National Renewable Energy Laboratory
Innovation for Our Energy Future

Hydrogen Deployment System Modeling Environment (HyDS-ME)

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19 May 2009

2009 Hydrogen Program Annual Merit Review

Project ID # an_07_bush

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Overview

Timeline

- Start: May 2005
- Finish: September 2009
- Complete: 85%

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

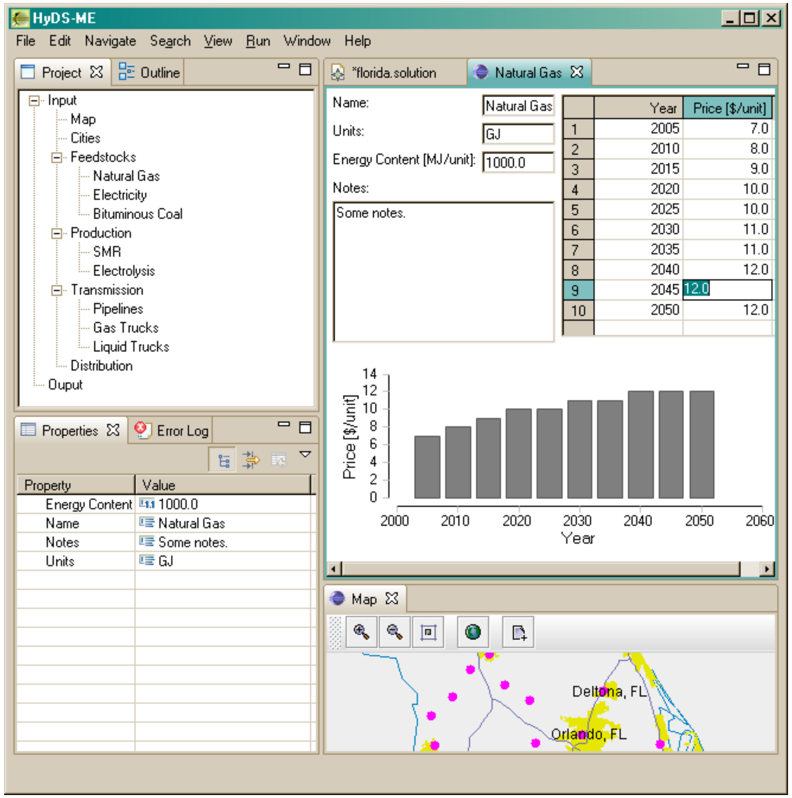
- Total Project Funding: $416k
  - 100% DOE-funded
- FY2008: $235k
- FY2009: $55k

Partners

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

Relevance

- HyDS-ME = "Hydrogen Deployment System Modeling Environment"
- Goals
  - Determine the optimal regional production and delivery scenarios for hydrogen, given resource availability and technology cost.
  - Geospatially and temporally represent infrastructure for production, transmission, and distribution.



- Key analysis questions for HyDS-ME
  - Which technologies will be used to provide hydrogen during the deployment?
  - What synergies are there between cities and their distance to markets?
  - How can cities leverage one another's demand, thereby reducing cost and risk of stranded investments?
  - Where can centralized versus distribution production technologies be most effective?

Relevance: Objectives

Objectives (AOP Tasks)

Evaluate and update HyDS-ME
- Assess state of tools
- Propose enhancements
- Implement enhancements

Perform scenario analysis
- Exercise the enhanced tool on a notional case study

Interoperability
- Expand the interoperability of HyDS-ME with tools such as HyDRA

Perform scenario analysis
- Understand how coal gasification with CCS systems might be introduced to serve western markets

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"

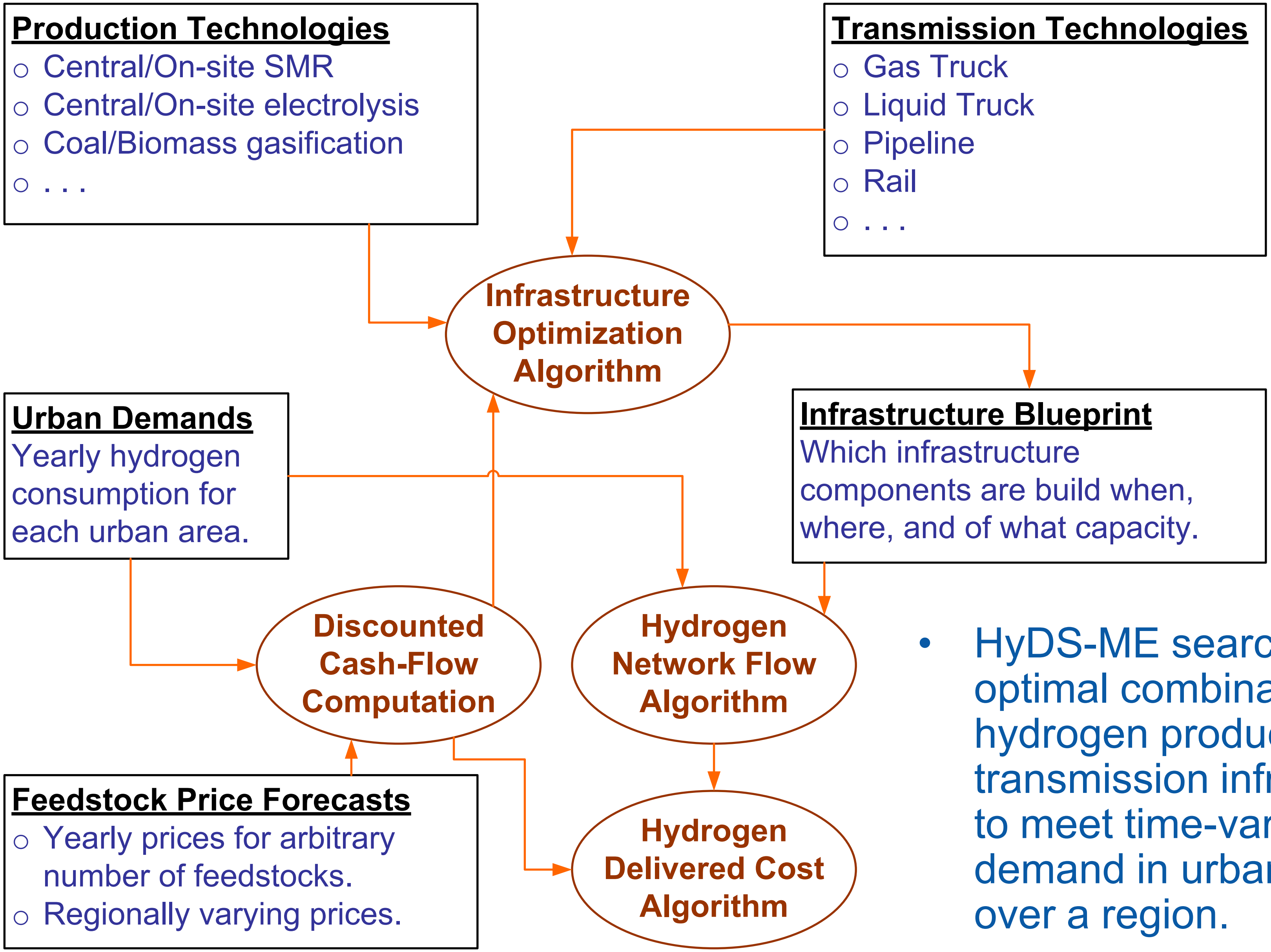
Systems Analysis – Studies & Analysis
"Long-term analysis"

Systems Analysis – Scenario Analysis Projects
"Infrastructure Analysis"

Relevance: Impact on Barriers

Barrier	***Impact***
Stove-piped/Siloed Analytical Capability [4.5.B]	• HyDS-ME can utilize inputs from H2a models. • HyDS-ME's XML-based input/output format is easily processed by common data import/export tools. • HyDS-ME has connectivity with GIS and relational databases.
Suite of Models and Tools [4.5.D]	• New HyDS-ME interoperablilty features open possibilities for integration with the MSM and related tools.
Unplanned Studies and Analysis [4.5.E]	• The input specifications to HyDS-ME have been generalized to broaden the classes of studies to which it can be applied. • HyDS-ME is now based on a transparent, open, model-driven architecture that makes adaptation to unplanned studies/analyses considerably easier.

Approach: How HyDS-ME Works



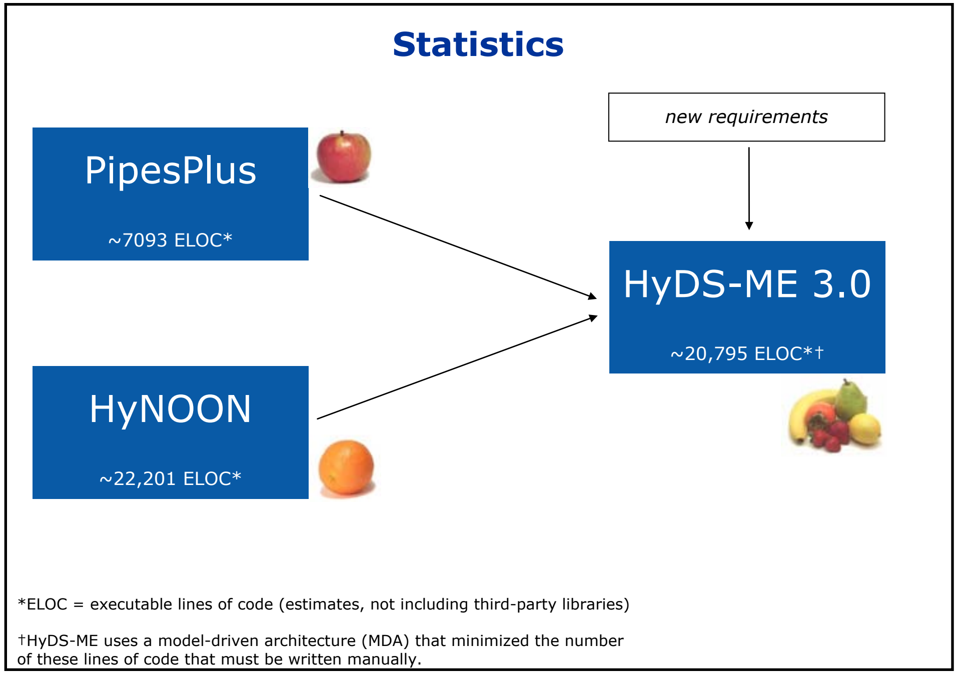
- HyDS-ME searches for optimal combinations of hydrogen production and transmission infrastructure to meet time-varying demand in urban areas over a region.

Approach: Milestones

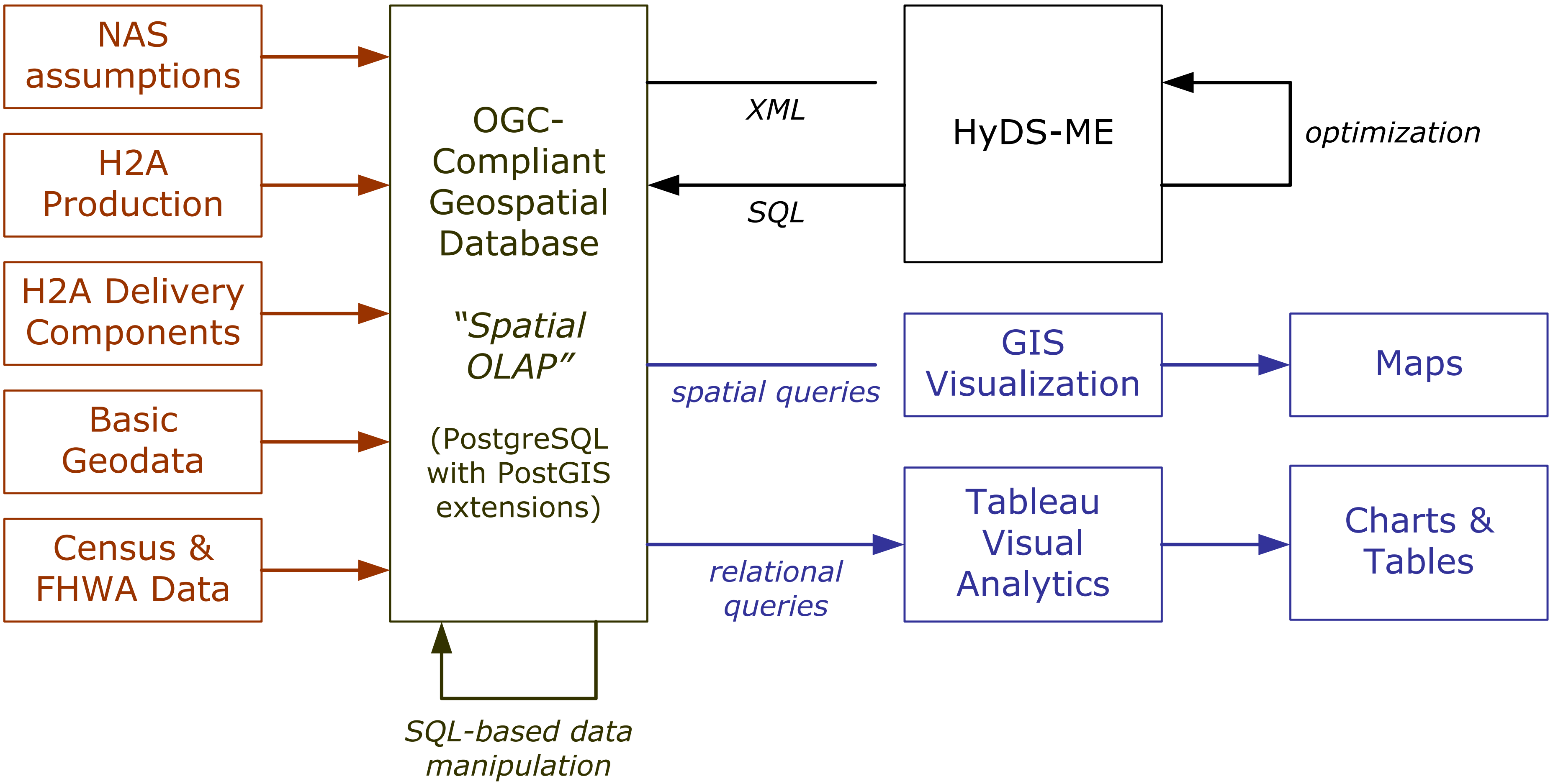
Milestone	***Title***	***Date***	***Status***
FY2008 – 2.7.7	Report identifying the necessary [model] updates	April 2008	Complete
FY2008 – 2.7.8	Completion of model updates	June 2008	Complete
FY2008 – 2.7.9	Completion of analyses	August 2008	Complete
FY2009 – 2.10.7	Completion of design and implementation for HyDS-ME interoperability with HyDRA	March 2009	Complete
FY2009 – 2.10.8	Completion of scenario analysis	September 2009	On schedule

Approach: Overarching Principles for HyDS-ME Update

- Transparency
  - Clearly document the algorithms and assumptions in the model so they are accessible to review and revision.
- Flexibility
  - Provide a foundation for quickly responding to currently unanticipated studies, scenarios, and analysis needs.
- Scalability & Performance
  - Ready optimization algorithms for (possibly radical) modification as scalability or performance issues arise (e.g., in national studies).
- Interoperability
  - Enable future connection of HyDS-ME with other hydrogen analysis tools (e.g., HyDRA, MSM, ReEDS).
- Maintainability
  - Clarify and document the software design to ease future modifications.
  - No proprietary libraries.



Approach: Data Flow for Typical Studies



Approach: H2A Costs Database

- Input data for HyDS-ME was populated from the analysis of ~250,000 runs of H2A models in order to populate a consistent database of production-, transmission- and distribution-related costs.
- Nine major pathways were considered.
- This is the standard input data set of HyDS-ME, but users can easily vary these cost assumptions for particular studies.

		Pathway								
		1	2	3	4	5	6	7	8	9
Scenario	***Transmission***	***L***	***P***	***P***	***G***	***G***	***P***	***P***	***P***	***P***
	Delivery	***L***	***L***	***L***	***G***	***G***	***G***	***G***	***P***	***P***
	Storage	***L***	***G***	***L***	***G***	***L***	***G***	***L***	***G***	***L***
Component	Compressed H2 Truck-Tube				T+D	T+D	D	D		
	Distribution Pipeline								D	D
	Gaseous Refueling Station				D+S	D+S	D+S	D+S	D+S	D+S
	Geologic Storage		S		S		S		S	
	GH2 Terminal				T+S	T+S	S	S		
	Liquid Refueling Station	D+S	D+S	D+S						
	Liquefier	S	S	S		S		S		S
	Liquid Terminal	T+S	S	S		S		S		S
	Liquid Tractor-Trailer	T+D	D	D						
	Pipeline Compressor		T	T			T	T	T	T
	Transmission Pipeline		T	T			T	T	T	T

G = Gas Trucks
L = Liquid Trucks
P = Pipelines

T = Transmission
D = Distribution
S = Storage

Technical Accomplishments & Progress

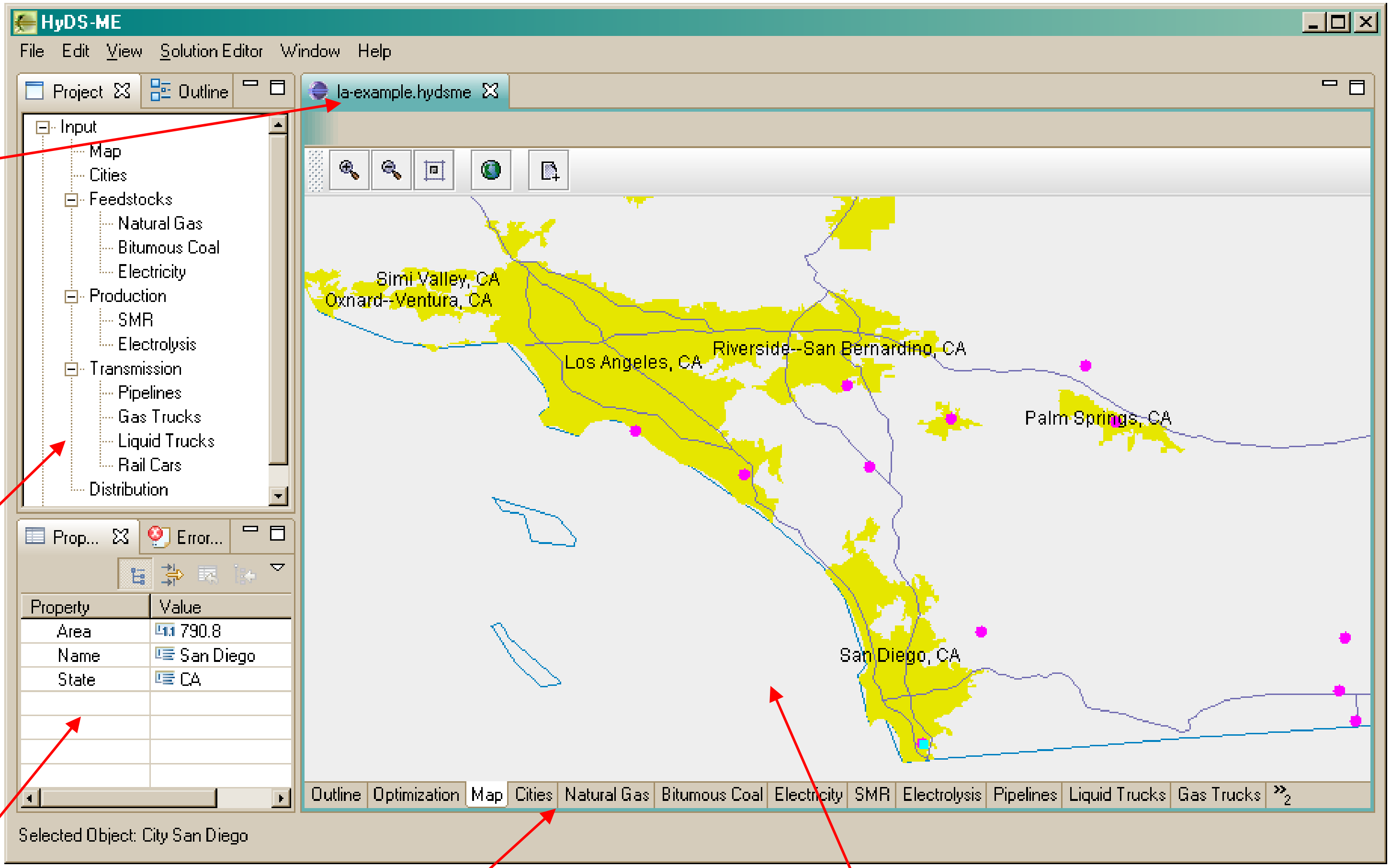
- Completed HyDS-ME updates
  - Approximately 20k lines of code reworked
  - Open, interoperable data formats
  - Increased flexibility, transparency
  - Faster optimization
- Completion of notional California study
  - Lessons learned regarding infrastructure optimization
  - Insights into infrastructure tradeoffs
  - Insights into California infrastructure
- Completion of interoperability task
  - Generic connectivity via XML, GIS, and relational databases
  - Opens future interoperability with MSM, HyDRA, and other tools
- Exploratory wind-hydrogen infrastructure study
- Design of CCS case study
- Publications
  - 3 presentations
  - 1 poster
  - 3 reports

Accomplishment: Redesigned User Interface

Each scenario analysis is a separate document—multiple one can be loaded simultaneously.

Index of inputs and results (links to worksheets for viewing and editing)

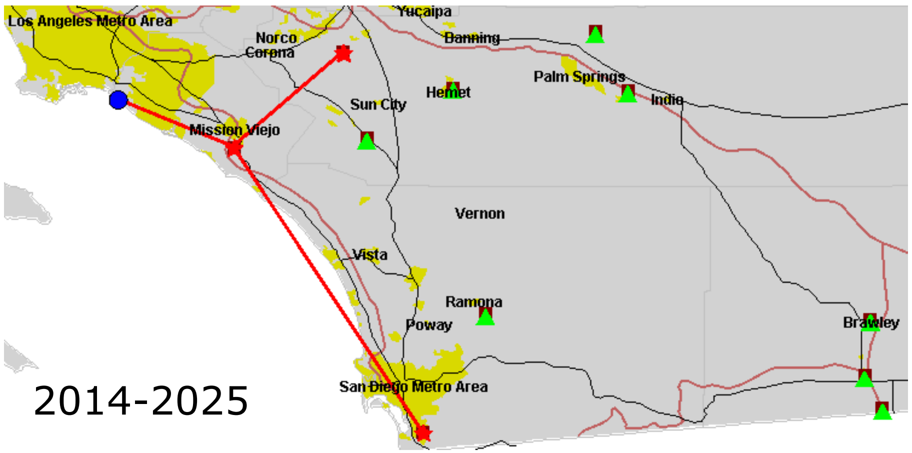
Properties of current selection

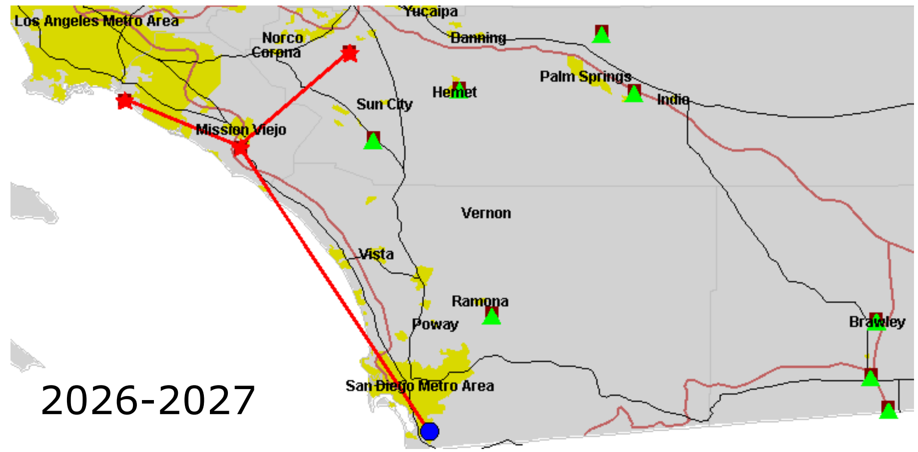


Tabs for each of category of input data

Map of cities, infrastructure, and arbitrarily chosen GIS layers.

Accomplishment: Optimal Temporal Layout of Hydrogen Infrastructure





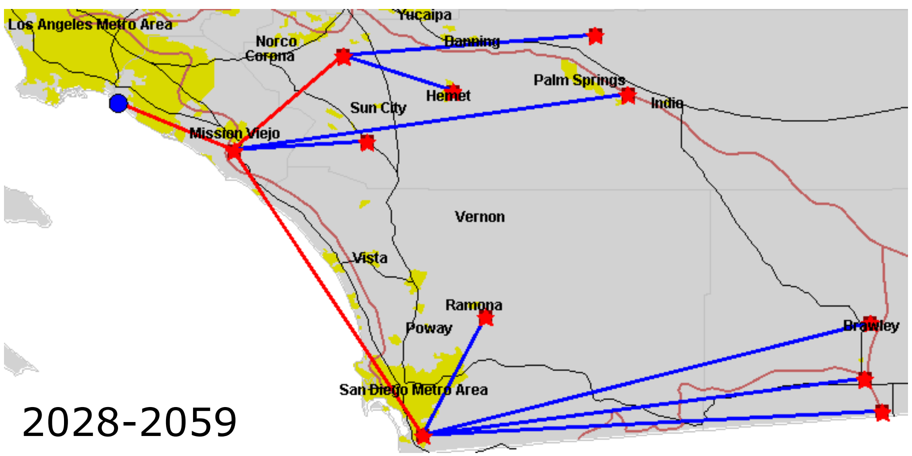
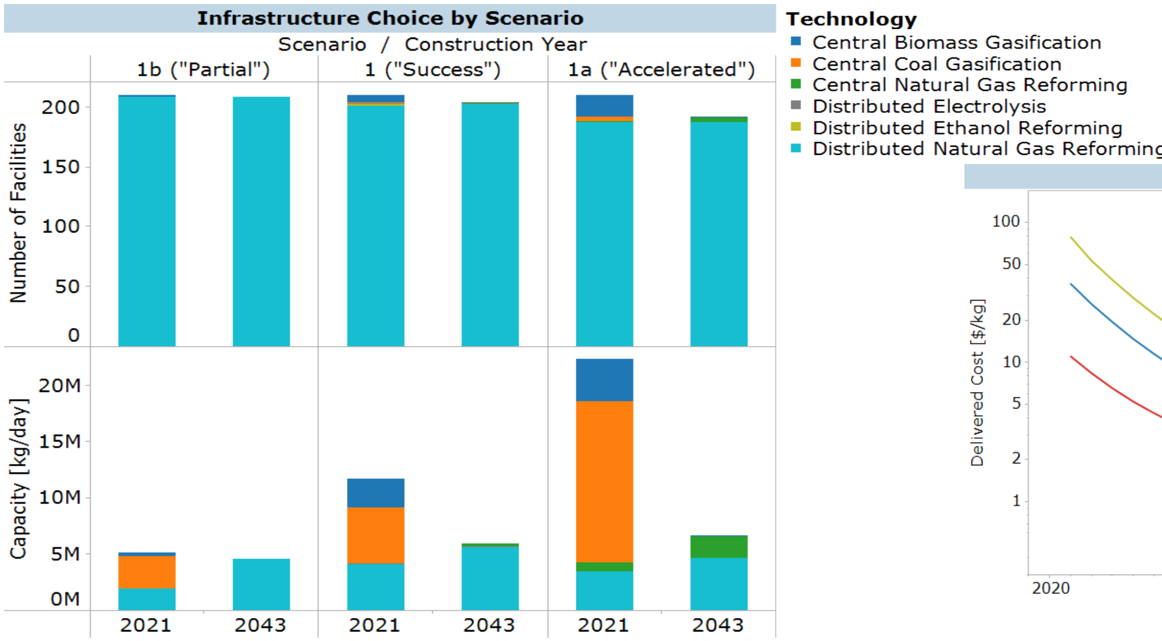


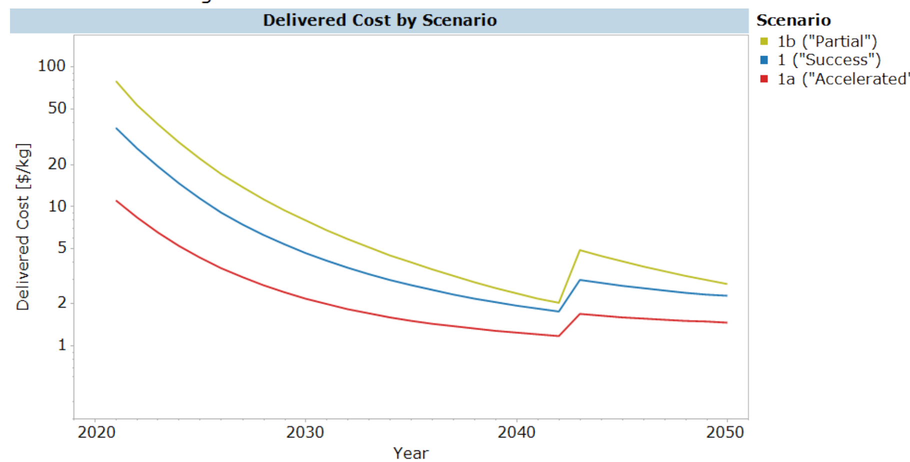
Figure 1. Geospatial layout of hydrogen infrastructure in example HyDS-ME optimization: blue circles represent SMR plants, green triangles electrolysis plants, red stars cities with hydrogen demand, red lines pipelines, and blue lines liquid truck transport.

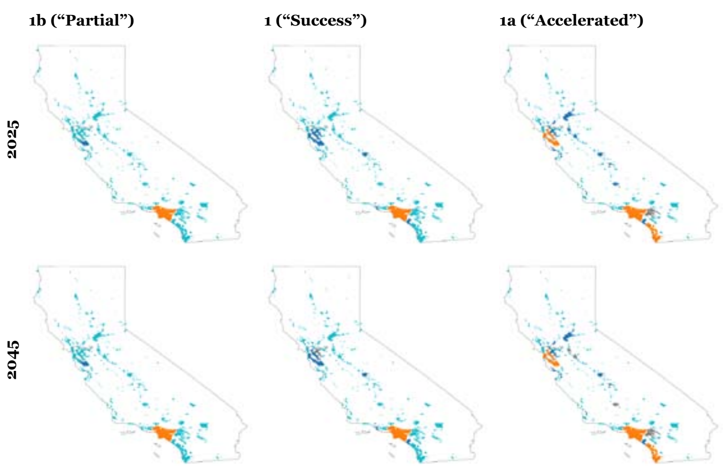
Accomplishment: Application to California

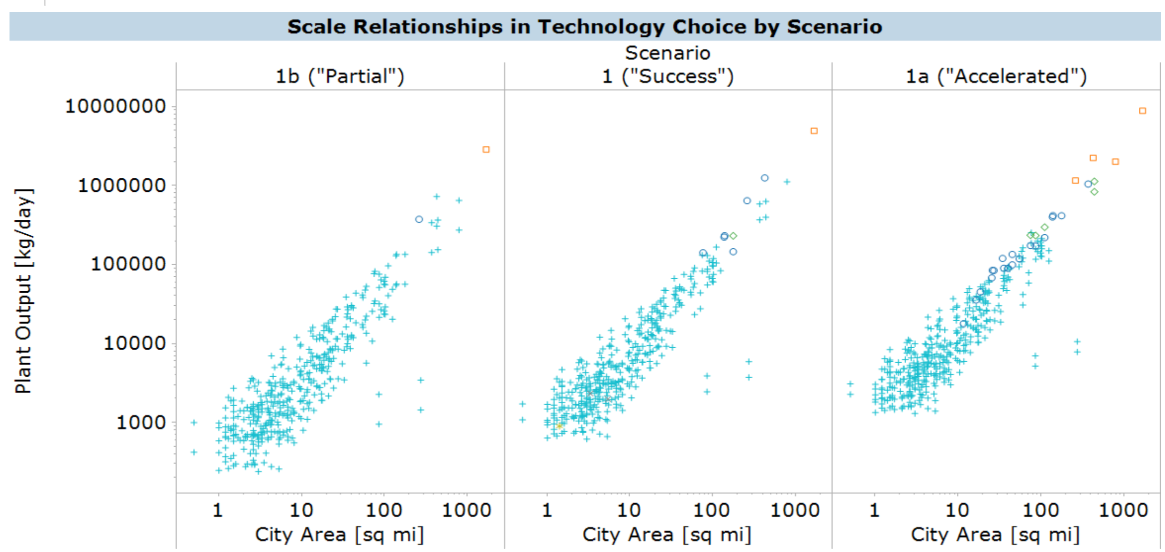
- The goal of this work is to highlight the strengths and weaknesses of HyDS-ME and the input data sets for it, and to understanding how feedstock price sensitivities influence market turning points in infrastructure choice.
- Observations and semi-insights:
  1. Pipeline infrastructure and (to a lesser extent) other transmission infrastructure is non-optimally costly for the levels of demand considered here—it is only when feedstock costs to onsite production technologies are raised substantially (or the deployment of those technologies forbidden) that transmission infrastructure comes into play significantly.
  2. Some of the potential technologies (e.g., central grid electrolysis) rarely come into use because they are generally more costly than others (e.g. central biomass gasification) in the cost inputs.
  3. Hydrogen cost may vary widely (an order of magnitude) with locality and with time.
  4. The construction of production plants that are not fully utilized in the early years of their lifetime substantially increases delivered hydrogen cost in those years.
- Detailed analysis of the interplay between technology costs will be required to verify and defend insights gained in optimization studies.

Demand Scenario Comparison



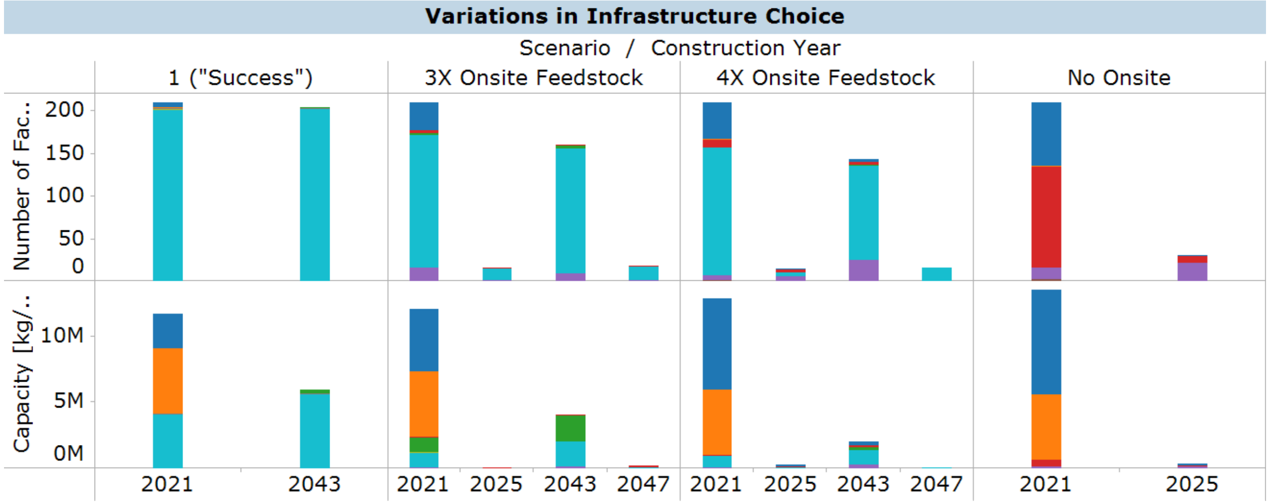


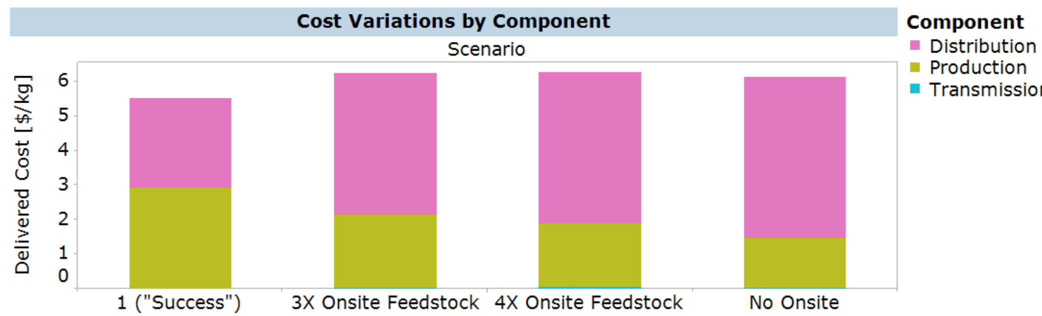


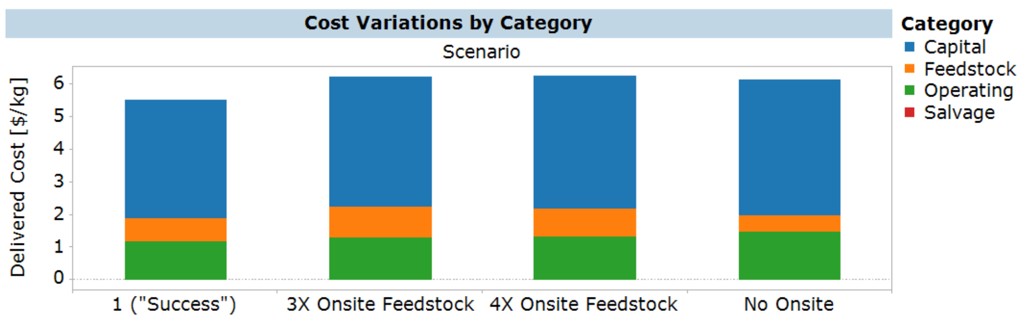


Feedstock Scenario Comparison

- We consider three simple scenarios involving the pricing of feedstocks for the onsite production technologies, with progressively higher feedstock prices.
- These scenarios mimic potential constraints that would limit the availability of feedstocks at points of onsite production within a city.







Collaborations, 2008-2009

- M. Melaina, O. Sozinova, D. Steward (NREL)
  - hydrogen infrastructure analysis
  - H2A models
- B. Roberts (NREL)
  - GIS-based resource assessment
- D. Thompson (independent subcontractor)
  - expertise in tuning optimization models

Proposed Future Work

- Application of HyDS-ME to more elaborate scenario analyses
- Directly representing additional key constraints to hydrogen infrastructure build-out explicitly within HyDS-ME
  - Global constraints on feedstock availability and competition
  - Right-of-way considerations
  - Accounting for the cost of new or upgraded feedstock-delivery infrastructure
  - More highly localized delivered-feedstock costs
- Developing a more sophisticated disaggregation of hydrogen demand corresponding to the NAS scenarios
- Elaborating on the existing HyDS-ME representation of blueprints for infrastructure build-out
  - Higher resolution of hydrogen infrastructure components
  - Staged/incremental capacity addition in HyDS-ME, where multiple production facilities (or pipelines) are constructed in a staggered fashion over the years
  - Fewer conditions on allowable hydrogen infrastructure networks
  - Directly representing the nuances of hydrogen delivery within urban areas

Summary

Relevance	• Integrated, cross-cutting model • Scenario-oriented analysis compatible with H2A models
Approach	• Searches for optimal combinations of hydrogen production and transmission infrastructure to meet time-varying demand in urban areas over a region.
Accomplishments	• Major enhancements and unification of model • Improved interoperability • Application to California hydrogen infrastructure • Design of CCS study
Collaborations	• NREL H2 analysis team • Optimization experts
Proposed Future Work	• Application of HyDS-ME to more elaborate scenarios • Elaboration of model for specific studies

Optional Supplemental Slides

Relevance: Capabilities & Uniqueness

- Semi-realistic optimization of physical build-out of H_2 infrastructure
  - Treatment of production, transmission, and distribution
    - Easy to add new technologies
    - Consistent physical and economic computations
  - Cost, cash flow, and price estimates
  - Spatial & temporal resolution of hydrogen infrastructure networks
  - Regional specificity
  - Exogenous, urban H_2 demands
- Flexible architecture
  - GIS-enabled
  - H2A-compatible
  - Interfaceable to other analysis and visualization tools
  - Straightforwardly adaptable for specialized analyses
  - Suitable for use on desktop, as a web service, or in a high-performance computing environment
- Transparency
  - Documented code & algorithms
  - Maintainable

Relevance: Analysis Topics

- Which technologies will be used to provide hydrogen during the deployment?
- What external influences and policies enable technologies to come online sooner?
- What synergies are there between cities and their distance to markets?
- How important and costly is it to serve rural areas?
- How can cities leverage one another's demand, thereby reducing cost and risk of stranded investments?
- Where can centralized versus distribution production technologies be most effective?
- How can do policy constraints and incentives influence hydrogen infrastructure build-out?

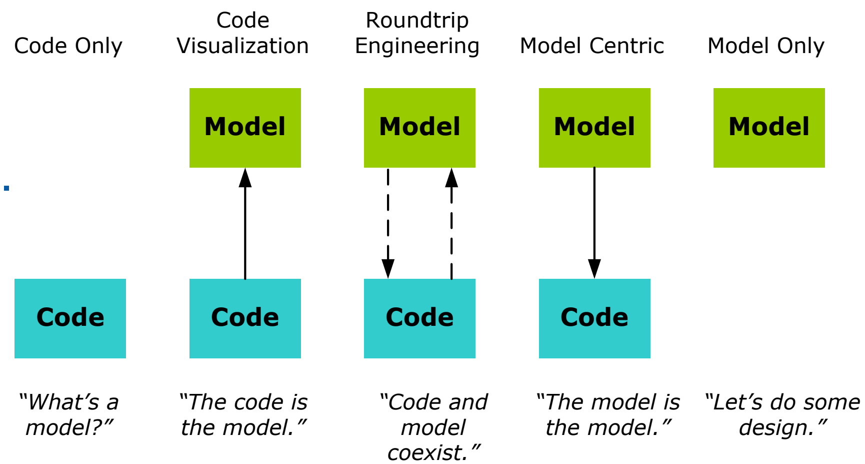
Source (partially): E. Brown, NREL 2008

Approach: Details of HyDS-ME Enhancement Effort

Item	*Description*
1.	Facilitate the import of the latest H2A cost data.
2.	Use a single GIS interface, and allow export to standard GIS analysis tools.
3.	Treat temporal (decadal) build-out of infrastructure.
4.	Allow nodes between cities in the pipeline network.
5.	Handle an arbitrary number of production, transport, and delivery modes.
6.	Rationalize the transportation and delivery costs.
7.	Generalize the demand curve inputs so they are not constrained to using particular data sets.
8.	Allow regional and yearly variation in all feedstock prices.
9.	Modify the user interface to ease the performance of sensitivity studies.
10.	Migrate the code and algorithms to a single programming language.
11.	Write technical (design and algorithm) documentation and user documentation that includes a tutorial.
12.	Move the source code and documentation into a configuration management and issue tracking system.

Approach: HyDS-ME Software Development

- Model-driven architecture
  - Focuses on specifying modeling objects using well defined notation.
  - Separates design from implementation.
  - Avoids platform dependence.
- Much of the implementation follows naturally from a well designed model.
  - Manipulating attributes.
  - Managing relationships.
  - Persistence/serialization.
- Object-oriented approach
  - Software organized into packages, classes, methods, and attributes.
  - Standard UML 2 class diagrams specify static structure.
- The structure of the software is transparent, and thus more easily maintainable and extendable.

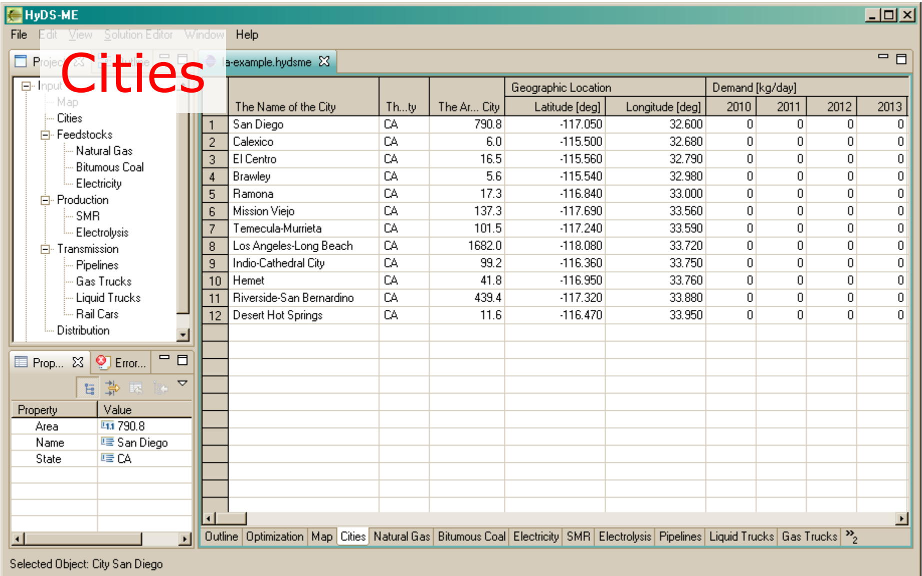


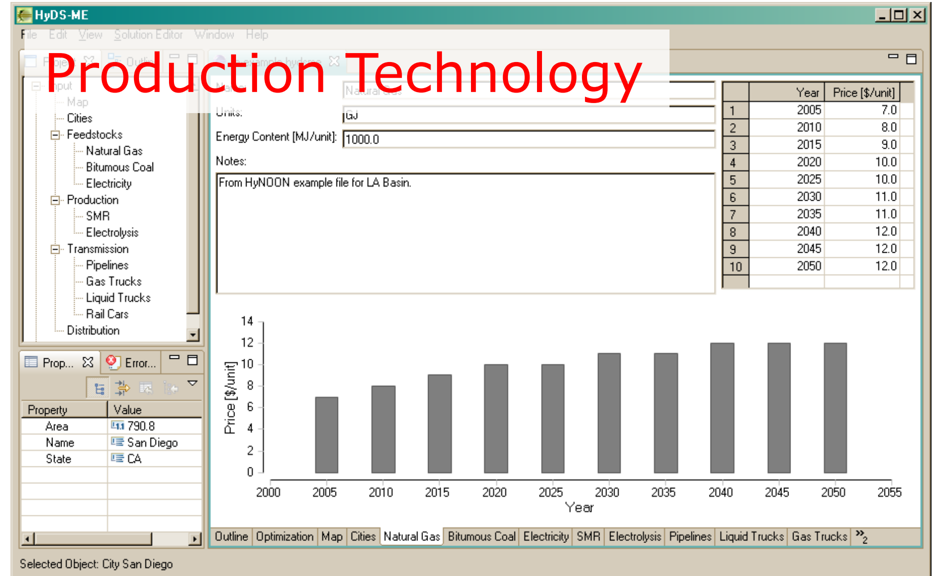
Source: <http://www.ibm.com/developerworks/rational/library/content/RationalEdge/feb04/3100_fig1.gif>

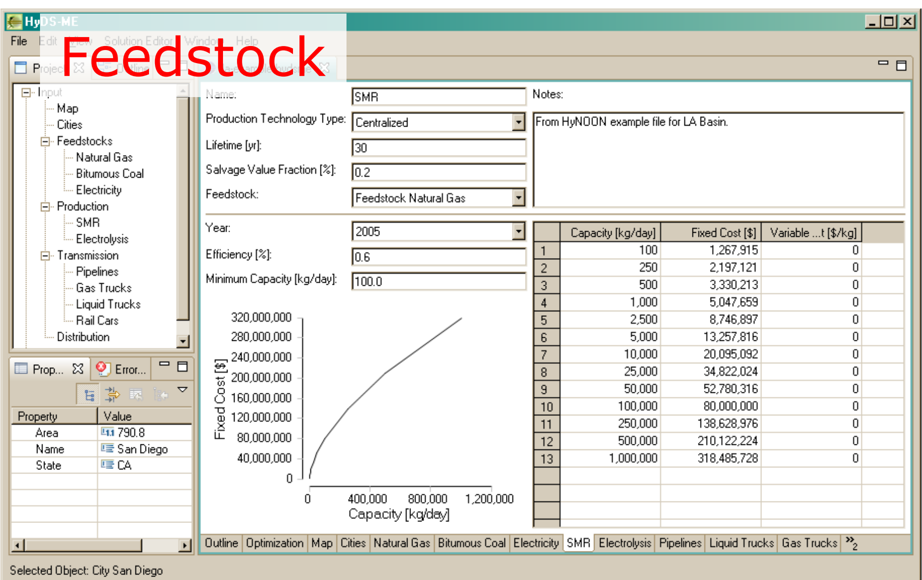
Approach: Architectural Details

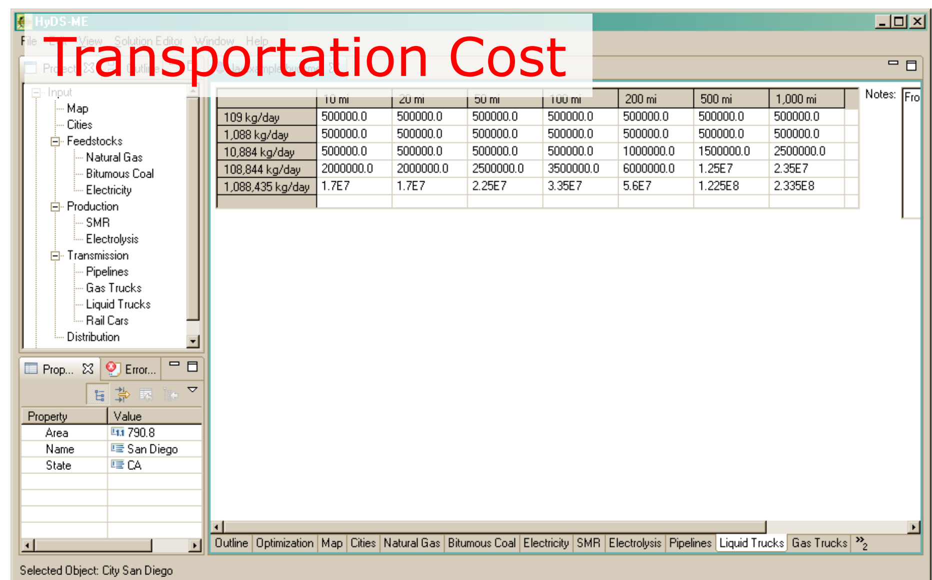
- Model-View-Controller [MVC] pattern
  - Model
    - UML 2 model represented via ECore
    - “Boiler plate” code generated by Eclipse Modeling Framework [EMF]
    - Hand-written implementation of algorithms (in Java)
  - View
    - Core GUI: Eclipse Rich Client Platform [RCP]
    - GIS: open-source GeoTools library
    - Charting: Business Intelligence Reporting Tools [BIRT]
    - EMF-generated master editor
    - Hand-written editors and viewers
  - Controller
    - EMF-generated adapters for model objects
    - Hand-written control logic
- Advantages
  - Very clean separation of architectural concerns
  - 100% open-source, free, redistributable
  - Platform-independent: Windows, Mac, Linux
  - Suitable for running “headless”
    - on supercomputers for large optimization problems / sensitivity studies, or
    - embedded in a web server.

Accomplishment: More User-Interface Examples



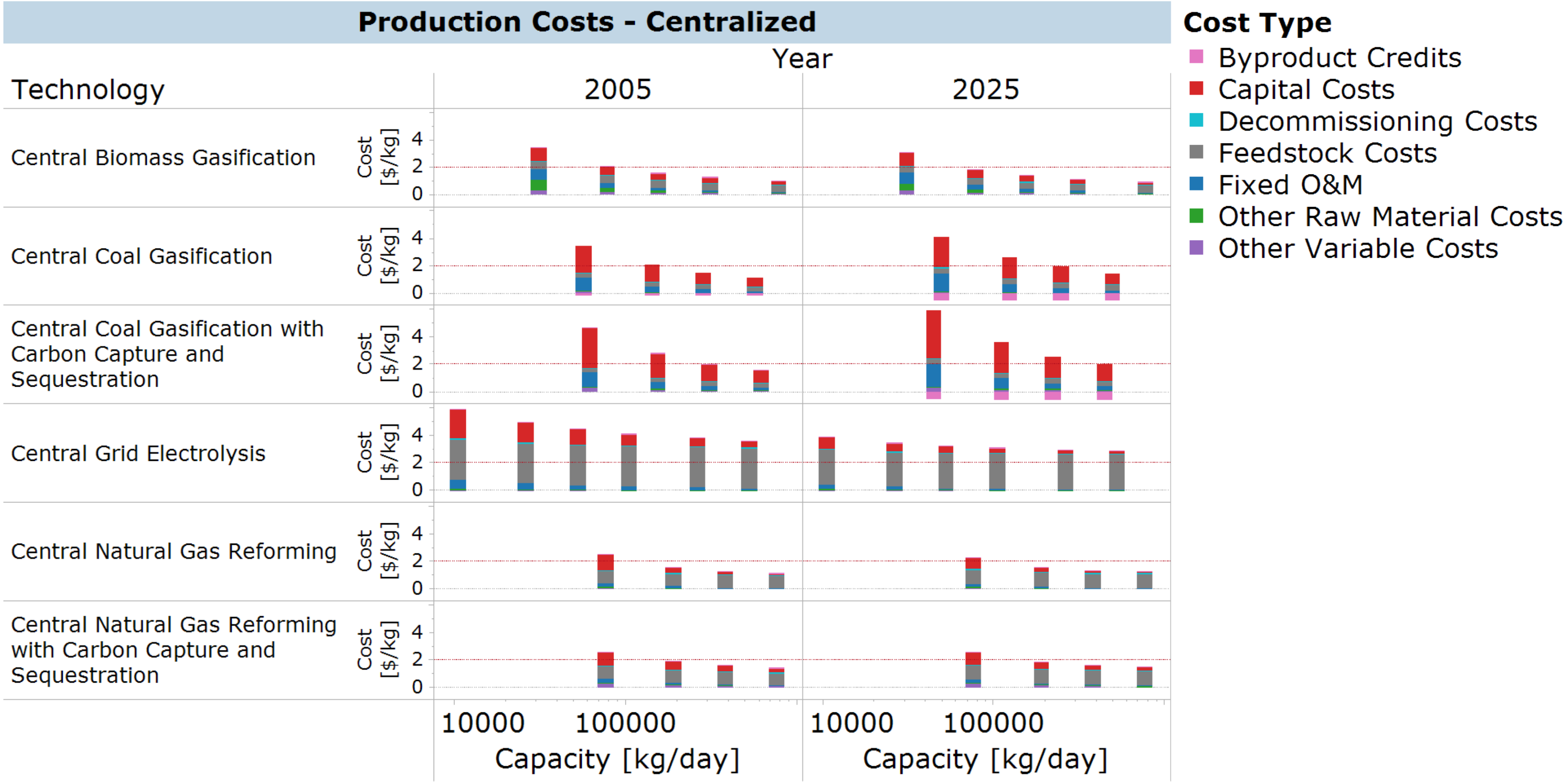






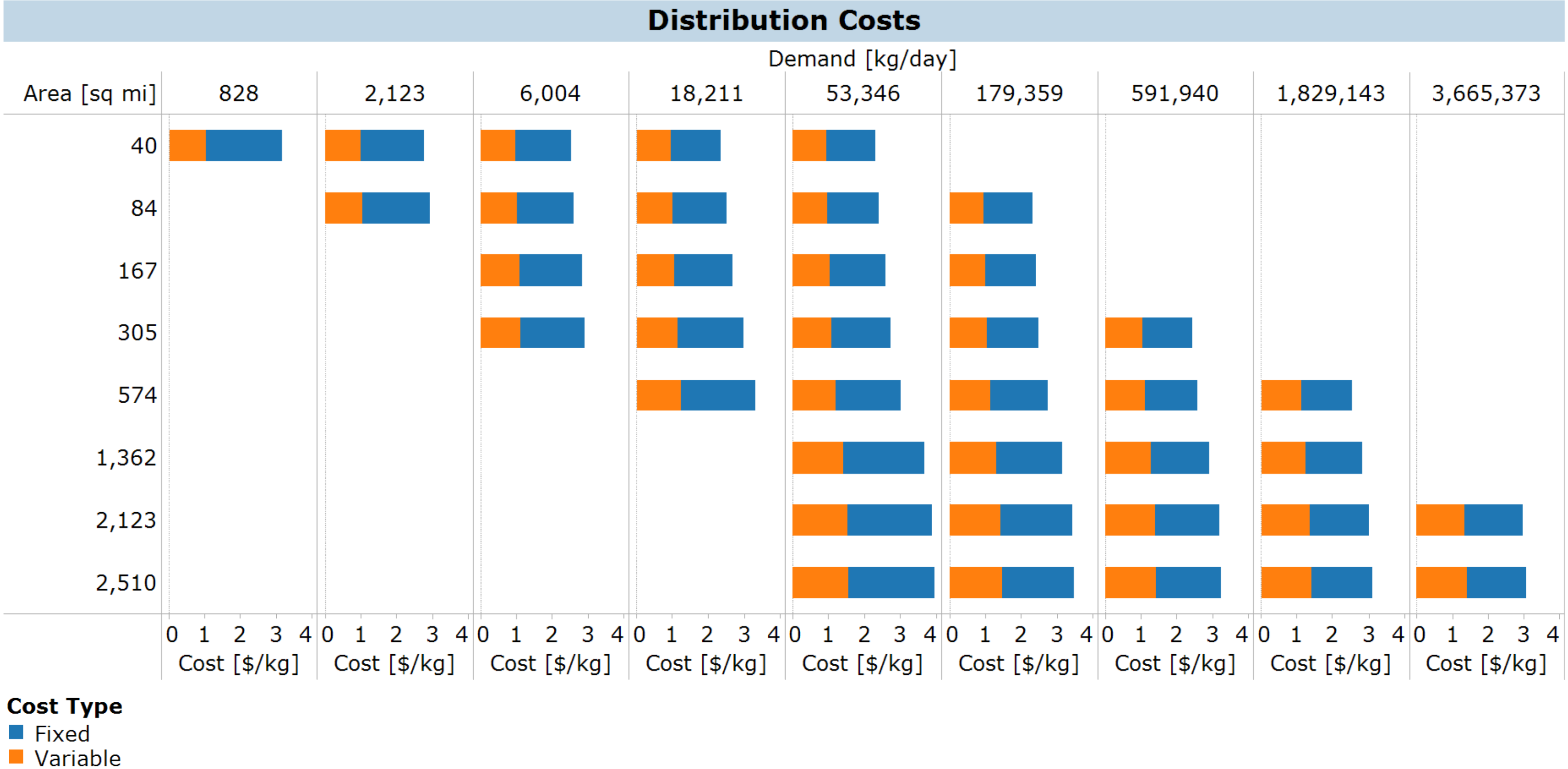
Accomplishment: Production Infrastructure Costs

- The results of H2A Production analyses were used to characterize production-related costs by plant scale, year, and technology type.



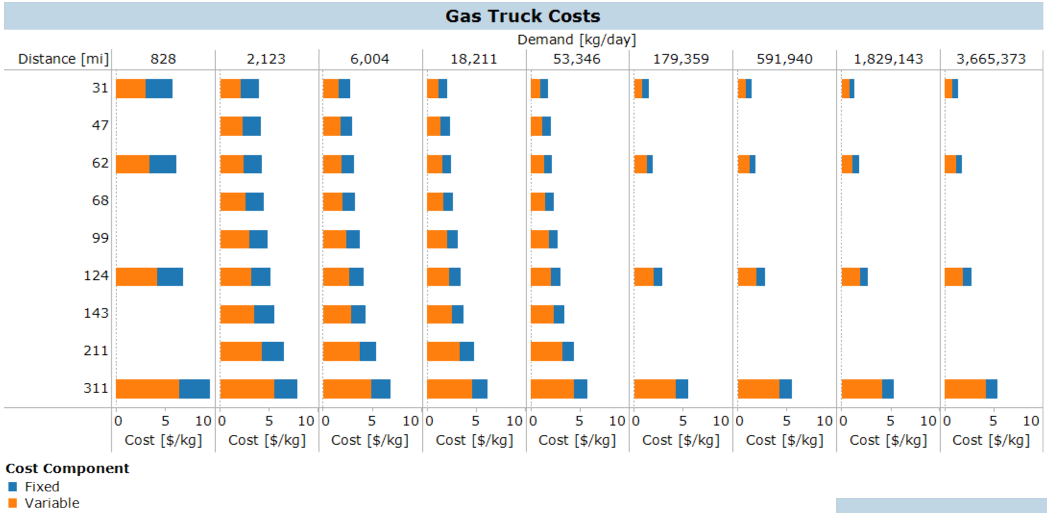
Accomplishment: Distribution Costs

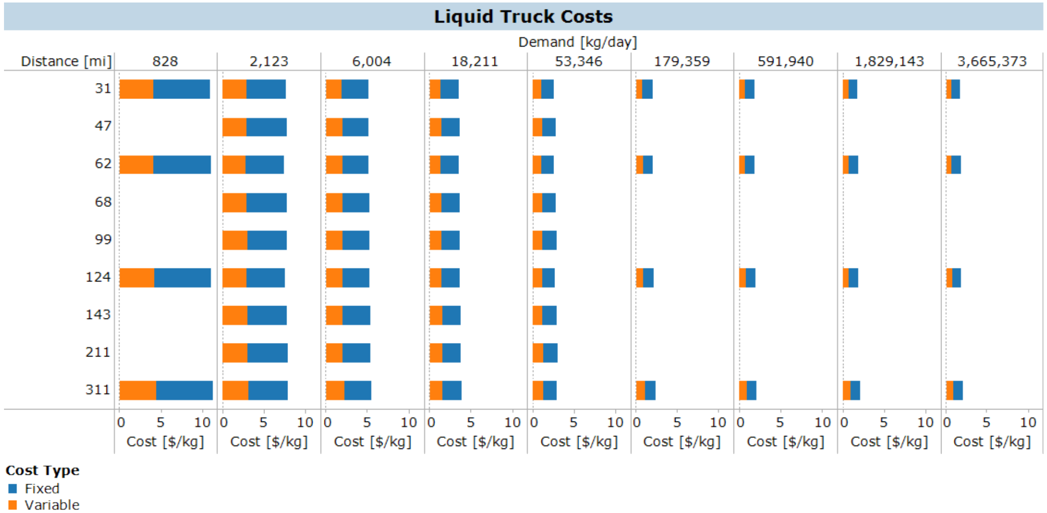
- The results of HDSAM analyses were used to characterize distribution-related costs for non-forecourt distribution of H_2.



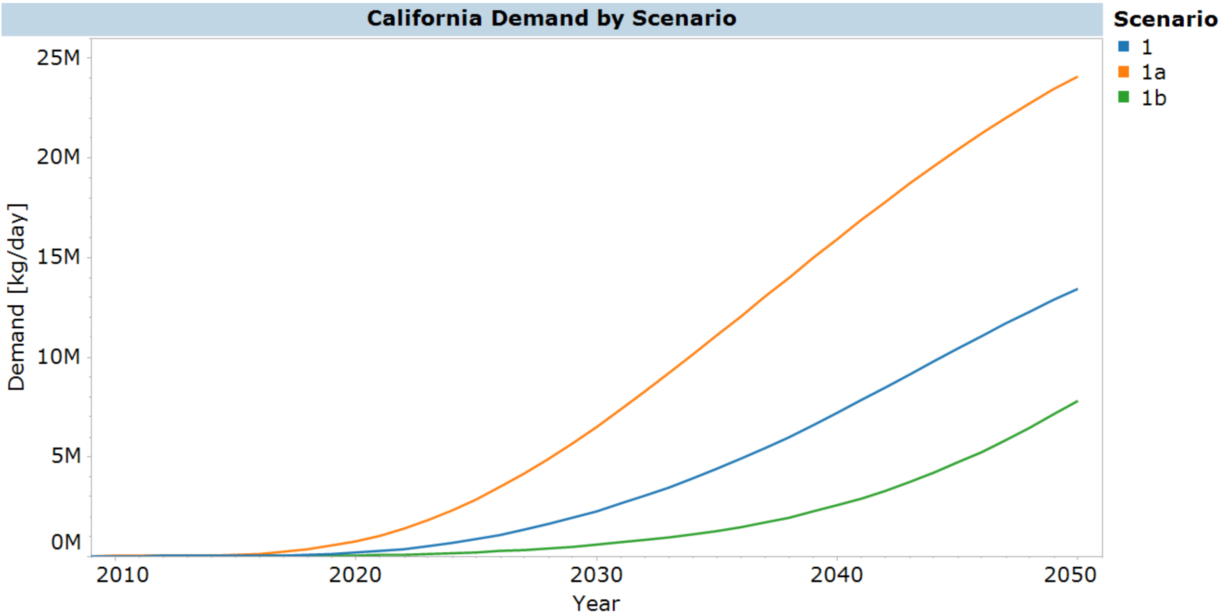
Accomplishment: Truck Transmission Costs

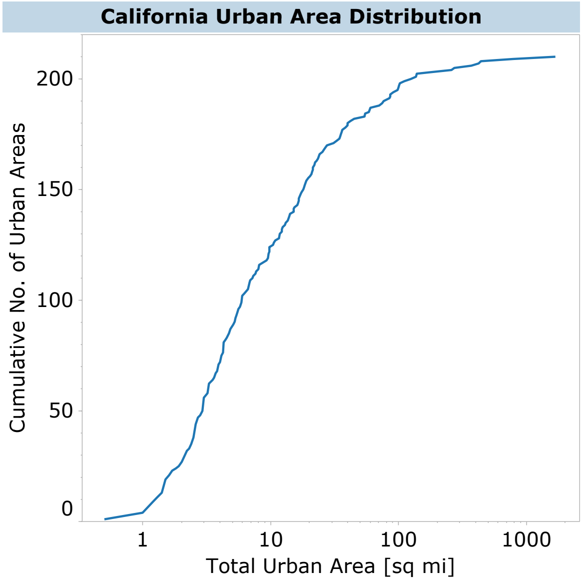
- The results of HDSAM analyses were used to characterize truck-related costs for non-forecourt distribution of H_2.

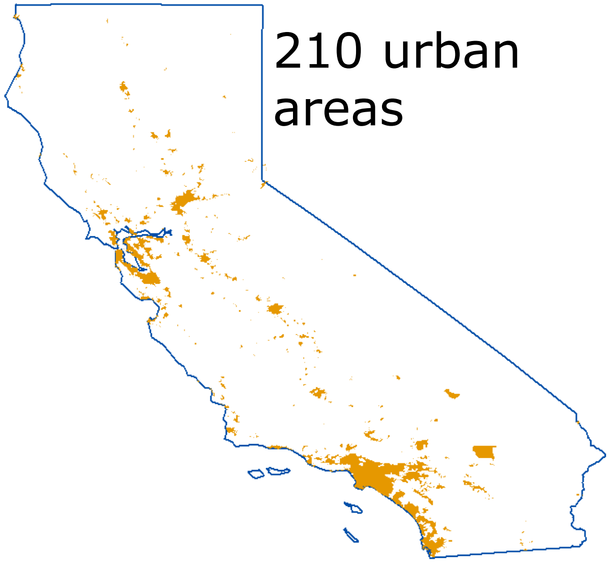


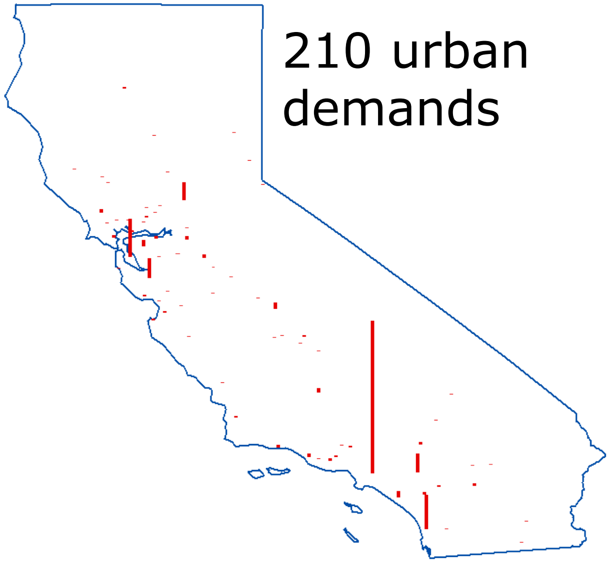


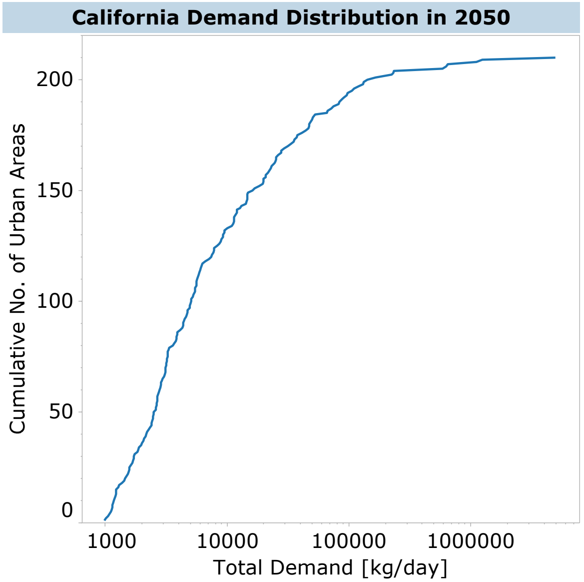
Accomplishment: California H_2 Demand



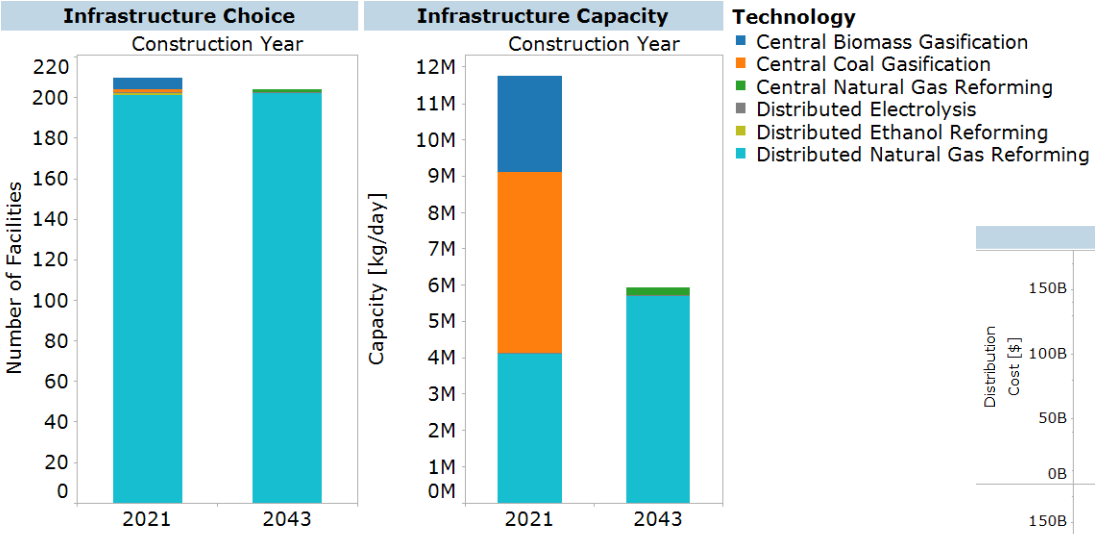


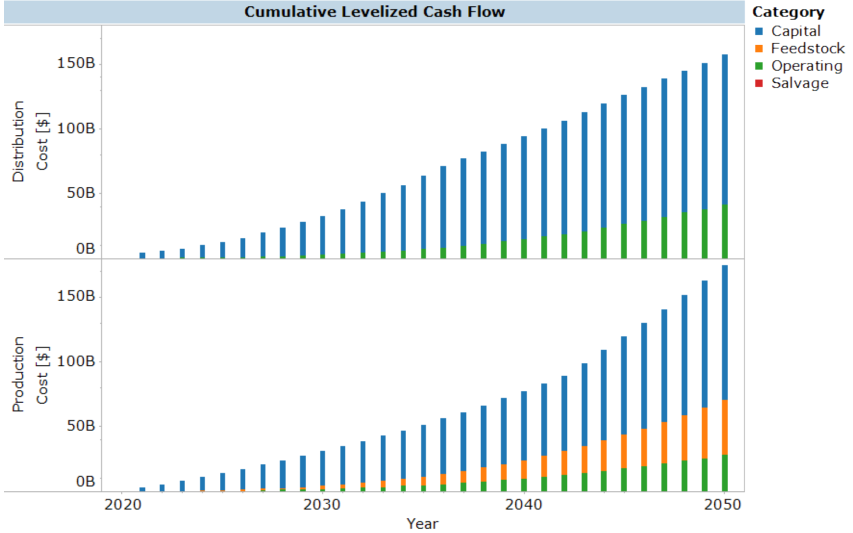




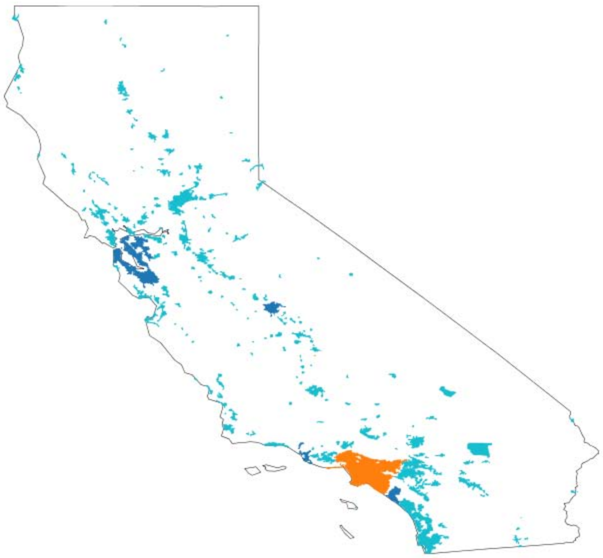


Accomplishment: Base Case – 1 "Hydrogen Success"

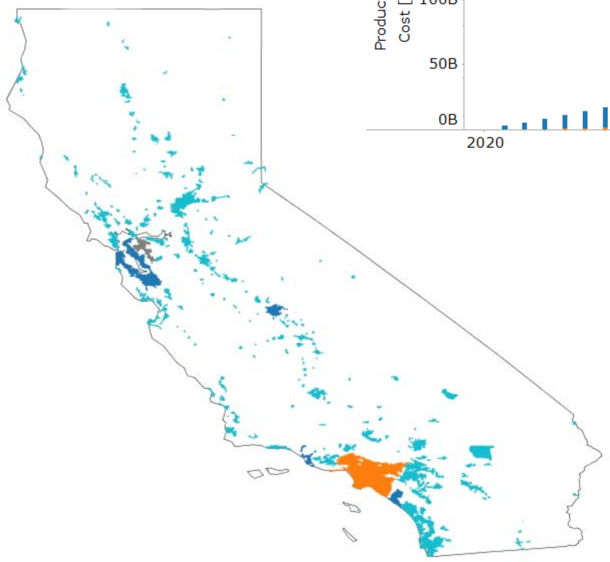




2025

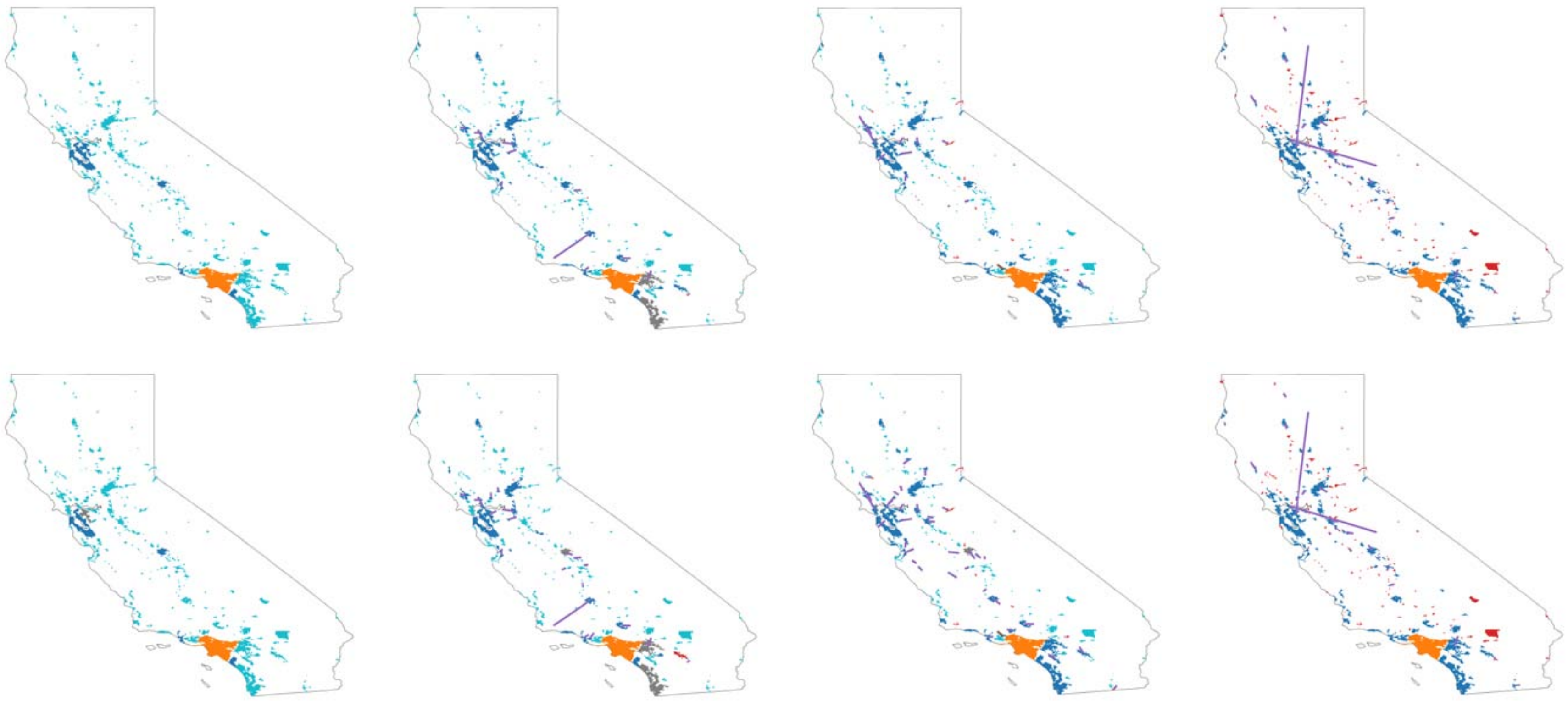


2045



Accomplishment: Geographic Details of Feedstock Scenarios

	1 ("Success")	3X Onsite F'stock	4X Onsite F'stock	No Onsite
2025				
2045				



Technology
- Central Biomass Gasification
- Central Coal Gasification
- Central Grid Electrolysis
- Central Natural Gas Reforming
- Distributed Electrolysis
- Distributed Ethanol Reforming
- Distributed Natural Gas Reforming
- Gas Truck
- Liquid Truck