NATIONAL RENEWABLE ENERGY LABORATORY

Infrastructure Analysis of Early Market Transition of Fuel Cell Vehicles

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Project ID # AN001

Overview

Timeline

- Start: May 2005
- Finish: October 2011*
- Complete: 90%

Barriers

- Stove-piped/Siloed Analytical Capability [4.5.B]
- Suite of Models and Tools [4.5.D]
- Unplanned Studies and Analysis [4.5.E]

Budget

- Total Project Funding: $946k
  - 100% DOE-funded
- FY2010: $250k
- FY2011: $220k

*Project continuation and direction determined annually by DOE

Partners

- 2005-2006: DTI, ORNL, ANL
- 2007: Mistaya Engineering
- 2008-2009: D. Thompson
- 2008-2010: NREL H2 analysts
- 2010-2011: Allegiance Consulting

SERA = Scenario Evaluation and Regionalization Analysis

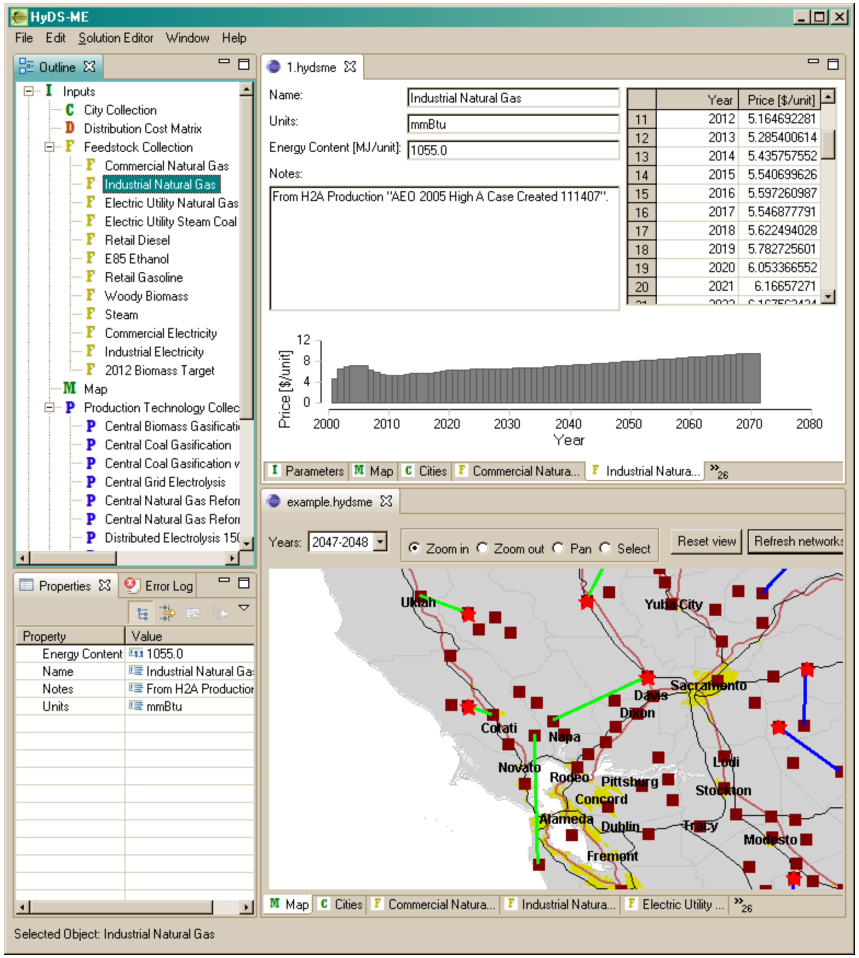
The SERA project studies regional build-outs of renewable energy infrastructures over time by optimizing on the delivered cost of hydrogen

Goals

- Determine optimal regional infrastructure development patterns for hydrogen, given resource availability and technology cost.
- Geospatially and temporally resolve the expansion of production, transmission, and distribution infrastructure components.

Key analysis questions

- 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? (e.g., central vs. onsite)



Relevance: Objectives

The SERA Project Activities Correspond Directly to Program Plan.

Objectives (AOP Tasks)

Interoperability
- Add functions to SERA to work with new HyDRA (Hydrogen Demand and Resource Analysis) tool features
- Import detailed H2A (hydrogen analysis) cost models into SERA

Infrastructure Integration
- Develop cost submodels representing a variety of alternative infrastructure development pathways

Scenario analysis
- Hydrogen production from biogas
- Niches for combined heat, hydrogen, and power (CHHP)
- Minimizing delivery cost of renewable hydrogen
- Implications of stakeholder behavior and consumer preferences
- Price points between competing technologies

Relevance to MYPP

Systems Analysis – Subtasks
"Maintain and Upgrade HyDS ME"

Systems Analysis – Objectives
"identify and evaluate early market transformation scenarios consistent with infrastructure and hydrogen resources"

Systems Analysis – Studies & Analysis
"Cross-cut analysis"

Systems Analysis – Models & Tools
"Integrated Models"

Systems Analysis – Scenario Analysis Projects
"Well-to-Wheels Analysis"

Systems Analysis – Studies & Analysis
"Long-term analysis"

Systems Analysis – Scenario Analysis Projects
"Infrastructure Analysis"

Relevance: Impact on Barriers

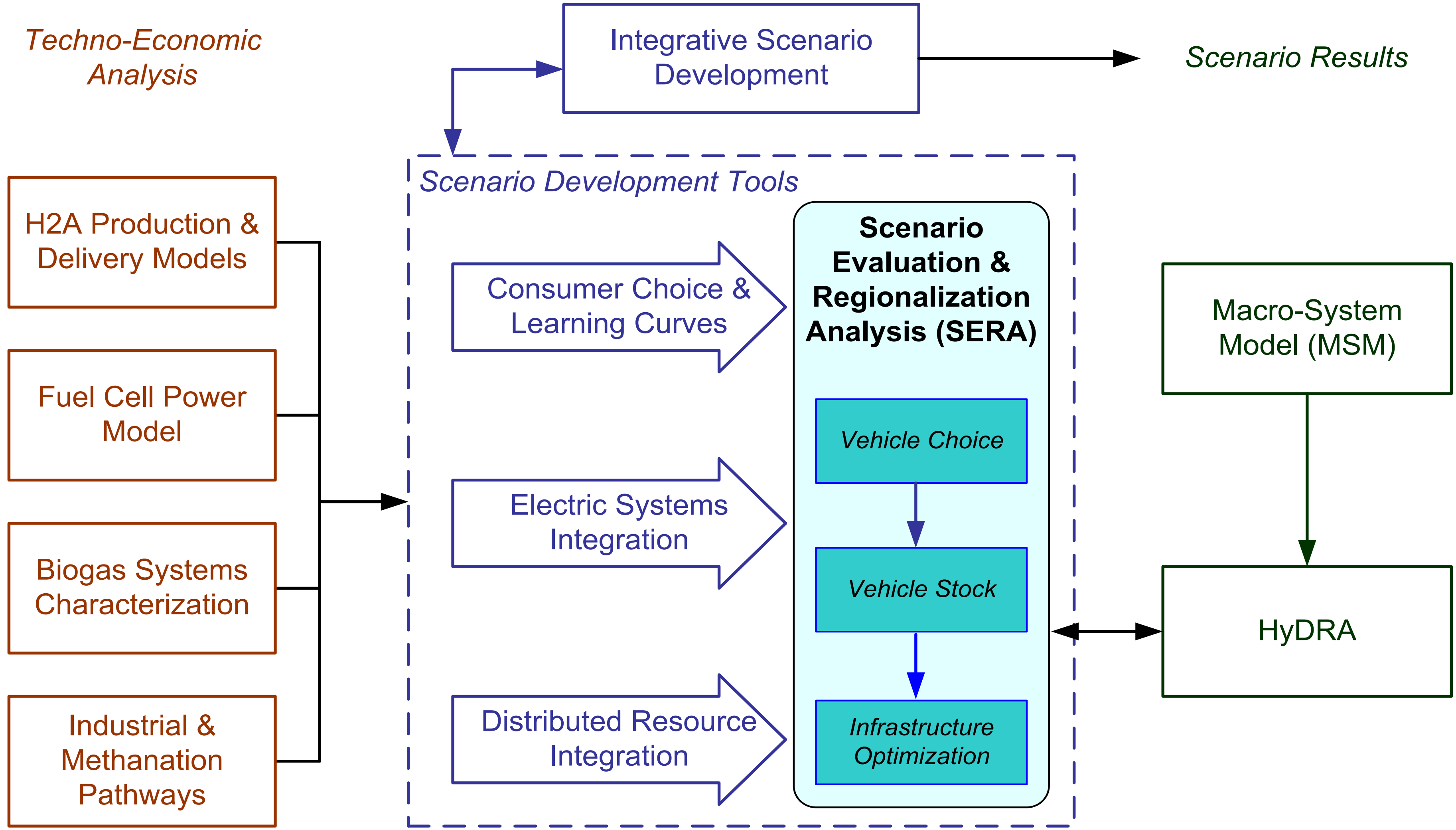
The SERA Project Directly Addresses Barriers in Program Plan.

Barrier	*Impact*
Stove-piped/Siloed Analytical Capability [4.5.B]	• SERA utilizes inputs from H2A models. • SERA's XML (extensible markup language) input/ output format is easily processed by common data import/export tools. • SERA has connectivity with geographic information systems (GIS) and relational databases. • SERA integrated vehicle choice and stock models.
Suite of Models and Tools [4.5.D]	• SERA is interoperable with the HyDRA (Hydrogen Demand and Resource Analysis) tool. • SERA interoperablility features open possibilities for integration with the Macro System Model (MSM) and related tools.
Unplanned Studies and Analysis [4.5.E]	• SERA's architecture is routinely improved and enhanced in order to make it more flexible for future analysis studies. • Each SERA study has a unique character and typically involves the incorporation of new technologies, synergies, or analysis scenarios.

Relevance: Context and Interconnectivity

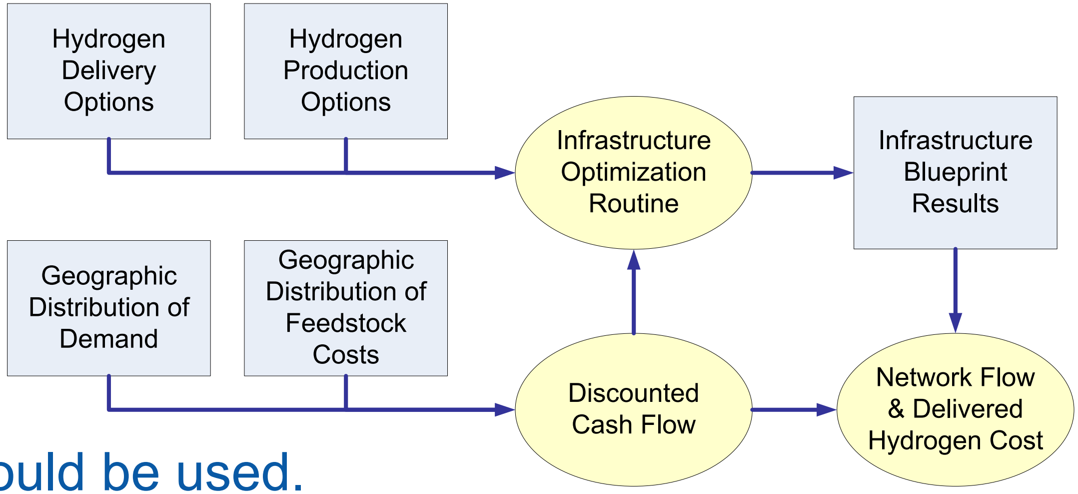
SERA Provides Core Infrastructure-analysis Capabilities.

SERA integrates results and data from multiple hydrogen analysis models and projects at NREL, and is interoperable with HyDRA

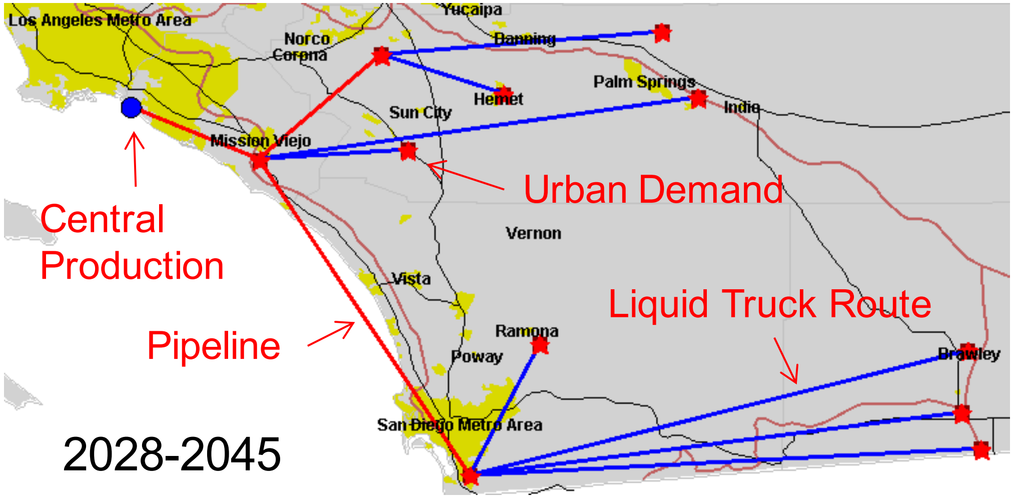


Approach: How SERA Infrastructure Optimization Works

SERA Optimizes Hydrogen Infrastructure in Deployment Scenarios.



- Objective function
  - Total discounted cash flow for the whole hydrogen infrastructure
    - This could also be done at five-year increments or in other time frames.
  - Other objective functions could be used.
- Constraints
  - Demands must be fully met: i.e., no shortfalls allowed.
  - Capacity constraints on technologies must be satisfied.
- Exogenous inputs
  - Annual H_2 demands at cities
  - Regional feedstock prices
  - Infrastructure characteristics
    - Production technologies
    - Transmission technologies
    - Distribution costs



Approach: Assumptions

SERA Technology Cost Input Assumptions are User-Configurable.

SERA uses input data from official H2A case studies and from provisional H2A results for specific studies or scenarios

- SERA is agnostic regarding the source of cost data
  - Production costs
    - Published H2A production model
    - New H2A production components (wind electrolysis, biogas, CHHP, etc.)
    - Special-purpose analyses
  - Delivery costs
    - Published H2A delivery components
    - New H2A delivery components (rail, composite tanks, etc.)
    - Older SERA studies relied on decomposing HDSAM output into transmission and delivery costs, but newer studies directly rely on H2A component costs, assembled into pathways.
  - Feedstock costs
    - EIA AEO energy price forecasts (national or regional) are used for most studies.
    - Some studies (e.g., biogas, electric grid) used specially developed feedstock costs.
- SERA somewhat limits the infrastructure configurations that are allowable in the optimization.

Approach: Milestones

The SERA Project is on Schedule for Completion of its Milestones.

FY	Milestone	Description	Date	Status
2010	2.8.5	Complete full integration of CHHP systems	Sep 2010	Complete
	2.8.6	Complete full integration of biogas systems	Jul 2010	Complete
2011	2.8.1	Complete integration with vehicle choice and stock models	Dec 2010	Complete
	2.8.2	Complete study on stakeholder behavior and consumer preferences	Apr 2011	In process*
	2.8.3	Complete full study on geographical and temporal price points for competing technologies	Jul 2011	On schedule
	2.8.4	Complete interoperability with new HyDRA features	Sep 2011	Ahead of schedule

**As of 3/11/2011*

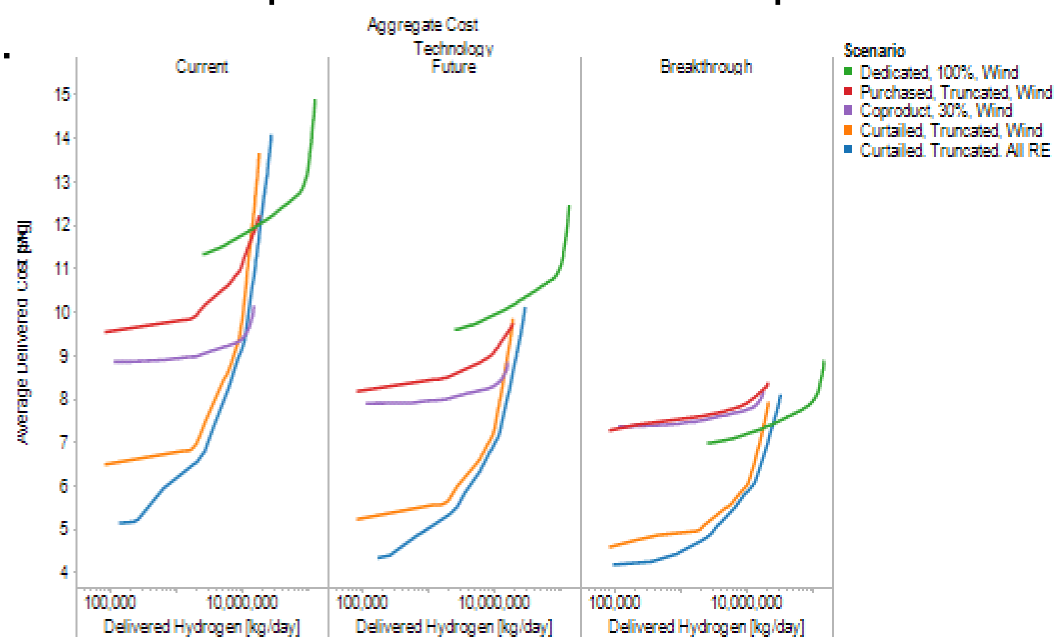
Multiple Scenario Analyses and Model Enhancements Have Been Completed.

- Cost model development
  - Addition of biogas, combined heat, hydrogen, and power (CHHP), and wind cost models for hydrogen production.
  - Addition of rail and composite-tank truck delivery pathways.
  - New, advanced method for rapidly incorporating updates to hydrogen analysis (H2A) cost models into SERA.
- New submodels
  - Vehicle choice
  - Vehicle stock
- First-of-kind studies
  - Hydrogen production from biogas
  - Niches for combined heat, hydrogen, and power (CHHP)
  - Minimizing delivery cost of renewable hydrogen
  - Implications of stakeholder behavior and consumer preferences
- Achieved significant enhancements in SERA usability
  - Cleaner user interface
  - Streamlined data storage mechanisms

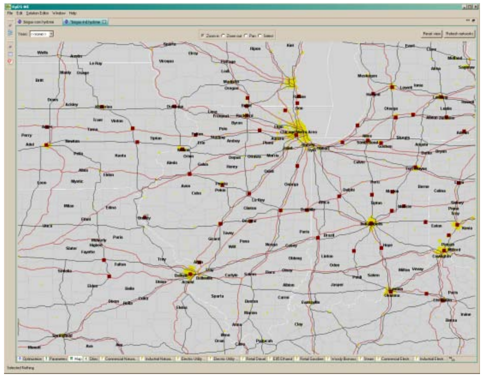
Insights Have Been Developed Into the Delivered Cost of Renewable Hydrogen Under Multiple Scenarios.

The geographic distribution of least-cost wind -to-hydrogen sources is unique from the general distribution of wind resources

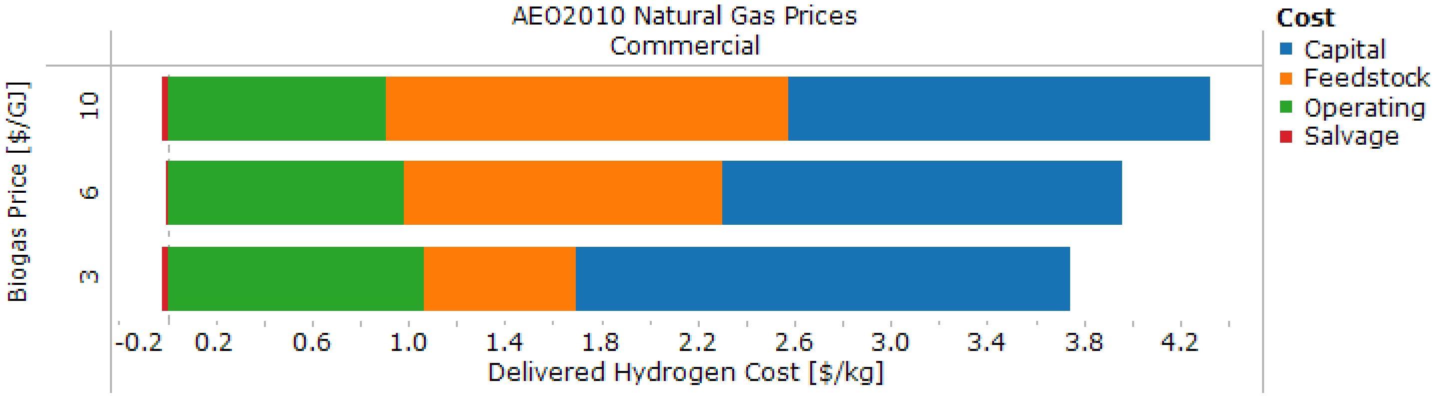
- Four delivery pathways dominate others in terms of cost:
  - LH2 (liquid hydrogen) rail for long distance and moderate quantity
  - LH2 truck for moderate distance and moderate quantity
  - GH2 (gaseous hydrogen) pipeline for moderate distance and large quantity
  - GH2 truck for short distance or small quantity
- Substantial wind energy curtailed from the production of electric power may be available for production.
  - Up to 2M kg/day is available at moderate cost ($4-6/kg), depending on technology maturity.
- Wind from purchased electricity at wind-sites or wind produced as a coproduct could have a $2/kg greater cost, but somewhat more availability.



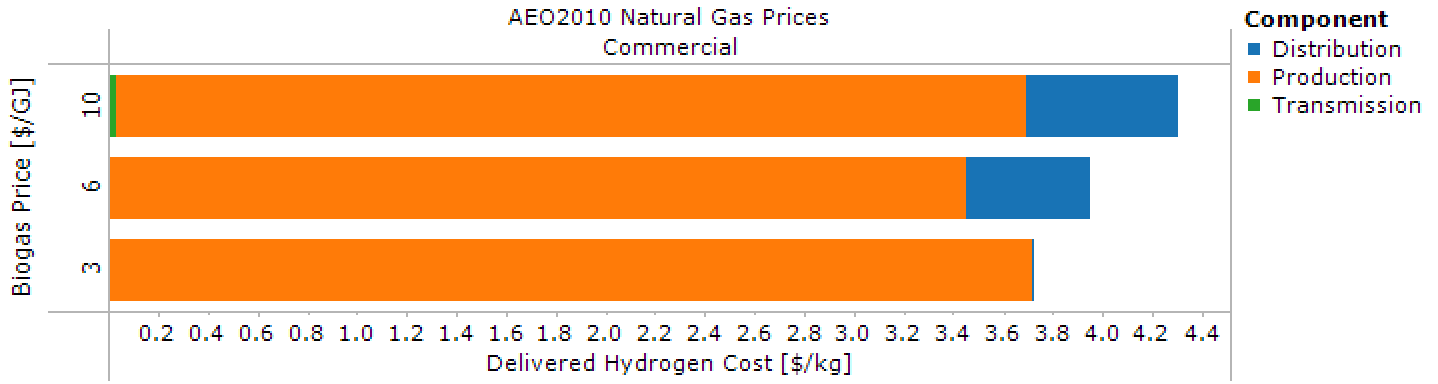
The SERA Study of Biogas-based Hydrogen in 58 Midwest Cities Highlights Niches for That Pathway.



- Distributed natural gas reforming is the primary competitor to biogas-based hydrogen-production.
- On-site/multiple-site biogas-based hydrogen-production can compete when natural gas prices are at AEO 2010 national average commercial price.
- Only the least expensive biogas feedstocks can compete when natural gas prices are at AEO 2010 national average industrial levels.



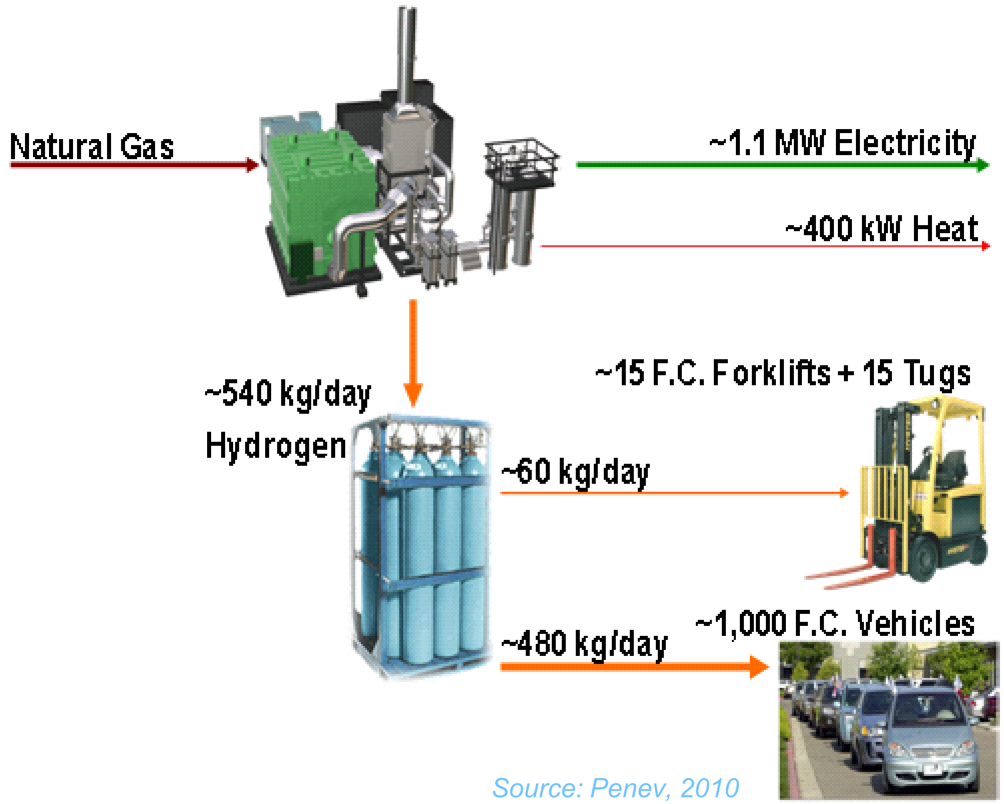
- Extensive hydrogen-pipeline networks do not develop.



The SERA Study of CHHP & On-site SMR in Early Transition Years Identifies Low Cost Mixes of These Technologies.

At low demand levels, CHHP may have a cost advantage over on-site SMR for certain hydrogen fueling stations

- *Goal:* To gain insights regarding the cost-competition between two prominent intra-urban hydrogen-production technologies relevant for the first decades of FCEV (fuel cell electric vehicle) use.
  - CHHP (combined heat, hydrogen, and power) technologies that can meet the heating and electric power demands of large buildings while also producing hydrogen. The hydrogen can then be transferred short distances to FCEV refueling stations via pipeline.
  - On-site SMR (steam methane reforming) technologies can produce hydrogen right at the FCEV refueling station site.



Source: Penev, 2010

The CHHP/SMR Study Aims Identify Low Cost Mixes of These Technologies During Early Transition Years.

Each SERA study requires unique boundary definitions, data preparation and vetting of technology assumptions

1. Estimate the number and type of buildings in the study area that could potentially be used for hydrogen production via CHHP technologies.

2. Develop simplified hydrogen-production cost models applicable to these buildings, in the case of CHHP, or for hydrogen production at the refueling station, in the case of SMR.

3. Downscale three National Academy of Sciences (NAS) national hydrogen-demand scenarios to the study area.

4. Estimate the placement of hydrogen refueling stations as a function of time, given the demand for hydrogen from FCEVs.

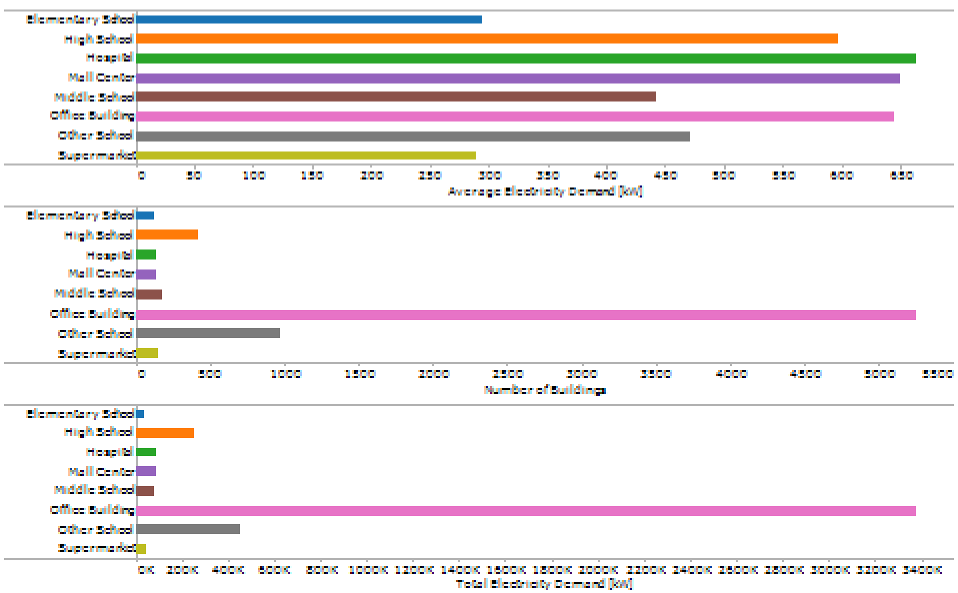
5. Compete CHHP versus SMR production of hydrogen on a per-refueling-station basis for each scenario.

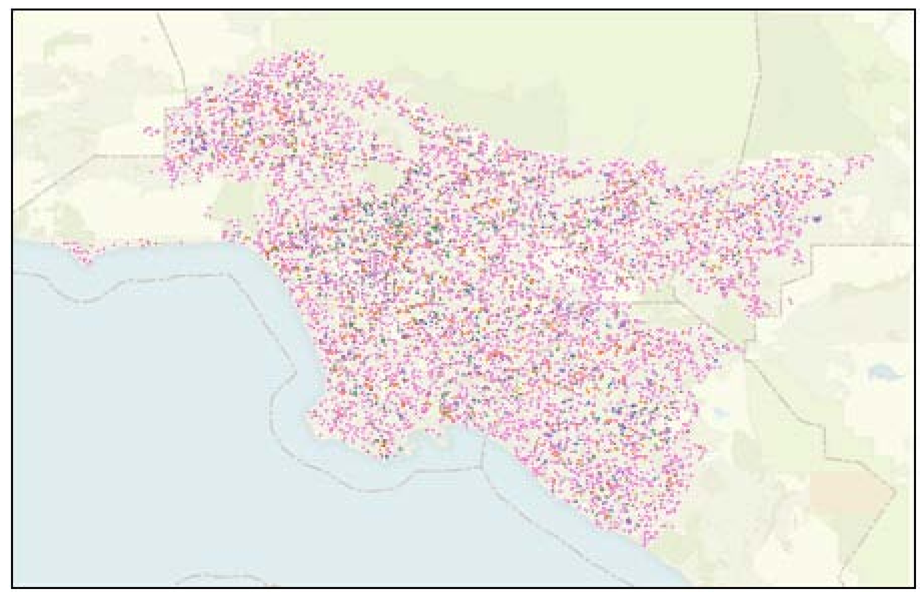
6. Assess the use and relative cost of CHHP and SMR in the study area.

The CHHP/SMR Study Identified Buildings That Could be Candidates for CHHP Deployment.

- Only the larger urban buildings (or building complexes) have sufficient electricity and heating demands to make the cost-effective CHHP-production of hydrogen for nearby FCEV refueling stations.
- CHHP may have other cost-effective applications beyond its use for supplying refueling stations.

Building Type	Average Electricity Demand [kW]	Source of Energy Data	Source of Geospatial Data
Elementary School	181.78	FCPower, NREL	NGA HSIP Gold
High School	525.35	FCPower, NREL	NGA HSIP Gold
Hospital	595.54	FCPower, NREL	NGA HSIP Gold
Hotel/Motel	50	Rough estimate	NGA HSIP Gold
Mall Center	650	Rough estimate	NGA HSIP Gold
Middle School	350	Rough estimate	NGA HSIP Gold
Office Building	600	Rough estimate	Rough estimate of numbers from EIA CBECS; uniform geographic placement
Other School	400	Rough estimate	NGA HSIP Gold
Supermarket	174.74	FCPower, NREL	NGA HSIP Gold



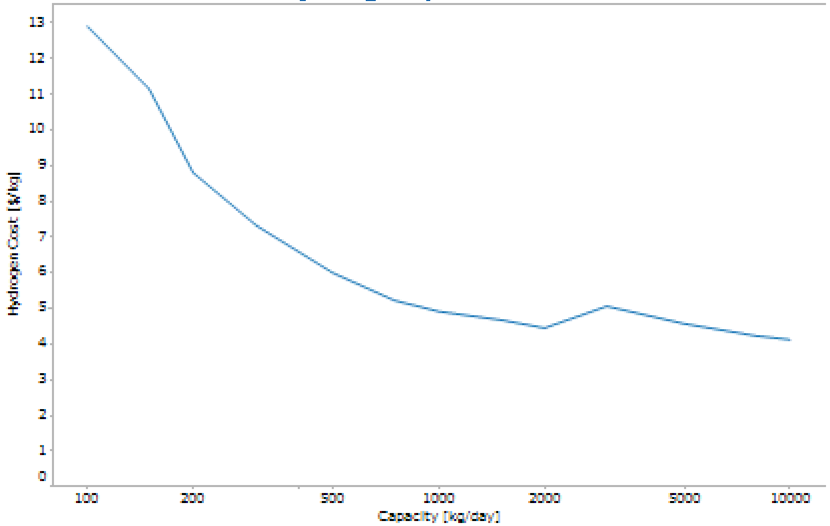


Hydrogen Production Cost Models Were the Basic Inputs for the CHHP/SMR Study.

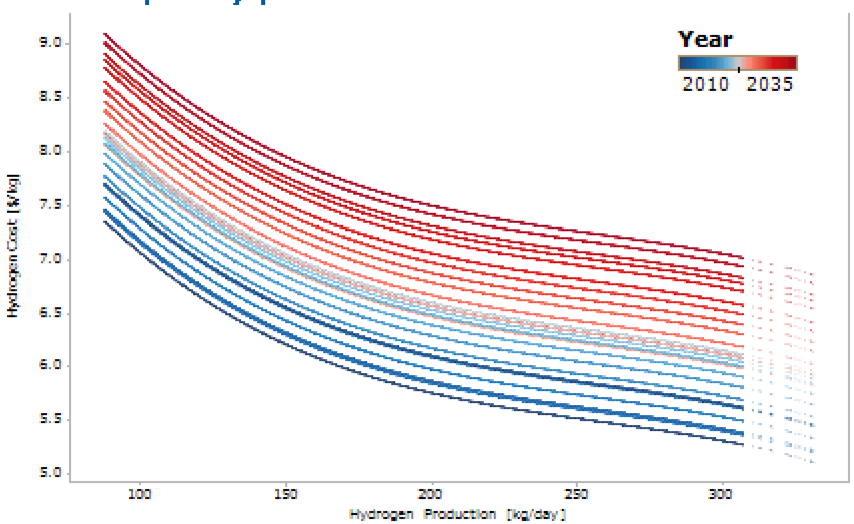
The CHHP study utilized cost functions from a series of complex Fuel Cell Power Model runs

- We use regional energy prices appropriate for the study area from the EIA Annual Energy Outlook (AEO).
- On-Site SMR
  - From H2A
  - AEO 2010 energy costs
- CHHP at buildings
  - From regression based on H2A
  - Cost of natural gas: AEO 2010
  - Cost of electric power: AEO 2010
  - State incentive: $2000/kW
  - Fuel cell cost: $3500/kW

SMR production costs for hydrogen generally decrease with the amount of hydrogen produced.



The cost of producing hydrogen via CHHP decreases with the quantity produced and increases with time.

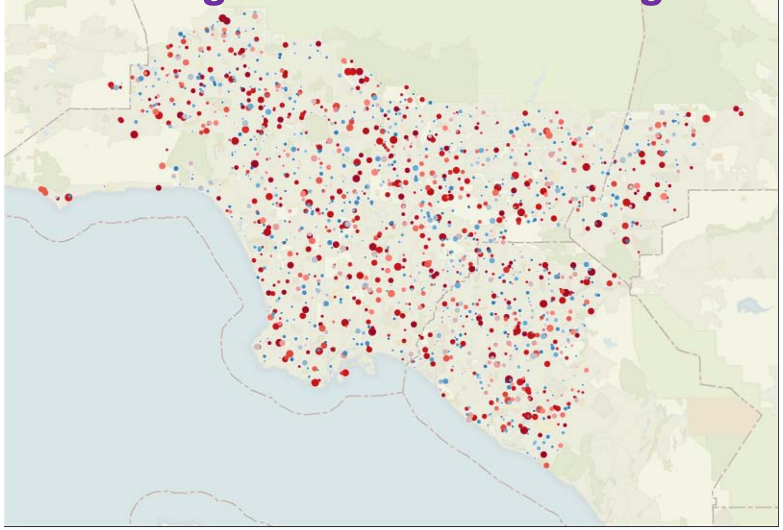


CHHP can Deliver Lower Cost Hydrogen Than On-site SMR Under Scenarios With Low Demand in Early Transition Years.

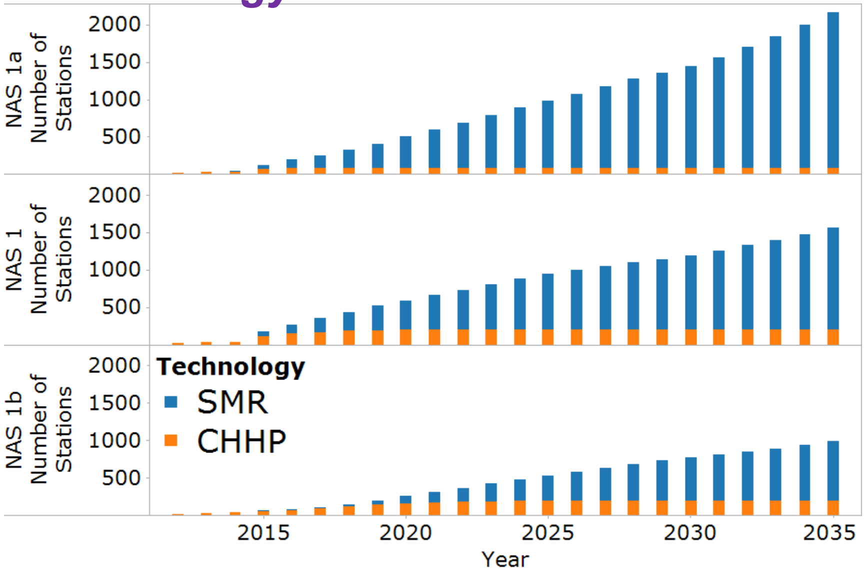
SERA estimates CHHP market share when competed against onsite SMR

- CHHP has an advantage over onsite SMR at smaller stations in the early transition.
- For larger stations in later years, SMR tends to have cost advantages over CHHP.
- Hydrogen cost from SMR or CHHP can vary dramatically, depending on conditions.

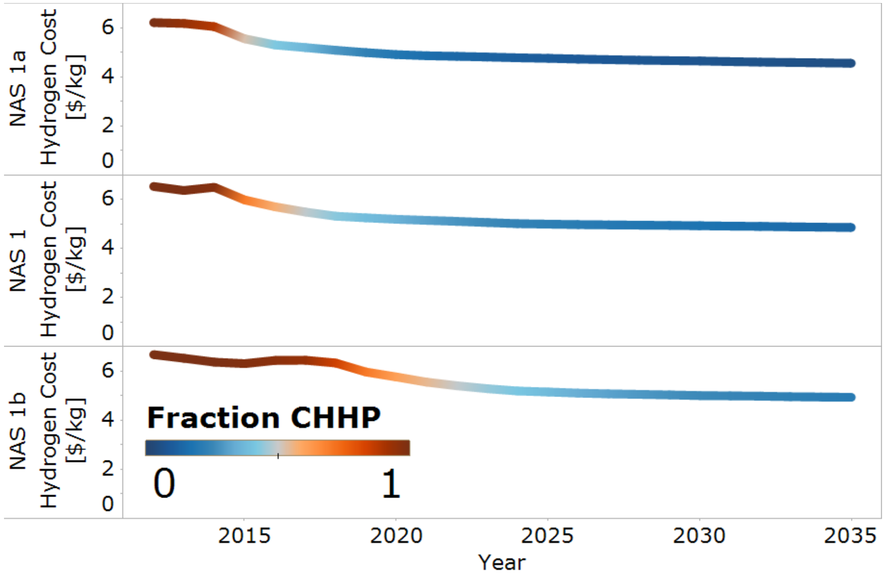
Refueling Stations in Los Angeles



Technology Mix for Three Scenarios



Delivered Cost for Three Scenarios



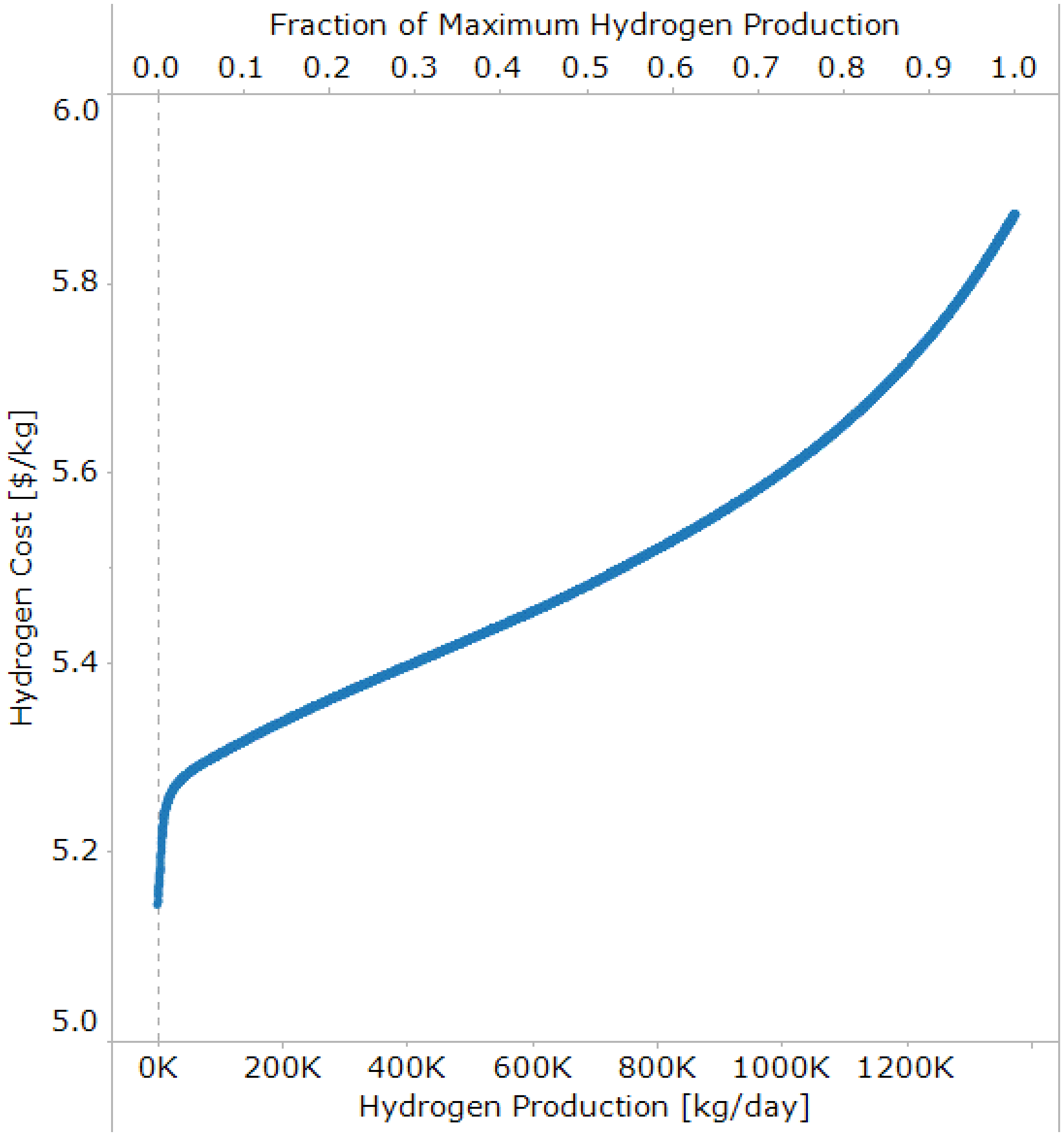
Parameterized Cost Curves Provide a Flexible Approach for Estimating On-site CHHP Costs Without Detailed Intra-urban Analysis.

<u>Example</u>

- AEO 2010 energy costs:
  - $10.1292/mmBtu
  - $0.12417/kWh
- State incentive:
  - $2000/kW
- Cost of fuel cell system:
  - $3500/kW
- Population:
  - 9.862M

- Under these conditions, the delivered cost of hydrogen ranges from $5.14/kg to $5.87/kg, depending upon the quantity produced.

- Note that the incentive lowers the cost by $2.13/kg.



Collaborations
The SERA Project had Minimal External Collaboration in 2010-2011.

- The project relies on collaborations with subject matter experts within NREL,
  - Hydrogen Technologies and Systems Center,
  - Energy Model & Forecasting Group,
  - Vehicle Technology Group,
  - NREL Data Analysis and Visualization Group,

  which, in turn, rely on external collaborations.

Proposed Future Work

Future Work Focuses on Scenario Analysis, not Modeling.

- The SERA software is essentially complete, but continued use of the tool in scenario studies requires . . .
  - regular updating H2A and other cost inputs,
  - software modifications to take advantage of new HyDRA features, and
  - minor usability enhancements in response to analyst requests.
- SERA will be applied to more complex deployment scenarios:
  - Identifying regional niches for production technologies and delivery infrastructure.
  - Feedback from computed delivered costs of hydrogen to consumer and stakeholder decisions.
  - Integration in multi-fuel studies.
- Integration in multi-fuel studies.
  - Collaborative exchange of data and scenarios assumptions with other models.
- Scenario focusing on opportunities for addressing cost barriers in early years of FCEV transition.

Summary

Relevance	• Integrated, cross-cutting model • Scenario-oriented analysis compatible with H2A cost models and feedback from stakeholder workshops
Approach	• SERA optimizes hydrogen production, transmission and distribution infrastructure to meet time-varying demand in urban areas over any specified region. • Integrated vehicle choice and stock models
Accomplishments	• Biogas, CHHP, and renewable hydrogen case studies • Interoperability with HyDRA • Integration improved cost models
Collaborations	• NREL H2 and vehicle analysis teams • Optimization experts and software engineers
Proposed Future Work	• Application of SERA to more complex scenarios • Add capabilities for specific studies