II.I.5 Hydrogen Production in a Greenhouse Gas Constrained Situation

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Objectives

- To examine plausible scenarios for a transition to a hydrogen economy through 2050 in a detailed quantitative manner.
- To explicitly illustrate the sequencing of major phases of the transition scenarios and their implications.
- To quantify the greenhouse gas (GHG) impactsof each of the transition scenarios, as well as the economic implications and energy impacts of the transition.
- To explore the spatial characteristics of the transition scenarios based on geographical information system (GIS) analyses for four greater metropolitan areas of the USA: Boston, Denver, Houston, and Seattle.
- To account for relevant techno-economic and policy factors:
  - demographic, spatial characteristics, and refueling infrastructure
  - electricity supply (including transmission and distribution) system characteristics/constraints
  - cost and performance of technologies (and future innovation) for hydrogen production, distribution, storage, and end-use (both transportation and stationary)
  - feedstocks for hydrogen production
  - regulatory contexts
  - timing and extent of transition pathways

Technical Barriers

This project is a cross-cutting analysis linked to the Technology Validation component of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan. It contributes to “testing complete system solutions that will address all elements of infrastructure and vehicle technology and investigate novel approaches…”. As a long-term scenario analysis, it also helps to “validate whether the technical targets for the individual components (developed within other subprograms) can still be met when integrated into a complex system…”.

Specifically, this project relates to the following subtasks within Technical Task 6 –“Technical Analysis”:

- “Analyze hydrogen and electricity as energy carriers and evaluate potential synergies from marrying the electrical transmission and transportation systems.”
- “Analyze integrated renewable hydrogen production systems that combine electrolysis powered by wind, solar, hydropower, or geothermal with biomass gasification systems.”

These tasks relate to the following Technology Validation barriers:

- A. Vehicles

- B. Storage
- C. Hydrogen Refueling Infrastructure
- D. Maintenance and Training Facilities
- F. Centralized Hydrogen Production from Fossil Resources
- G. Hydrogen from Nuclear Power
- H. Hydrogen from Renewable Resources
- I. Hydrogen and Electricity Coproduction

Approach

This project examines the possible evolutionary paths of hydrogen technologies and a hydrogen infrastructure that meets the objectives laid out in the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan to realize energy security, environmental, and economic benefits.

<u>This project's analysis:</u>

- Takes an integrated approach, considering the entire hydrogen fuel cycle from energy resource through production and distribution to end-use.
- Considers the use of hydrogen as an energy carrier to replace existing fuels.
- Takes a long-term perspective, constructing plausible scenarios by which hydrogen could expand in a gradual and orderly manner until it comprises the majority of transportation fuel use. A total of 6 plausible scenarios per city are being examined.
- Accounts for the important spatial aspect of infrastructure development, using a GIS analysis to create realistic infrastructure development scenarios to 2050 for four cities: Denver, Houston, Boston, and Seattle.
- Accounts for various feedstocks (biomass, coal, natural gas) and electricity in hydrogen production facilities and various delivery options to refueling centers (pipeline, tanker truck, on-site production).
- Quantifies the greenhouse gas impacts deriving from various integrated technological pathways for each city.
- Relies on techno-economic assumptions of the hydrogen analysis community, research literature, and technology developers.
- Benchmarks the analysis against the Annual Energy Outlook 2003 (AEO2003), an energy and policy periodic report derived from the National Energy Modeling System (NEMS) of the DOE's Energy Information Agency.

Accomplishments

Research accomplishments to date include the following steps.

- Identified techno-economic parameters underlying hydrogen production pathways based on primary literature and interaction with experts.
- Identified vehicle techno-economic parameters.
- Constructed a computer model for tracking the full fuel cycle impacts of growth in hydrogen demand on hydrogen production, fuel cell vehicle sales/stocks, energy use, costs, and greenhouse gasimpacts.
- Analyzed city-specific aspects of scenario development, including vehicle types, penetration rates, and refueling infrastructure.
- Constructed GIS maps produced by displaying consolidated metropolitan statistical area (CMSA) regions by census block and layering onto these census blocks the geocoded locations of existing private and public refueling stations.

- Analyzed how density and scale of demand influence cost of delivery.
- Determinedspatial distribution of density of demand for each city via techno-economic and GIS analysis.
- Analyzed supply requirements and feasible production and distribution pathways.

Future Directions

The work for the coming months consists of refining the scenarios and finalizing results. Intermediate results will be used to the refine the details of the scenario construction. In particular:

- The spatial GIS analysis will determine the growth over time in demand and demand density, and the relative contribution of different hydrogen production pathways and distribution modes (i.e., pipeline, delivered, and on-site production).
- The demand requirements derived from the national and city-specific analyses will be inputs to the NEMS analysis of the electricity sector, yielding impacts on the electricity system and energy resource fuel prices.
- Integrated energy system effects will provide economic results (costs and benefits relative to the corresponding reference scenarios)
- Net environmental impacts will be examined from the integrated full-cycle perspective.

Introduction

This research project is perhaps the first quantitative assessment of alternative hydrogen futures that attempts to explore vehicle and infrastructure technology and environmental, regulatory, and economic systems within an integrated analysis. Specifically, the project seeks to quantify the greenhouse gas (GHG) impacts of a transition to a hydrogen economy in four greater metropolitan areas of the U.S. The direction and magnitude of the GHG impacts depends upon a number of factors including demographic and spatial characteristics, technology cost and performance of hydrogen fuel cell vehicles, regulatory contexts, timing and extent of transition pathways, technologies used for producing hydrogen, and features of the hydrogen distribution infrastructure. This project models the transition to a hydrogen economy in the four cities using the a computer model developed at Tellus, and NEMS, the National Energy Modeling System used by the Department of Energy.

Approach

The approach to this project has two main components: (1) to synthesize current techno-economic knowledge for each of the components of the hydrogen infrastructure (production, transmission, distribution) and hydrogen end-use technologies (vehicle and stationary), including current appraisals of future techno-economic prospects; and (2) to integrate this information into plausible scenarios to derive the cost and benefit (both economic and GHG) implications of transitioning to a hydrogen economy. Such an approach will capture the significant trends in technological progress while offering policymakers - through the scenario analysis - a view of the implications of these trends. The GIS component of the analysis allows for region-specific results.

Results

With respect to the first analytical component mentioned above, we have assembled and synthesized the relevant techno-economic information for hydrogen infrastructure and end-use technologies. Based on information available in public domain literature and discussions with experts in the field (including those participating in the Hydrogen Analysis group convened by the DOE) we have identified and vetted techno-economic parameters. We have also acquired and analyzed the information necessary for the GIS aspects of the research, which entailed producing geocoded maps representing hydrogen fuel demand for the four cities of interest: Boston, Denver, Houston, and Seattle. Figure 1 presents this information in the case of the Seattle CMSA, disaggregated by hydrogen demand for personal vehicles (red dots) and centrally-fueled fleet vehicles (blue dots). These

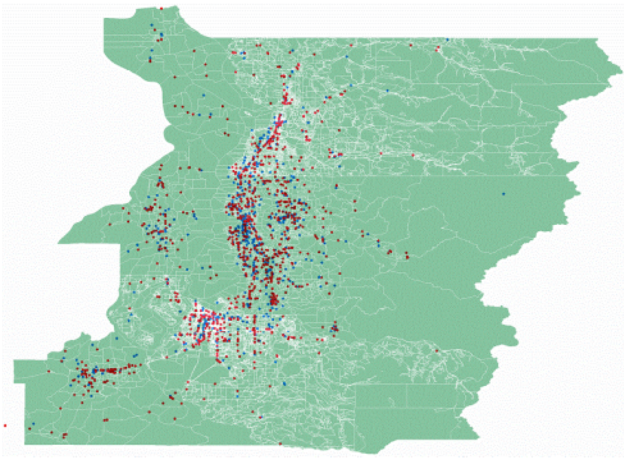

Figure 1. Hydrogen Demand Distribution in the Seattle CMSA

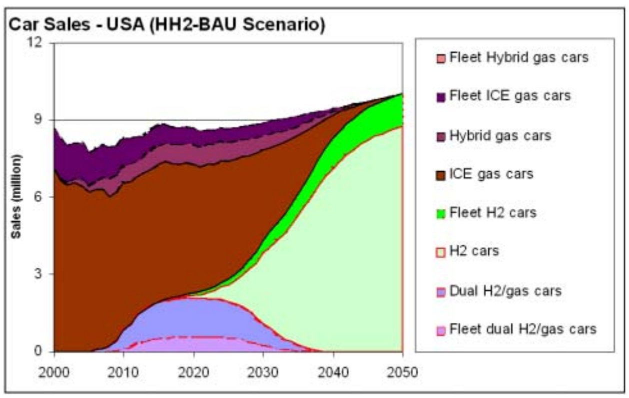

Figure 2. One Scenario Projection for Disaggregated Demand Groups

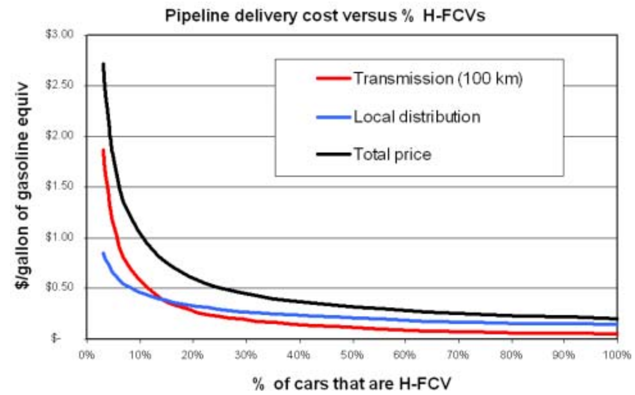

Figure 3. Sensitivity of Hydrogen Delivery Cost with Demand Density

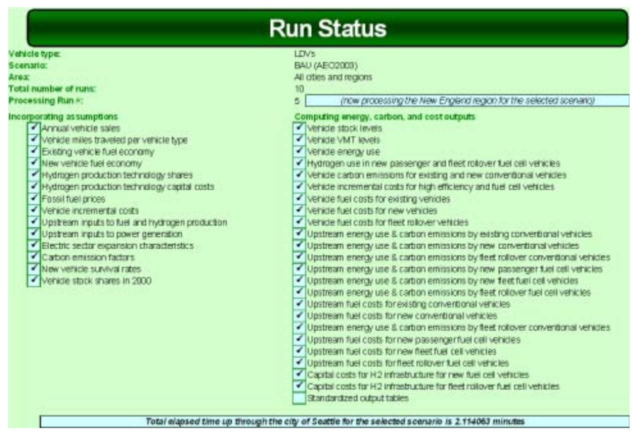

Figure 4. Screenshot from Hydrogen Infrastructure Scenario Modeling Utility

maps, combined with a set of alternative scenario projections for disaggregated demand groups over time (Figure 2), will determine the evolution of the total hydrogen demand and its geographical distribution. The geographical distribution of hydrogen demand, and in particular the density of demand, is critical to the relative cost-effectiveness of the options for production of hydrogen and delivery to the end-user. Figure 3 illustrates the sensitivity of delivery cost to demand density for a particular idealized demand geometry.

We have also created the analytical platform for integrating this information into plausible and self-consistent scenarios. Based on assumptions and analysis drawn from EIA's NEMS and energy-economic analysis drawn from the literature and experts, we've completed the platform for constructing the hydrogen infrastructure scenarios. (Figure 4 presents a screen-shot illustrating the analytical elements of the hydrogen scenario model.) We are now in the process of constructing the scenarios and drawing conclusions about like hydrogen transition pathways.

Conclusions

The techno-economic assumptions, analytical framework, and GIS analysis are essentially completed. Based on this foundation, the scenarios are now under construction. Up to this point, various intermediate conclusions can be reported, with implications regarding the pending higher-level final conclusions.

- There exist considerable and important synergies between hydrogen infrastructure development and other GHG-reducing strategies, such as energy efficiency, development of renewables, transportation policies, etc. Developing a hydrogen infrastructure that can serve a considerable fraction of the potential hydrogen demand is much more practicable if it is done in concert with other policies aimed at energy efficiency and renewables.
- Given the renewable energy resources and their distribution, providing sufficient quantities of hydrogen from renewable or other zero-carbon pathways is likely to be challenging and only achievablewith considerable policy and fiscal support. Autonomous market development of a substantive hydrogen infrastructure, especially one with GHG benefits, is doubtful.
- Much of metropolitan areas may eventually be served by pipeline hydrogen, but there will remain large areas of the county where pipeline delivery of hydrogen will not be cost-effective. This will reduce the achievable environmental benefits of shifting to hydrogen because the alternatives – on-site production and tanker distribution – are less likely to have net GHG benefits.
- The use of renewable electricity to displace high-carbon sources of electricity (especially coal) is a much more cost-effective GHG-reduction strategy than the use of renewable electricity to displace transportation fuels. (See Figure 5.)

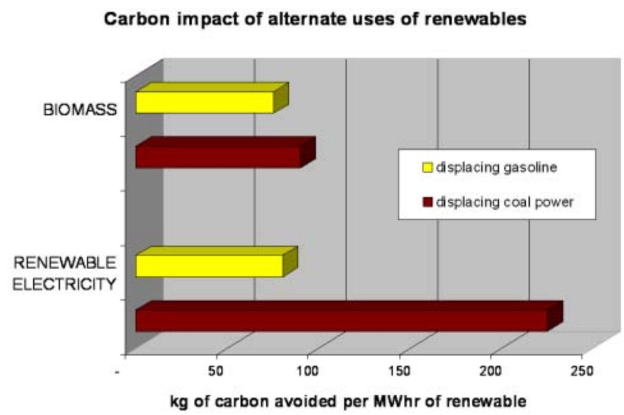

Figure 5. Relative GHG Impact of Electricity Displacement versus Transport Fuel Displacement

FY 2004 Presentations

1. *Renewable Hydrogen: the economic and policy context. (Lessons from an integrated scenario analysis).* Presented at *RENEWABLE HYDROGEN ,* April 10-11, 2003, Washington, DC. Forum sponsored by the American Solar Energy Society.
2. *The Transition to a Renewable Hydrogen Economy* presented at a symposium sponsored by Cape and Islands Energy Self-Reliance, April 26, 2003.
3. *The Transition to a Hydrogen Economy* presented at Boston University, October 9, 2003.
4. *The Carbon – Hydrogen Bond: The interaction between global warming and the "hydrogen economy"* Presented at Cornell University, March 1, 2004.
5. *Issues, Assumptions, & Analysis of a Hydrogen Transition in Four Cities in the USA* presented at Tellus Institute, June 16, 2004.