NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Regional Supply of Hydrogen

Marc Melaina (P.I.)
Michael Penev (Presenter)
National Renewable Energy Laboratory
DOE Hydrogen and Fuel Cells Program
2017 Annual Merit Review and Peer Evaluation Meeting
June 6, 2017

Project ID
SA063

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

Overview

Timeline

Start: October, 2016

End: September, 2017*

* Annual direction determined by DOE

Barriers

4.2 Technical Approach:
Infrastructure Analysis

4.5 A. Future Market Behavior:
Scenarios to understand vehicle-fuel interactions

4.5 E. Unplanned Studies and Analysis
Response to H2USA public-private partnership and infrastructure deployment goals

Budget

FY17 Planned DOE Funding: $125K

Funds Received to Date: $125K

Partners

External References

- Oil & Gas Journal
- H2A
- HDSAM

Planned Reviewers

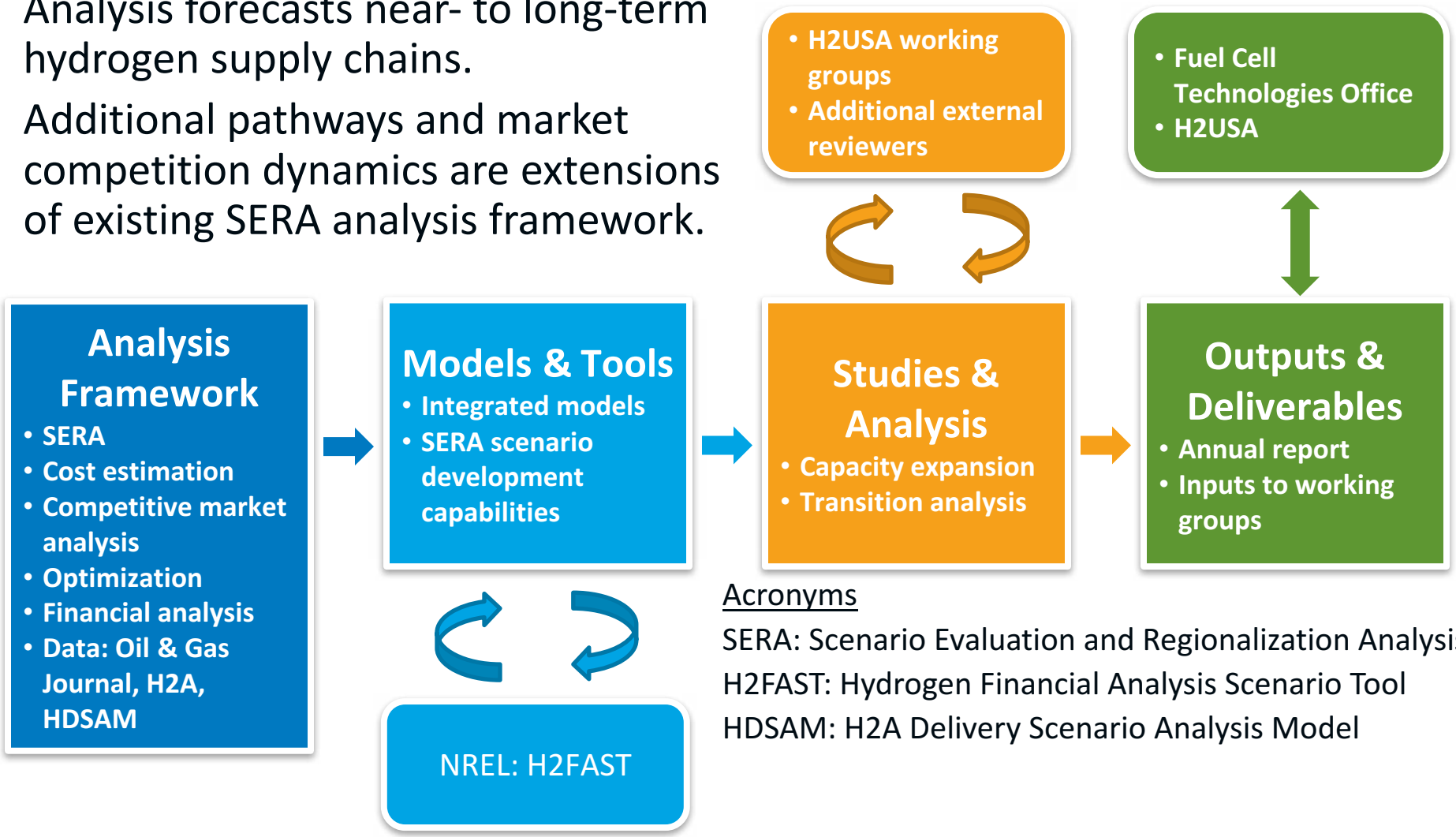
- H2USA working group members
- California Energy Commission
- Academic experts
- Fuel Pathways and Integration Tech Team (FPITT)

Production dynamics analysis enables forecast of competitive retail price and availability of fuel

Relevance/Impact 1

Analysis forecasts near- to long-term hydrogen supply chains.

Additional pathways and market competition dynamics are extensions of existing SERA analysis framework.



Acronyms

SERA: Scenario Evaluation and Regionalization Analysis

H2FAST: Hydrogen Financial Analysis Scenario Tool

HDSAM: H2A Delivery Scenario Analysis Model

Analysis of production expansion dynamics forecasts infrastructure equipment and finances

Relevance/Impact 2

Objectives

- Evaluate existing hydrogen production capacity and hypothetical excess capacity
- Forecast production capacity expansion requirements for growing FCEV market demand
- Simulate regional supply chain network dynamics
- Incorporate market competition considerations

Impacts on FCTO barriers during reporting period

- Enhanced analysis of future hydrogen production and retail fueling market behavior (Barrier A)
- Provide timely analytical capabilities to FCTO (Barrier E)

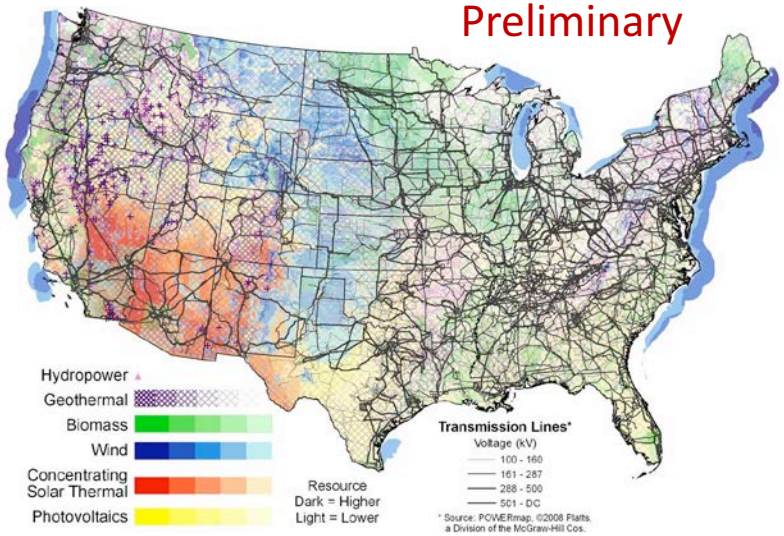
Forecasting incorporates updated and comprehensive supply chain pathways and market competition.

Modeling Approach Leverages SERA Framework

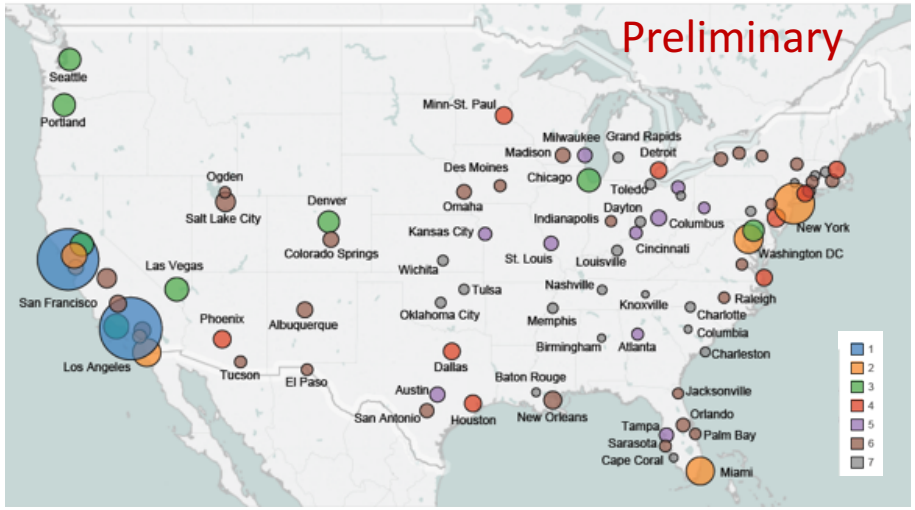
Approach 1

- The ***Scenario Evaluation and Regionalization Analysis*** (SERA) modeling framework develops optimized hydrogen supply networks in response to FCEV hydrogen demands
- Accounts for the geography of energy resource availability, extraction and conversion costs, transmission and distribution costs, and retail station network costs
- Competes multiple supply chain technologies to identify least-cost supply options both temporally and spatially

Resource & Infrastructure Considerations



Demand: FCEV Urban Market Diffusion Tiers



Build on Conventional Hydrogen Supply Pathways

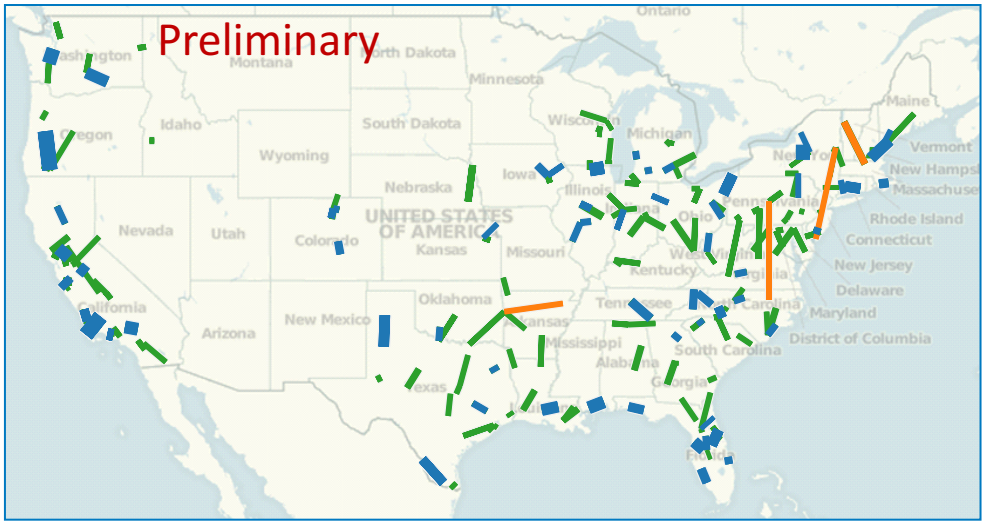
Approach 2

Central Production (200,000+ kg per day)

- Natural gas steam methane reformation (SMR) with and without carbon capture and storage (CCS)
- Biomass gasification and coal gasification (with and without CCS)
- Electrolysis
- Emerging technologies (photoelectrochemical, solar thermo-chemical)

Onsite or "forecourt" production at the retail station (SMR, electrolysis)

Delivery Pathways (pipeline transmission, liquid or gaseous truck/rail delivery)



Map indicates estimated least-cost, long-term transmission modes from central production facilities to urban demand centers (~2050)

SERA optimizes production and delivery networks to multiple urban demand centers over time

Economic Drivers for New Infrastructure Investments

Economics drivers influencing incremental investments

- Internal rate of return (H2FAST financial analysis across supply chain components)
- 5 year demand growth horizon
- Capacity function of demand growth rate
- Potential installations
- Growth of market (internal and external FCEV market forecasts)
- Investment risk reduction from emerging track record
- Total cost of ownership of FCEVs, including policy support

Modeling approach will account for a broad range of influences on the decision to invest in new hydrogen production capacity

Incorporation of Market Competition

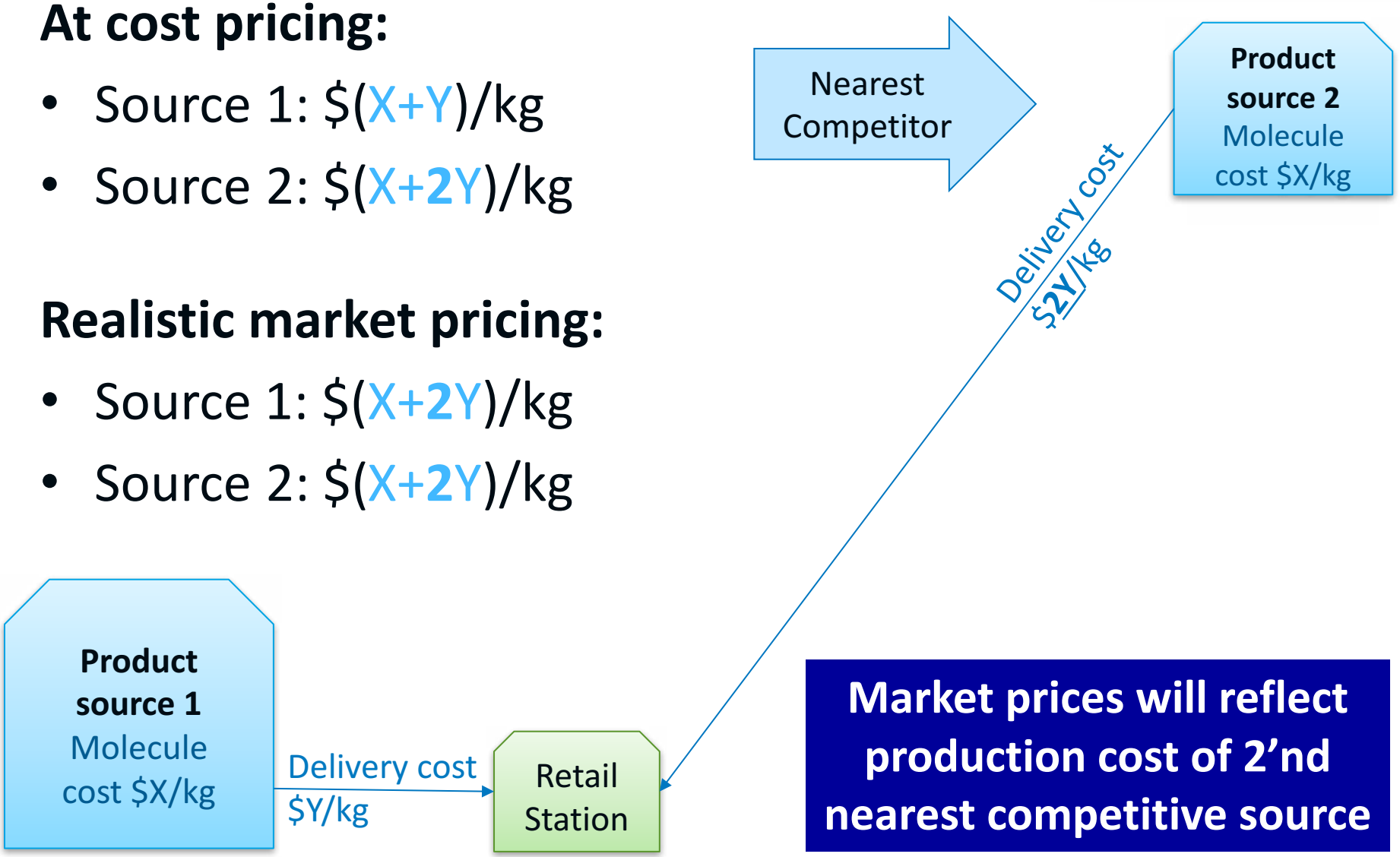
Approach 4

At cost pricing:

- Source 1: $(X+Y)/kg
- Source 2: $(X+2Y)/kg

Realistic market pricing:

- Source 1: $(X+2Y)/kg
- Source 2: $(X+2Y)/kg



Market prices will reflect production cost of 2'nd nearest competitive source

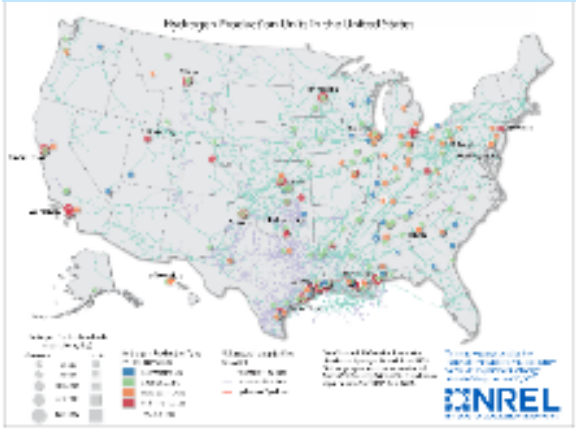
Overview: Regional Production Dynamics

Approach 5

- ✓ Account for current production assets
- ✓ Produce design for semi-central (hub & spoke) production
- Update production pathways costs in SERA
- Add SERA algorithms for market competitiveness and pricing
- Incorporate renewable pathway forcing function (% by year)

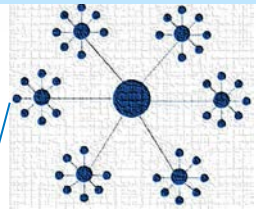
SERA algorithms optimize across multiple integrated sub-modules

Production Inventory

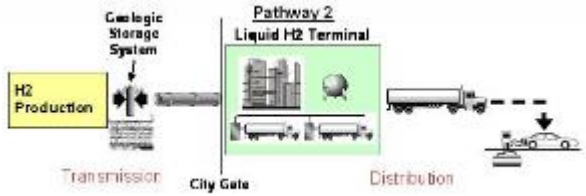


Competition pricing algorithm

Hub & Spoke



Updated delivery pathways

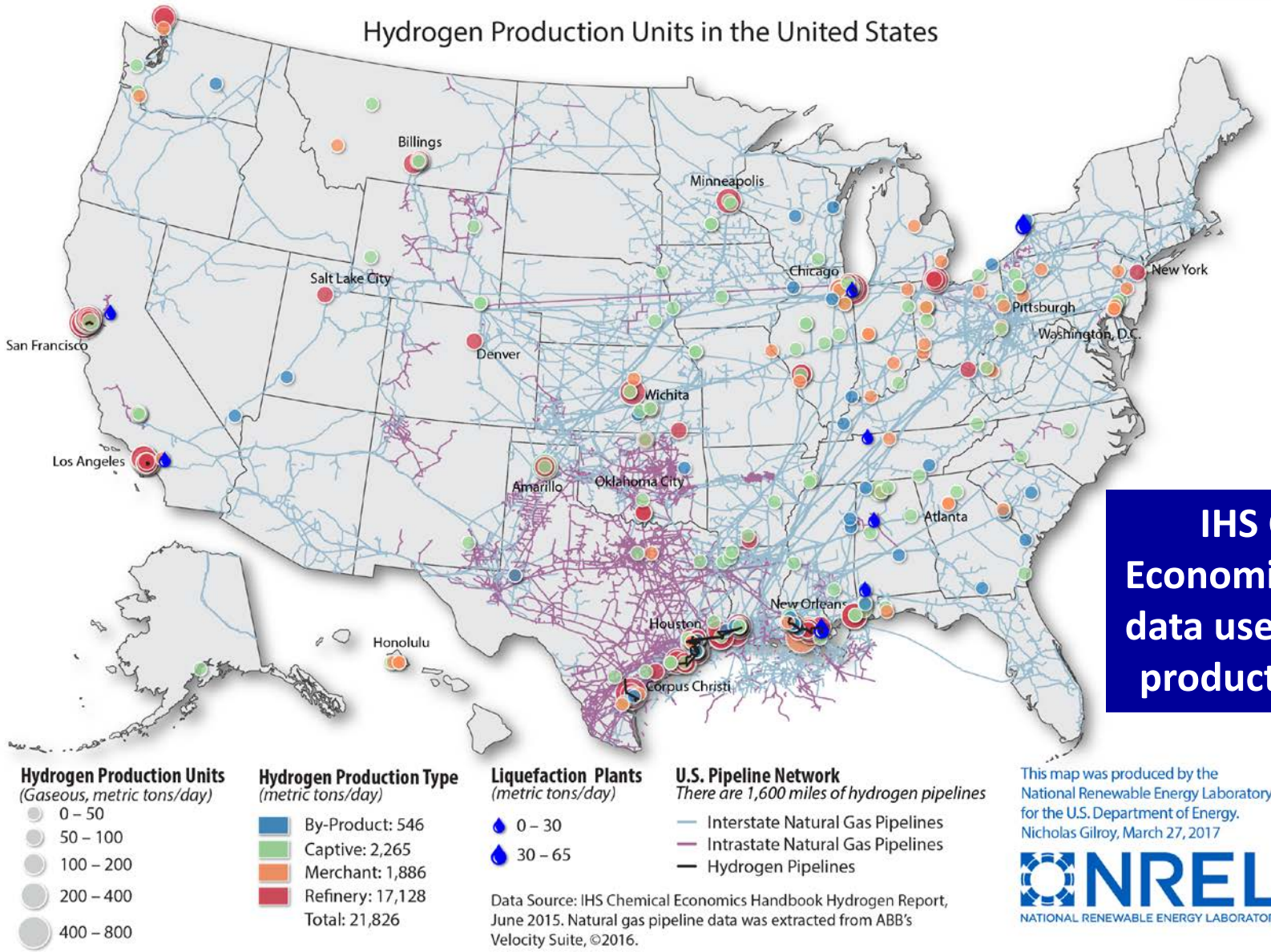


SERA Infrastructure Optimizer

- Resource considerations
- Demand growth
- Existing capacity
- Rights of way
- Lowest cost technology option
- Geographic optimization

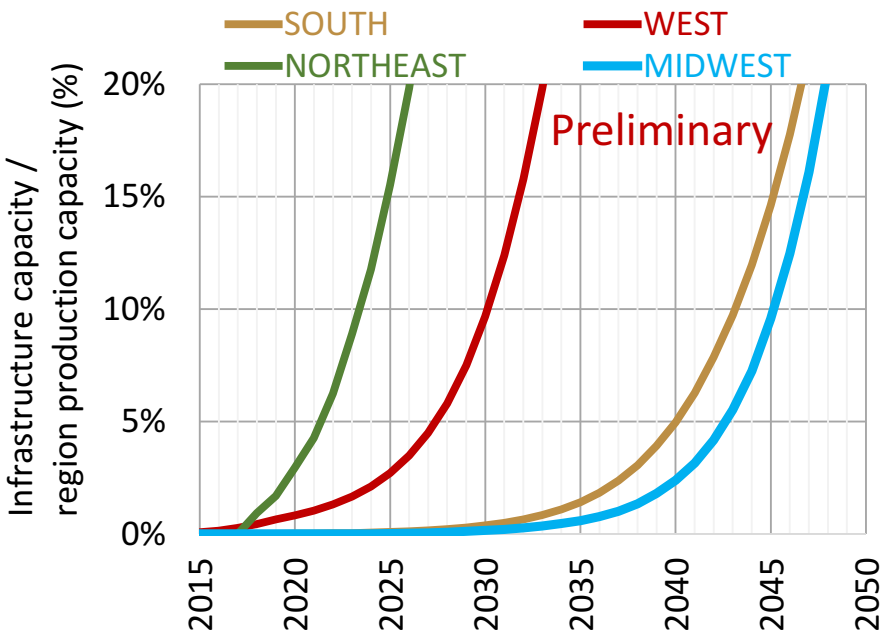
Optimized Hydrogen Production Locations & Transmission

Existing Production Resource Scale and Type

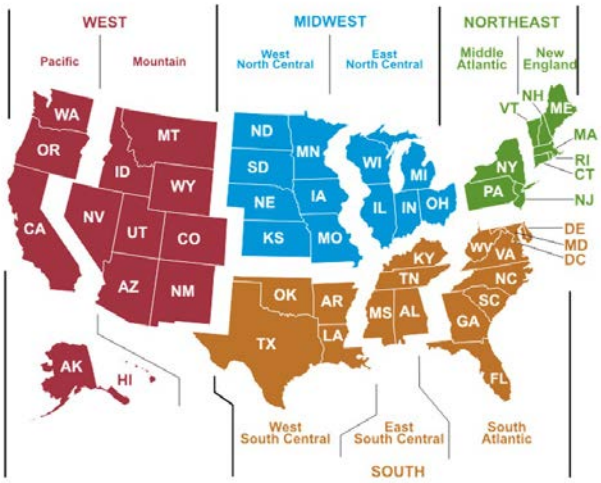


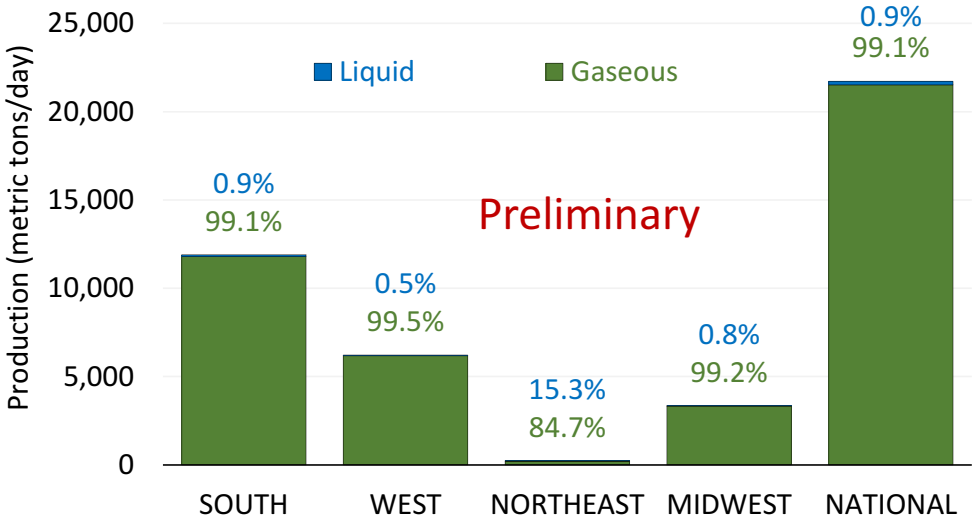
IHS Chemical Economics Handbook data used for existing production capacity

National Level Breakdown by Census Region



Based on regional demand from H2USA National Scenarios





Northeast likely to see first stresses in regional supply

Approximate order of stress on regional capacities:

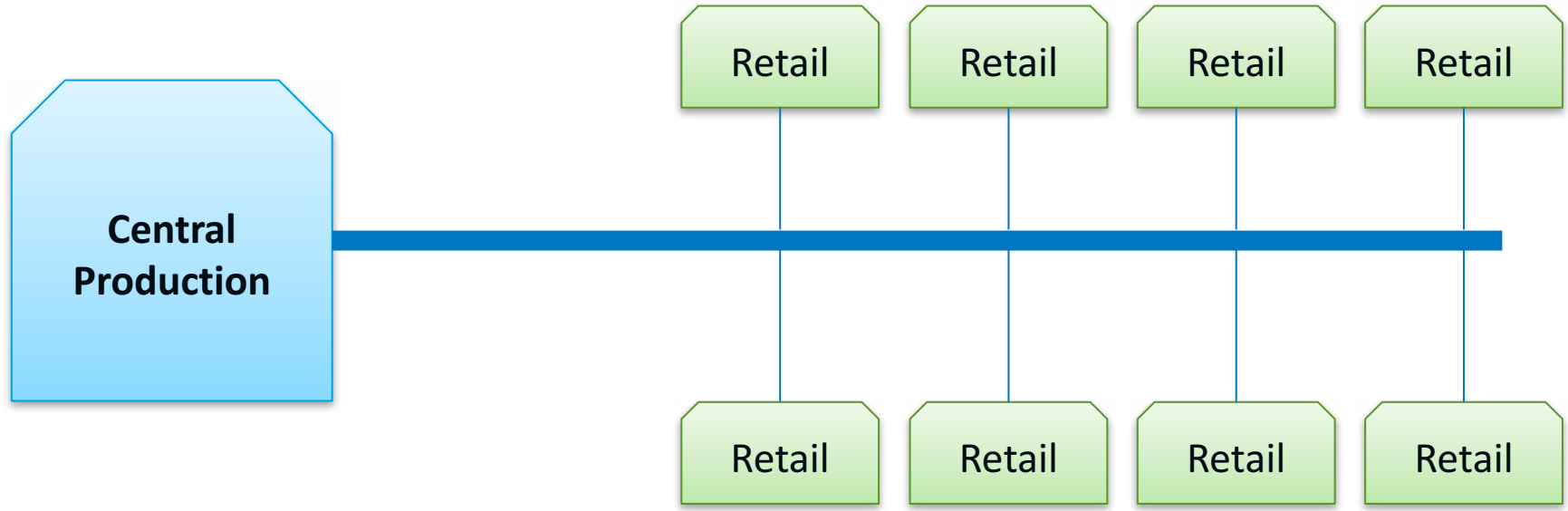
1. Northeast
2. West
3. South
4. Midwest

Existing Framework for Central Production with Long-distance Transmission Pipeline Network Build-Out

Central Production with Transmission Pipeline roll-out framework is being reconsidered

Central production network expansion

+ simplify retail station delivery
+ eliminate delivery truck emissions
+ reduce station storage requirement
+ enable siting on small urban sites
- large up-front investment
- high investor risk
- long demand ramp-up period / poor return on investment
- subsequent investments for off-shoots may still be needed

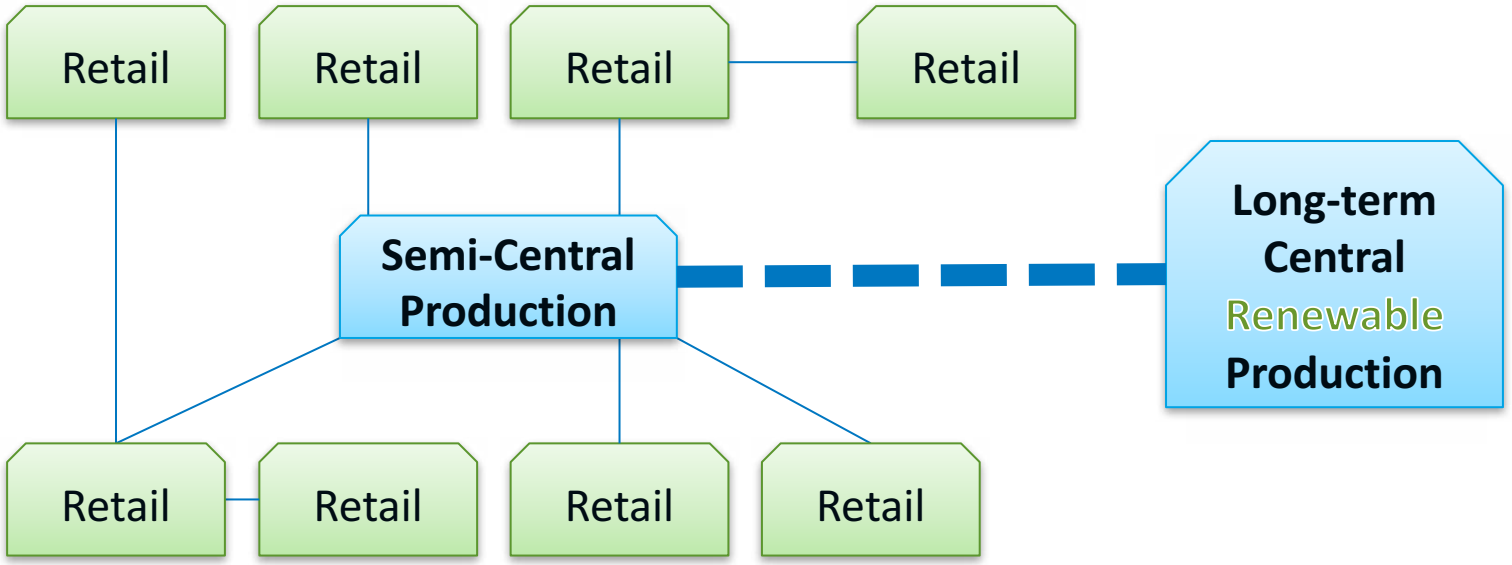


Framework for Semi-central Network Build-Out

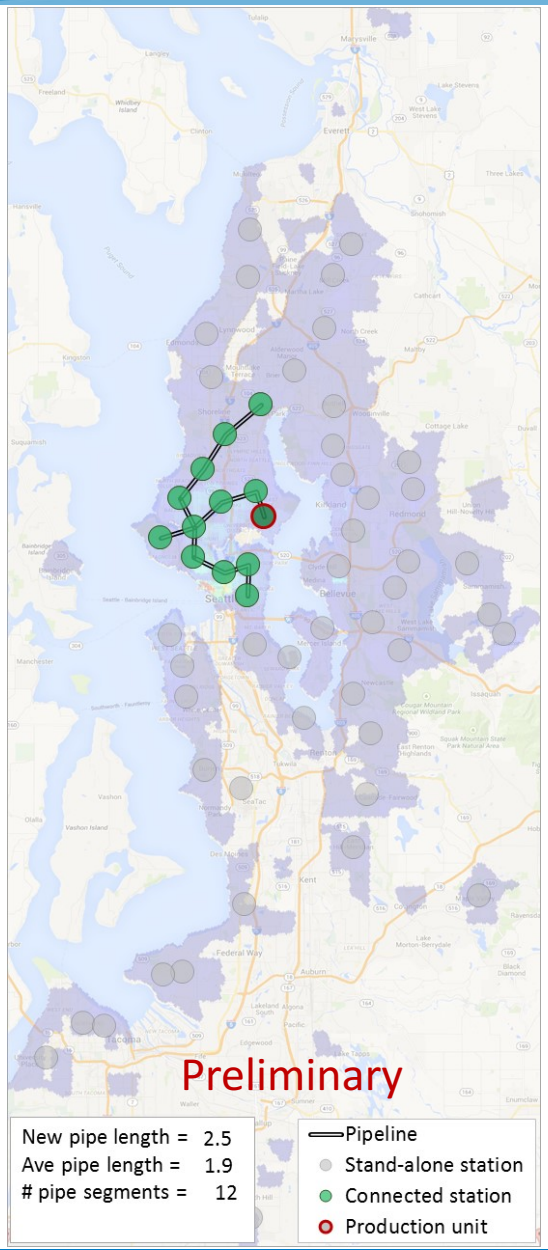
Semi-central pipeline network is being incorporated as a near-term network expansion option

Semi-central network expansion

+ simplify retail station delivery
+ eliminate delivery truck emissions
+ reduce station storage requirement
+ enable siting on small urban sites
+ smaller incremental investments
+ lower investment risk
+ quicker capital utilization ramp-up
+ allow diversity of production
+ higher resilience and redundancy of supply



Semi-Central Production & Connectivity Example: Seattle Retail Station Expansion



Example coverage station connections: Seattle, WA

- Average pipe length = 1.9 miles/station
- Fuel processing can be upgraded or incrementally scaled
- Bulk storage can be centralized
- Final compression and cascade storage would be distributed

Nominally ~2 miles of pipeline is needed per station for coverage network

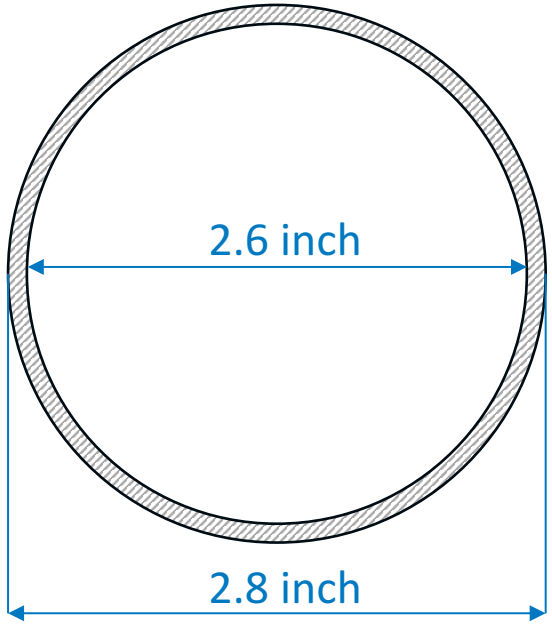
Semi-Central techno-economics benchmark

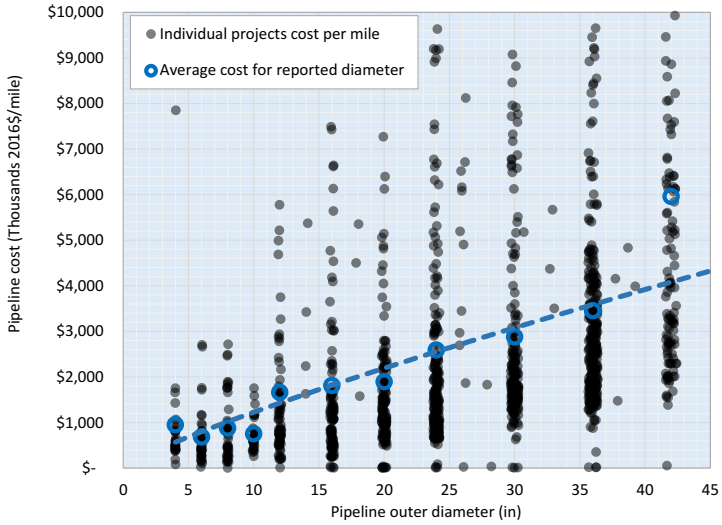
Pipe diameter scoping parameters:

- 25,000 kg/day flow capacity
- 2 mile length
- Inlet pressure 400 psig
- Pressure drop 100 psig
- Steel: A106 grade B (35,000 psi yield strength)

Estimates:

- pipe inner diameter = 2.6 in
- wall thickness = 0.1 in (3x safety factor)
- H2 stored in 2 mile pipe = 30 kg
- Pipeline material weight 2 miles = 18,000 lb





1321 pipeline projects
1991 through 2016
Reported in Oil & Gas Journal
Examples use 6in pipe = $800K/mile

Take away:
Anticipated requirement: 900 psi, 3”OD
Adopt conservative cost estimate of $800K/mile for 6” OD pipe

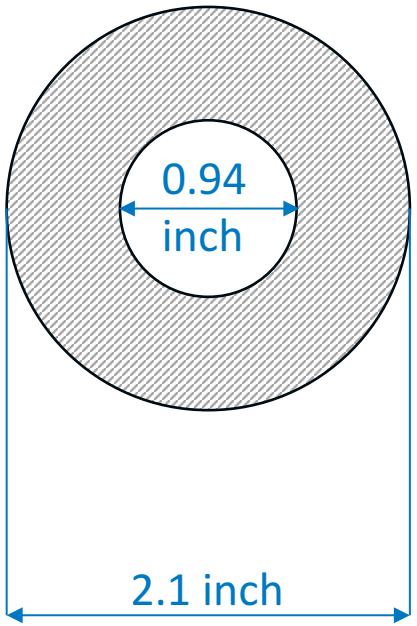
Centralized Dispensing-Level Compression

Pipe diameter scoping parameters:

- 25,000 kg/day flow capacity
- 2 mile length
- Inlet pressure 13,750 psig
- Pressure drop 12,500 psig
- Steel: A106 grade B (35,000 psi yield strength)

Estimates:

- pipe inner diameter = 0.94 in
- wall thickness = 0.55 in (3x safety factor)
- H2 stored in 2 mile pipe = 70 kg
- Pipeline material weight 2 miles = 93,000 lb

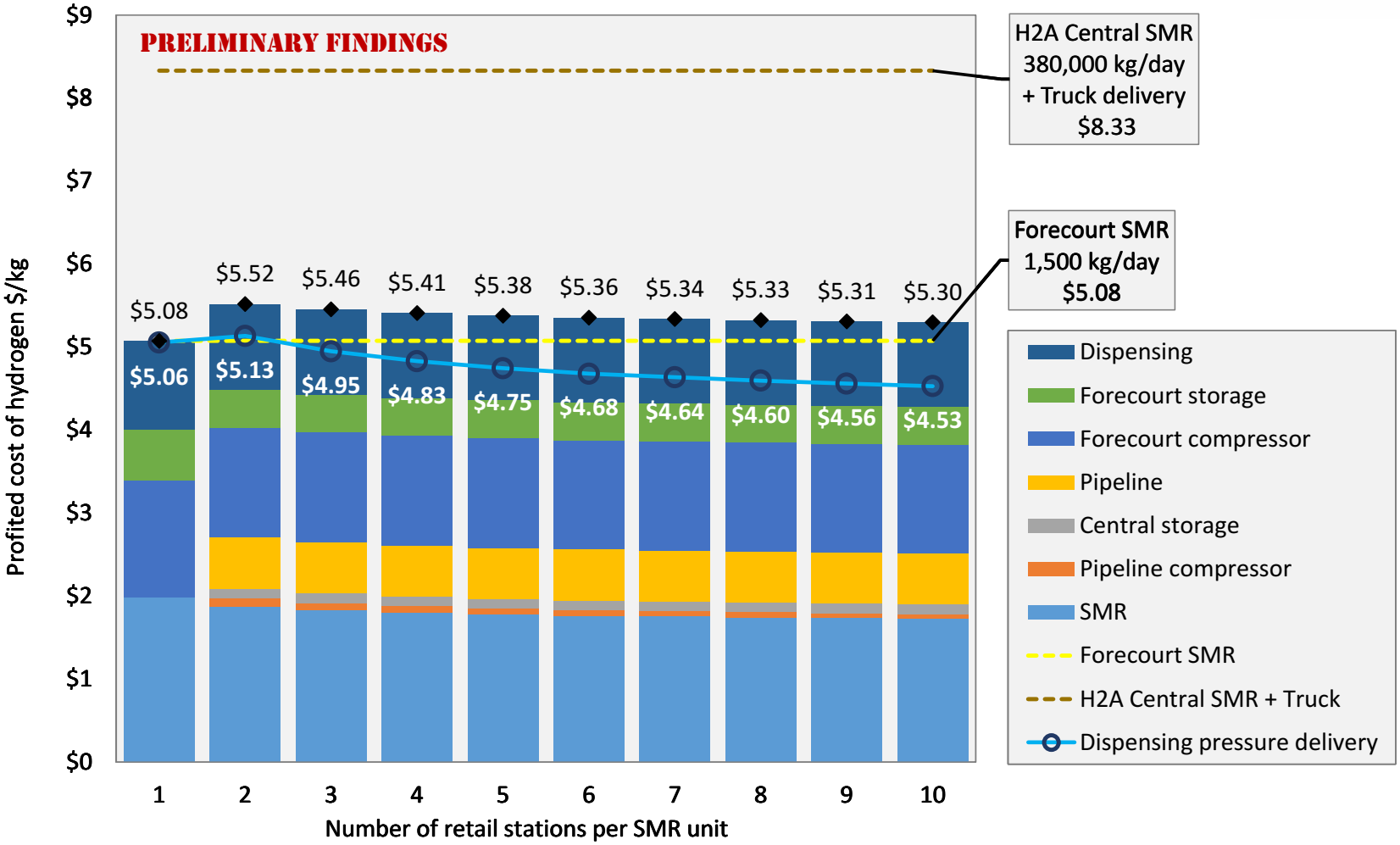


Other benefits:

- economies of scale for compressor
  - central compressor is much cheaper than many smaller compressors
  - improved compressor oversight and reliability
- greatly improved back-to-back fill capability
- retail footprint minimized (can site on small urban retail sites)
  - no on-site storage
  - no storage set-back distances
  - no compressor
  - no maintenance access setbacks

Take away: Centralizing compression can provide significant performance, siting, and economic benefits.

Semi-Central Dispensed Cost Benchmark



Economies of scale favor centralized production and compression

Collaboration

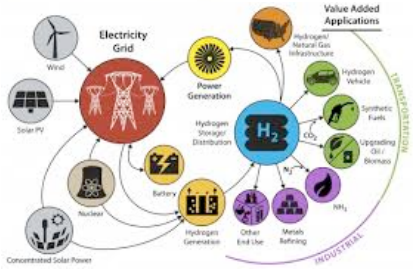
- Argonne National Laboratory
  - HDSAM and H2A Delivery Components Model
- IHS, Oil & Gas Journal
  - Empirical data on real-world projects
- California Energy Commission
  - Leveraging development of SERA analysis capabilities and real-world data updates resulting from support provided to annual CEC/CARB Joint Agency Reports (CEC-funded project)

Proposed Future Work

Future Work 1

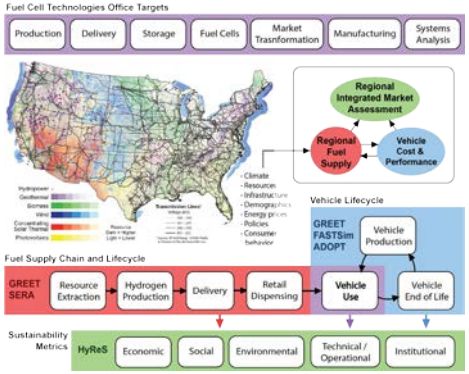
- Continue SERA updates based upon improvements and innovations in hydrogen production and delivery components
- Investment decision parameters and valuation metrics will be updated in response to stakeholder feedback (H2USA, others)
- Integration of investment decision financial metrics with hydrogen sustainability indicators (HyReS framework)
- Account for influence of additional market drivers and growth
  - Power-to-gas with natural gas pipeline blending opportunities
  - Promising near-term, non-FCEV markets identified through H2@Scale
  - Low Carbon Fuel Standard (LCFS) price signals in California

H_2 USA



H2@Scale

SERA



HyReS

Project Summary

Summary 1

Relevance

- Complete estimates of existing assets and potential excess production capacity.
- Analysis will provide enhanced forecasts of near- to long-term hydrogen supply chains.

Approach

- Additional pathways and market competition extend existing SERA analysis framework.
- Least-cost investment decisions account for a wide range of market influences.
- Market competition based upon production/delivery cost of nearest competitor.

Technical Accomplishments and Progress

- Current production assets by capacity and type (primary source: IHS Market Report)
- Identification of Northeast as potentially constrained production region.
- Developed modeling framework for semi-central production with spoke-hub distribution pipelines, with eventual transition to large-scale central renewable production.
- Completed preliminary cost estimates for spoke-hub pipeline distribution networks.

Collaboration

- Reliance on updates to ANL's HDSAM model; IHS Market Report; External reviewers
- Leveraging empirical data and SERA analyses conducted for California Energy Commission

Proposed Future Research

- Update investment decision metrics in response to stakeholder feedback (H2USA, others)
- Integrate investment decision metrics with sustainability indicators (HyReS project)
- Account for additional market drivers and growth opportunities (P2G, H2@Scale, LCFS)

Questions?

Contact:
Michael.Penev@nrel.gov

Technical Back-Up Slides

(Include this “divider” slide if you are including back-up technical slides **[maximum of five]**. These back-up technical slides will be available for your presentation and will be included in the USB drive and Web PDF files released to the public.)

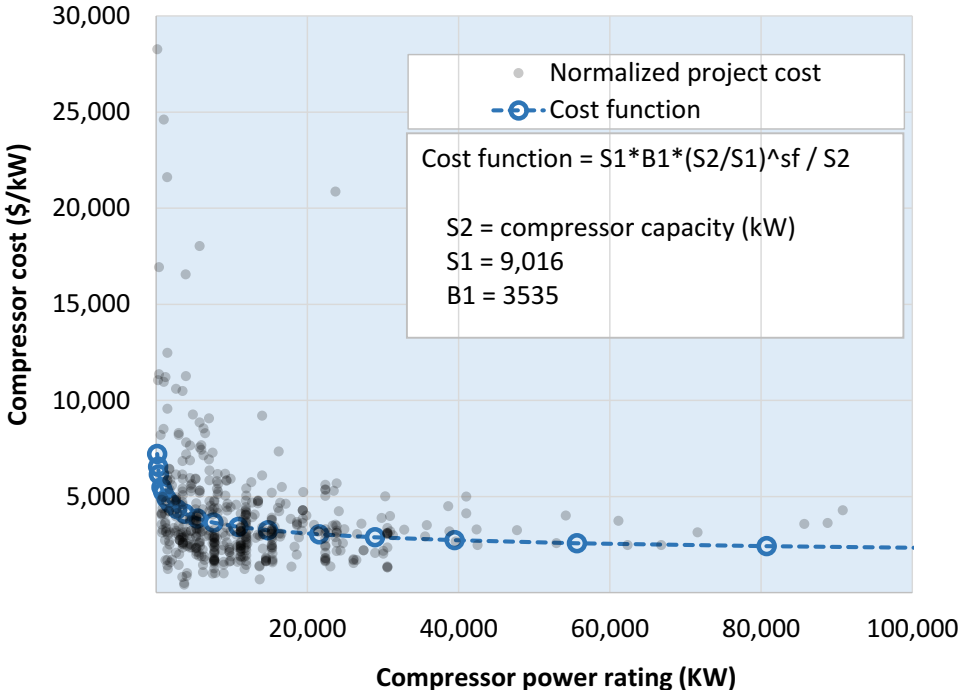
List of Acronyms

CARB	California Air Resources Board
CEC	California Energy Commission
DOE	Department of Energy
FCEV	Fuel Cell Electric Vehicle
FPITT	Fuel Pathway Integration Technical Team
H2A	Hydrogen Analysis (model)
H2FAST	Hydrogen Financial Analysis Scenario Tool (model)
H2USA	Hydrogen USA (public private partnership)
HDSAM	Hydrogen Delivery Scenario Analysis Model
HyReS	Hydrogen Regional Sustainability
IHS	Information Handling System
LCFS	Low Carbon Fuel Standard
SERA	Scenario Evaluation Regionalization Analysis (model)
SMR	Steam Methane Reformer

Semi-Central techno-economics benchmark

Compressor Cost Function:

- Monotonic cost function sought for compressors spanning central and forecourt
  - Allow multiple project size analysis
  - Allow multiple pressure scenario analysis
- Oil & Gas Journal data was used for petroleum industry compressors
  - Complete project cost – fully installed and commissioned



488 compressor projects
2001 through 2016
Reported in Oil & Gas Journal

Compressor cost estimates used from petroleum industry reports