U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Systems Analysis Overview

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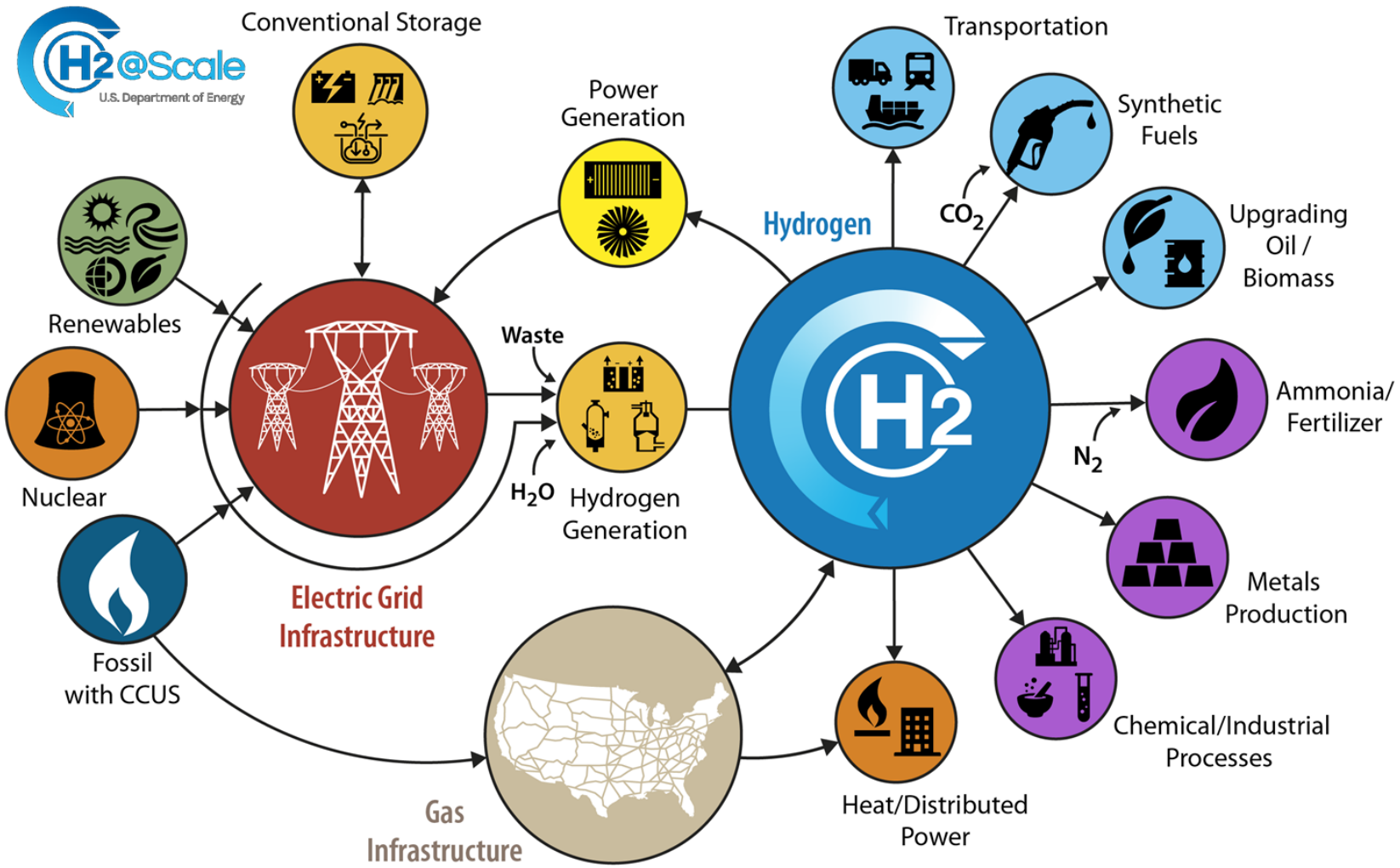
Hydrogen in the U.S. – Modeling Challenges

March 24, 2022

H2@Scale: Enabler for Deep Decarbonization across Sectors and Jobs



Key Opportunities

- **Industry and Chemicals**
  Steel, ammonia, cement, syn fuels (e.g., aviation), exports
- **Transportation**
  Trucks, marine, buses, etc.
- **Power and Energy Storage**
  Long duration storage, NG blending, turbines, fuel cells

U.S. Snapshot

- 10 MMT of H_2/yr produced today with scenarios for 2-5X growth.
- +10 MMT H_2 would ~ double today's solar or wind deployment
- Potential for 700K jobs, $140B by 2030

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Hydrogen Energy Earthshot

"Hydrogen Shot"

"1 1 1"
$1 for 1 kg clean hydrogen in 1 decade

Launched June 7, 2021
Summit Aug 31-Sept 1, 2021

Bipartisan Infrastructure Law - Hydrogen Highlights

- **Covers $9.5B** for clean hydrogen:
  - $8B for at least four regional clean hydrogen hubs
  - $1B for electrolysis research, development and demonstration
  - $500M for clean hydrogen technology manufacturing and recycling R&D

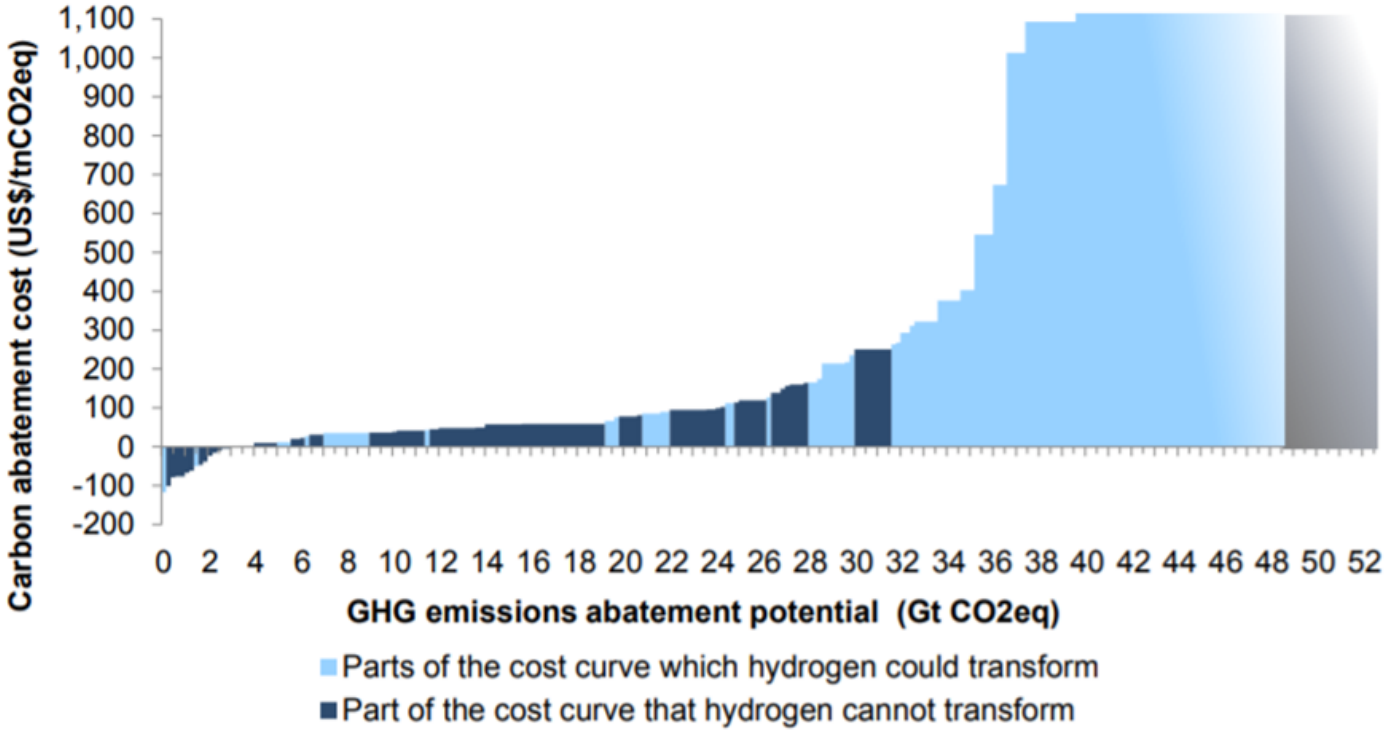
President Biden Signs the Bipartisan Infrastructure Bill on November 15, 2021.
Photo Credit: Kenny Holston/Getty Images

- **Aligns with Hydrogen Shot priorities by directing work to reduce the cost of clean hydrogen to $2 per kilogram by 2026**
- **Requires developing a National Hydrogen Strategy and Roadmap and Clean Hydrogen Standard**

December 8, 2021 Webinar: www.energy.gov/eere/fuelcells/articles/doe-update-hydrogen-shot-rfi-results-and-summary-hydrogen-provisions

Systems Analysis Focus Areas

Recent analyses have focused on identifying the role of hydrogen in hard-to-decarbonize sectors



Cost of decarbonization increases significantly after 50%.[1]

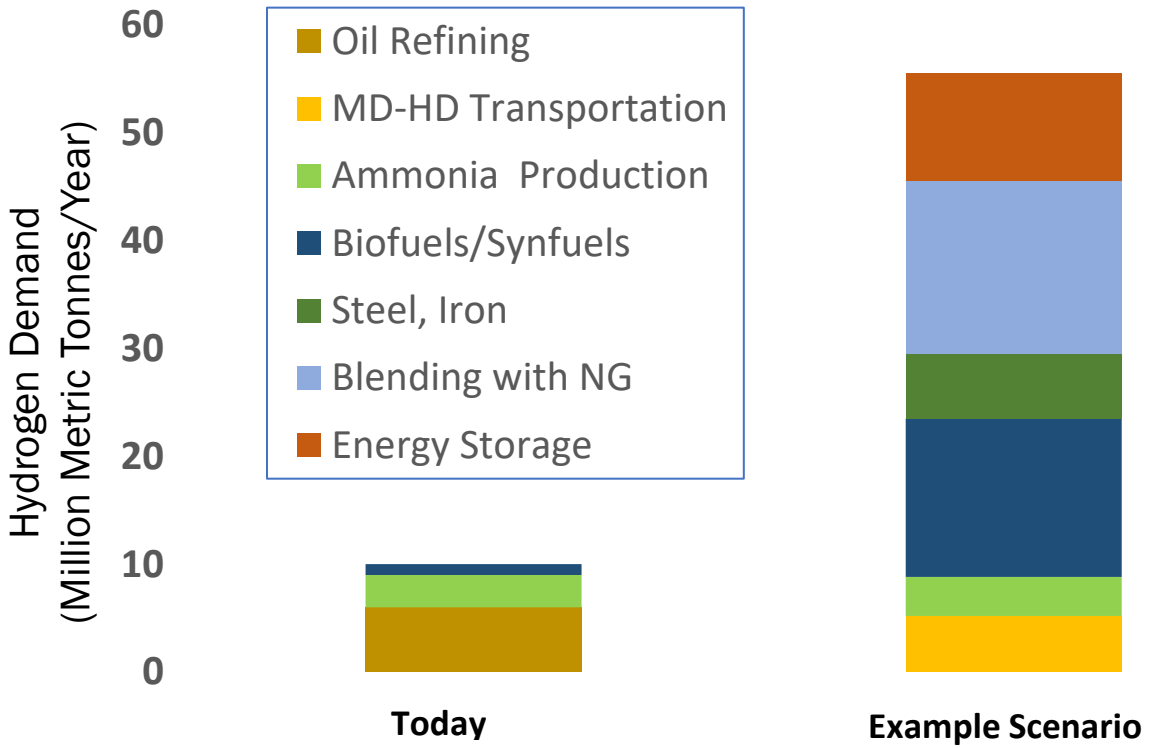
Recent and ongoing analyses are characterizing:

- Role of hydrogen in long duration energy storage
- Impact of hydrogen use on life cycle emissions of industrial applications
- Market segmentation in medium/heavy-duty transportation
- Supply and demand potential for hydrogen
- Impact of growth in hydrogen and fuel cells on global sustainability

1. Source: Goldman Sachs, https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-rise-of-clean-hydrogen/report.pdf

Key Reports Released in 2020

Comprehensive multi-lab analysis determined potential for growth in U.S. hydrogen demand of at least 2-5 x current consumption



Preliminary demand scenario based on published H2@Scale analysis and additional ongoing TEA

- **Resource Assessment for Hydrogen Production**[1]
  Determined technical potential of hydrogen supply
- **Assessment of Potential for Future Demands for Hydrogen in the United States**[2]
  Assessed price points and market potential for hydrogen in 8 sectors.
- **The Technical and Economic Potential of the H2@Scale Concept within the United States**[3]
  Assessed growth potential for hydrogen supply and demand in 5 scenarios

1. https://www.nrel.gov/docs/fy20osti/77198.pdf
2. https://greet.es.anl.gov/publication-us_future_h2
3. https://www.nrel.gov/docs/fy21osti/77610.pdf

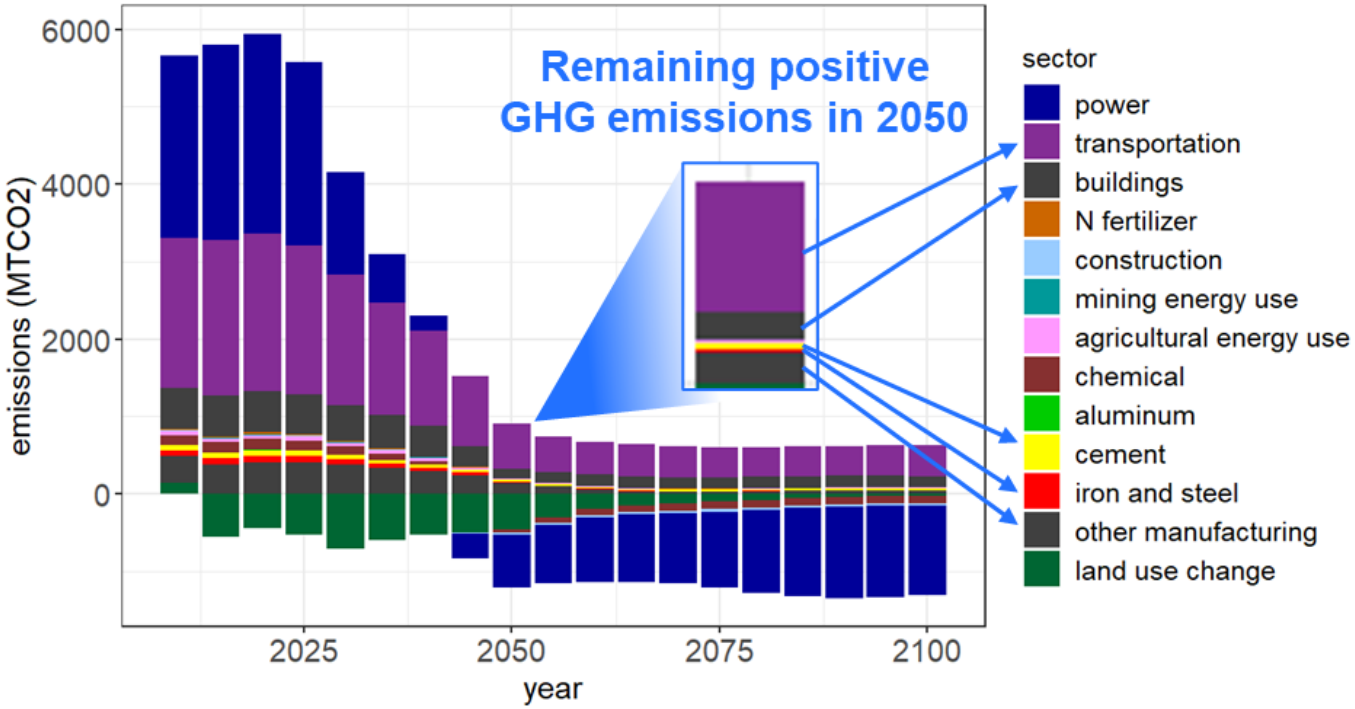
Hydrogen Energy Integrated Assessment: Updating H_2 in GCAM

GCAM: Global Change Analysis Model

GCAM represents linkages between five systems: energy, water, land, economic, and climate systems, at local, regional, and global scales

Current estimates of cost and performance of H_2 and fuel cell technologies will be incorporated into GCAM across all relevant pathways in industry and transportation

Example GCAM scenario before hydrogen updates



Anticipated GCAM Results

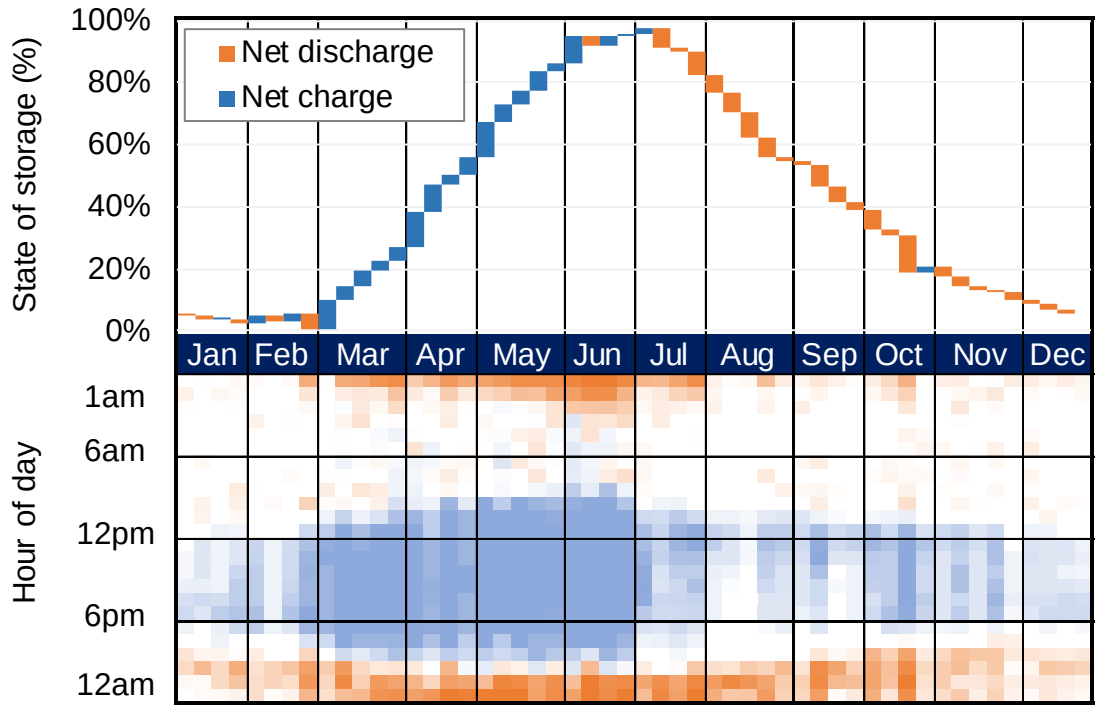
- Market shares and energy prices by sector
- GHG and criteria emission reductions
- GHG abatement costs compared to other options
- Land use, water use and other sustainability metrics

GCAM identifies which sectors are economically difficult to decarbonize to reach Net Zero GHGs

Competitiveness of Long Duration Energy Storage

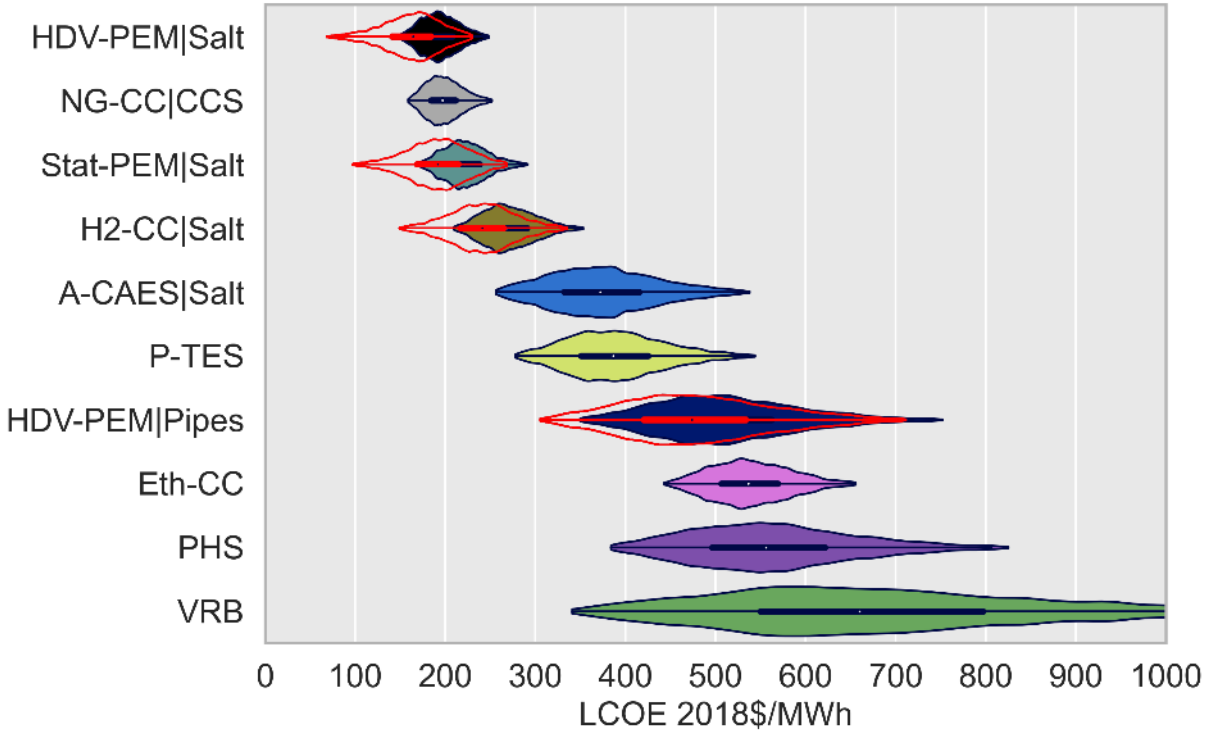
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Modeling of 85% renewable grid in Western Interconnect to inform energy storage capacity factors



Example capacity factor for technology with 40% round-trip efficiency

Analysis of current and future costs for long duration energy storage



Monte Carlo analysis of future costs

Hydrogen technologies are among the lowest cost pathways for multi-day energy storage

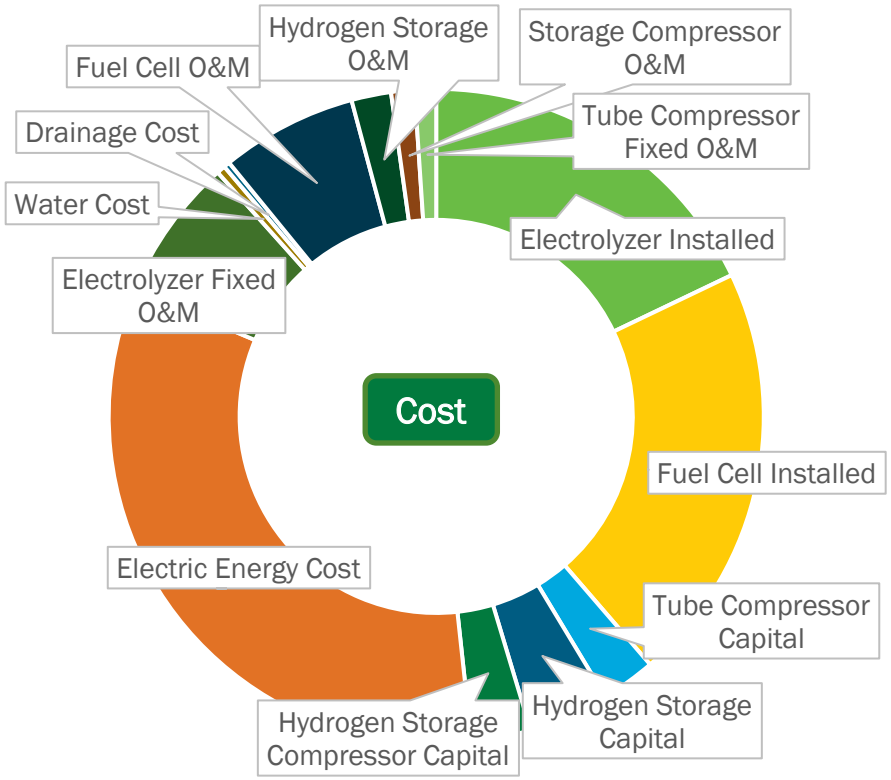
Analysis led by DOE-Strategic Analysis and co-funded with Solar Energy Technologies Office and Wind Energy Technologies Office.
Grid modeling informed by EPRI and five member utilities

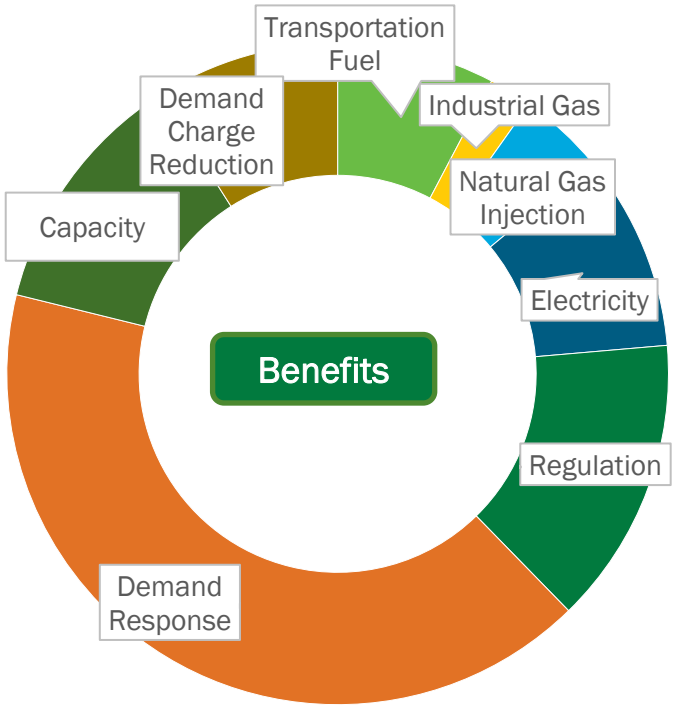
Hydrogen Energy Storage Techno-economic Assessment Model

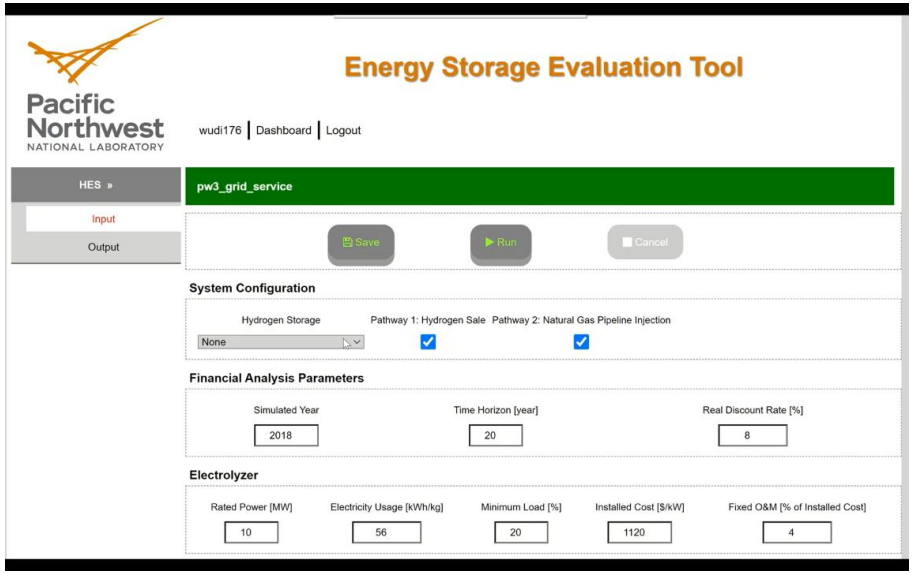
New tool for hydrogen energy storage valuation toward multiple energy delivery pathways and grid services

Key Inputs: Price of electricity and various grid services, price point of regional demands for hydrogen

Key Outputs: Financial analysis of costs and net profit over life of system, from all revenue streams considered







HESET models the operation of a user-defined energy storage system, to allow users to optimize component size and revenue streams

Co-funded with DOE Office of Electricity | Now in beta testing at: https://eset.pnnl.gov

Hybridized Nuclear Plants Producing Hydrogen

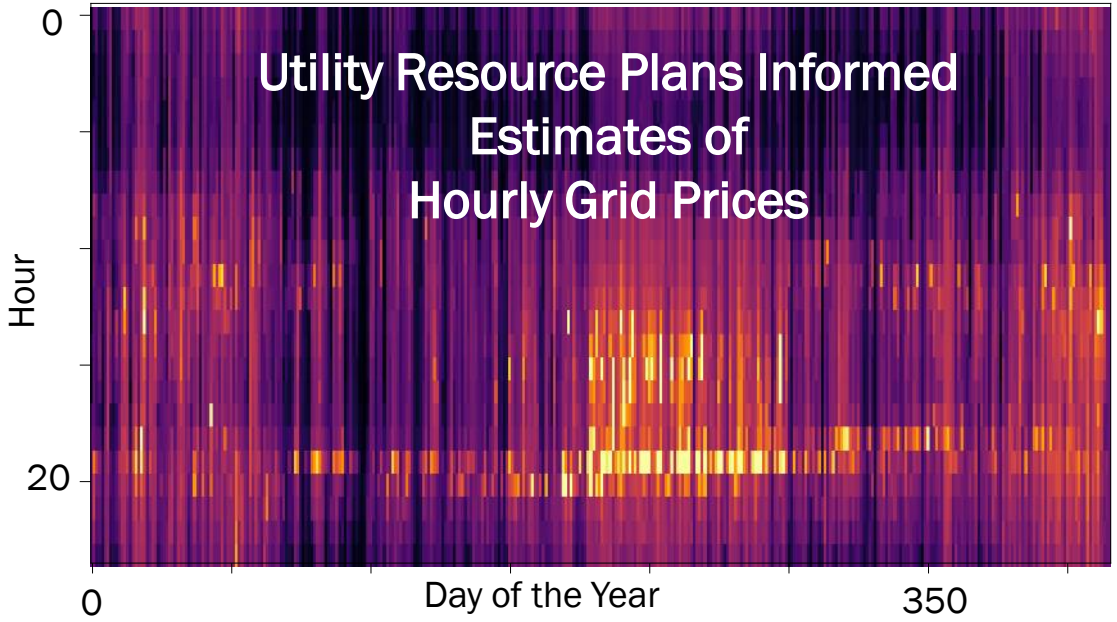
Used state-of-the art analysis tools to estimate the value of integrating hydrogen production at two Xcel Energy nuclear power plants

- Estimated grid prices with and without hydrogen integration
- Optimized operating strategy for hybrid energy system
- Assessed size of regional hydrogen market

Next Steps

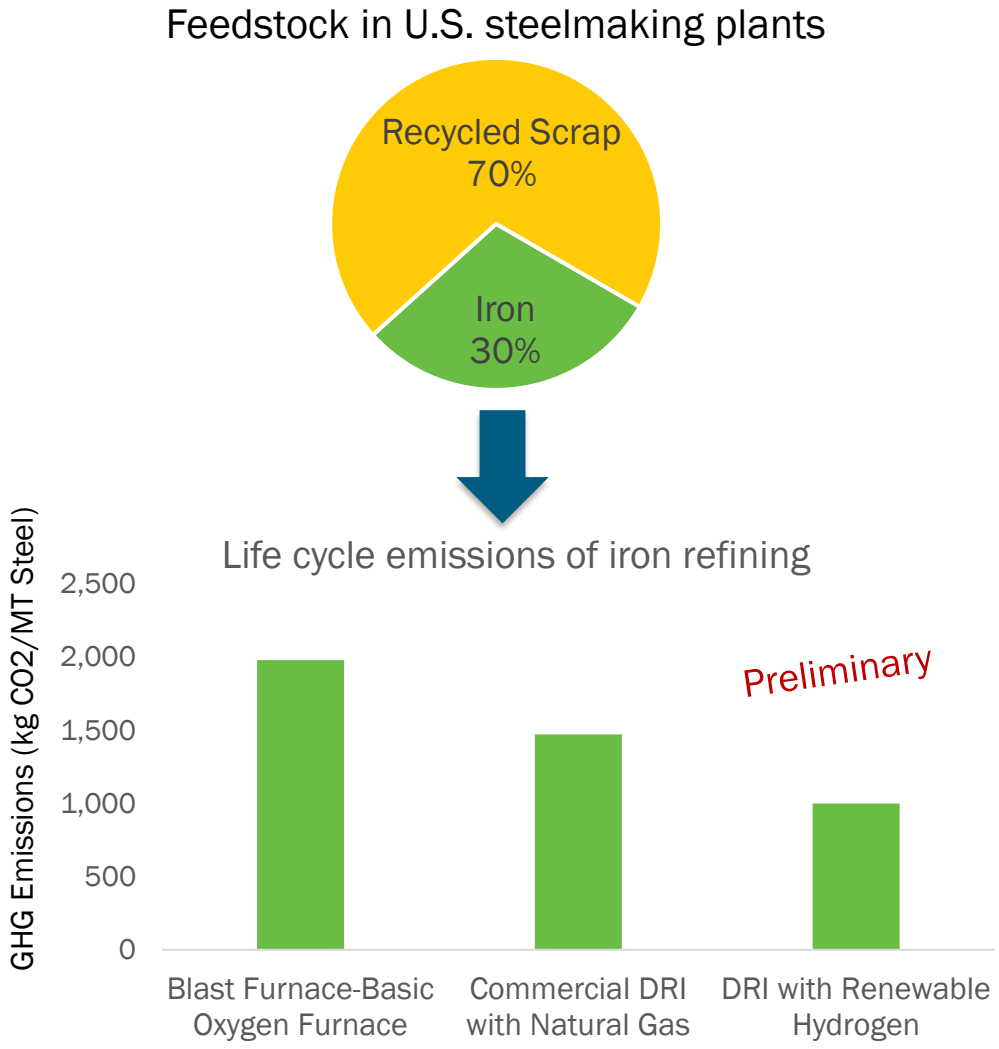
- Identifying parameters necessary for profitability, including:
  - Technology cost
  - Hydrogen market size
  - Decarbonization drivers

Collaboration with Office of Nuclear Energy

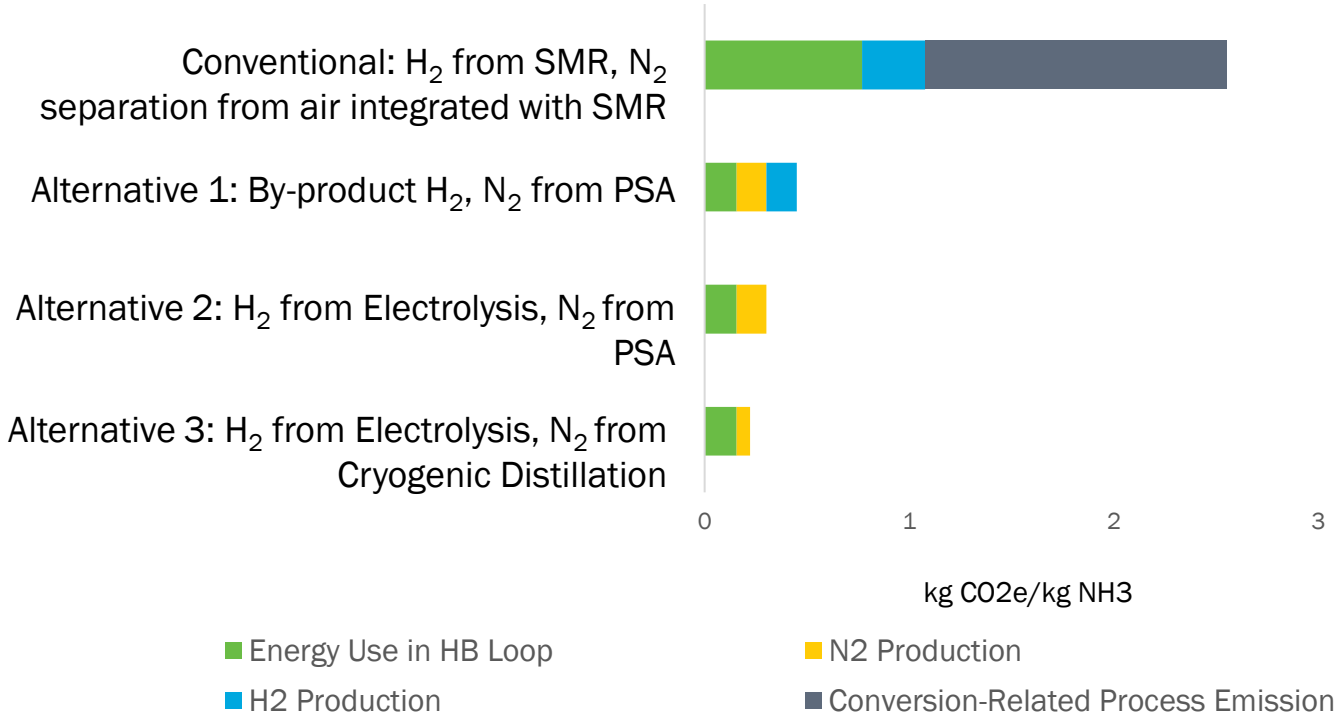


Industrial Applications for Hydrogen: Life Cycle Analysis

Hydrogen use in iron refining can reduce life cycle emissions by 30-50%[1]



Clean hydrogen use in ammonia production can reduce life cycle emissions by over 80%[2]



Steam methane reforming is largest contributor to life cycle emissions of conventional ammonia production

1. *In collaboration with DOE- Strategic Analysis and Advanced Manufacturing Office. For more information, please see SA 174*

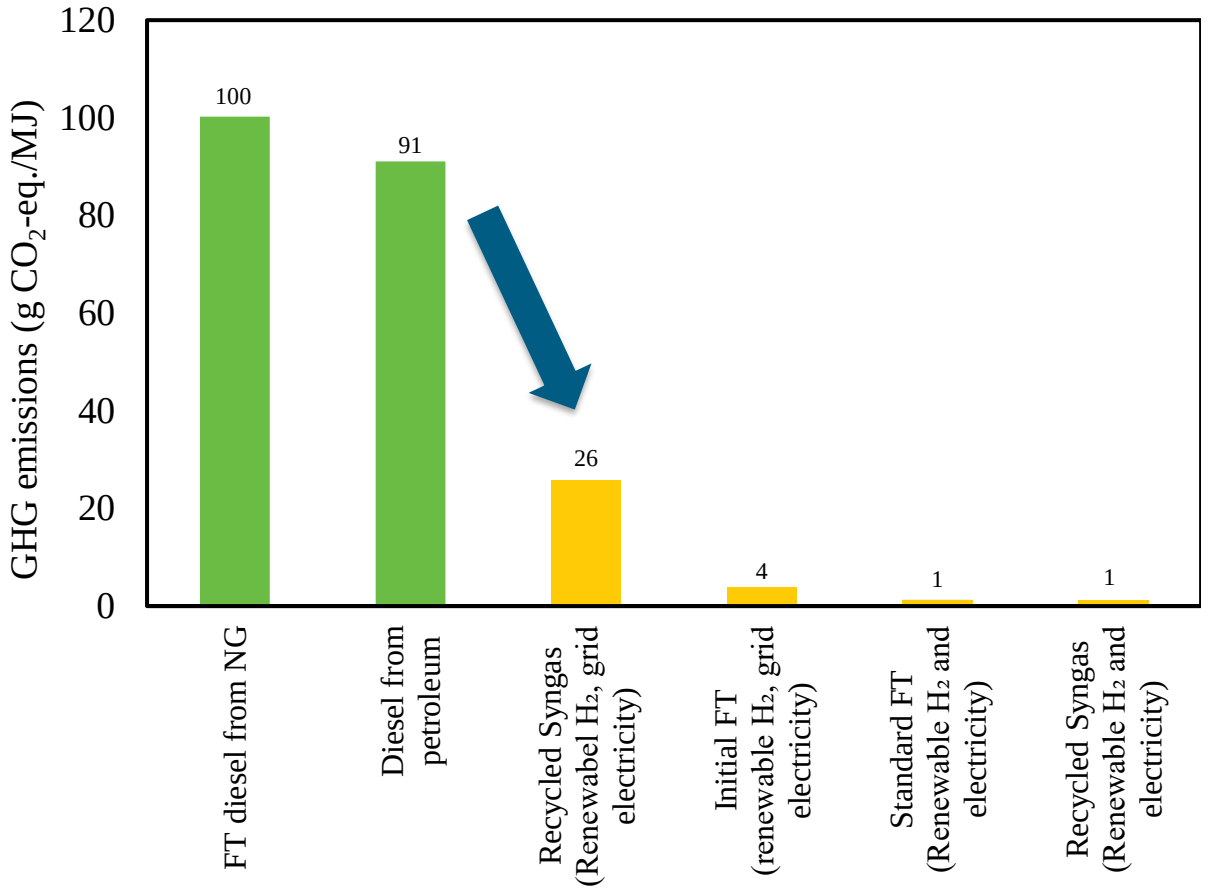
2. *Source: https://pubs.rsc.org/en/content/articlelanding/2020/gc/d0gc02301a#!divAbstract*

Analysis funded by DOE Advanced Research Projects Agency- Energy

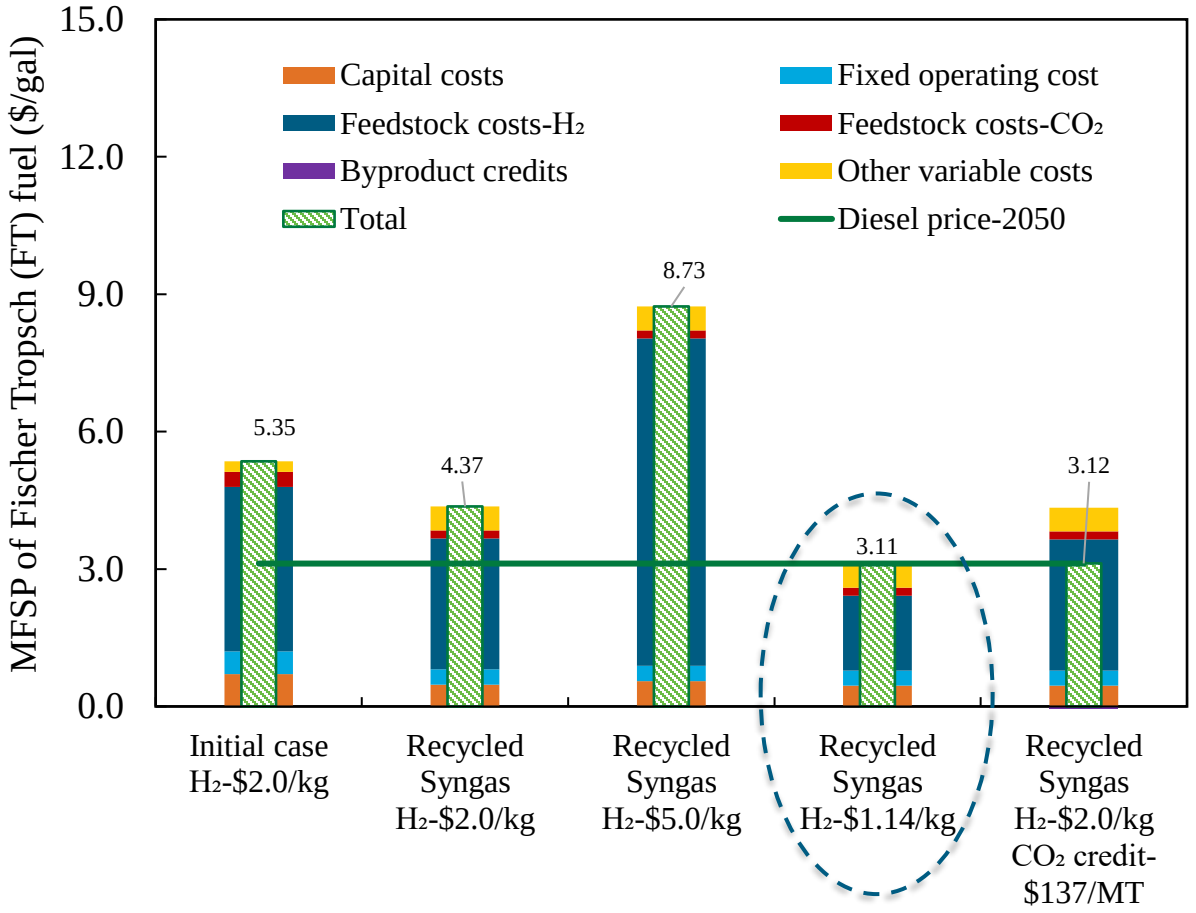
Industrial Applications for Hydrogen: Synthetic Fuels

Argonne NATIONAL LABORATORY

Fuels synthesized from hydrogen and concentrated CO_2 can achieve >70% lower emissions than conventional diesel



Hydrogen cost of ~$1/kg needed to enable competitive production



Conducted in coordination with DOE-EERE Bioenergy Technologies Office, in support of Net Zero Carbon Tech Team

Fore more information, please see SA 174

Medium- and Heavy-duty Trucks Market Segmentation

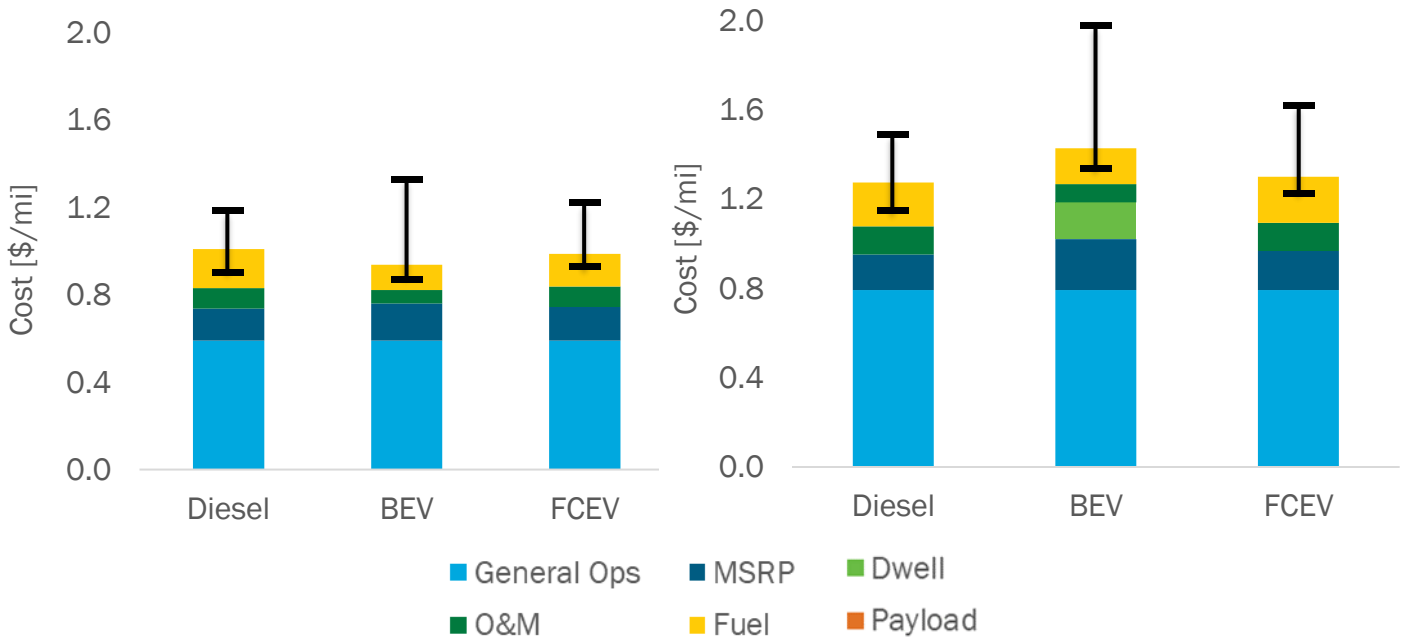
Total Cost of Ownership (TCO) of Class 4 and 8 fuel cell trucks achieves parity with diesel if HFTO targets are met

Class 8 (300-mile)

- Single-shift operations
- 60,000 mi/yr
- 16.7 years life

Class 8 (500-mile)

- Multi-shift operations
- 150,000 mi/yr
- 6.7 years life



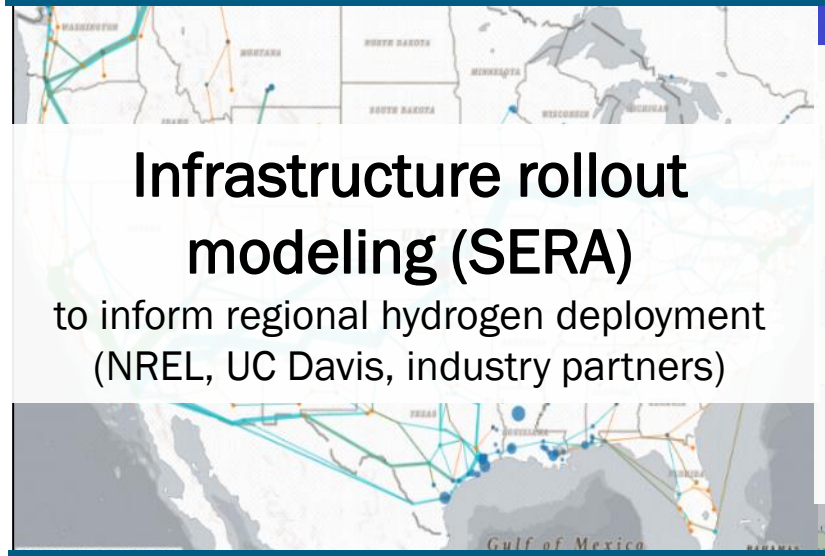
Error bars reflect uncertainty in fuel prices and O&M costs
For more information, please, see SA 169
Project completed in conjunction with DOE Vehicle Technologies Office
Report to be published in 2021

- **Key assumptions:**
  - Real-world drive cycles
  - Estimates of cost based on current technology and R&D success
- **Impact of payload and time constraints on TCO evaluated**
  - FCEVs are more attractive in scenarios with time constraints (e.g., multi-shift) or longer ranges
  - Vehicle classes with higher fuel economy had narrower gap in TCO between fuel cells and diesel
- **Range of TCO values reflects uncertainty in fuel prices and O&M cost**
  - Cost of fuel is largest driver of TCO
- **Future work: Analysis and data gathering to identify size of MDHD truck market segments and vocations and assess TCO in additional classes**

Collaborations Across Industry, Academia, and Government

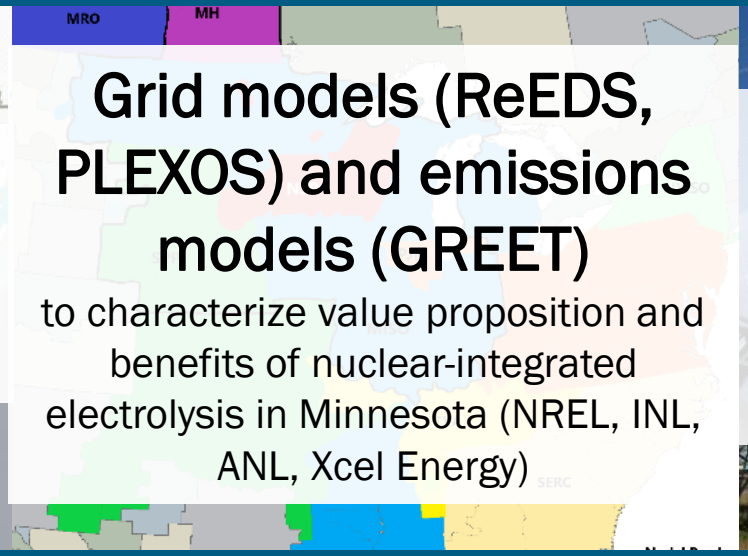
Tools developed through Systems Analysis projects inform real-world deployments and demonstrations

Examples



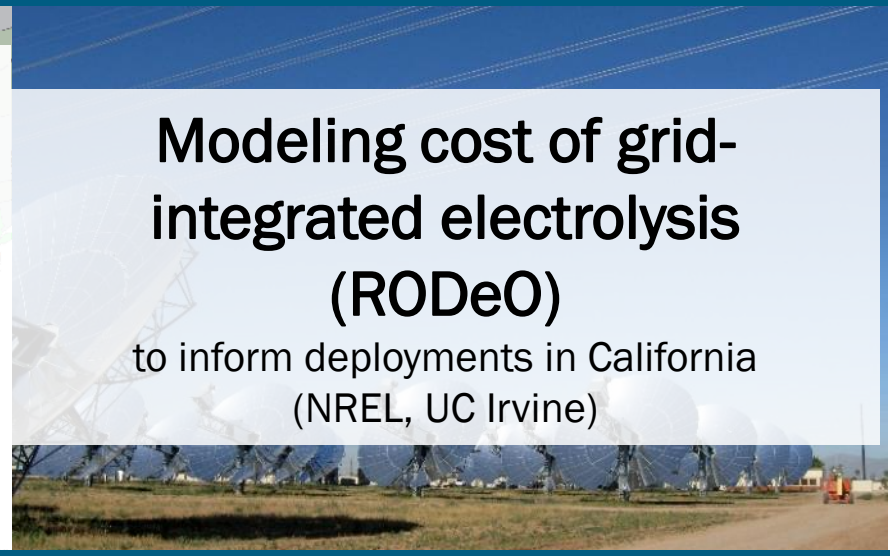
Infrastructure rollout modeling (SERA)

to inform regional hydrogen deployment (NREL, UC Davis, industry partners)



Grid models (ReEDS, PLEXOS) and emissions models (GREET)

to characterize value proposition and benefits of nuclear-integrated electrolysis in Minnesota (NREL, INL, ANL, Xcel Energy)

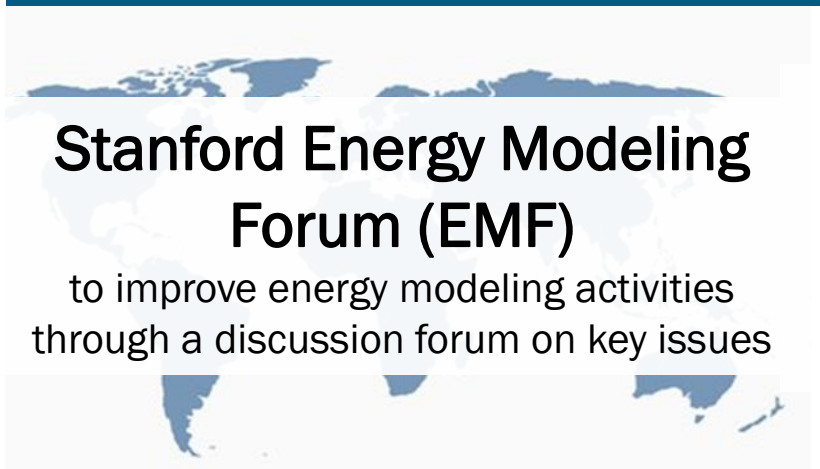


Modeling cost of grid-integrated electrolysis (RODeO)

to inform deployments in California (NREL, UC Irvine)

Systems Analysis projects are coordinated and informed by the stakeholder community

Examples



Stanford Energy Modeling Forum (EMF)

to improve energy modeling activities through a discussion forum on key issues

Global Change Analysis Model (GCAM)

Stakeholders across government are funding model updates to inform decarbonization scenarios

IPHE H_2 Production Task Force

Representatives from 13 countries and the European Commission developing standardized approaches to life cycle analysis to inform global trade

Key Analysis Gaps for Future Work

- Impacts of decarbonization drivers/policies on hydrogen markets, and market segmentation relative to other low-carbon solutions
- Impacts of hydrogen markets on EJ and sustainability metrics, such as regional water use
- Infrastructure rollout scenarios to support growth in demand
- Potential size of hydrogen export markets

Thank you!