VIII.4 Energy Systems Analysis: HyDS Modeling Environment

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Projected model development end-date: September 2006; scenario analysis to continue at the discretion of DOE.

Objectives

- Determine the technologies that will be used to provide hydrogen during the transition to a hydrogen economy.
- Understand the cost reductions and performance improvements that will be required to make hydrogen technologies come on-line sooner.
- Determine what external influences/polices will enable hydrogen technologies to come on-line sooner.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section (4.5) of the Hydrogen, Fuel Cells, and Infrastructure Technologies Program Multi-Year Research, Development, and Demonstration Plan:

(B) Lack of Consistent Data, Assumptions, and Guidelines

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

Accomplishments

- Developed the HyDS Modeling Environment (HyDS ME):
  - Developed a minimum spanning tree algorithm to account for production and delivery economy of scale, geographic extent, and natural gas price forecasts.
  - Created direct connection with H2A Production spreadsheets via the Cost Curve Module.
  - Simplified, via regression analysis, outputs from the H2A Scenario Model to inform delivery infrastructure costs.
  - Improved GIS representation of cities via combination of Urban Area and Urban Cluster (above 10,000 people) census datasets.
  - Added liquid delivery option.
- Completed various scenario runs and generalized results.

Introduction

A hydrogen economy will require substantial infrastructure investment. The nature of that infrastructure, i.e. the source of production and the mode of transportation and distribution, has been a topic of considerable research in the last few years. Researchers have compiled component costs from steam methane reforming to tractor/trailer and storage costs (NREL's H2A). Others have addressed infrastructure from a national perspective (ORNL's HyTRANS, OnLocation's NEMS-H2), or considered one city at a time (DTI). These models also consider temporal aspects of a hydrogen transition. Other research has combined components to deal with a specific portion of the delivery system (H2A Scenario Model) or laid out infrastructure for a specific region or metropolitan area (UC-Davis).

The HyDS Modeling Environment, or HyDS ME, is a GIS-based infrastructure optimization model. The model combines existing cash flow models, GIS capability, and an optimization routine to determine the layout of a least-cost infrastructure. The user chooses the region, a forecasted year, desired hydrogen vehicle penetration, natural gas forecasts, plus other options before optimizing for the least-cost infrastructure. A regional supply curve is output along with a map of the infrastructure.

Approach

The HyDS ME uses a modified minimum spanning tree algorithm to compete different production and delivery technologies to determine a least-cost solution. This falls in the optimization realm of graph theory. A graph is a set of nodes and edges, or lines that connect the nodes. A minimum spanning tree is a special subset of edges that connect all the nodes within the graph at a least cost. That is, a minimum spanning tree answers the colloquial question: How can one connect all the dots (nodes) with least effort, or cheapest cost?

In essence, an urban area has three choices. It can either (1) serve its own load with distributed hydrogen, (2) serve its own load with central hydrogen, or (3) piggyback onto a neighboring community's central hydrogen production. Within each of these three choices, there are many options for production, transportation, and distribution. The various pathways are summarized in Figure 1.

As cities are added to the minimum spanning tree, costs are updated to reflect new economies of scale that are realized in production, transportation, and distribution. This iterative solution allows for regional clusters to develop, leveraging the demands of nearby larger cities, thus creating an interdependent delivery network. Below is a table of the production, transportation, and distribution options available for hydrogen pathway optimization within the HyDS ME

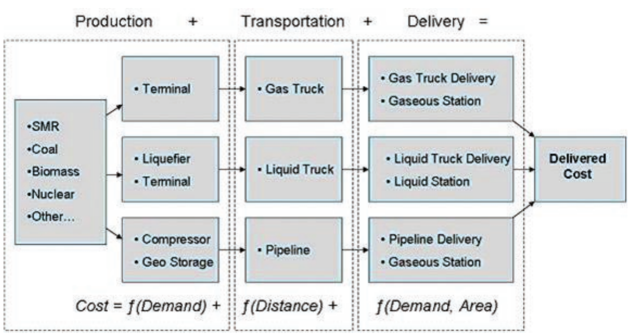

FIGURE 1. Pathway Options and Costs

(Table 1). Production costs come directly from H2A Production spreadsheets. Transportation and delivery costs come from regression analysis of hundreds of H2A Scenario Model runs.

The hydrogen demand is exogenously defined through user-input vehicle penetration and household vehicle information. The total hydrogen demand for a city is prefaced on the Census 2000 household vehicle population for each Urbanized Area (UA)[1] multiplied by the assumed penetration. It is possible to define a different vehicle penetration for each urban area. If this detail is unwarranted, a single penetration is applied uniformly across the selected region.

Results

The hydrogen economy transition results in a central production versus a distributed production interface. That is, there will be large demand centers with large central facilities that use pipelines to distribute to nearby communities. Further out, when communities become small and distant, distributed technology dominates as the cost of delivering ever smaller amounts of hydrogen overwhelm marginal increases in production economy of scale.

In Figure 2, the Chicago/Detroit area was selected to illustrate results that can be produced by the HyDS ME; any region in the U.S. can be modeled in a similar manner. The black splotches represent urbanized

[1]An Urban Area (UA) is defined as a core census block group that have a population density of 1,000 people per square mile plus all contiguous areas with more than 500 people per square mile and the total population is 50,000 people or greater. US Census Bureau Website; http://www.census.gov/geo/www/ua/ua_2k.html

TABLE 1. Production, Transportation, and Delivery Infrastructure Available Within the HyDS ME

Production, Transportation, and Delivery Technologies

Central Production	**Distributed Production**	**Transportation & Delivery***
SMR w/out CCS SMR w/ CCS Coal Gasification w/out CCS Coal Gasification w/ CCS Biomass Wind Wind w/ Co-Product Nuclear Hi Temp Etrol Nuclear Sulfur-Iodine	SMR (100 kg/day) SMR (1500 kg/day) Electrolysis (100 kg/day) Electrolysis (1500 kg/day)	Compressed Gas Truck Liquid Truck Pipeline

*Transportation and Delivery is further divided into component parts

Transportation and Delivery Components

Compressed Gas Truck	Liquid Truck	Pipelines
Truck & Trailer Compressor Terminal Station	Truck & Trailer Liquefier Terminal Station	Transportation Pipeline Distribution Pipelines Compressor Station

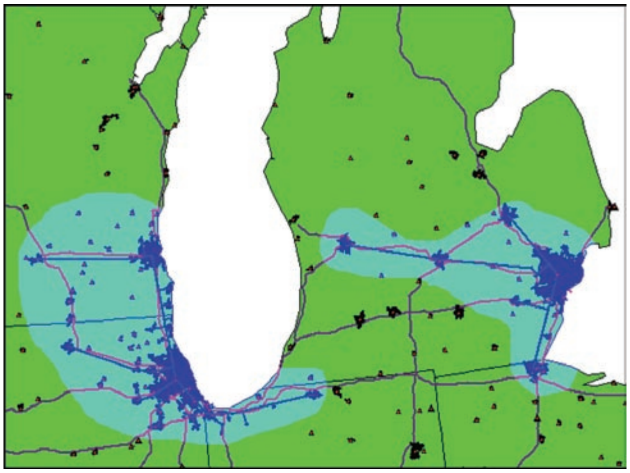

FIGURE 2. Central versus Distributed Interface, Chicago/Detroit

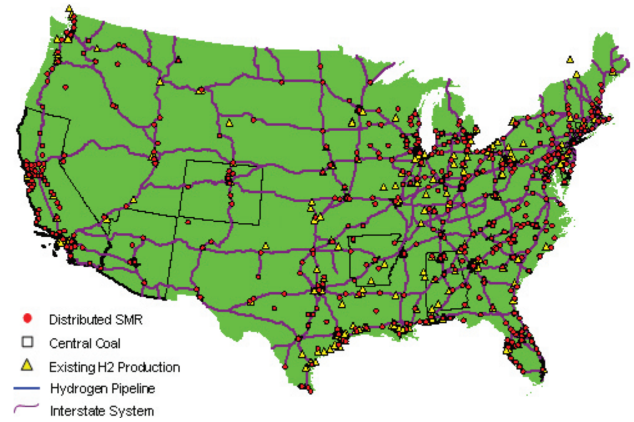

FIGURE 3. $6.26/MMbtu Natural Gas Price at 15% Penetration

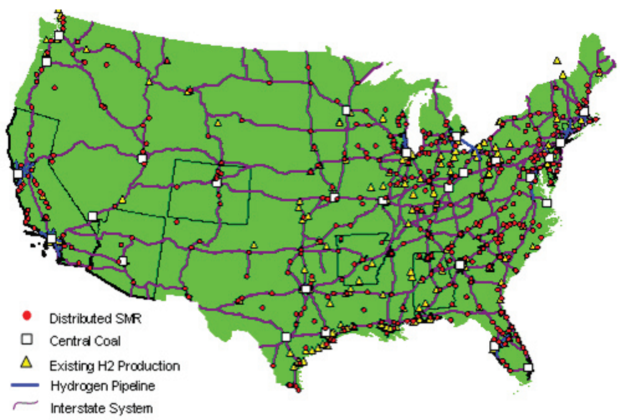

FIGURE 4. $12.00/MMBtu Natural Gas Price at 15% Penetration

areas. Thin black lines represent state boundaries and the purple lines represent the Interstate system. The blue lines connecting urban areas represent hydrogen pipelines. The shaded area represents the extent of the pipeline network or cluster. For example, the left shaded area represents the pipeline cluster centered on Chicago. The right shaded area represents the pipeline cluster anchored by Detroit. Communities outside these two clusters opt for distributed hydrogen production rather than join the cluster due to high transportation and distribution costs. This difference in production technology defines the central versus distributed production interface.

The geographic extent of the central distributed production is sensitive to the price of natural gas. Steam methane reforming (SMR) is the clear winner with regard to distributed technologies. The feedstock, natural gas, is the primary driver determining distributed SMR costs. When natural gas costs are sufficiently low, distributed SMR is the least-cost infrastructure, beating central technologies on price.

For instance, consider two scenarios: the base case of $6.26/MMBtu[2] and a sensitivity case of $12/MMBtu natural gas at 15% penetration (Figure 3 and 4). Note the results are prefaced on H2A Production and H2A Scenario Model cost assumptions. Feedstock forecasts, excluding natural gas, are based on the AEO2005 High A forecast.

In the base case, distributed natural gas dominates. The cost of 1,500 kg/day distributed resource is $2.78/kg. No central technologies can compete with hydrogen at that price.

The sensitivity case demonstrates a large transition to coal gasification. Twenty-seven production centers proximal to the largest demand areas emerge. Communities near these centers leverage the new production via transportation pipelines. Communities too small and distant from these centers use distributed steam methane reforming.

The supply curve for the contiguous United States is displayed in Figure 5. The x-axis represents the cumulative hydrogen demand from least expensive to most expensive. The y-axis represents the total delivered cost. From left to right, the prices rise depending on the central plant size, relative transportation costs, and intra-city delivery costs. Eventually, the cost to build and transport from central production reaches the price of distributed SMR using $12/MMbtu natural gas ($3.80/kg). Communities opt for the less expensive SMR rather than assuming ever larger transportation and delivery costs associated with central production.

The 82 urban areas that chose central technology represents 18% of the urban areas and 7.8M kg/day, or 69% of the total demand (11.3M kg/day). The remaining 366 urban areas represent 3.5M kg/day, or 31% of the total demand. That is, a small number of large urban areas have the majority of the potential

[2]AEO2006 forecasted 2015 High A natural gas price in 2003 dollars.

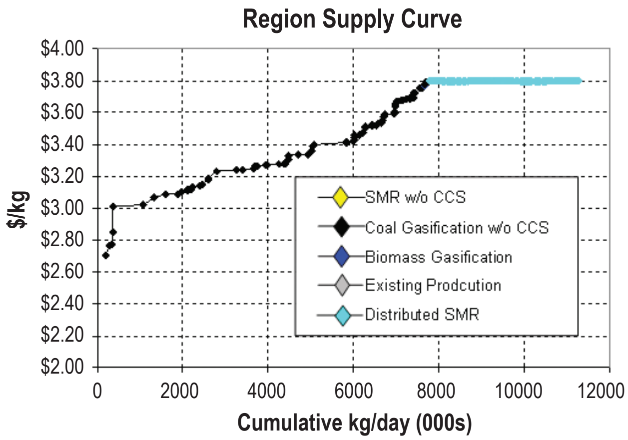

FIGURE 5. Hydrogen Supply Curve for the Contiguous United States at 15% Penetration

hydrogen demand due to sheer market size. The remaining small and disparate communities suffer from their own small market size as well as their relative distance from demand centers.

Conclusions

The HyDS ME provides a platform for analyzing hydrogen infrastructure impacts. Geographic characteristics such as vehicle population, size, and relative distances to larger markets are considered. Production, transportation, and delivery costs and their relative economies of scale are considered together on a regional basis.

The natural gas price is a major driver in determining least-cost hydrogen infrastructure. Distributed steam methane reforming is a least-cost infrastructure choice at 15% and lower penetration of vehicles. Natural gas price drives SMR costs. With nearly double natural gas price assumed ($12/MMBtu), central technologies may serve up to 69% of the total demand of hydrogen nationwide at 15% penetration. Smaller and more rural urban areas suffer from small market size and distance from major demand centers.

Future Directions

- Use model in various analysis tasks regarding hydrogen infrastructure analysis.
- Make HyDS ME available to the hydrogen analysis community.
- Improve outputs from model after receiving feedback from users. Maintain and fix bugs.

Presentations

1. FY 2006 Hydrogen Program Review.
2. Delivery Tech Team Presentation (July 26).
3. DOE Hydrogen Transition Analysis Meeting (August 9-10).