VII.7 Hydrogen Deployment System Modeling Environment (HyDS-ME)

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Objectives

The Hydrogen Deployment System Modeling Environment (HyDS-ME) is a geospatially and temporally oriented analysis model that determines the optimal production and delivery scenarios for hydrogen, given resource availability and technology cost. The objects of the most recent phase of the project are:

- Evaluate the effectiveness of the HyDS-ME tool, design enhancements to it, and update the tool's capabilities.
- Perform several scenario analyses:
  - Exercise the enhanced tool on a notional case study.
  - Complete a study involving a mix of stationary and vehicular hydrogen uses.
- Expand the interoperability of HyDS-ME with tools such as HyDRA.

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) Stove-piped/Siloed Analytical Capability
(D) Suite of Models and Tools
(E) Unplanned Studies and Analysis

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 Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 3.** Begin a coordinated study of market transformation analysis with H2A and Delivery models. (1Q, 2006)
- **Milestone 5.** Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios. (4Q, 2009)
- **Milestone 8.** Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for technology readiness. (4Q, 2014)
- **Milestone 24.** Complete the linear optimization model (HyDS) to analyze the optimum production facilities and infrastructure for hydrogen demand scenarios. (4Q, 2008)
- **Milestone 26.** Annual model update and validation. (4Q, 2008; 4Q, 2009; 4Q, 2010; 4Q, 2011; 4Q, 2012; 4Q, 2013; 4Q, 2014; 4Q, 2015)

Accomplishments

- Completed the HyDS-ME software updates, which involved the reworking of approximately 20k lines of code and the development of an enhanced architecture supporting open/interoperable data formats, increased flexibility/transparency, and faster optimization computations.
- Completed a notional California study documenting lessons learned regarding infrastructure optimization, insights into infrastructure tradeoffs, and insights into regional infrastructure.
- Improved the interoperability capabilities of HyDS-ME by providing generic connectivity via extensible markup language, geographic information systems (GIS), and relational databases in order to open future connectivity between it and the Macro-System Model, HyDRA, and other tools.
- Completed an exploratory national wind-hydrogen infrastructure study.

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Introduction

The HyDS-ME fills a unique and important niche in the temporal and geospatial analysis of hydrogen infrastructure build-out for production and delivery [1-3]. It nicely complements other hydrogen analysis tools and is well suited to address the potential analysis scenarios involving the temporally specific geospatial deployment of hydrogen production and transmission infrastructure. Its key capabilities are (i) a semi-realistic optimization of physical build-out of hydrogen infrastructure, (ii) the unified treatment of production, transmission, and distribution, (iii) the ease with which new technologies can be added to an analysis, (iv) the consistent physical and economic computations, (v) the ability to estimate costs and cash flows, (vi) the spatial and temporal resolution of hydrogen infrastructure networks, (vii) regional specificity, and (viii) the allowance for exogenously specified urban hydrogen demands. Its internal architecture is flexible, and it is compatible with GIS and the H2A models [4,5].

HyDS-ME is designed to answer questions such as [6]:

- Which technologies will be used to provide hydrogen during infrastructure build-out?
- What synergies are there between cities and their distance to markets?
- How important and costly is it to serve rural areas?
- How can cities leverage one another's demand, thereby reducing cost and risk of stranded investments?
- Where can centralized versus onsite production technologies be most effective?
- How might external influences or policy constraints/incentives influence hydrogen infrastructure build-out?

Approach

In order to answer such questions, HyDS-ME supports analyses aimed at identifying optimal infrastructure to meet specified annual urban hydrogen demands, perhaps coupled to other multiple objectives and constraints. Cash flows are computed, detailed by infrastructure component, city, and region, and these provide insights into components of hydrogen costs, which are determined by year, volume, and locality. Three methods of long distance hydrogen transport are considered: pipeline, gaseous truck, and liquid truck. The major use of HyDS-ME is for studying potential turning points in infrastructure choice via sensitivity analysis on infrastructure, feedstock, and fuel cost inputs in the context of the complex transient and transitional interactions between increasing hydrogen demand and hydrogen infrastructure construction. With carefully constructed input data sets, HyDS-ME can also weigh tradeoffs between investments in various infrastructure types, given policy constraints (greenhouse gases, etc.).

Figure 1 shows the interrelationship between the input parameters for HyDS-ME and the algorithms applied to them in order to compute the delivered cost of hydrogen. The infrastructure networks are optimized using a simulated annealing algorithm that explores the large set of potential build-out plans that meet the input requirements for hydrogen delivery at cities over time. The hydrogen transport computations are based on graph-theoretic algorithms for determining optimal flows in networks. The cash flow computations rely on standard discounting approaches. Figure 2 shows an illustrative example of the geospatial results of hydrogen infrastructure optimization.

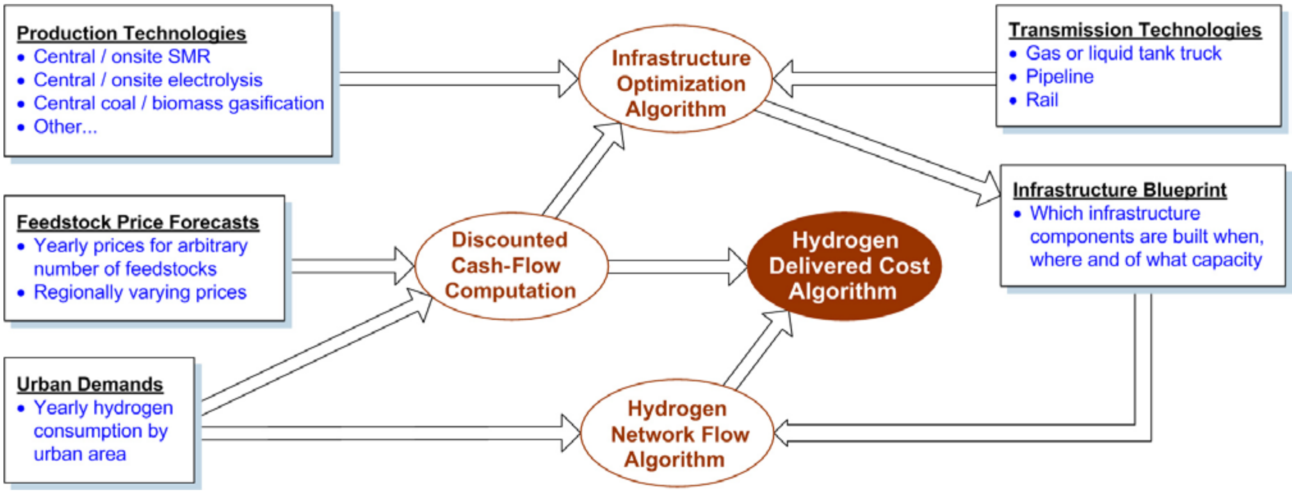

FIGURE 1. HyDS-ME Input and Output Data, And Algorithms

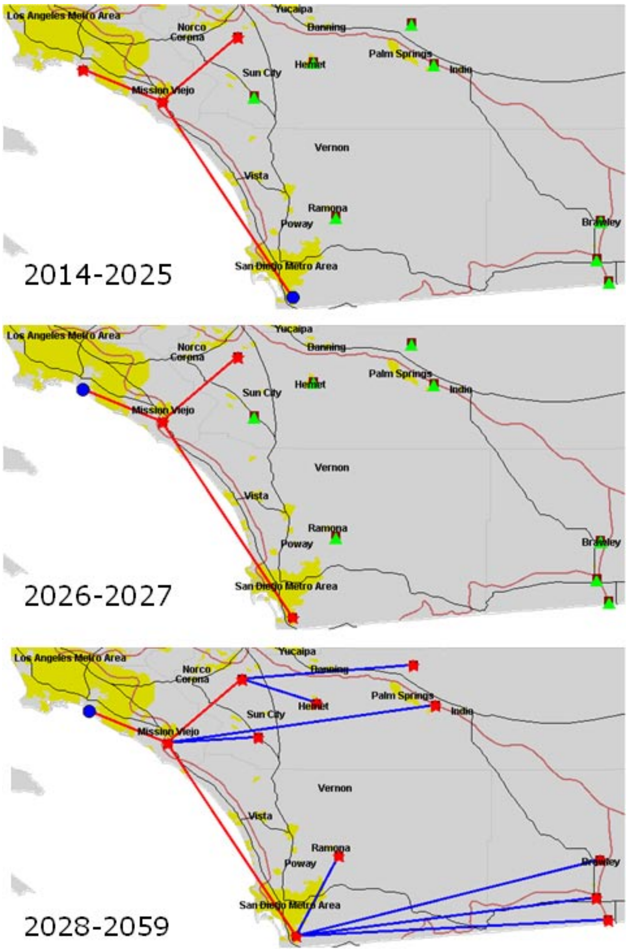

FIGURE 2. Geospatial layout of hydrogen infrastructure in example HyDS-ME optimization: blue circles represent steam methane reformer plants, green triangles electrolysis plants, red stars cities with hydrogen demand, red lines pipelines, and blue lines liquid truck transport.

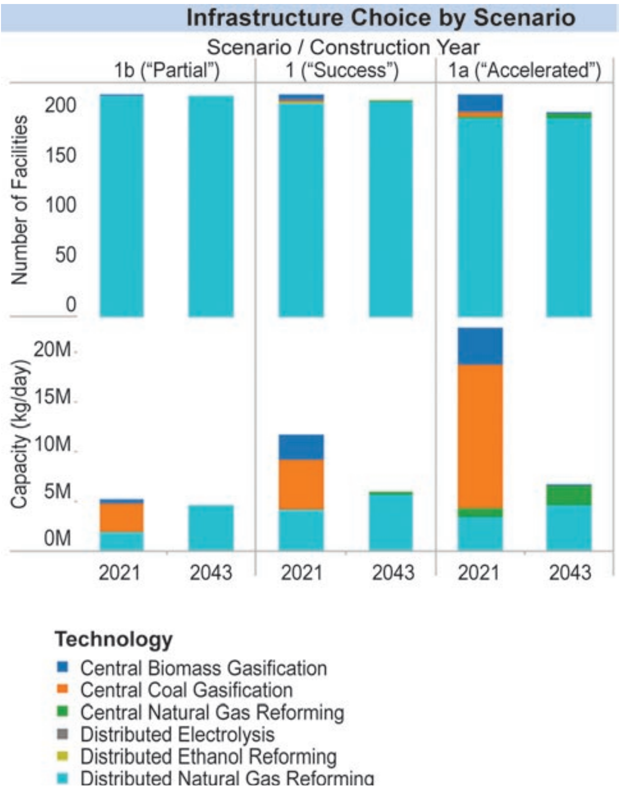

FIGURE 3. Comparison of infrastructure build-out in the three NAS-inspired demand cases for a California case study.

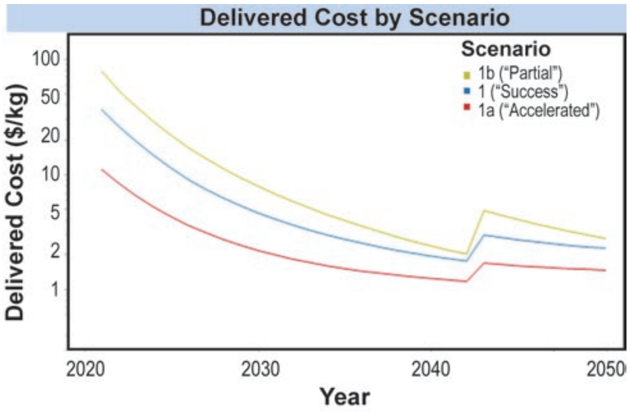

FIGURE 4. Consumption-weighted delivered hydrogen costs for the three NAS-inspired demand scenarios.

Results

The most recent HyDS-ME notional case study involved studying the demand and feedstock sensitivities for hydrogen infrastructure build-out in California. Starting with canonical infrastructure, operating, and feedstock costs inferred from H2A models and demand profiles for California consistent with the 2008 National Academy of Sciences (NAS) scenarios [7], we develop a base case where infrastructure placement is optimized to reduce the total levelized production, transmission, and delivery costs for hydrogen. This results in localized hydrogen production (i.e., no long distance transport of hydrogen) with onsite production applications being the dominant method of providing hydrogen (see Figure 3). The consumption-weighted delivered hydrogen cost falls below $10/kg in 2026 and below $4/kg in 2032 in our base-case scenario, which roughly corresponds to the NAS "Hydrogen Success" scenario; in our scenario corresponding to the NAS "Accelerated Hydrogen", that cost falls below $2/kg beyond 2030 (see Figure 4).

We also considered three simple scenarios involving the pricing of feedstocks for the onsite production technologies. The first two involve simply tripling or quadrupling the prices of the ethanol, natural gas, or electricity used by the three onsite technologies. The third involves assuming that feedstocks for those technologies are prohibitively expensive, so those technologies are forbidden in the optimization. In effect these scenarios mimic the potential constraints (not modeled directly in HyDS-ME) that would limit the availability of feedstocks at points of onsite production within a city: the lack of sufficient distribution infrastructure (natural gas pipelines, electric power transmission lines, or ethanol transport) may increase the local feedstock cost or prevent its delivery altogether. To varying degrees, these scenarios force the use of transmission infrastructure. When the prices of particular feedstocks increase, centralized applications with long-distance transport of hydrogen via truck become more prominent.

This notional study of hydrogen-infrastructure in California highlights several insights regarding the regional build-out of that infrastructure. First, pipeline infrastructure and (to a lesser extent) other transmission infrastructure is non-optimally costly for the levels of demand considered here – it is only when feedstock costs to onsite production technologies are raised substantially (or the deployment of those technologies forbidden) that transmission infrastructure comes into play significantly. Second, some of the potential technologies (e.g., central grid electrolysis) rarely come into use because they are generally more costly than others (e.g. central biomass gasification) in the cost inputs. Third, hydrogen cost may vary widely (an order of magnitude) with locality and with time. Fourth, the construction of production plants that are not fully utilized in the early years of their lifetime substantially increases delivered hydrogen cost in those years.

Conclusions and Future Directions

In summary, HyDS-ME is an effective, integrated, cross-cutting model for optimization-analysis studies of hydrogen infrastructure build-out compatible with the H2A models: it searches for optimal combinations of hydrogen production and transmission infrastructure to meet time-varying demand in urban areas over a region.

The next steps for HyDS-ME are to take the lessons learned in recent applications of the tool and to further exercise its analysis capabilities with ever more realistic input data sets in computing and visualization environments that allow thorough exploration of the cost-issues around regional hydrogen-infrastructure build-out:

- Application of HyDS-ME to more elaborate scenario analyses.
- Directly representing additional key constraints to hydrogen infrastructure build-out explicitly within HyDS-ME:
  - Global constraints on feedstock availability and competition.
  - Right-of-way considerations.
  - Accounting for the cost of new or upgraded feedstock-delivery infrastructure.
  - More highly localized delivered-feedstock costs.
- Developing a more sophisticated disaggregation of hydrogen demand corresponding to the NAS scenarios.
- Elaborating on the existing HyDS-ME representation of blueprints for infrastructure build-out:
  - Higher resolution of hydrogen infrastructure components.
  - Staged/incremental capacity addition in HyDS-ME, where multiple production facilities (or pipelines) are constructed in a staggered fashion over the years.
  - Fewer conditions on allowable hydrogen infrastructure networks.
  - Directly representing the nuances of hydrogen delivery within urban areas.

FY 2009 Publications/Presentations

1. B. Bush. "Technical Highlights of the Hydrogen Deployment System Modeling Environment (HyDS-ME)". 27 Aug 2008 & 25 Sep 2008. (presentation)

2. B.W. Bush. "Hydrogen Deployment System Modeling Environment (HyDS-ME): Updates & Enhancements for FY2008". Strategic Energy Analysis & Applications Center, National Renewable Energy Laboratory, 30 Sep 2008. (report)

3. B. Bush. "Overview of the Hydrogen Deployment System Modeling Environment (HyDS-ME), Version 3.0". 2 Oct 2008. (presentation)

4. B. Bush, M. Melaina, O. Sozinova, D. Thompson. "Hydrogen Deployment System Modeling Environment (HyDS-ME) Notional California Case Study". National Renewable Energy Laboratory, 28 Jan 2009. (report)

5. B. Bush, M. Melaina, O. Sozinova, D. Thompson. "HyDS-ME Notional California Case Study". 5 Feb 2009. (presentation)

6. B. Bush, M. Melaina, O. Sozinova. "Optimal Regional Layout of Least-Cost Hydrogen Infrastructure". National Hydrogen Association Conference & Expo 2009. (poster)

7. B.W. Bush. "HyDS-ME Interoperability". Strategic Energy Analysis Center, National Renewable Energy Laboratory, 31 Mar 2009. (report)

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1. Parks, K. *Hydrogen Deployment System Modeling Environment (HyDS ME) documentation milestone report, FY 2006.* NREL/MP-560-40763. Golden, CO: National Renewable Energy Laboratory, October 2006.

2. Lambert, T. *Overview of HyNOON.* 20 December 2006 (unpublished).

3. Bush, B.W. *Hydrogen Deployment System Modeling Environment (HyDS-ME) Updates & Enhancements for FY2008.* 30 Sep 2008 (unpublished).

4. "H2A Production Models and Case Studies". Version 2.1.2. *DOE H2A Production Analysis.* <http://www.hydrogen.energy.gov/h2a_production.html>. Accessed 17 Jan 2009.

5. "H2A Delivery Scenario Model". Version 2.0. *DOE H2A Delivery Analysis.* <http://www.hydrogen.energy.gov/h2a_delivery.html>. Accessed 17 Jan 2009.

6. Brown, E.S. *Transportation sector market transition: using history and geography to envision possible hydrogen infrastructure development and inform public policy.* NREL/TP-670-43497. Golden, CO: National Renewable Energy Laboratory, August 2008.

7. National Research Council Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies. *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen.* Washington, D.C.: National Academies Press, 2008.