked Planned for 2007
 - Develop APR catalyst and reactor that converts glucose to hydrogen.
 - Develop APR catalyst and reactor that effectively converts sugar alcohols to hydrogen.
 - Investigate hydrogenation technologies that convert both monosaccharides and polysaccharides to sugar alcohols
 - Investigate the integration of the hydrogenation technology with the APR technology.
 - Calculate the thermal efficiency and economics of the baseline APR system utilizing sugars or sugar alcohols as the feedstock.
 - Evaluate the baseline APR system against US Hydrogen program goals and determine whether to proceed to development of the demonstration system.

Future Work beyond 2007

- Develop the detail design of the demonstration APR hydrogen generation system (10 kg/day).
- Fabrication of the integrated hydrogen generation system.
- Evaluate APR hydrogen generation system performance against US Hydrogen program goals.

Summary

- Initiated Project in September 2005 with limited funding.
- Initial work with higher concentrations of glucose shows promise.
- Virent has already built and operate a 6 NM³/h Alpha Unit utilizing glycerol as a feedstock.
- Virent will soon be starting up a second generation reactor system for generation of hydrogen from glycerol
- Will continue work with sugars as funding is available.