VIII.5 Macro-System Model

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Objectives

- Develop a macro-system model (MSM) aimed at:
  - Performing rapid cross-cutting analysis.
  - Utilizing and linking other models.
  - Improving consistency of technology representation (i.e., consistency between models).
  - Supporting decisions regarding programmatic investments and focus of funding through analyses and sensitivity runs.
  - Supporting estimates of program outputs and outcomes.
- 2006/2007 objectives:
  - Incorporate additional hydrogen pathway technologies.
  - Validate use of models in pathways.
  - Complete comparative and trade-off analyses.
  - Revisit alternatives for the MSM methodology.
  - Begin development of robust MSM methodology that can accommodate multiple users.

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:

(B) Stove-piped/Siloed Analytical Capabilities
(C) Inconsistent Data, Assumptions and Guidelines
(D) Suite of Models and Tools

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE Systems Analysis milestones from the Systems Analysis section of the April 27, 2007 version of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 5**: Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios. (4Q, 2009)
- M**ilestone 6**: Complete analysis of the impact of hydrogen quality on the hydrogen production cost and the fuel cell performance. (4Q, 2010)
- **Milestone 14**: Complete input/output guidelines for the Macro-System Model. (3Q, 2005)
- **Milestone 15**: Select model for analysis and incorporate into Macro-System Model. (4Q, 2005)
- **Milestone 16**: Develop initial model architecture. (4Q, 2005)
- **Milestone 17**: Capture Macro-System Model requirements, description, and usage in a description document. (2Q, 2006)
- **Milestone 18**: Complete a usable "test version" of the Macro-System Model with links to the H2A Production and Delivery models and the Argonne National Laboratory (ANL) GREET model. (2Q, 2006)
- **Milestone 23**: Complete the first version of the Macro-System Model for the analysis of the hydrogen fuel infrastructure to support the transportation systems. (4Q, 2008)
- **Milestone 27**: Complete the second version of the Macro-System Model to include the analytical capabilities to evaluate the electrical infrastructure. (2Q, 2011)

Accomplishments

- Developed a proof-of-concept version of the MSM and put it to use for programmatic analysis.
- Linked H2A Production cases with the Hydrogen Delivery Scenario Analysis Model (HDSAM), the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, and physical property information from the Hydrogen Analysis Resource Center (HyARC) and validated the use of those models
- Performed preliminary sensitivity analyses to help the community understand effects of research outputs.

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Introduction

At the program's behest, we are developing a macro-system model to analyze cross-cutting issues because no existing model sufficiently simulates the entire system including feedstock, conversion, infrastructure, and vehicles with the necessary level of technical detail. In addition, development of the MSM exposes inconsistencies in methodologies and assumptions between different component models so that they can be identified and corrected when necessary.

An initial version of the MSM has been developed. It links H2A Production, HDSAM, GREET, and physical property information from HyARC to estimate the economics, primary energy source requirements, and emissions of multiple hydrogen production/delivery pathways. The MSM has been used for several analyses to compare pathways and to understand the effects of varying parameters on pathways' results.

Approach

The MSM is being developed as a tool that links or federates existing models across multiple platforms. This approach was chosen because the task of building a single monolithic model incorporating all of the relevant information in the existing models would have been overwhelming, as the necessary expertise to do so was spread among half a dozen DOE laboratories and a dozen or more universities and private contractors. Linking models allows model users that depend on data from component models to continue using their models while retrieving data from component models in a less labor-intensive manner.

The MSM is being built on a federated object model (FOM) framework. That framework links together models and is exemplified by the Department of Defense high level architecture (HLA) [1]. The general framework is extensible (accommodates new models with a minimum of difficulty), distributable (can be used by multiple people in different areas of the country), and scalable (to large numbers of participating models). The initial version of the MSM has been developed and uses Java and JCom's Java bridge to transfer data between the models and Microsoft Excel for data identification and calculations.

Results

Levelized hydrogen costs, primary energy requirements, and emissions have been estimated for multiple pathways. Figure 1 shows results for production of hydrogen from woody biomass via gasification in central plants using current technology followed by liquefaction and delivery of liquid hydrogen in trucks. To distribute 116,000 Btu of hydrogen (lower heating value – essentially equivalent to the energy

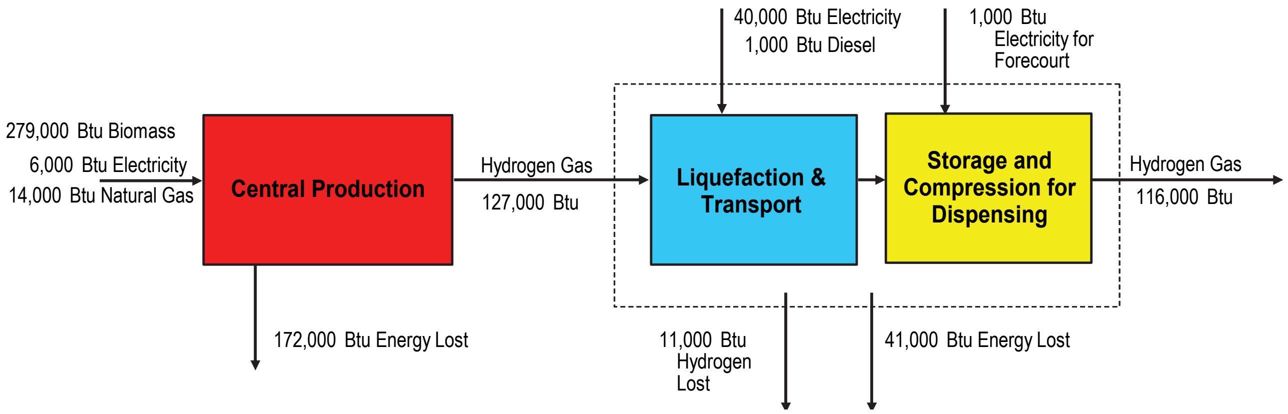

FIGURE 1. Pathway Results for Central Hydrogen Production from Woody Biomass with Liquid Hydrogen Delivered via Trucks

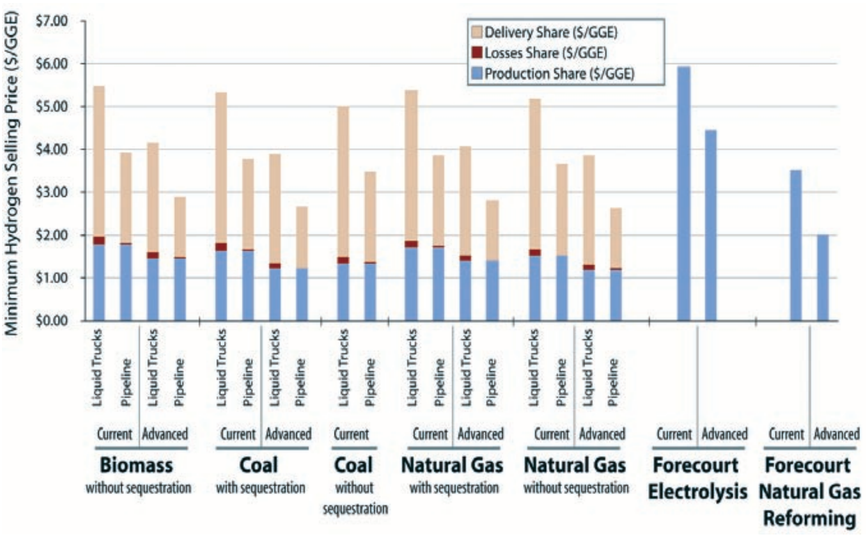

FIGURE 2. Comparison of Levelized Costs for Multiple Pathways

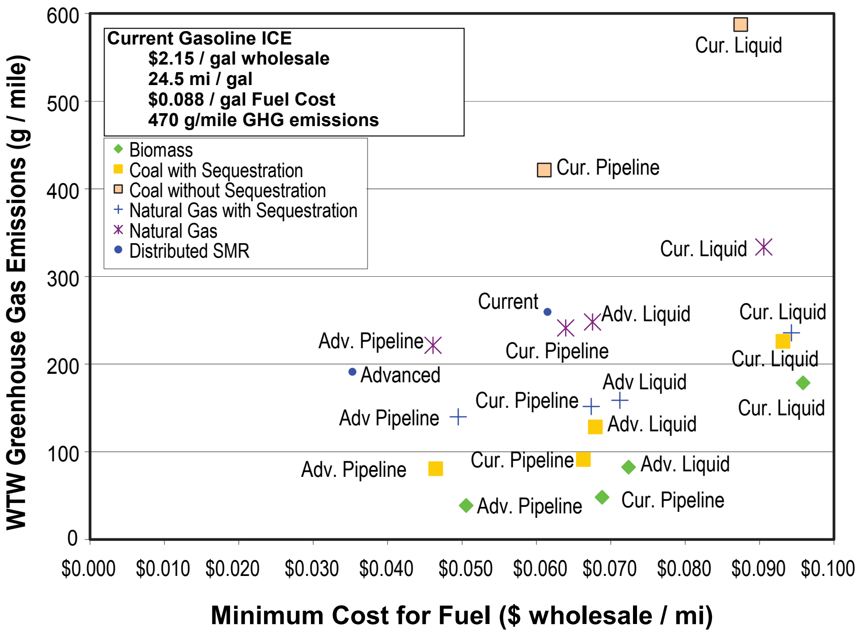

FIGURE 3. Levelized Cost and Greenhouse Gas (GHG) Emissions for Multiple Pathways

in 1 gal gasoline and 1 kg hydrogen), 127,000 Btu of hydrogen need to be produced – 11,000 Btu are lost due to unrecovered boiloff. In addition, 40,000 Btu of electricity are necessary to liquefy the hydrogen; 1,000 Btu of diesel to transport the hydrogen; and 1,000 Btu to compress the hydrogen to load it onto the vehicles. To produce the necessary hydrogen, biomass, electricity, and natural gas are required as shown in the figure. The levelized cost at the pump for this pathway is estimated to be $5.47/kg.

One of the primary factors for comparing pathways is levelized cost (including operating costs and capital costs with a 10% discounted cash flow rate of return). Figure 2 compares the levelized hydrogen costs of multiple pathways. The results for many of the pathways include both current and future technologies and the pathways with central production have results of both liquid hydrogen delivered in trucks and gaseous hydrogen delivered via pipeline. The levelized cost for each pathway is broken into the production cost, the cost of producing extra hydrogen that is lost due to leaks, and the cost of delivery and distribution.

Other results are important to compare as well. Figure 3 shows the estimated levelized cost of hydrogen for many pathways plotted against each pathway's estimated well-to-wheels greenhouse gas emissions. The biomass pathways have the lowest greenhouse gas emissions but may be expensive. In all the cases shown, pipeline delivery is less expensive and has lower greenhouse gas emissions than delivery of liquid hydrogen in trucks (250,000 person city with 50% hydrogen penetration).

The MSM also eases the process of generating sensitivity results. Figure 4 shows the sensitivity of well-to-wheel greenhouse gas emissions, petroleum use, and fossil-energy use to production efficiency and vehicular fuel economy. The sensitivity was run on current distributed steam methane reforming technology with a base production efficiency of 69%. The base fuel economy of the vehicle is 57 mi/gasoline gallon equivalent. The effect of the range around fuel economy is much greater than that around production efficiency.

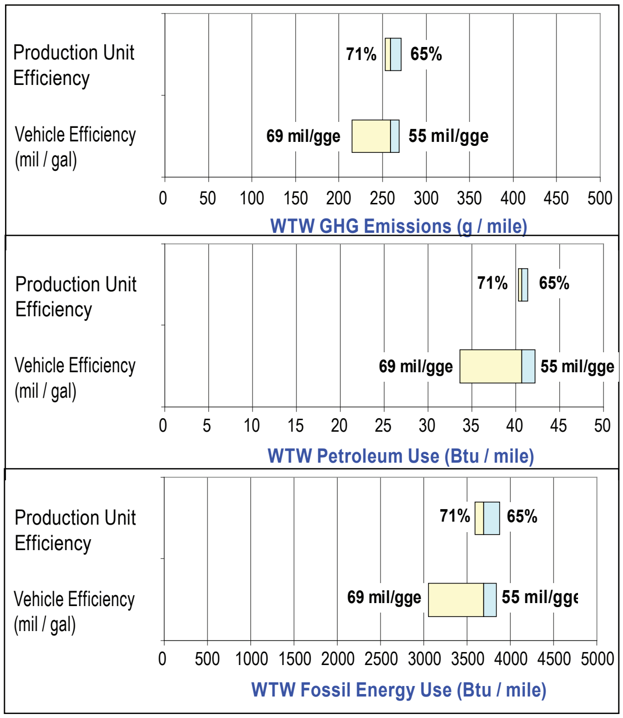

FIGURE 4. Effect of Production Efficiency and Vehicular Fuel Economy on Distributed Steam Methane Reforming (SMR)

Conclusions and Future Directions

An initial version of the MSM has been developed to compare the economics, primary energy source requirements, and emissions of different hydrogen production/delivery pathways and is being used for comparative and sensitivity analyses. The MSM can help identify which combinations are most likely to be developed and some of the environmental tradeoffs between the pathways.

The next steps for the MSM involve:

- Reviewing the current version,
- Developing a user interface and making the MSM available so that more analysts can use it, and
- Adding additional models and data sources. These include the HyPRO transition model and the HyDRA spatial model.

FY 2007 Publications/Presentations

1. Ruth, Mark F., Keith B. Vanderveen, Timothy J. Sa. "Use of Federated Object Modeling to Develop a Macro-System Model for the US Department of Energy's Hydrogen Program." Proceedings of the 2006 Winter Simulation Conference; pp. 1438-1445.

2. Presentation at Analysis Deep Dive Part 2. San Antonio, TX; March 22, 2007.

References

1. Judith S. Dahmann, Richard Fujimoto, and Richard M.Weatherly. The Department of Defense high level architecture. In Winter Simulation Conference, pages 142–149, 1997.