CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

Hydrogen in the Transport Sector and Infrastructure Planning

Hydrogen and Analytical Tools Webinar Series

May 1, 2024

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Webinar & Speaker Introductions

Agenda

- Overview of the Clean Energy Solutions Center
- The capacity for hydrogen to decarbonize the transport sector and ownership costs of different propulsion technologies for medium and heavy-duty vehicles
- Q&A
- Overview of the Scenario Evaluation and Regionalization Analysis (SERA) model
- Q&A

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Overview of the Clean Energy Solutions Center

Presented by Jal Desai, National Renewable Energy Laboratory

May 1, 2024

The Clean Energy Solutions Center

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

OBJECTIVE

To accelerate the transition of clean energy markets and technologies.

RATIONALE

Many developing governments lack capacity to design and adopt policies and programs that support the deployment of clean energy technologies.

AMBITION/TARGET

Support governments in developing nations of the world in strengthening clean energy policies and finance measures

ACTORS

Leads:

Operating Agent:

NREL
Transforming ENERGY

Partners:

More than 40 partners, including UN-Energy, IRENA, IEA, IPEEC, REEEP, REN21, SE4All, IADB, ADB, AfDB, and other workstreams etc.

ACTIONS

- **Deliver** dynamic services that enable *expert assistance*, *learning, and peer-to-peer sharing of experiences. Services are offered at no-cost to users.*
- **Foster** dialogue on emerging policy issues and innovation across the globe.
- **Serve** as a first-stop clearinghouse of clean energy policy resources, including policy best practices, data, and analysis tools.

UPDATES

Website:
www.cleanenergyministerial.org/initiatives-campaigns/clean-energy-solutions-center

Factsheet:
www.nrel.gov/docs/fy22osti/83658.pdf

Requests: Now accepting Ask an Expert requests!

The Clean Energy Solutions Center

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CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

Ask an Expert Service

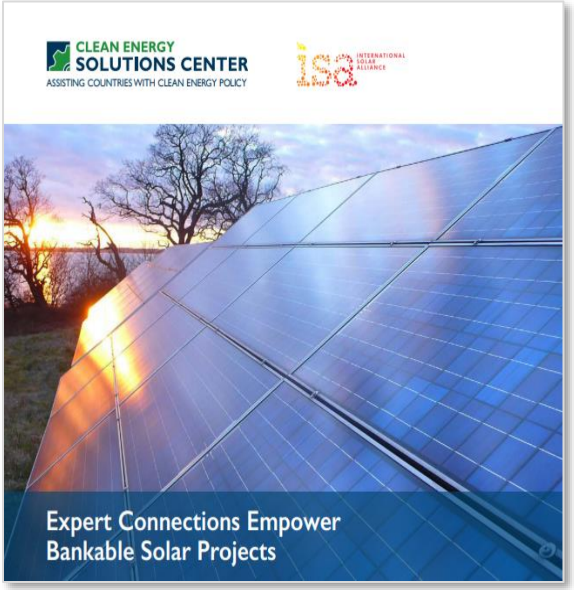
- Ask an Expert is designed to help policymakers in developing countries and emerging economies identify and implement ***clean energy policy*** and finance solutions.
- The Ask an Expert service features a network of more than **50** experts from over **15** countries.
- Responded to **300+** requests submitted by **90+** governments and regional organizations from developing nations since inception

Training and Capacity Building

- Delivered over **300** webinars training more than **20,000** public & private sector stakeholders.

Resource Library

- Over **1,500** curated reports, policy briefs, journal articles, etc.



For additional information and questions, reach out to Jal Desai, NREL, jal.desai@nrel.gov

Webinar Speakers

Daniella Rough

International Program Manager

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Alicia Birky

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Hydrogen Systems Analyst

National Renewable Energy Laboratory

Justin Bracci

Hydrogen Systems Infrastructure Analyst

National Renewable Energy Laboratory

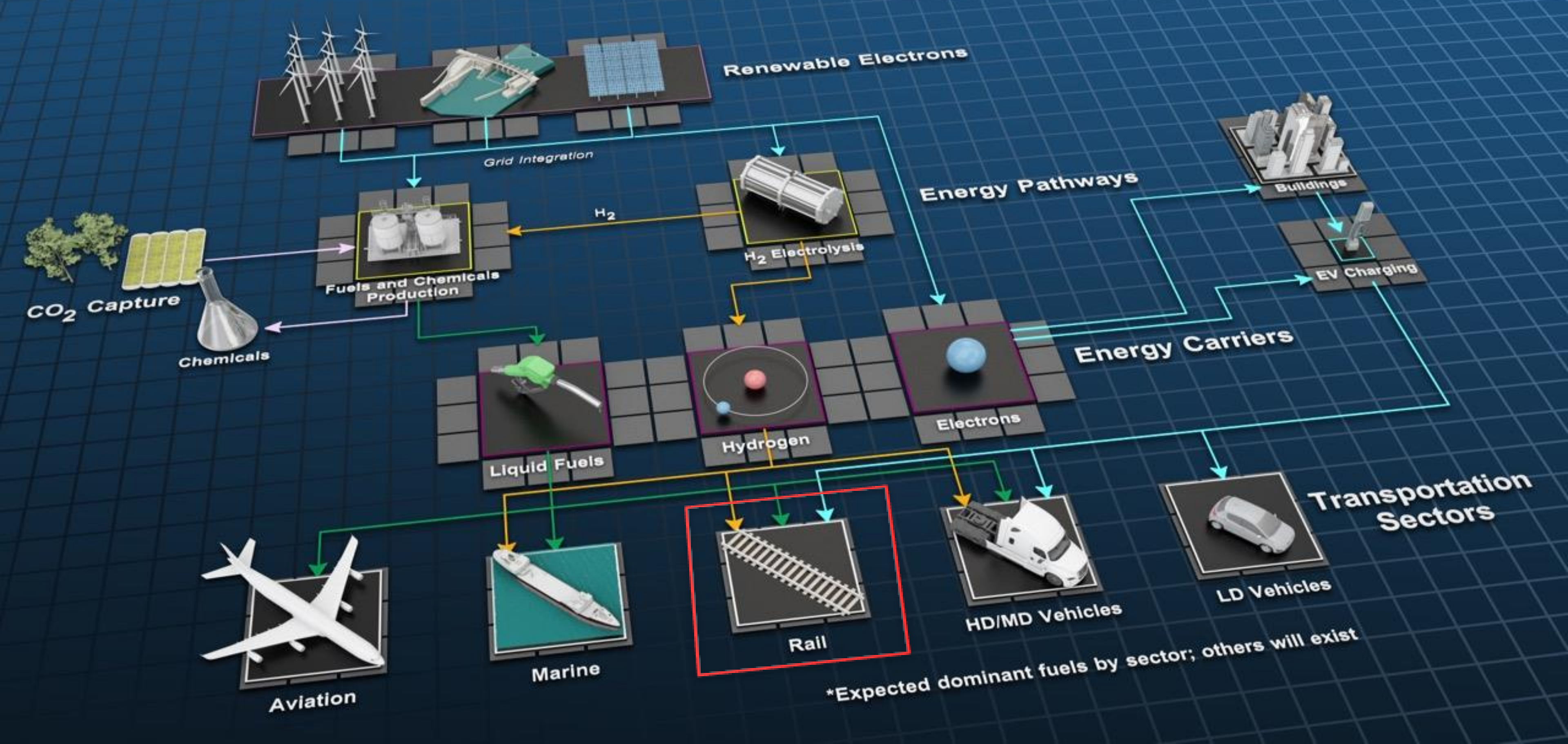
Transportation decarbonization analysis research at NREL

Evan Reznicek, Alicia Birky, and Justin Bracci

May 1, 2024

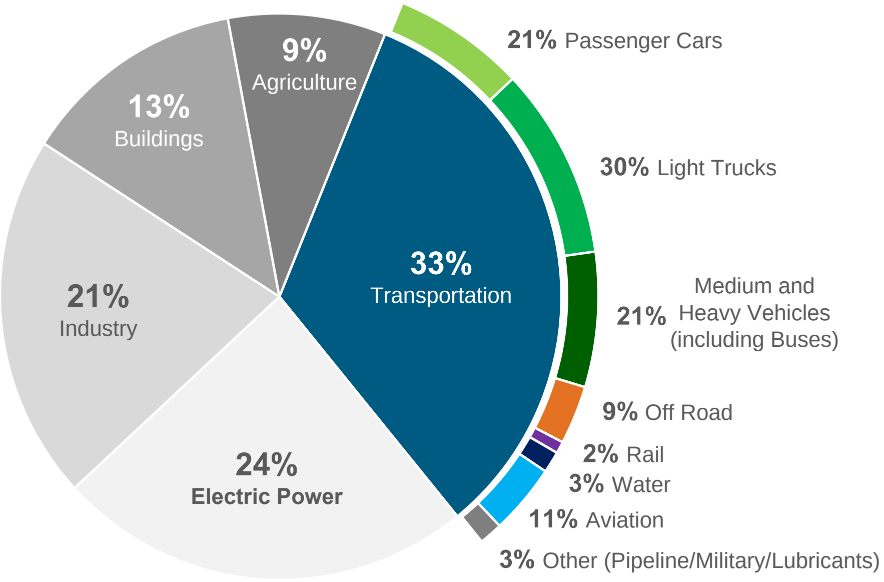
NREL's Vision for Decarbonizing the Transportation Sector

Illustration by Josh Bauer, NREL



Transportation is the Largest Source of U.S. Greenhouse Gas (GHG) Emissions

2019 U.S. GHG Emissions



Source: US National Blueprint for Transportation Decarbonization

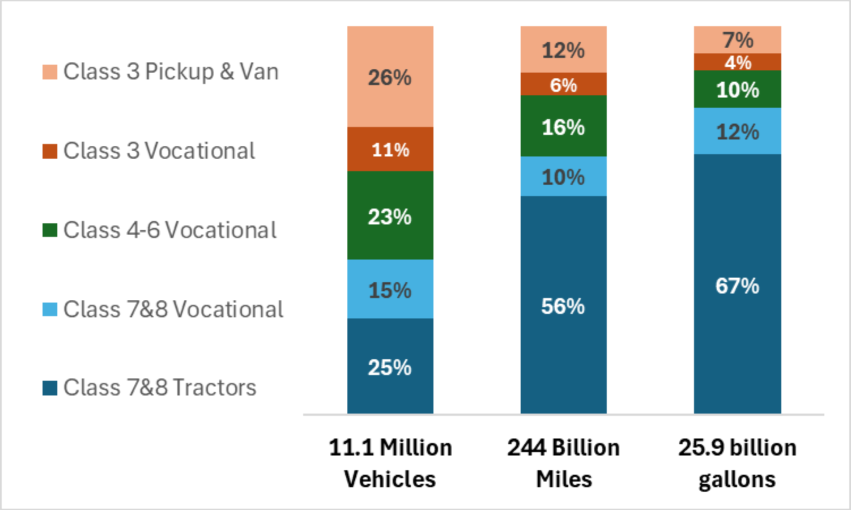
Source: Ledna et al., iScience 27, 109385 (2024). https://doi.org/10.1016/j.isci.2024.109385

- Responsible for **criteria pollutants** that contribute to poor air quality and disproportionally impact disadvantaged communities
- Main driver of **global petroleum demand**

To address climate change, the US has established a goal to **eliminate nearly all transport emissions by 2050**.

Medium and Heavy-Duty Vehicles are the second-largest piece, at 21% of total transportation emissions

M/HDV Market Overview



Source: 2021 Vehicle Inventory and Use Survey

- The U.S. M/HDV market includes 11M vehicles and consumers nearly 26 billion gallons of petroleum fuel, primarily diesel per year
- Vehicle use (VMT) and fuel economy vary greatly across classes and applications
    - HDVs (Classes 7-8) are 40% of vehicles but account for 78% of energy and emissions
    - Tractors are 25% of vehicles and 67% of energy and emissions

DOE-funded NREL hydrogen transportation projects

- H2@Scale Program CRADA: California Hydrogen Infrastructure Research Consortium
  - Data collection from operational stations, component failure fix verifications, and new fueling methods for M/HDV applications
- Heavy-Duty Hydrogen Fueling Station Corridors
  - Assess ranges of levelized cost of dispensed hydrogen to meet H_2 fueling demand for HDV sector to support development of H_2 fueling corridors in the U.S.
- Assessment of Heavy-Duty Fueling Methods and Components
  - Provide industry stakeholders with key supporting info for selecting and implementing HD fueling protocols
  - Assess new HD fueling components using partner protocol strategies at NREL's HD fueling station
- Hydrogen Component Reliability Database (HyCReD)
  - Platform to develop a common database for hydrogen component failures and failure rates

DOE Super Truck 3 FCEV Projects

- PACCAR: ~$33M to develop 18 **Class 8** battery-electric and fuel cell vehicles with advanced batteries, and a megawatt charging station.
- Daimler Trucks North America: ~$26M to develop and demonstrate two **Class 8** fuel cell trucks with **600-mile** range and 25,000-hour durability, and **equivalent payload capacity** to diesel.
- Ford Motor Company: ~$25M to develop and demonstrate five hydrogen fuel cell electric **Class 6 Super Duty** trucks, while targeting cost, payload, towing, and **refueling times** equivalent to conventional gasoline trucks.

NREL is supporting the Ford ST3 project with operational data analysis, total cost of ownership (TCO) and emissions analysis, and market assessment

- General Motors: ~$26M to develop and demonstrate four hydrogen fuel cell and four battery-electric **Class 4-6 trucks**, while also focusing on the development of clean hydrogen via electrolysis and clean power for fast charging.

NREL Transportation Technology and Market Assessment Tools

T3CO

T3CO: The Transportation Technology Total Cost of Ownership tool enables levelized assessments of the full life cycle costs of advanced technology commercial vehicles. T3CO is fully integrated with NREL's vehicle simulation tool, FASTSim, to enable vehicle optimization and TCO estimation over different duty cycles.

TITAN

TITAN: The Truck Integrated Technoeconomic Analysis tool couples T3CO with market cost-based adoption and stock turnover models.

ADOPT

HD ADOPT: The HD version of NREL's Automotive Deployment Options Projection Tool is an integrated technology evolution, market adoption, and stock modeling tool. This version was recently modified to simultaneously analyze multiple on-board H_2 storage technologies and includes H_2 combustion.

TEMPO

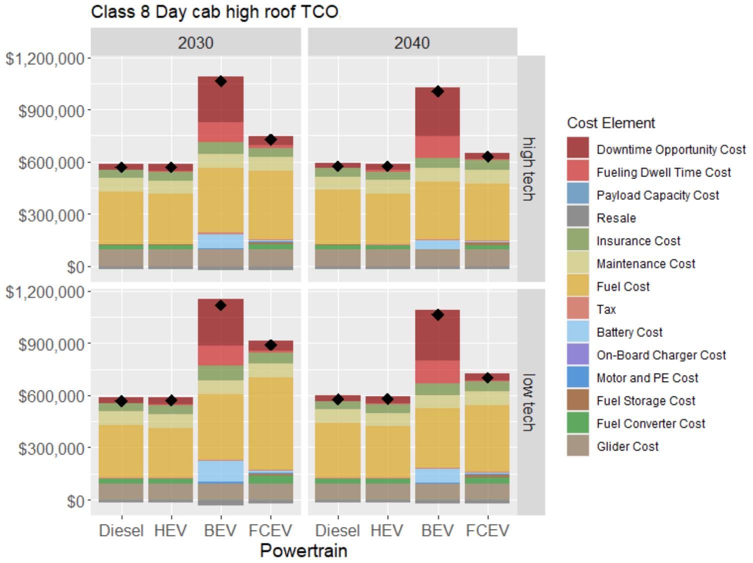
TEMPO: NREL's Transportation Energy & Mobility Pathway Options Model is an all-inclusive transportation demand model that covers the entire United States.

ALTRIOS

ALTRIOS: NREL's Advanced Locomotive Technology and Rail Infrastructure Optimization System is the first fully integrated, open-source software to simulate and optimize the rollout of cost-effective locomotive technologies for decarbonization.

Total Cost of Ownership is a Primary Metric for Technology Adoption

- Commercial vehicles are tools, and adoption of new technology is driven by functionality, reliability, and cost
- Medium- and heavy-duty commercial vehicles operate in diverse vocations with varied performance and economic requirements
- Total cost of ownership is a critical metric for mass adoption of advanced commercial vehicles
  - Energy is the second largest cost after labor
  - Downtime for charging and payload capacity loss are real costs

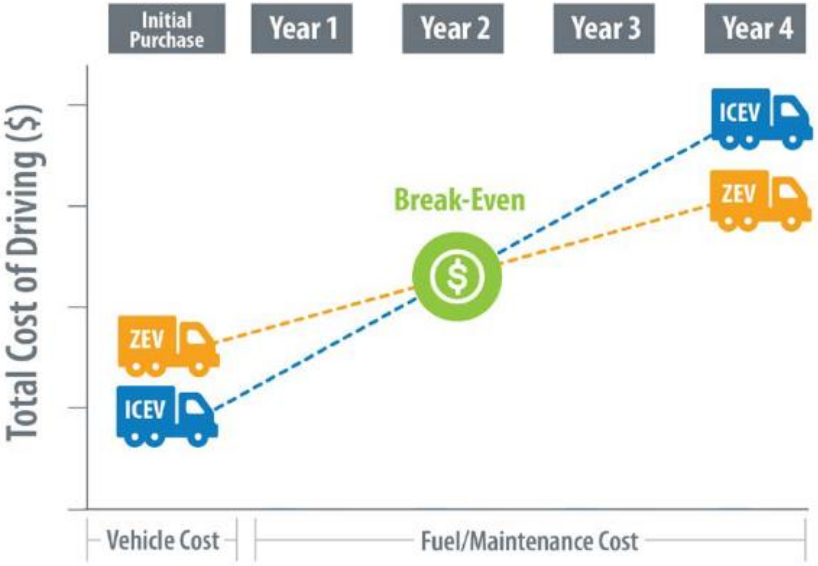


Example TCO for a day cab tractor in regional freight delivery; BEV and FCEV with 300-mile range. https://www.nrel.gov/transportation/t3co.html

TEMPO and TITAN assess vehicle adoption based on break-even/payback period preference

- M/HDV fleets make decisions based on economics, considering both upfront and recurring costs
- The **total cost of driving (TCD)*** can be used to compare costs of different M/HDV technologies over relevant decision-making time horizons
- These metrics typically include:
  - Upfront vehicle purchase cost
  - Discounted fuel & maintenance costs
  - Policies (tax credits, incentives)
- When considering ZEVs, studies may also consider:
  - Opportunity cost of charging time (for EVs)
  - Payload limitations

Other metrics may include driver wages & insurance, tolls, taxes & fees, & resale value



Illustrative example of TCD for ZEV vs ICEV. ZEVs may have higher upfront costs but lower operational costs, making them competitive with ICEVs over a multi-year time horizon.
Source: Ledna *et al* (2022).

*Total cost of driving considers upfront cost, fuel & maintenance cost, and opportunity cost of EV recharging time

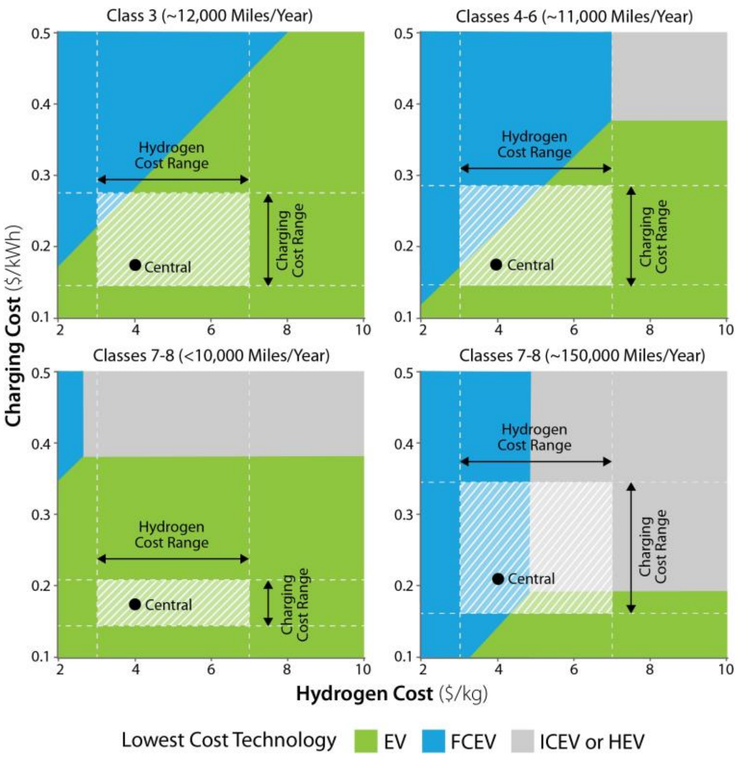
Source: Ledna et al., iScience 27, 109385 (2024). https://doi.org/10.1016/j.isci.2024.109385

TEMPO results: With 12 Million MHDVs on the Road Different Solutions Needed

If DOE vehicle technology and fuel targets are met, **ZEVs can reach total-cost-of-driving parity with diesel by 2035** for all vehicle classes and use cases – depending on relative energy price assumptions

- **EVs** are very competitive for class 3 and class 4-8 with short trips/low VMT
- **FCEVs** can provide solutions for long-haul and challenging applications (H_2 at $4/kg)
- Sustainable fuels can also help: Even if ZEV sales reached 100% in 2035, **5M legacy diesel vehicles would remain on the road in 2050** (~25% of stock).

2035 Projections



Diesel price: $3.74-$4/gal

Source: Ledna et al., iScience 27, 109385 (2024). https://doi.org/10.1016/j.isci.2024.109385

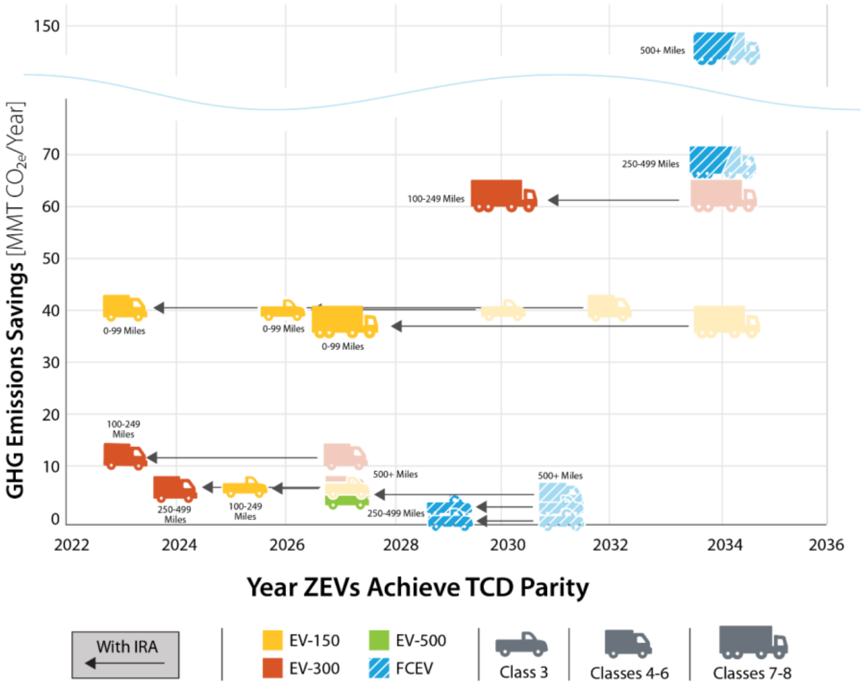
TEMPO results: ZEVs are rapidly becoming cost-competitive

With current incentives, EVs could achieve total-cost-driving[1] parity with diesel this decade

- Class 3-6 EVs and short-haul Class 7-8 EVs with 150-300 miles of range achieve parity before 2028
- Focus on manufacturing and infrastructure scale-up and effective grid integration

FCEVs can provide solutions for long-haul and challenging applications

- Focus on reducing H_2 price below $4-5/kg and demonstrating feasibility (*e.g.*, corridors)



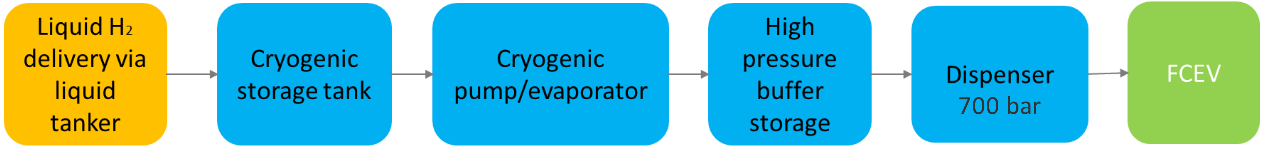
[1]Total cost of driving considers upfront cost, fuel & maintenance cost, and opportunity cost of EV recharging time. Findings are based on Central Assumptions, with IRA.

Source: Ledna et al., iScience 27, 109385 (2024). https://doi.org/10.1016/j.isci.2024.109385

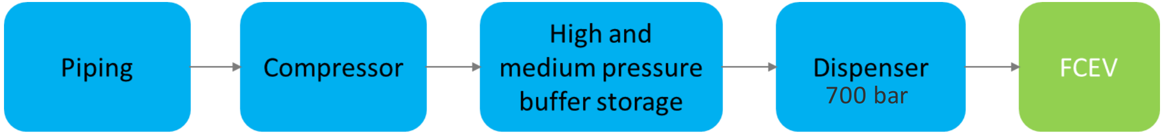
Levelized cost of dispensed hydrogen for heavy-duty vehicles to support H_2 fueling corridors in the U.S.

- Technoeconomic analysis of HD hydrogen fueling stations using HDSAM
- Identify levelized cost contribution of each station component and identify potential areas of improvement
- Considers two types of hydrogen fueling station supply configurations*

(1) Liquid H_2 delivery to hydrogen fueling station



(2) On-site gaseous H_2 produced and piped short distance to fueling station



*Note: Pathways chosen due to higher level of commercial readiness

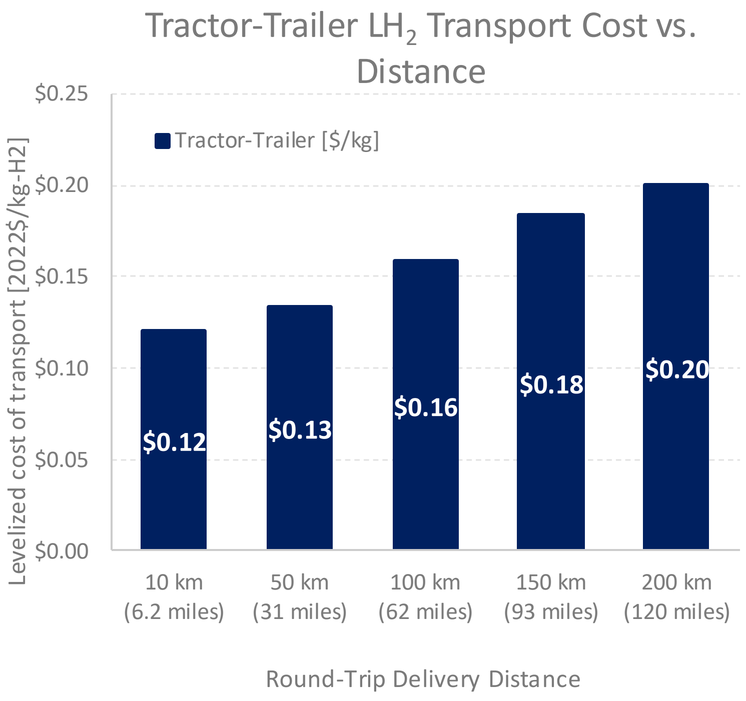
Levelized cost of dispensed hydrogen: key parameters

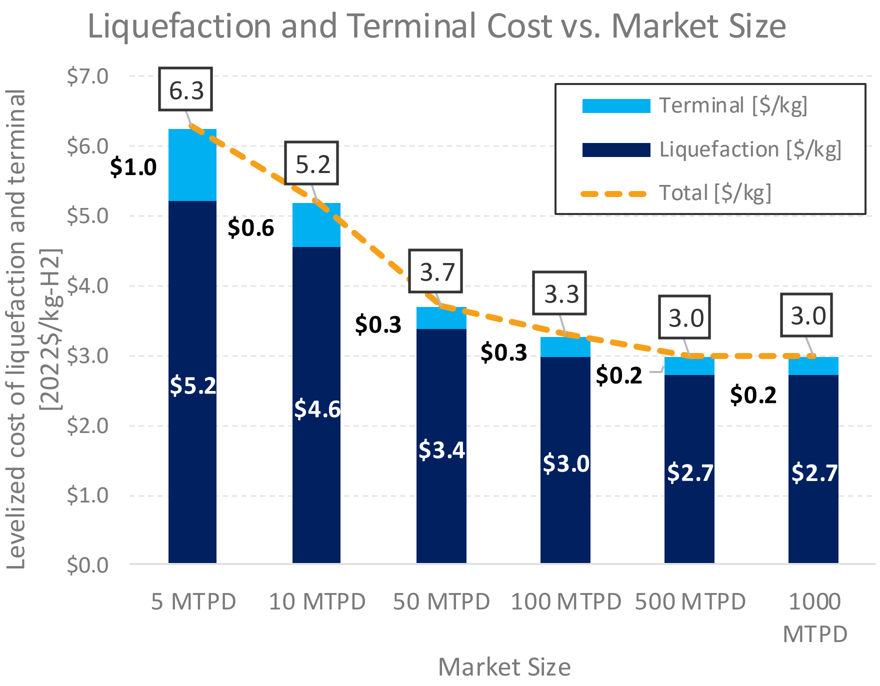
Refueling Parameters	Assumption
Fill rate [kg/min]	5
Dispensed hydrogen per truck [kg]	50
State of charge at refueling [%]	15-25
Hours of operation [hours]	18
Refueling demand profile	Back-to-Back
Vehicle linger time [mins]	5
Fleet size to station size ratio	20 vehicles per MTPD capacity

Delivery Parameters	Assumption
Production cost [USD/kg]	1.5*
Liquefier and terminal size [MTPD]	50
Baseline LH_2 delivery distance [km]	100
On-site production piping length [km]	0.1

*Note: Assumed cost used as a place holder. Based on median production cost for predominant form of production today: https://liftoff.energy.gov/clean-hydrogen/

Liquefaction is a major cost contributor in the LH_2-supplied station pathway





Source: HDSAM v4.5

HRS Costs Breakdown by Component at 4 MTPD, 700-bar dispensing

Components	On-Site GH2 Station	LH2 Station
Compressors and Pumps	8 total compressors Energy: 5.5 kWh/kg CAPEX: $6.96 MM	4 LH_2 pumps Energy: 0.54 kWh/kg CAPEX: $5.18 MM
Storage	401 kg cascade storage 3,100 kg low-pressure storage CAPEX: $8.36 MM	10,720 kg cryogenic tank 241 kg cascade storage CAPEX: $1.91 MM
Dispensers (2)	CAPEX: $0.37 MM	CAPEX: $0.37 MM
Refrigeration and Heat Exchanger	2 condensing/heat exchange units 16 ton capacity each CAPEX: $0.57 MM	2 heat exchangers 1 evaporator CAPEX: $1.14 MM
Electrical, Controls, and Other	BoP and electrical equipment CAPEX: $0.56 MM	BoP and electrical equipment CAPEX: $0.27 MM
Indirect Capital Costs	$3.9 MM	$2.04 MM
Capital Cost (Total, per kg-day)	$20.7 MM $5,170/kg-day	$10.9 MM $2,730/kg-day

Source: HDSAM v4.5

Key Considerations:

- Storage size may vary depending on station requirements, station operating profile, and access to reliable supply and delivery
- Requirement for heat exchangers may also differ per station developer requirements (e.g. pre-cooling needs).
- Safety code and standards must also be met when deciding station location and considering space requirements.

HRS Costs Breakdown by Component at 18 MTPD, 700-bar dispensing

Components	On-Site GH2 Station	LH2 Station
Compressors and Pumps	20 total compressors Energy: 4.1 kWh/kg CAPEX: $17.4 MM	9 LH_2 pumps Energy: 0.54 kWh/kg CAPEX: $11.7 MM
Storage	963 kg cascade storage 5,950 kg low-pressure storage CAPEX: $16.7 MM	10,720 kg cryogenic tank 803 kg cascade storage CAPEX: $3.75 MM
Dispensers (5)	CAPEX: $0.92 MM	CAPEX: $0.92 MM
Refrigeration and Heat Exchanger	5 condensing/heat exchange units 16 ton capacity each Energy: 0.09 kWh/kg CAPEX: $1.32 MM	5 heat exchangers 1 evaporator CAPEX: $2.59 MM
Electrical, Controls, and Other	BoP and electrical equipment CAPEX: $0.58 MM	BoP and electrical equipment CAPEX: $0.56 MM
Indirect Capital Costs	CAPEX: $8.49 MM	CAPEX: $4.48 MM
Capital Cost (Total, per kg-day)	$45.4 MM $2,520/kg-day	$24.0 MM $1,330/kg-day

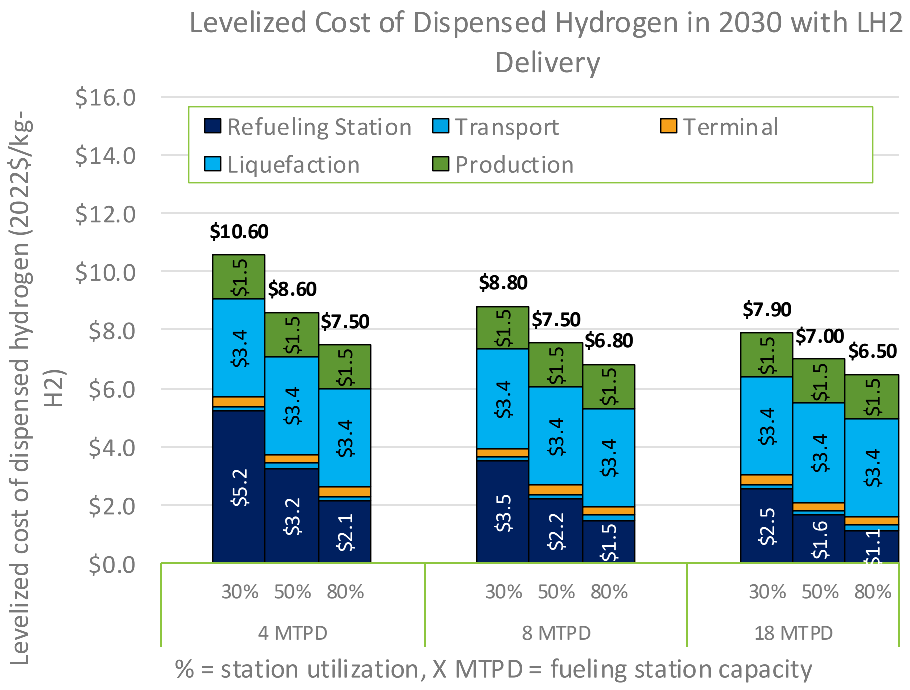
Source: HDSAM v4.5

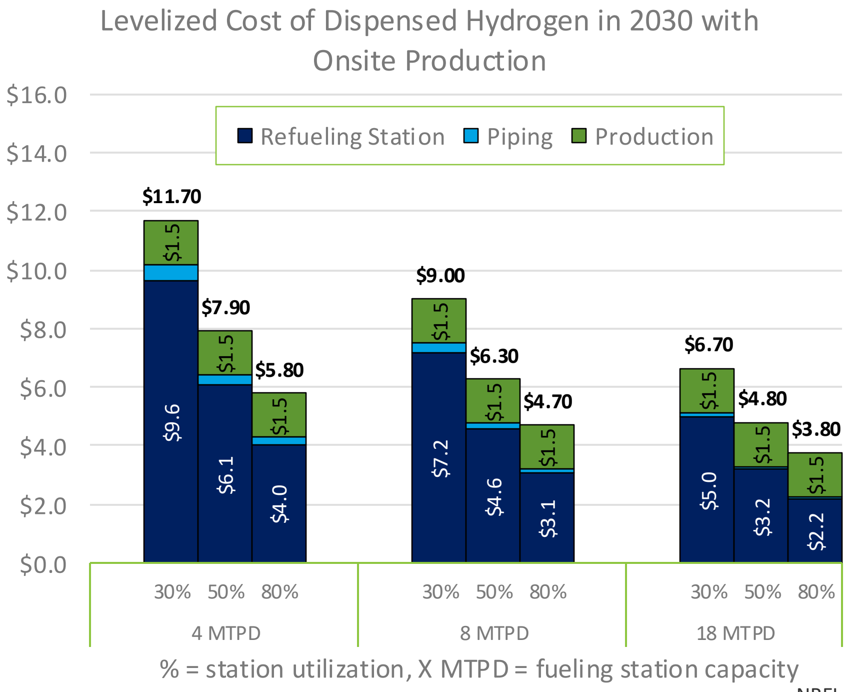
Key Considerations:

- Storage size may vary depending on station requirements and access to reliable supply and delivery.
- Requirement for heat exchangers may also differ per station developer requirements (e.g. pre-cooling needs).
- Long-distance pipeline delivery scenario not modeled here.

Potential *dispensed LCOH* can vary widely depending on many conditions

Conditions include HRS utilization rate and up-time, fill rates, on-site storage, delivery method and distance





Source: Bracci et. al 2024

Note: Prices are not retail. Retail prices may include additional markup and subject to numerous dynamics not accounted for in this analysis.

Summary

- Reducing commercial vehicle carbon emissions is a critical component of achieving climate change goals
- The M/HDV market is highly diverse and cost-effective solutions vary by application
- ZEV adoption in commercial vehicles will be driven by economics
  - Vehicle and energy prices and infrastructure availability are key assumptions in H_2 vehicle market projections
- Hydrogen dispensed costs must be reduced to <$5/kg for significant market penetration
  - This goal might be achievable with adequate technology progression and deployment at scale

Thank You

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NREL Transforming ENERGY

Hydrogen Techno-economic Capabilities - SERA

***S**cenario **E**valuation **R**egionalization **A**nalysis*

CESC Hydrogen Webinar – May 2024

Justin Bracci

Photo from iStock-627281636

Outline

1. SERA Overview
2. SERA Case Study
3. Why is SERA Important
4. SERA Limitations

SERA Overview: What Does SERA do?

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

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:

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

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

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:

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

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?

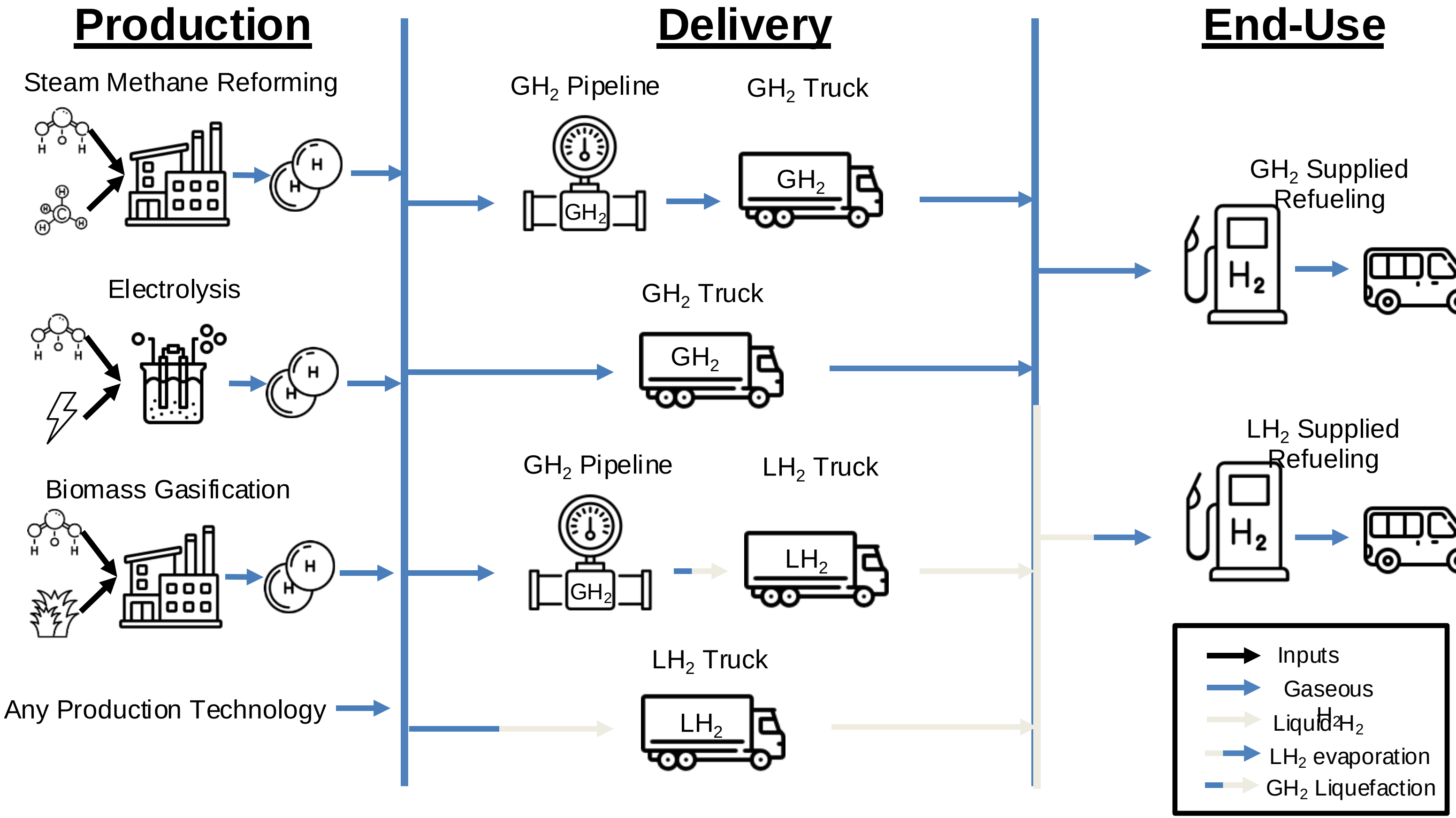
Delivery

- 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: H_2 Supply Chain Infrastructure Optimization

INPUTS

Demand

Location Growth Type

Productio
n

Candidate Locations Type

Delivery

Network Type

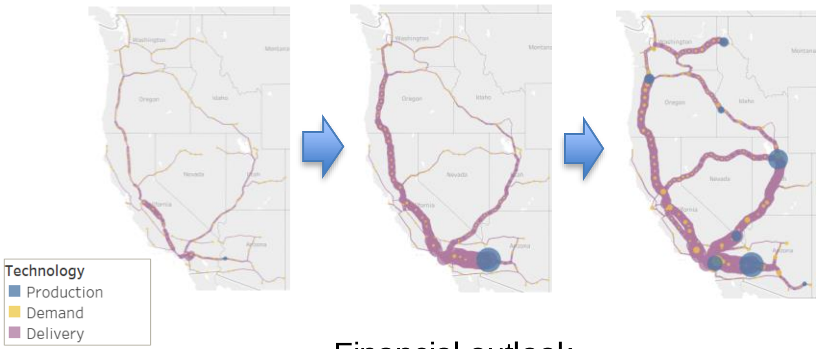
Cost

Capital and Operating

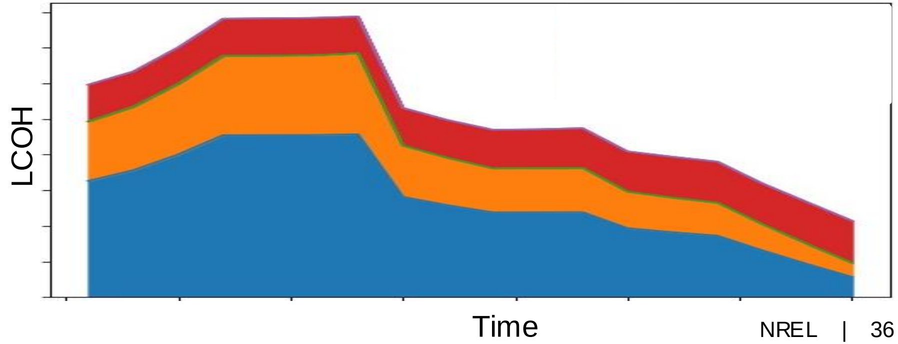
SERA

OUTPUTS

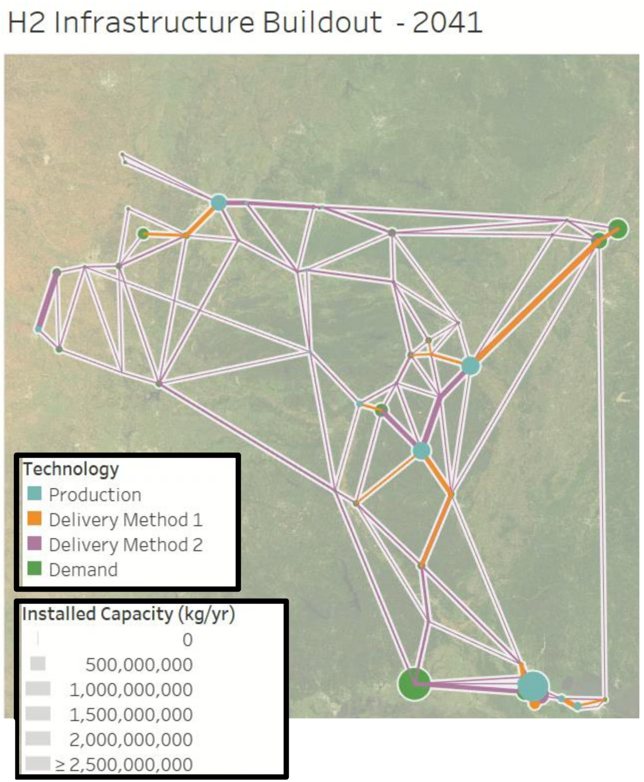
Optimized Infrastructure buildout

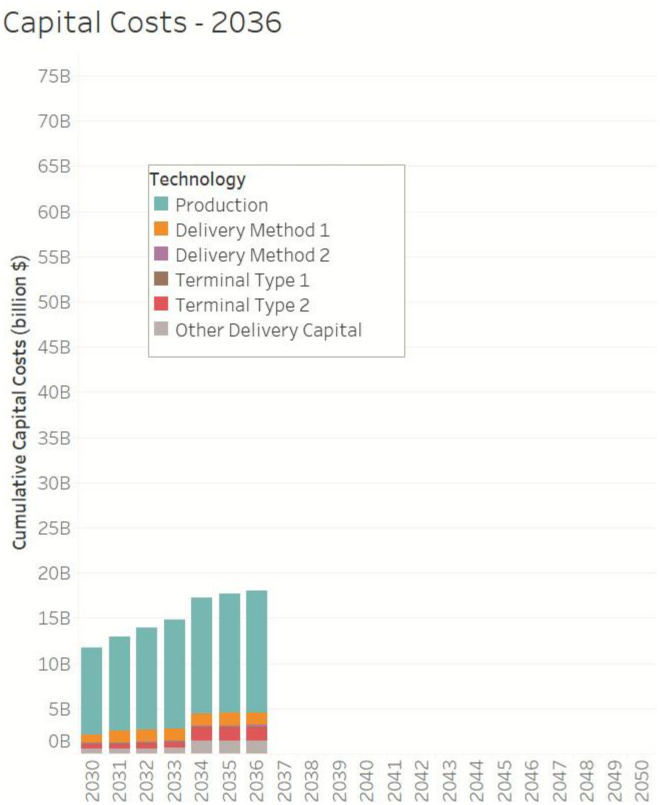


Financial outlook



SERA Sample – Animation of a Regional Network



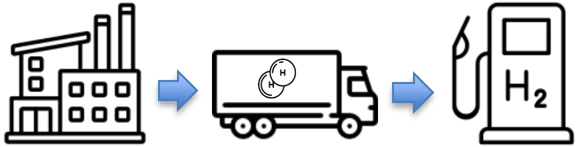


Model Updates

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

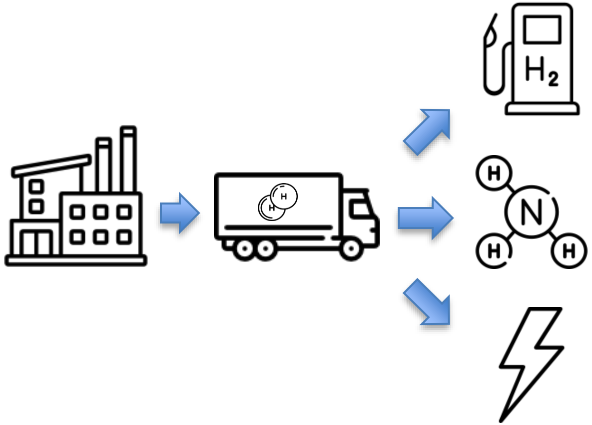
Problem

SERA only able to consider one demand type at a time



Solution

Update SERA so multiple demand types can be considered



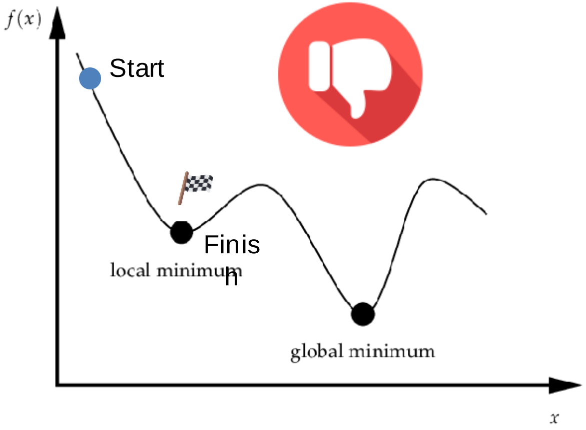
Note: Detailed list of updates in backup slides

Model Updates

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

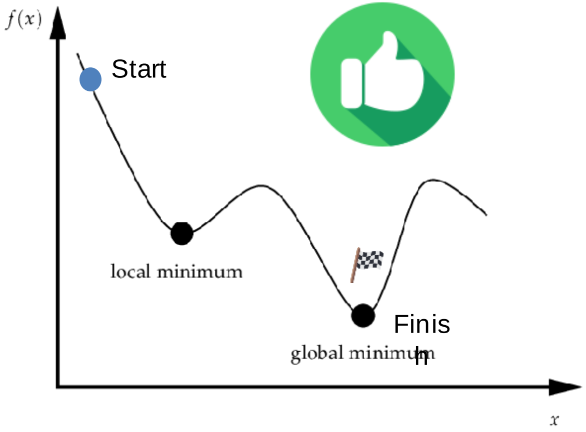
Problem

SERA finding local minimum solution



Solution

Updated SERA to include heuristics starting point indicator for improved solving



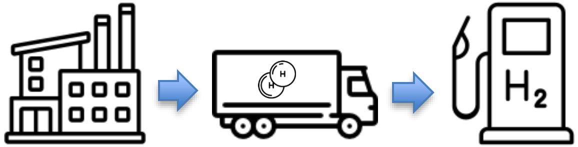
Note: Detailed list of updates in backup slides

Model Updates

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

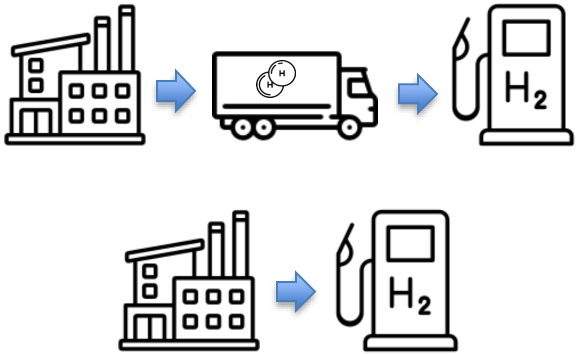
Problem

SERA can only model central production



Solution

Updated SERA to enable both central and onsite hydrogen production



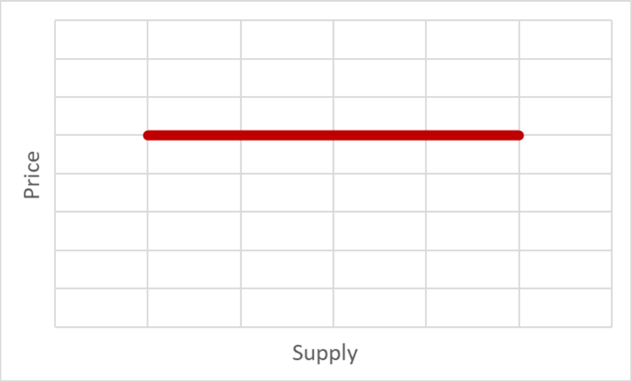
Note: Detailed list of updates in backup slides

Model Updates

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

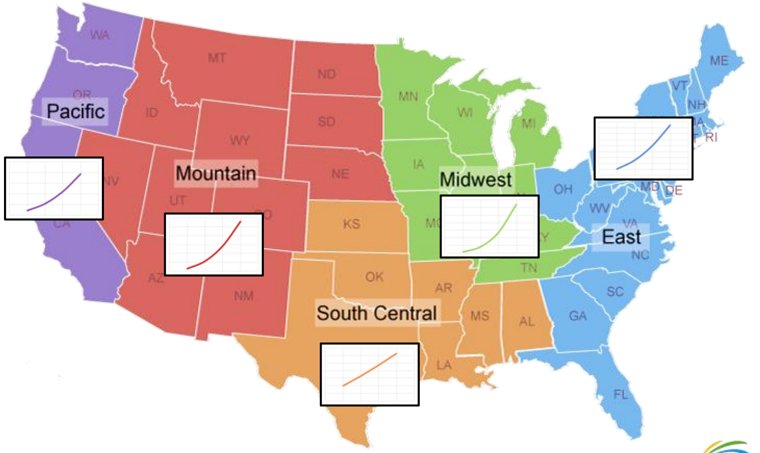
Problem

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



Solution

Implement user-defined supply curves by region



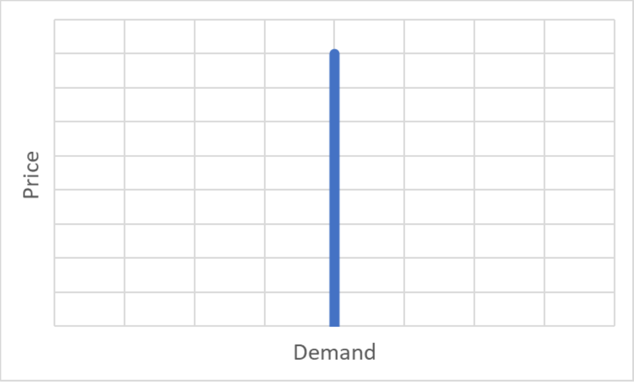
Note: Detailed list of updates in backup slides

Model Updates

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

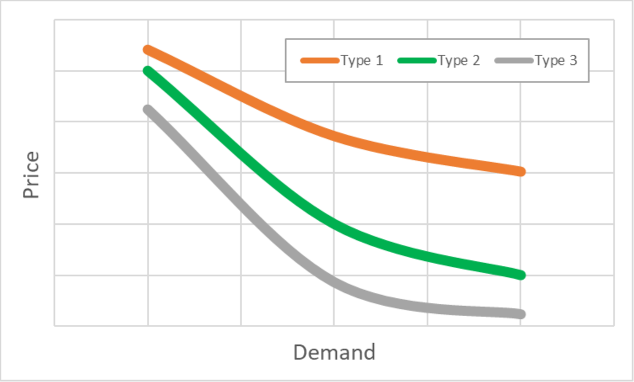
Problem

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



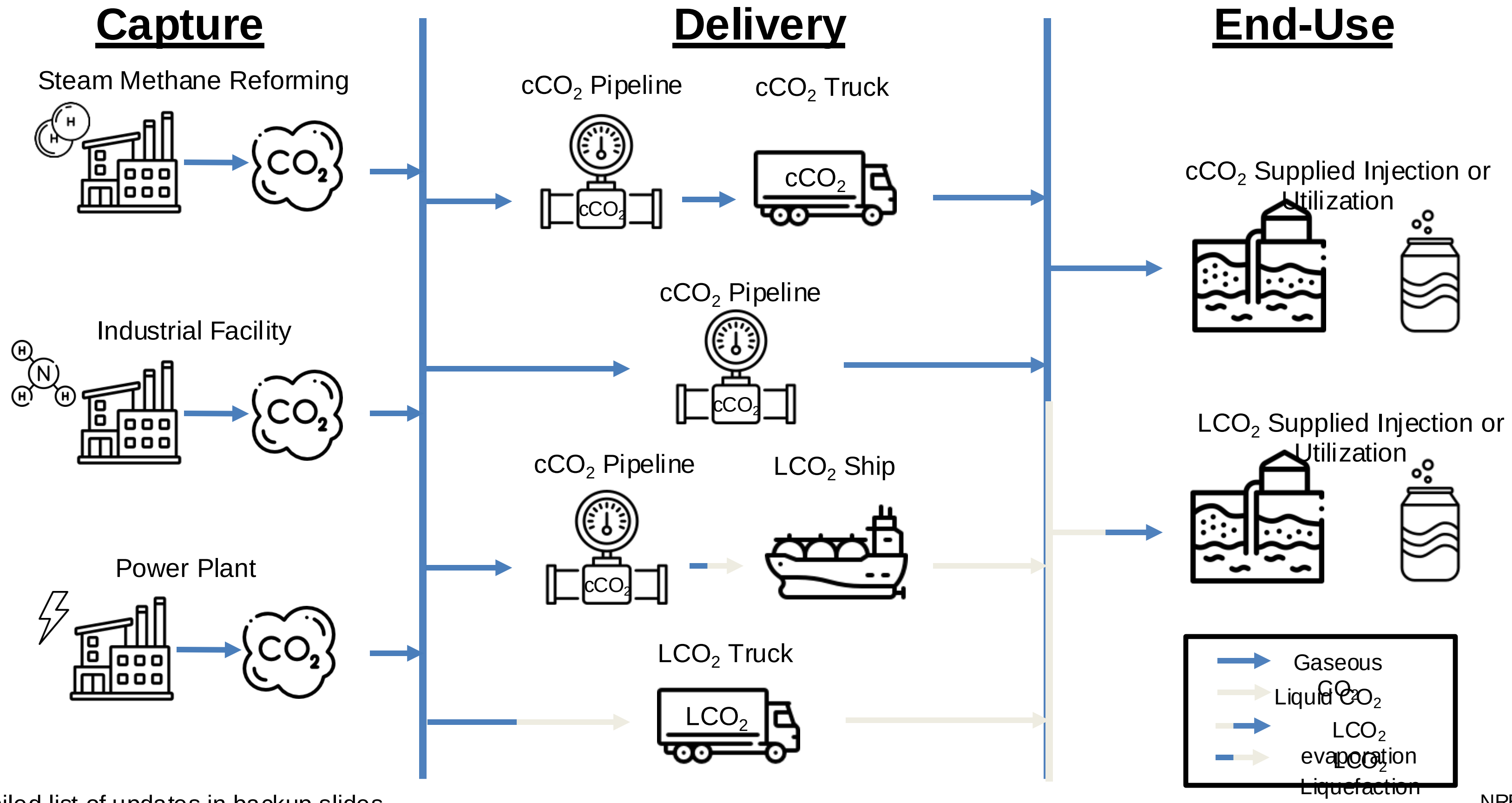
Solution

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

SERA Case Study

HEVI-LOAD Project

Preliminary

HEVI-LOAD Project

Our Team

<u>Project Objective:</u>

Determine the optimal placement and cost of hydrogen refueling stations to support long-haul FCEVs across the United States by 2032

NREL — NATIONAL RENEWABLE ENERGY LABORATORY

Predict long-haul heavy-duty FCEV adoption by 2032

TEMPO

BERKELEY LAB

Predict how much and where H_2 demand will be for long-haul FCEVs using OD freight data

HEVI-LOAD Model

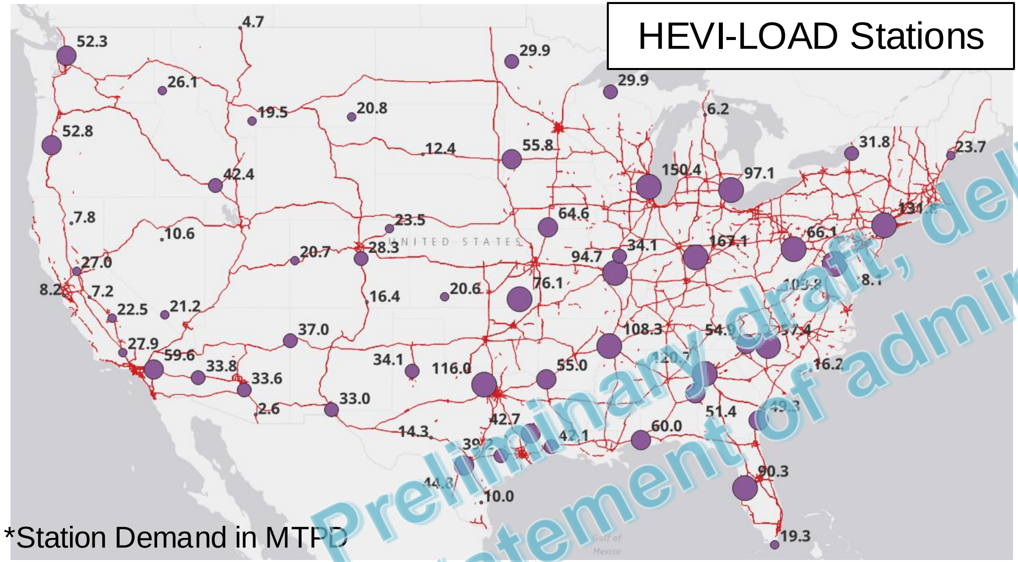
NREL — NATIONAL RENEWABLE ENERGY LABORATORY

Estimate H_2 infrastructure buildout and costs to support long-haul FCEV demand

SERA

SERA Input Assumptions

63 stations total

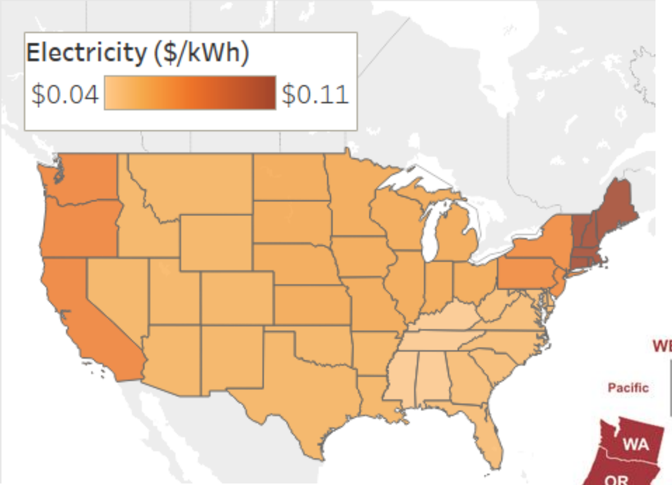


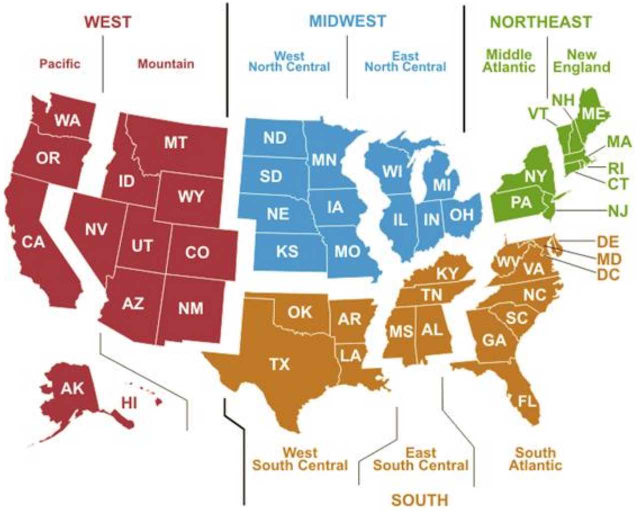
*Station Demand in MTPD

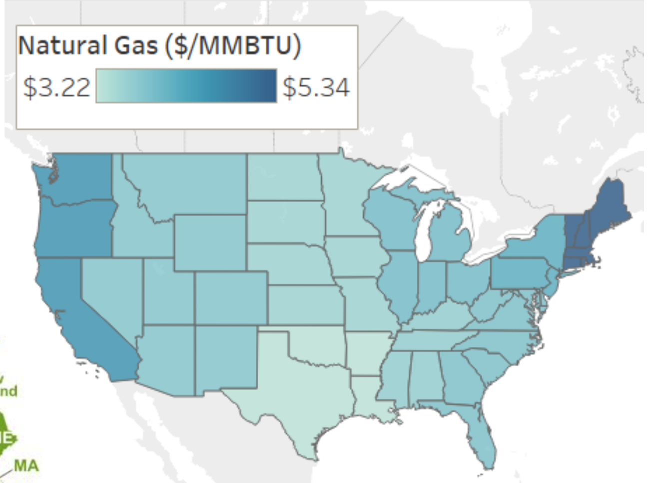
- Allow only grid electrolysis production and allow production at any location
- Use base line electrolysis cost data ($899/kW, 0.9 scaling factor, 55 kWh/kg-H2 electrical system efficiency)

- Station spacing – set at about 300 miles apart (63 stations total across U.S.)
  - Additional stations placed in major demand areas
  - Sensitivity with 200 miles spacing also performed (103 stations total across U.S.)
- Model year – 2032
- Class 6-8 FCEV demand
  - ~1% of class 6-8 vehicles are FCEV in 2032
  - 82% of FCEVs are class 8 trucks
- Delivery pathways – gaseous and liquid trucking
- Feedstock prices – from EIA AEO2023
- Station utilization rate - 50%

2032 Energy/Feedstock Prices from EIA AEO2023



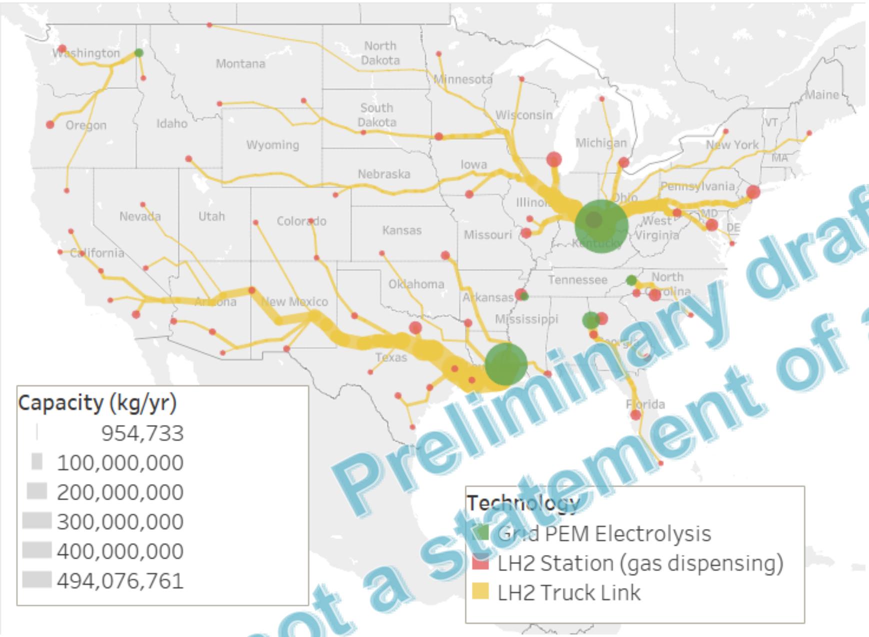




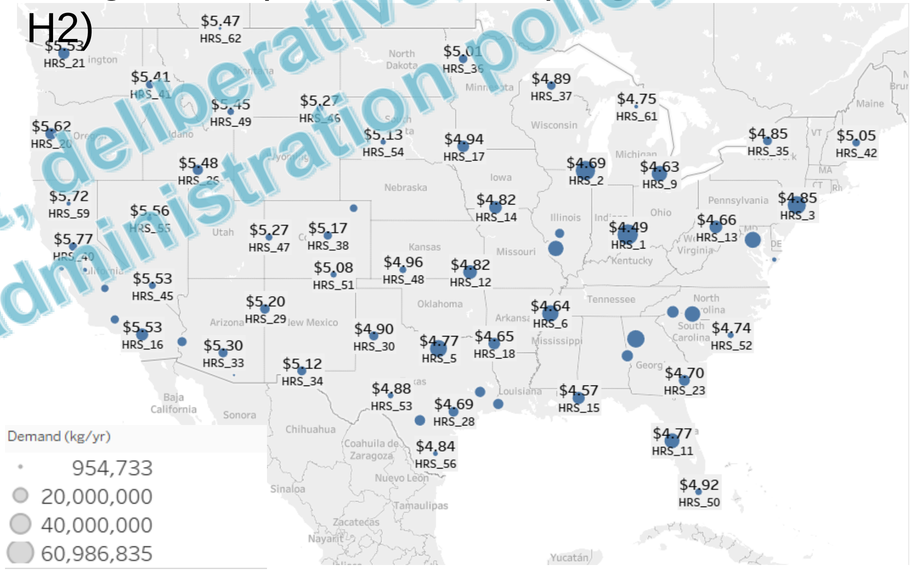
Prices are in $2020 dollars

SERA Results: 300-mile Spacing

2032 Infrastructure Buildout



Marginal Dispensed Costs ($/kg-H2)

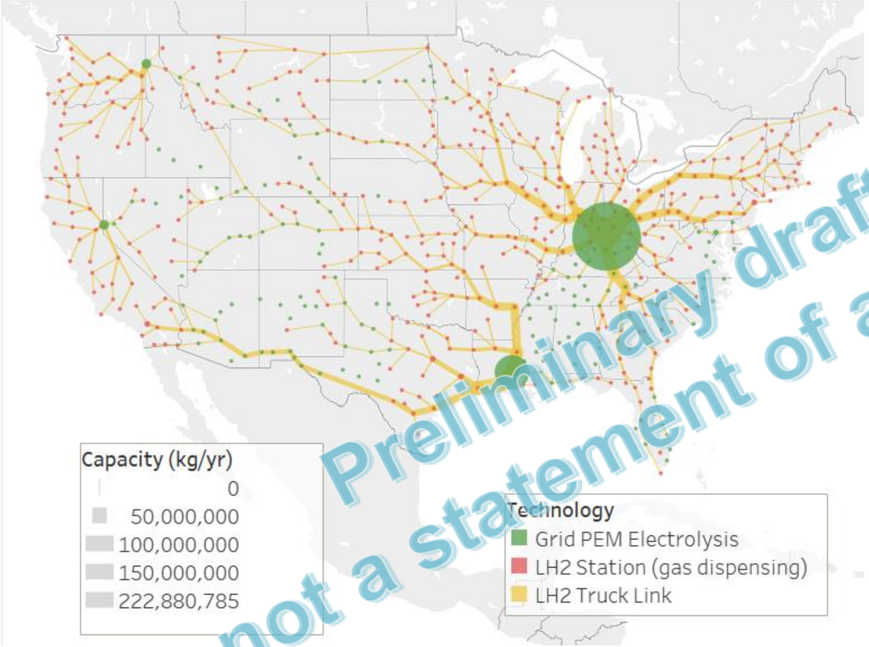


System LCOH dispensed: $6.87/kg-H2

Costs are in $2020 dollars

Other SERA Outputs

Infrastructure Buildout



EIA Region	H2 Production Capacity [t/d]	CAPEX* [$M]	PEM Electricity Requirement [GWh]
East North Central	0	$0	0
East South Central	1026	$2,299	18545
Middle Atlantic	0	$0	0
Mountain	248	$682	4484
New England	0	$0	0
Pacific	0	$0	0
South Atlantic	96	$266	1727
West North Central	12	$49	223
West South Central	31	$103	559
Total	**1,413**	**$3,399**	**25,537**

* CAPEX for electrolysis is in 2020 dollars

Why is SERA Important?

The Importance of SERA

- 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.
- Used to translate/inform/validate hydrogen infrastructure costs across numerous NREL tools such as ReEDS and FINITO.
- Used to translate/inform/validate hydrogen infrastructure costs across DOE tools and initiatives including GCAM and NEMS.
- Be publicly-available, but closed-source, for all to use as necessary for their applications.

SERA Limitations

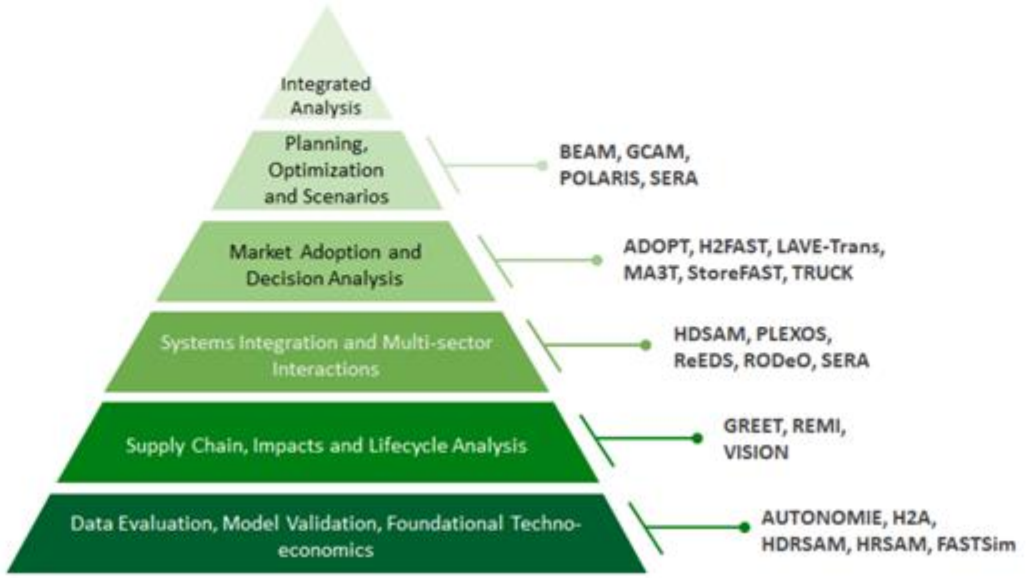
SERA Limitations

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)

Thank You!

Tools Spotlight: Supporting decision making

Decision-making workflow for hydrogen deployment

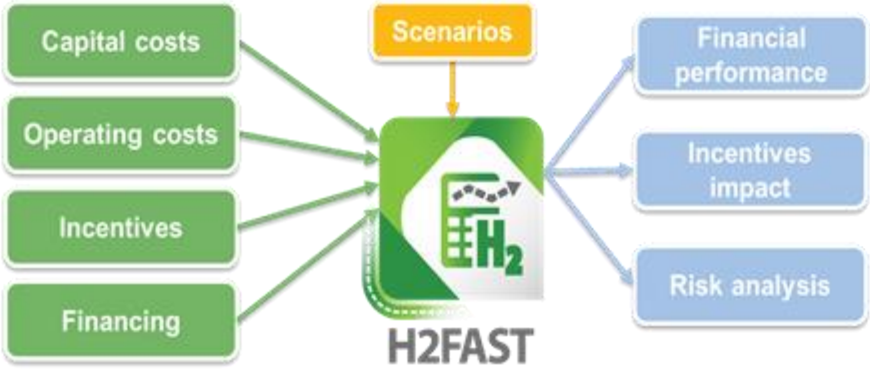


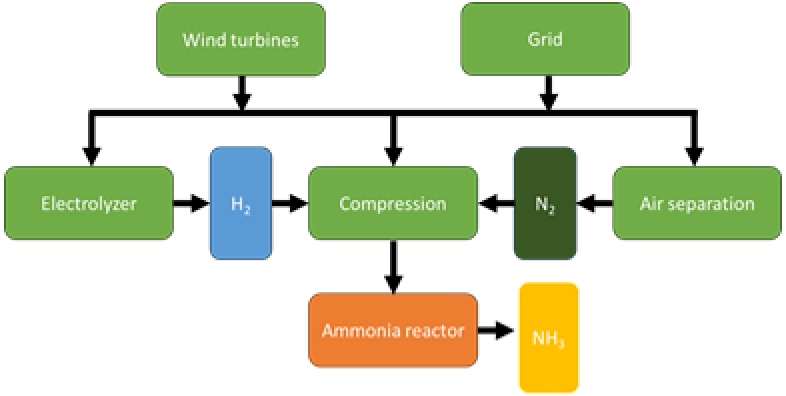
ADOPT: Automotive Deployment Options Projection Tool, Autonomie: (a vehicle system simulation tool), BEAM: Behavior, Energy, Autonomy, and Mobility, FASTSim: Future Automotive Systems Technology Simulator, GCAM: Global Change Assessment Model, GREET: Greenhouse gases, regulated emissions, and energy use in Technologies Model, H2A: The Hydrogen Analysis Project, H2FAST: Hydrogen Financial Analysis Scenario Tool, HDRSAM: Heavy-Duty Refueling Station Analysis Model, HDSAM: Hydrogen Delivery Scenario Analysis Model, HRSAM: Hydrogen Refueling Station Analysis Model, LAVE-Trans: Light-Duty Alternative Vehicle Energy Transitions, PLEXOS: (an integrated energy model), POLARIS: (a predictive transportation system model), ReEDS: Regional Energy Deployment System, REMI: Regional Economic Models, Inc., RODeO: Revenue Operation and Device Optimization Model, SERA: Scenario Evaluation and Regionalization Analysis, StoreFAST: Storage Financial Analysis Scenario Tool, VISION: (a transportation energy use prediction model).

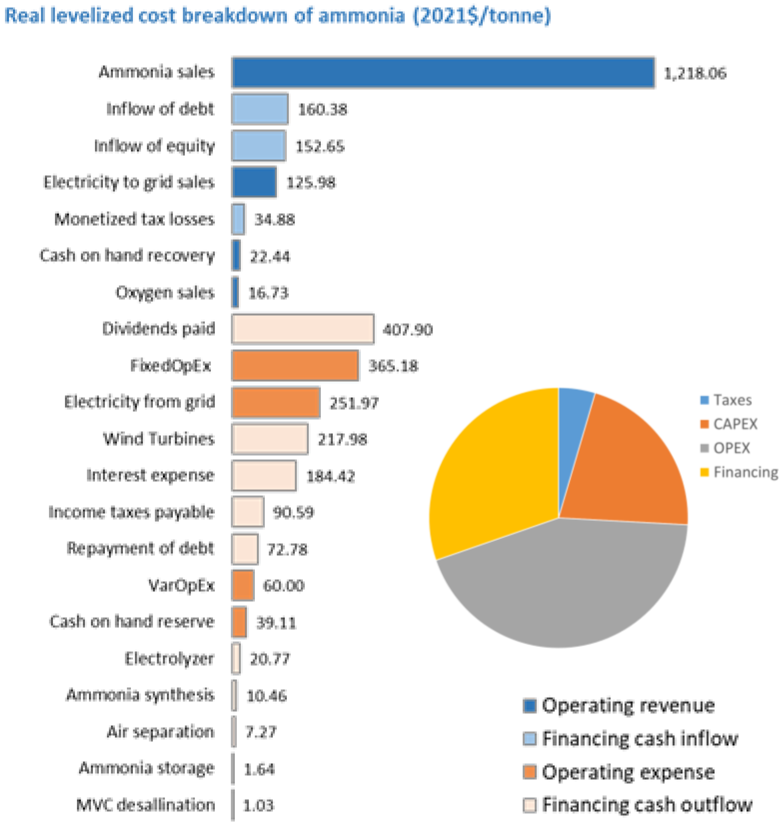
Source: https://www.hydrogen.energy.gov/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf

- **Hydrogen Analysis Production (H2A)**: Transparent reporting of process design assumptions and a consistent cost analysis methodology for hydrogen production at central and distributed (forecourt/filling-station) facilities. H2A includes biomass, coal, electrolysis, natural gas, and emerging production pathways.
- **Revenue, Operation, and Device Optimization (RODeO)**: Explores optimal system design and operation considering different levels of grid integration, equipment cost, operating limitations, financing, and credits and incentives.
- **Scenario Evaluation and Regionalization Analysis (SERA)**: Provides insights that can guide hydrogen infrastructure development and transportation investment decisions and accelerate the adoption of hydrogen technologies (city to national levels).
- **Hydrogen Financial Analysis Scenario Tool (H2FAST)**: Provides a quick and convenient in-depth financial analysis for hydrogen fueling stations and hydrogen production facilities.

Case Study Analysis Using H2FAST

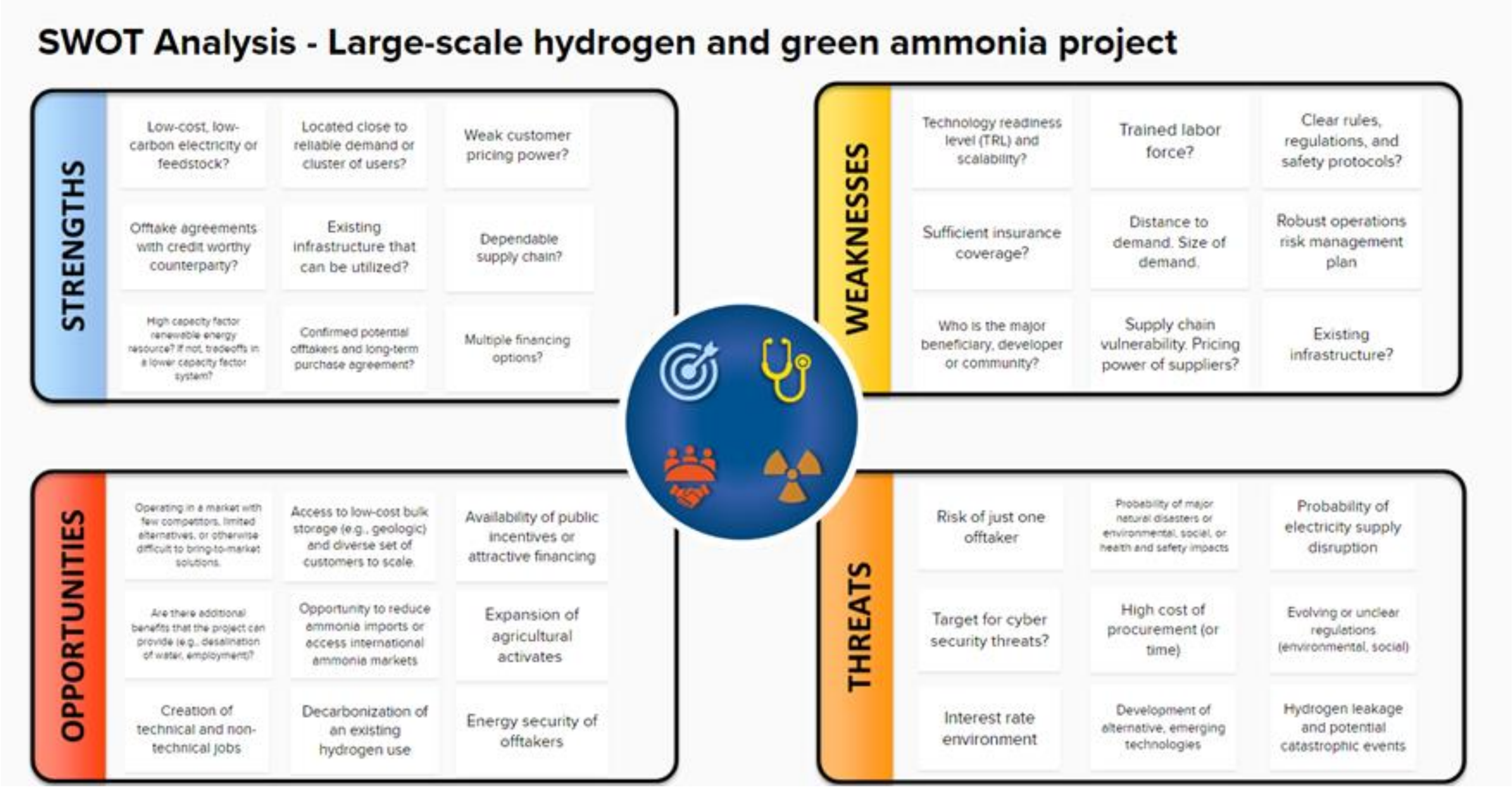






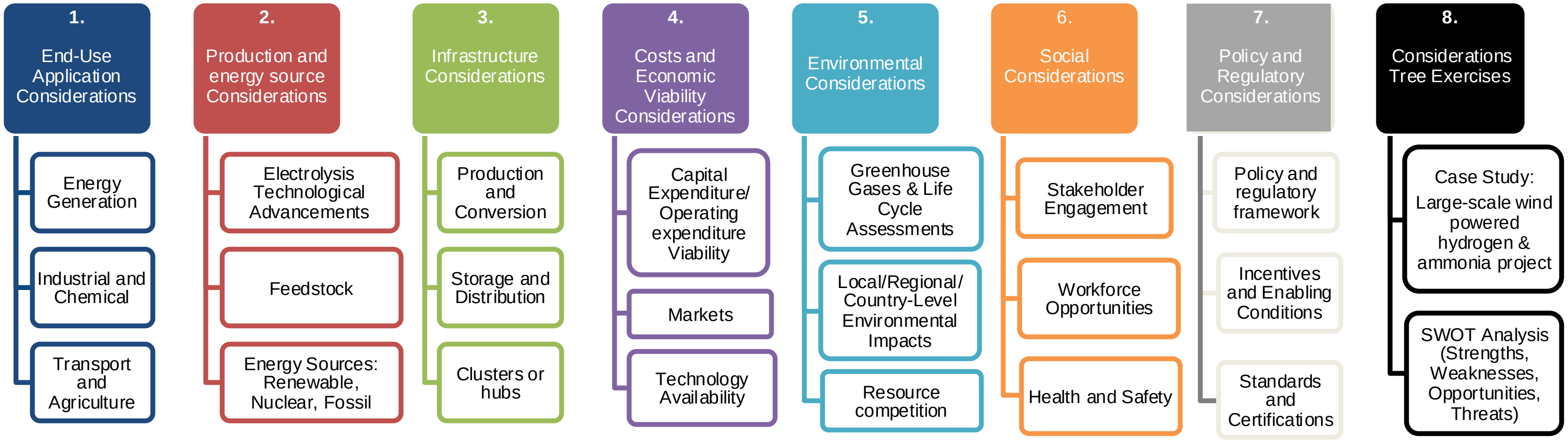
Sources:
https://www.nrel.gov/hydrogen/h2fast.html
https://pubs.acs.org/doi/full/10.1021/acssuschemeng.7b02070

SWOT Analysis



Guiding Sustainable Hydrogen Integration: USAID-NREL Partnership's Capacity-Building Approach

- **Background:** Growing need from Missions and country partners to respond to requests related to hydrogen, and key considerations in costs, benefits and tradeoffs when making strategy, policy and investment decisions.
- **Objective:** Build understanding and capacity of USAID Missions and country partners to make informed decisions, as they look to potentially support hydrogen and its derivatives.
- **Format:** Key topics are organized into a "considerations tree" to help stakeholders think through technical, regulatory, economic, environmental, social, and analytical questions.



Explore the Hydrogen Considerations Tree

Executive Deck

Fact Sheet

Reach out if interested in more information for your country or project: **daniella.rough@nrel.gov.**

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

Thank you!

Questions? Contact Expert@CleanEnergySolutions.org.

The next installment in this series will focus on applying all the knowledge gained throughout this Hydrogen and Analytical Tools series.

Register today!