

# Infrastructure Analysis of Early Market Transition of Fuel Cell Vehicles



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**National Renewable  
Energy Laboratory**

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**2010 Annual  
Merit Review and  
Peer Evaluation  
Meeting**

**Project ID # AN001**

This presentation does not contain any proprietary, confidential, or otherwise restricted information

# Overview

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## Timeline

- Start: May 2005
- Finish: December 2010
- Complete: 85%

## Budget

- Total Project Funding: \$726k
  - 100% DOE-funded
- FY2009: \$115k
- FY2010: \$250k

## Barriers

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

## Partners

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

## Relevance: Drawing Upon Past Rollout Scenarios

## Stakeholder inputs documented

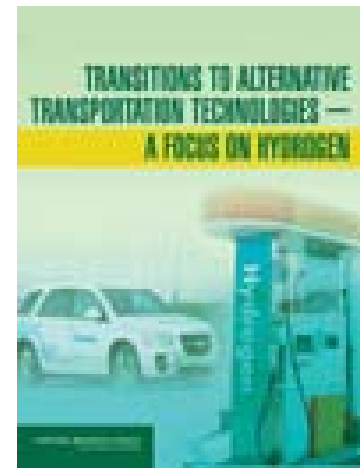
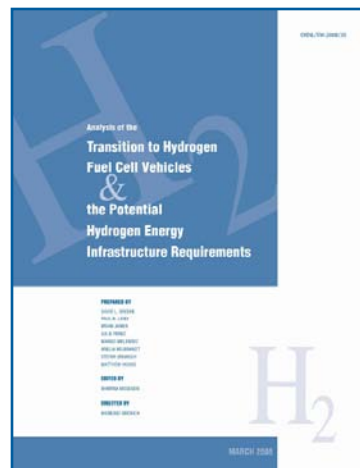
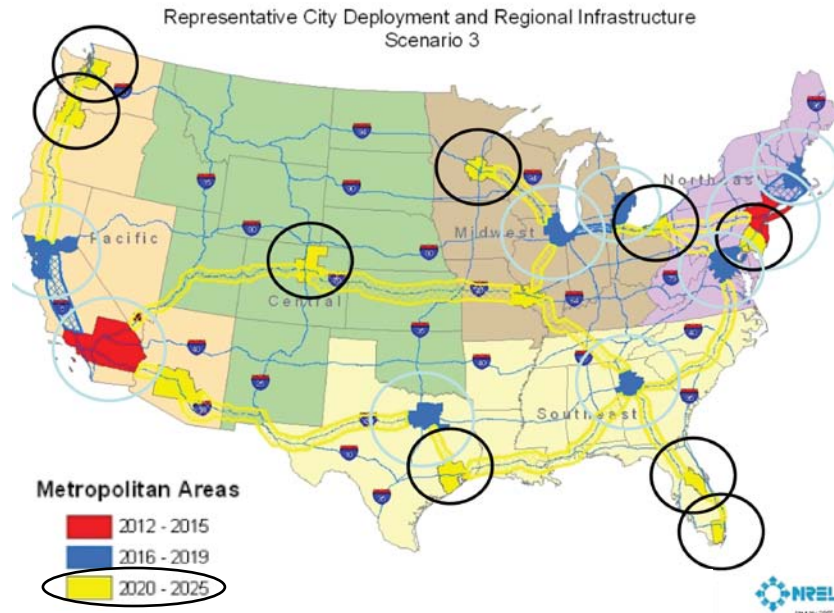
- Past efforts have collected stakeholder feedback on issues related to the hydrogen transition, and to infrastructure rollout specifically.

## Market adoption rates estimated

- The Transitions study from ORNL presents market adoption rates, as does the 2008 report from the National Academy of Sciences

***Need: Greater spatial detail to assess renewable pathways***

- Both studies relied upon semi-spatial models, but did not resolve resource-to-demand pathways through an integrated supply system or with a high level of geographic detail



# Relevance: New Analytic Capabilities within the Scenario Evaluation and Regionalization Analysis (SERA) Model

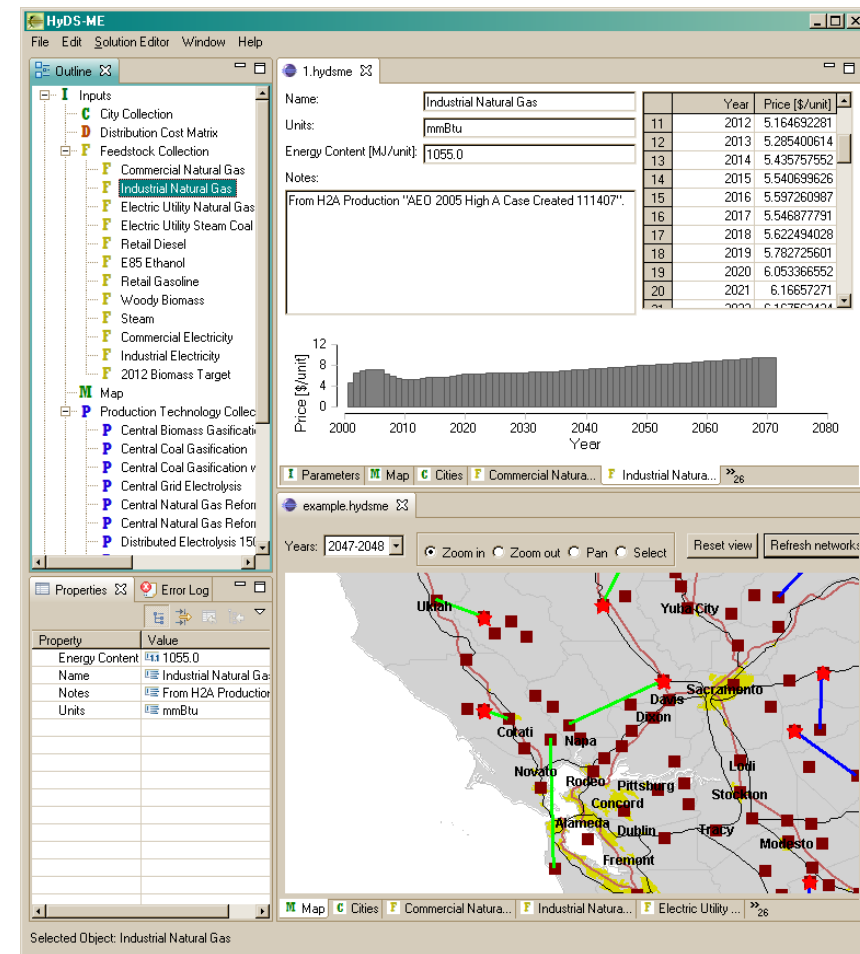
*SERA is a tool for studying regional build-outs of renewable energy infrastructures over time by optimizing on the delivered cost of hydrogen*

## 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

## Objectives (AOP Tasks)

### Interoperability

- Expand the interoperability of SERA with tools such as HyDRA
- Import detailed H2A cost models into SERA

### Perform scenario analysis

- Transportation of wind hydrogen
- Refueling station placement within urban areas
- Revised baseline scenarios
- Combined heat, hydrogen, and power (CHHP)
- Biogas production of hydrogen

## 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”

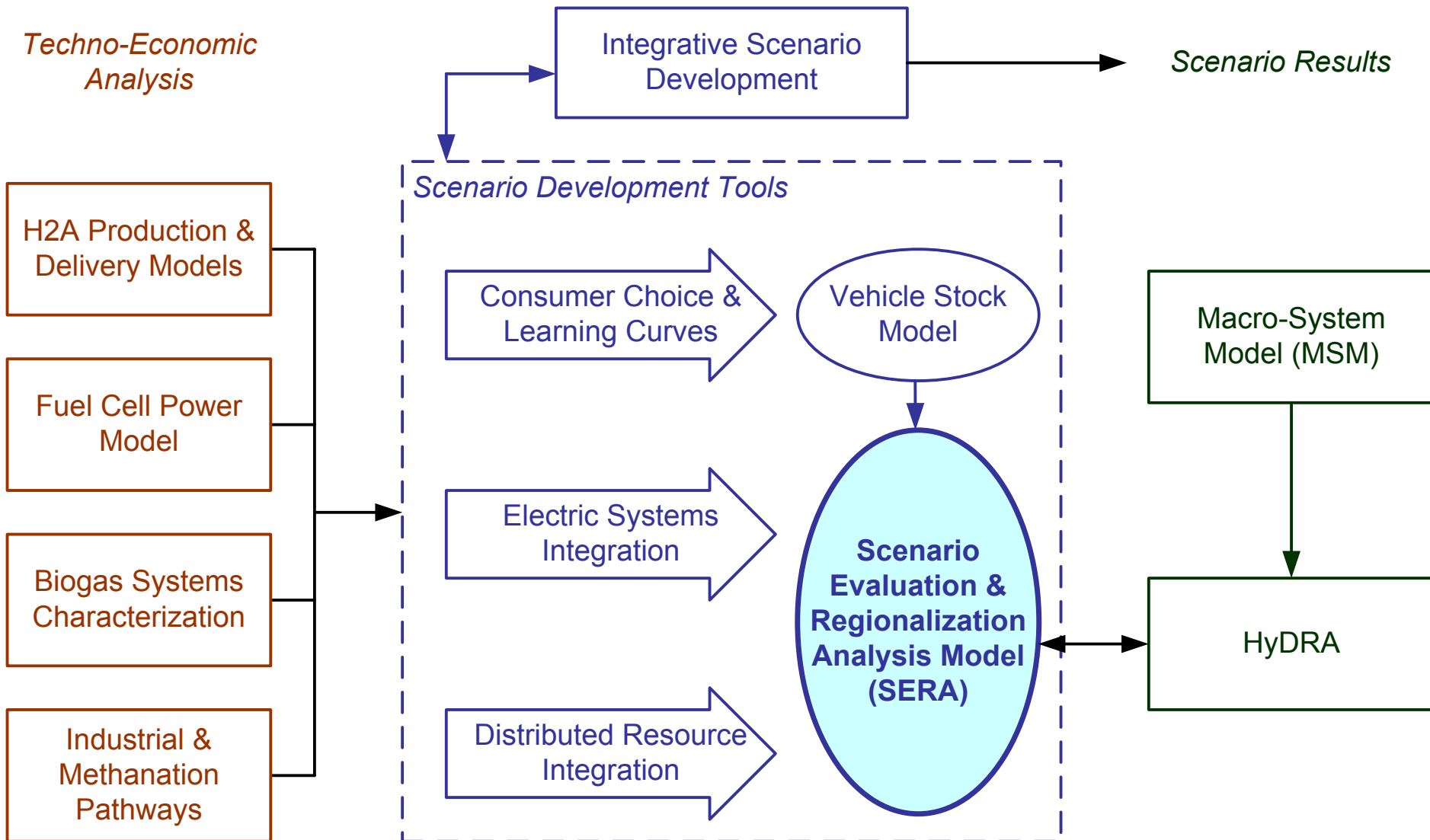
### Systems Analysis – Scenario Analysis Projects

“Infrastructure Analysis”

## Relevance: Impact on Barriers

| <b><i>Barrier</i></b>                            | <b><i>Impact</i></b>                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stove-piped/Siloed Analytical Capability [4.5.B] | <ul style="list-style-type: none"><li>• SERA utilizes inputs from H2A models.</li><li>• SERA's XML-based input/output format is easily processed by common data import/export tools.</li><li>• SERA has connectivity with GIS and relational databases.</li></ul>                                                                 |
| Suite of Models and Tools [4.5.D]                | <ul style="list-style-type: none"><li>• SERA is interoperable with HyDRA</li><li>• SERA interoperability features open possibilities for integration with the MSM and related tools.</li></ul>                                                                                                                                    |
| Unplanned Studies and Analysis [4.5.E]           | <ul style="list-style-type: none"><li>• SERA's architecture is routinely improved and enhanced in order to make it more flexible for future analysis studies.</li><li>• Configure SERA to address issues of station design, updated costs, modular expansion; response to dialogue with industry and other stakeholders</li></ul> |

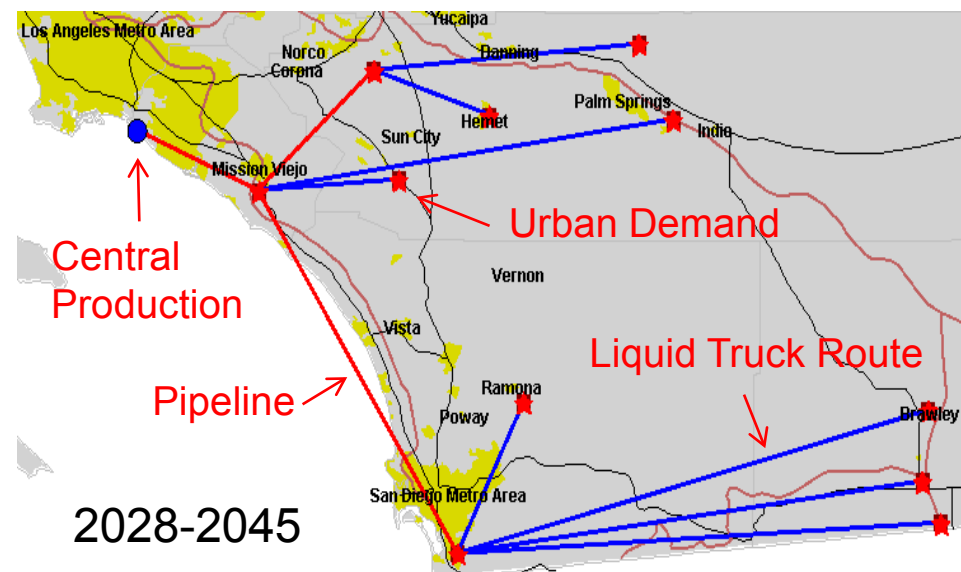
# Relevance: Context and Interconnectivity



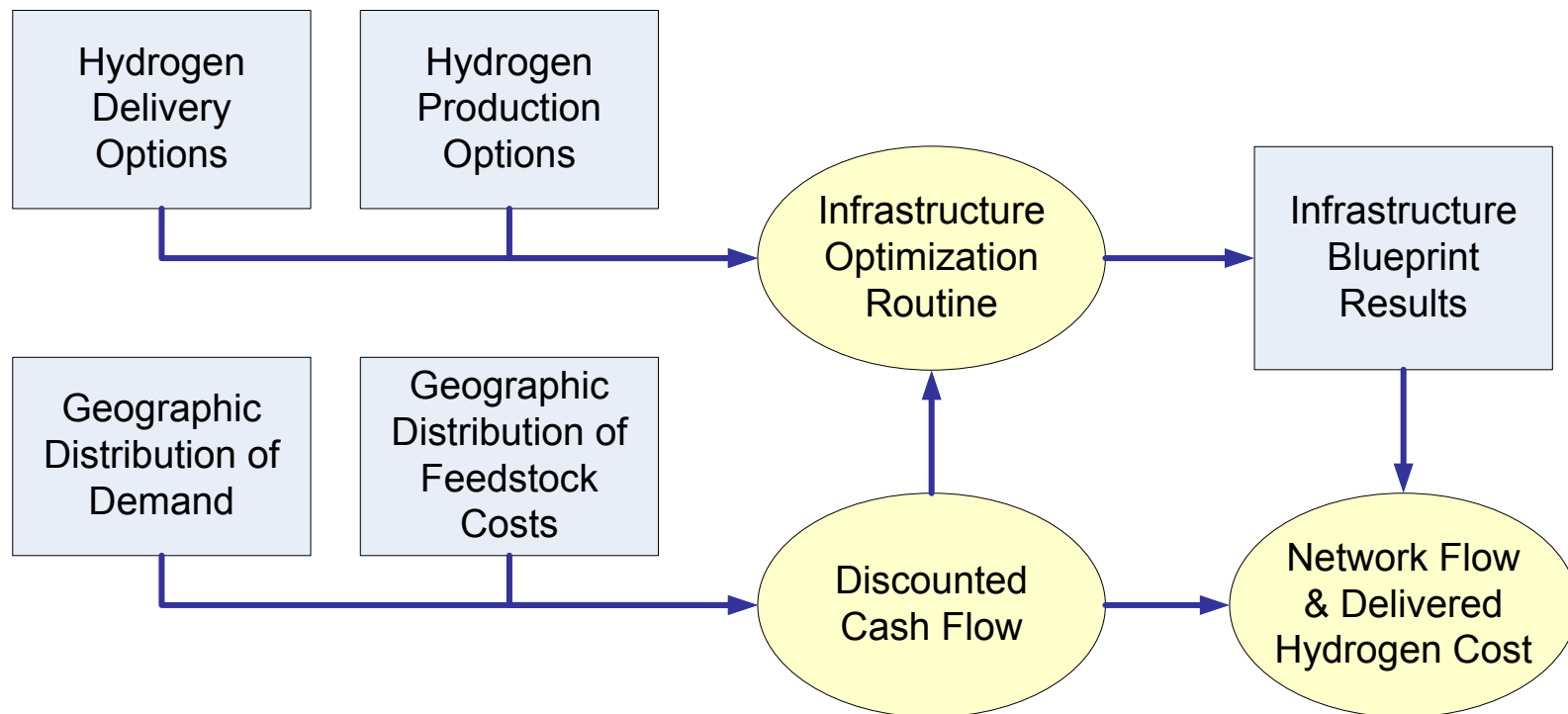
# Approach: Staged Analysis of Market Transition Scenarios

- *Preview studies* scope out issues in new analysis areas.
  - Data availability and quality
  - Scenario definition
  - Provisional modifications to analytic tools
  - Exploratory statistics and visualization
- *Full studies*, which typically follow preview studies, provide mature, repeatable analyses.
  - Robust data collection, preparation, and vetting
  - Integrated modifications to analytic tools
  - Rigorous statistical analysis
  - Polished visualizations

- FY2010 Study Subjects
  - Baseline scenarios with detailed geographic roll-out
  - Intra-urban placement of refueling stations
  - Combined heat, hydrogen, and power (CHHP)
  - Biogas systems



# Approach: How SERA Works



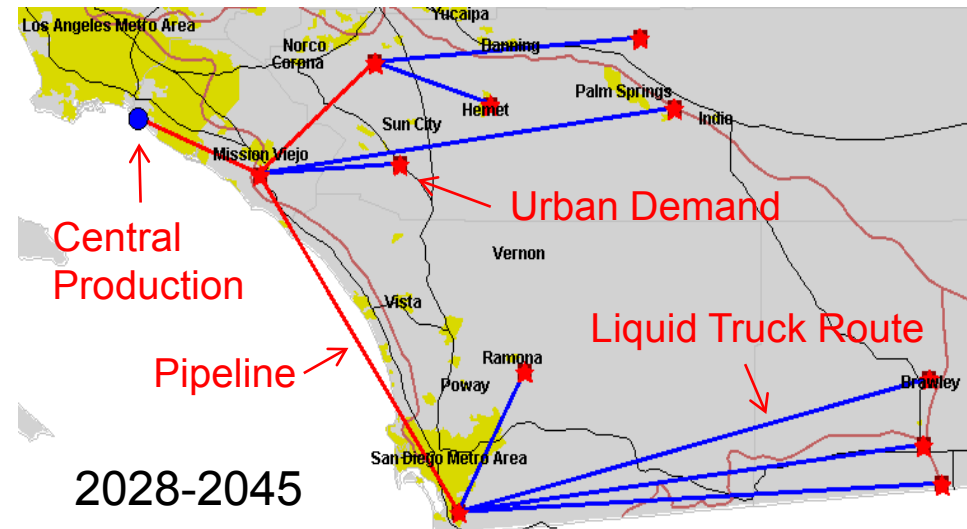
***SERA searches for optimal infrastructure architectures to meet time-varying demands in multiple urban areas within a specified region.***

# Approach: Milestones

| <b><i>FY</i></b> | <b><i>Milestone</i></b> | <b><i>Description</i></b>                   | <b><i>Date</i></b> | <b><i>Status</i></b> |
|------------------|-------------------------|---------------------------------------------|--------------------|----------------------|
| 2009             | 2.10.8                  | Completion of scenario analysis             | Sep 2009           | Complete             |
| 2010             | 2.8.1                   | Complete preview of CHHP systems            | Dec 2010           | Complete             |
|                  | 2.8.2                   | Complete interoperability with HyDRA        | Mar 2010           | Complete             |
|                  | 2.8.3                   | Complete base case scenarios                | Apr 2010           | Complete             |
|                  | 2.8.4                   | Complete preview of biogas systems          | Jun 2010           | On schedule          |
|                  | 2.8.5                   | Complete full integration of CHHP systems   | Jul 2010           | On schedule          |
|                  | 2.8.6                   | Complete full integration of biogas systems | Aug 2010           | On schedule          |

# Approach: Optimization Problem

- Objective function
  - Total discounted cash flow for the whole H<sub>2</sub> 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.
  - Lifetimes of infrastructure components must be respected.
  - Transmission networks must be “tree-like”: i.e., no loops or cycles are allowed currently.
- Exogenous inputs
  - Annual H<sub>2</sub> demands at cities
  - Regional feedstock prices
  - Infrastructure characteristics
    - Production technologies
    - Transmission technologies
    - Distribution costs



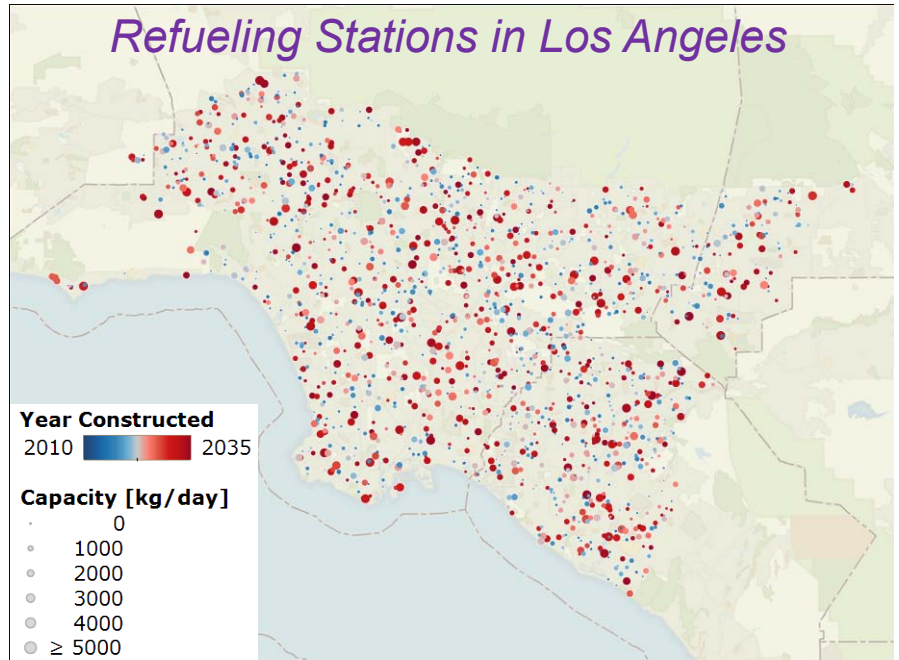
# Technical Accomplishments & Progress

*Recent development has added realism and enhanced the analytic capabilities of the SERA model. Baseline runs have been completed.*

- Completed first-of-kind preview studies:
  - Wind-hydrogen infrastructure study
  - Spatiotemporal refueling modeling analysis
  - Analysis of combined heat, hydrogen, and power (CHHP) competition with on-site SMR
- Constructed new spatially and temporally detailed baseline scenarios:
  - Staged rollout of FCVs by urban area in a manner fully consistent with published NAS scenarios
  - Analysis of FCV 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

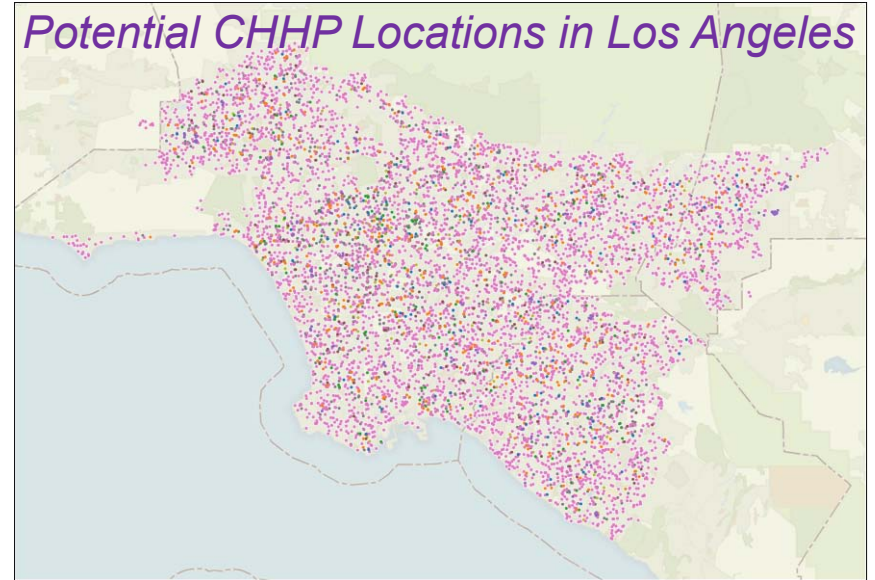
# Accomplishment: Spatiotemporal Refueling

- We implemented a spatiotemporal station placement technique that produces semi-realistic spatial, temporal, capacity distributions for hydrogen refueling stations:
  1. Time-dependent hydrogen demand for the urban area is used to estimate the number of stations that would be built in each year.
  2. The stations are sized stochastically according to an empirically determined capacity distribution.
  3. The stations are located stochastically within the urban area of interest.
- This station network expansion algorithm is based upon empirical for existing gasoline stations, simulations of how those networks have evolved over time, and the resulting station size distributions. (cf. Melaina and Bremson, 2008)

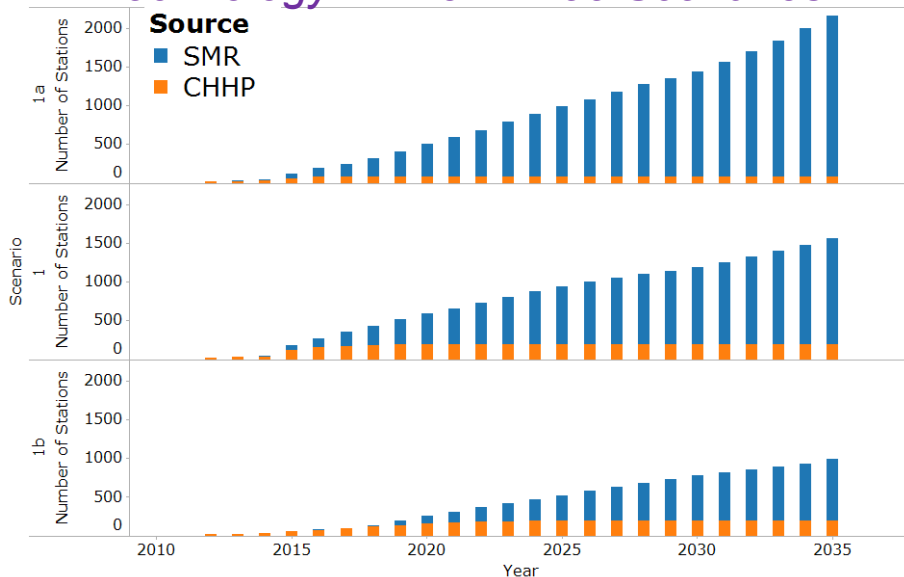


# Accomplishment: Low-Cost Mixes of CHHP & On-Site SMR

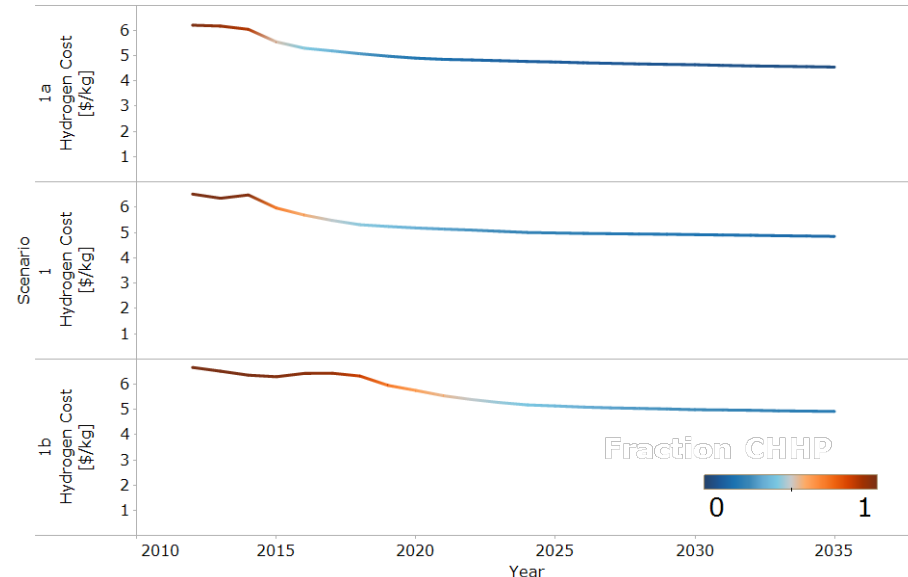
- **Goal:** To gain insights regarding the cost-competition between two prominent intra-urban hydrogen-production technologies relevant for the first decades of fuel-cell vehicle (FCV) use.
- **Hypothesis:** In cases where there is a low demand for hydrogen in the early years of FCV scenarios, CHHP may have cost advantages over on-site SMR production for certain refueling stations.



*Technology Mix for Three Scenarios*



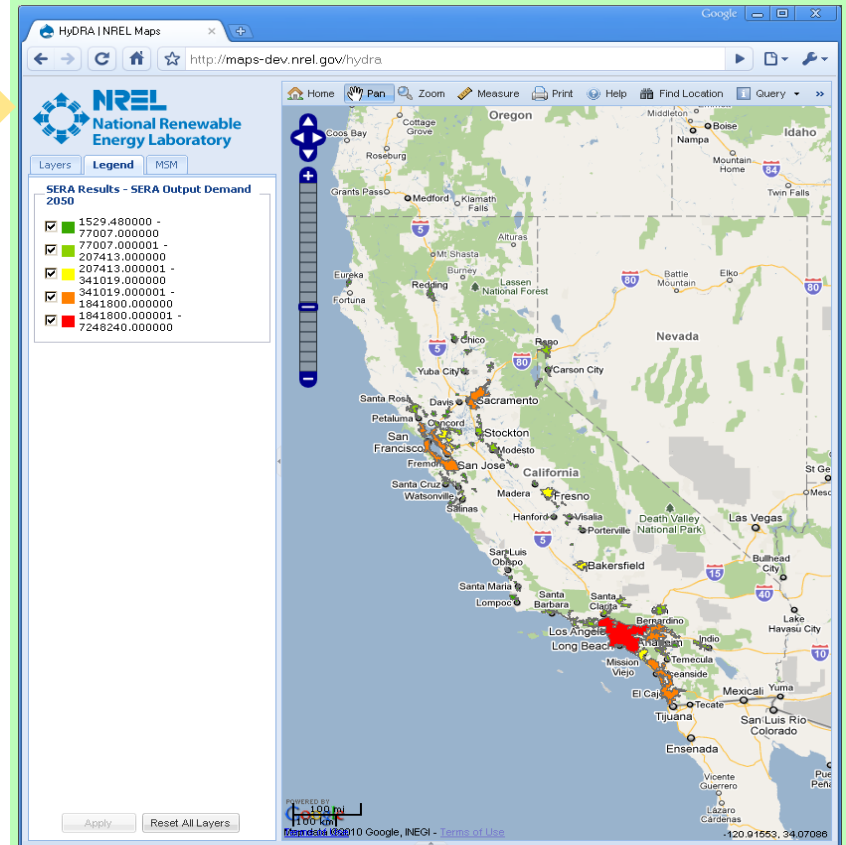
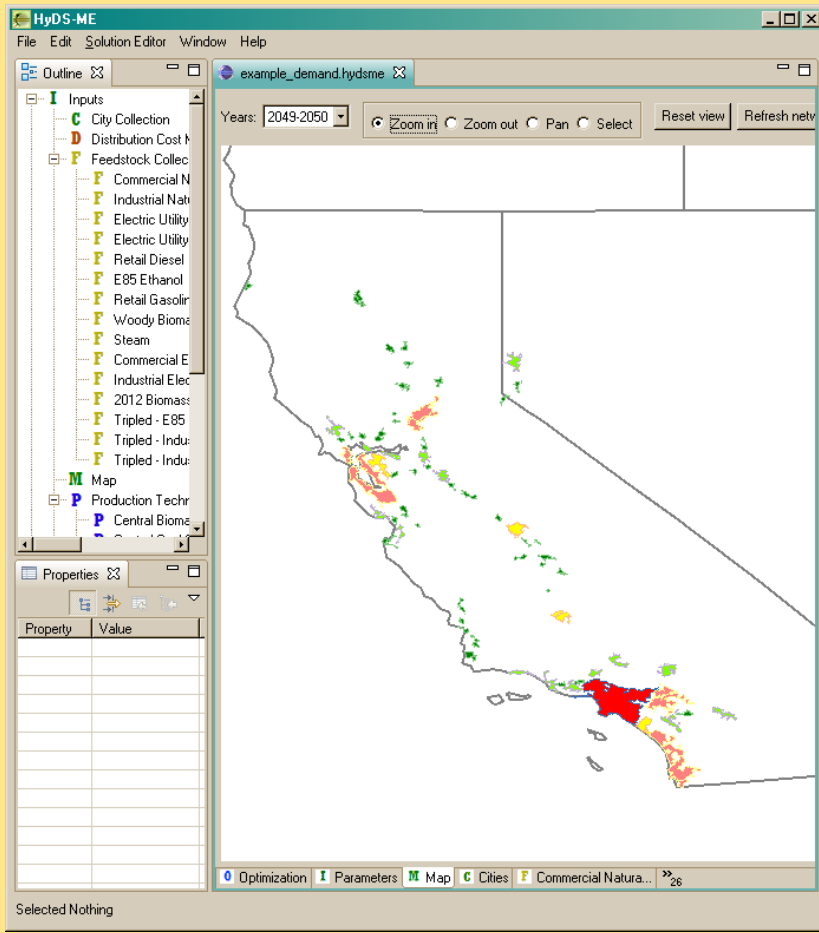
*Delivered Cost for Three Scenarios*



# Accomplishment: Interoperability with HyDRA

## SERA provides . . .

- Hydrogen infrastructure, by year
- Hydrogen delivered cost, by year



## HyDRA provides . . .

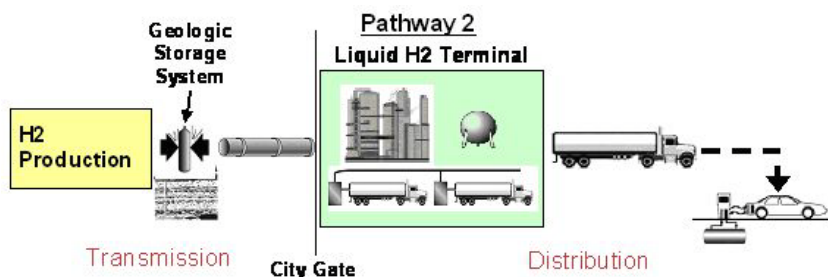
- Hydrogen demand scenarios
- Energy/feedstock price forecasts
- Existing infrastructure
- Background information

# Accomplishment: SERA Input Costs Restructuring

## Target:

- Substitute Delivery Cost Curves with the Delivery Components built inside the SERA Model

### EXAMPLE: Pipeline delivery pathway



### Components:

- Compressor
- Geo storage (or liquid storage)
- Pipeline transport
- City Gate Terminal

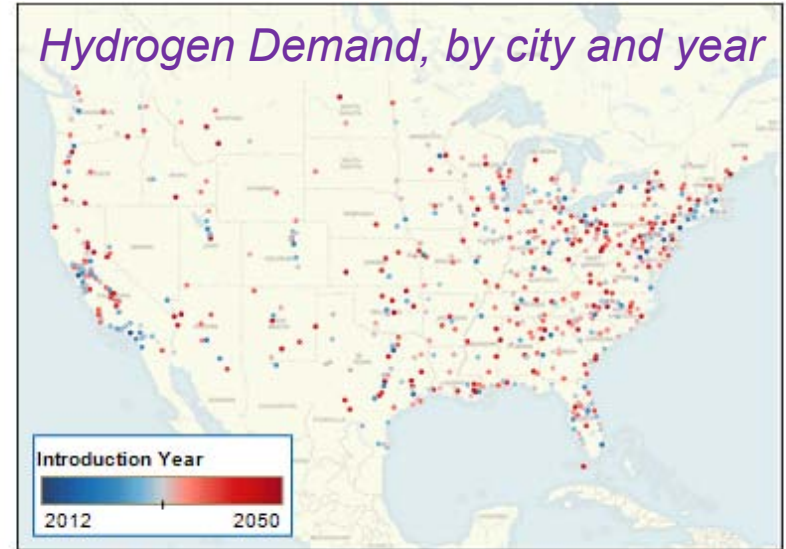
*60% complete at the end of March 2010*

## Benefits:

- Components calculations use H2A standards, but allow maximum flexibility in constructing pathways (i.e., mixed pathways allowed).
- Costs become better structured.
- Cost dependencies become transparent.
- Cost equations are not fits or regressions—they represent actual calculations of several device's regimes and their costs.
- Process of building infrastructure becomes even more flexible (branched pipelines, storage sharing etc.).
- Rail transport included.

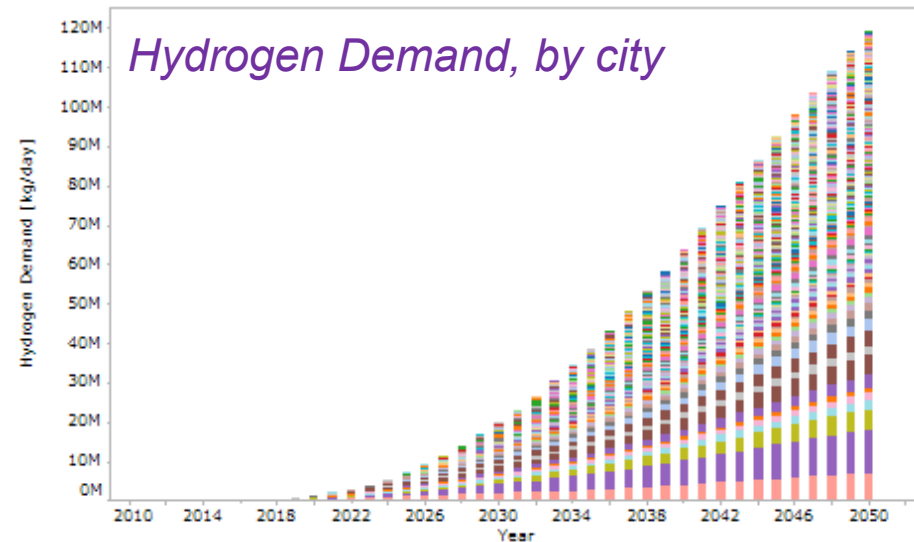
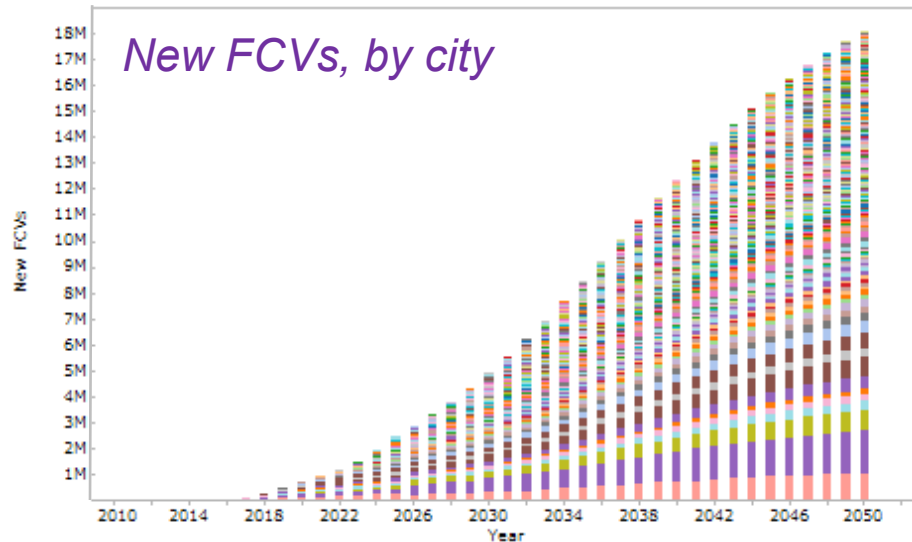
# Accomplishment: New detailed FCV-rollout scenario

The resulting scenario matches the NAS scenario in terms of FCV introduction, FCV stock, VMT, and hydrogen demand on a year-by-year basis in addition to matching the city-specific schedule in the study.



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# Collaborations, 2009-2010

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- M. Melaina, O. Sozinova, D. Steward, K. Webster (NREL Hydrogen Technologies and Systems Center)
  - Hydrogen infrastructure analysis
  - H2A models
  - Cost models
  - CCS
- D. Getman, D. Hettinger, B. Roberts (NREL Data Analysis and Visualization Group)
  - GIS-based resource assessment
  - Interoperability with HyDRA
- D. Thompson (independent subcontractor)
  - Expertise in tuning optimization models
- J. Svede (subcontractor)
  - Software engineering

# Proposed Future Work

- Current and near term
  - We are iteratively improving the detail and accuracy of the cost models in SERA in order to support more complex scenarios.
  - We have developed a geospatially disaggregated FCV introduction scenario that is consistent with the aforementioned NAS scenario.
  - CHHP and biogas technologies are being incorporated into SERA and exercised in case studies.
  - CHHP and biogas technologies will be examined in comparison to a “baseline” scenario.
- Long term
  - We will be examining price points between competing technologies, such as delivered “drop-in” tanks vs. onsite SMR and electrolysis production.
    - These price points will be resolved geographically and temporally as demand increases across multiple cities in a given region.
  - Questions about stakeholder behavior and consumer preferences will be examined (e.g., preference for station types, rollout strategies, green hydrogen).
  - We are planning to couple SERA to a discrete-choice model for hydrogen demand.

# Summary

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## 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.

## Accomplishments

- CHHP preview study
- Interoperability with HyDRA
- New scenarios for national FCV roll-out
- Integrated improved cost models

## Collaborations

- NREL H2 analysis team
- Optimization experts and software engineers

## Proposed Future Work

- Application of SERA to more elaborate scenarios
- Elaboration of model for specific studies

# Optional Supplemental Slides

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# Approach: Data Flow for Typical Studies

