II.I.4 Technical and Economic Studies of Regional Transition Strategies toward Widespread Use of Hydrogen Energy

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Objectives

- Assist the DOE in identifying promising paths for developing hydrogen infrastructure
  - Develop new simulation tools to evaluate alternative pathways toward widespread use of hydrogen 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 hydrogen infrastructure development
- Conduct regional case studies of hydrogen infrastructure transitions
- Work with H_2A hydrogen analysis core group to develop models of hydrogen delivery systems

Technical Barriers

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

- A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis

Approach

- Develop new simulation tools to assess alternative transition strategies toward widespread use of H_2 under various demand scenarios and regional conditions
- Explore use of various techniques (geographic information system analysis, mathematical programming) to find the lowest-cost strategy for building a widespread H_2 energy system
- Carry out regionally specific case studies of hydrogen infrastructure development

Accomplishments

- Implemented simple geographic information system (GIS)-based method for modeling hydrogen demand spatially over time
- Implemented engineering/economic models of hydrogen technologies (production, storage, distribution and refueling systems)
- Developed GIS maps of potential resources for H_2 production, existing infrastructure; GIS data base for studying hydrogen supply and demand
- Explored optimization methods to design lowest-cost system connecting supply and demand, and find lowest-cost transitions
- Participated in H_2A group

Future Directions

Remainder of Phase I (5/04-9/04)

- Develop simulation tools to study regional hydrogen transitions
  - Update hydrogen energy system component cost and performance models to reflect new data available from H2A
  - Compare hydrogen demand models with other work in the literature and ongoing within DOE
  - Further develop mathematical optimization methods to find lowest-cost infrastructure solutions
  - Develop GIS data base for studying hydrogen infrastructure in the Midwest, including natural gas steam reforming and coal power plant supply options
- Continue work with H2A group on delivery analysis

Phase II (10/04-4/06)

- Add capability to model renewable hydrogen
- Conduct geographic specific case studies of hydrogen infrastructure development

Introduction

The current lack of an extensive hydrogen (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. The DOE has identified the need to find viable transition strategies toward widespread use of hydrogen.

In this work, we are developing simulation tools to evaluate alternative pathways toward widespread use of hydrogen 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 being explored. 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 hydrogen infrastructure development.

Approach

The main thrust of the work is to develop new simulation tools to assess alternative transition strategies toward widespread use of H_2 under various demand scenarios and regional conditions. The work is carried out in several steps:

- Develop engineering/economic models of hydrogen energy system components: H_2 demand, H_2 production systems, H_2 transmission and distribution, H_2 refueling stations, CO_2 sequestration.
- Use GIS data to study spatial relationships between H_2 demand, H_2 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 and multiple H_2 demand sites, using GIS data.
- A secondary part of the project is working with the H2A, DOE's team of hydrogen system analysts, to develop "base case" data and scenarios for hydrogen delivery systems.

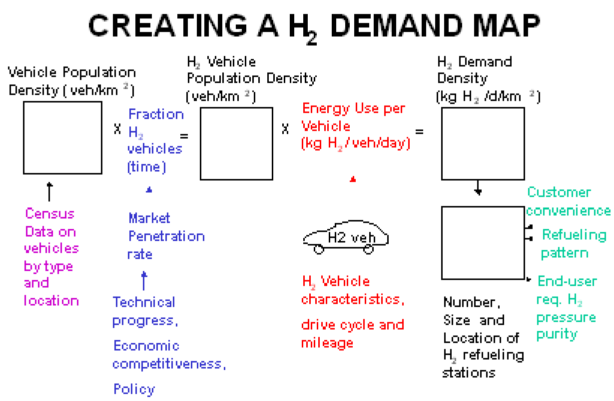

Figure 1. Method for Calculating Hydrogen Demand in Space and Time

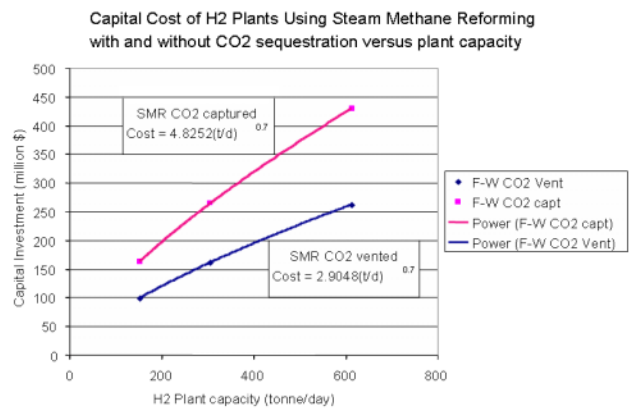

Figure 2. Example of Engineering/Economic Cost Data Developed: Capital Cost of a Large Steam Methane Reformer Hydrogen Plant Versus Plant Capacity

Results

Implement simple GIS-based method for modeling hydrogen demand spatially over time

Understanding the evolution of a hydrogen fuel delivery infrastructure depends on the spatial and time characteristics of the hydrogen demand. We have developed a simple method to model the magnitude, spatial distribution, and time dependence of hydrogen demand, based on GIS data on populations, projections for energy use in hydrogen vehicles, and market penetration rates. This method for calculating a map of average hydrogen demand is illustrated in Figure 1.

Implement engineering/economic models of hydrogen technologies (production, storage, distribution and refueling systems)

We have implemented models for the cost and performance of hydrogen production, storage, distribution and refueling systems as a function of scale. We consider a variety of possible hydrogen supply and delivery options that are likely to be important in future hydrogen energy systems:

Centralized, large-scale production of hydrogen from:

- Steam reforming of natural gas with and without CO_2 sequestration
- Coal gasification with and without CO_2 sequestration
- Biomass gasification
- Large-scale electrolysis

Distributed production of hydrogen at refueling sites from:

- Natural gas reforming
- Electrolysis using off-peak power

For centralized production, we consider hydrogen delivery via truck (compressed gas or liquid) and via gas pipeline. For fossil-based hydrogen with CO_2 sequestration, we consider a disposal system for CO_2.

At refueling stations, we assume that hydrogen is dispensed to vehicles as a compressed gas for onboard storage at 5000 psi.

Cost and peformance estimates are drawn from previous hydrogen infrastructure studies by the principal investigator and her colleagues, and from other studies in the literature and ongoing (see list of references). An example of the kind of data developed is shown in Figure 2. These will be updated when the H2A models become available.

Develop GIS maps of potential resources for H_2 production, existing infrastructure; GIS data base for studying H_2 supply and demand

We have developed a preliminary geographic information system data base to study the relationship between hydrogen supply and demand, and existing infrastructure. This is shown in Figure 3 for the case of coal-derived hydrogen in Ohio. The darker areas indicate higher population density (and

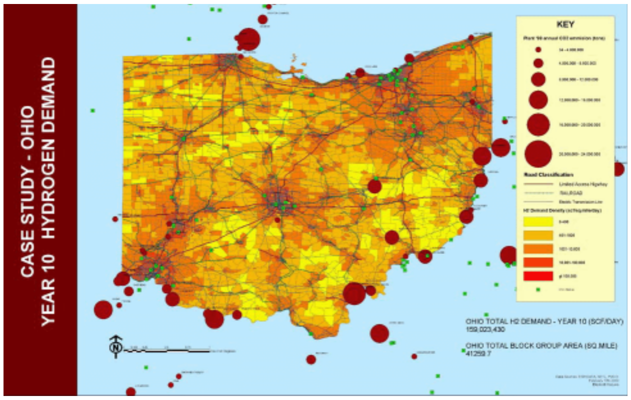

Figure 3. Geographic Information System Map of Potential Hydrogen Demand and Supply in Ohio

higher hydrogen demand); circles indicate coal-fired power plants that could be converted to make hydrogen. Roads and rights of way for pipelines and electric transmission are shown. This kind of map is useful for matching supply and demand.

Explore optimization methods to design lowest-cost system connecting supply and demand, and find lowest-cost transitions

As a first step, we developed an EXCEL-based spreadsheet model to design a hydrogen supply system to meet a specified steady-state demand. We estimate infrastructure design and cost as a function of a relatively small number of variables embodying averaged and/or simplified information about:

- H_2 markets (fraction of H_2 vehicles in fleet, station size and coverage; rural v. urban)
- Geographic factors (size and geographic density of demand, idealized model of a city)
- Cost and performance of H_2 technologies (vehicles and infrastructure)

Preliminary results from this model are shown in Figure 4. The delivered H_2 cost is plotted as a function of the fraction of hydrogen vehicles in the fleet. We see that the lowest-cost supply option depends on the level of hydrogen use in the city. For a small market penetration level, onsite production is favored, but at high fractions of H_2 vehicles, pipeline distribution is the lowest-cost option.

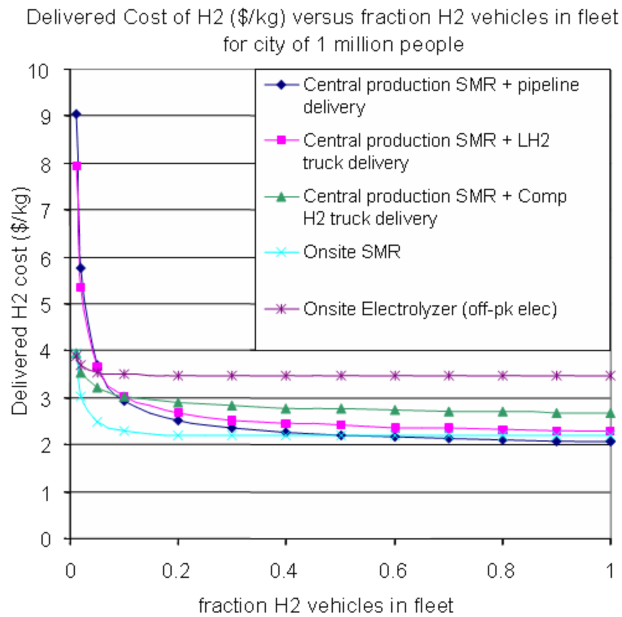

Figure 4. Results from Simplified Model of Hydrogen Infrastructure Costs

Participation in H_2A group

In 2003, DOE convened H_2A, a group of analysts studying hydrogen energy systems. The goal is to produce a credible, well-documented set of information on hydrogen production, delivery and forecourt refueling technologies and options. The principal investigator has been active in the H_2A effort since its beginning. Her accomplishments in the H_2A work include:

- Member of the H_2A “core team” of 10 analysts
- Lead role in H_2A team analyzing hydrogen delivery infrastructure
- Developed information on alternative pathways for delivering hydrogen to consumers
- Developed base case scenarios for hydrogen delivery; wrote an EXCEL spreadsheet model for defining delivery “base case” scenarios
- Maintained close collaboration with researchers at DOE, National Renewable Energy Laboratory, Argonne National Laboratory on analyzing hydrogen delivery options, and interacted with industry advisors
- Gave a presentation at the NHA Analysis Symposium on delivery team’s work in April, 2004

Conclusions

In Phase I of this project, we made significant progress toward our goal of developing new simulation tools for modeling regional hydrogen energy infrastructure development.

- We implemented a simple method for modeling geographically specific scenarios for future hydrogen energy demand using GIS data.
- We modeled cost and performance of hydrogen infrastructure components, including hydrogen production, storage, distribution, and refueling systems, as a function of scale and energy prices.
- We developed GIS maps showing primary energy sources for hydrogen production in a given location.
- We implemented a simple analytic model for design and cost estimation of hydrogen infrastructure in terms of simplified models of hydrogen markets, geographic factors and technical assumptions.

Also, we contributed to the H_2A project through developing models of hydrogen delivery systems.

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1. J.M. Ogden, "Where Will the Hydrogen Come From? Systems Considerations and Hydrogen Supply," chapter in Hydrogen Transitions, ed. D. Sperling and J. Cannon, the Proceedings of the 9th Biennial Conference on Transportation and Energy, Asilomar, CA, July 30-August 1, 2003.
2. J. M. Ogden, "Potential Roles for Hydrogen in the Future Energy System," invited lecture at the Chautauqua Institution, Chautauqua, NY, August 7, 2003.
3. J.M. Ogden, "Modeling Hydrogen Energy Systems," presentation at Sandia National Laboratory, Livermore, CA, August 29, 2003.
4. J. M. Ogden and Elizabeth Kaijuka, "Technical and Economic Assessment of Transition Strategies Toward Widespread Use of Hydrogen as an Energy Carrier, Phase I Final Report: July 2002-August 2003", Report to the United States Department of Energy Hydrogen, Fuel Cells and Infrastructure Technologies Program for Phase I of NREL contract number SCM-2-32067-01, January 13, 2004.
5. J.M. Ogden, M. Mintz and M. Ringer, "H2A Delivery Analysis," presented at the H2A Industry Review Meeting, February 23-25, 2004, Washington, DC.
6. J.M. Ogden, "Hydrogen as a Future Transportation Fuel," seminar at UC Berkeley, Energy and Resources Group, April 20, 2004.
7. J.M. Ogden, M. Mintz, M. Ringer, "Hydrogen Delivery Analysis," presented at the National Hydrogen Association Meeting, Los Angeles, CA, April 28, 2004.
8. C. Yang and J.M. Ogden, "A Simplified Integrated Model for Studying Transitions to a Hydrogen Economy," presented at the National Hydrogen Association Meeting, Los Angeles, CA, April 28, 2004.
9. J.M. Ogden, "Hydrogen Delivery Model for H2A Analysis: A Spreadsheet Model for Hydrogen Delivery Scenarios," final report prepared for the National Renewable Energy Laboratory under NREL Contract No. SCM-2-32067-01, May 15, 2004.