VII.1 Scenario Evaluation, Regionalization and Analysis (SERA) Model

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Objectives

The Scenario Evaluation, Regionalization and Analysis (SERA) model[1] 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 the most recent phase of the project are:

- Expanding the interoperability of SERA with the Hydrogen Demand and Resource Analysis (HyDRA) model [1]. The interoperability with HyDRA generally involves providing compatible data formats and conforming to HyDRA's data schemas.
- Developing sub-models within SERA to represent a variety of alternative infrastructure development pathways, including the utilization of stationary power combined heat and power (CHP) or combined heat, hydrogen, and power (CHHP) applications, and hydrogen production from biogas resources. These pathways are sensitive to various time metrics associated with infrastructure dynamics.
- Continuing and expanding the work on case studies using the SERA model, focusing on early markets in California and also extending the analysis to national scenarios.

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.

Accomplishments

Completed first-of-kind preview studies:

- Wind-hydrogen infrastructure study.
- Spatiotemporal refueling modeling analysis.
- Analysis of CHHP competition with on-site steam methane reforming (SMR).
- Constructed new spatially and temporally detailed baseline scenarios:
  - Staged rollout of fuel cell electric vehicles (FCEVs) by urban area in a manner fully consistent with published National Academy of Sciences (NAS) scenarios.
  - Analysis of FCEV rollout on national scale.

Achieved significant enhancements in SERA usability:

- Two-way interoperability with HyDRA.
- More detailed and adaptable cost models.
- Revisions to user interface.
- Improvement of database schema.

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[1] SERA was formerly known as the Hydrogen Deployment System Modeling Environment (HyDS-ME).

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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, (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 [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?

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 (greenhouse gases, etc.). 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 2 shows sample SERA output in the form of an optimized hydrogen infrastructure network.

Results

The software development work on enhancing SERA's interoperability with HyDRA resulted in several new technical capabilities in SERA: SERA can now retrieve map layers from HyDRA via Web feature services (WFS), can style map layers using symbology consistent with HyDRA (e.g., consistent colors and shapes for visual representations), and can retrieve regional cost data from HyDRA via WFS. Conversely, HyDRA can now ingest analysis results output from SERA: (i) hydrogen infrastructure networks, by year and (ii) delivered hydrogen costs, by year.

Additionally, we enhanced the SERA cost models by substituting current delivery cost curves with H2A

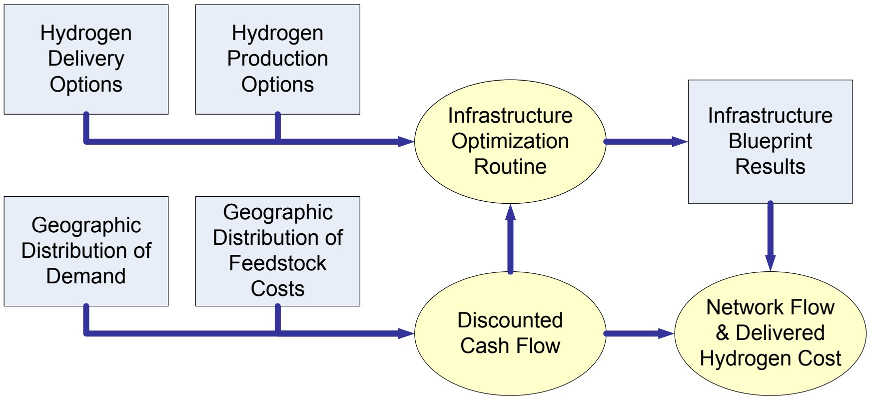

FIGURE 1. SERA Input and Output Data, and Algorithms

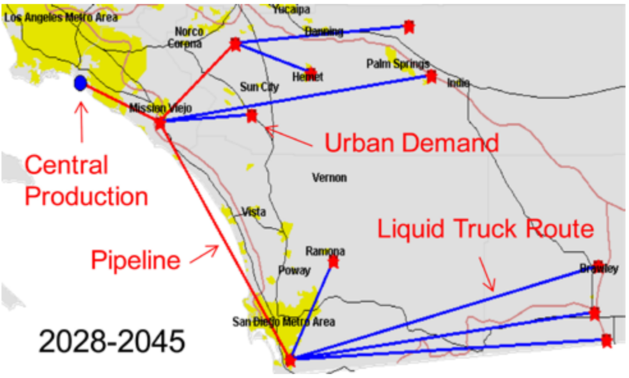

FIGURE 2. Illustrative Hydrogen Infrastructure Network Output from SERA

delivery components built inside the SERA model. This allows us to use H2A standards, but achieve maximum flexibility in constructing pathways (e.g., mixed pathways) within the analyses.

We completed a preliminary study that examines the relative cost-effectiveness of supplying hydrogen refueling stations via CHHP or on-site SMR for a large urban area, under three FCEV penetration scenarios. The major conclusions of this work are: (i) CHHP-based hydrogen production for use in nearby hydrogen refueling stations typically only has cost advantages over on-site SMR hydrogen production at some of those refueling stations, particularly for the early years of FCEV penetration scenarios where hydrogen demand and station sizes are initially low; (ii) variations in SMR or CHHP facility and energy-input costs can dramatically affect the overall cost of hydrogen, but they do not affect the mix of CHHP and SMR deployment as strongly; and (iii) for these scenarios and this study region, hydrogen costs typically drop from slightly above $6/kg in early years to below $5/kg in later years.

In conjunction with the CHHP work, we implemented a spatiotemporal station placement technique that produces realistic spatial, temporal, capacity distributions for hydrogen refueling stations. This station network expansion algorithm is based upon empirical data for existing gasoline stations, simulations of how those networks have evolved over time, and the resulting station size distributions.

Other SERA efforts involved the construction of a new, highly detailed FCEV rollout scenario that matches the standard NAS scenarios [4] in terms of FCEV introduction, FCEV stock, vehicle-miles traveled, and hydrogen demand on a year-by-year basis in addition to matching the city-specific schedule in the study. Analysis of these scenarios using SERA indicates that the more accelerated demand scenarios have lower delivered costs of hydrogen, time-averaged delivered costs ranging ~$3.5/kg to ~$5/kg, and that the details of infrastructure choice are quite sensitive to feedstock costs and the infrastructure cost models.

Finally, we completed a preview study of the SERA biogas capability: this involved (i) provisionally incorporating the latest NREL biogas systems characterization into SERA, (ii) performing an illustrative analysis of infrastructure build-out highlighting the significance of biogas pathways, and (iii) developing insights for future in-depth studies involving biogas pathways. SERA uses cost estimates from the H2A biomethane systems model in conjunction with those from the H2A production model to evaluate the delivered cost of biogas-originated hydrogen. In the sample analysis that we performed (on a test case of Midwestern cities), the optimal choice of infrastructure often hinges upon the difference between biogas and natural gas prices: when the biogas price, plus the processing cost to biomethane, is less than the natural gas price, the biogas pathways have lower costs. In general, the most competitive biogas scenario is where a single large biogas plant supplies a dozen or more (typically small) on-site SMR plants.

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 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 SERA 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. We are also iteratively improving the detail and accuracy of the cost models in SERA in order to support more complex scenarios. In particular, we plan to examine price points between competing technologies, such as delivered "drop-in" tanks vs. on-site SMR and electrolysis production. These price points will be resolved geographically and temporally as demand increases across multiple cities in a given region. Future SERA work will also address questions about stakeholder behavior and consumer preferences will be examined (e.g., preference for station availability, fuel costs, green hydrogen): to this end, we are planning to couple SERA to a discrete-choice model for hydrogen demand.

FY 2010 Publications/Presentations

1. B. Bush, M. Melaina, O. Sozinova. "Spatiotemporal Layout of Hydrogen Refueling Stations". National Renewable Energy Laboratory, 30 October 2009. (management report)

2. Brian Bush, Marc Melaina, Michael Penev, Olga Sozinova, Darlene Steward. "Exploration of Low Cost Mixes of CHHP and On-Site SMR in an Urban Area". National Renewable Energy Laboratory, 6 January 2010. (management report)

3. Brian Bush, Marc Melaina, Olga Sozinova. "Hydrogen Infrastructure Analysis Using SERA". 24 March 2010. (presentation)

4. B. Bush, D. Getman, D. Hettinger, J. Levene, M. Melaina. "Interoperability between SERA and HyDRA". National Renewable Energy Laboratory, 31 March 2010. (management report)

5. B. Bush, M. Melaina, "SERA Base Case Scenarios", 30 April 2010. (management report)

6. Brian W. Bush, Olga Sozinova, Marc W. Melaina, "Optimal Regional Layout of Least-Cost Hydrogen Infrastructure", presented at the 2010 NHA Hydrogen Conference & Expo, 4 May 2010. (conference presentation)

7. Brian W. Bush, Olga Sozinova, Marc W. Melaina, "Optimal Regional Layout of Least-Cost Hydrogen Infrastructure", proceedings of the 2010 NHA Hydrogen Conference & Expo, 28 May 2010. (conference proceedings)

8. Brian W. Bush, "Infrastructure Analysis of Early Market Transition of Fuel Cell Vehicles", presented at the 2010 Annual Merit Review and Peer Evaluation Meeting, 8 June 2010. (conference presentation)

9. B. Bush, A. Jalalzadeh, M. Melaina, G. Saur, "SERA Biogas Capability Preview", milestone presentation, 30 June 2010. (management report)

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2. "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.

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4. 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.