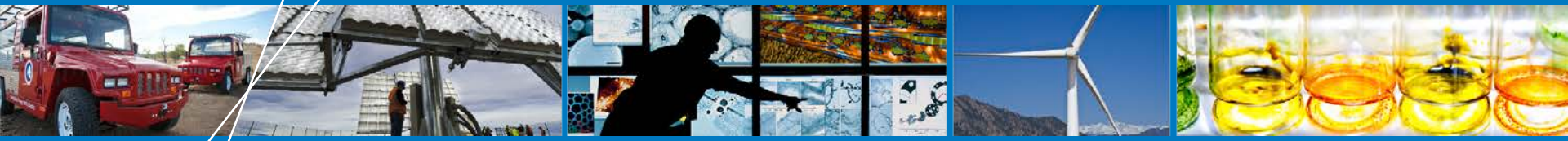
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Infrastructure Analysis of Early Market Transition of Fuel Cell Vehicles



2012 Annual Merit Review and Peer Evaluation Meeting

Brian W Bush

National Renewable Energy Laboratory

15 May 2012

Project ID #AN001

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

The SERA project is a mature analysis activity focused on the breadth of early market transition issues for FCEVs.

Timeline

Start: May 2011

Finish: September 2012

Complete: 70%

Barriers

4.5.B. Stove-piped/Siloed Analytical Capability

4.5.D. Suite of Models and Tools

4.5.E. Unplanned Studies and Analysis

Budget

Total Project Funding: $350k

100% DOE-funded

FY2011: $120k

FY2012: $230k

Partners

Allegiance Consulting

Los Alamos National Laboratory

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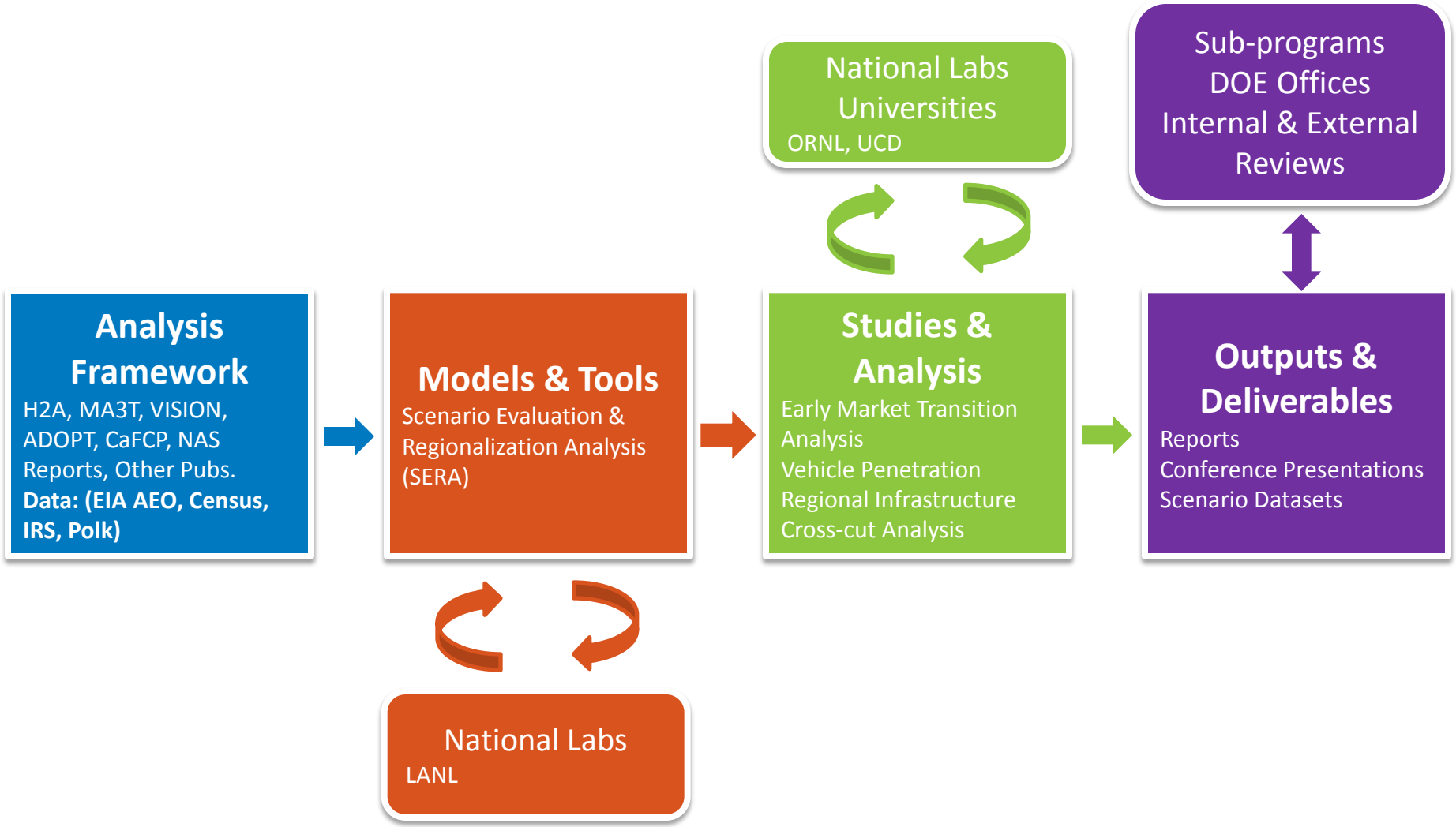


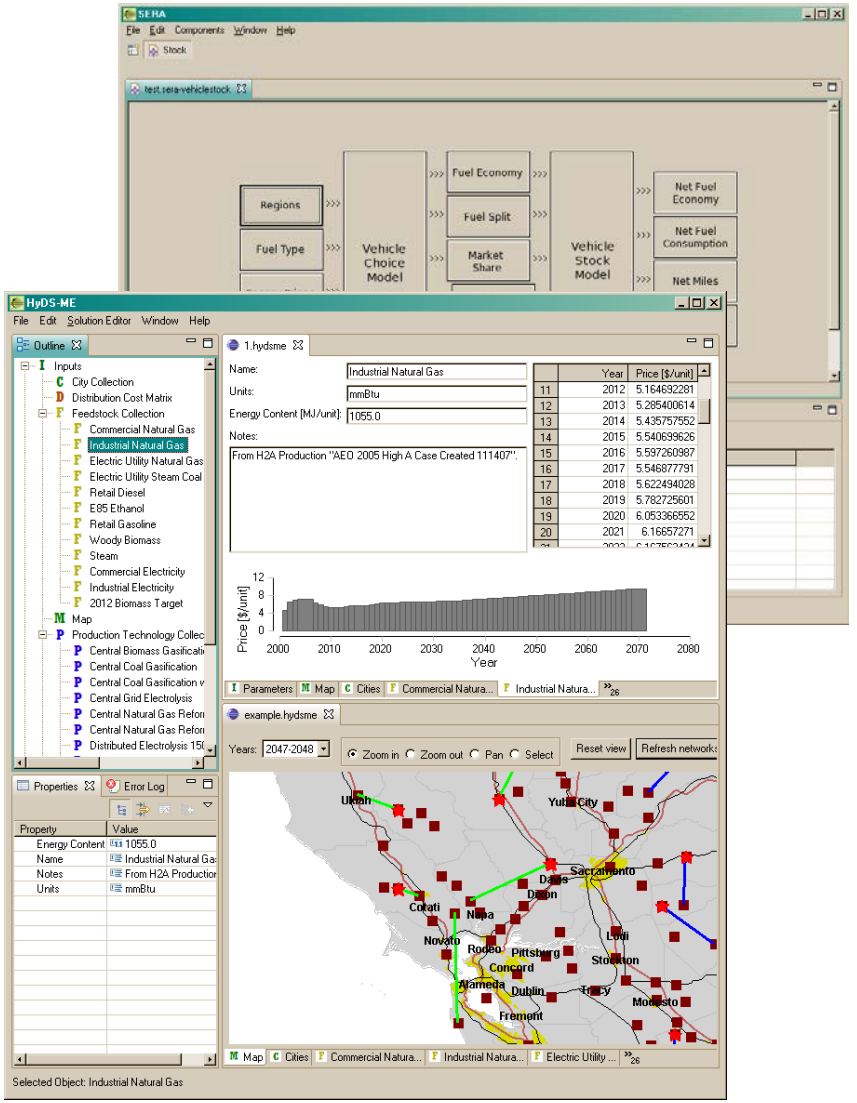
SERA is a suite of tools for studying the cost implications of regional build-outs of renewable energy infrastructures.

Goals

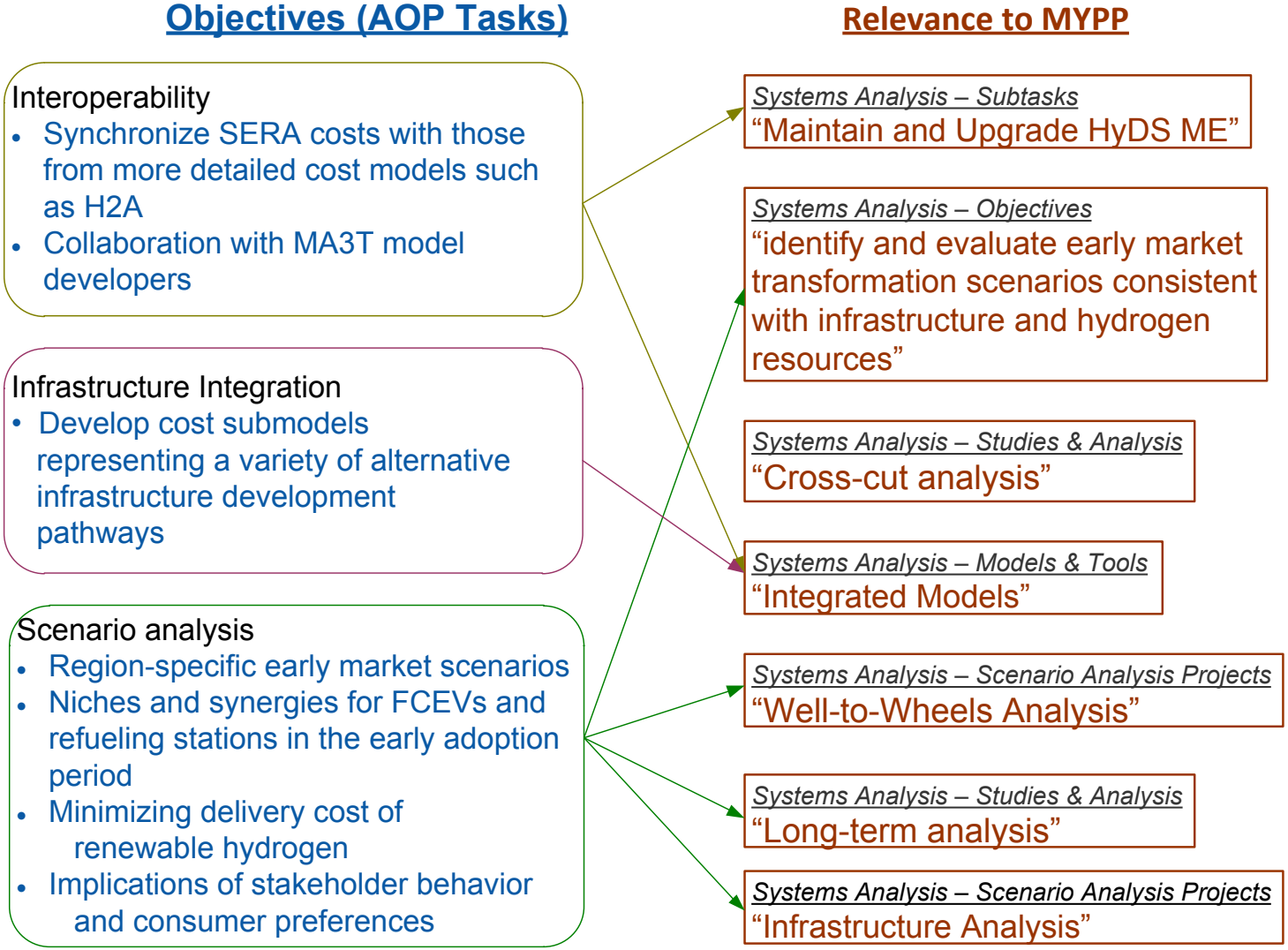
- Generate self-consistent vehicle adoption and hydrogen demand scenarios relevant to early market transition of FCEVs.
- Determine optimal regional infrastructure development patterns for hydrogen, given resource availability and technology cost.
- Geospatially and temporally resolve the expansion of production, transmission, and distribution infrastructure components.
- Identify niches and synergies related to refueling station placement and early FCEV adoption areas.

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?



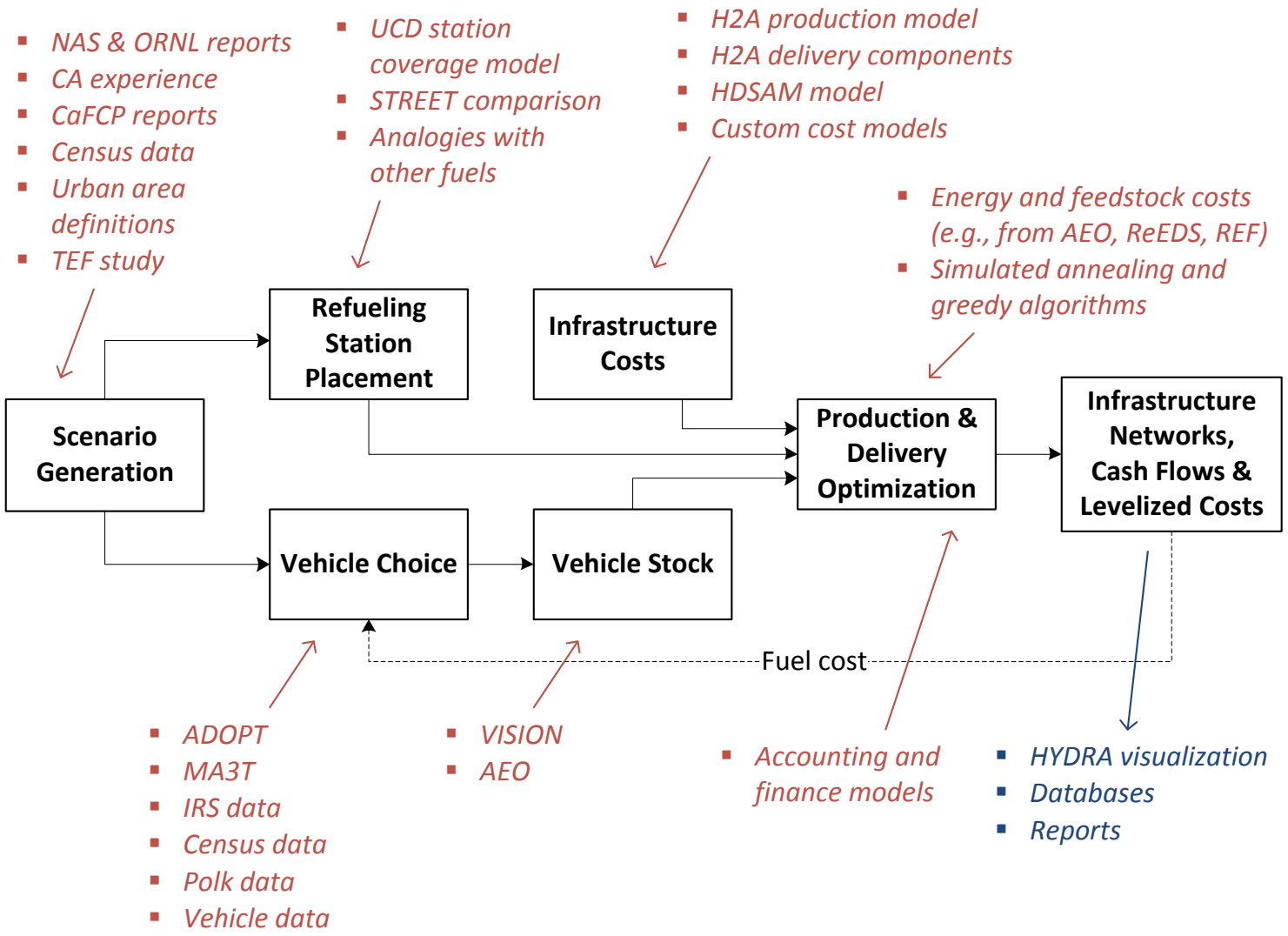
The SERA project activities correspond directly to the program plan.



The SERA Model integrates assumptions and data from multiple sources and related modeling efforts.

General Features

- High level of customizability
- User-defined geographic detail
- User-defined vehicle types, classes, and characteristics
- Disaggregated computations
- Agnostic about sources of cost data
- Choice of algorithms
- Interoperable with other models
- Easy to add new submodels for special-purpose studies



SERA uses input 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.**
- **SERA does not incorporate supply or demand curves, except implicitly when feedback between prices and consumer choice is included in the analysis.**

The spatiotemporal details of cash flow were estimated for early market infrastructure and vehicle rollouts.

Construct local scenarios for *early market* infrastructure clustering and vehicle rollout.

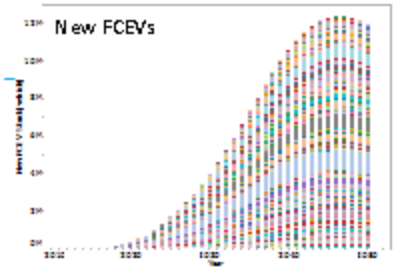
Tune nationwide scenarios to observations and lessons learned in local early market evolution and planning.

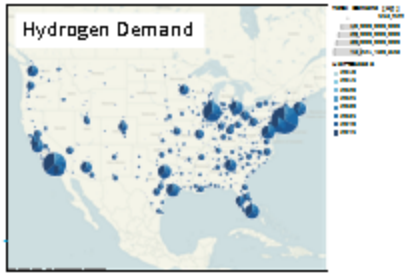
Refine methodology for locating and sizing stations within urban areas.

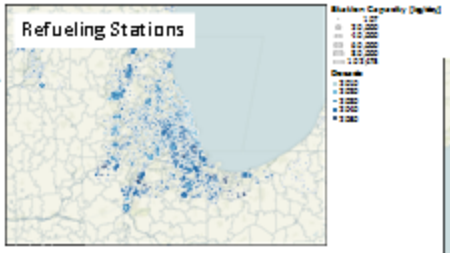
Develop methodology for locating FCEVs at households within urban areas.

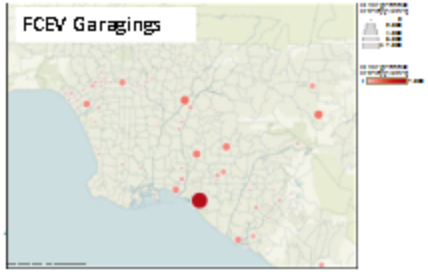
Refine methodology for optimizing the choice of hydrogen production and delivery infrastructure.

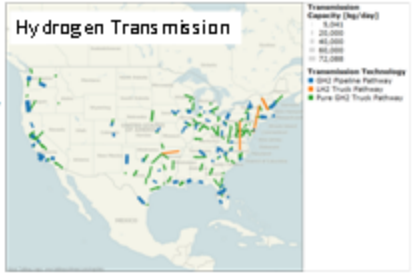
Compute cash flows and delivered costs for hydrogen.

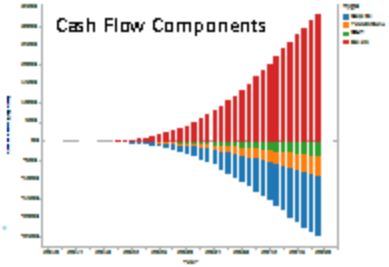






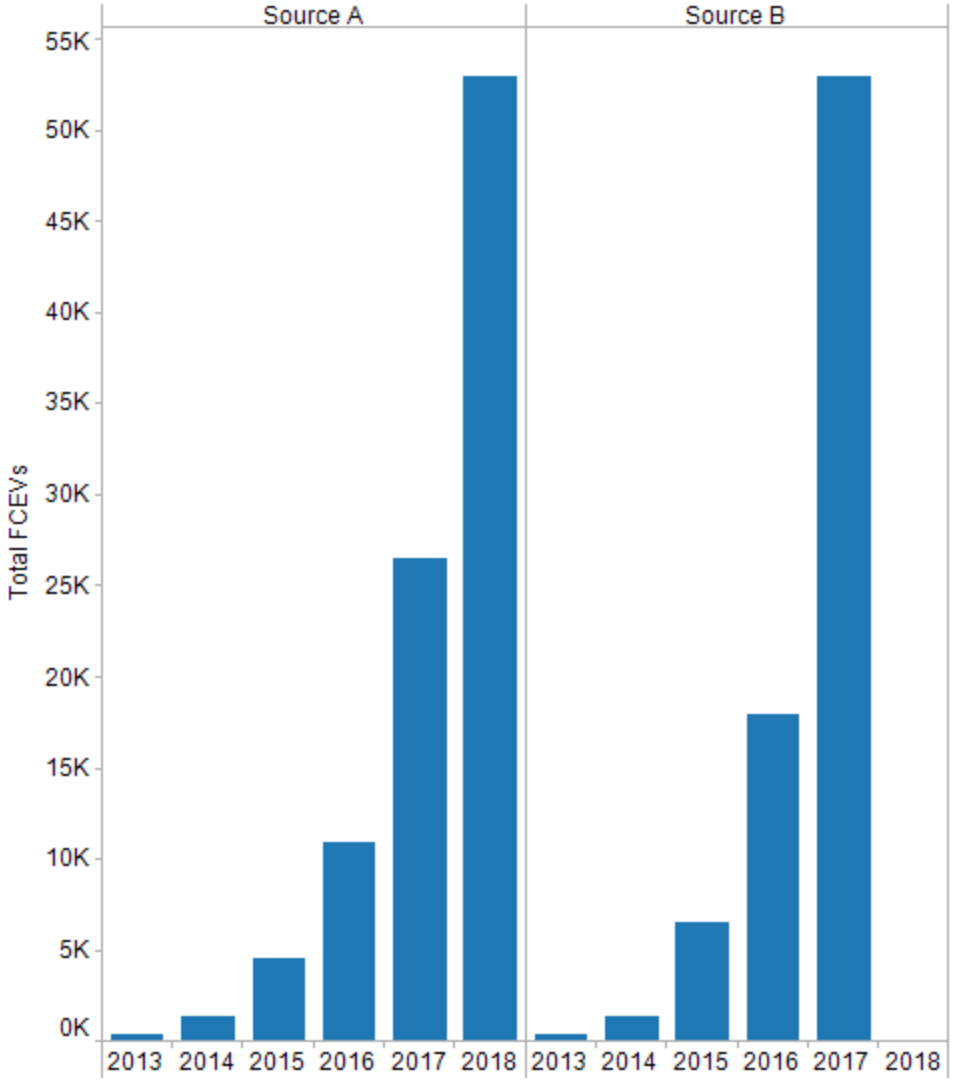






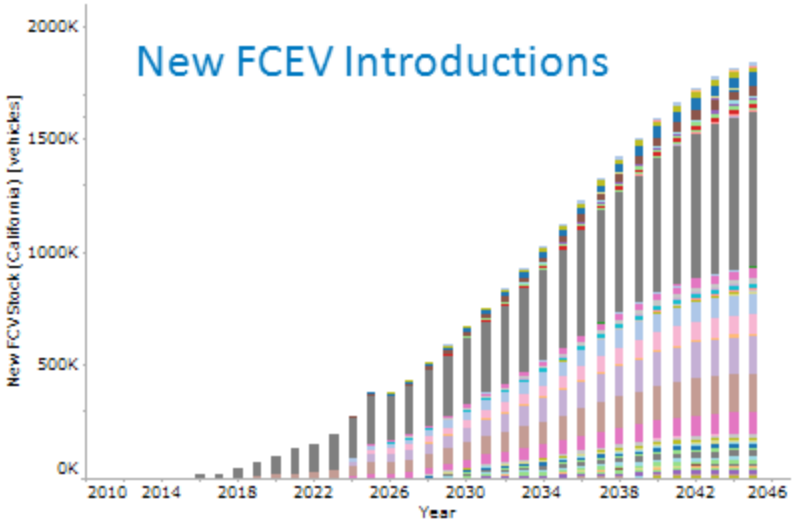
Early market scenarios were constructed from published plans for FCEV introductions in California.

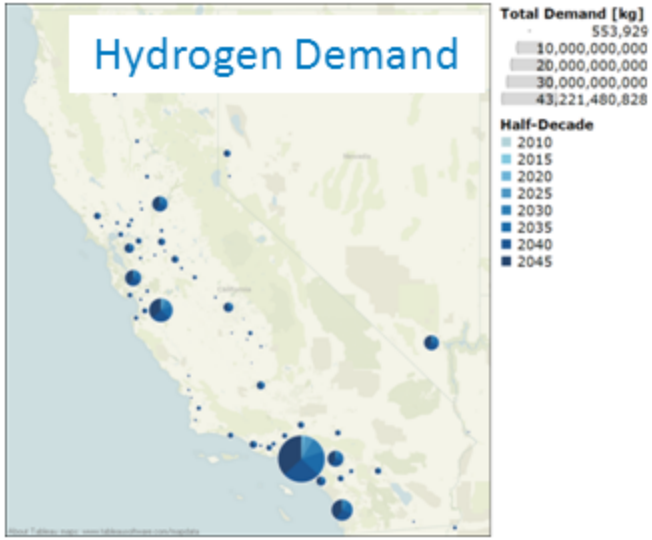
- **The early years of published nationwide scenarios typically are much more aggressive than the anticipated experience in California.**
- **Estimates for FCEV introduction in California were analyzed and then used as a basis for generalization to early market experience nationwide.**



The early market estimates were generalized to create a NAS-compatible nationwide scenario.

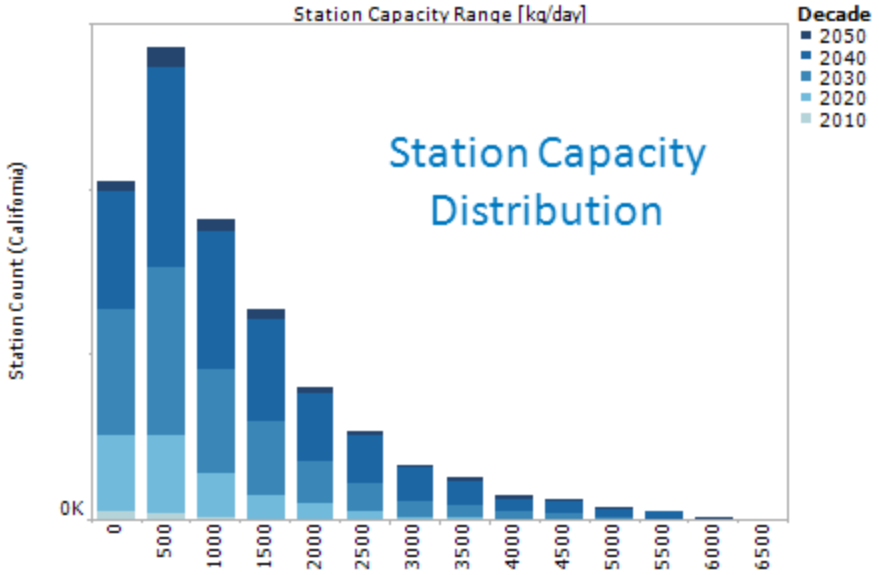
- **Meld the California short-term estimates with long-term national scenarios.**
  - Early years of NAS scenarios for FCEV station rollout and vehicle adoption are adjusted downwards by approximately 50%.
  - Later years of the new scenario matches the high-penetration conditions of NAS scenarios.
  - Middle years of the new scenario gradually transitions between California-like early years and NAS-like later years.
- **Consider the approximately 600 largest urban areas.**
- **Maintain rigorous self-consistency between scenario parameters.**
  - FCEV vehicle introduction
  - Stock turnover
  - Vehicle-miles traveled
  - Demand for hydrogen fuel

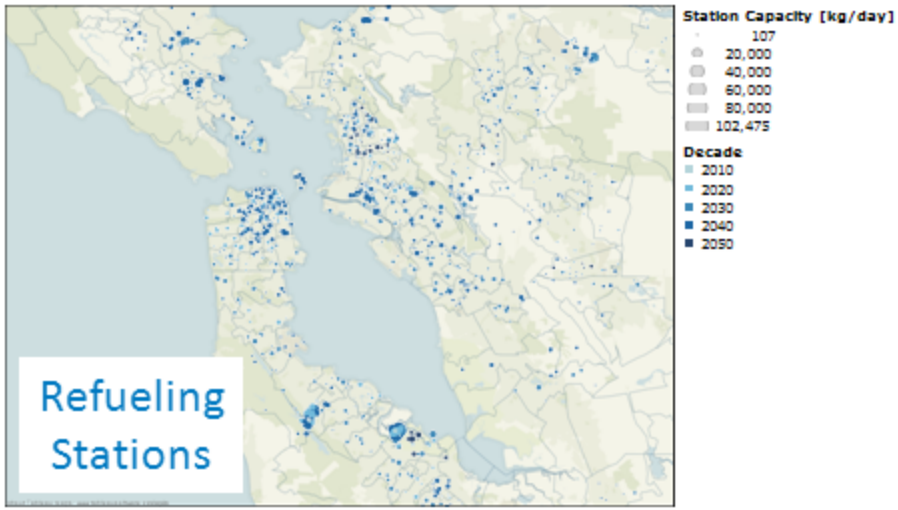




In order to study clustering effects, refueling stations are placed at the ZIP code level.

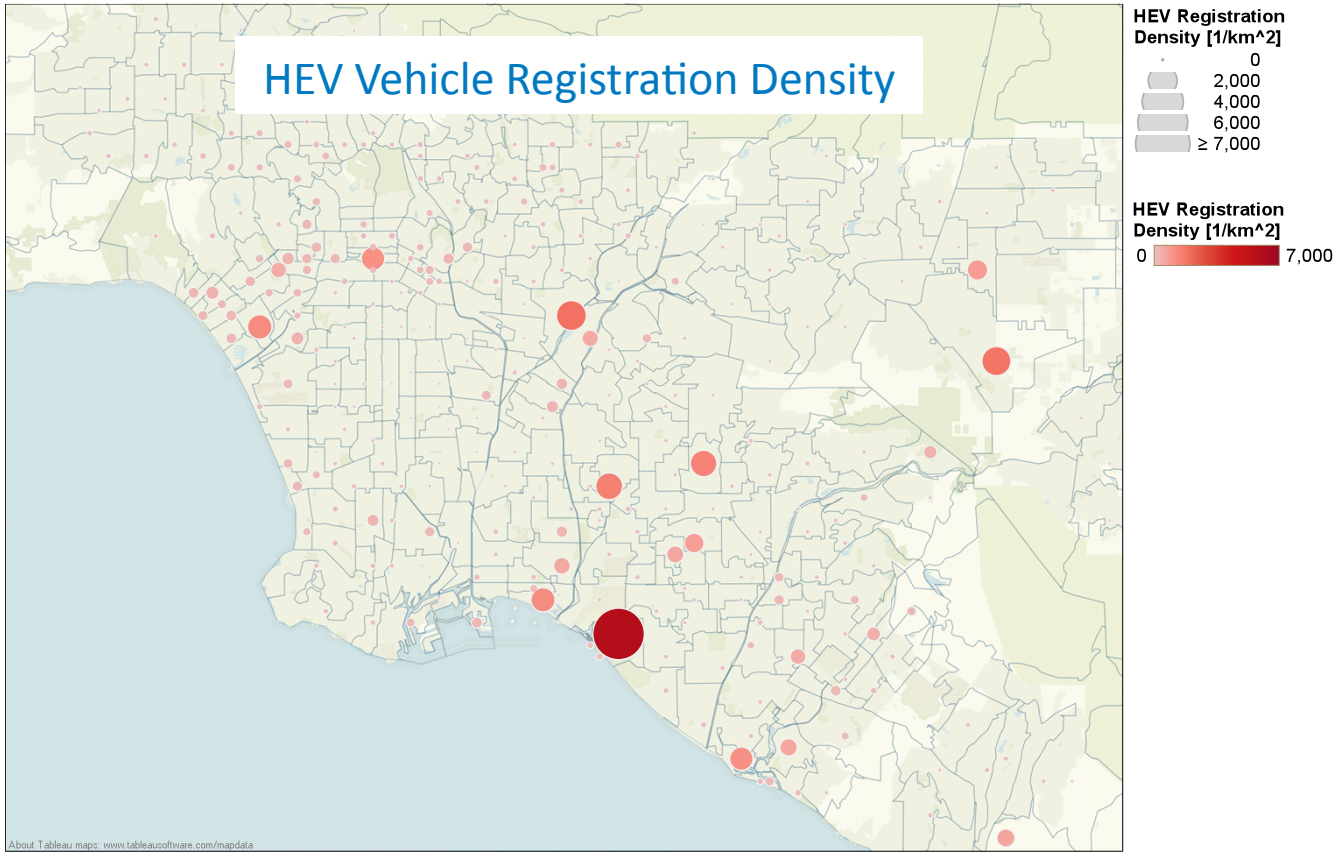
- **Refueling stations are sized in accordance with empirically observed capacity distributions for gasoline stations.**
  - The size of the average new station increases over time, as overall demand for hydrogen grows.
  - Station sizes are chosen stochastically.
- **ZIP codes with high numbers of garaged HEVs are attractors for refueling stations.**



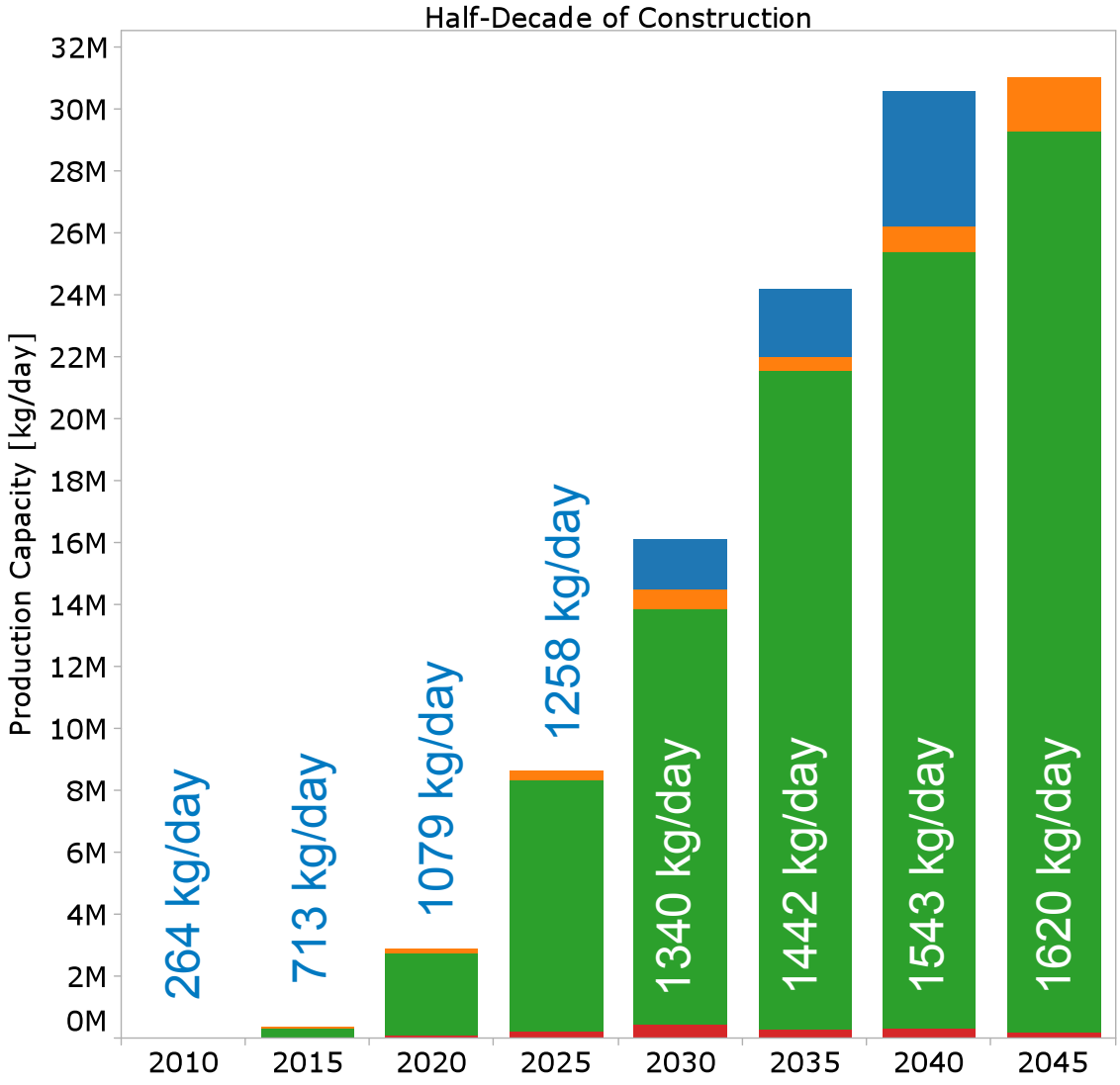


In order to study clustering effects, FCEVs are garaged at the ZIP code level.

- **FCEVs are garaged in ZIP codes proportionally to the observed frequencies of HEVs registered there.**



Optimal choice of production technology depends on feedstock prices and demand conditions.



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.

Optimal choice of transmission infrastructure depends on nearness of production centers and demand conditions.

Transmission Capacity [kg/day]

- 5,041
- 20,000
- 40,000
- 60,000
- 72,088

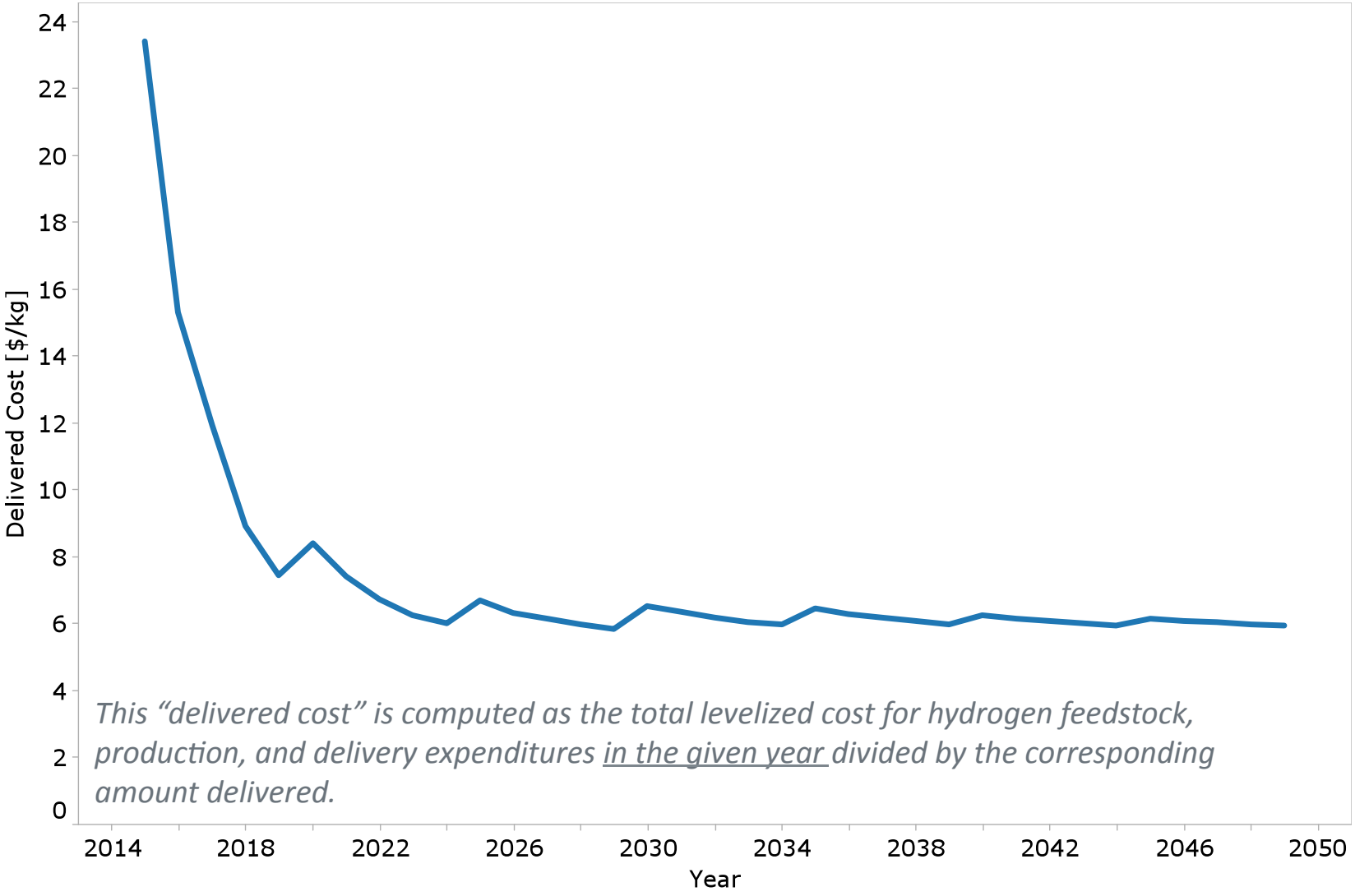
Transmission Technology

- GH2 Pipeline Pathway
- LH2 Truck Pathway
- Pure GH2 Truck Pathway

Gaseous hydrogen pipelines are favorable for high flow conditions and moderate distances.

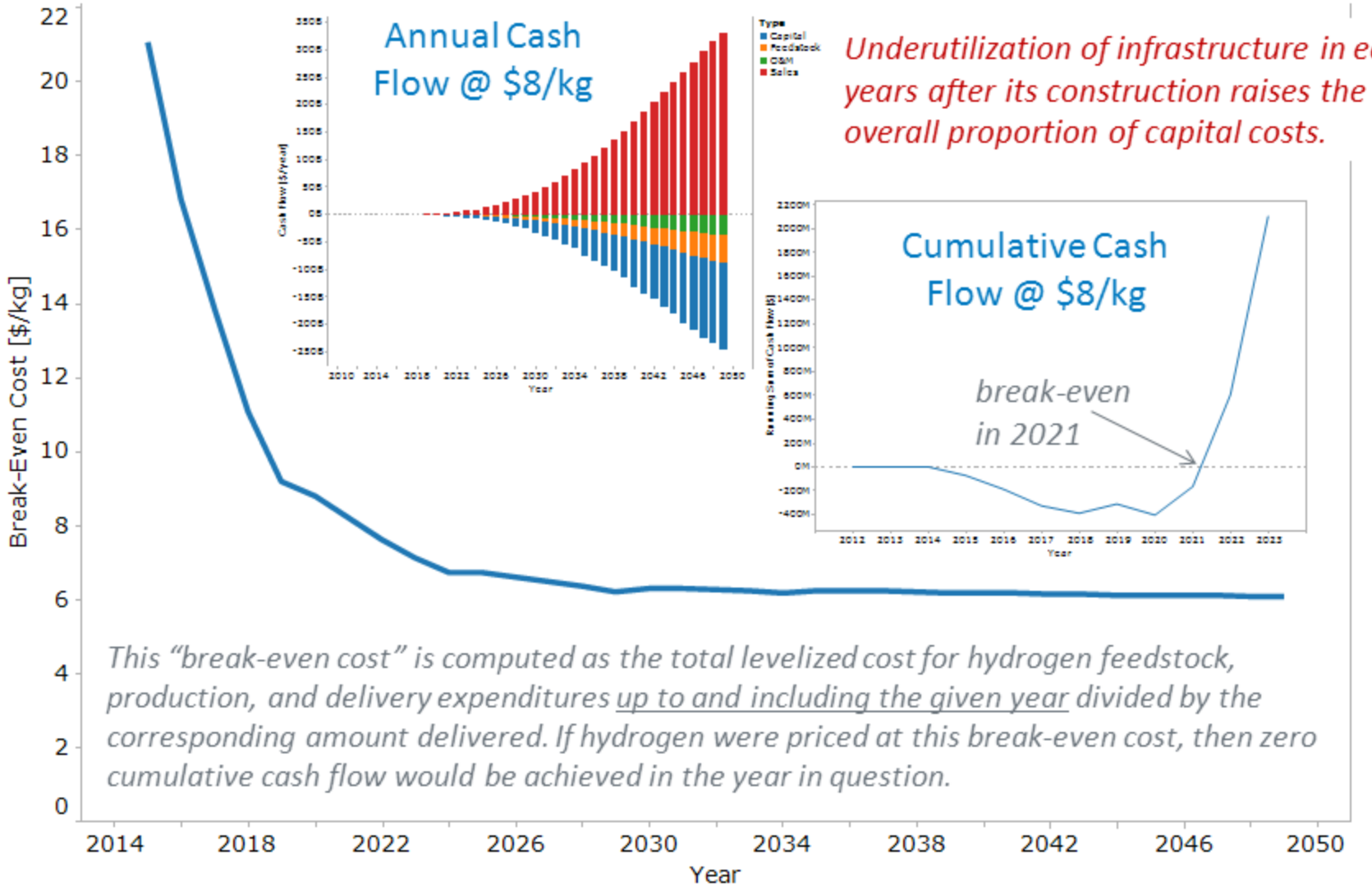
Truck delivery predominates at lower flow (i.e., for gaseous transport) or longer distance (i.e., for liquid transport).

Long-term levelized delivered costs for hydrogen tend towards $6.00/kg nationally.



This "delivered cost" is computed as the total levelized cost for hydrogen feedstock, production, and delivery expenditures in the given year divided by the corresponding amount delivered.

Zero cumulative cash flow is achieved between 2018 and 2025 if hydrogen is priced at $11.00/kg or $6.75/kg.



The SERA project had increased external collaborations in 2011-2012.

- ORNL
  - MA3T model and scenarios
- UC Davis
  - Consultation regarding station coverage
- California Fuel Cell Partnership
  - Early market scenarios

- 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 an extensive network of external collaborations.

Future work will elaborate on the realism of early market scenarios and associated cash flows.

- **The SERA software is essentially complete, but continued use of the tool in scenario studies requires . . .**
  - regular updating H2A and other cost inputs, including empirical cost data
  - tuning for particular scenario analyses
  - 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.
- **SERA can be integrated into multi-fuel studies.**
  - Studying tradeoffs between FCEVs and BEVs.
  - Collaborative exchange of data and scenarios assumptions.
  - Scenario 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	• More realistic early market scenarios • High level of FCEV and refueling station detail • Computation of cash flows for optimal infrastructure
Collaborations	• NREL H2 and vehicle analysis teams • Other modeling groups
Proposed Future Work	• Application of SERA to more complex scenarios • Add capabilities for specific studies

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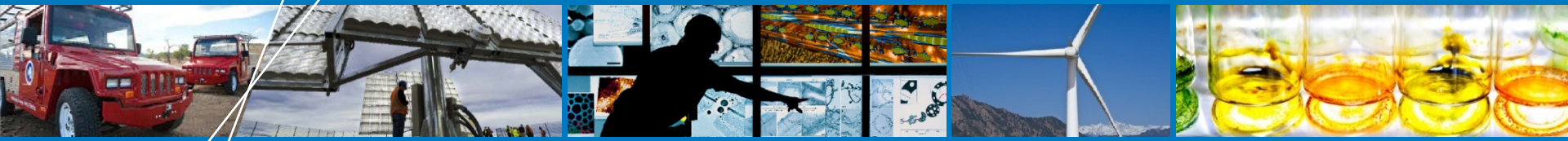
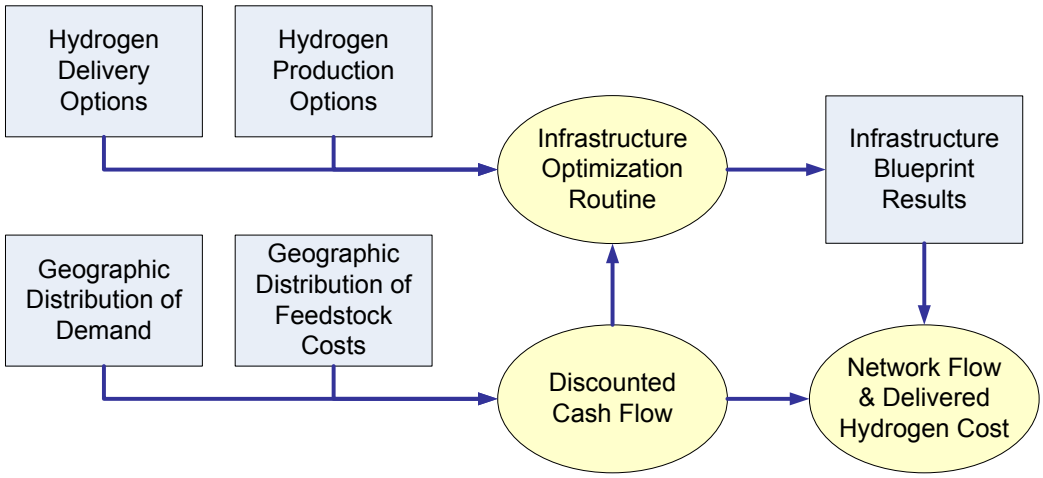
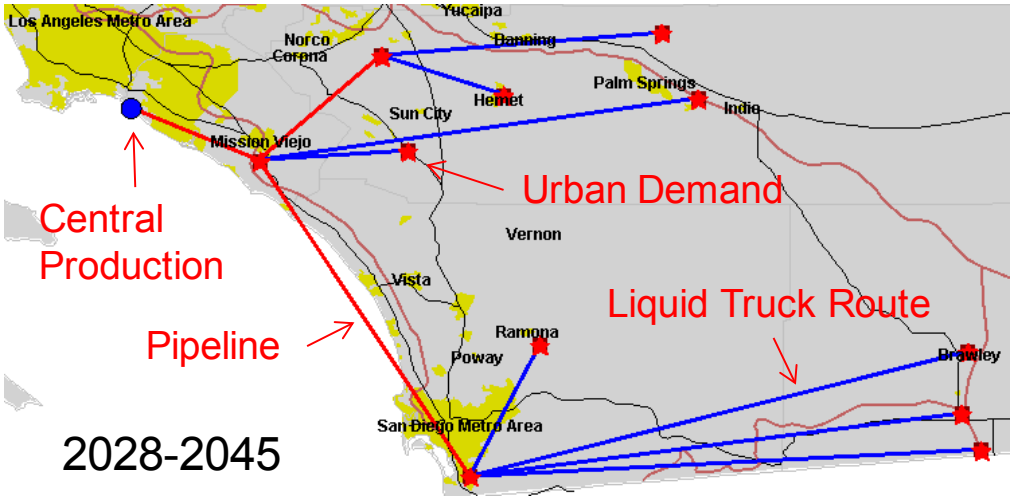


Technical Backup Slides

Optimal infrastructure depends on complex geographic, techno-economics, and demand profiles.

- **Objective function**
  - Piecewise (five-year) discounted cash flow for the whole hydrogen infrastructure is minimized.
  - This could also be done at five-year increments or in other time frames.
  - Other objective functions could be used.
- **Constraints**
  - Capacity constraints on technologies must be satisfied.
  - Demands must be fully met.
- **Exogenous inputs**
  - Annual H2 demands at cities
  - Regional feedstock prices
  - Infrastructure characteristics
  - Production technologies
  - Transmission technologies
  - Distribution costs





SERA integrates the best available data from a variety of sources into its analyses.

- **Data sources**
  - AEO 2011 Reference Case for energy and feedstock prices
  - H2A production model for centralized and on-site hydrogen production costs
  - H2A delivery components models, assembled into pathways, for hydrogen transmission and delivery costs
  - US Census definitions for urban areas
  - Polk data for vehicle registrations
- **Assumptions**
  - Placement of hydrogen production and delivery infrastructure is optimized in sequential half-decade time "windows" in such a manner as to minimize the average delivered cost of hydrogen in each period.
  - Levelized costs, broken down into capital, operating/maintenance, and feedstock categories obtained from H2A, are used for cash flow computations.
- **Caveats**
  - Numerous alternative methods for computing cash flows and levelized costs are available. This study uses one that is consistent with H2A results and with the level of detail generally available in SERA.

The SERA project directly addresses barriers in the program plan.

Barrier	*Impact*
Stove-piped/Siloed Analytical Capability [4.5.B]	• SERA utilizes inputs from H2A models. • SERA's XML-based input/output format is easily processed by common data import/export tools. • SERA has connectivity with GIS and other databases. • SERA integrated vehicle choice and stock models.
Suite of Models and Tools [4.5.D]	• SERA is interoperable with HyDRA. • SERA interoperablility features open possibilities for integration with the 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.

The SERA project is on schedule for completion of its milestones and deliverables.

Fiscal Year	*Milestone/ Deliverable*	*Description*	*Date*	*Status*
2011	M2.8.2	Scenarios for Early Market Clustering	Jul 2011	Complete
	M2.8.3	Cash Flows in Scenarios for Early Market Clustering	Sep 2011	Complete
	D2.8.5	Final report	Sep 2011	Complete
2012	M2.8.1	Preliminary scenario results	Mar 2012	On schedule
	M2.8.2	Integrated scenario results	Jun 2012	In process
	D2.8.5	Final scenarios draft	Aug 2012	In process