DOE Hydrogen Program

# FLORIDA HYDROGEN INITIATIVE

Stephen Adams, Chairman
Florida Hydrogen Initiative, Inc.

April 17, 2008

Project ID #TVP1

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The Florida Hydrogen Initiative (FHI) is a non-profit organization incorporated under the laws of the State of Florida to move Florida to the forefront of the nation's hydrogen economy. The Florida Hydrogen Initiative uses its resources to aid the development of a robust Florida-based hydrogen industry thereby establishing Florida as the cornerstone of a southeastern hydrogen hub. The nonprofit corporation is comprised of public leaders, university researchers, citizens, and industry representatives.

# The Florida Hydrogen Initiative, Inc. develops Florida's Hydrogen Infrastructure by:

- Brokering partnerships for applied technology demonstration projects throughout the state;
- Sponsoring research in the production, storage and use of hydrogen fuels:
- Facilitating technology transfers between the public and private sectors to create, build and strengthen high-growth potential, high technology companies.

# Four Projects Funded by FHI

The FHI is a grantee of the US Department of Energy Hydrogen Program and has funded four projects to date:

1. The HyTech Rest Area project is being conducted by EnerFuel, Inc., which will demonstrate the use of Hydrogen derived from citrus waste in a fuel cell located at a Florida Turnpike rest area;

2. The Development of Location Strategies for the Initial Hydrogen Refueling Infrastructure in Florida that would be required to support consumer demand and a hydrogen powered car rental fleet for Orlando, Florida. This project is being conducted by Rollins College;

3. Designing and Building a museum exhibit to tour 18 Florida Science Museums to inform and educate the public about Hydrogen's potential and use as an energy carrying medium and the future role of hydrogen in energy distribution. This project is being conducted by the Orlando Science Center.

4. The On-site Reformation of Diesel Fuel for Hydrogen Fueling Station Application project is being conducted by the University of Central Florida, Florida Solar Energy Center in partnership with Cheveron Technology Ventures. The goal of this research is to develop a cost effective energy efficient fuel reformation process that can be used for the production of high purity hydrogen from sulfurous liquid fuels. Once developed, this process will be used in hydrogen fueling stations and remote fuel cell based electrical generation stations in areas with no access to natural gas.

# Hydrogen Technology (HyTech) Rest Area

Michel Fuchs

EnerFuel, Inc.

4/17/2008

Project ID #TVP1

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# Project Overview

## Timeline

- Start – Oct 2006
- Finish – Sept 2008
- 60% complete

## Budget

- Total project funding
  - DOE - $550K
  - Contractor - $632K
- Funding received in FY07
  - $176.5K
- Funding for FY08
  - $190.5K

## Partners

- Florida Turnpike Enterprise – Provide cost-free site location & promotion
- Progress Energy – Technical assistance in power grid interface

## Barriers

- Barriers
  - C. Performance
  - D. Feedstock Issues
  - E. System Thermal and Water Management
  - G. Startup and shut-down time and Energy/Transient Operation
- Targets

| | 2003 | 2005 | 2011 |
|---|---|---|---|
| **Electrical Energy Eff.** | **30%** | **32** | **40** |
| **Transient response time** | **<3ms** | **<3ms** | **<3ms** |

## Subcontractors

- Anderson Consulting – Identify citrus derived methanol source/process
- Technology Research & Development Authority – Assist in demo site preparations & public relations

# Objectives

| | |
|---|---|
| Overall | • Design, construct and demonstrate a 10kW$_{net}$ PEMFC stationary power plant operating on citrus derived methanol<br>• Achieve an electrical energy efficiency >32%<br>• Demonstrate transient response time <3ms |
| 2007 | • Identification of citrus derived methanol source and optimum process<br>• Identification of fuel processor supplier<br>• Identification of fuel cell stack supplier<br>• Identification of site layout |
| 2008 | • Production of fuel cell grade methanol<br>• Identification of all permits required for construction<br>• Construction and installation of HyTech site<br>• Promotion of HyTech site |

# Milestone

| Month/Year | Milestone or Go/No-Go Decision |
|---|---|
| Oct-07 | Milestone: Identify company that will provide the citrus derived methanol. Do a complete chemical analysis to obtain how much raw methanol is needed for the program. |
| Jun-08 | Milestone: Obtain all permits required for construction, including fire Marshall, Orange County, and National Environmental Policy Act permits. |
| Jun-08 | Milestone: Process raw methanol to fuel cell grade via distillation. |
| Sept-08 | Milestone: Civil and electrical installations of the site completed. Start the operation of the power plant. Install a booth display to promote HyTech rest area. |
| Dec-08 | Milestone: Benchmark performance of the power plant and identify the effect of citrus derived methanol on long-term operation. |

# Plan & Approach

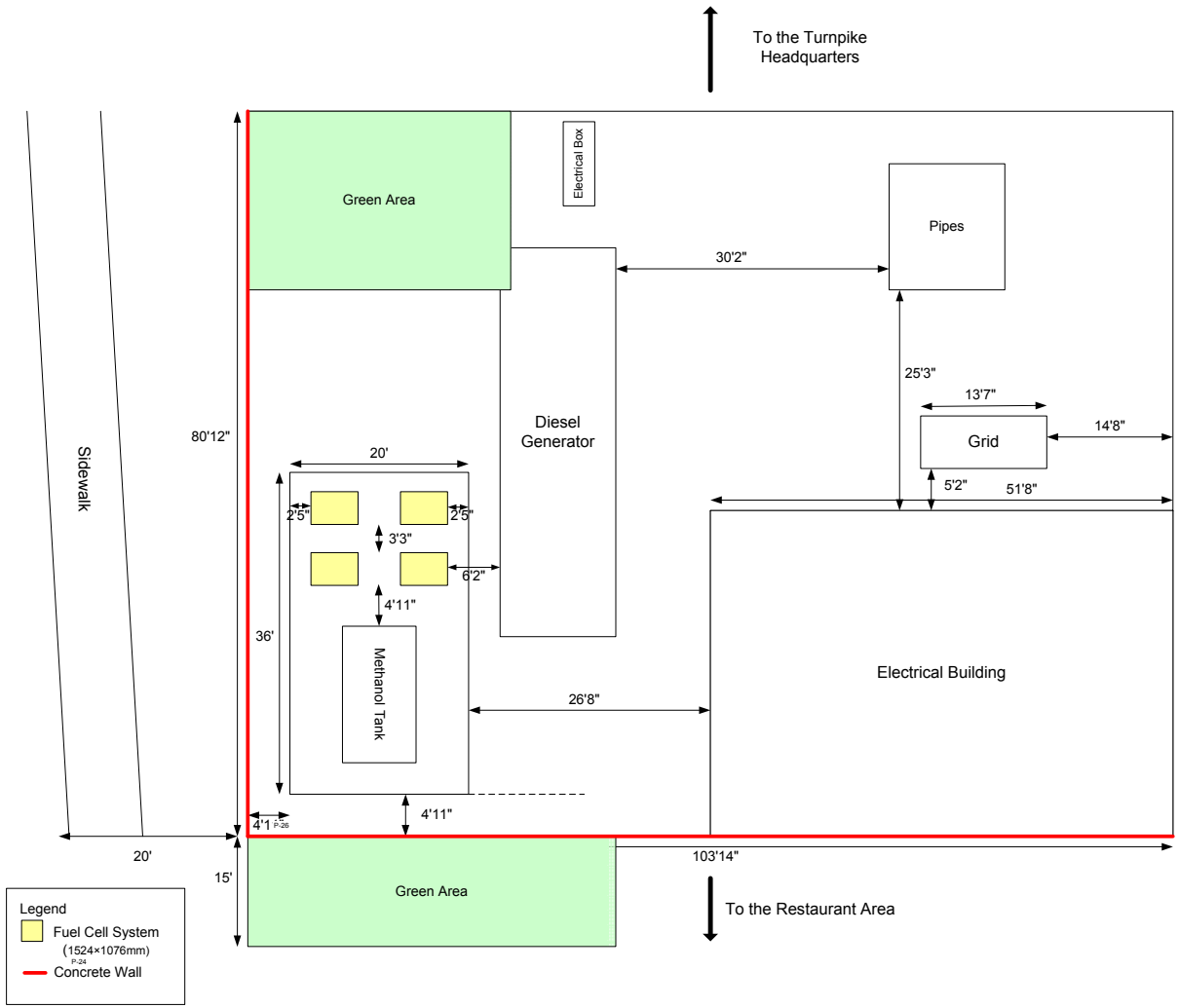
- Task 1: Citrus derived methanol
  - Identify source
  - Clean-up methanol to fuel cell grade
  - Test methanol for compatibility w/ reformer
  - Work out transportation, storage logistics and associated NEPA compliance
  - Identify/establish safety protocols for use
- Task 2: Demo site preps
  - Obtain permitting & NEPA compliance for methanol storage
  - Identify electrical interface requirements
  - Establish location for fuel cell power plant and methanol storage
- Task 3: Fuel cell power plant design
  - DMFC vs. standard PEMFC trade study
  - Identify fuel cell stack source
  - Identify reformer source
  - Design system through modeling
- Task 4: Power plant construction and testing
  - Construct power plant
  - Test and debug power plant
  - Benchmark performance
- Task 5: Power Plant installation and demonstration
  - Install power plant at demo site
  - Operate system for 3 months

# Accomplishments

- <u>Fuel cell system demonstration site</u>
  - Selected the Florida's Turnpike Enterprise's Turkey Lake Service Plaza as demonstration site
  - Met with Florida's Turnpike Enterprise to secure approval and support
  - Selected methanol storage container
  - Selected location of power plant and methanol storage container
  - Selected company to perform electrical and civil construction
  - Selected the waste methanol supplier
  - Completed composition analysis of raw methanol
  - Obtained fuel processors and fuel cell stacks
  - Identified process to purify raw methanol

# Accomplishments

- **Fuel cell system demonstration site**



# Future Work (FY07 – FY08)

- <u>FY08 – Site preparation</u>
  - Construct, test and bench mark power plant
  - Power plant ready for delivery by end of September 2008
  - Install power plant at Turkey Lake Service Plaza demo site
  - Power portion of service plaza for period of 3 months

- <u>FY08 – Analysis of fuel cell power plant under operation</u>
  - Determine overall electrical efficiency
  - Document system transient response to load changes
  - Determine effects of citrus derived methanol on long term power plant performance
  - Assess requirements for future projects and for future commercialization

# HyTech Rest Area
# Project Summary

- **Relevance**
  - Demonstrate the value of citrus waste as a viable source of fuel for generation of electrical power
- **Approach**
  - Construct and demonstrate a stationary fuel cell power plant operating off citrus derived methanol
- **Technology collaboration**
  - Participation with Florida citrus ethanol producers and the state of Florida
- **Proposed future projects**
  - Develop commercial stationary fuel cell power plant design for use with citrus and food waste derived methanol

# Hydrogen Refueling Infrastructure and Rental Car Strategies for Commercialization of Hydrogen in Florida

Lee Lines[1], Michael Kuby[2], Ronald Schultz[3], Zhixiao Xie[3]

Rollins College[1], Arizona State University[2],
Florida Atlantic University[3]

April 17, 2008

**Project ID #TVP-1**

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# Overview

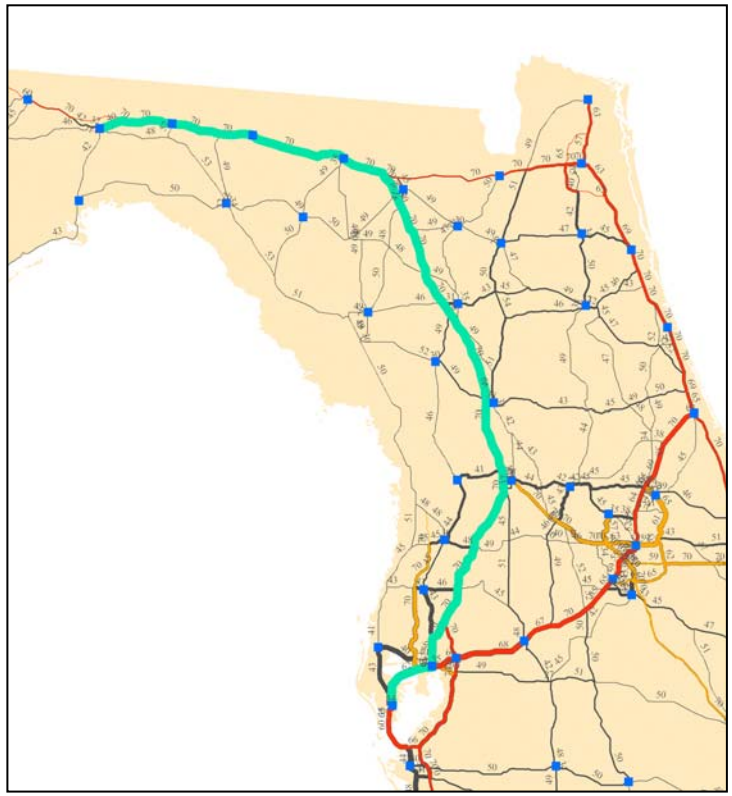
| Timeline | Barriers Addressed |
| --- | --- |
| •Start: August 1, 2005<br>•End: June 30, 2007<br>•100 percent complete | •Infrastructure barriers<br>•Analysis barriers<br>•Market barriers<br>•Financial/cost barriers |
| **Budget** | **Partners** |
| •Total project funding<br>–DOE share: $160K<br>–University share: $40K<br>•$160K received in FY06-07<br>•$0K for FY08 | •Rollins College (Winter Park, FL)<br>•Arizona State University<br>•Florida Atlantic University |

# Objectives

- Further develop a model for optimal location of a system of hydrogen refueling stations
- Use model to recommend location strategies for refueling stations at two scales:
  - Statewide
  - Orlando area
- Investigate feasibility of a hydrogen rental car business based at the Orlando International Airport
  - Survey of car renters
  - Analysis of barriers and solutions
- These objectives are linked by the infrastructure barrier—most car renters in Orlando could be served by very few stations

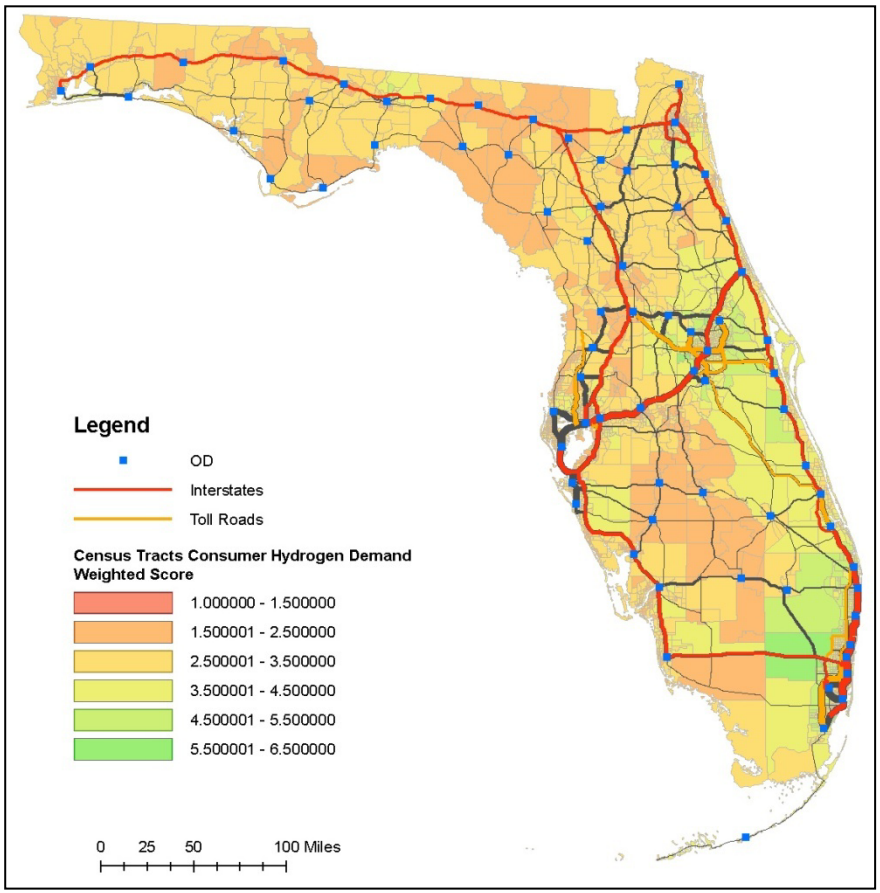
# Modeling Approach

- Integrates operations research and GIS into a Spatial Decision Support System.
- Locates a given number of stations to maximize the number of trips (or VMT) that can be refueled given a reasonable driving range.
- Model assumes drivers "stop along their way" to refuel, more than once if necessary.
- Trips consist of the fastest paths over network between each origin and destination.
- Clustering/connecting not predetermined, but these strategies emerge (see example).
- Can be applied at urban, state, or national scale.



Least-travel-time path
from Tallahasse to Clearwater

# Adapting NREL's Consumer Demand Model




Adjust the traffic flow by a consumer demand factor averaged for the origin and destination zones.

***Variables (weight)***

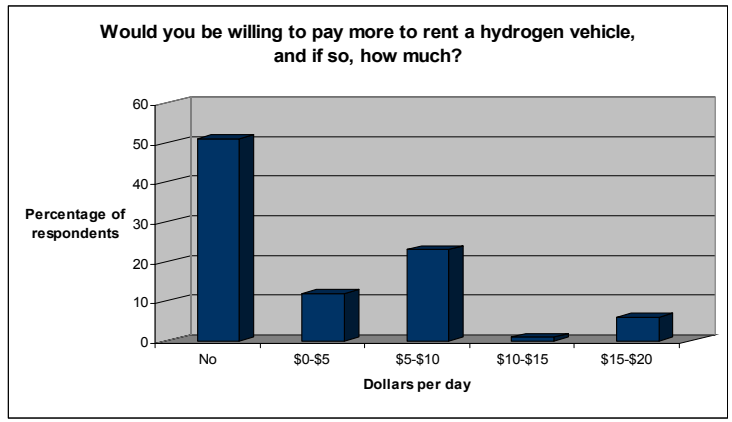
- Median Household Income (23%)
- Percentage of people with bachelor's degrees (18%)
- Percentage of workers age 16+ who commute more than 20 minutes (18%)
- Percentage of Households with 2+ Vehicles (23%)
- Clean Cities Coalitions, by county (18%)

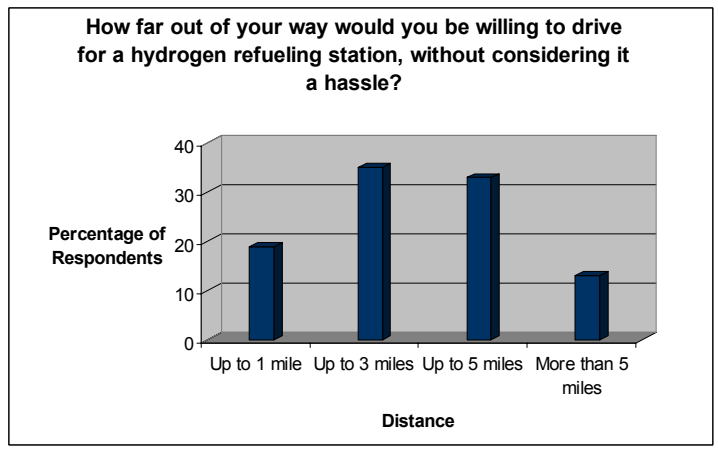
# Accomplishments

- **Completed final report since last review.**
- **Integrated FY07's separate analyses of statewide station infrastructure, Orlando station infrastructure, and Orlando rental car feasibility, into one consistent set of final recommendations.**
- **Organized final recommendations into five tiers (or stages) of station infrastructure development.**

# Orlando Renter Survey Results (n=435)

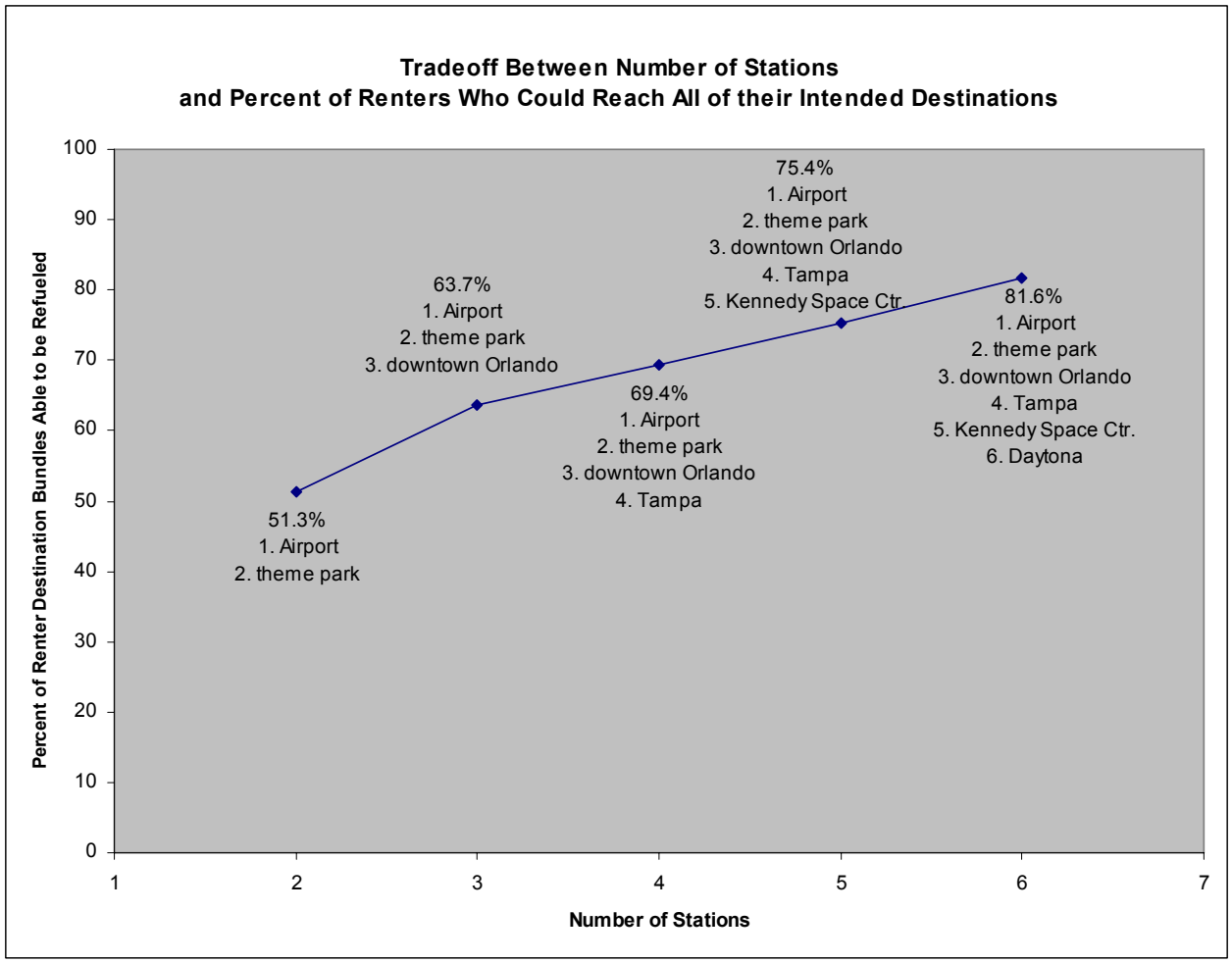
| Feature* | All Respond-ents | Those Willing To Pay More** |
|---|---|---|
| Map of refueling stations in Florida and Orlando | 4.3 | 4.4 |
| Ability to exchange for a gasoline car at no extra cost | 4.0 | 3.9 |
| Priority parking at theme parks | 3.9 | 3.9 |
| Using a pollution-free vehicle | 4.4 | 4.7 |
| Fuel cost per mile comparable to gasoline | 4.4 | 4.4 |
| Opportunity to test drive first | 3.8 | 3.9 |
| Driving range of vehicle (miles between refuelings) | 4.4 | 4.5 |
| Vehicle performance (acceleration, noise) | 4.1 | 4.0 |
| Opportunity to experience a new technology | 4.0 | 4.1 |
| Availability of insurance | 4.3 | 4.3 |
| Full-service refueling by a trained attendant | 4.0 | 4.1 |
| On-call, roadside repair/refueling service | 4.4 | 4.5 |



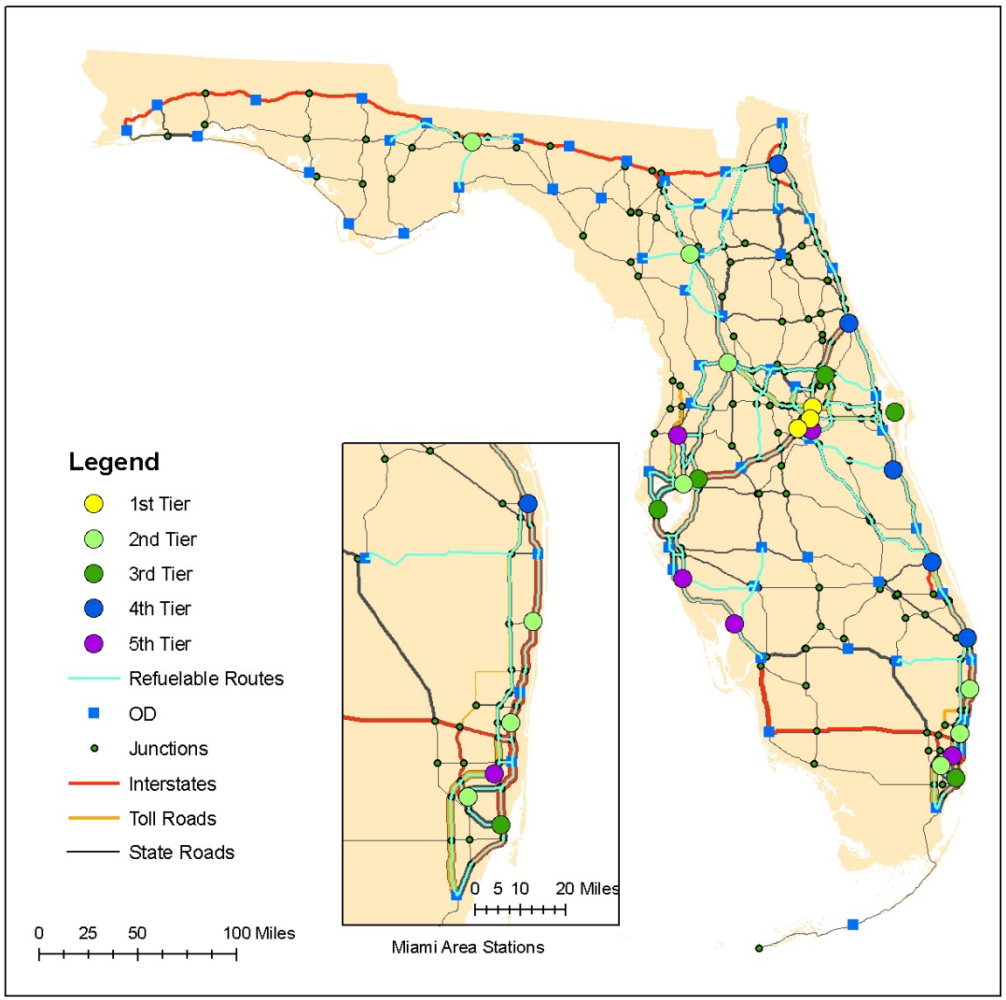

**The survey question was: "Rank the importance of the following features in convincing you to rent a hydrogen car on a future trip to Orlando, on a scale from 1 (not important) to 5 (very important)?" The features are listed here in the exact wording and order in which they appeared on the survey. *Of the 435 respondents, 211 indicated they would be willing to pay more to rent a hydrogen car.*

# 3 Stations Could Satisfy 64% of Renters




- Airport station already exists
- Theme park station is in Tier 1
- Downtown Orlando station (Tier 1) could serve renters, I-4, and E-W expressway.
- Tampa station is in Tier 2 of the statewide network, serves residents, beachgoers, MLB spring training
- Additional benefit per station declines after 3 stations
- Kennedy Space Center station (Tier 3) would be at Visitors Center, not I-95, for tie-in with $H_2$ space uses.
- Daytona station is in Tier 5, and could tie in with car-racing enthusiasts.

# Statewide Network Recommendations




***Tier 1:*** airport, downtown, and theme park stations in Orlando for the $H_2$ rental-cars.

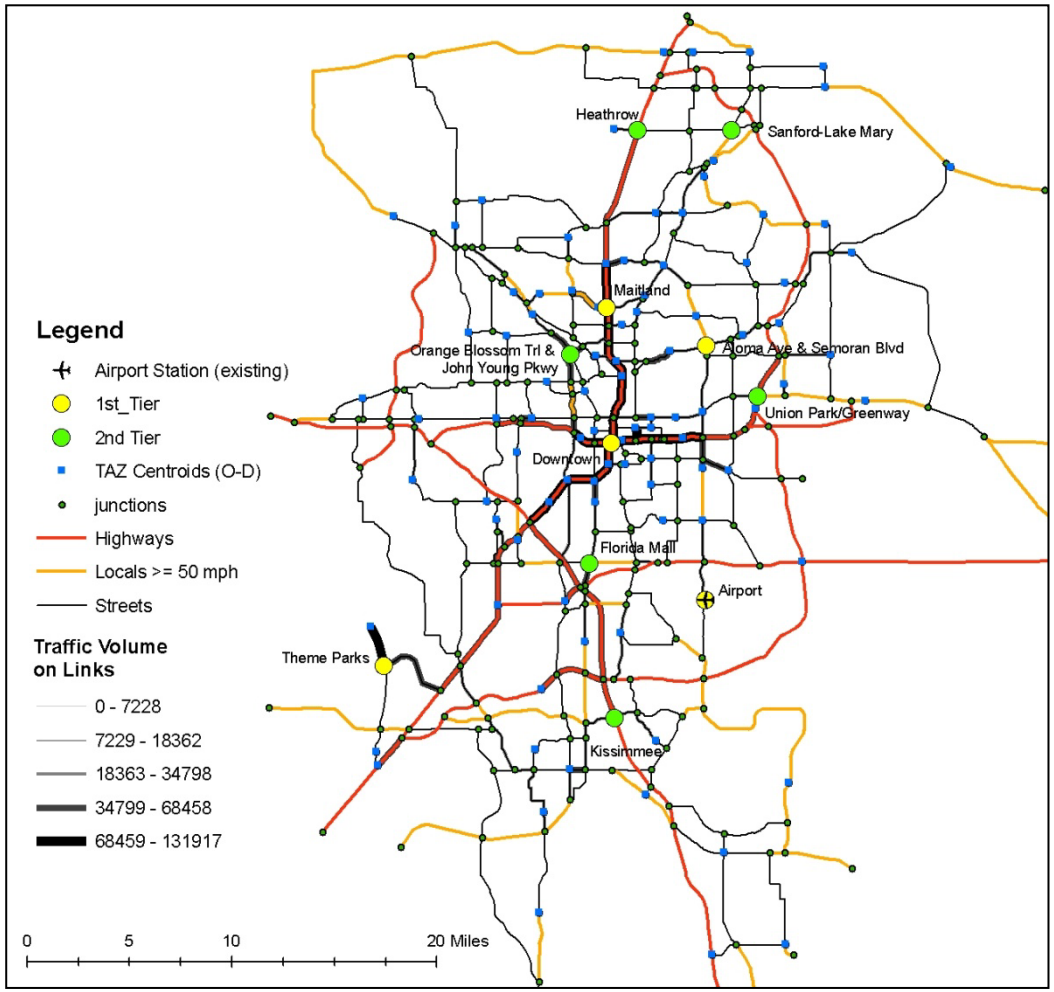
***Tier 2:*** 7 stations create a corridor from Miami Lakes to Ft. Lauderdale to Delray Beach, and a connected triangle between Tampa, Orlando, and Gainesville (plus Tallahassee, not connected).

***Tier 3:*** fleshes out the Orlando, Tampa, and Miami clusters, and Kennedy Space Center.

***Tier 4:*** connects the network up I-95 from Palm Beach Gardens to Jacksonville.

***Tier 5:*** extends I-75 network north and south of Tampa, and adds to the Miami and Orlando clusters.

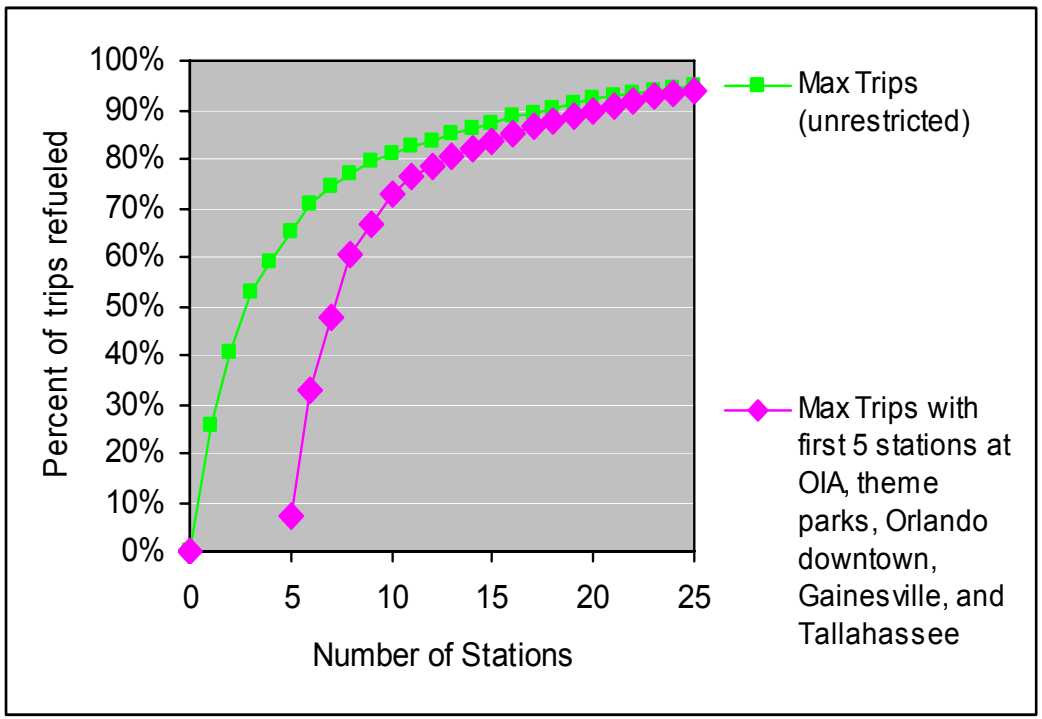
# Orlando Network Recommendations




***Tier 1:*** airport, downtown, and theme park stations essential to the rental-car business, plus two other stations on the northern side of town at traffic funnel points that capture heavy traffic flows not otherwise captured by the other three stations.

***Tier 2:*** six stations including stations in Kissimmee and Sanford recommended for the statewide network.

# Tradeoff for Placing Stations for H2 Rental Cars and State Universities




Building the first five stations to serve both $H_2$ rental cars in Orlando and high-visibility fleets at UF and FSU involves a sacrifice in terms of the number of intercity trips served; however, this applies only to the early stages of infrastructure development. It is possible to make up most of this difference in network coverage by the time 15 stations are built. In this scenario, the stations serving the $H_2$ rental cars would have a built-in guaranteed early source of demand. Likewise, the Tallahassee and Gainesville stations may serve less intercity demand but would be ideally located for early adopters among scientists and professors making, as well as university and government fleets. Keep in mind also that *intra*-city trips in Gainesville and Tallahassee are not included in the demand shown in the pink tradeoff curve.

# Future Work (after this project)

- **Work with DOE and Florida officials on implementation.**
- **Apply to other networks (metro, state, national, trans-national).**
- **Apply to other fuels.**
- **Extend model to consider drivers detouring off shortest paths (theoretical work underway).**
- **Extend model to simultaneously consider local and long-distance trips. Consistent inter-city and intra-city flow databases are the main hurdle.**

# Summary

- ***Modeling:*** **maximize trips or VMT able to be refueled with given number of stations and vehicle range.**
- ***Florida Infrastructure:*** **Five tiers: cluster in Miami-Palm Beach and Tampa-Orlando before connecting clusters.**
- ***Orlando Infrastructure:*** **Key freeway and arterial junctions for first 10-15 stations.**
- ***Renter Survey:*** **Two added stations (3 total) could serve 64% of renters.**
- ***Rental-Car Feasibility:*** **Orlando is an ideal location for the first $H_2$ rental business. Benefits will be felt nationally as $H_2$ rental cars generate publicity and word-of-mouth. First experience with $H_2$ could be positive, with customer support, centralized maintenance, and conveniently located refueling stations. Supply of reasonably priced cars will determine *when* it is feasible. Start planning now.**
- ***First Step:*** **Build two more Orlando stations: downtown and near theme parks.**

# Contacts

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# Assessment of Public Understanding of the Hydrogen Economy Through Science

Dr Brian Tonner
The Orlando Science Center

April 18, 2008

Project ID#TVP1

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# Overview

- Timeline
  - January 1 – April 15, 2008
- Barriers
  - Assessing current public understanding of hydrogen as an energy carrying medium
  - Increasing public understanding of hydrogen's future role in energy distribution
  - Showcase effects of decisions about energy consumption played on a global scale

•Budget: $255,020.00

-DOE $199,500.00

-OSC $55,520.00

• Partners

•US Department of Energy

•Florida Hydrogen Initiative

•US Department of Education

•Florida Solar Energy Center

•University of Central Florida

•I.d.e.a.s at Disney MGM Studios

# Objectives

H2NOW
THE 2007 HYDROGEN X-CHANGE

## Outcome objectives

- Regional and nationally touring hydrogen "expo"
- Assess current public understanding about hydrogen science and engineering
- Increase public understanding of hydrogen science and engineering

## Sample learning outcomes

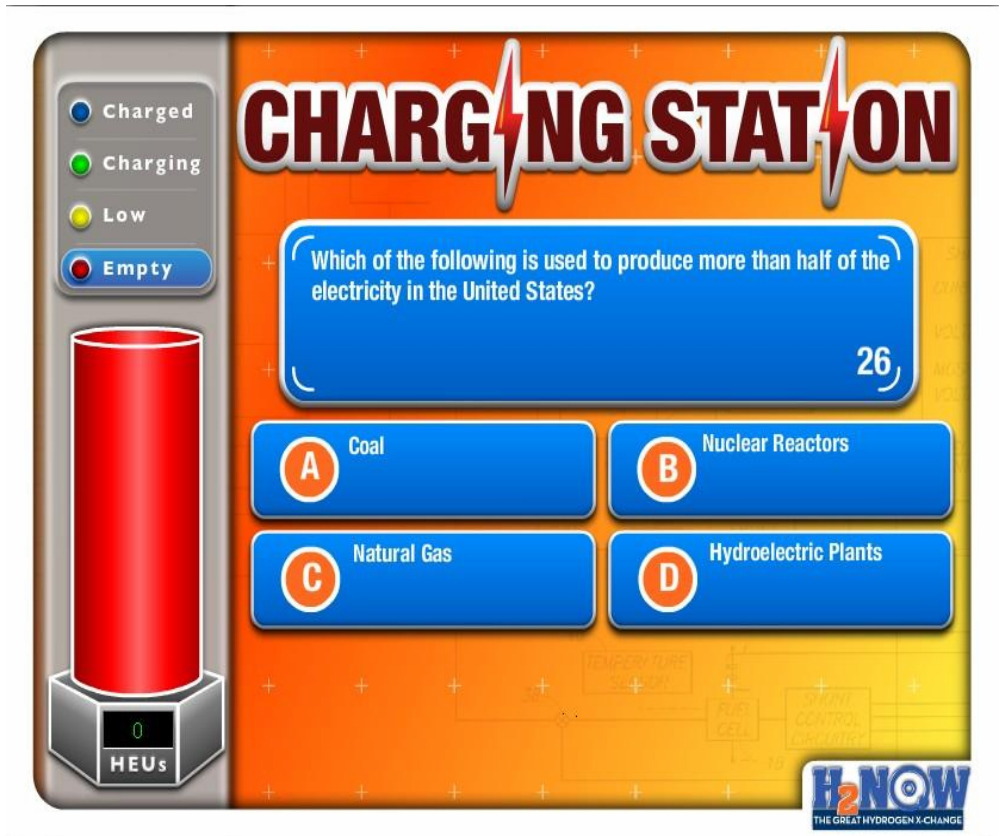
- Hydrogen is not a source of energy. It stores energy that is produced by other means, such as solar, geothermal, hydroelectric, coal, gas or nuclear energy.
- Experts believe that our energy budget for the future will be met by a combination of energy sources, including nuclear, coal, petroleum, hydrogen, and gas.
- One major benefit of using hydrogen to fuel transportation vehicles is that hydrogen produces no carbon dioxide when it is burned.

# Milestones

- ✓ Hydropolis fabrication complete
- ✓ H2Now charging stations in fabrication
- ✓ Software/visitor interface finalized
- ✓ Visitor evaluation begins May 1 ‘08
- ✓ H2Now Great Hydrogen X-Change public opening June 1‘08

# The Visitor Experience: H2Now Hydrogen X-Change

- <u>At the H2Now Charging Stations</u> --
- Opinions about hydrogen and alternative energy sources
- Increasing levels of content that addresses hydrogen as an energy source
- Charging the hydrocell with earned Hydrogen Energy Units through question and answer prompts



# The Visitor Experience: H2Now Hydrogen X-Change

•<u>At the Hydropolis</u> --

•Powering various interactive 'city' elements with earned Hydrogen Energy Units stored in the hydrocell

•Each hydrocell is equipped with RFID – radio frequency identification – to transmit its unique 'address' to hydropolis. The hydropolis computers access the address to read how many Hydrogen Energy Units the visitor has earned.

# Future Work

**An exciting exhibition touring throughout Florida beginning February, 2009**

Targeted tour venues include:

- Museum of Science & Industry - Tampa
- Museum of Science & History – Jacksonville
- Museum of Science – Miami
- Museum of Arts & Sciences - Daytona
- Florida Solar Energy Center - Cocoa
- Museum of Discovery & Science – Ft Lauderdale
- Museum of Art & Science - Tallahassee

# Summary

- H2Now: the Great Hydrogen X-Change opens at Orlando Science Center June 2008.

- H2Now is an exciting touring exhibition enhancing public awareness of hydrogen as a renewable, alternative energy source.

- A professionally designed story describing environmental impacts of global warming. Visitors will see the effects of their decisions played out on a global scale

# On-site Reformation of Diesel Fuel for Hydrogen Fueling Station Applications

Cunping Huang#, Franklyn Smith#, Karthikeyan Ramasamy#, Clovis Linkous#, Nazim Muradov#, Ali T Raissi# & James Stevens*

#Florida Solar Energy Center – University of Central Florida
*Chevron Technology Ventures, Houston, TX

June 9, 2008

Project ID# TVP1

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# Objectives

- Design, fabrication & testing of a compact gas desulfurization unit
- Design & fabrication of diesel fuel pre-reformer
- System integration of pre-reformer & sulfur scrubbing units
- Data collection & analysis of integrated system
- Technoeconomic analysis of $H_2$ fueling station:
  - Improve efficiency & reduce on-site/distributed hydrogen production costs
  - Reduce system complexity for lower capital costs
  - Improve reliability & availability

# Milestones

- Design, fabrication & testing of the desulfurization unit – 06/30/08 (completed)
- Design & fabrication of diesel pre-reformer – 06/30/08 (75% complete)
- System integration of pre-reformer & sulfur scrubbing units – 09/30/08
- Technoeconomic analysis of $H_2$ fueling station – 01/30/09

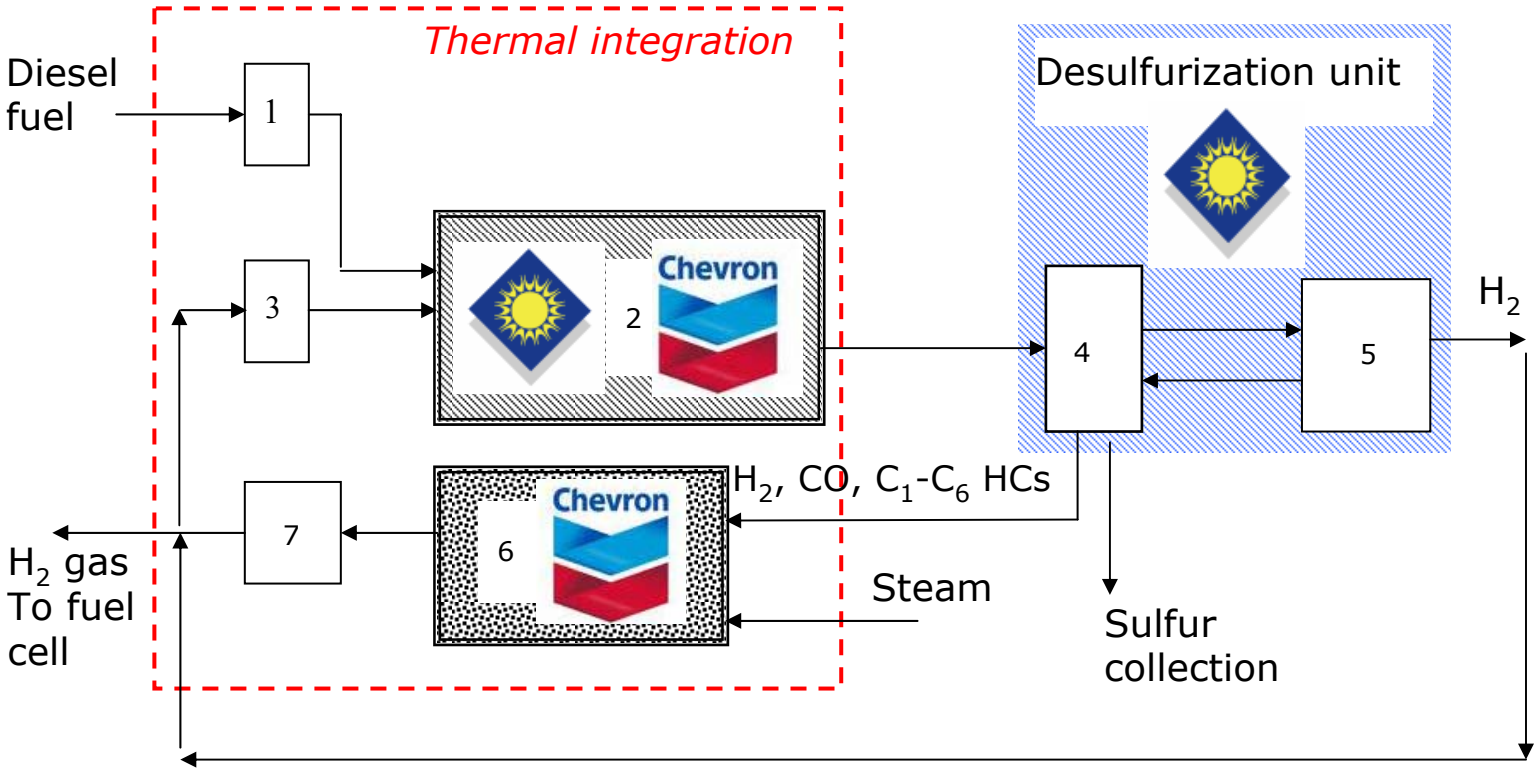
# Approach

- Conduct literature survey of various approaches to $H_2$ S scrubbing
- Use 2500 ppm $H_2$ S in nitrogen feed gas as the surrogate for diesel pre-reformer output gas, optimize scrubber operating parameters for lowering [$H_2$ S] to <50 ppm
- Design, build & demonstrate a functional system capable of delivering 1 kWth of $H_2$ power

# Technical Accomplishments/ Progress/Results

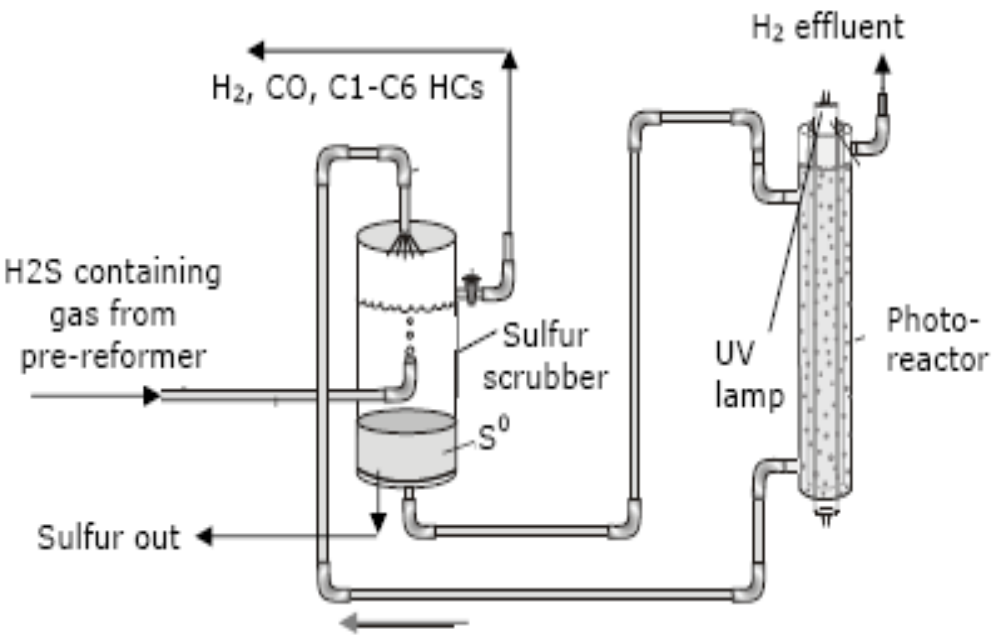
- Evaluated UV photolytic and metal chelate systems for $H_2S$ scrubbing
- Identified several metal chelate systems that could reduce $H_2S$ concentration to <50 ppm, while the UV photolytic process was limited by the sulfur precipitation equilibrium
- Continuous scrubbing of 2500 ppm $H_2S$ was demonstrated for 100's of hours, representing several turnovers of metal chelate solution
- Construction of a pre-reformer unit nearly complete.

# Schematic of Diesel-to-$H_2$ Reforming Unit




1-vaporizer, 2- pre-reformer, 3- $H_2$ compressor, 4-$H_2S$ stripper, 5- $H_2$ capture, 6- steam reforming unit, 7- gas-conditioning and purification unit.

# Initial Approach – Photolytic Sulfur Removal from Diesel Pre-Reformate




**Hydrogen evolution:**

$$2HS^- + 2h\nu \longrightarrow H_2(g) + S_2^{2-}(aq)$$
(photolytic)

**Sulfur precipitation:**

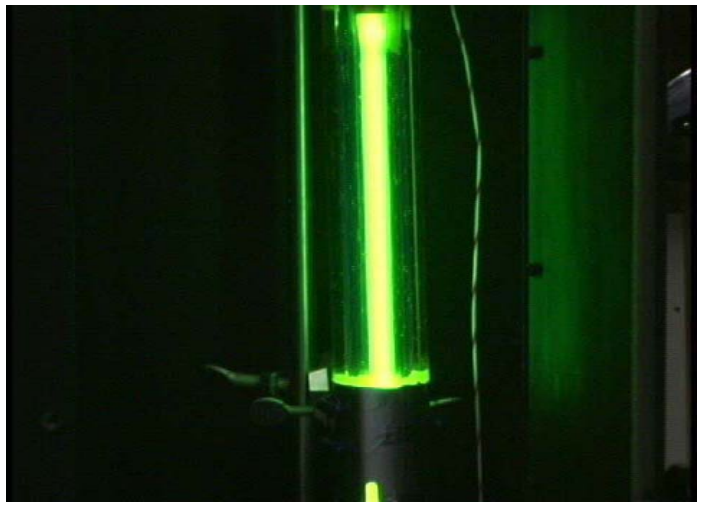
$$S_2^{2-}(aq) + H_2S(aq) = S(s) + 2HS\ (aq)$$

**Overall reaction:**

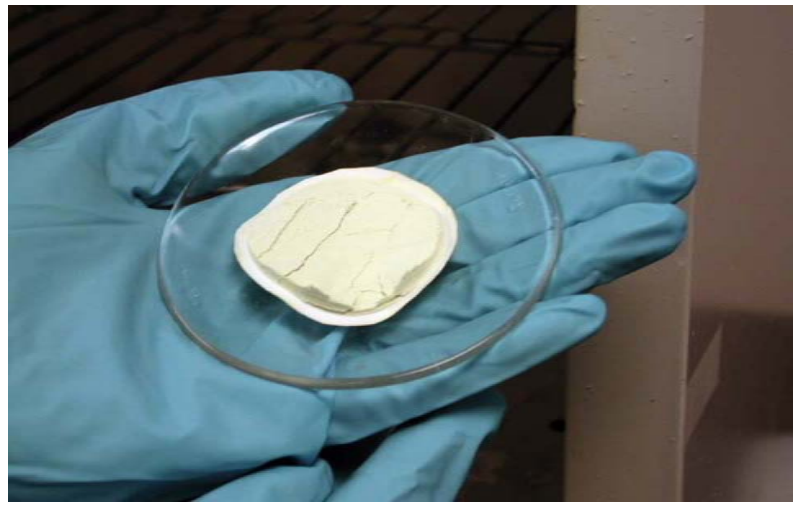
$$H_2S + 2h\nu = H_2 + S(s)$$

- No electrodes or catalysts needed
- Equimolar amounts of sulfur & $H_2$ produced
- Moderately alkaline system not corrosive
- UV lamp performance life >10,000 h

# Scrubber/Photoreactor for Sulfur Removal Built & Demonstrated



$H_2$ evolving from sulfide solution under LP Hg lamp



Elemental sulfur recovered from HS- photolysis & subsequent precipitation

- **$H_2$ & sulfur obtained in 1:1 ratio as predicted by reaction stoichiometry**
- Equilibrium constraints did not allow scrubbing down to 50 ppm $H_2S$, necessary to protect steam reforming catalyst
- Pressurization of pre-reformer effluent improved scrubbing efficiency, but was not effective below 10 atm threshold.

# Present Approach – Iron Redox Scrubbing of $H_2S$

**Sulfur scrubbing:**

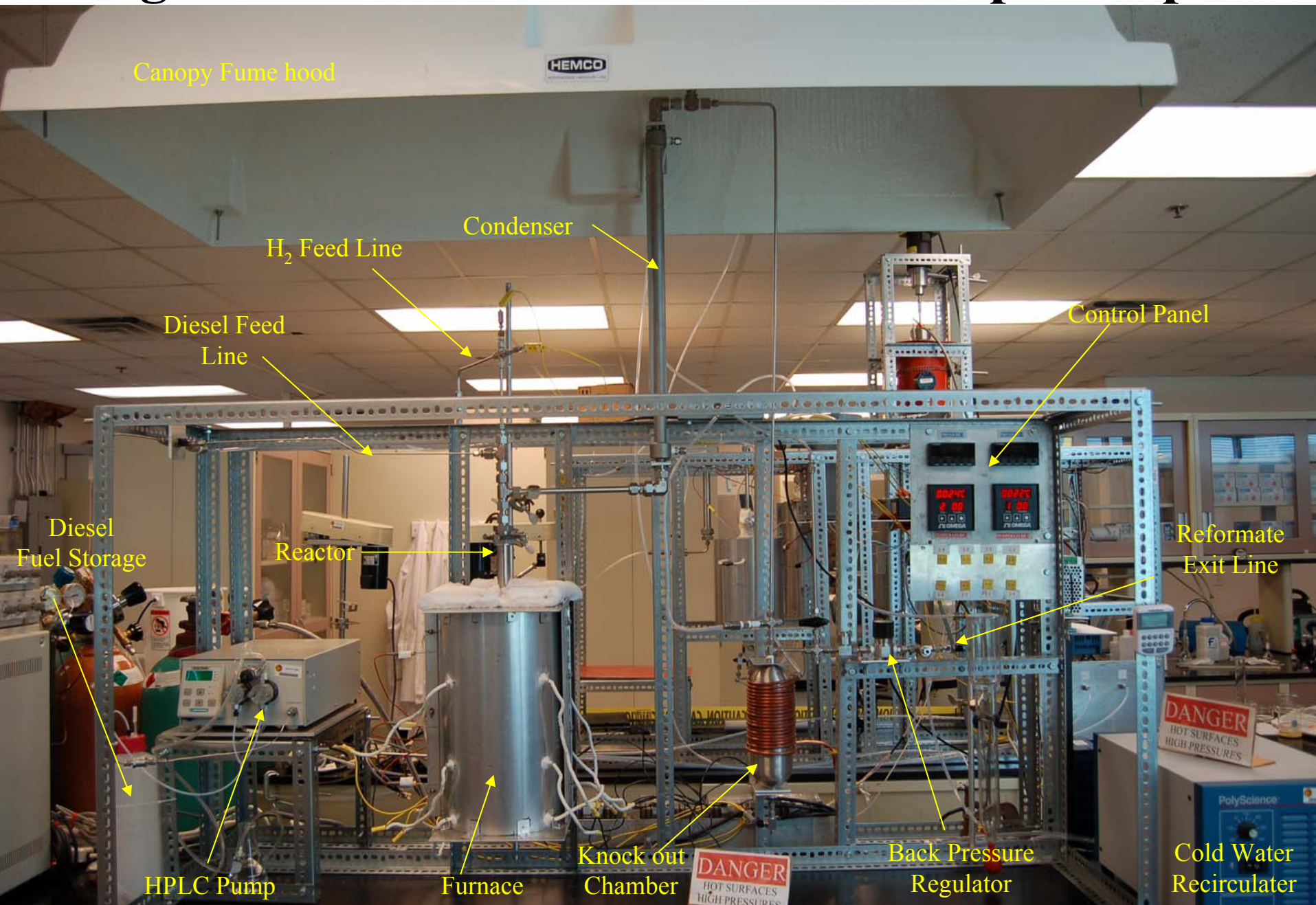
$$H_2S(aq) + 2Fe^{3+} \rightarrow S^o(s) + 2Fe^{2+} + 2H^+$$

**Photolytic/electrolytic regeneration:**

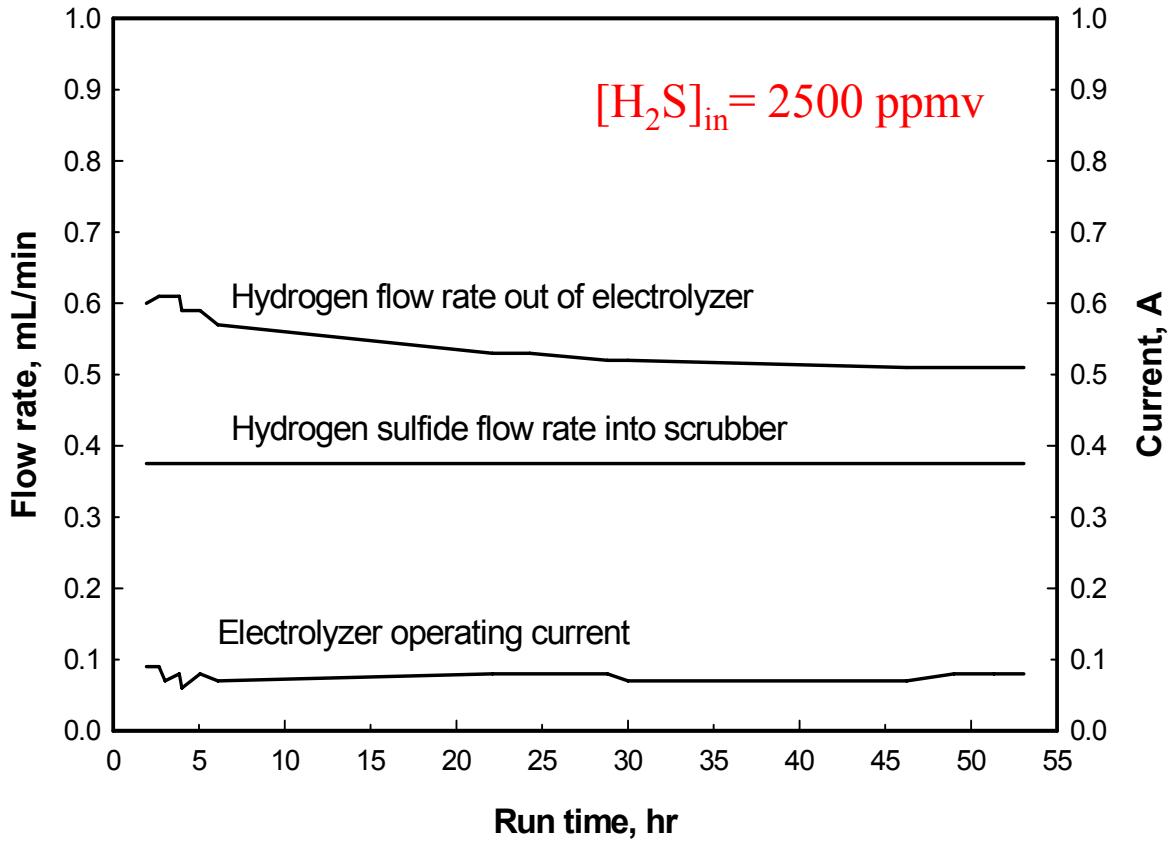
$$2Fe^{2+} + 2H^+ \rightarrow 2Fe^{3+} + H_2$$

Several systems found to reduce $H_2S$ to single ppm levels

# High Sulfur Diesel Pre-Reformer Exp. Setup



# Performance Curve for Steady State Electrolytic Operation




**Desulfurization unit operated successfully for more than 50 hours continuously having reached steady state condition, $[H_2S]_{exit}$= 0 ppmv**

# Future Work

- Testing & validation of the pre-reformer
- Testing and validation of the scrubber subject to non-$H_2$ S organo-sulfur contaminants in the gas
- Testing & validation of the integrated pre-reformer & desulfurization unit
- Technoeconomic analysis of diesel-to-hydrogen fueling station concept.

# Summary

- Developed an effective & simple diesel-to-hydrogen sulfur scrubbing unit suitable for small-scale vehicular fueling station applications
- Identified the best metal chelate system capable of reducing $H_2S$ concentration to less than 50 ppmv
- Demonstrated continuous scrubbing of 2500 ppm $H_2S$ for 100's of hours, representing several turnovers of metal chelate solution.