

Hydrogen from Glycerol: A Feasibility Study

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Project Overview

Timeline

- Project Start: October 2009
- Project End: TBD

Budget

- FY10 - \$100K + TBD

Barriers

- D. Feedstock Issues
- E. Greenhouse Gas Emissions

Partners

- 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

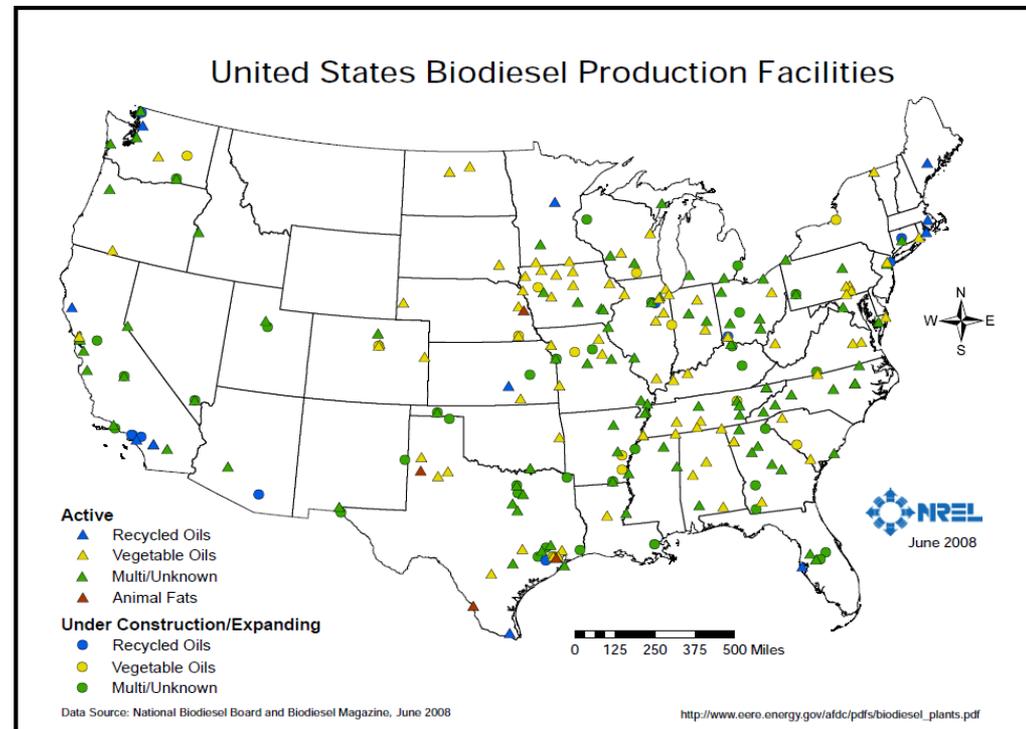
Opportunity

- 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 H₂ 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 H₂ to refuel fuel cell vehicles
 - Glycerol can also be used by reformat-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 H₂ 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

<u>Biodiesel</u>		
US Biodiesel Production Capacity (2008)	19.0	10 ⁹ lb/year
US Biodiesel Production (2008)	5.2	10 ⁹ lb/year
<u>Glycerol</u>		
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 H₂ Purification

Refueling Station

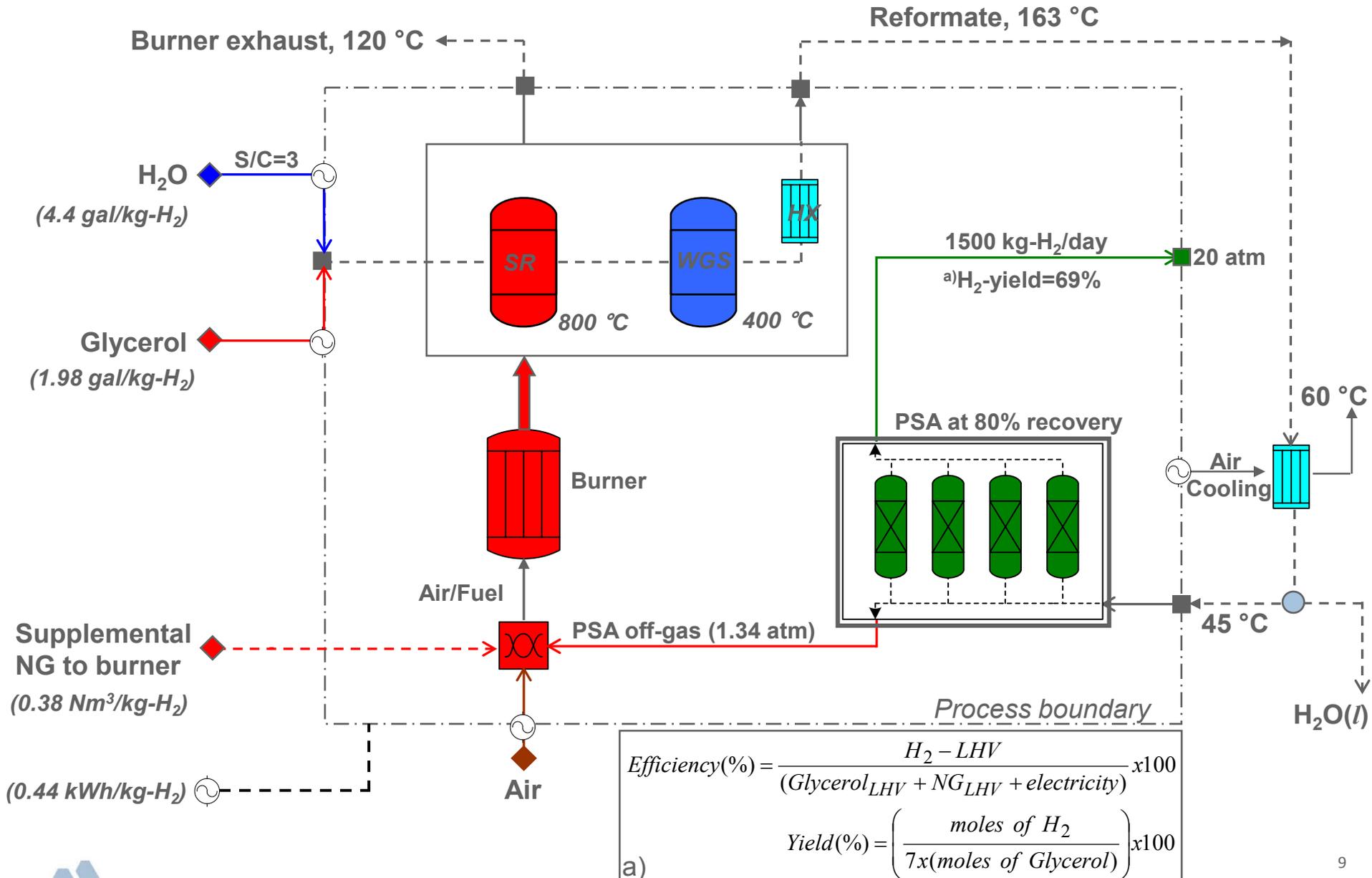
- Compression, Storage, and Dispensing

Cost Analysis

- H2A



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



Technical Accomplishments and Progress

Base Case: Cost of H₂ from glycerol is estimated at \$4.86/kg

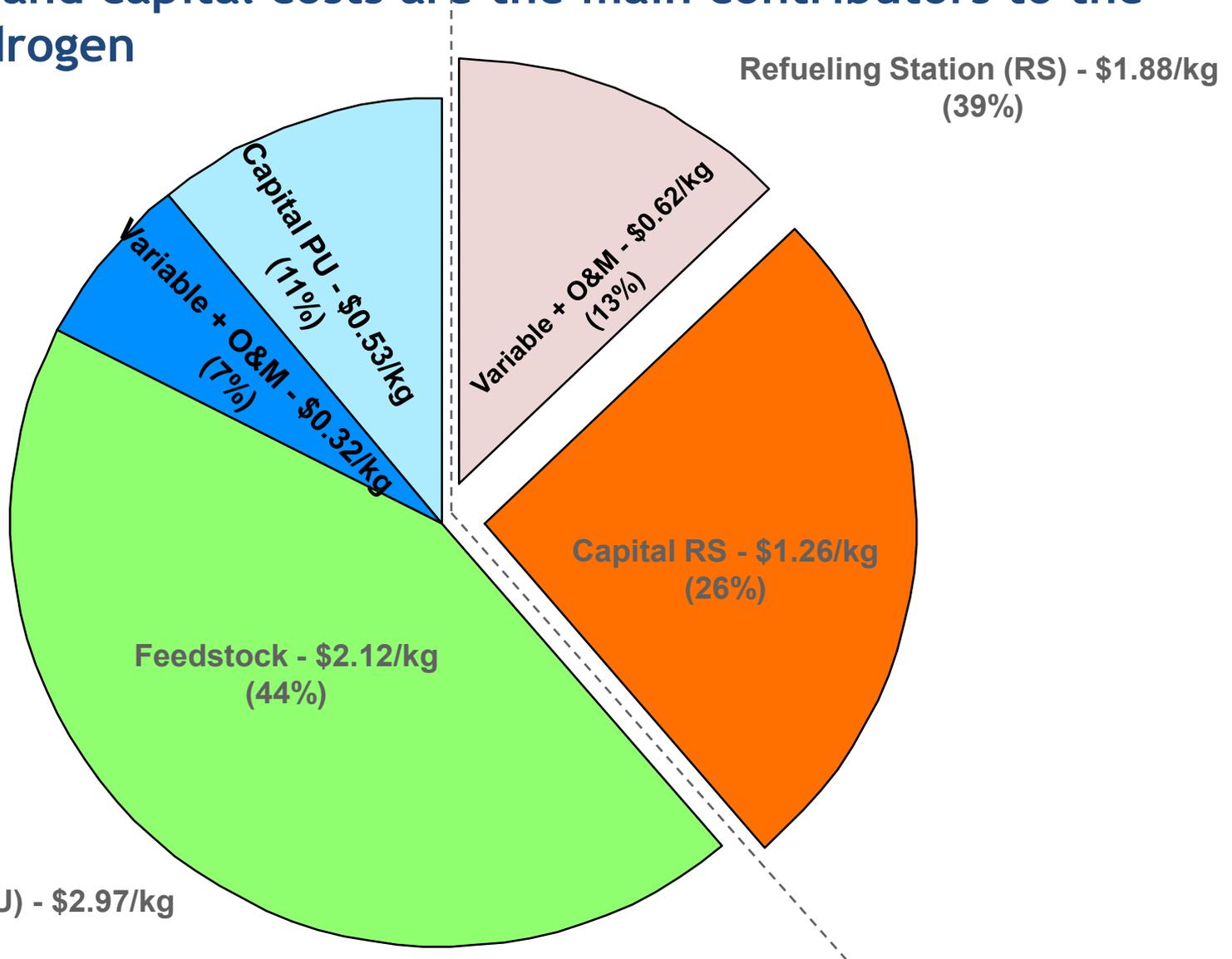
Distributed Production of Hydrogen from Bio-Derived Renewable Liquid Fuels

Characteristics	Units		<i>H2A (v2.1.3) Glycerol</i>	<i>H2A (v2.1.3) Ethanol</i>
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
<i>Hydrogen Cost</i>	<i>\$/kg</i>		<i>4.86</i>	<i>4.83</i>



Technical Accomplishments and Progress

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

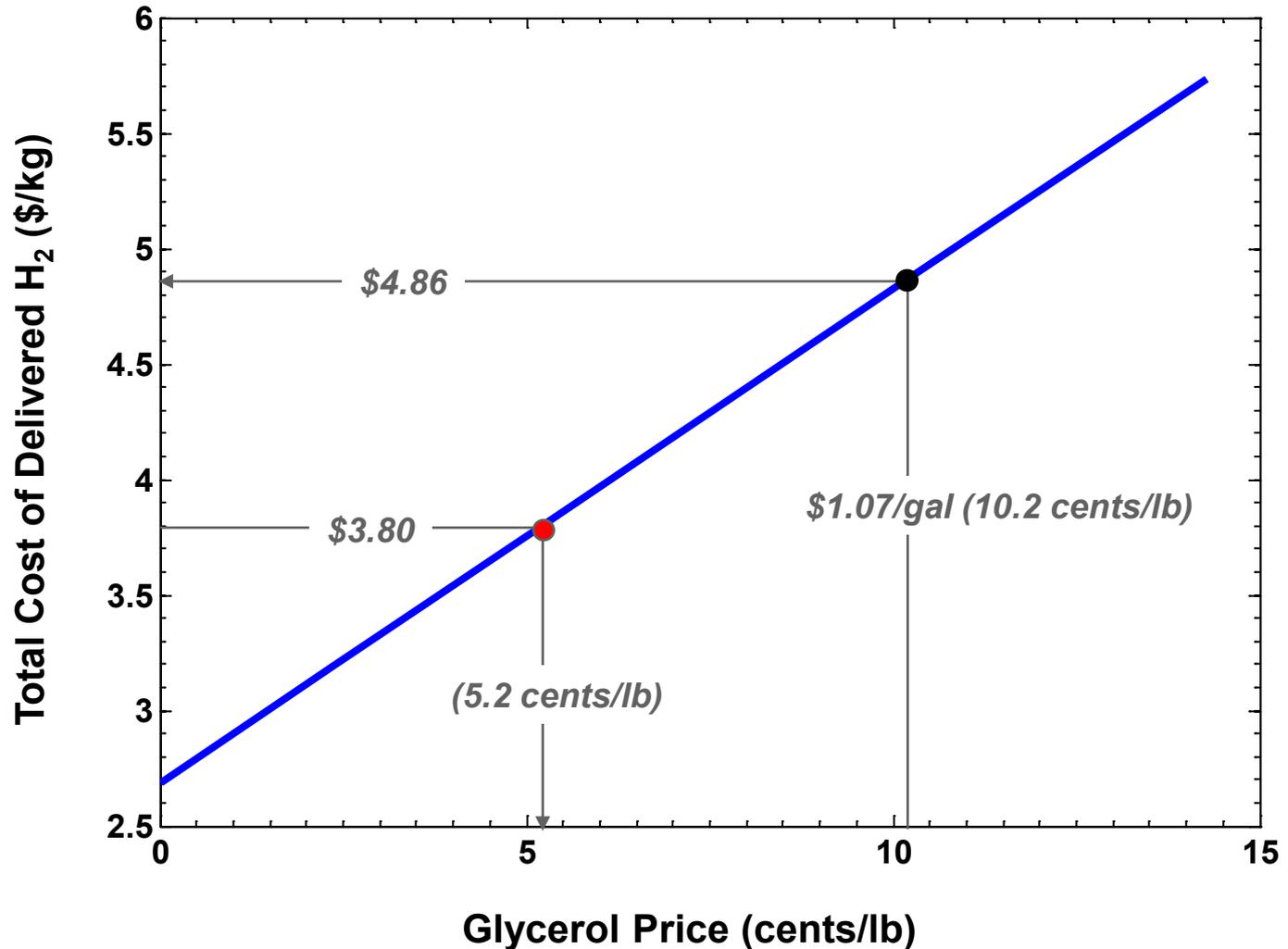


Production Unit (PU) - \$2.97/kg
(61%)



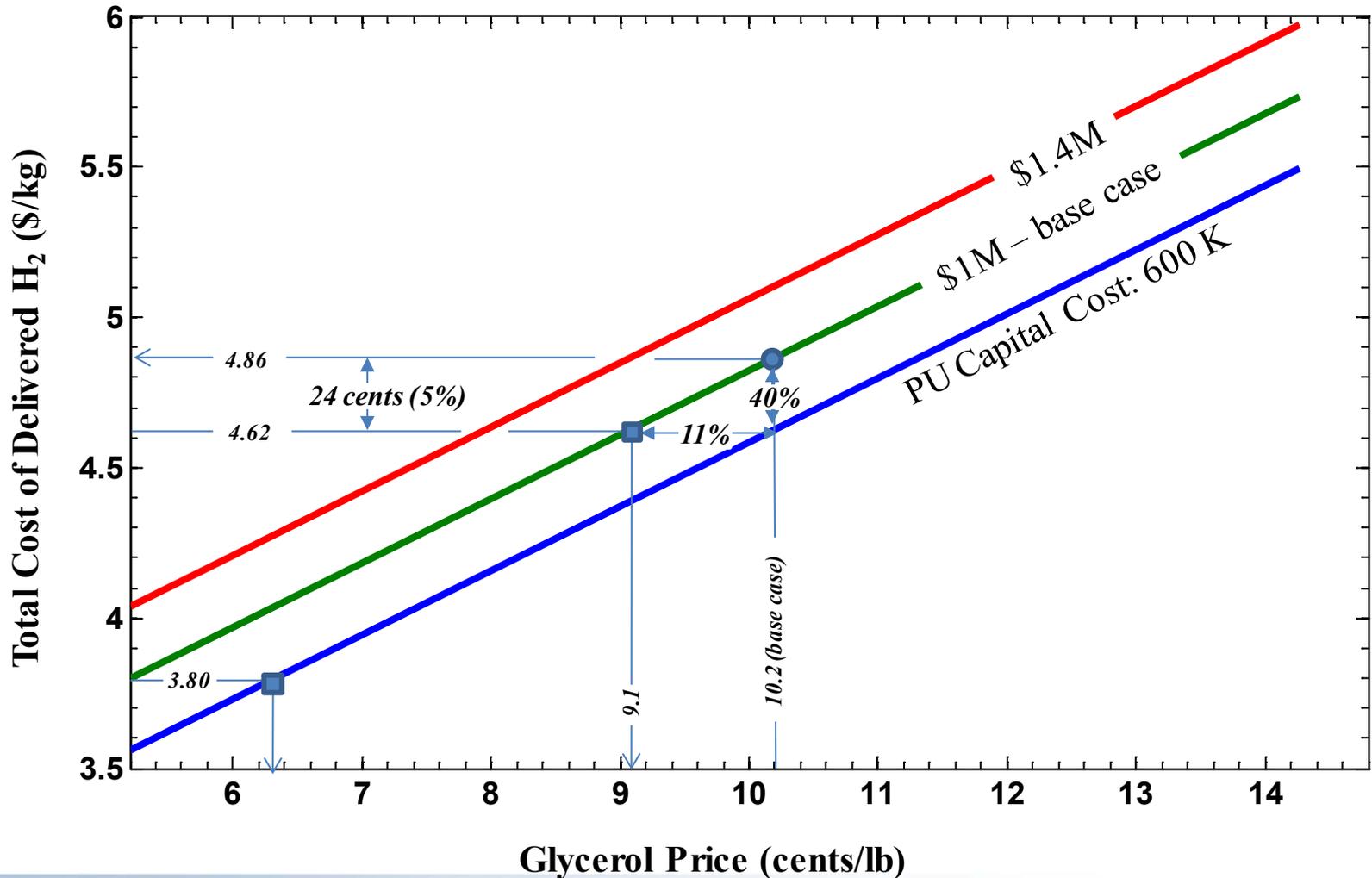
Technical Accomplishments and Progress

Glycerol price needs to be < 5.2 cents/lb ($\$0.55/\text{gal}$) to meet the hydrogen cost target of $\$3.80/\text{kg}$



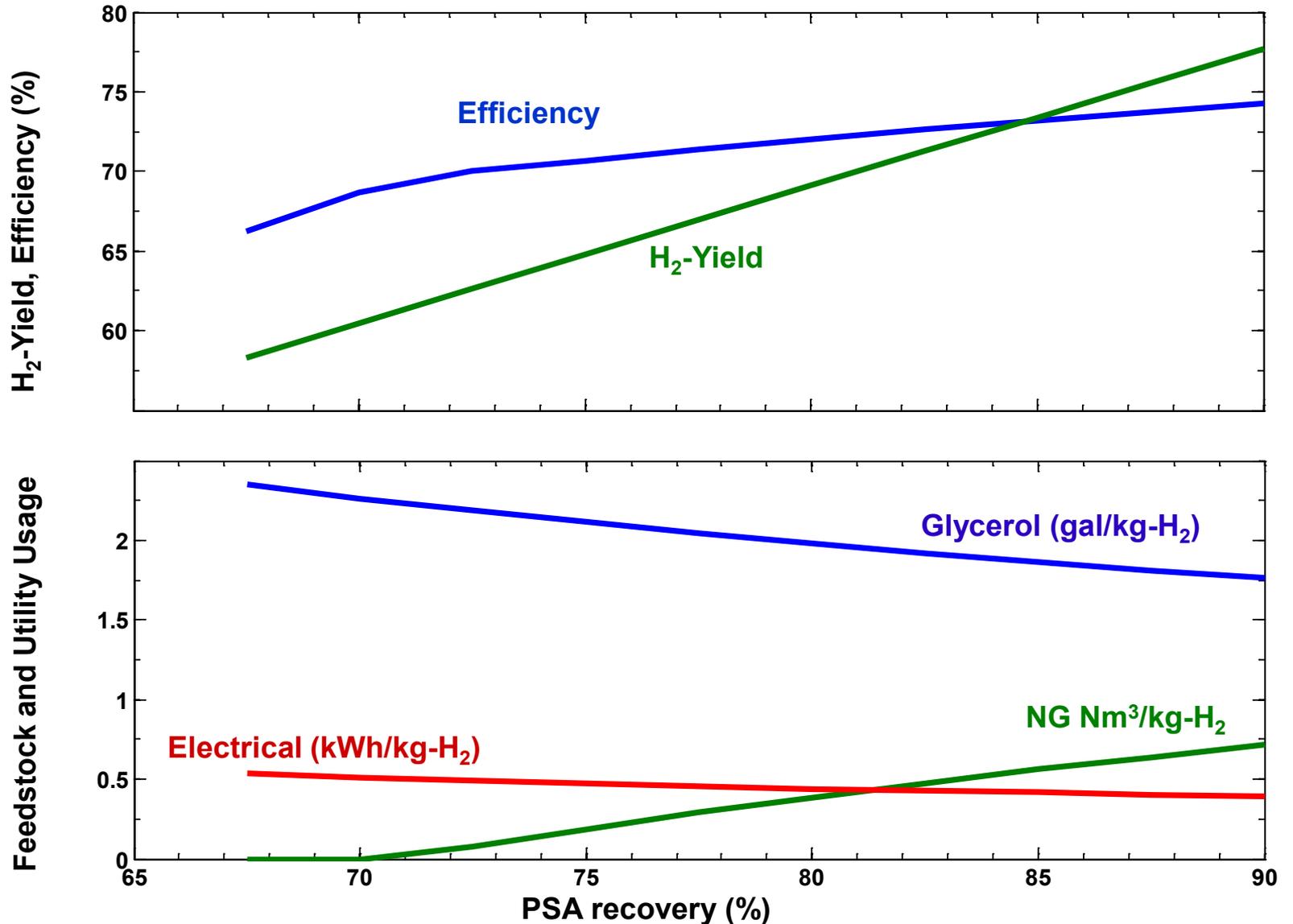
Technical Accomplishments and Progress

Changing the cost of H₂ 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 <i>Produced</i> 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 <i>Capacity</i> 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 H₂ cost is \$4.86/kg
 - Cost of H₂ 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.)

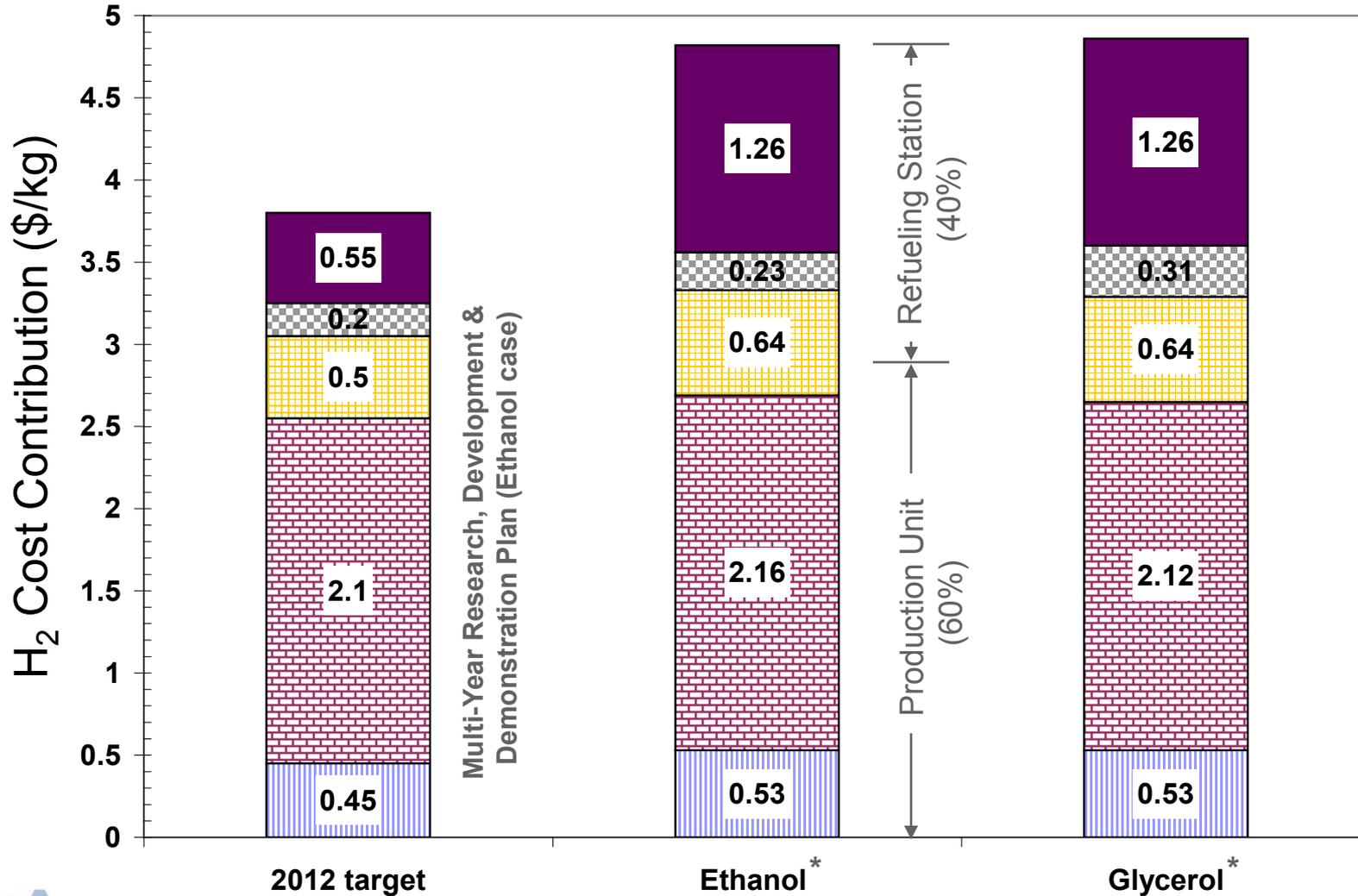


Supplementary Slides



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

- Storage, Compression, Dispensing Capital Cost
- Variable O&M including Utilities
- Fixed O&M
- Feedstock Cost
- Capital cost



*H2A (v2.1.3)