Hydrogen from Glycerol: A Feasibility Study

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Project ID: PD003

Project Overview

<u>Timeline</u>

- Project Start: October 2009
- Project End: TBD

<u>Barriers</u>

- D. Feedstock Issues
- E. Greenhouse Gas Emissions

<u>Budget</u>

- FY10 - $100K + TBD

<u>Partners</u>

- TBD

Relevance - Technical Overview

Background

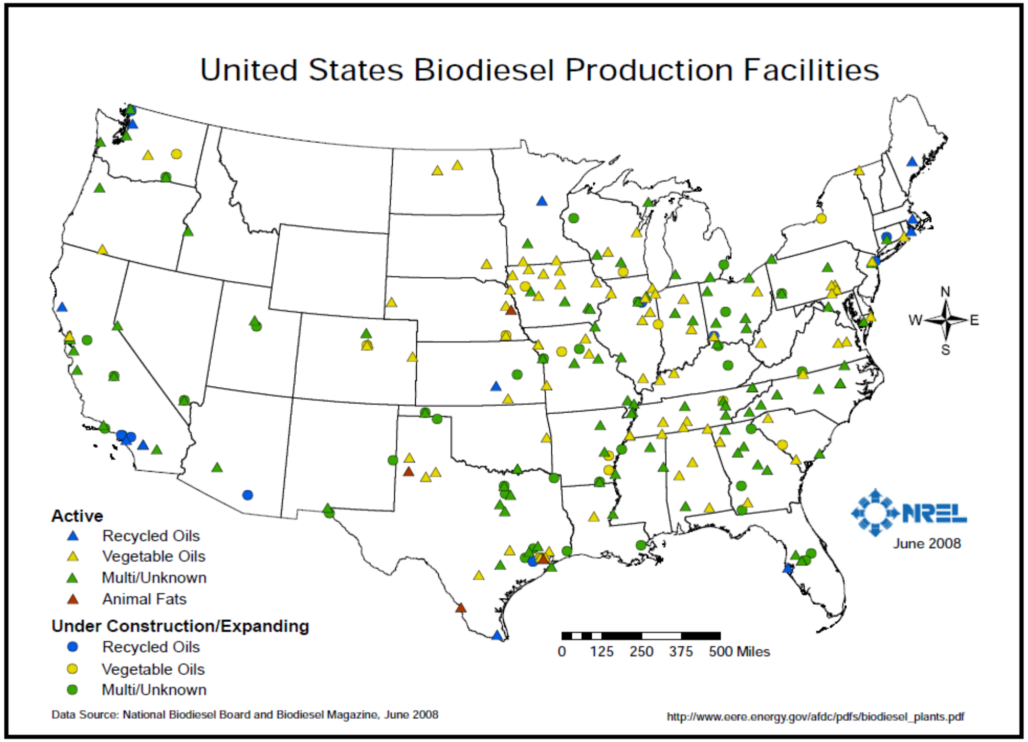
- The rapid growth in biodiesel production has led to an abundance of glycerol
- The crude glycerol, containing salts and methanol, has to be disposed as hazardous waste

Opportunity

- The alcohol and water content in crude glycerol is acceptable for reforming
- Secondary products from crude glycerol are attractive to biodiesel producers

Relevance - Glycerol can contribute to the mix of feedstock used in the H_2 refueling infrastructure

- Glycerol, a product of biomass and animal fats, is a renewable resource
- As a liquid, glycerol has high energy density (heating value) and is easy to transport
- Glycerol can be converted to H_2 to refuel fuel cell vehicles
  - Glycerol can also be used by reformate-based stationary fuel cell systems
- The hydrogen can be generated at or close to biodiesel production facilities
- Glycerol production capacity (2008) can yield 200,000 kg of H_2 per day



Relevance - Objective

Objective

- Evaluate the economic feasibility of producing hydrogen from glycerol derived as a byproduct of the biodiesel industry
  - For the distributed production of hydrogen
  - Based on the steam reforming of glycerol, followed by purification using pressure swing adsorption

Approach

- Review the availability and price of glycerol
- Evaluate hydrogen-from-glycerol process at a distributed hydrogen production facility using systems analysis
- Estimate cost of hydrogen and its sensitivities

Technical Accomplishments and Progress
Glycerol supply and price

Biodiesel		
US **Biodiesel** Production Capacity (2008)	19.0	10^9 lb/year
US **Biodiesel** Production (2008)	5.2	10^9 lb/year
Glycerol		
US Crude Glycerol from Biodiesel (2008)	0.52	10^9 lb/year
World Production of Glycerol (2008)	3.8	10^9 lb/year
World Demand for Glycerol (2005)	2.0	10^9 lb/year
Price of Crude Glycerol	3 – 10	cents/lb
Price of Refined Glycerol	40 – 50	cents/lb

Technical Accomplishments and Progress
Systems analysis was followed by cost estimation using H2A

Production Unit

- Crude Glycerol Feed
- Steam Reformer
- Water Gas Shift Reactor
- Pressure Swing Adsorption Unit for H_2 Purification

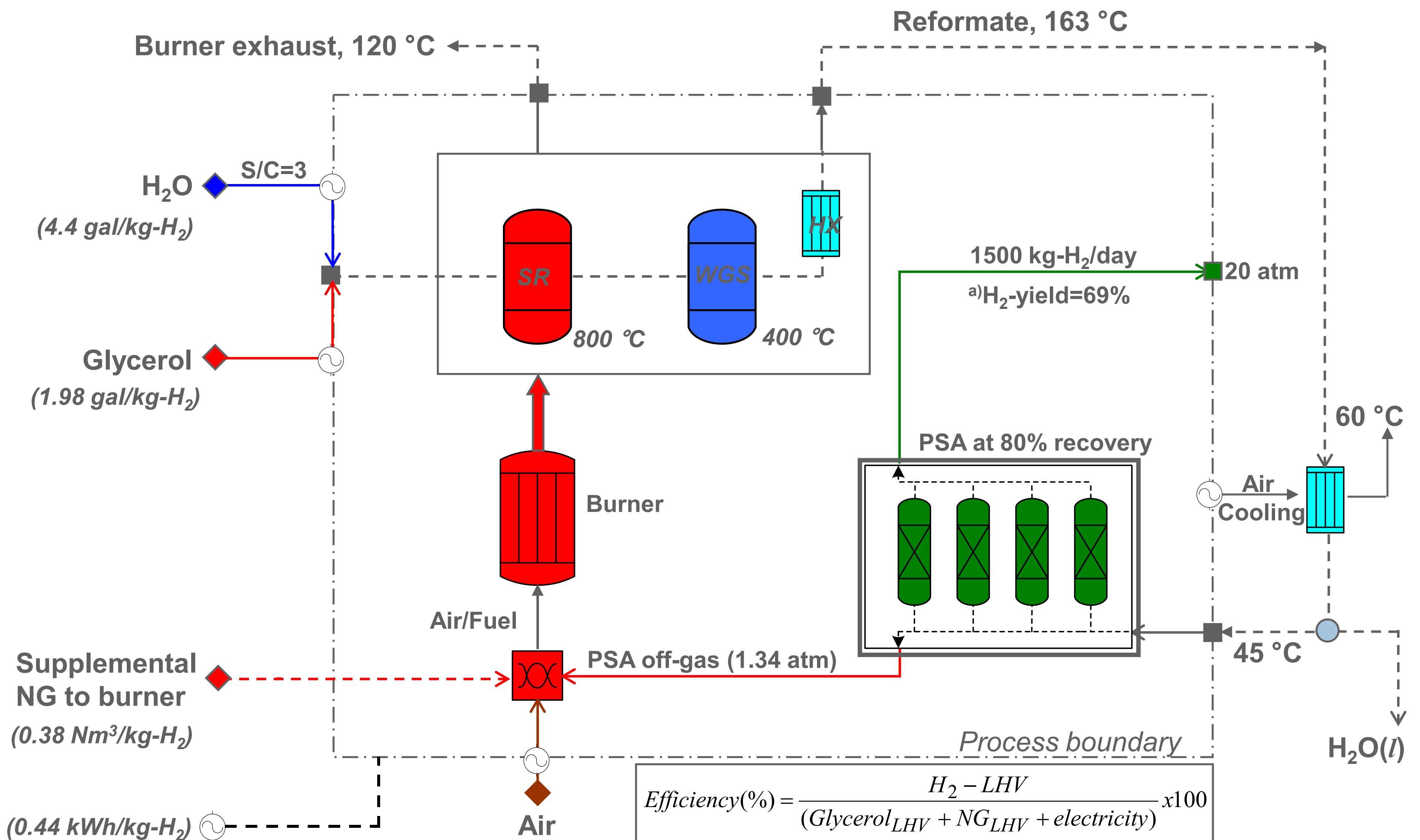
Refueling Station

- Compression, Storage, and Dispensing

Cost Analysis

- H2A

Base Case: Converting glycerol to hydrogen with an efficiency[(a)] of 72%



$$Efficiency(\%) = \frac{H_2 - LHV}{(Glycerol_{LHV} + NG_{LHV} + electricity)} x100$$

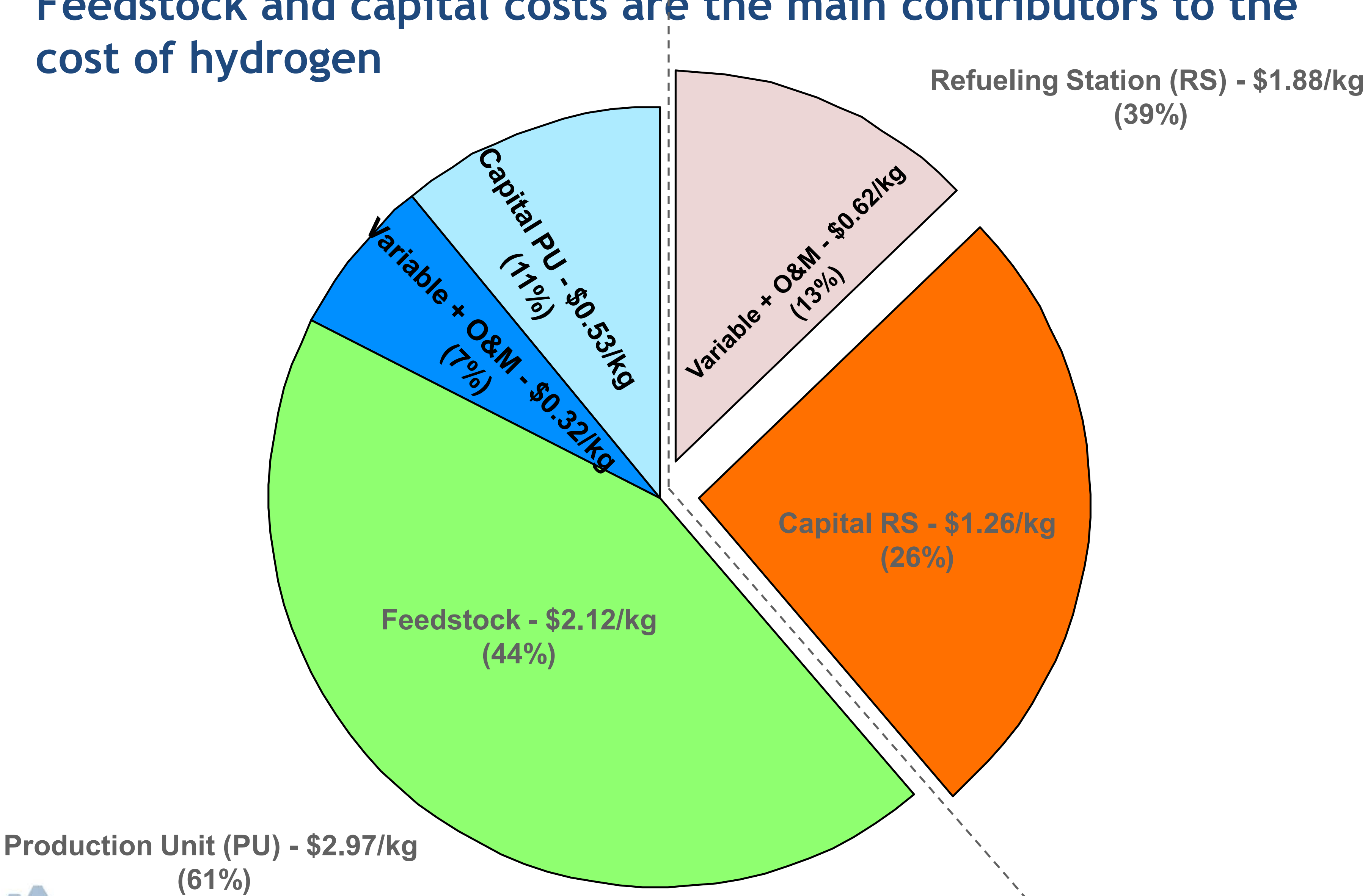
$$Yield(\%) = \left(\frac{moles\ of\ H_2}{7x(moles\ of\ Glycerol)}\right) x100$$

a)

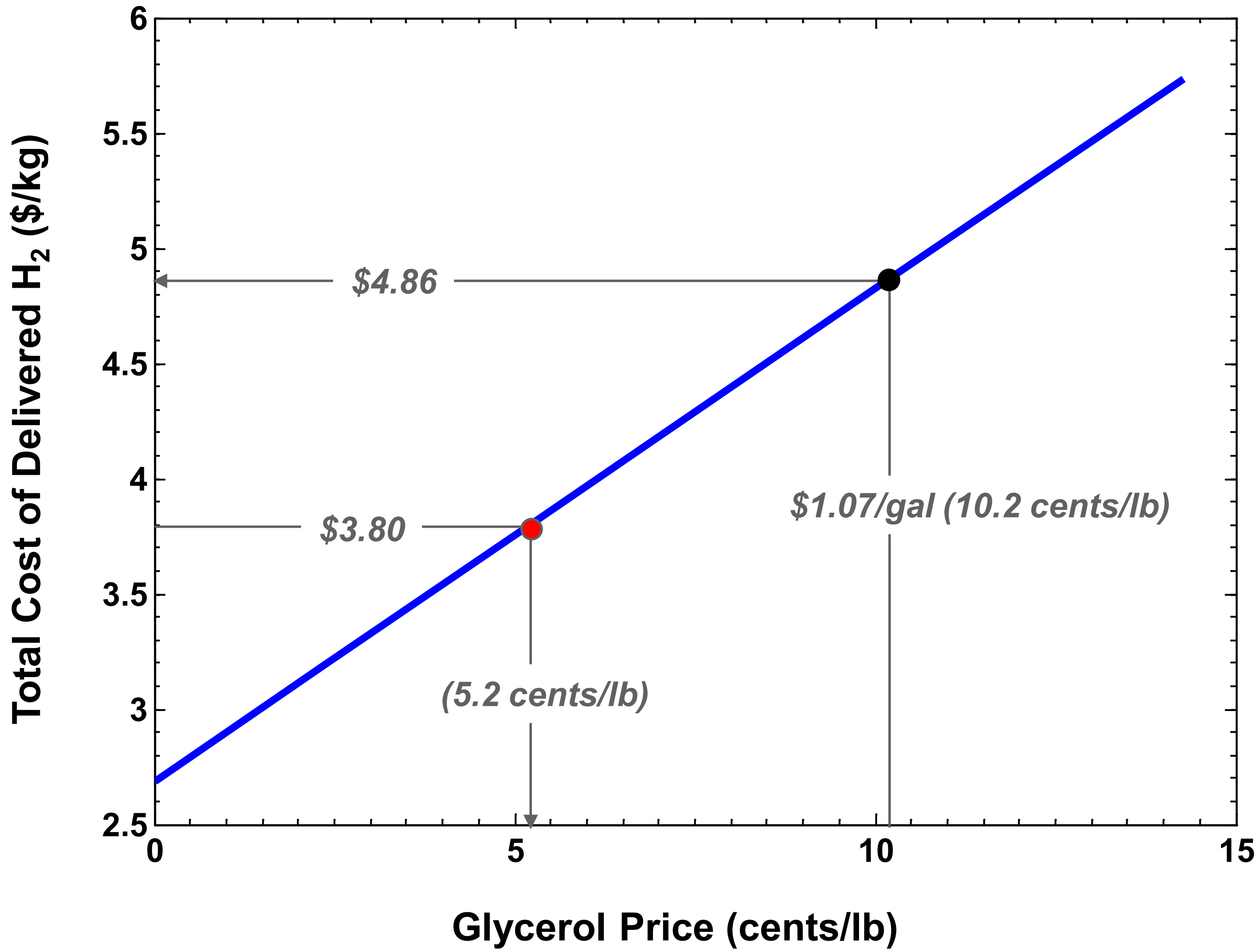
Technical Accomplishments and Progress
Base Case: Cost of H_2 from glycerol is estimated at $4.86/kg

Distributed Production of Hydrogen from Bio-Derived Renewable Liquid Fuels				
Characteristics	Units		***H2A (v2.1.3) Glycerol***	***H2A (v2.1.3) Ethanol***
Production Unit Energy Efficiency	%		72.0	72.0
Operating Capacity Factor	%		85.2	85.2
Production Unit Capital Cost (Uninstalled)	$		1.0M	1.0M
Feedstock Cost	$/gal		1.07 (0.10 ¢/lb)	1.07
Hydrogen Cost	***$/kg***		***4.86***	***4.83***

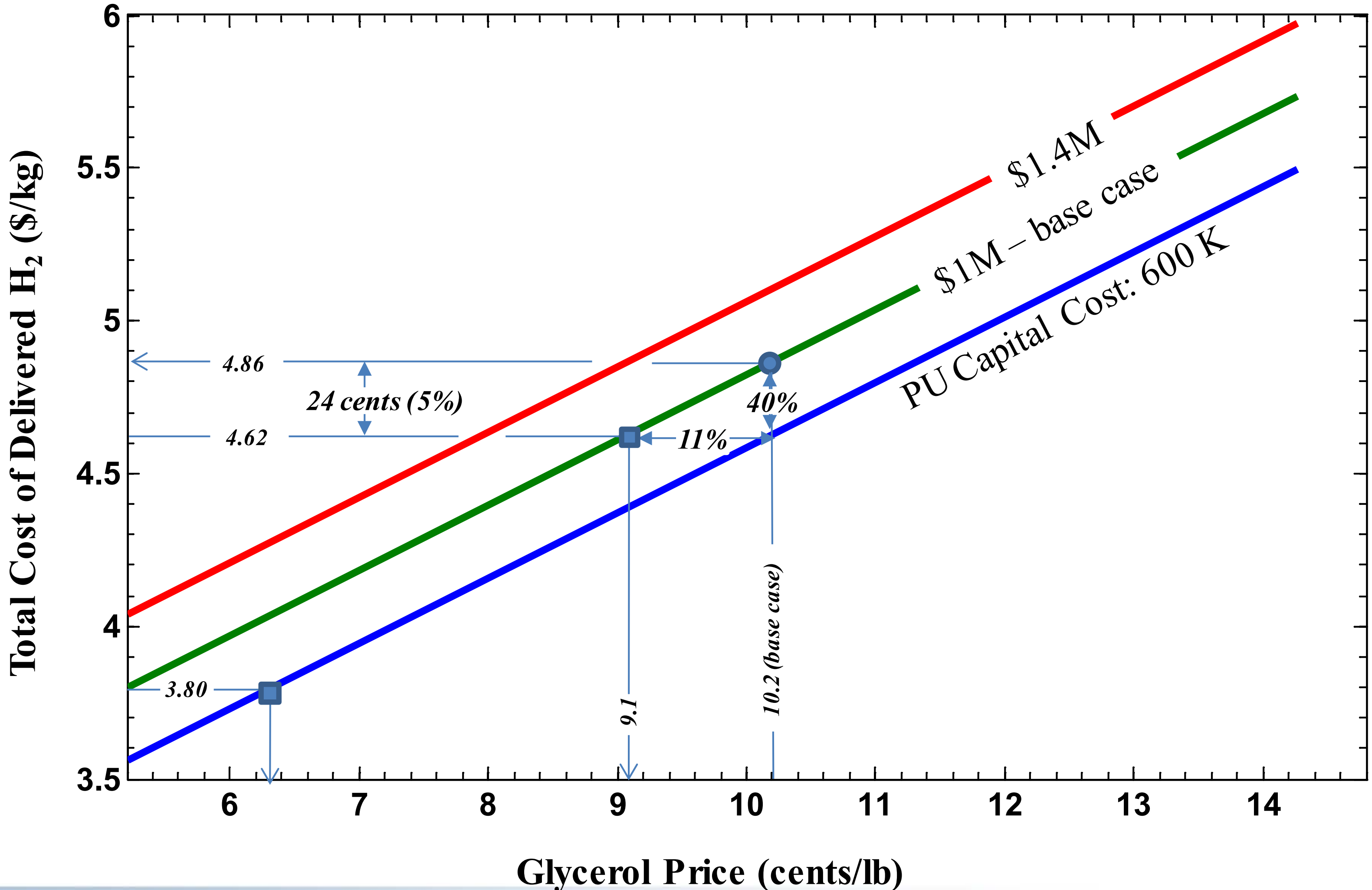
Technical Accomplishments and Progress
Feedstock and capital costs are the main contributors to the cost of hydrogen



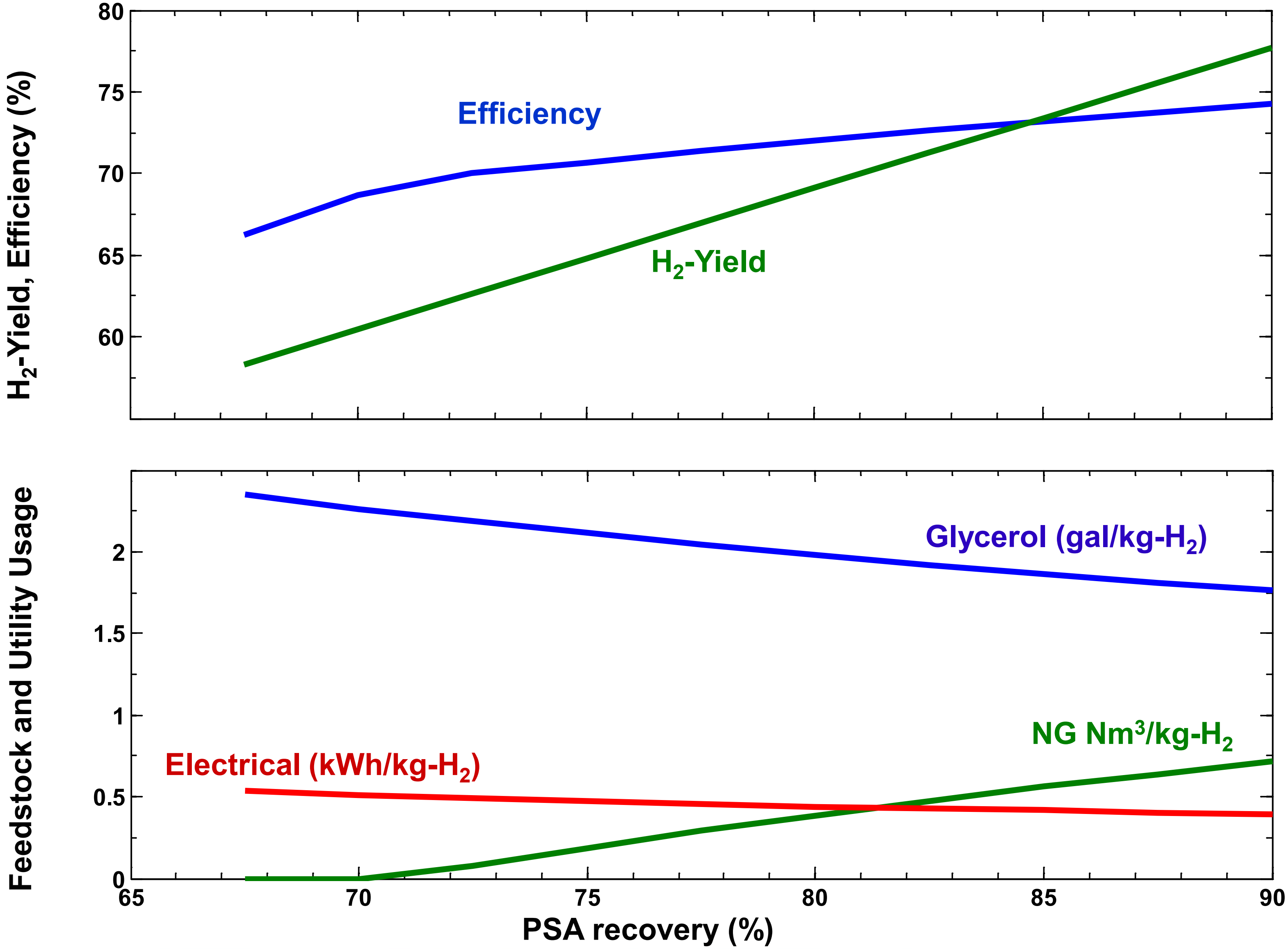
Technical Accomplishments and Progress
Glycerol price needs to be <5.2 cents/lb ($0.55/gal) to meet the hydrogen cost target of $3.80/kg



Technical Accomplishments and Progress
Changing the cost of H_2 by 5% would require 40% change in capital cost or, 11% change in feedstock price



Technical Accomplishments and Progress
Hydrogen yield improves with higher PSA recovery, but requires more natural gas to meet reforming energy needs



Technical Accomplishments and Progress
A hydrogen cost of $3.80/kg may be achievable with process maturity

	← "Better"	Base	"Worse" →
H_2 Cost	**$3.80/kg**	**$4.86/kg**	**$5.90/kg**
Feedstock Cost	**$0.74/gal** *7 cents/lb* ↓	**$1.07/gal** *10.2 cents/lb*	**$1.58/gal** *15 cents/lb* ↑
Efficiency	**74%** ↑	**72%**	**72%**
Capital (PU)	**$750K** ↓	**$1M**	**$1M**
Plant Capacity Factor	**95%** ↑	**85.2%**	**85.2%**

Technical Accomplishments and Progress
Some Projections

US Crude Glycerol *Produced* from Biodiesel (2008)	0.52	10^9 lb/year
H_2 from Glycerol (Base Case)	0.505	kg-H_2/gal- glycerol
H_2 from Crude Glycerol	55	10^3 kg-H_2/day
Distributed H_2 Production Center Capacity (operating at 85% of capacity)	1275	kg/day
No. of Distributed H_2 Production Centers	43	

US Crude Glycerol *Capacity* from Biodiesel (2008)	19.0	10^9 lb/year
Capacity / Production Factor (2008)	3.7	

Collaborations

- The system diagram was modified from a similar system used by DTI for hydrogen-from-ethanol
- Collaboration plans will depend on future direction of this project
  - Catalysis, clean-up, etc.

Summary

- Glycerol supply is outpacing its demand as a result of the biodiesel industry
  - Biodiesel industry, researchers are seeking high value secondary products from glycerol

- Glycerol is renewable and can be efficiently converted to hydrogen (72% efficiency is feasible)
  - When the PSA recovery is 80% or more
  - When the steam-to-carbon molar ratio is ≈3

- With crude glycerol at $1.07/gal (10 ¢/lb) the estimated H_2 cost is $4.86/kg
  - Cost of H_2 produced from glycerol is similar to that from ethanol

- The cost of hydrogen is highly sensitive to the price of the feedstock

- To achieve the target H2 cost of $3.80 /kg with a glycerol price of 7 ¢/lb, need a combination of
  - Process efficiency of 74%
  - Capital cost of $750 K
  - Plant operating capacity of 95%

Proposed Future Work

- Extend systems analysis to evaluate most promising production process and operating conditions
  - Define range of operating conditions (T, P, S/C, …)
- Identify key challenges with glycerol reforming
  - Feed delivery, conversion, coke formation, crude glycerol cleanup, etc.
- Address technical barriers
  - Feed delivery, catalysis, reactor design, etc.)

Supplementary Slides

The new version of H2A increases the contribution of the Refueling Station costs