III.5 Technical and Economic Studies of Regional Transition Strategies Toward Widespread Use of Hydrogen Energy

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Contract Number: XCM-4-44000-01

Start Date: April 1, 2004 (Phase I)
Projected End Date: January 30, 2005 (Phase I); July 1-November 30, 2005 (Phase II)

Objectives

- Assist the DOE in identifying promising paths for developing hydrogen (H_2) infrastructure.
- Use GIS-based simulation tools to evaluate alternative pathways toward widespread use of H_2, under various demand scenarios and regional conditions.
- Understand which factors are most important in finding viable transition strategies.
- Develop *rules of thumb* for future regional H_2 infrastructure development.
- Conduct regional case studies of H_2 infrastructure transitions
- Work with H2A core group to develop models of H_2 delivery systems.

Technical Barriers

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

- E. Lack of Understanding of the Transition of a Hydrocarbon-Based Economy to a Hydrogen-Based Economy

Approach

Three tasks were performed: 1) improving UC Davis' existing regional H_2 infrastructure models, 2) applying these tools to study H_2 infrastructure costs under various demand scenarios and regional conditions, and 3) participation in the H2A delivery group.

Accomplishments

<u>Task 1: Extended UC Davis' simulation tools to improve</u>

- GIS-based method for estimating regional H_2 demand
- Engineering/economic models of H_2 components (refueling stations, pipelines)

- Methods for designing a H_2 infrastructure (idealized models of distribution systems in cities; methods for siting stations)

Task 2: Carried out regionally specific case studies of H_2 infrastructure development

- Combined spatial tools and geographic data with engineering and economic models for H_2 infrastructure
- Developed methods that can be used anywhere in the U.S.
- Developed GIS database, including H_2 demand, potential H_2 supply, existing infrastructure, CO_2 sequestration sites
- Designed optimized H_2 infrastructure, estimated costs, performance, emissions for several H_2 delivery pathways in a specific region:
  - Centralized production from coal w/carbon capture and sequestration and H_2 pipeline delivery
  - Onsite natural gas reforming

Task 3: Participation in H2A group

- Member of H2A team analyzing H_2 delivery infrastructure
- Developed base case scenarios for H_2 delivery
- Developed Excel model for H_2 delivery system design and cost
- Presentation to FreedomCar Delivery Tech Team on H2A's work
- Co-author of presentation at 2005 NHA Conference on H2A delivery team's work, March 2005

Future Directions

- Work with the National Renewable Energy Laboratory and DOE to integrate UC Davis infrastructure models with other H_2 analysis models, to answer specific questions related to the development of H_2 infrastructure development. The goal is to make the best use of existing modeling tools to understand which factors are most important in finding viable transition strategies under different regional conditions.
- Develop *rules of thumb*, as a means to more efficiently study infrastructure development in succeeding years.

Introduction

The current lack of an extensive (H_2) infrastructure is often cited as a serious barrier to the introduction of H_2 as an energy carrier, and to the commercialization of technologies such as H_2 vehicles. Because H_2 can be made at a wide range of scales (from household to large city) and from a variety of primary sources (fossil, renewable and nuclear), there are many possible pathways for producing and distributing H_2 to users. The DOE has identified the need to find viable transition strategies toward widespread use of H_2.

In this work, we developed and applied simulation tools to evaluate alternative pathways toward widespread use of H_2 under various demand scenarios and regional conditions. Geographic information system (GIS) data are utilized as input to analysis, and to visualize results. The use of mathematical programming or other methods to screen the large design space of possible transition pathways for optimum solutions is employed. Using these techniques we carried out a series of regional case studies for H_2 infrastructure development. The goal is to understand which factors are most important in finding viable transition strategies under different regional conditions and to develop *rules of thumb* for future H_2 infrastructure development.

Approach

In earlier work, we developed GIS-based models for regional H_2 infrastructure design and cost. In this research, we extended these models, and applied them to geographic specific case studies.

- Improve engineering/economic models of H_2 energy system components, in particular refueling stations and H_2 pipeline systems.

- Use GIS data to study spatial relationships between H_2 demand, supply, primary resources, CO_2 sequestration sites, and existing infrastructure in a particular region.
- Explore use of various techniques (GIS analysis, mathematical programming) to find the lowest cost strategy for building a widespread H_2 energy system. Given a specified H_2 demand and resources for H_2 production, design a system to deliver H_2 to users at the lowest cost. Examine which transition paths give the lowest overall cost over time.
- Carry out regionally specific case studies of H_2 infrastructure development, involving multiple H_2 plants, multiple H_2 demand sites, using GIS data.

A second part of the project is working with the H2A, DOE's team of H_2 system analysts to develop base case data and scenarios for H_2 delivery systems

Results

Task 1: Improve UC Davis' regional H_2 infrastructure models

We made several improvements to UC Davis' existing simulation models for regional H_2 infrastructure development.

We improved our GIS-based methods for estimating spatially resolved H_2 demand for vehicles. The improved method is illustrated in Figure 1. Starting with U.S. census data at the block level, we estimate H_2 demand (kg/day) as proportional to (population) x (vehicles/person) x (fraction of H_2 vehicles in the fleet) x (H_2 use per vehicle). We then set thresholds to identify areas with sufficient H_2 demand for infrastructure development. Our method for estimating H_2 demand is set up as an interactive *calculator* that runs with ARCGIS software, and can be used anywhere in the U.S.

We improved some of the engineering/economic models of H_2 components used in our model, particularly for refueling stations and pipelines. As cost and performance models for H_2 system components become available from H2A, these will be incorporated into the model, as well.

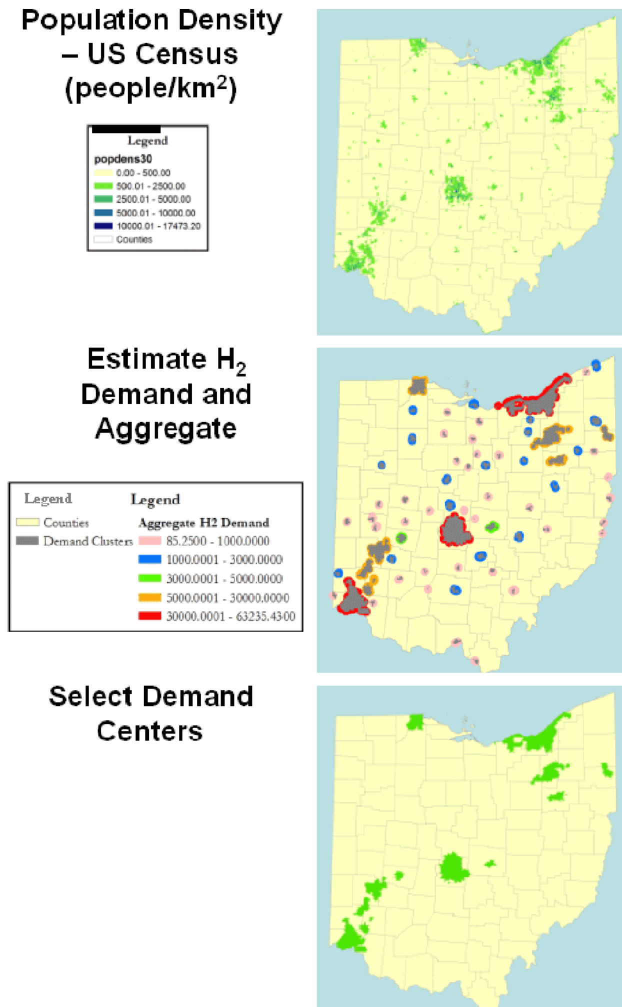

Figure 1. Improved GIS-Based Method for Estimating Regional H_2 Demand

We developed methods for designing and costing H_2 delivery infrastructure within cities, based on idealized models of truck and pipeline distribution systems in cities and approximate methods for siting stations. Results for the delivery system layout for trucks and pipelines are shown in Figure 2, for a circular city with 25 refueling stations.

As cost and performance models for H_2 system components become available from H2A, these will be incorporated into the model, as well.

Task 2: Carry out regionally specific case studies of H_2 infrastructure development

To better understand the issues for regional H_2 energy systems, we carried out a GIS-based analysis of H_2 infrastructure development in a particular region, the state of Ohio. The first step was developing a GIS database that includes estimates of H_2 demand, potential H_2 supply, existing infrastructure, and CO_2 sequestration sites (Figure 3). Demand areas are shown in green. Existing power plants, rights of way (electric and gas transmission lines), roads and CO_2 sequestration sites (brine wells) are indicated.

The question is how to link H_2 demand to supply in the lowest cost way. We used optimization methods (based on input from the GIS database) and conducted sensitivity studies to design low cost infrastructure. Several H_2 supply pathways were analyzed: central coal to H_2 plant with carbon capture and sequestration with pipeline delivery of H_2, and onsite production of H_2 via small scale steam methane reforming. An optimized infrastructure design is shown in Figure 4. A single large coal plant supplies the entire state via pipelines.

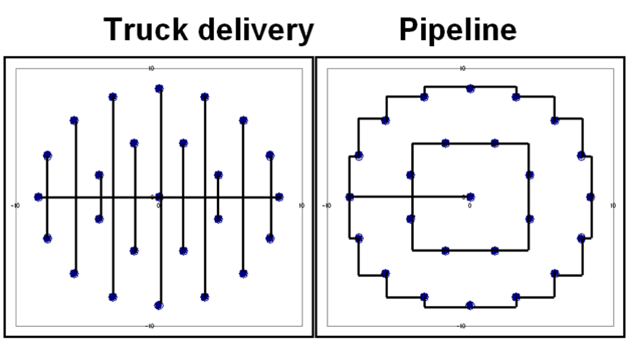

Figure 2. Distribution System Layout for Idealized City Models for Truck and Pipeline Delivery

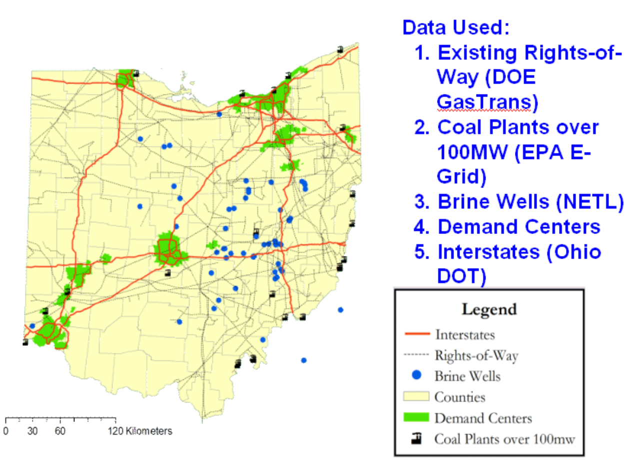

Figure 3. GIS Database Developed for Regional H_2 Infrastructure Analysis

We used our cost models for H_2 infrastructure to find the delivered cost of H_2 at 10% and 50% market penetration. These are shown in Figure 5. We see that onsite natural gas reforming is preferred at low market penetration level (10%), but at 50% central production with pipelines is preferred. The overall delivered H_2 cost is in the range of $2.5-3.5/kg.

Task 3. Participation in H2A group

In 2003, DOE convened H2A, a group of analysts studying H_2 energy systems. The goal is to produce a credible, well-documented set of information on H_2 production, delivery and forecourt refueling technologies and options. Project contributions to the H2A work include:

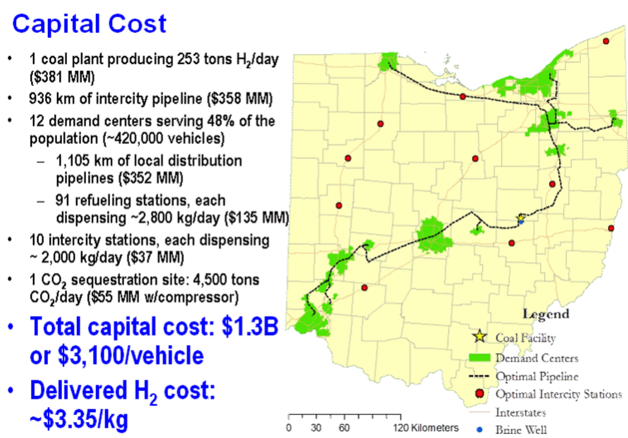

Figure 4. Optimized H_2 Infrastructure at 10% Market Penetration of H_2 Vehicles

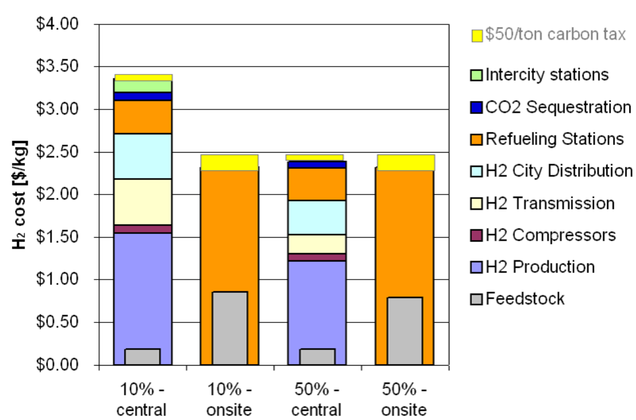

Figure 5. Delivered H_2 Cost ($/kg) (Centralized production from coal with carbon capture and sequestration and pipeline delivery vs. onsite steam methane reformer at 10% and 50% market penetration of H_2 vehicles.)

- Developed base case scenarios for H_2 delivery. Wrote an Excel spreadsheet model for defining delivery base case scenarios.
- Maintained close collaboration with researchers at DOE, NREL, and Argonne National Laboratory on analyzing H_2 delivery options plus interaction with industry advisors.
- Gave presentations on the delivery team's results to the DOE FreedomCar Tech team, July 2004
- Co-authored presentation at the National Hydrogen Association Meeting, March 2005.

Summary

This year, we made significant progress toward our goal of developing new simulation tools for modeling regional H_2 energy infrastructure development. We extended the capabilities of UC Davis' simulation models. We carried out regionally specific case study of H_2 infrastructure development, implemented tools that could be used anywhere in the U.S. We contributed to the H2A delivery team effort.

In future work, we plan to work with NREL and DOE to integrate UC Davis infrastructure models with other H_2 analysis models, to answer specific questions related to the development of H_2 infrastructure development. The goal is to make the best use of existing modeling tools to understand which factors are most important in finding viable transition strategies under different regional conditions. We hope to develop "rules of thumb", as a means to more efficiently study infrastructure development in succeeding years.

Special Recognitions & Awards/Patents Issued

1. In May 2005, Joan Ogden received an R&D Excellence award from the DOE Hydrogen Fuel Cells and Infrastructure Technologies Program for "Outstanding Achievement in Developing the Hydrogen Production Model Known as H2A".

FY 2005 Publications/Presentations

1. J. Ogden, "Roles for Hydrogen in a Future Sustainable Transportation System," presented at the
2. Transportation Research Board Integrating Sustainability Meeting, Baltimore, MD, July 12, 2004.
3. J. Ogden, "Hydrogen Delivery Analysis for the H2A Project," invited talk to the USDOE FreedomCar Technical Team, July 27, 2004.
4. J. Ogden, Research at UC Davis on Design and Analysis of Hydrogen Distribution Infrastructure," presented to the USDOE FreedomCar Fuel Pathways Technical Team, October 14, 2004.
5. J. Ogden, "Hydrogen Research at UC Davis," Presentation at Lawrence Livermore National Lab, October 21, 2005
6. J. Ogden, "The Outlook for Hydrogen as an Energy Carrier," presented at the Annual Meeting of the American Society of Mechanical Engineers, November 15, Anaheim, CA
7. J. Ogden, "Hydrogen Supply: Pathways and Strategies," presented to the United States Congress, Hydrogen and Fuel Cell Caucus, Washington, DC, January 11, 2005.
8. J. Ogden, C. Yang, N. Johnson, J. Ni., Z. Lin, "Technical And Economic Assessment Of Transition Strategies Toward Widespread Use Of Hydrogen As An Energy Carrier," Draft Final Report to the United States Department of Energy Hydrogen, Fuel Cells and Infrastructure Technologies Program For Phase I of NREL contract number XCM-4-44000-01, January 31, 2005
9. J. Ogden, "Hydrogen as an Energy Carrier," Presented to the Humphrey Scholars Program, University of California, Davis, Feb. 2, 2005.
10. J. Ogden, "Overview of Hydrogen System Modeling at ITS-Davis", Presentation at Sandia National Laboratory Feb. 18, 2005.
11. J. Ogden, "Infrastructure Development for the Hydrogen Economy," presented at the PowerGen Conference, Las Vegas, NV, March 3, 2005.
12. J. Ogden,"Pathways to a H2 Economy: Early Results from the Hydrogen Pathways Program," Department of Environmental Science and Policy, Faculty Seminar, University of California, Davis, March 16, 2005.
13. J. Ogden, "H2 as an Energy Carrier: Pathways and Strategies," presented at the California Biomass Collaborative Forum, Sacramento, CA, March 1, 2005.
14. Christopher Yang and Joan Ogden, "Analyzing Natural Gas Based Hydrogen Infrastructure – Optimizing Transitions From Distributed To Centralized H_2 Production," Proceedings of the 2005 National Hydrogen Association Meeting, Washington, DC, March 2005.
15. Jason Ni, Nils Johnson, Joan Ogden, Christopher Yang, and Joshua Johnson, ìEstimating Hydrogen

Demand Distribution Using Geographic Information Systems (GIS),î Proceedings of the 2005 National Hydrogen Association Meeting, Washington, DC, March 2005.

16. N. Johnson, C. Yang J. Ni, J. Johnson, Z. Lin, and J. Ogden, ìDesign of a Fossil Fuel-Based Hydrogen Infrastructure with Carbon Capture and Sequestration: Case Study in Ohio,î Proceedings of the 2005 National Hydrogen Association Meeting, Washington, DC, March 2005.

17. M. Mintz, Jerry Gillette, James Burke, John Molburg, and Joan Ogden*, "*Development Of Hydrogen Delivery Scenarios For Transportation Applications, " presented at the 2005 National Hydrogen Association Meeting, Washington, DC, March 2005.

18. J. Ogden, "Prospects for Hydrogen in California," presented at the Workshop on Energy and Sustainable Growth in California: New Horizons for Innovation and Adoption sponsored by the Center for Sustainable Resource Development and the Giannini Foundation, April 22, 2005, Berkeley, CA.