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 H₂A 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 H₂ 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 H₂ 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 H₂ 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 H₂A 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\textsubscript{2}) infrastructure is often cited as a serious barrier to the introduction of H\textsubscript{2} as an energy carrier and to the commercialization of technologies such as H\textsubscript{2} vehicles. Because H\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{2} demand, H\textsubscript{2} production systems, H\textsubscript{2} transmission and distribution, H\textsubscript{2} refueling stations, CO\textsubscript{2} sequestration.
- Use GIS data to study spatial relationships between H\textsubscript{2} demand, H\textsubscript{2} supply, primary resources, CO\textsubscript{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\textsubscript{2} energy system. Given a specified H\textsubscript{2} demand and resources for H\textsubscript{2} production, design a system to deliver H\textsubscript{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\textsubscript{2} infrastructure development, involving multiple H\textsubscript{2} plants and multiple H\textsubscript{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.
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 CO₂ sequestration
- Coal gasification with and without CO₂ 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 CO₂ sequestration, we consider a disposal system for CO₂.

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

Cost and performance 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 H₂ production, existing infrastructure; GIS data base for studying H₂ 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
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:

- H₂ markets (fraction of H₂ 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 H₂ technologies (vehicles and infrastructure)

Preliminary results from this model are shown in Figure 4. The delivered H₂ 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 H₂ vehicles, pipeline distribution is the lowest-cost option.

*Participation in H₂A group*

In 2003, DOE convened H₂A, 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 H₂A effort since its beginning. Her accomplishments in the H₂A work include:

- Member of the H₂A “core team” of 10 analysts
- Lead role in H₂A 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 H2A project through developing models of hydrogen delivery systems.

References


FY 2004 Publications/Presentations


