DOE Hydrogen Program

FLORIDA HYDROGEN INITIATIVE

Stephen Adams, Chairman

Pam Portwood, Executive Director

Florida Hydrogen Initiative, Inc.

May 18, 2009

Project ID
#tvp_05_portwood

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.

FHI Project Selections – Approach

- The FHI Program was envisioned as a broad-based Florida Program using its resources to aid the development of a robust hydrogen industry thereby establishing Florida as the cornerstone of a southeastern hydrogen hub.

- FHI did not initiate projects, rather an open, competitive request for proposals was issued and the best projects were selected to receive funding.

- Critical in the selection of projects and evidenced in the currently funded projects are the very large cost share from the FHI Project Partners.

Three Projects Currently Funded by FHI

The FHI is a grantee of the US Department of Energy Hydrogen Program and has three currently funded projects:

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. 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.

3. 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.

DOE Hydrogen Program

Hydrogen Technology (HyTech) Rest Area

Michel Fuchs

EnerFuel, Inc.

1501 Northpoint Parkway, West Palm Beach, FL

May 18, 2009

Project ID #TVP05

Project Overview

Timeline

- Start – Oct 2006
- Finish – Sept 2009
- 75% complete

Budget

- Total project funding
  - DOE - $550K
  - Contractor - $632K
- Funding received for FY07
  - $191.0K
- Funding received for FY08
  - $160.9K
- Funding for FY09
  - 198.1K

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 - Relevance

Overall	• Design, construct and demonstrate a 10kW$_{net}$ PEMFC stationary power plant operating on citrus derived methanol • Achieve an electrical energy efficiency >32% • Demonstrate transient response time <3ms
2008	• Production of fuel cell grade renewable methanol • Identification of all permits required for construction • Construction and installation of HyTech site • Promotion of HyTech site
2009	• Demonstrate fuel cell power plant operating on renewable methanol and providing power to service plaza • Evaluate fuel cell power plant performance • Present results of project

Milestones

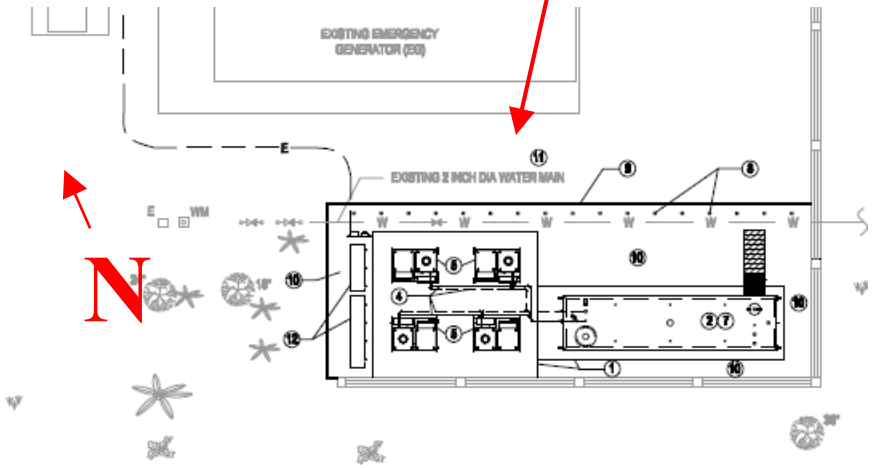
Month/Year	Milestone or Go/No-Go Decision
May-08	Milestone: Received fuel cell systems with onboard fuel reformers Milestone: Satisfied all NEPA requirements
July-08	Milestone: tested operation of fuel cell systems on commercial grade methanol
Jan-09	Milestone: Identified commercial bio-methanol supplier able to provide entire 5000 gallons necessary for project
Apr-09	Milestone: Obtain all permits required for construction, including Florida Turnpike Enterprise, Fire Marshall and County permits.
Jun-09	Milestone: Complete construction of fuel cell demonstration site.
Sept-09	Milestone: Complete fuel cell power plant, operating on renewable methanol and providing power to service station, demonstration phase.

Plan & Approach

- **Task 1: Citrus derived methanol** — 85% Complete
  - 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** — 85% Complete
  - 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** — 100% Complete
  - 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** — 85% Complete
  - Construct power plant
  - Test and debug power plant
  - Benchmark performance
- **Task 5: Power Plant installation and demonstration** — 0% Complete
  - Install power plant at demo site
  - Operate system for 3 months

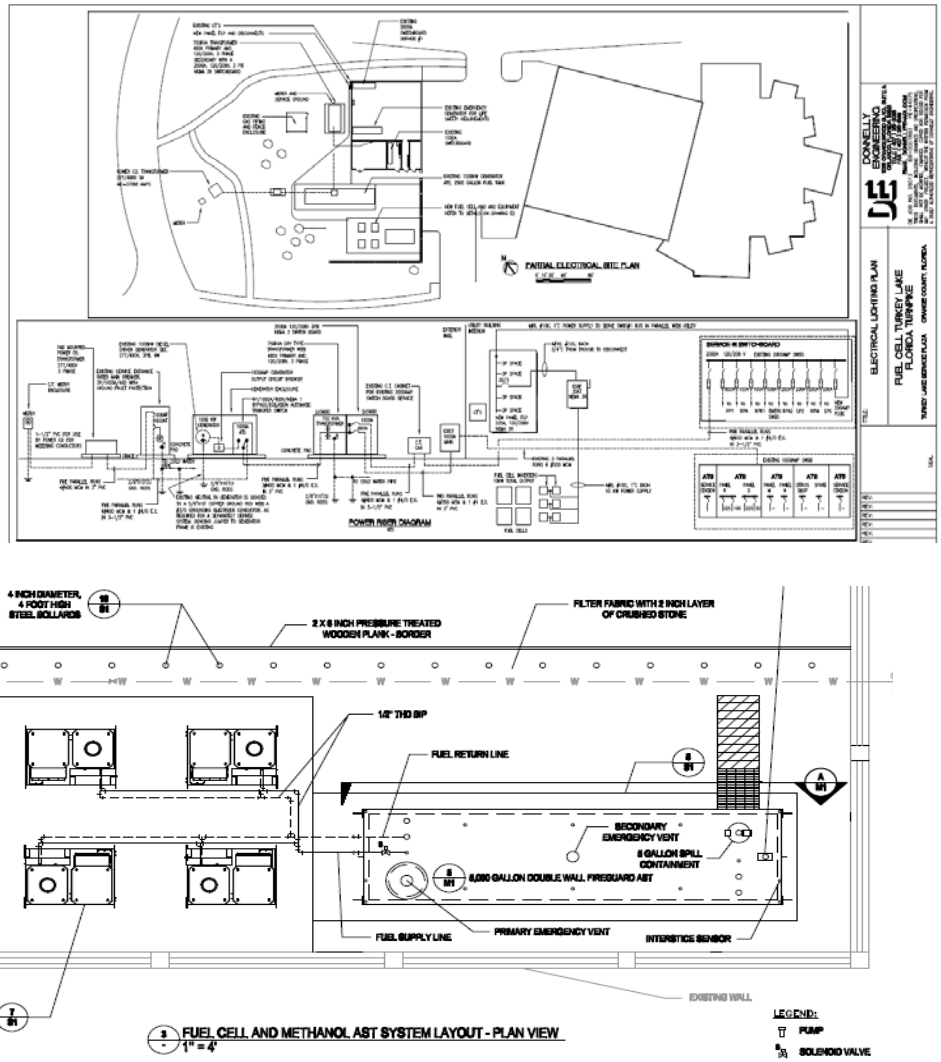
Accomplishments

- Selected the Florida's Turnpike Enterprise's Turkey Lake Service Plaza as demonstration site
- Selected replacement feedstock for bio-methanol
- Met with Florida's Turnpike Enterprise to secure approval and support
- Selected methanol storage container
- Selected location of power plant and methanol storage container



Accomplishments (cont.)

- Finished electrical and mechanical engineering drawings
- Selected the bio-methanol supplier
- Obtained fuel cell systems with onboard fuel processors
- Started inverter/fuel cell system pre-installation testing at EnerFuel facility



Collaborations

Partners

- Participation with the Technological Research and Development Authority (TRDA) of Florida to promote project objectives
- Participation from Progress Energy to guide fuel cell system interfacing with service plaza electrical infrastructure
- Participation from the Florida Turnpike Enterprise (FTE) for use of their service plaza

Future Work
(FY08 – FY09)

- **FY09 – Site preparation**
  - Secure all permits necessary to begin construction phase
  - Construct fuel cell demonstration site
  - Transport bio-methanol to site
  - Power portion of Turkey Lake service plaza for period of 3 months
- **FY09 – Analysis of fuel cell power plant under operation**
  - Determine overall electrical efficiency
  - Document system transient response to load changes
  - Determine effects of Bio-derived methanol on long term power plant performance
  - Assess requirements for future projects and for future commercialization

FY09 – Submission of Final Project Report

Project Summary

- **Relevance**
  - Demonstrate the value of bio-methanol as a viable "clean" source of fuel for generation of renewable electrical power
- **Approach**
  - Utilize a PEM based fuel cell power plant, with onboard reforming, to convert bio-methanol to usable electrical power
  - Demonstrate project at high visibility service plaza on the Florida Turnpike
- **Technology collaboration**
  - Participation with the Technological Research and Development Authority (TRDA) of Florida to promote project objectives
  - Participation from Progress Energy to guide fuel cell system interfacing with service plaza electrical infrastructure
  - Participation from the Florida Turnpike Enterprise (FTE) for use of their service plaza
- **Proposed future projects**
  - Develop and participate in additional alternative power generation and renewable fuel projects that lead to the development of viable commercial "clean" power solutions

2009 DOE Hydrogen Program Assessment of Public Understanding of the Hydrogen Economy Through Science

JoAnn Newman
The Orlando Science Center

May 18, 2009

Project ID# TVP05

Overview

- **Timeline**
  - January 1, 2006
  - December 31, 2008
  - 91% complete
- **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**

Total project funding = $255,020

- DOE $199,500
- OSC $55,520

- **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

Relevance

Objectives

• Create awareness among all science center audiences on hydrogen as a renewable energy resource

•Assess current public understanding about hydrogen science & technology

•Increase public understanding of hydrogen science & engineering

Impact

•Evaluation for cognitive and affective learning outcomes in progress

•Anecdotal evidence & limited evaluation to date suggests limited pre-knowledge but high interest

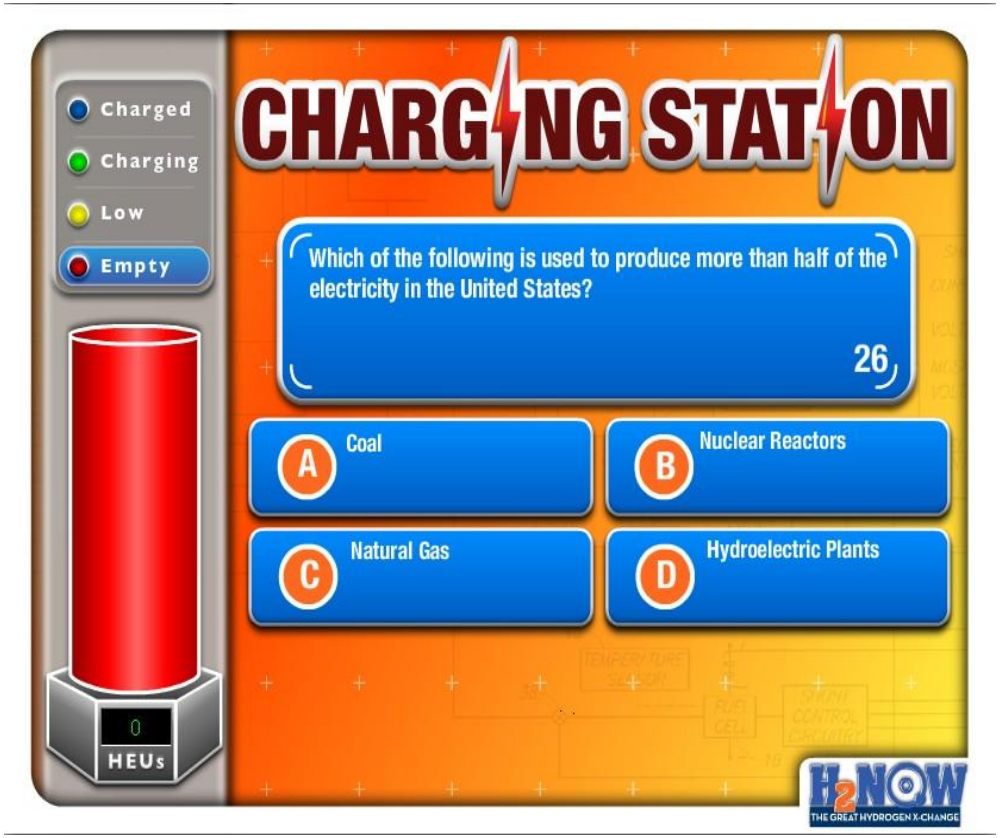
•Visitor interest level in exhibit overall is moderately high.

•Visitors enjoy the content presented

Approach

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



Approach

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.

Technical Accomplishments and Progress

Accomplishments to date:

H2Now, the Great Hydrogen Xchange, opened for public testing August 15, 2008

- Charging stations and Hydropolis completed and installed June 30, 2008
- Software installation and testing July 1-Aug 15

Public testing revealed significant problems with custom software

- Software designer completed critical analysis mid-Jan, 2009
- Software designer began 40% software rewrite mid-January 2009

Limited cognitive and affective testing conducted between mid-August and mid-December, 2008

Technical Accomplishments and Progress

- New software to be installed March 3, 2009
- New software testing through March 8, 2009
- Cognitive and affective evaluation Slated to resume on March 9, 2009
- Estimated completion of evaluation on or about March 20, 2009

Collaborations

Project Collaborator: Progress Energy Foundation

- Exhibit Presenting Sponsor
- Industry
- Outside of the DOE H2 Program

Progress Energy provided funds to OSC to be recognized as the presenting sponsor for H2Now: the Great Hydrogen Xchange. "Presented by Progress Energy" is used throughout the exhibit as well as in all collateral material relating to the exhibit

Sponsorship extends the exhibit's 'reach' to all of Progress Energy's regional service area: 9 Central Florida counties

Proposed Future Work

One item remains to complete OSC's obligations per the grant terms:

- Complete public assessment and evaluation to determine affective and cognitive success towards educational objectives of the H2Now exhibition

Future work entails conducting on-site evaluation to test educational effectiveness. Work will begin March 9, 2009 and end on or about March 20, 2009. Results will be tabulated and submitted

Summary

- H2Now: the Great Hydrogen X-Change opened at Orlando Science Center August 15, 2008.

•H2Now enhances public awareness of hydrogen as a renewable, alternative energy source.

•The interactive exhibit, and its important educational messages, has attracted the Progress Energy Foundation as a Presenting Sponsor.

•Initial results from visitor observation and feedback reveal that OSC visitors find H2Now enjoyable, educational, and informative

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

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

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

May 18-22, 2009

Project ID # TVP05

Overview

Timeline

- Project start date: 01/21/08
- Project end date: 03/20/09
- Percent complete: 100%

Budget

- Total project funding: $500K
  - DOE share: $300K
  - Contractor share:
    Chevron: $150K
    FSEC: $50K
- $ 167,500 funding for FY08
- $ 132,500 funding for FY09

Barriers addressed

Distributed Hydrogen Production & Storage:

B. Hydrogen Storage
C. Lack of Hydrogen Refueling Infrastructure Performance & Availability Data
D. Maintenance & Training Facilities
E. Codes & Standards

Partners

- Chevron Technology Ventures, LLC
- **Project lead:** UCF – FL Solar Energy Center

Objectives/Relevance

- Development of a compact, self-contained high-sulfur diesel fuel utilization system for hydrogen fueling station applications.
- Development of an electrolytic desulfurization unit that functions by scrubbing & splitting H_2S to form H_2 & sulfur using an efficient regenerable redox system.
- Development of a stable catalyst for hydro-cracking of high-S diesel fuel to light hydrocarbons (C_1-C_6) & a compact fuel pre-reformer.
- Operation & validation of an integrated unit composed of pre-reformer & sulfur scrubber capable of generating an output gas containing less than 50 ppmv of H_2S.

Milestones

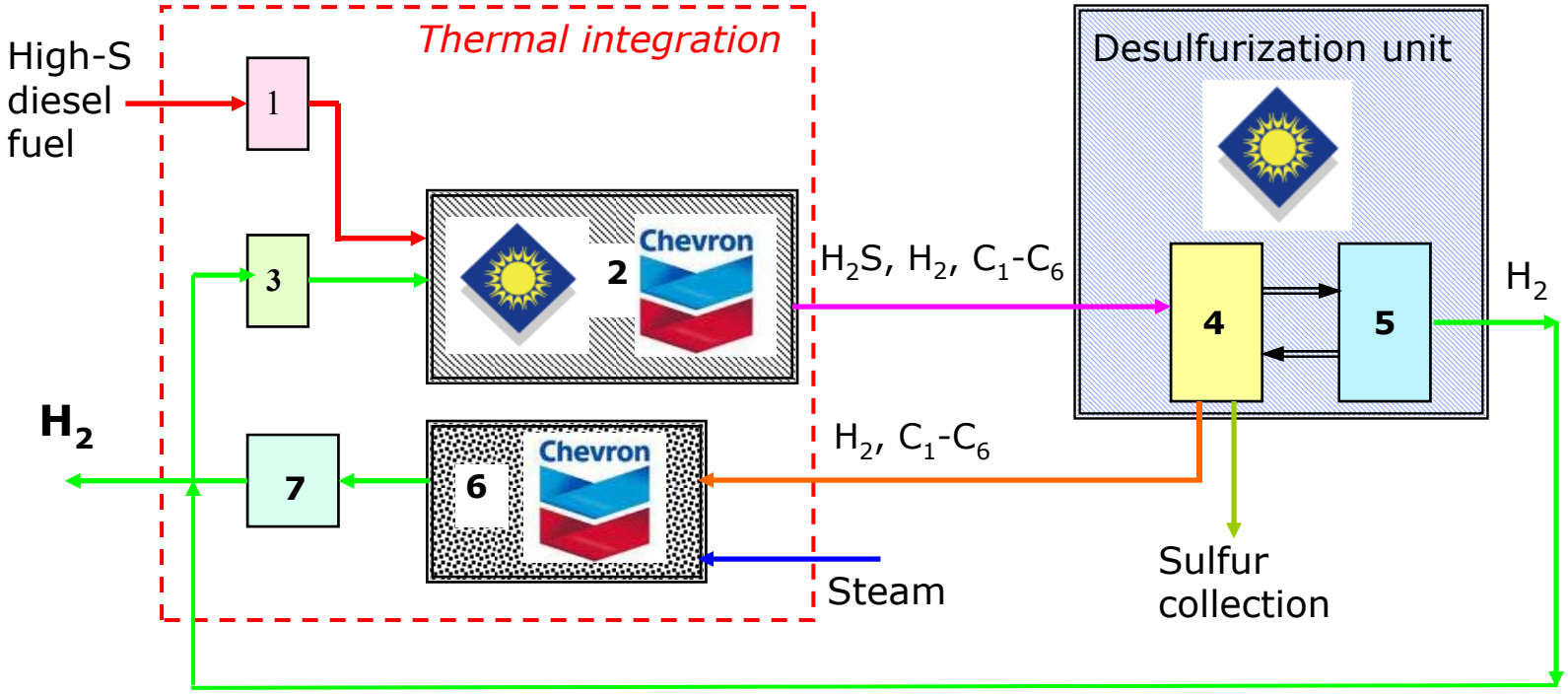
- Design, fabrication & validation of the desulfurization unit – 06/30/08 (completed)
- Design & fabrication of diesel fuel pre-reformer – 09/30/08 (completed)
- Integration of the pre-reformer & sulfur scrubber & system validation testing – 01/30/09 (completed)
- Data collection & analysis of the fully integrated system– 02/30/09 (completed)

Approach

- Use diesel with addition of 3000-5000 ppmw of thiophene as surrogate high-S hydrocarbon fuel.
- Perform catalytic hydrocracking-desulfurization of high-S diesel fuel to light (C_1-C_6) hydrocarbons suitable for H_2 generation *via* conventional steam reforming process.
- Develop a robust bi-functional catalyst for hydrocracking of high-S diesel (up to 5000 ppmw sulfur) and hydrogenation of sulfur-organics to H_2S with high selectivity.
- Design an efficient & optimized H_2S-scrubber capable of lowering [H_2S] in the pre-reformate to <u>less than 50 ppmv</u>.

Technical Accomplishments/ Progress/Results

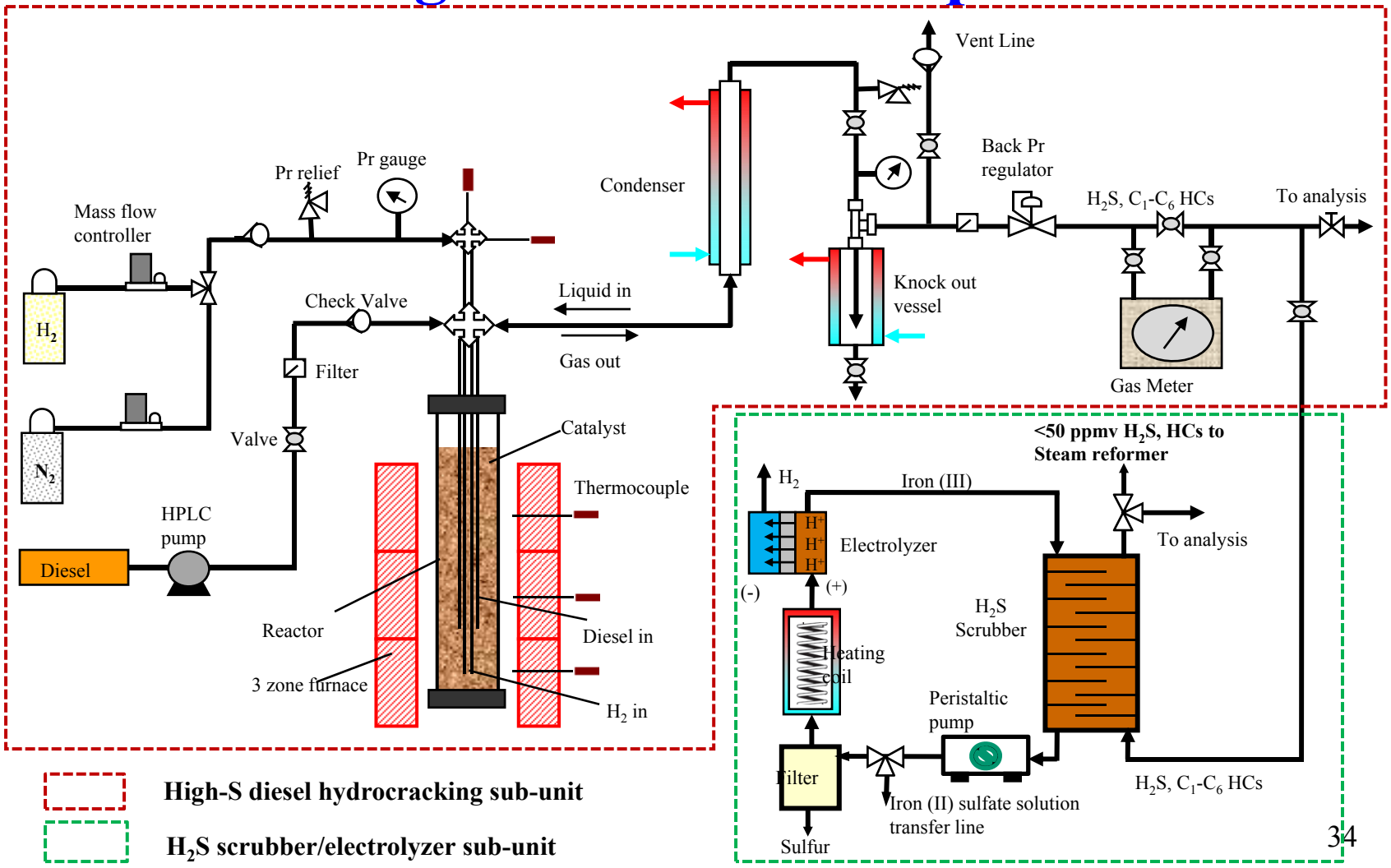
Division of Project Labor



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

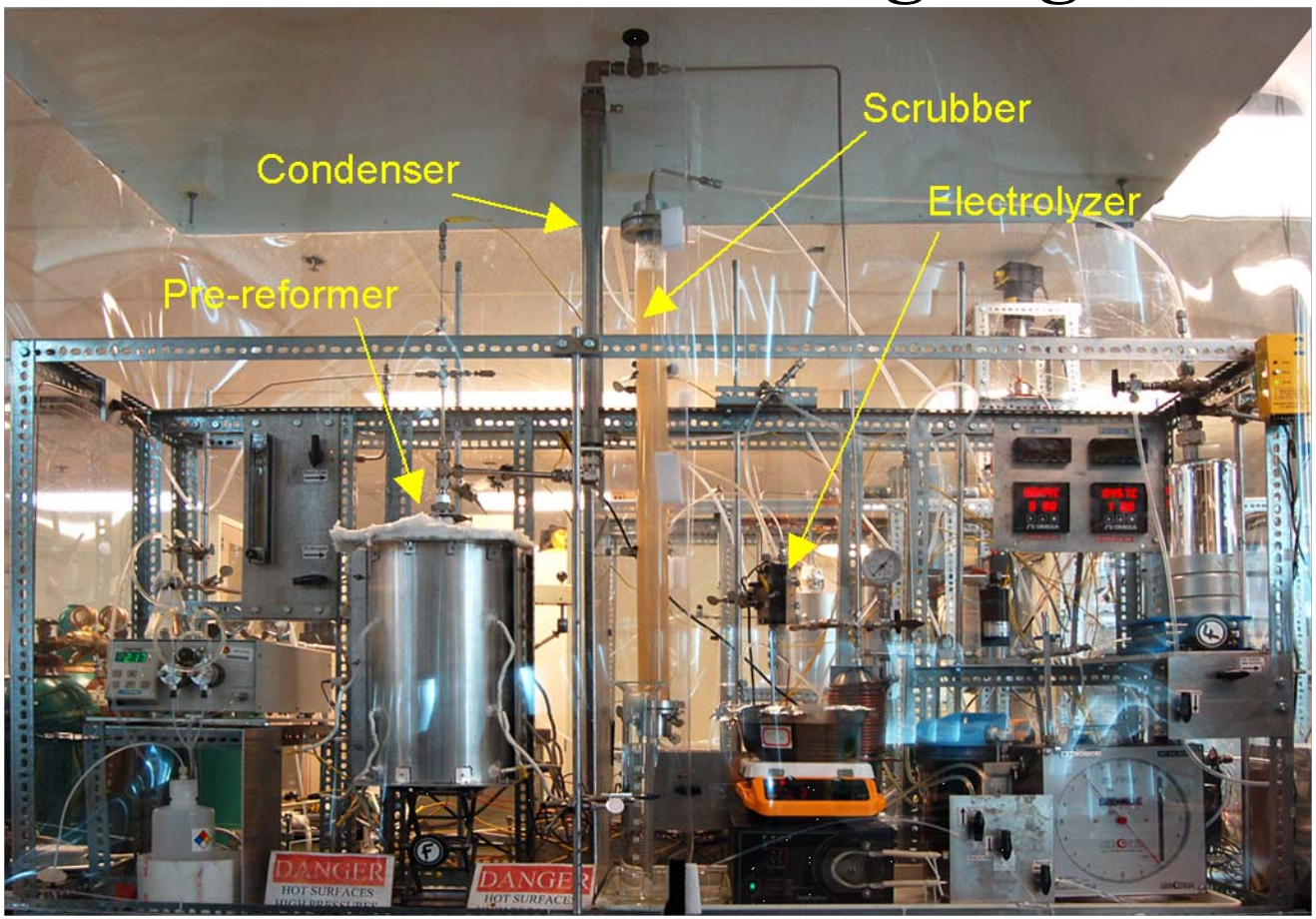
Technical Accomplishments/ Progress/Results

Schematic Diagram of FSEC Experimental Setup



Technical Accomplishments/ Progress/Results

Bench-Scale Unit for Converting High-S Fuel to H_2



Technical Accomplishments/ Progress/Results

- Developed novel Fe-redox/electrolyzer system for H_2S scrubbing and splitting to H_2 & sulfur.
- Demonstrated continuous removal of up to 2500 ppmv H_2S for 100 hrs, representing several complete turnovers of the Fe-redox system.
- Designed & built a compact pre-reformer for converting high-S diesel to light hydrocarbons at 97% yield.
- Fully integrated pre-reformer & sulfur-scrubber operated continuously for several days with sulfur removal efficiency of >95%.

Technical Accomplishments/ Progress/Results

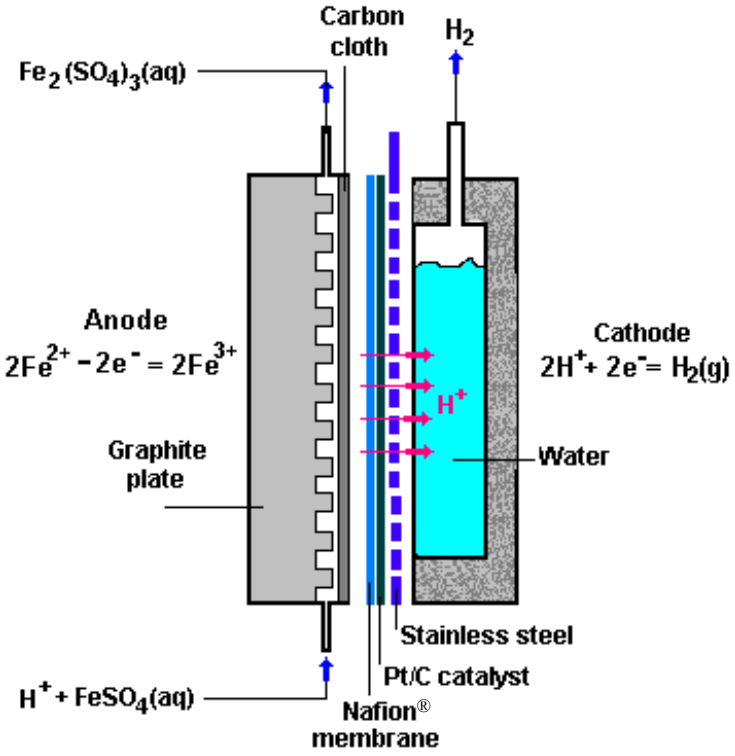
Iron-based Redox System for H_2S Scrubbing & Splitting

H_2S scrubbing:

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

***Electrolytic regeneration*:**

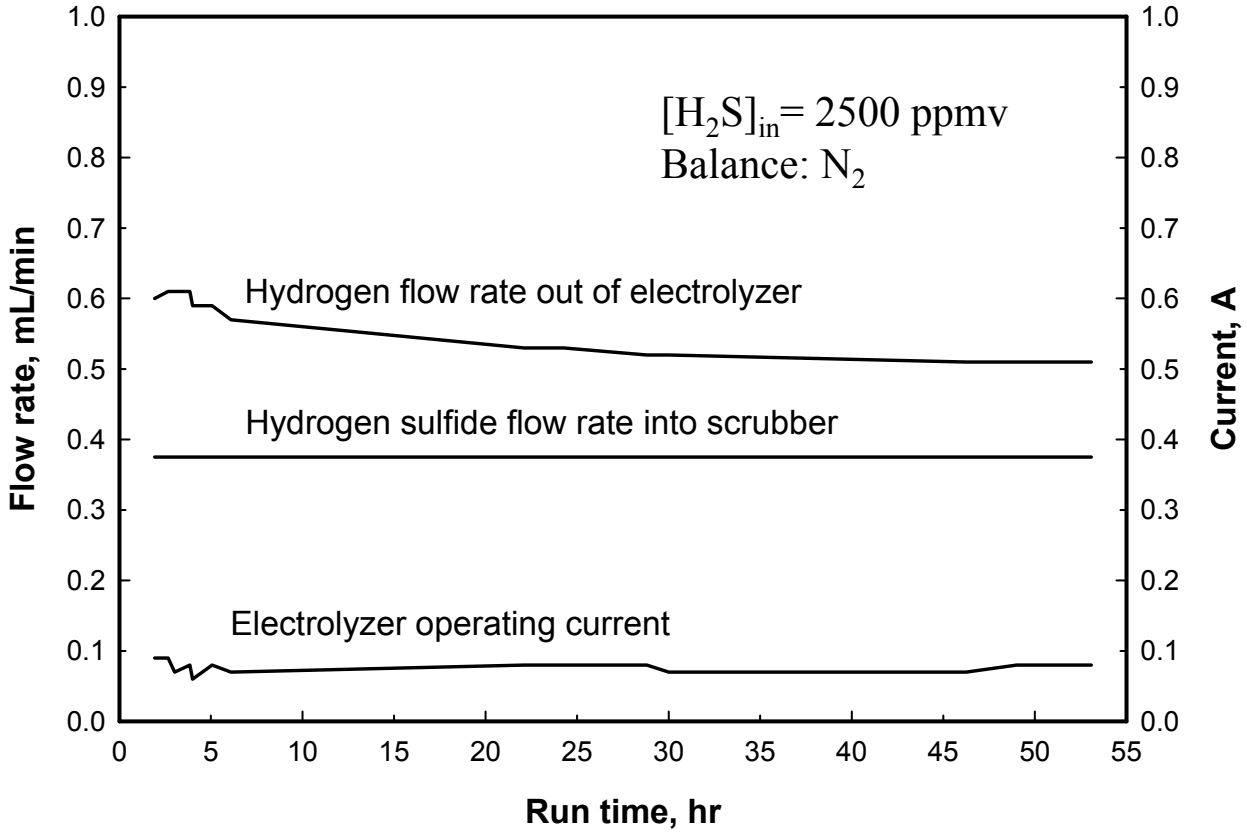
$$2Fe^{2+} + 2H^+ \rightarrow 2Fe^{3+} + H_2$$



Concentration of H_2S in the reformate was reduced from 100s to single ppm levels.

Technical Accomplishments/ Progress/Results

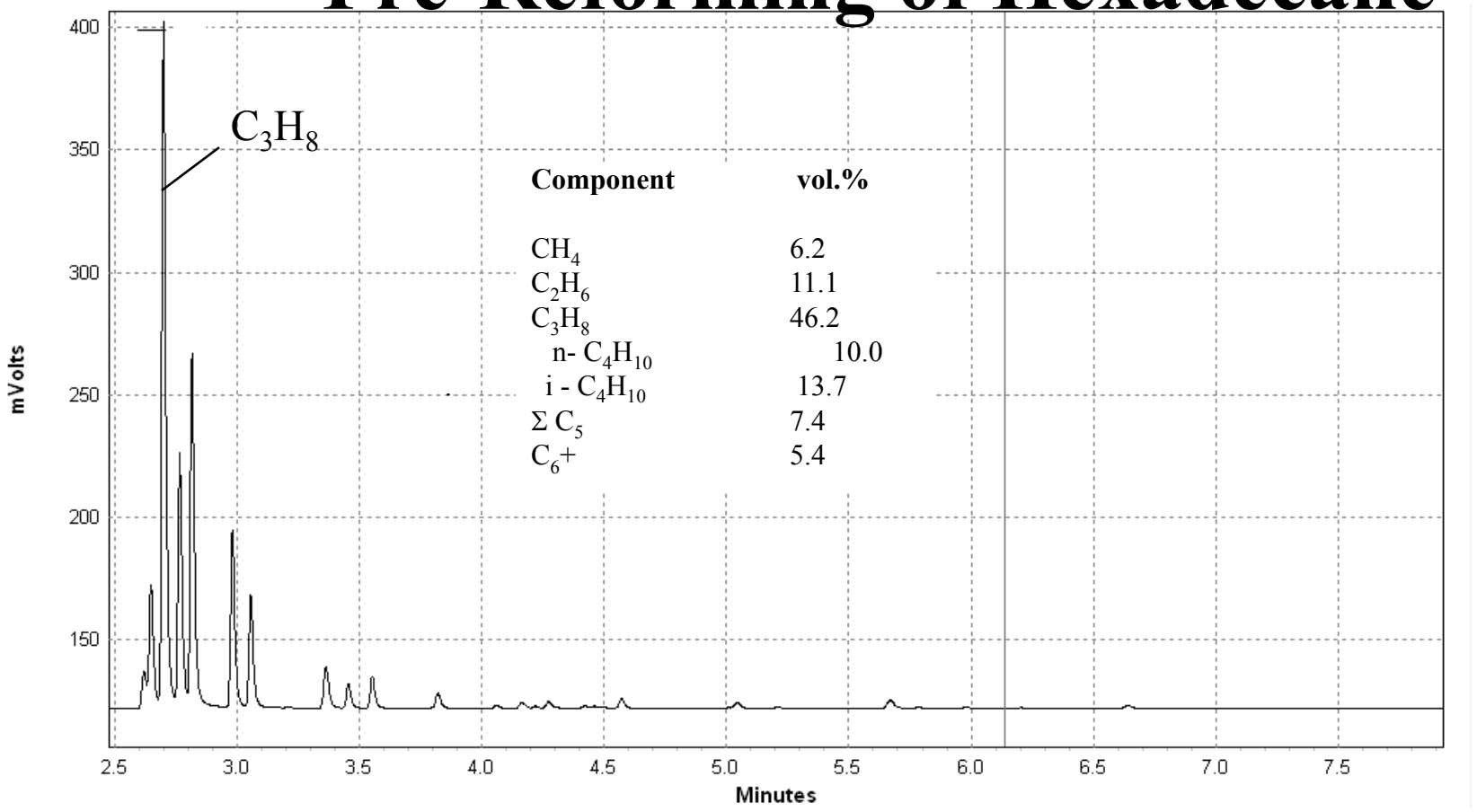
Steady State Operation of Electrolyzer with Fe-redox System



Desulfurization unit performed well for more than 50 hrs of continuous operation under steady state conditions, $[H_2S]_{exit} \approx 0$ ppmv

Technical Accomplishments/ Progress/Results

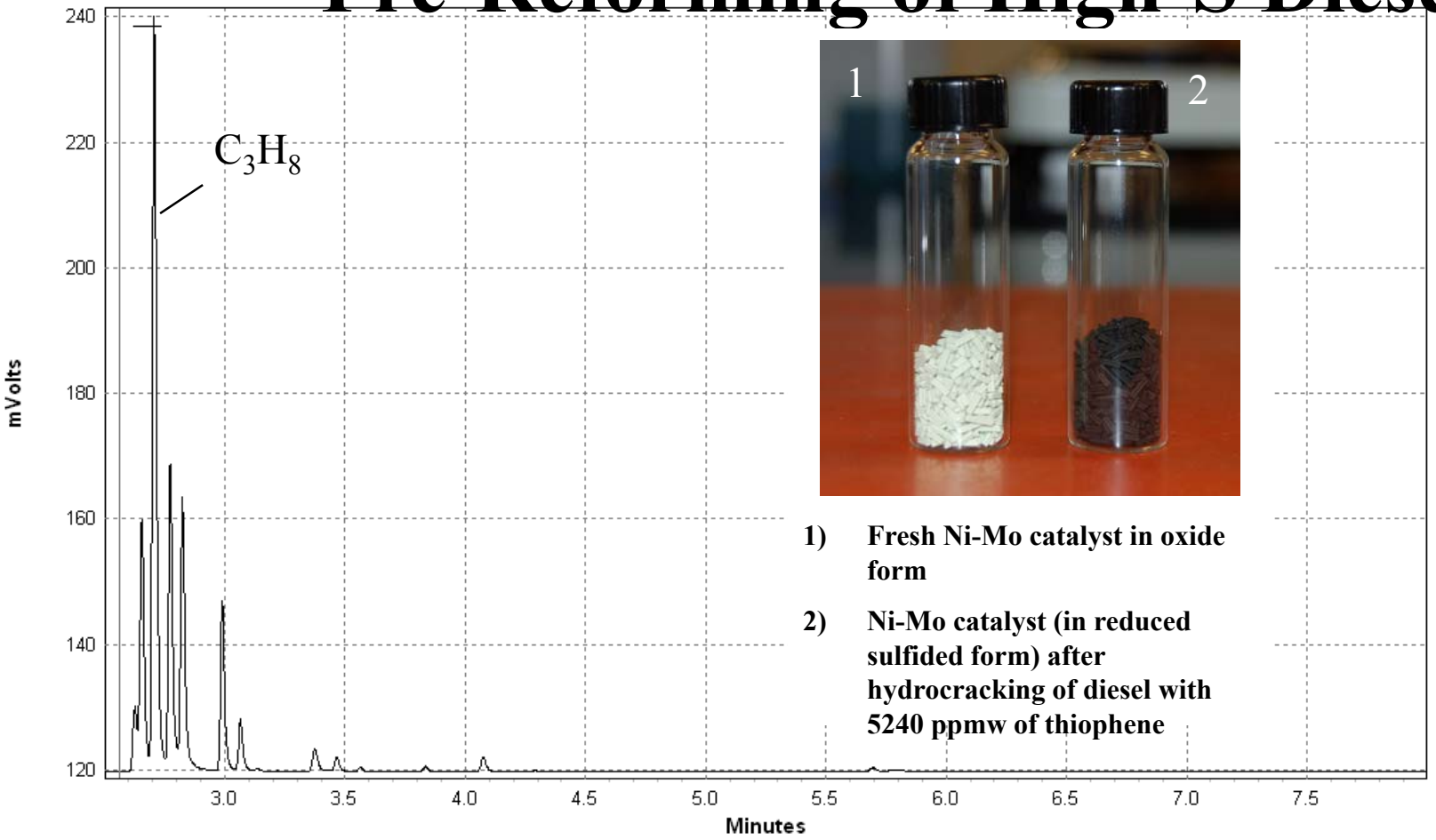
Pre-Reforming of Hexadecane



GC/FID of pre-reformate produced from hexadecane containing 5240 ppmw of thiophene. Catalyst: a mixture of zeolite and Ni-Mo/Al_2O_3 (2:1 weight ratio).

Technical Accomplishments/ Progress/Results

Pre-Reforming of High-S Diesel



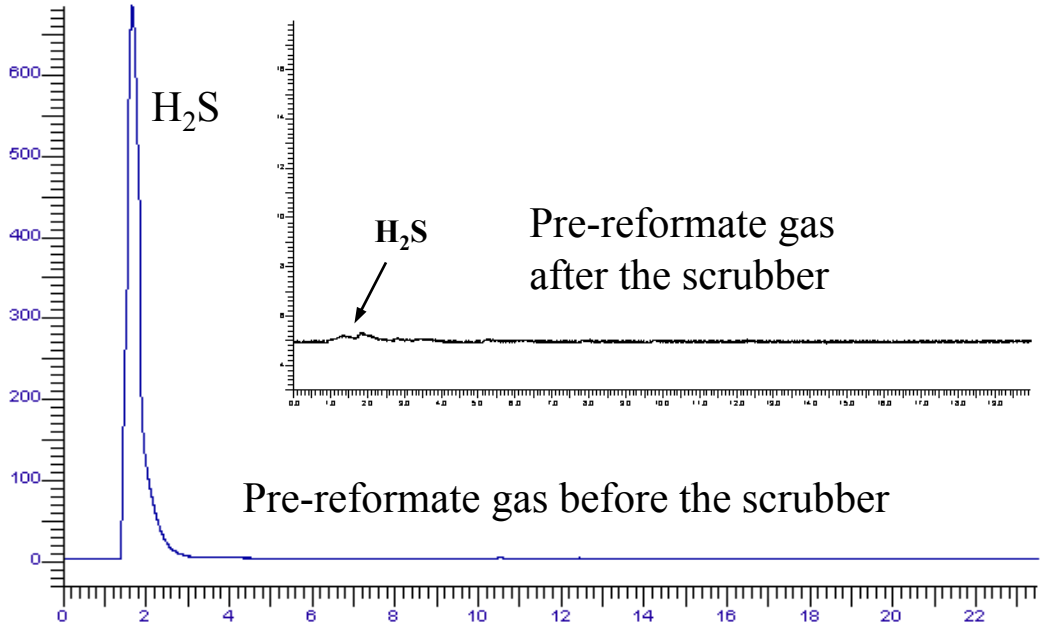
1) **Fresh Ni-Mo catalyst in oxide form**

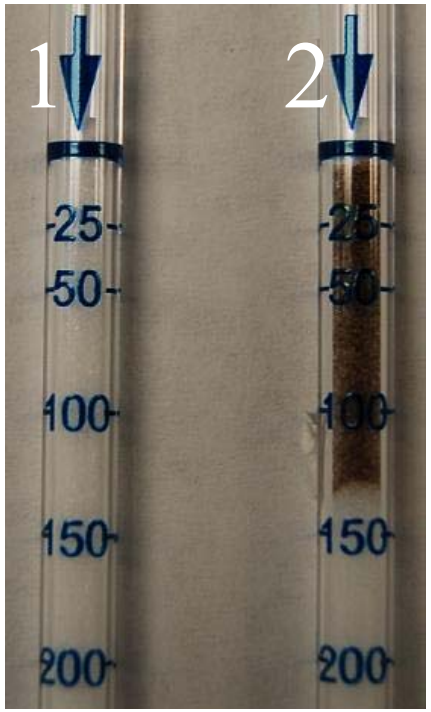
2) **Ni-Mo catalyst (in reduced sulfided form) after hydrocracking of diesel with 5240 ppmw of thiophene**

GC/FID of pre-reformate gas produced from diesel fuel containing 5240 ppmw of thiophene. Catalyst: a mixture of zeolite and Ni-Mo/Al_2O_3 (2:1 by weight).

Technical Accomplishments/ Progress/Results

GC/FPD Chromatogram of Diesel Pre-Reformate





Determination of H_2S in the pre-reformate gas using gas detection tube method.
1- original tube,
2- tube after passing the pre-reformate gas.

Sulfur removal efficiency: >95%

$$\eta = \frac{(molesH_2S)_{out} - (molesC_4H_8S)_{out}}{(molesC_4H_8S)_{in}} \cdot 100\%$$

Future Work

- Submit Final Report.
- Since the project ended in March 2009, no further work is planned for this project.
- If additional funding does become available, the process will be demonstrated for converting high-S sub-quality natural gas to hydrogen.

Summary

- Developed a novel diesel-to-hydrogen conversion process employing a catalytic pre-reformer coupled to an efficient sulfur scrubbing unit suitable for fueling station applications.
- Identified a high-efficiency regenerable iron-redox system capable of reducing H_2S concentration in the reformate to less than 10 ppmv.
- Developed novel catalyst formulations for pre-reforming high-sulfur diesel fuel to C_1-C_6 hydrocarbons with 97% yield.
- Demonstrated operation of a fully integrated pre-reformer-desulfurization unit for 100 continuous hrs, with sulfur removal efficiency of over 95%.

The Team

FSEC tasks:

- Design, fabrication & evaluation of a compact, self-contained desulfurization unit.
- Development & testing of the pre-reforming catalysts.
- Integration of the pre-reformer & desulfurization units.

CTV tasks:

- Pre-reforming catalyst development & analysis.
- Design of the pre-reforming reactor & advising FSEC on the operation and troubleshooting of the pre-reforming reactor.