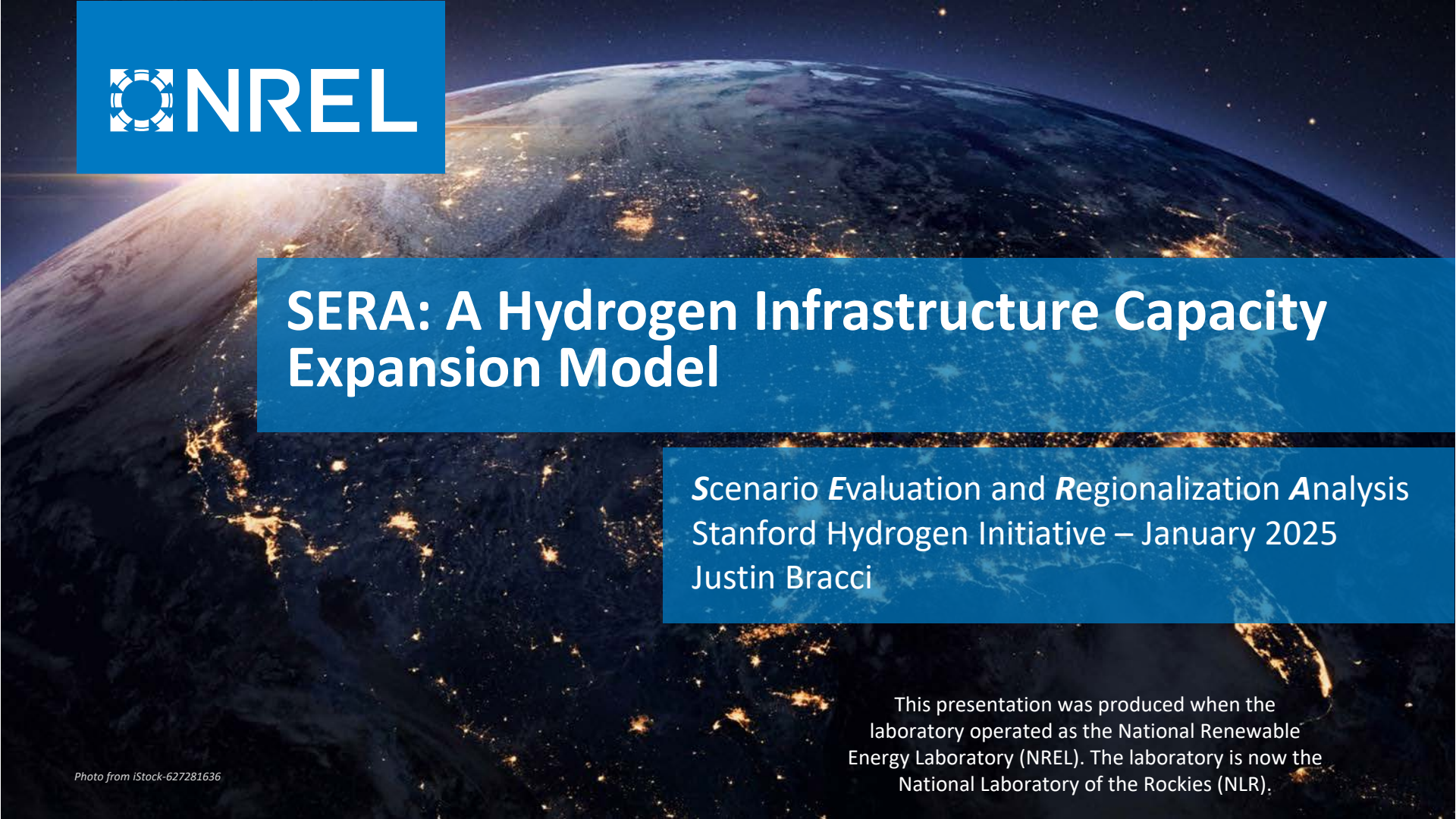


SERA: A Hydrogen Infrastructure Capacity Expansion Model

Scenario ***E***valuation and ***R***egionalization ***A***nalysis

Stanford Hydrogen Initiative – January 2025

Justin Bracci

This presentation was produced when the laboratory operated as the National Renewable Energy Laboratory (NREL). The laboratory is now the National Laboratory of the Rockies (NLR).

Photo from iStock-627281636

What is SERA?

SERA (**S**cenario **E**valuation and **R**egionalization **A**nalysis Model) version 2.0 - Given inputs of demand, feedstock and utility prices, and technology costs (production, storage, transmission, distribution, filling, etc.) SERA will optimize the user-defined network by building out supply chain infrastructure in a least-cost manner temporally and geographically to meet demand and maximize social welfare.

Objective Function:

$$\sum_{y \epsilon Y} \left(\frac{1}{1+r}\right)^{y} (D - I - F - O)$$

where,

Demand Benefit (area under the demand curve): $D = \sum_{n \epsilon N} \left(\sum_{dt \epsilon DT} \sum_{sd \epsilon SD} (DP_{n,y}^{dt,st} d_{n,y}^{dt,st}) \right)$ ***Price of Demand Segment* Quantity of Satisfied Demand***

Investment Costs: $I = \sum_{n \epsilon N} \left(\sum_{pt \epsilon PT} IC^{pt} K_{n,y}^{pt,new} + \sum_{pw \epsilon PW} \sum_{s \epsilon S_{pw}^{unext}} (IC^{s,pw} K_{n,y}^{s,pw,new} + IC^{stor,s,pw} K_{n,y}^{stor,s,pw,new}) \right) + \sum_{l \epsilon L} \sum_{pw \epsilon PW} \sum_{s \epsilon S_{pw}^{ext}} IC^{l,s,pw} K_{l,y}^{s,pw,new}$

Production Technologies ***Pathway Nodal Technologies and Storage*** ***Pathway Links***

Fixed Costs: $F = \sum_{n \epsilon N} \left(\sum_{pt \epsilon PT} FC^{pt} K_{n,y}^{pt} + \sum_{pw \epsilon PW} \sum_{s \epsilon S_{pw}^{unext}} (FC^{s,pw} K_{n,y}^{s,pw} + FC^{stor,s,pw} K_{n,y}^{stor,s,pw}) \right) + \sum_{l \epsilon L} \sum_{pw \epsilon PW} \sum_{s \epsilon S_{pw}^{ext}} FC^{l,s,pw} K_{l,y}^{s,pw}$

Operating Costs: $O = \sum_{n \epsilon N} \sum_{t \epsilon T} \left(\sum_{pt \epsilon PT} OC_{n,y,t}^{pt} p_{n,y,t}^{pt} + \sum_{pw \epsilon PW} \left(\sum_{s \epsilon S_{pw}^{unext}} (OC_{n,y,t}^{s,pw} f_{n,y,t}^{s,pw} + OC_{n,y,t}^{stor_{in},pw} f_{n,y,t}^{stor_{in}s,pw} + OC_{n,y,t}^{stor_{out},pw} f_{n,y,t}^{stor_{out}s,pw}) + \sum_{s \epsilon S_{pw}^{ext}} \sum_{l \epsilon L_n} \left(OC_{l,y,t}^{s,pw} f_{l,n \to n',y,t}^{s,pw} \right) \right) \right)$

The model is piece-wise linear such that the user can minimize cost over specified time segments of, or the entire, time window.

What does SERA 2.0 answer today?

SERA

Where should we build hydrogen infrastructure to support demand and what will it cost?

Production

- Where should production be placed?
- Where does it make sense for centralized production?
- When does electrolysis become cost-competitive with ATR-CCS and where?

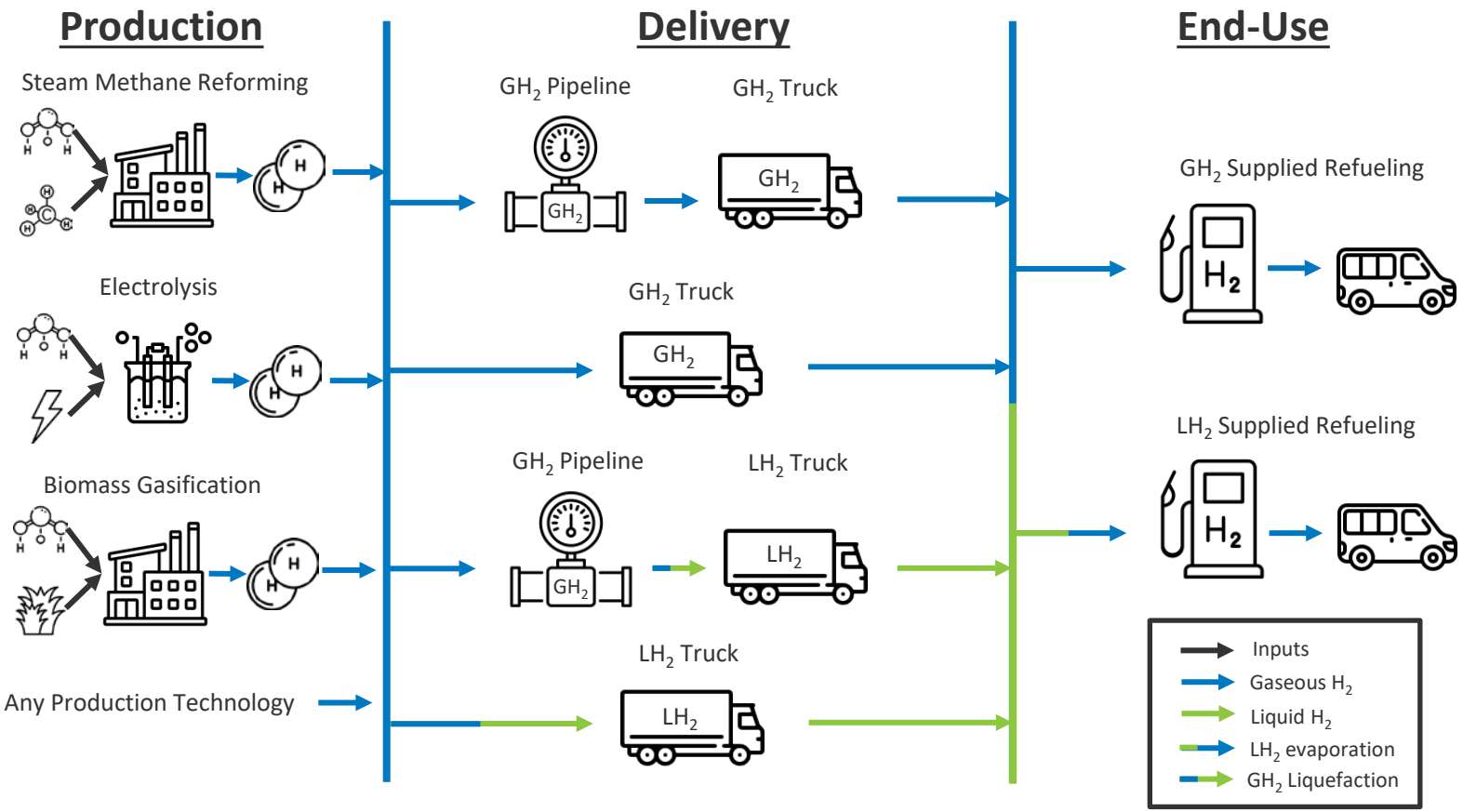
Delivery

- What road network or pipeline ROWs should be utilized to connect supply with demand?
- Is it cheaper to connect supply with demand using trucks or pipelines?
- Which delivery pathway is optimal at different throughput and delivery distances?

End-Use

- What is the cost of infrastructure for different demand types?
- Should end-use applications be supplied with liquid or gaseous hydrogen?
- What is the LCOH dispensed at a refueling station or other end-use facility?

SERA optimizes production, transmission, delivery and dispensing construction technology, timing, and location

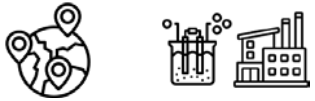


SERA: Data Inputs

Demand

- Hydrogen demand locations as latitude and longitude coordinates
- How demand grows at each location over time (annual or sub-annually)
- Type of demand (NH_3, HRS, electricity generation, etc.)
- Material and energy flows at demand site
- Leverages: Station placement model (HySPASe, HEVI-LOAD) client input, and HDSAM (ANL)

Production



- Candidate production locations as latitude and longitude coordinates
- Existing production facility locations, size, and H_2 cost
- Type of production facilities available (SMR, electrolysis, etc.)
- Material and energy flows at production site
- Leverages: Client input, existing H_2 infrastructure databases (IEA), and H2A(lite)

Delivery

- User-defined road network to connect production to demand (links)
- Type of delivery pathways (GH_2 vs LH_2, truck vs. pipeline)
- Material and energy flows during delivery and preparation for delivery
- Leverages: Client input on acceptable delivery methods, National Highway System, and HDSAM

Cost

- Financial parameters (IRR)
- Material and energy costs and how those vary geographically
- Infrastructure capital and operating costs and how those vary with economies of scale and technology learning
- Leverages: HDSAM, H2FAST, H2A(lite), EIA AEO feedstock costs, GreenHEART, RODeO, client input

SERA: Data Inputs and Outputs

INPUTS

Demand

Location Growth Type

Production

Candidate Locations Type

Delivery

Network Type

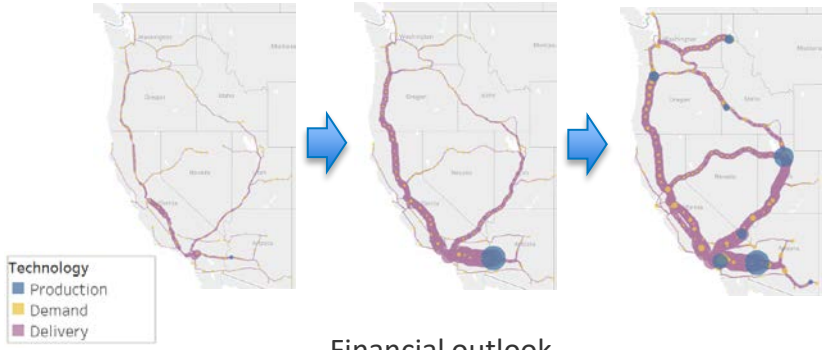
Cost

Capital and Operating

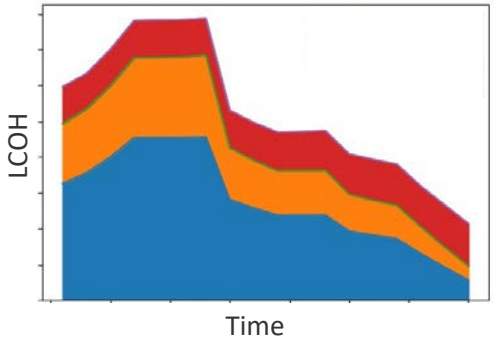
SERA

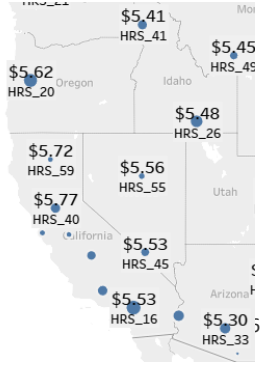
OUTPUTS

Optimized Infrastructure buildout

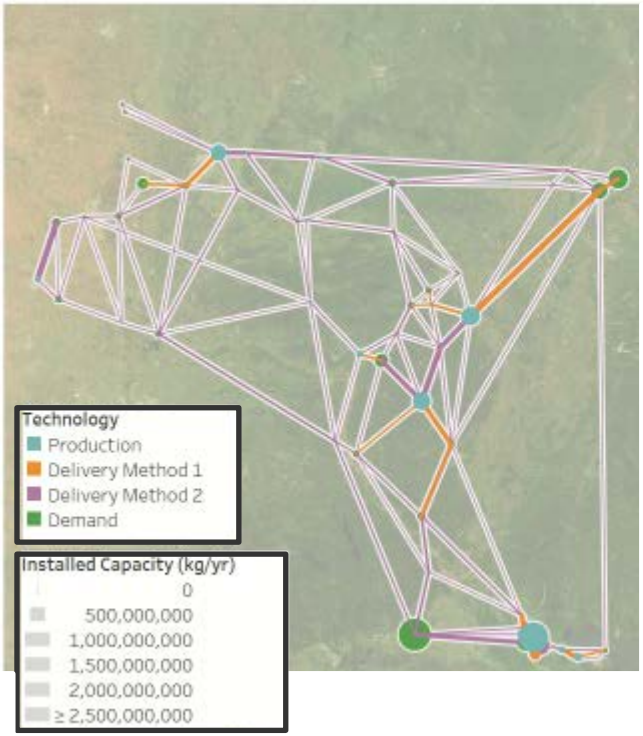


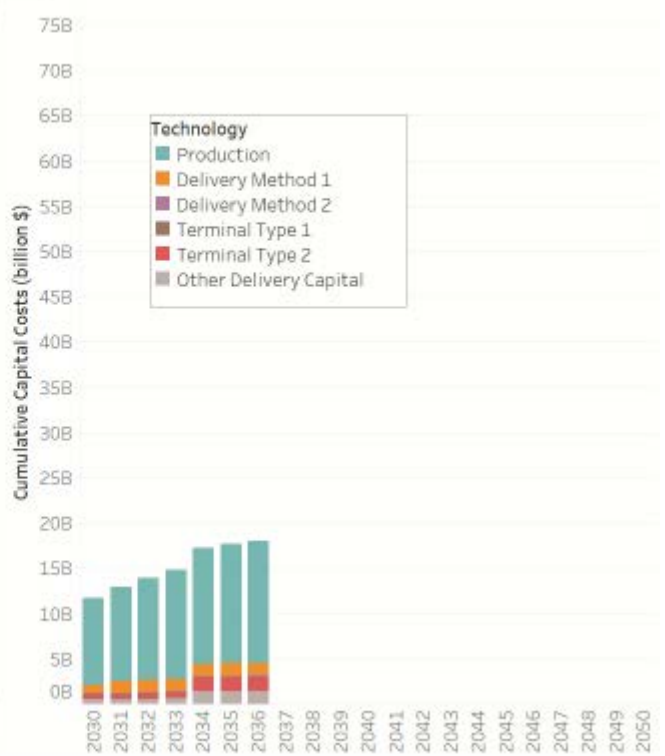
Financial outlook





SERA Sample – Animation of a Regional Network



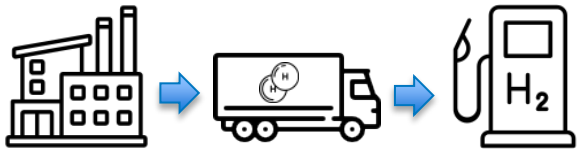


Model Updates

SERA was recently converted to the Julia programming language and upgraded with the following capabilities.

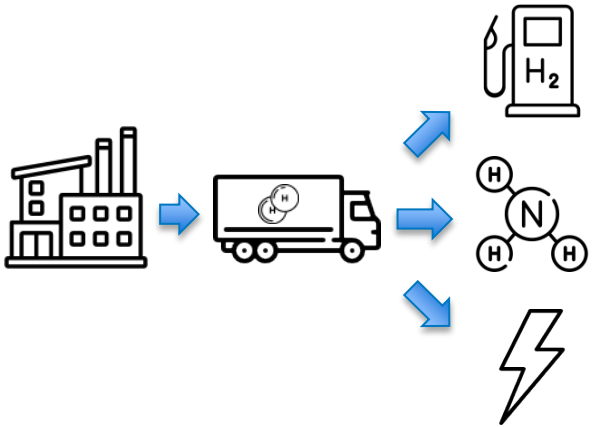
Problem

SERA only able to consider one demand type at a time



Solution

Update SERA so multiple demand types can be considered



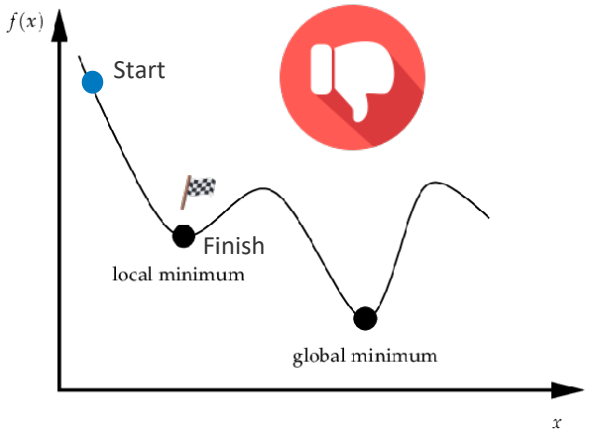
Note: Detailed list of updates in backup slides

Model Updates

SERA was recently converted to the Julia programming language and upgraded with the following capabilities.

Problem

SERA finding local minimum solution



Solution

Updated SERA to include heuristics starting point indicator for improved solving

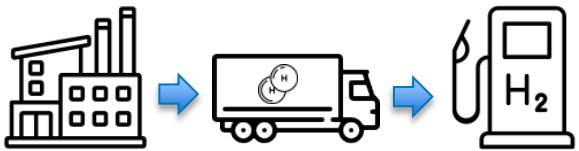
Note: Detailed list of updates in backup slides

Model Updates

SERA was recently converted to the Julia programming language and upgraded with the following capabilities.

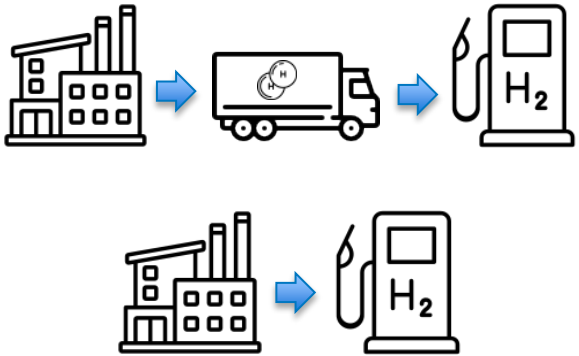
Problem

SERA can only model central production



Solution

Updated SERA to enable both central and onsite hydrogen production



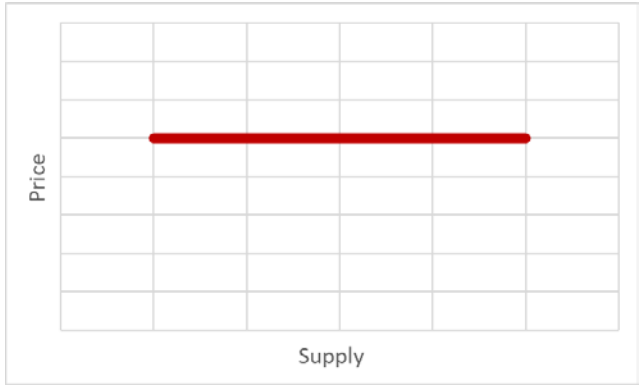
Note: Detailed list of updates in backup slides

Model Updates

SERA was recently converted to the Julia programming language and upgraded with the following capabilities.

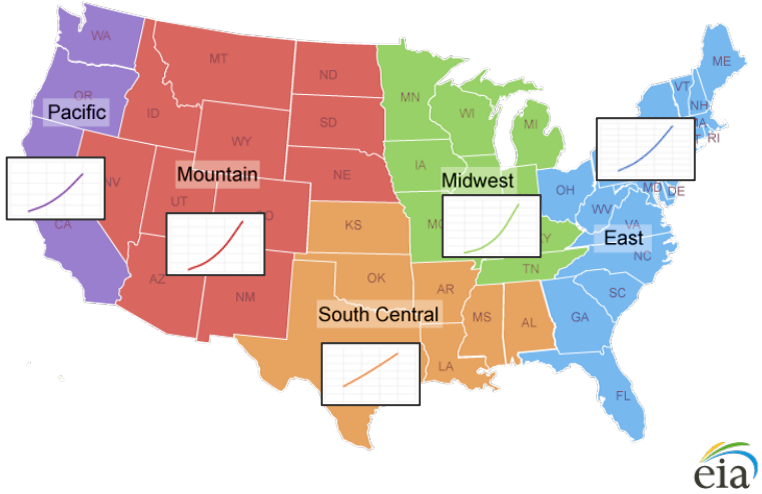
Problem

SERA can build an any amount of supply with no incremental cost



Solution

Implement user-defined supply curves by region



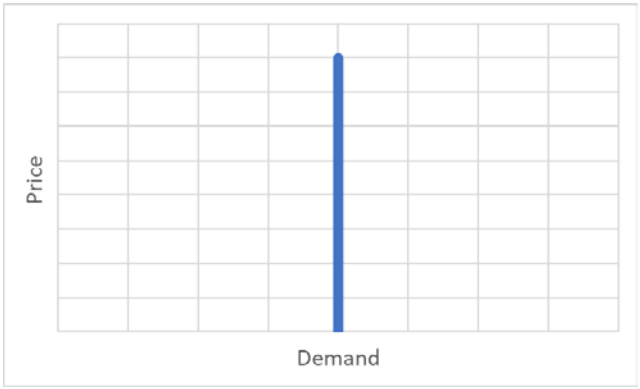
Note: Detailed list of updates in backup slides

Model Updates

SERA was recently converted to the Julia programming language and upgraded with the following capabilities.

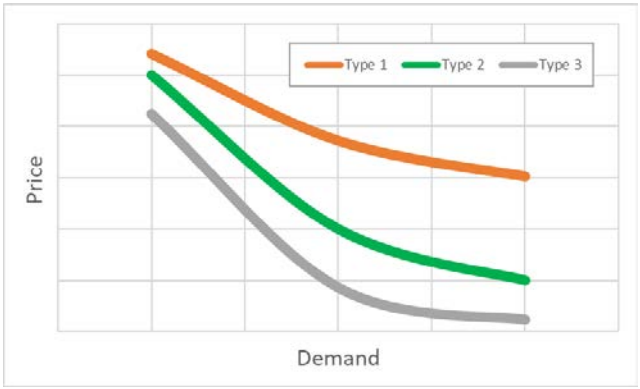
Problem

SERA can fulfill specified amount of demand no matter the price point



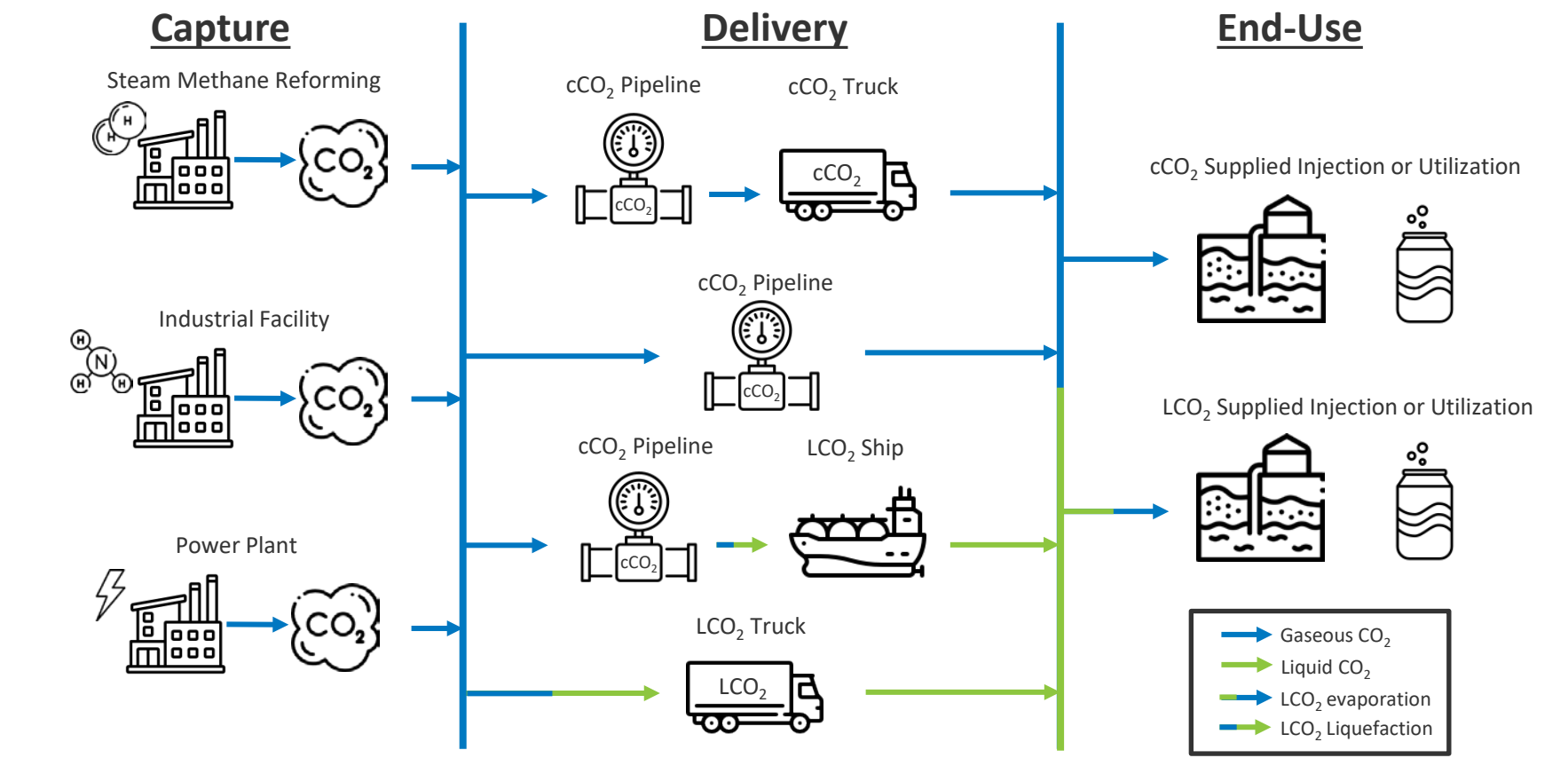
Solution

Implement user-defined demand curves for each demand category



Note: Detailed list of updates in backup slides

SERA can be used for any fuel or material, including CO_2



Note: Detailed list of updates in backup slides

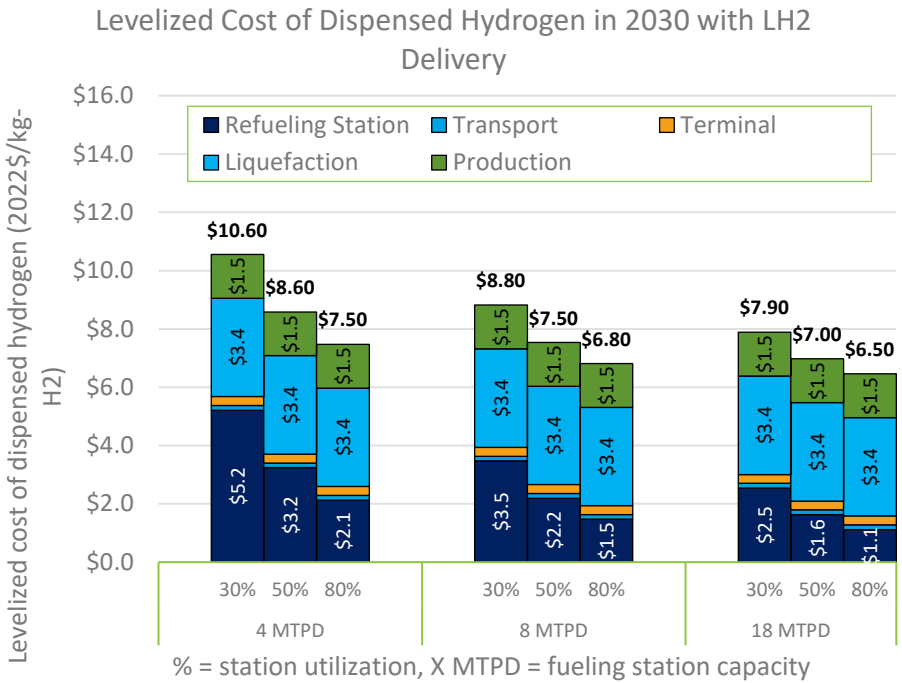
The Importance of SERA and How to Access the Model

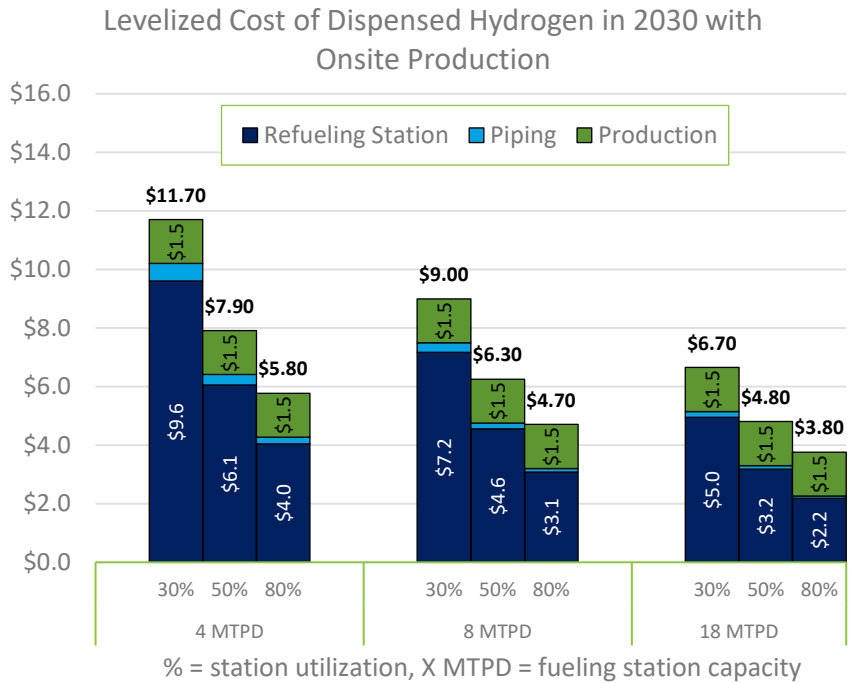
- Only one other tool similar to SERA in the market. HOWDI by UT Austin.
- SERA will support Hydrogen Hub Teams in their infrastructure planning.
- Support OCED investment decisions in Hydrogen Hubs.
- Can be integrated with NREL's electricity capacity expansion model, ReEDS
- The model is publicly-available, but closed-source, for all to use as necessary for their applications.

- Stanford University can work with the tool using two approaches:
  1) Sign a license agreement and work with model themselves
  2) Contract directly with NREL using a Technical Services Agreement

Other Work – Levelized Cost of Dispensed Hydrogen

Potential *dispensed LCOH* can vary widely depending on many conditions, including station size and station utilization rate.



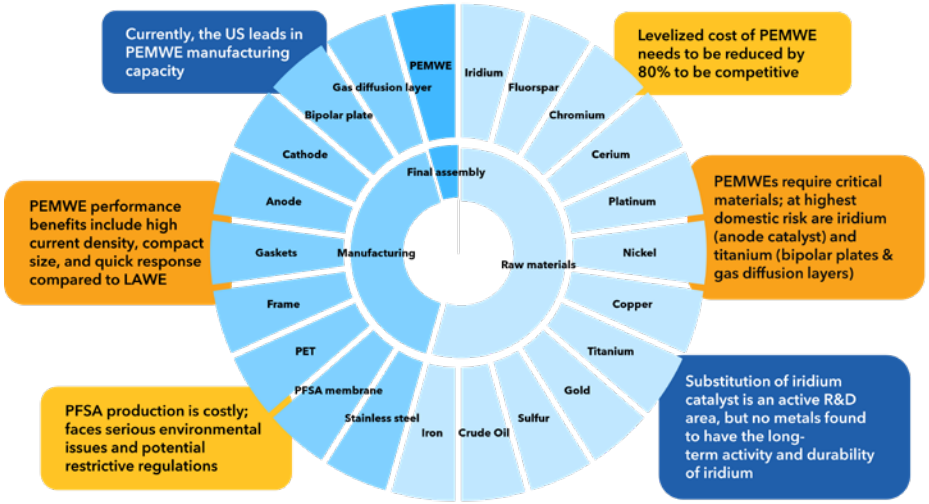


Source: Bracci et. al 2024

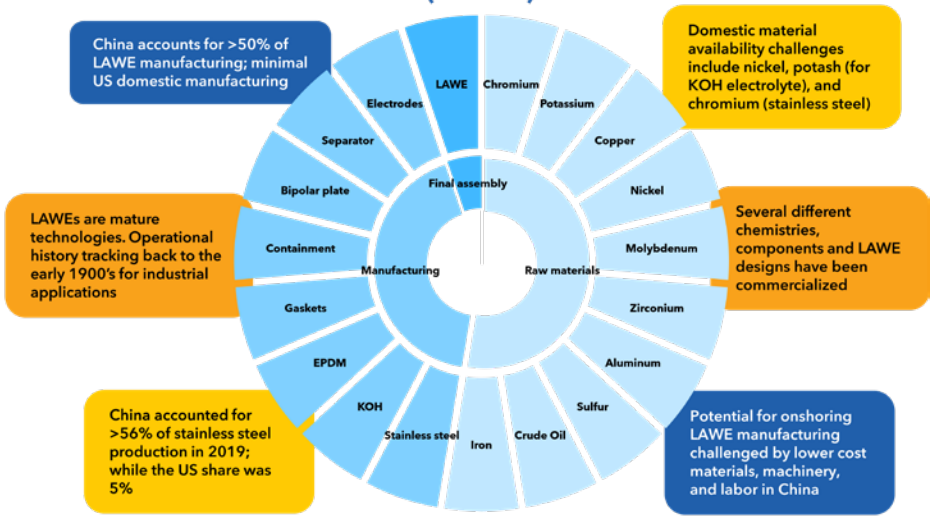
https://www.nrel.gov/docs/fy24osti/88818.pdf

Other Work – Electrolyzer Supply Chain Readiness

Proton Exchange Membrane Water Electrolyzers (PEMWE)



Liquid Alkaline Water Electrolyzers (LAWE)



https://www.nrel.gov/docs/fy24osti/89704.pdf

MESC
OFFICE OF MANUFACTURING AND ENERGY SUPPLY CHAINS

Publications and Current Research

NREL H_2 Systems Analysis Team

Long Duration Energy Storage

Financial analysis

Export potential

Metal hydride storage

Techno-economic analysis

Medium and Heavy-Duty FCEV

Electrolyzer supply chain readiness

Ports

Pipeline simulation

Hybrid and integrated energy systems

Capacity expansion modelling

Hydrogen feasibility studies

Hydrogen sustainability

Infrastructure optimization

Reversible fuel cells

HDV Dispensing

Aviation and Marine

Stationary fuel cells for power generation

Keep up-to-date with our latest publications:
https://www.nrel.gov/hydrogen/systems-analysis.html

Thank You!

NREL/PR-5400-92466

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Backup Slides

Publicly-Available Models and Tools

NREL H_2 Systems Analysis Team

Models	Short Description	Source Code/ Open or Close-sourced	Inputs	Outputs	URL
H2A/ H2FAST/ ProFAST	Financial analysis models	Excel / Python Open	Financial, cost, technical performance parameters	Levelized cost of hydrogen, NPV, IRR, payback period	• https://www.nrel.gov/hydrogen/h2a-production-models.html • https://github.com/NREL/ProFAST
RODeO	Optimizes system design and operation for a hybrid system to maximize revenue	Python, Matlab, GAMS / Open	Energy and demand charges, electrical demand, output demand, tech assumptions, operational and financial parameters	Optimal system configuration and operation on hourly timescale.	https://github.com/NREL/RODeO
SERA	Capacity expansion model	Julia / Closed	Demand, network, electricity and fuel prices, production technologies, delivery pathways, technology costs	Infrastructure deployment, supply-chain component costs and delivered hydrogen price	https://www.nrel.gov/hydrogen/sera-model.html
BlendPATH	Combines pipeline simulation modeling with TEA	Python / Open	Pipeline technical and physical parameters	Levelized cost of transport for pipelines	https://github.com/NREL/BlendPATH

SERA: Scenario Evaluation and Regionalization Analysis Model

The Scenario Evaluation and Regionalization Analysis (SERA) model provides insights that can guide infrastructure development and transportation investment decisions and accelerate the adoption of hydrogen at scale, whether for fuel cell electric vehicles or non-transportation applications.

The SERA model can evaluate both the supply and demand sides of the hydrogen market. The SERA model has been used to:

https://www.nrel.gov/hydrogen/sera-model.html

NREL Model Fast-Tracks Hydrogen Supply Chain Infrastructure Deployment

July 22, 2024 | By Natasha Headland | Contact media relations

Share

The use of clean hydrogen and fuel cells for transportation applications—particularly for medium- and heavy-duty vehicles—is a key part of a portfolio of solutions to decarbonize U.S. transportation. Realizing the potential of clean hydrogen as a transportation fuel, however, will require successful widespread deployment of hydrogen fueling infrastructure.

Reducing the informational and financial risks associated with infrastructure investment decisions is vital to accelerate the adoption of hydrogen as a transportation fuel. This can be accomplished by helping stakeholders forecast hydrogen demand and minimize the cost of building infrastructure.

The U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) Scenario Evaluation and Regionalization Analysis (SERA) model helps answer the question, "What is the least-cost hydrogen infrastructure deployment strategy over time to support demand?"

https://www.nrel.gov/news/program/2024/nrel-model-fast-tracks-hydrogen-supply-chain-infrastructure-deployment.html

Publications

These publications describe the SERA modeling framework.

Scenario Evaluation and Regionalization Analysis (SERA) Model: Demand Side and Refueling Infrastructure Buildout, NREL Technical Report (2019)

SERA Scenarios of Early Market Fuel Cell Electric Vehicle Introductions: Modeling Framework, Regional Markets, and Station Clustering, NREL Technical Report (2013)

These publications provide examples of how SERA has been used to explore hydrogen infrastructure deployment scenarios.

California Hydrogen Analysis Project: The Future Role of Hydrogen in a Carbon-Neutral California, University of California, Davis Institute of Transportation Studies Report (2023)

Modeling future hydrogen supply chains in the western United States under uncertainties: an optimization-based approach focusing on California as a hydrogen hub, *Sustainable Energy & Fuels* (2023)

Modeling Hydrogen Refueling Infrastructure to Support Passenger Vehicles, *Energies* (2018)

National Hydrogen Scenarios: How Many Stations, Where, and When?, Report Prepared by NREL for the H2USA Locations Roadmap Working Group (2017)

SERA Limitations

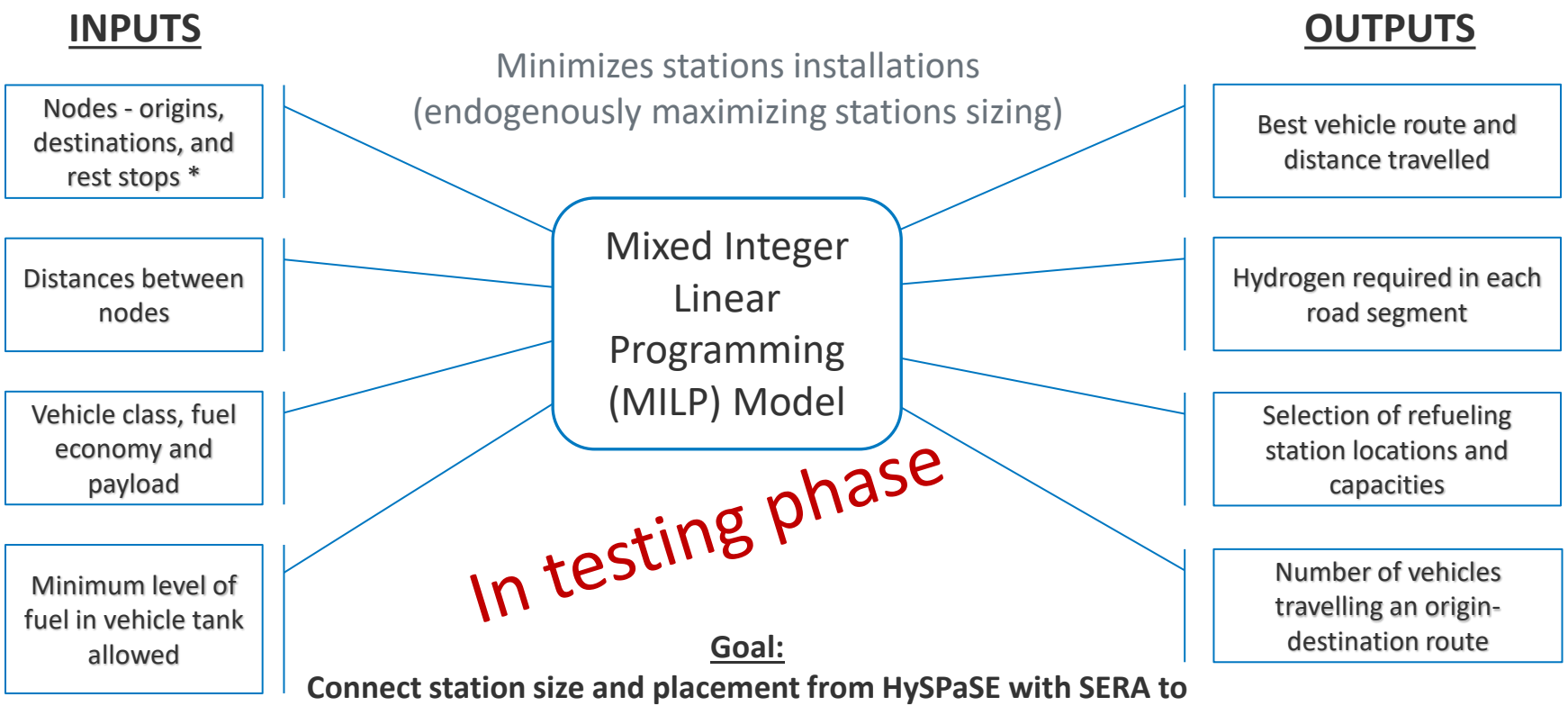
Limitation	Possible solution? Is SERA the answer?
Best suited over longer time horizons (Many years).	Yes. SERA is a capacity expansion modeling tool.
Only minimizes over cost…currently.	Yes. We are adding capabilities to minimize over quantifiable externalities (e.g. emissions).
Does not optimize equipment operation for shorter time periods (days, hours, minutes, seconds).	No. SERA not designed to optimize operations, but SERA soft links with other tools to accommodate more complex technology representations.
Electrolysis-coupled with renewables not currently represented.	This can be incorporated easily to give fine resolution of how renewable electrolysis impacts the cost of delivered hydrogen against other technologies (e.g. gas reforming)

Model Updates

Detailed List of SERA Updates in FY23

No	Problem	Solution
1	SERA could not model policy constraints like clean production and utilization rate requirements.	SERA now includes bespoke constraints which can model various policy related requirements.
2	SERA was not connected to grid models.	Added soft-linkages to grid expansion models for updating electricity price inputs and representing grid production and storage constraints within SERA.
3	SERA had a simplistic intra-year storage representation without linepacking.	SERA now models both inter-year and intra-year storage evolution in addition to including linepacking in hydrogen pipelines as a potential storage resource.
4	Could not model different types of demand (e.g., refueling station, industrial demands, etc.) in the same SERA run.	SERA has been updated to accommodate these type of SERA runs ensuring that only eligible pathways can be used to satisfy different types of demand.
5	The solver may not have been finding global optimal solution.	Introduced a starting point indicator heuristic to the scenario.yaml file to tell SERA which production/delivery component costs to use in initial iteration to search the entire solution space and warm start from identified optimum.
6	SERA included additional unnecessary component costs when co-located production and demand	Pathways without transportation stage for onsite production units are now allowed in SERA.
7	SERA assumed infinite amount of supply for technologies	Added user-defined supply curves for production technologies. User defines the maximum capacity of production infrastructure build-out possible in a region before feedstocks prices rise.
8	SERA assumed inelastic demand for hydrogen regardless of willingness to pay.	By adding user-defined demand curves, SERA is now able to realistically represent optimized supply and demand balance, and report resulting marginal prices.

Hydrogen Stations Placement and Sizing Model (HySPaSE)



* Freight origins and destinations from DOT FAF5 database