

## V.E.4 Global Assessment of Hydrogen-Based Technologies\*

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*Subcontractors:*

*Argonne National Laboratory, Argonne, Illinois*

*\*Congressionally directed project*

### Objectives

- Synthesize the state-of-practice for four potential hydrogen-based technologies.
- Compare performance, emissions, and fueling characteristics of the four technologies (instrumentation).
- Compare the four technologies in light of their potential role in a full-scale deployment.
- Assess hydrogen infrastructure needs to support deployment (at local and regional levels).
- Offer education and training programs to increase the knowledge of the new technologies.
- Increase the awareness of the new technologies through various mechanisms, such as promotional materials for public media, a web-site, college programs, and a Hydrogen Fair in the southeast to demonstrate the various vehicle technologies, pumping stations, hydrogen storage, safety issues, etc.

### Technical Barriers

This project addresses the following technical barriers of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Technology Validation
  - A. Vehicles
  - B. Storage
  - C. Hydrogen Refueling Infrastructure
- Hydrogen Codes and Standards
  - D. Large Number of Local Government Jurisdictions (approximately 44,000)

### Approach

- Evaluate candidate hydrogen-fueled vehicles for near and long-term use in the Southeastern U.S. in terms of their efficiency, performance, and emissions.
- Conduct rigorous performance and exhaust emissions testing of hydrogen technologies:
  - Internal combustion engine (ICE) vehicles fueled with hydrogen-CNG fuel mixtures (15-50% hydrogen, 50-85% CNG).
  - ICE vehicles fueled with pure hydrogen.
  - Hydrogen powered fuel cell vehicles.

- Estimate resource requirements and costs for the infrastructure needed to deliver new fuels to advanced technology vehicles. Argonne's CHAIN model will be used to develop cost estimates and define additional hydrogen pathways.
- Evaluate the ability of the vehicle technologies described previously to contribute to improved air quality in the Southeast, with special attention given to the Birmingham metropolitan area.
- Determine the feasibility of using hydrogen fuel cell technologies for electric power generation and its potential impacts on air quality.
- Establish The Southeast Hydrogen Technology Consortium (SHTC) to examine ways to establish a hydrogen infrastructure in the southeast and enhance the infrastructure and application of the technology.

### **Accomplishments**

- Ford F-150s have been tested at Argonne National Laboratory using the dynamometer facility in their Transportation Technology R&D Center. The Ford F-150s have been tested for emissions of carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), total hydrocarbons (THC), and nitrous oxides (NO<sub>x</sub>), and fuel efficiency (equivalent miles per gallon of gasoline). Tests were performed using different blends of compressed hydrogen (H<sub>2</sub>) and compressed natural gas (CNG) employing several different driving cycles. In September 2004, tests are planned for a Ford F-150 operating solely on compressed hydrogen (100% H<sub>2</sub>).
- The UAB study team has used Argonne's PSAT (Partnership for a new generation of vehicles Systems Analysis Toolkit) vehicle simulation software to model the performance, efficiency, and emissions of several prototype vehicles powered by hydrogen fueled internal combustion engines.
- Collected data for inputs to the Birmingham regional AirCred model and began coding model.
- Work has been devoted modeling electric power generation employing fuel cells using GCTool software developed by Argonne National Laboratory. Different configurations are currently being investigated.

### **Future Directions**

- Evaluate additional test vehicles (hydrogen ICE and hydrogen fuel cell) for performance and emissions;
- Simulate and compare hydrogen fueled vehicles to conventional ICEs in terms of performance and emissions.
- Use results of vehicle tests and simulations to evaluate potential impacts of a hydrogen vehicle deployment on regional air quality.
- Investigate infrastructure requirements for a Southeast regional hydrogen vehicle deployment, including potential hydrogen producers and transport mechanisms. Investigate codes and standards related to hydrogen fueling stations.

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### **Introduction**

Hydrogen fueled vehicles hold the potential to reduce the emissions of pollutants and greenhouse gases currently associated with conventional gasoline and diesel fueled vehicles. Hydrogen-based vehicle technologies, however, are still in the very early stages of development and their performance characteristics compared to conventional internal combustion engines (ICEs) are not well established. There are currently several promising hydrogen technologies available but their potential for

widespread deployment requires further evaluation. They include hydrogen fueled internal combustion engines, hydrogen-fueled hybrid electric vehicles, and hydrogen fuel-cell vehicles.

Any assessment of the potential for large scale deployment of these hydrogen technologies must be based on measured vehicle performance characteristics, not simply estimates. Only with realistic emissions and vehicle performance measures can we develop reasonable estimates of what impacts a large scale deployment would have



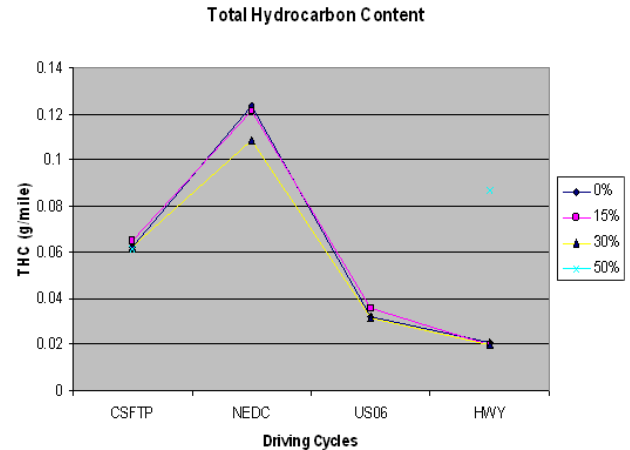
**Figure 1.** Ford F-150 Truck on Dynamometer at Argonne National Lab

on air quality and which vehicle technologies offer the most promising near term and long term benefits.

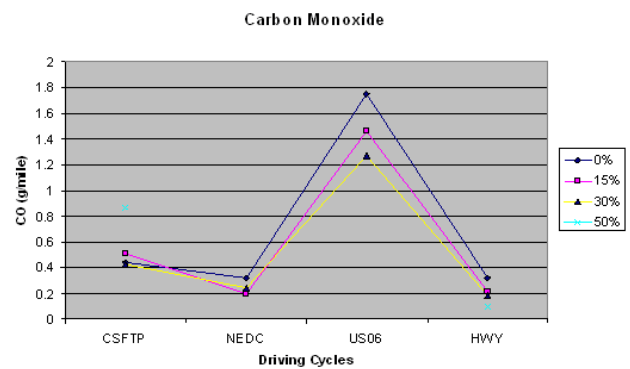
### **Approach**

The research will follow two primary tracks: (1) an evaluation of the performance characteristics of four hydrogen fueled vehicle technologies, and (2) an investigation of hydrogen infrastructure requirements. The study will examine four promising hydrogen vehicle technologies: methane fueled ICE vehicles, hydrogen fueled ICE vehicles, hydrogen fueled hybrid-electric vehicles, and hydrogen fuel cell vehicles. The performance and emission characteristics of each type of vehicle will be measured and the results of these tests will be incorporated into the PSAT vehicle simulation model. The PSAT model outputs will then be input into the AirCred and Greenhouse Gas Energy and Emissions in Transportation (GREET) models to estimate the air quality impacts of a large scale deployment of hydrogen vehicles in the Southeastern United States.

The second thrust of the research will be to investigate the infrastructure that such a large scale vehicle deployment would require. Based on the results from earlier portions of the study, estimates of the hydrogen demand for a large scale vehicle deployment will be developed and the cost of the additional infrastructure required to meet this demand will be assessed.



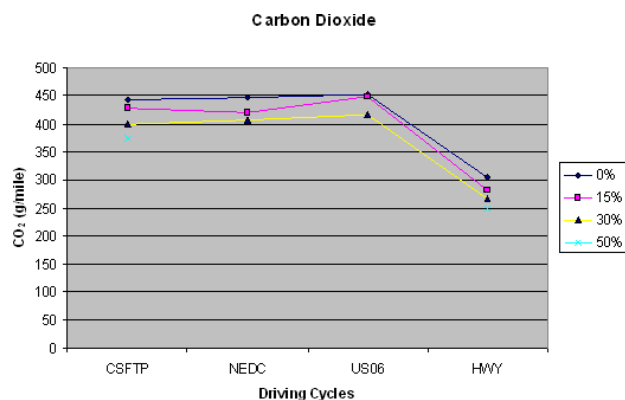
**Figure 2.** Comparison of the Total Hydrocarbon Emissions Achieved For Different Fuel Blends of Hydrogen and Compressed Natural Gas for Different Driving Cycles



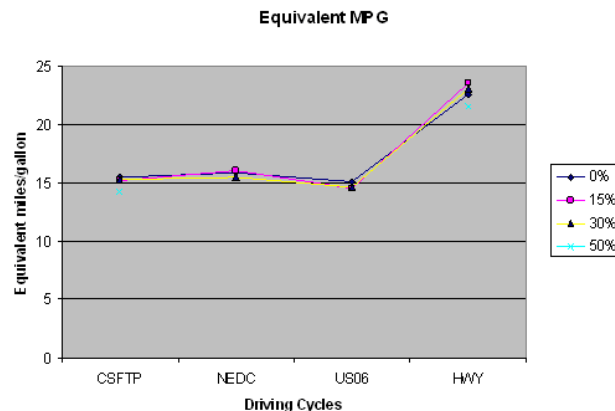
**Figure 3** Comparison of Carbon Monoxide Emissions Achieved for Different Fuel Blends of Hydrogen and Compressed Natural Gas for Different Driving Cycles

### **Results**

Results from the vehicle tests are shown in Figures 2 through 5. Figure 2 compares the emissions of total hydrocarbons for the different driving cycles for the various blends of hydrogen/compressed natural gas; the New European Driving Cycle has the highest emissions and the highway fuel economy cycle has the lowest. Figure 3 compares the emissions of carbon monoxide for the different driving cycles for the various blends of hydrogen/compressed natural gas; the US06 has the highest



**Figure 4** Comparison of Carbon Dioxide Emissions Achieved for Different Fuel Blends of Hydrogen and Compressed Natural Gas for Different Driving Cycles



**Figure 5** Comparison of Fuel Economy Achieved for Different Fuel Blends of Hydrogen and Compressed Natural Gas for Different Driving Cycles

emissions and the New European driving cycle and the highway fuel economy cycle have the lowest CO emissions. Figure 4 compares the emissions of carbon dioxide for the different driving cycles for the various blends of hydrogen/compressed natural gas; the highway fuel economy cycle has the lowest emissions (approximately  $\frac{2}{3}$  that achieved using the other driving cycles); the other driving cycles resulted in comparable CO<sub>2</sub> emissions. Figure 5 compares the fuel economy achieved employing each of the driving cycles. The highway fuel economy cycle resulted in the highest fuel economy (approximately 23 MPG), compared to a fuel economy of approximately 15 MPG for the other driving cycles.

Significant findings and conclusions from this task to date are summarized below:

- The HWFET cycle exhibited lower TH, CO and CO<sub>2</sub> and higher efficiency compared to the NEDC, CSFTP and US06 driving cycles.
- Maximum value of emissions for other cycles did not show any consistent trend.
- The fuel economy for NEDC, CSFTP and US06 were nearly the same while the HWFET cycle showed the highest efficiency.
- Total hydrocarbons, CO, and CO<sub>2</sub> decreased with an increase in hydrogen concentration
- NO<sub>x</sub> emissions increased with an increase in hydrogen concentration

- Hydrogen concentration did not have a significant effect on the efficiency of different driving cycles

## **FY 2004 Publications/Presentations**

### *Presentations*

1. Upadhyaya, J., R.W. Peters, and F.H. Fouad, 2003. "Use of Fuel Cell Technology in Electric Power Generation", Paper presented at the 2003 American Institute of Chemical Engineers (AIChE) Meeting, San Francisco, CA, (November 16-21).

### *Papers Accepted for Presentation*

1. Dutta, S., R.W. Peters, F.H. Fouad, M.J. Duoba, and H. Ng, 2004. "Emissions Performance on a Ford F-150 Using Various Fuel Blends on Compressed Natural Gas and Hydrogen" submitted and accepted for presentation in the session on "Environmental Impact of Fuel Cell Technology" at the 2004 Annual American Institute of Chemical Engineers (AIChE) Meeting, Austin, Texas, November 7–12, 2004.
2. Upadhyaya, J., R.W. Peters, F.H. Fouad, T. Das, J.F. Miller, and W.F. Podolski, 2004. "Environmental Impact of Fuel Cell Technology for Electric Power Generation" submitted and

accepted for presentation in the session on “Environmental Impact of Fuel Cell Technology” at the 2004 Annual American Institute of Chemical Engineers (AIChE) Meeting, Austin, Texas, November 7–12, 2004.

### **Other Activities**

1. Thesis successfully defended by Samrat Dutta in July 2004.; thesis topic was “An Investigation on Emissions and Efficiency from Hydrogen Blended Compressed Natural Gas”.

