XI.1 Infrastructure Analysis of Early Market Transition of Fuel Cell Vehicles

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Project End Date: Project continuation and direction determined annually by DOE

Fiscal Year (FY) 2012 Objectives

In order to analyze the infrastructure requirements and infrastructure-cost implications of early market transitions to fuel cell vehicles (FCEVs), we use the Scenario Evaluation, Regionalization and Analysis (SERA) model, which 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 objectives of this analysis-oriented project are:

- Improve interoperability of SERA with other models and with data sources:
  - Synchronize SERA costs with those from more detailed cost models such as H2A
  - Collaboration with MA3T model developers
- Enhance integration of a variety of infrastructure models into SERA:
  - Develop cost submodels representing a variety of alternative infrastructure development pathways
- Perform scenario analysis using SERA:
  - Region-specific early market scenarios
  - Niches and synergies for FCEVs and refueling stations in the early adoption period
  - Minimizing delivery cost of renewable hydrogen
  - Implications of stakeholder behavior and consumer preferences

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section (4.5) of the Fuel Cell Technologies Program's 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 is contributing to achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies Program's Multi-Year Research, Development and Demonstration Plan:

- Milestone 3. Begin a coordinated study of market transformation analysis with H2A and Delivery models.
- Milestone 5. Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios.
- Milestone 24. Complete the linear optimization model (HyDS) to analyze the optimum production facilities and infrastructure for hydrogen demand scenarios.
- Milestone 26. Annual model update and validation.

FY 2012 Accomplishments

- Early market scenarios were constructed from published plans for FCEV introductions in California, and then these early market estimates were generalized to create a National Academy of Sciences (NAS)-compatible nationwide scenario.
- In order to study clustering effects in those scenarios, refueling stations and FCEV garaging locations were estimated, nationwide, at the ZIP code level.
- The optimal choice of production technology was computed as a function of feedstock prices and demand conditions. Similarly, the optimal choice of transmission infrastructure is based on calculations sensitive to the nearness of production centers and demand conditions.
- By calculating cash flows, we determined that, for these scenarios, long-term levelized delivered costs for hydrogen tend towards $6.00/kg nationally and zero cumulative cash flow is achieved between 2018 and 2025 if hydrogen is priced at $11.00/kg or $6.75/kg, respectively.

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Introduction

The SERA model fills a unique and important niche in the temporal and geospatial analysis of hydrogen infrastructure build-out for production and delivery. It nicely complements other hydrogen analysis tools and is well suited to contribute to scenario analysis involving the temporally specific geospatial deployment of hydrogen production and transmission infrastructure. Its key capabilities are (i) an optimization of the 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, including refueling stations; (vii) regional specificity; and (viii) the allowance for exogenously specified urban hydrogen demands. Its internal architecture is flexible, and it is compatible with geographic information systems and the H2A models [1,2,3]. SERA is designed to answer questions such as: Which pathways will provide least-cost hydrogen for a specified demand? What network economies can be achieved by linking production facilities to multiple demand centers? How will particular technologies compete with one another? How does clustering of refueling stations and FCEV garaging affect infrastructure requirements and costs?

Approach

In order to answer such questions, SERA 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. Four methods of long distance hydrogen transport are considered: pipeline, gaseous truck, liquid truck, and railroad. The major use of SERA 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, SERA can also weigh tradeoffs between investments in various infrastructure types, given policy constraints (e.g., green house gas). Figure 1 shows the interrelationship between the input data for SERA 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.

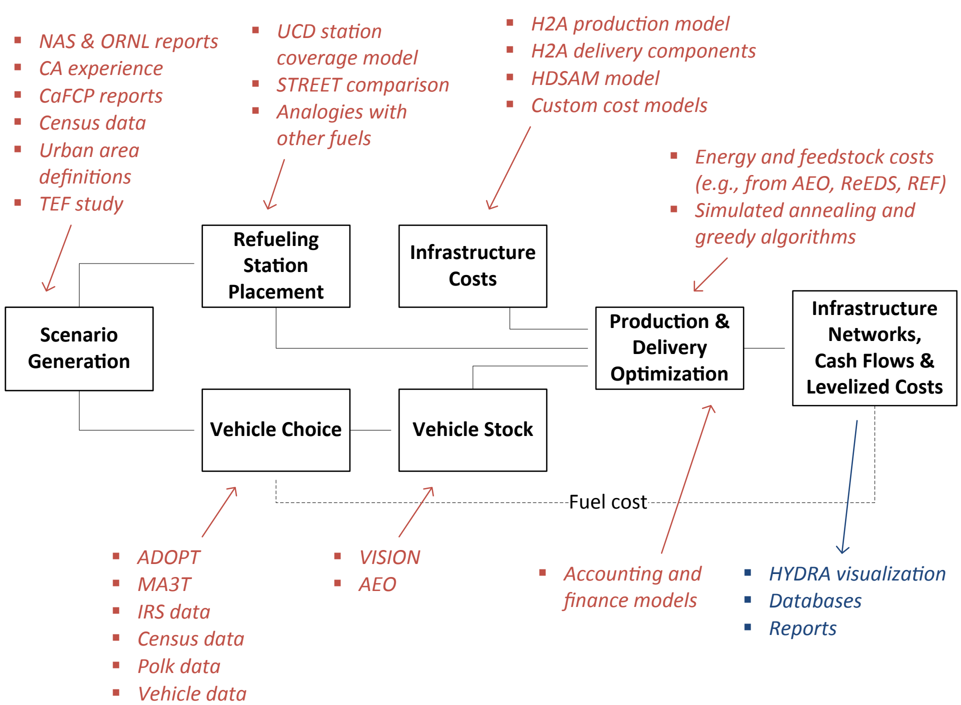

FIGURE 1. SERA input and output data and algorithms

We developed detailed temporal and spatial scenarios for early market infrastructure clustering and vehicle rollout for use in SERA by tuning nationwide scenarios to observations and lessons learned in California early market evolution and planning. In order to examine the regional implications of these nationwide scenarios, we refined our methodology for locating and sizing stations within urban areas and developed a new methodology for locating FCEVs at households within urban areas. We next refined our methodology for optimizing the choice of hydrogen production and delivery infrastructure in SERA and applied that optimization in order to understand the cash-flow implications of the detailed temporal and spatial scenarios for early market infrastructure clustering and vehicle rollout. This allowed us to gain insight into the nuances of cash flows within FCEV-rollout scenarios. As part of this work, a repeatable process for developing and refining detailed temporal and spatial scenarios for early market infrastructure clustering and vehicle rollout has been incorporated into SERA.

Results

The resulting scenarios, which partially account for early-market intra-urban clustering effects, are characterized by their more aggressive FCEV roll-outs than the standard NAS scenarios: These scenarios were calibrated to the early market adoption rates anticipated by stakeholder within the California Fuel Cell Partnership, and comparable (but later) infrastructure rollout patterns are extended to all major U.S. urban areas. In the middle and long term, these scenarios approach the standard NAS scenarios (“accelerated”, “success”, and “partial success” scenarios).

Analyses of these scenarios focused on understanding the infrastructure build-out and the cash-flow implications in temporal and spatial detail, by optimizing the choice of hydrogen production and delivery infrastructure. Figures 2 and 3 summarize the properties of the optimal hydrogen infrastructure for the early-market “hydrogen success” scenario. Note particularly that the average refueling station capacity grows from small early-market conditions (~250 kg/day) to larger mature-market conditions (~1,500 kg/day) that resemble the H2A design cases [3].

These early-market clustering analyses highlighted the following insights:

- Low natural gas costs in most regions and the favorable economies of scale for large coal plants lead to the predominance of central natural gas reforming and coal gasification.
- Central grid electrolysis has niches in areas of low electricity prices.
- Onsite natural gas reforming is optimal in low-demand conditions.

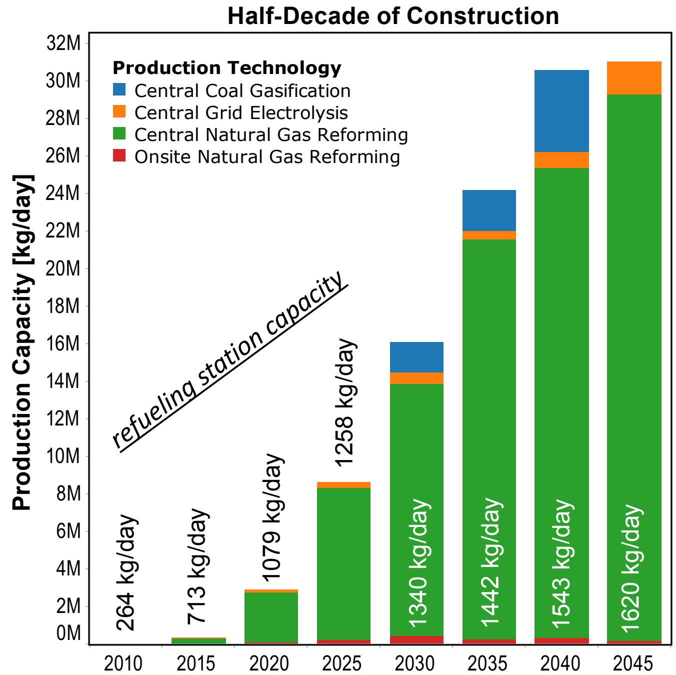

FIGURE 2. Production infrastructure build-out under the early-market “hydrogen success” scenario

- Gaseous hydrogen pipelines are favorable for high flow conditions and moderate distances.
- Truck delivery predominates at lower flow (i.e., for gaseous transport) or longer distance (i.e., for liquid transport).
- Long-term levelized delivered costs for hydrogen tend towards $6.00/kg nationally.
- Zero cumulative cash flow is achieved between 2018 and 2025 if hydrogen is priced at $11.00/kg or $6.75/kg, respectively. (See Figure 4 for an example.) However, the use of alternative accounting methods for cash flow or different financing assumptions would alter this conclusion.
- Underutilization of infrastructure in the first couple of years after its construction raises the overall proportion of capital costs.

Conclusions and Future Direction

In summary, SERA is an effective, integrated, cross-cutting model for optimization-analysis studies of hydrogen infrastructure build-out compatible with the H2A models. It will be applied to more complex deployment scenarios such as (i) identifying regional niches for production technologies and delivery infrastructure and (ii) assessing the influence of feedback from computed delivered costs of hydrogen to consumer and stakeholder decisions. In particular, we plan to compare scenarios involving three different types of

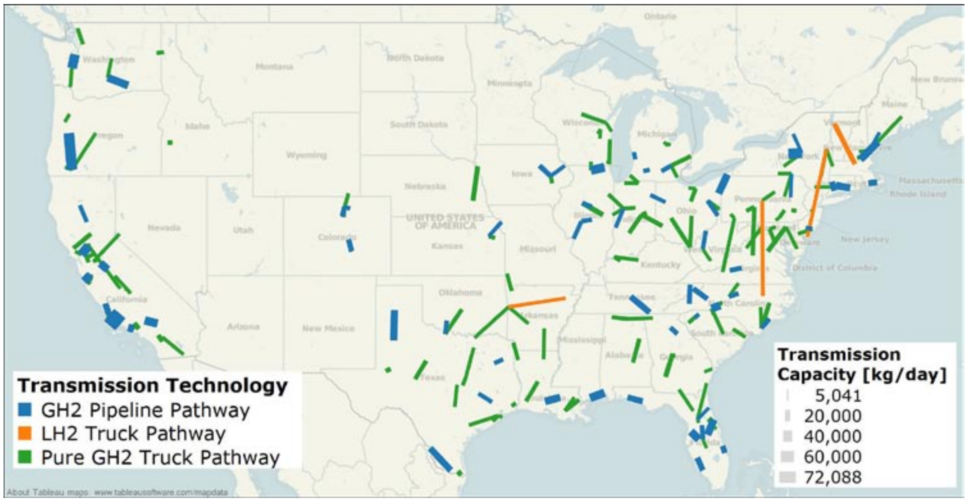

FIGURE 3. Transmission infrastructure build-out under the early-market "hydrogen success" scenario

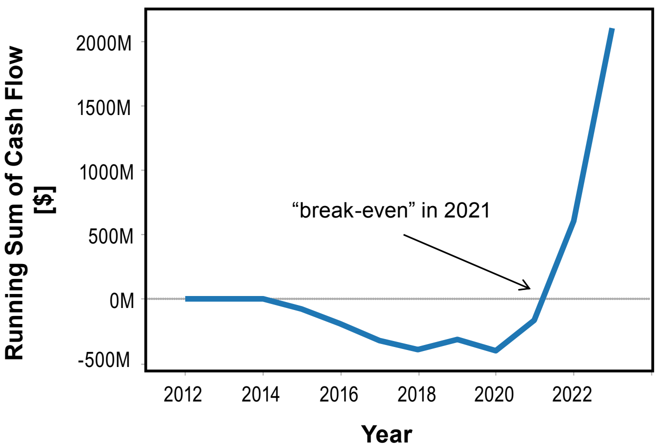

FIGURE 4. Cumulative cash flow, nationwide, if hydrogen is priced at $8.00/kg in the early-market "hydrogen success" scenario

subsidies: (1) vehicles only (e.g. $7,500/vehicle); (2) vehicles and fuels; versus (3) vehicles and fuels and stations. The results will be analyzed in terms of metrics such as fuel cost per mile for FCEVs vs. plug-in hybrid electric vehicles/battery electric vehicles, investments for FCEV stations and electric vehicle supply equipment, utilization ratios, extent of station coverage, economies of scale, penetration rates, and charger ratios.

FY 2012 Publications/Presentations

1. B. Bush, O. Antonia, M. Melaina, D. Steward, J. Svede, K. Webster, "Summary of SERA Capabilities", Management Report, 18 October 2011.

2. B. Bush, M. Melaina, "Cash Flows in SERA Scenarios for Early Market Clustering", Presentation to FFPIT, 20 March 2012.

3. B. Bush, M. Melaina, "SERA Overview and Recent Scenario Analyses", Presentation to UC Davis STEPS Team, 23 March 2012.

4. B. Bush, M. Melaina, K. Webster, "SERA Scenarios for Early Market Clustering", Management Report, 31 July 2011.

5. B. Bush, M. Melaina, K. Webster, "Cash Flows in SERA Scenarios for Early Market Clustering", Management Report, 15 October 2011.

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1. "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.

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

3. "H2A Delivery Components Model." Version 2.0. *DOE H2A Delivery Analysis*. http://www.hydrogen.energy.gov/h2a_delivery.html. Accessed 17 Jan 2009.