XI.7 Effects of Technology Cost Parameters on Hydrogen Pathway Succession

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Fiscal Year (FY) 2012 Objectives

- Develop a macro-system model (MSM):
  - Aimed at performing rapid cross-cutting analysis
  - Utilizing and linking other models
  - Improving consistency between models
- Improve understanding of options and tradeoffs in the evolution of hydrogen production and delivery infrastructure for transportation with a specific focus on:
  - What is a likely succession of hydrogen pathways?
  - What factors influence the sequence most?

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

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

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 1.1: Complete an analysis of the hydrogen infrastructure and technical target progress for hydrogen fuel and vehicles. (2Q, 2011)
- Milestone 2.1: Complete the 2nd version of the Macro-System Model to include the analytical capabilities to evaluate the electrical infrastructure. (2Q, 2011)
- Milestone 2.2: Annual model update and validation. (4Q, 2011 through 4Q, 2020)

FY 2012 Accomplishments

- Linked the HyPro pathway progression model to the MSM framework.
- Performed numerous MSM-HyPro runs utilizing up-to-date production and delivery data from H2A and the Hydrogen Delivery Scenario Analysis Model (HDSAM).
- Performed an analysis on effects of technology cost parameters on hydrogen pathway succession.

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Introduction

At the DOE Hydrogen Program's behest, we are developing an MSM 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. Version 1.0 of the MSM was developed previously and is available to the hydrogen analysis community. It links H2A Production, HDSAM, the Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET) model, and physical property information from the Hydrogen Analysis Resource Center to estimate the economics, primary energy source requirements, and emissions of multiple hydrogen production/delivery pathways.

Version 2.0 of the MSM links the HyPro [1] model that is a MatLab®-based computer model developed by

Directed Technologies Inc. under contract to the DOE for calculation of the expected "pump price" of hydrogen (i.e. the profited cost of hydrogen ready to be dispensed into a customer's vehicle at the dispensing station) for a variety of production/delivery/dispensing pathways in an area of uniform demand density over a span of years. By postulating the yearly hydrogen demand and calculating which supply infrastructure pathway is expected to provide the least expensive hydrogen in any given year, the model projects infrastructure build-out over time. This build-out projection takes into consideration potential advances in technology, underutilization of facilities in the early years of a station coming on line, potential stranded assets, feedstock cost differences, economies of scale for the production equipment, and "learning curve" capital cost reductions due to repetitious fabrication of multiple systems. The build-out projection allows for only one "winner" each year and all the pathways built that year will have the same combination of technologies. In reality, there is likely to be a diversity of opinion regarding demand level and price projections that will lead to more than one technology being built out each year.

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 because 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. In addition, it provides a common platform for data exchange necessary to update integrated models when the component models have been updated.

The MSM is being built on a framework inspired by an example of a federated object model (FOM). The MSM uses a common interlingua that 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 a larger number of participating models) using exogenous data. FOMs are exemplified by the Department of Defense high-level architecture [2]. Version 2.0 of the MSM uses Ruby and Ruby interfaces to Microsoft Excel and other platforms to collect, transfer, and calculate data.

Results

All runs include an exogenous demand curve based on the form recommended by the National Academy of Sciences [3] adapted for Los Angeles and 50% penetration of fuel cell electric vehicles (FCEVs). The fuel economy assumed for the FCEVs is 45 miles per gallon gasoline equivalent (mpgge).

The base case scenario uses default inputs from H_2 production and delivery models and its results are shown in Figure 1. The analysis shows the forecourt steam methane reforming (FCSMR) production option as the most cost-effective (by a large margin of >\$1/kgH_2) in the early years of hydrogen FCEV market development. This option is replaced by central coal gasification with pipeline delivery when the market matures and advanced technology options (both production and delivery) are available. The base case is associated with significant greenhouse gas emissions (GHGs) brought about by coal gasification (not shown).

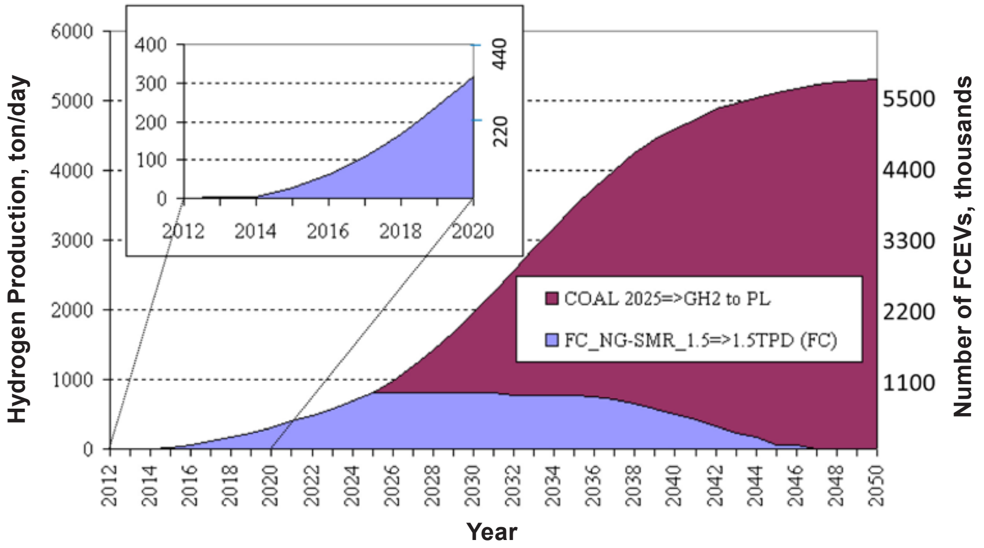

FIGURE 1. Hydrogen production for the base case hydrogen pathway evolution scenario

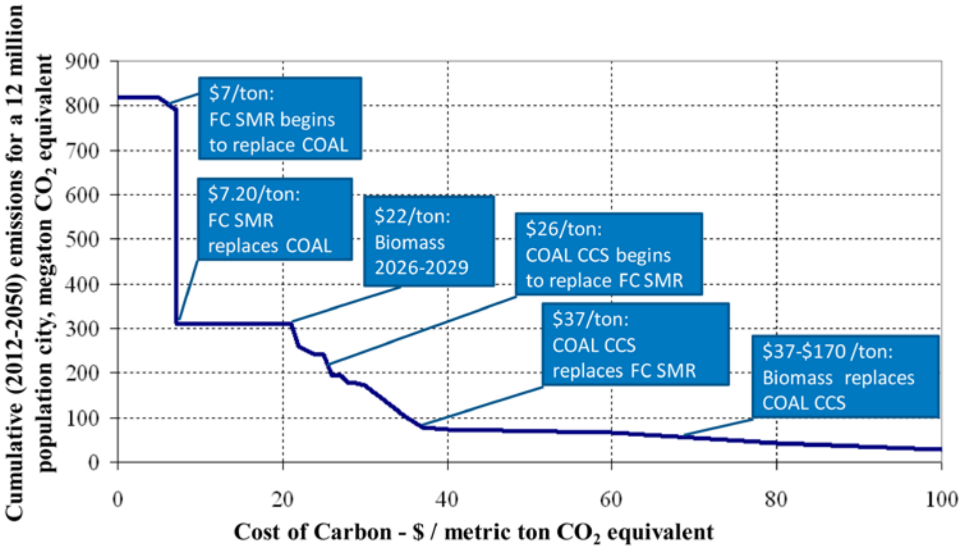

FIGURE 2. Cumulative GHG emissions from hydrogen production facilities as affected by a cost of carbon

Figure 2 shows the effects of a cost of carbon on technology selection. Low costs of carbon do not affect the technology mix or the GHG emissions. Then, at moderate levels (7-7.14 \$/metric ton CO_2 equivalent), FCSMR becomes more economical than coal gasification and results in a large (62%) reduction in the overall amount of GHGs. Further increases in carbon costs up to about 21\$/metric ton) does not induce any technology changes: between \$7.14/ton and \$21/ton the cost optimal scenario involves only FCSMR hydrogen production for any year under consideration (2012-2050). Biomass gasification becomes competitive for several years at carbon cost level of \$22/ton. (Biomass feedstock projected price is gradually increasing so there is no sharp takeover as in the COAL–FCSMR case at ~\$7/ton cost of carbon.) Between \$26/ton and \$37/ton carbon cost, coal gasification with carbon capture and sequestration (COAL CCS) replaces FCSMR as the preferred advanced technology option (for years 2027-2050).

As shown in Figure 2, increased costs of carbon open the markets for more expensive but cleaner technologies. Thus, consumer costs (levelized cost plus cost of carbon) go up and the carbon footprint goes down. However, the amount paid for carbon emissions is limited by the incremental cost of related technologies. Figure 3 shows this effect by reporting both the average levelized cost of hydrogen and the portion of that cost that pays for carbon emissions in 2050. Irregularities observed on the hydrogen cost and GHG tax curves are inflicted by technology breakthrough points that cause one technology to replace others.

In scenarios where coal without CCS is not allowed, distributed SMR is the only technology selected. The increase in SMR capital cost to make other technologies competitive was analyzed. The results are shown in Figure 4 and indicate that other technologies do not become cost competitive until capital cost of distributed SMR is increased by over 70%. Increased forecourt natural gas SMR capital costs would result in replacing it with even more capital intensive central production technologies, biomass gasification and coal gasification with carbon capture and sequestration. The replacement with higher capital cost technologies becomes possible only because of relatively low biomass and coal feedstock prices.

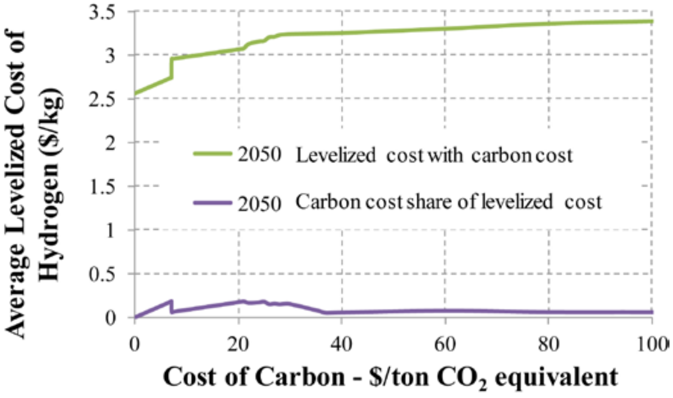

FIGURE 3. Effects of a cost of carbon on the average levelized cost of hydrogen and the portion paid for carbon emissions

Conclusions and Future Directions

- Based on current cost projections and a required 10% internal rate of return, distributed SMR is the most cost-effective technology to roll out in the early commercial stage.

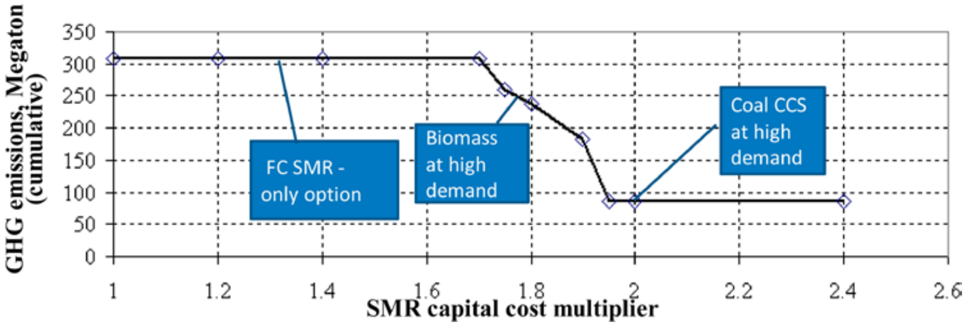

FIGURE 4. Effects of increased SMR capital costs on GHG emissions due to technology selection

- Central coal (without CCS) is the most cost-effective technology at higher demand growth if carbon emissions are not limited.
- The cost of carbon limits coal without CCS. It is replaced by distributed SMR, biomass, and coal with CCS as the cost increases.
- Distributed SMR is the most cost-competitive technology when central coal without CCS is not allowed. Other technologies need large capital or feedstock cost reductions to become competitive.

No additional funding is planned for this analysis. If we had additional funding, we would like to:

- Update the analysis using new versions of H2A, HDSAM, and GREET.
- Update the analysis with 200 kg/day stations, tube trailer delivery, and tri-generation options.
- Spread out technology improvement (potentially using learning curves).
- Use supply curves instead of single values
- Add unforeseen randomness to the demand function.

Within ongoing projects, the MSM is being updated. An analysis of the parameters used in estimating levelized cost and energy use and emissions is underway.

FY 2012 Publications/Presentations

1. Diakov, V; Ruth, M.F.; James, B.; Perez, J.; Spisak, A. "Technical Breakthrough Points and Opportunities in Transition Scenarios for Hydrogen as Vehicular Fuel," NREL Report No. 53489 (2011) http://www.nrel.gov/docs/fy12osti/53489.pdf.

2. Diakov V., Ruth, M., James, B., Perez, J. and Spisak, A. "Technical breakthrough points and opportunities in transition scenarios for hydrogen as vehicular fuel." Presentation at the Fuel Cell Seminar, Washington, D.C., October 2011.

3. Diakov, V., Ruth, M., Goldsby, M., Sa, T. (2011) "Macro-System Model for Hydrogen Energy Systems Analysis in Transportation." In the International Mechanical Engineering Conference and Exhibit, Paper 63815, Denver, CO, November 2011.

4. Diakov, V; Ruth, M.F.; Sa, T.J., Goldsby, M.E. "WREF 2012: Macro-Systems Model for Hydrogen Energy Systems Analysis in Transportation," World Renewable Energy Conference Presentation. May 15, 2012.

5. Diakov, V; Ruth, M.F.; Sa, T.J., Goldsby, M.E. "WREF 2012: Macro-Systems Model for Hydrogen Energy Systems Analysis in Transportation," World Renewable Energy Conference Proceedings. In Press.

References

1. James, B. D., P. O. Schmidt, J. Perez. 2008. Using HyPro to evaluate competing hydrogen pathways. Report on DOE contract DE-FG36-05GO15019. Available via http://www.hydrogen.energy.gov/pdfs/progress07/viii_1_james.pdf [Accessed May 20, 2011].

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

3. National Academy of Sciences. 2004. The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs, National Academy Press, Washington, D.C.