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

Hydrogen Markets

Hydrogen and Analytical Tools Webinar Series

March 20, 2024

Housekeeping - Zoom

- This webinar is **being recorded** and will be shared with attendees.
- You will be **automatically muted** upon joining and throughout the webinar.
- Please use the **chat feature** to add comments and share input.
- Please use the **Q&A function** in your toolbar to ask questions.

- If you have **technical issues**, please use the chat feature to message Sophie Schrader.
- You can adjust your audio through the **audio settings.** If you are having issues, you can also dial-in and listen by phone. Dial-in information can be found in your registration email.
- We will be launching a **survey** when the event ends. Your feedback is highly valuable to us!

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Webinar & Speaker Introductions

Daniella Rough, NREL

Agenda

Speaker	Topic	Duration
Daniella Rough	Welcome, housekeeping, series intro, agenda, speaker intros, CESC intro	15 mins
Timothy Walters	DOE Regional Strategy for Hydrogen	10 mins
Jesse Cruce	Hydrogen Markets	30 mins
Daniella, Timothy, Jesse, Omar	Q&A	15 mins
Omar Guerra	RoDEO tool	30 mins
Daniella, Timothy, Jesse, Omar	Q&A, wrap up, and closing	20 mins

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Overview of the Clean Energy Solutions Center

Presented by Jal Desai, National Renewable Energy Laboratory

Webinar Speakers

Daniella Rough

International Project Manager

National Renewable Energy Laboratory

Timothy Walters

International Advisor

Department of Energy

Jesse Cruce

Engineer and Market Researcher in the Complex Decision Analysis Group

National Renewable Energy Laboratory

Omar Guerra Fernández

Research Engineer

National Renewable Energy Laboratory

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

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

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

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Regional Hydrogen Stragegy

Hydrogen and Analytical Tools Webinar Series

Timothy Walters, DOE

20 March, 2024

U.S. Department of Energy – Office of International Affairs

- What are we doing
  - U.S. National Clean Hydrogen Strategy and Roadmap
  - H2Hubs
  - Hydrogen Interagency Task Force
  - Hydrogen Shot

- Western Hemisphere Efforts
  - Safety
  - Certification
  - Community Engagement

- Goal
  - Accelerate the use of clean hydrogen in the region
  - Reduce cost of developing and deploying hydrogen

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Hydrogen Markets

Hydrogen and Analytical Tools Webinar Series

Jesse Cruce, NREL

20 March, 2024

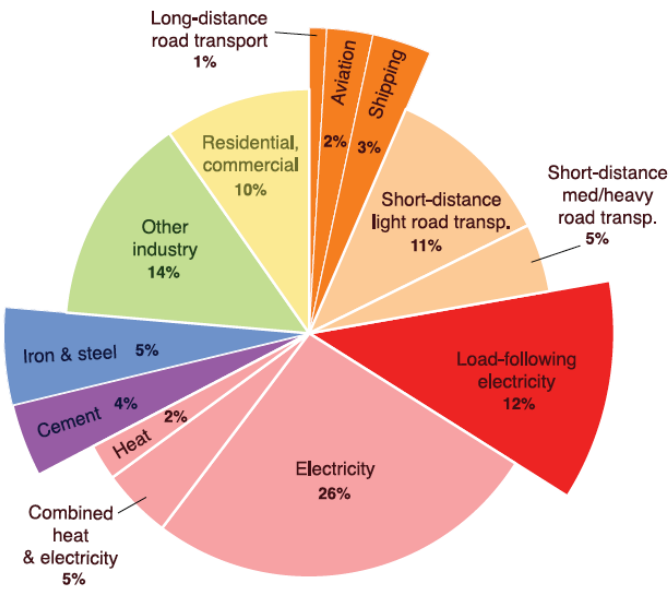
Overview

(1) Hydrogen demand and potential market projections

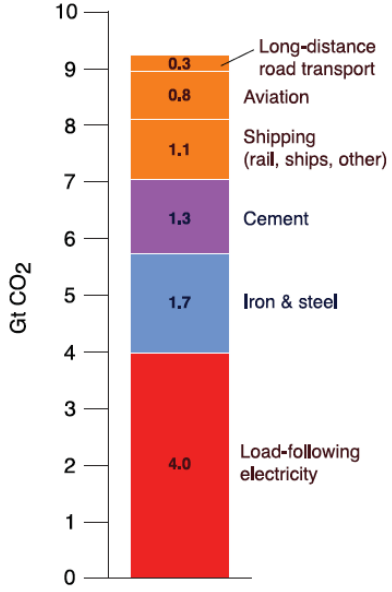
(2) Exports of hydrogen and/or hydrogen-derivatives

Hydrogen Demand & Market Projections

Several energy and industrial sectors have been identified as “hard-to-decarbonize”



A **Global fossil fuel & industry emissions, 2014 (33.9 Gt CO_2)**



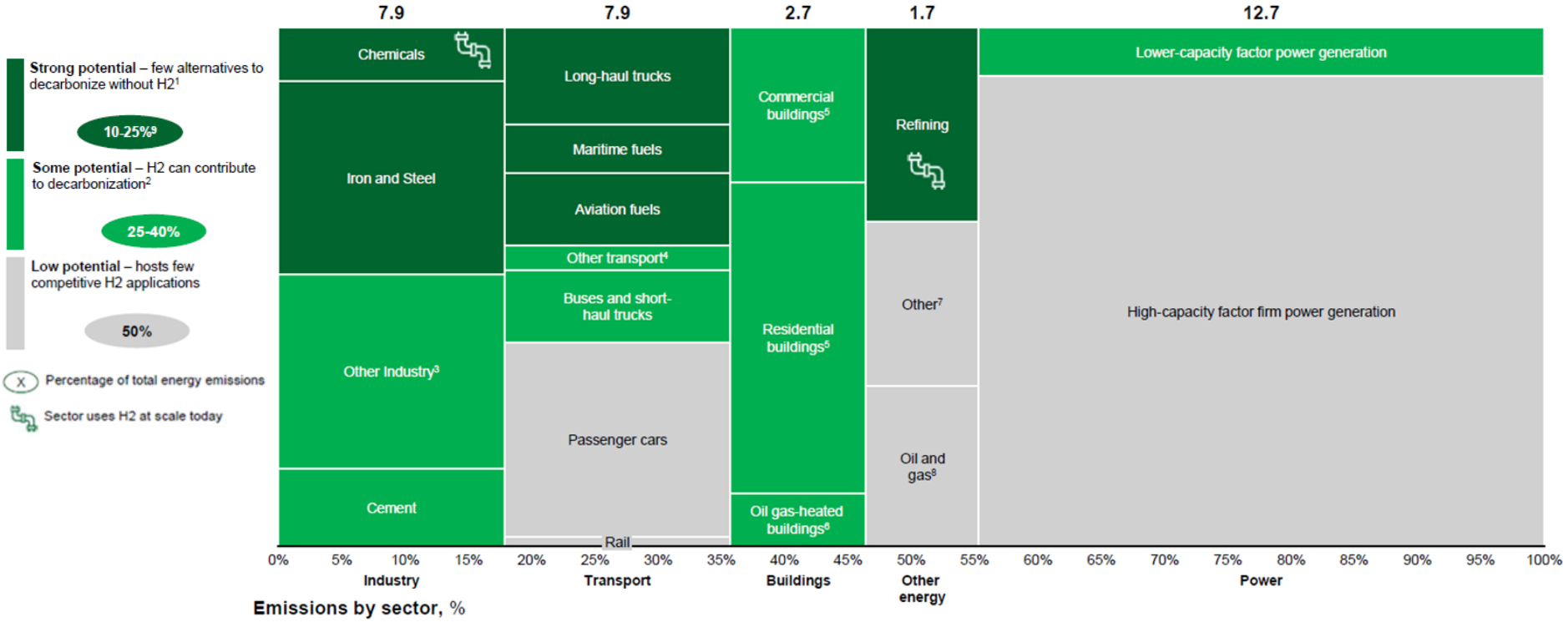
B **Difficult-to-eliminate emissions, 2014 (9.2 Gt CO_2)**

Key challenge areas

- Electricity resource adequacy
- Iron & Steel
- Cement
- Long-distance transportation

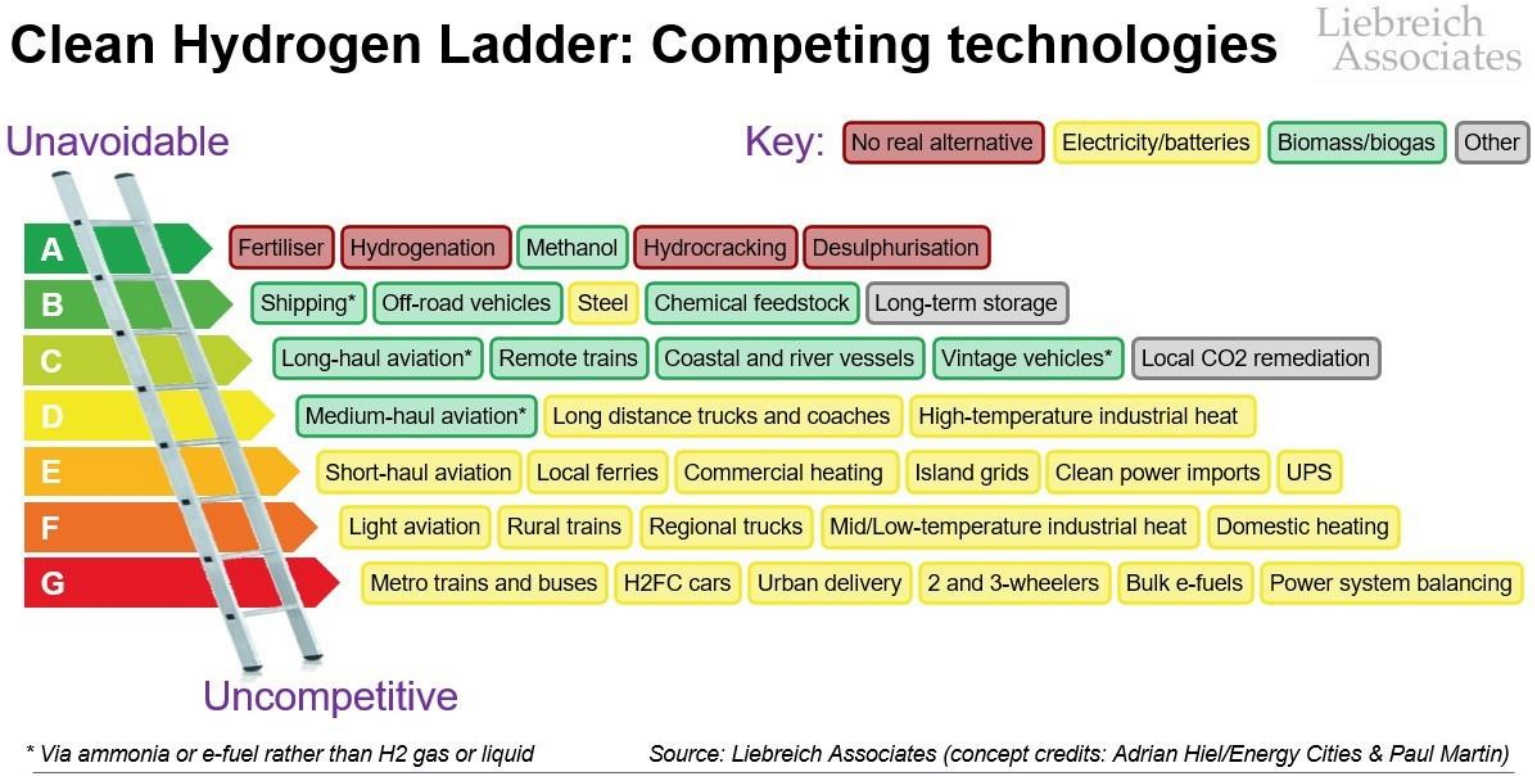
Source: Adapted from S. J. Davis et al., *Science* **360** (2018). DOI: 10.1126/science.aas9793

Hydrogen (+derivatives) have strong potential demand for some sectors, but other use cases are less certain



Source: DOE-Pathways to Commercial Liftoff: Clean Hydrogen liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

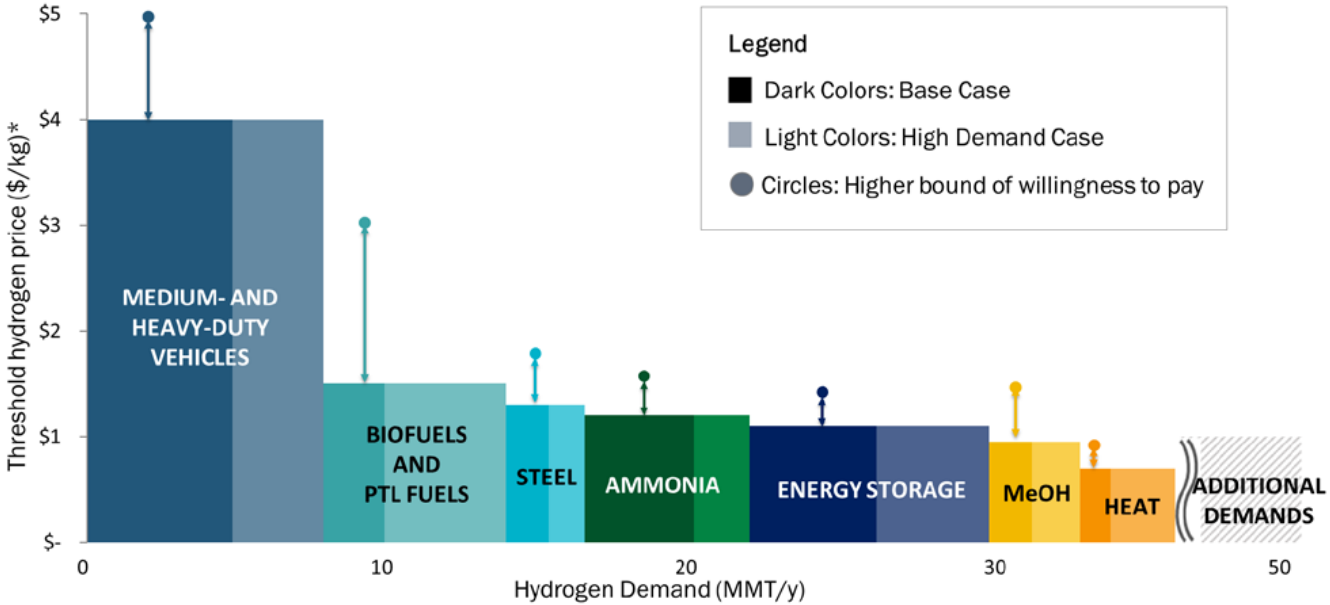
Potential uses for hydrogen compete against the next lowest-cost alternative technology



Source: www.linkedin.com/pulse/clean-hydrogen-ladder-v40-michael-liebreich/

Delivered price of hydrogen may impact early market opportunities and rate of near-term demand growth

U.S. Hydrogen Demand vs. Threshold Price, by Sector



Total H_2 Potential Demand

- Trucks: ≃ 10%-15% total energy
- Aviation: 100% sustainable aviation fuel using hydrogen
- Steelmaking: ≃ 10% using H_2
- Ammonia: 100%
- ≃50% of methanol
- Blends with natural gas for high-temperature heat (?)
- Additional applications include stationary power, synfuels, and exports (?)

*Price at point of use (includes production, storage, delivery, and dispensing)

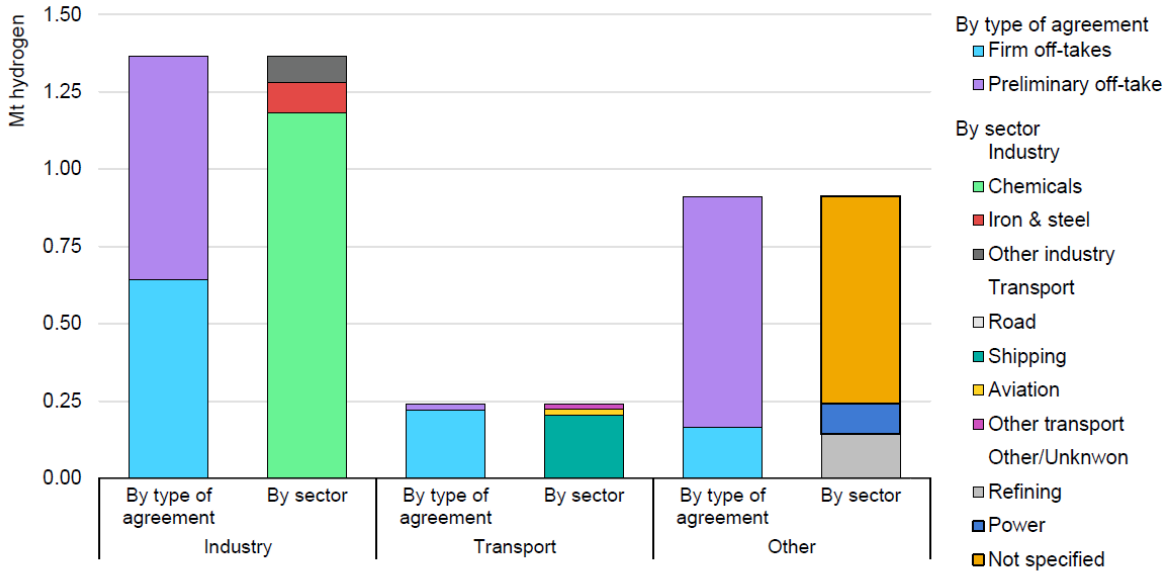
PTL: Power-to-Liquids
MeOH: Methanol

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

Most H_2 demand by 2030 will likely be as a drop-in replacement for existing industrial uses, especially ammonia and refining

Worldwide Hydrogen Demand

Figure 2.13 Potential demand for low-emission hydrogen that can be achieved with announced private off-take agreements by 2030



IEA. CC BY 4.0.

Source: IEA Global Hydrogen Review 2023 www.iea.org/reports/global-hydrogen-review-2023

Early 2030s H_2 Demands

Likely large demands

- Ammonia
- Refining
- Methanol

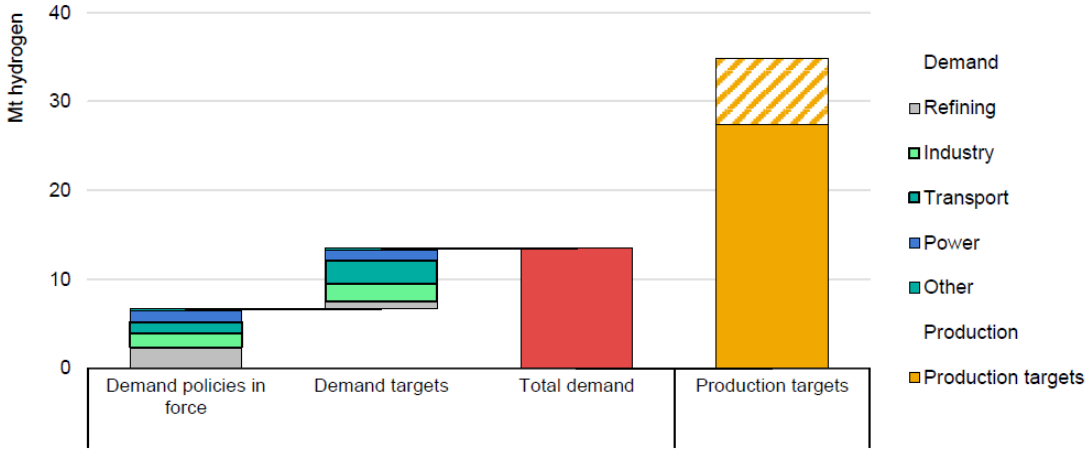
Smaller demands

- Transportation fuel (H_2 and/or derivatives)
- Feedstock for sustainable aviation fuel (SAF) and other synthetic or green fuels
- Natural gas blending projects (including power generation)

Uncertainty about actual hydrogen demand through the early 2030s is seen as a major risk for market players

- Current targets for H_2 production are **2-2.5x higher** than targets for H_2 demand
- Likely, additional policies and support may be needed to bolster demand during early stages of market development
  - High cost of hydrogen + high cost of switching for many uses

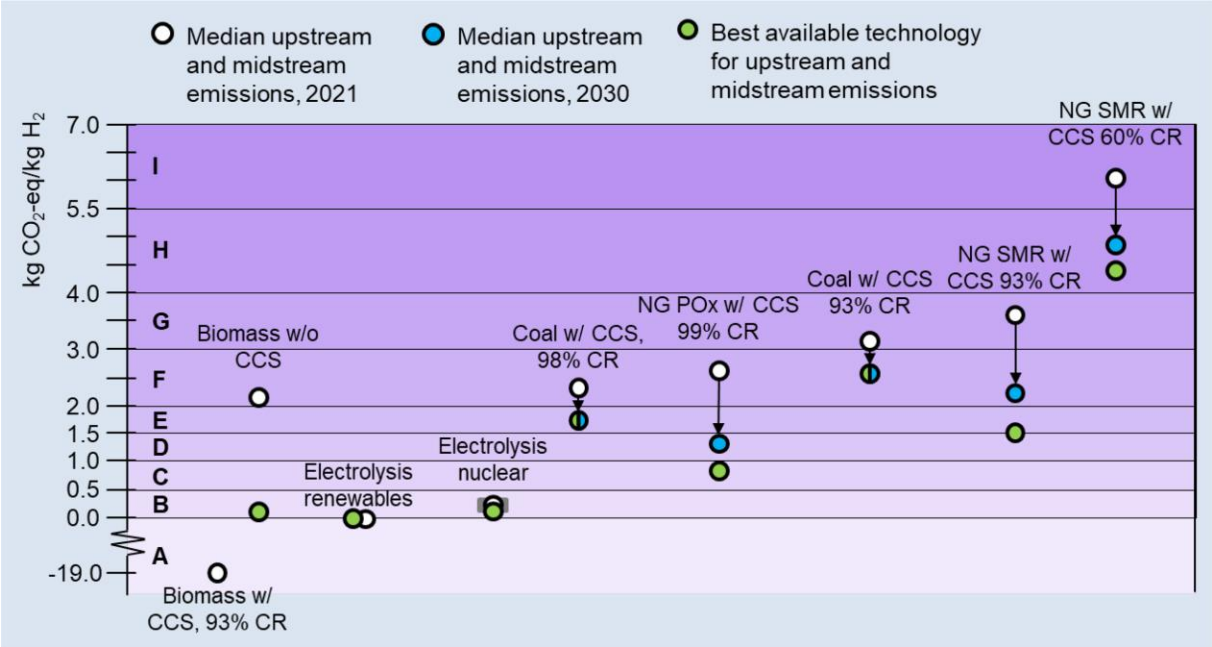
Figure 2.12 Potential demand for low-emission hydrogen created by implemented policies and government targets, and production targeted by governments, 2030



Source: IEA Global Hydrogen Review 2023 www.iea.org/reports/global-hydrogen-review-2023

National and global standards/certifications defining “low-carbon”, “renewable” and/or “clean” H_2 may impact market opportunities for each

Example Potential Quantitative System for Emission Intensity Levels of H_2 Production



Examples:

- CertifHy certificates
- ISO/TS 19870
- IPHE* Emissions Standards

- (In U.S.) 3 Pillars of Clean Hydrogen
  - Time matching (hourly)
  - Additionality
  - Regionality

* International Partnership for Hydrogen and Fuel Cells in the Economy

Source: IEA Global Hydrogen Review 2023 www.iea.org/reports/global-hydrogen-review-2023

Hydrogen Export Markets

Tradeoffs between export product types and total delivered costs depend on the planned end-use

Pure Hydrogen (€/kg)

- Total cost for carrier production, storage, transmission, and decomposition
- Uncertain target market price and rate of market growth through the early 2030s

Energy Carriers and Fuels (€/MWh, €/L, or €/ton)

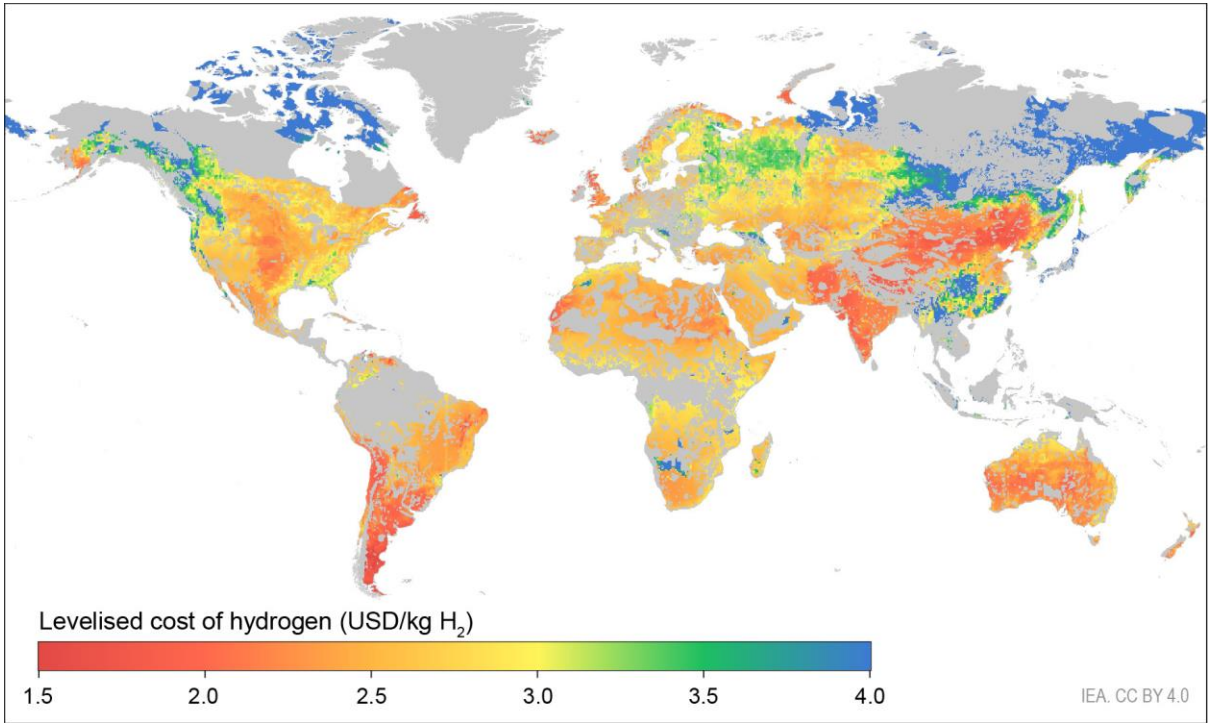
- Either pure H_2 or derivative
- End-use cost competes against next-best alternative (e.g., batteries, biofuels)

Industrial Chemicals (€/ton)

- Derivative as the final product
- Known global market prices, ranges, and sizes based on fossil-based incumbents

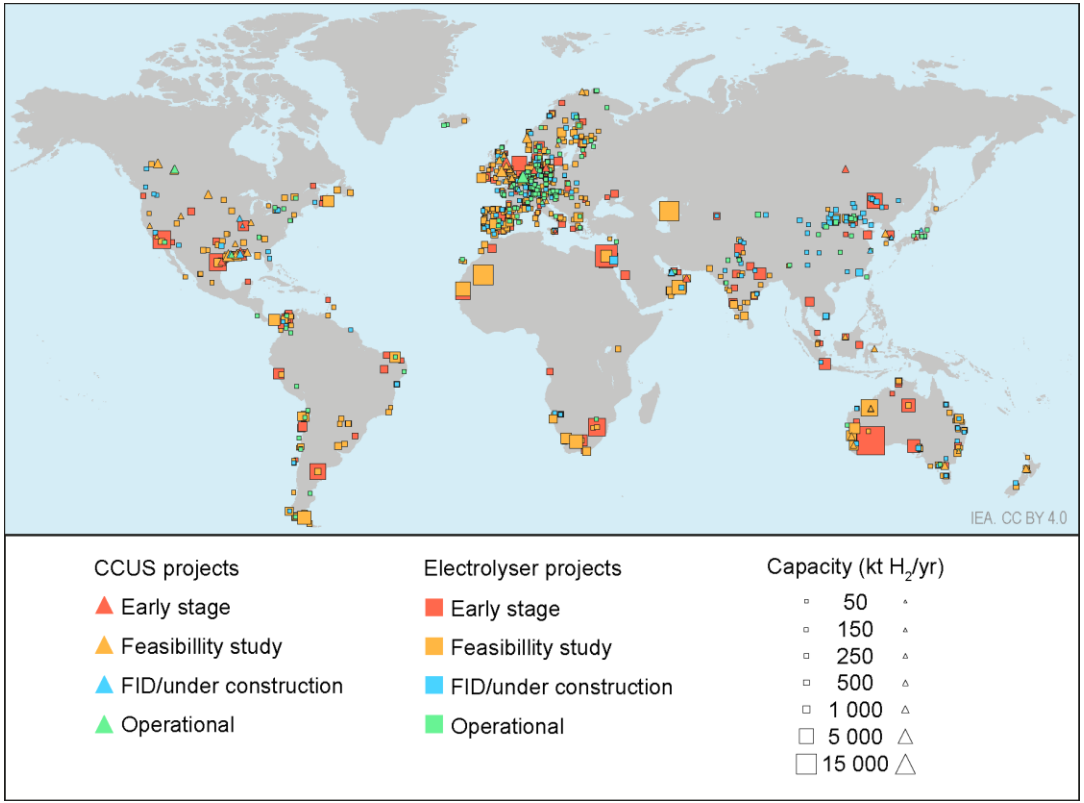
Regions with good renewable resources have the potential to produce low-cost hydrogen (as low as $1.5/kg by 2030)

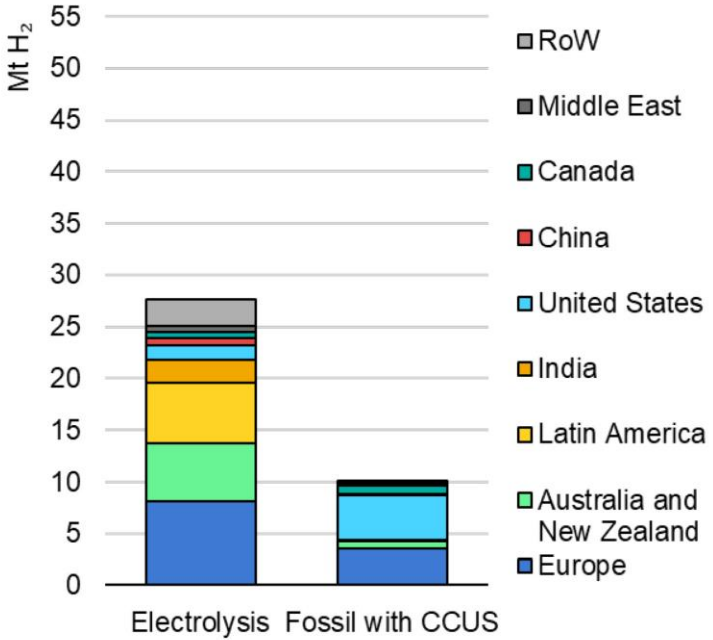
Hydrogen production cost from hybrid solar PV and onshore wind, 2030



Source: IEA Global Hydrogen Review 2023 www.iea.org/reports/global-hydrogen-review-2023

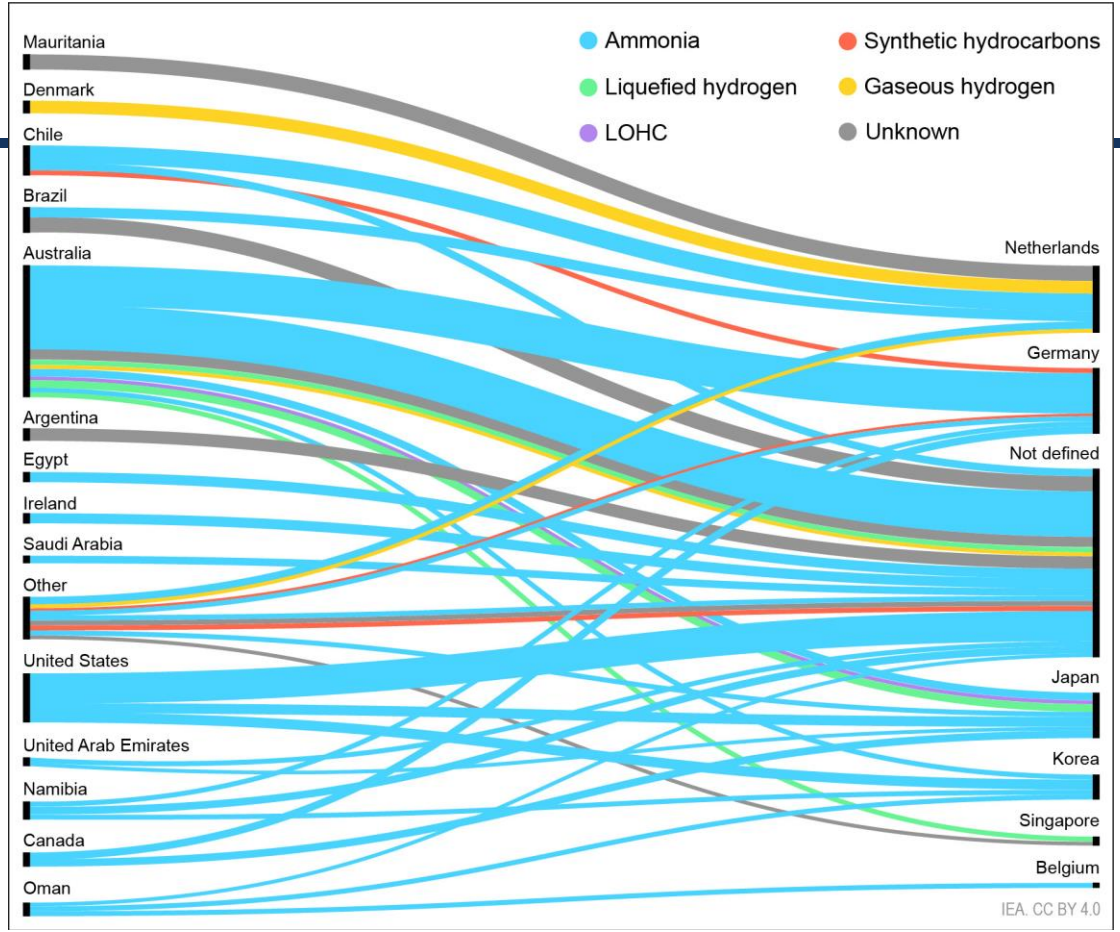
Current announced H_2 projects concentrated in Europe (high demand) and in high-RE (low H_2 cost) regions





Proposed H_2 Exports

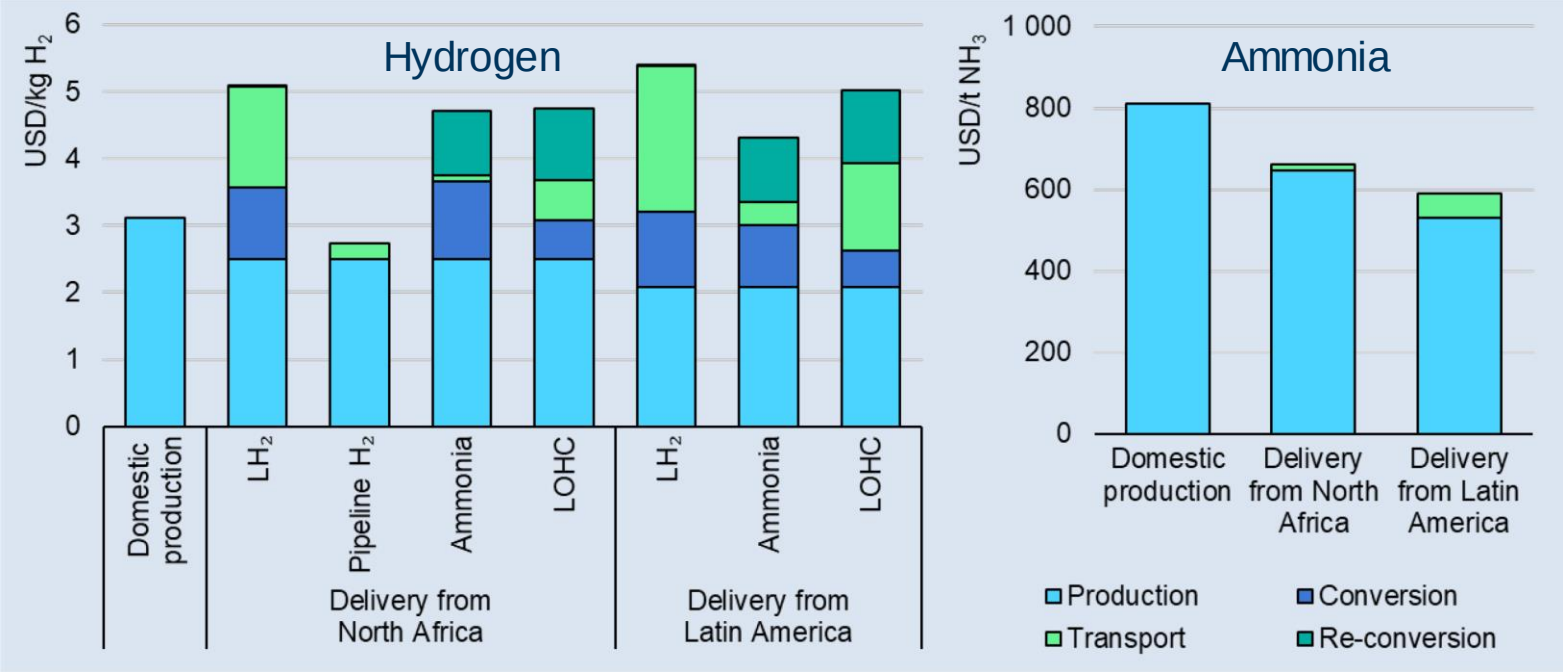
- An increasing number of export/import proposals worldwide
  - Major importers include Germany, Netherlands, Japan, and Korea
- However, 60% of currently proposed export projects do not have an identified destination country
- 80% of the planned export volume is for ammonia, primarily as the end-use product



Source: IEA Global Hydrogen Review 2023 www.iea.org/reports/global-hydrogen-review-2023

Total supply chain costs for H_2 exports compete with local production, so market competitiveness may vary

Domestic estimated production costs for Northern Europe compared to imports, 2030

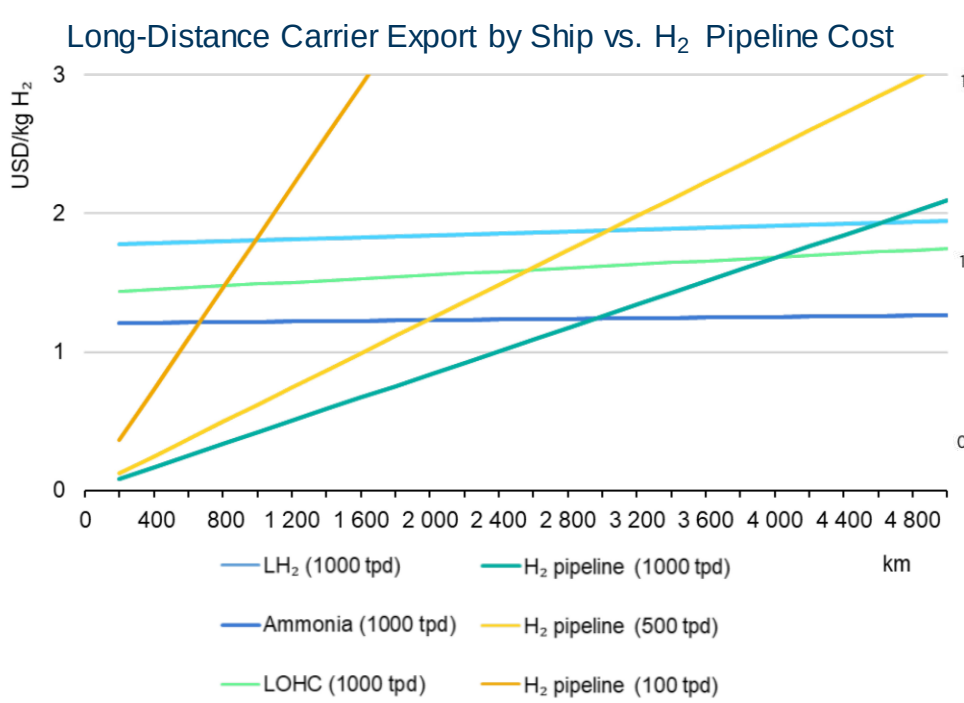


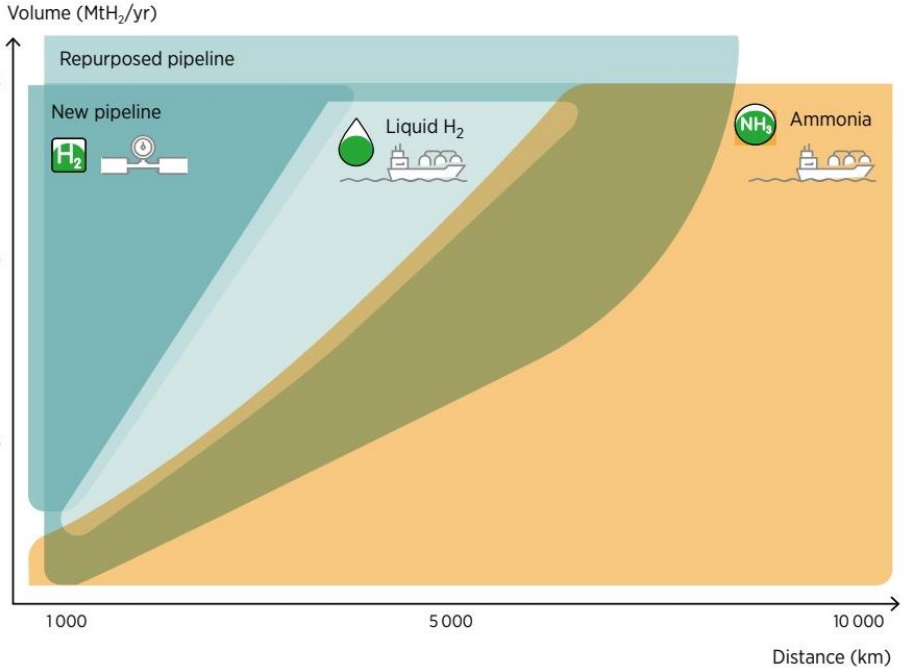
Source: IEA Global Hydrogen Review 2023 www.iea.org/reports/global-hydrogen-review-2023

Supply chain costs for exports include carrier conversion, transportation, storage, and potentially re-conversion

Carrier	Conversion	Transportation	Storage	Reconversion
H_2 Gas	None	Pipelines are low cost, but other options are high cost	Low cost when geologic storage available, otherwise very high cost	None
Liquid H_2	Very high cost (up to \$1.5-3/kg H_2)	Shipping costs are higher than ammonia	Moderate, but requires continuous cooling to mitigate boil-off losses	Minimal
Ammonia	Moderate (~\$1/kg H_2)	Shipping costs are relatively low; rail and pipeline are also options	Low cost	Moderate, but increases total delivered costs for pure H_2 end-uses
Methanol	Moderate, but depends on CO_2 cost			
Liquid Organic Hydrogen Carrier (LOHC)	Moderate, depending on the carrier	Many LOHCs require round-trip transportation, increasing costs		

Lowest cost carrier for H_2 export depends on distance, availability of H_2 pipelines, and other supply chain costs

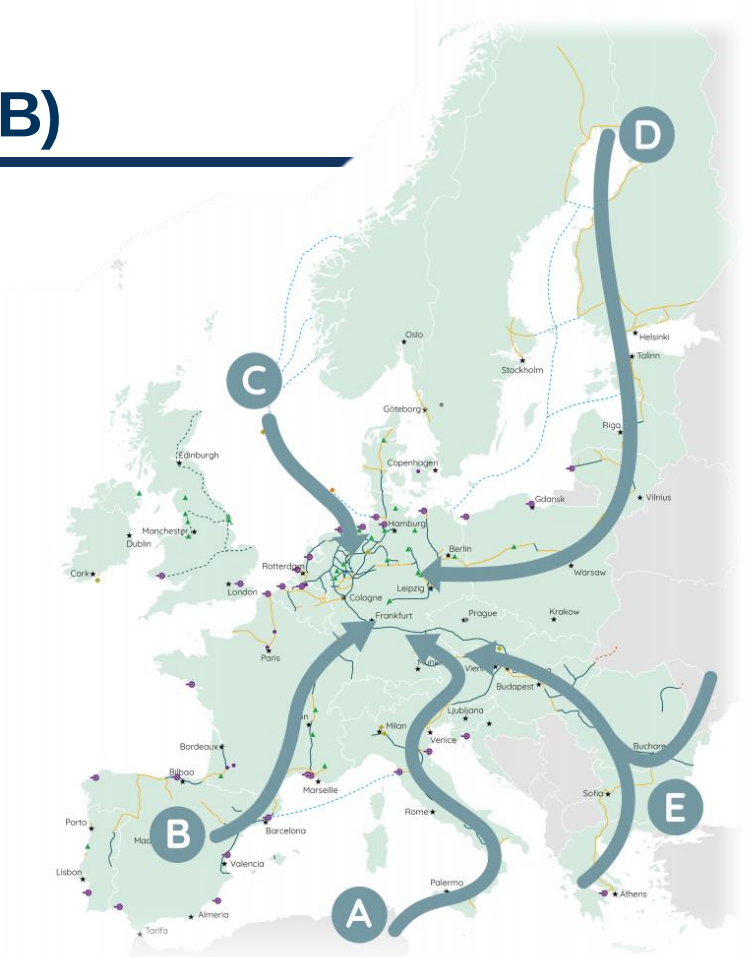




Source: (Left) IEA Global Hydrogen Review 2021 www.iea.org/reports/global-hydrogen-review-2021
(Right) IRENA www.irena.org/Digital-Report/Geopolitics-of-the-Energy-Transformation#page-2

Export Example: European Hydrogen Backbone (EHB)

- Proposed pan-European hydrogen pipeline network
- Completion goal of early 2030s
- Interconnect major supply, storage, and demand regions
  - Germany expected to be a major hydrogen importer
  - Netherlands began construction of new H2 pipeline section in Oct 2023
- Current challenges of rising costs and investment recovery during early stages of market development



Source: European Hydrogen Backbone ehb.eu/newsitems#ehb-publishes-five-potential-hydrogen-supply-corridors-to-meet-europe-s-accelerated-2030-hydrogen-goals

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Thank you!

Jesse R. Cruce | jesse.cruce@nrel.gov

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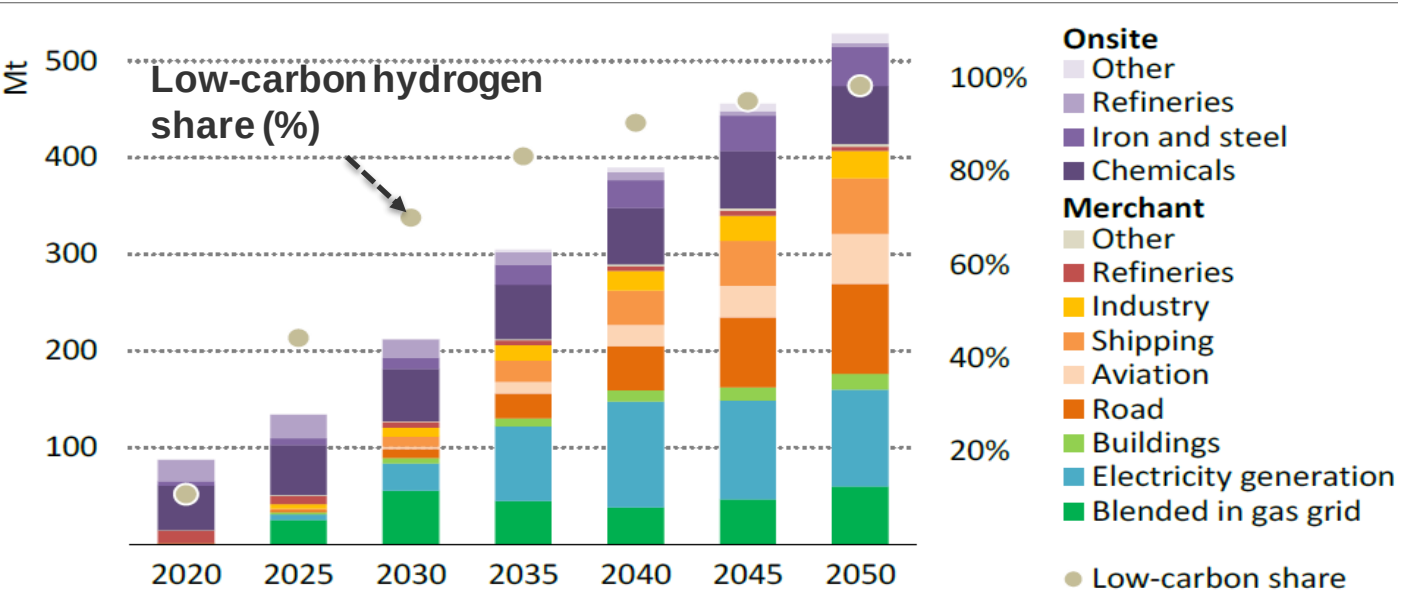
Overview of the RODeO™ Tool: Unlocking the Potential of Hydrogen Technologies

Presented by Omar Guerra, National Renewable Energy Laboratory

Hydrogen Deployment Pathway for a Net-Zero Emissions Energy Sector by 2050



- Hydrogen demand is projected to grow (> 5-fold increase from 2020 to 2050)
- Diversified hydrogen demand (new applications, e.g., hydrogen blending, seasonal storage, etc.)
- Decarbonized hydrogen production (new technologies, e.g., renewable-driven water electrolysis)

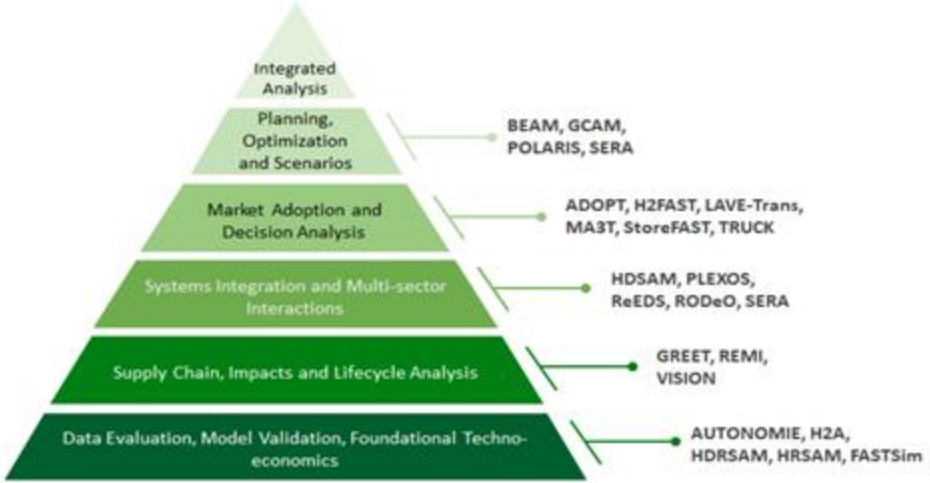
Ref: https://www.iea.org/reports/net-zero-by-2050

Near-Term Opportunities

- Refineries
- Ammonia production
- Blending with Natural Gas

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).

- **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.

RODeO™ - Revenue, Operation, and Device Optimization tool

- Before RODeO™, hydrogen technologies were analyzed as **constant electrical loads or generators** and could not easily consider **multi-sector integration**.
- However, with the transition to a more renewable energy system load and generation should be **more flexible**.

- In partnership with the Department of Energy's (DOE) Hydrogen and Fuel Cell Technology Office, and the California Air Resources Board, we developed RODeO™.
- RODeO™ is **open-source, advanced optimization** tool to consider multi-sector, multi-value stream, flexible operation of hydrogen systems to **lower their energy costs**, **improve performance**, and **achieve environmental goals**.

Working together with public and private sectors to unlock the potential of hydrogen technologies

Public entities

- DOE Hydrogen and Fuel Cell Technologies Office
- DOE Water Power Technologies Office
- California Air Resources Board (CARB)
- California Energy Commission
- University of California, Irvine

RODeO™

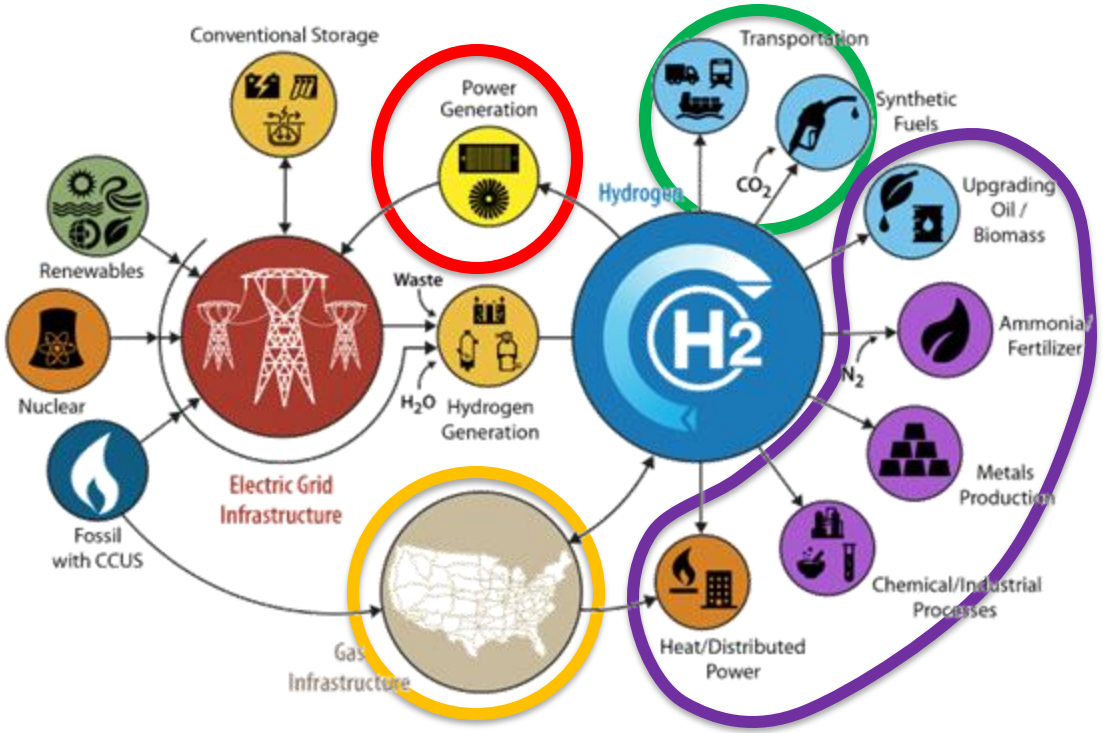
Revenue, Operation, and Device Optimization

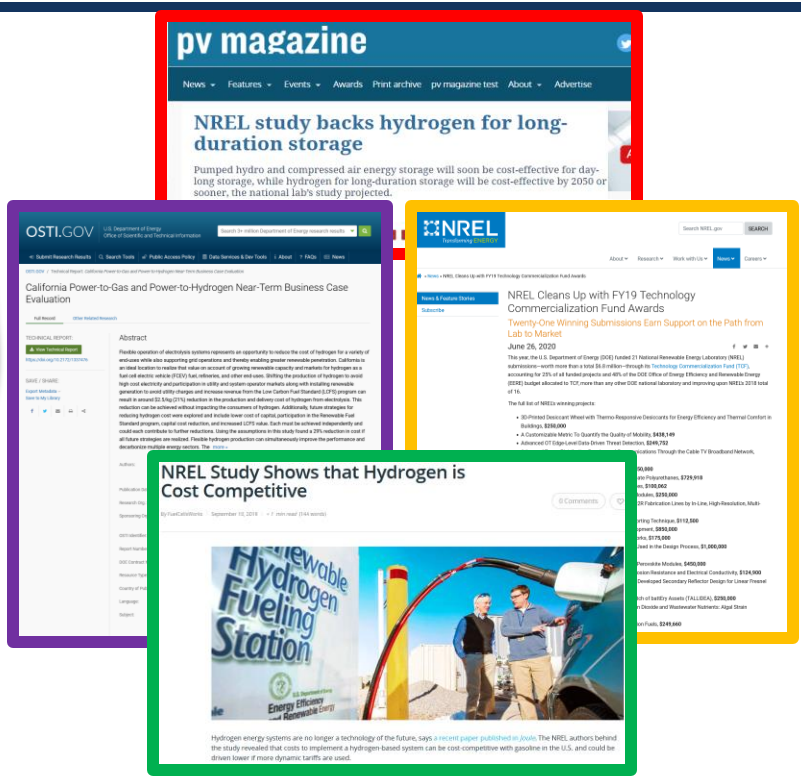
- RODeO has been used in more than 15 projects involving the public and private sectors
- RODeO's project budgets total around $2.5 million dollars

Private entities

- PG&E
- SoCalGas
- EPRI
- Antora Energy
- Woodside
- Statoil
- Versa power
- Valley Transit Authority

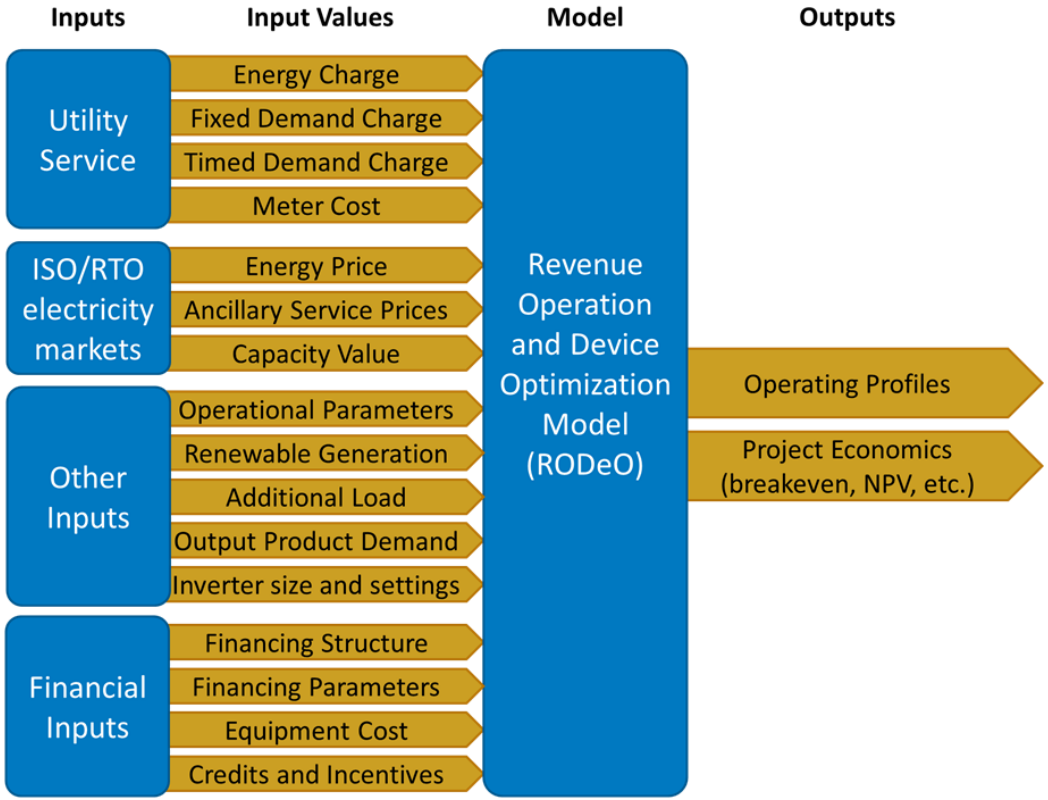
RODeO™ identifies opportunities for hydrogen technologies





Source: U.S. Department of Energy
Hydrogen and Fuel Cell Technologies Office

RODeO™: Model Structure



RODeO™

Revenue, Operation, and Device Optimization

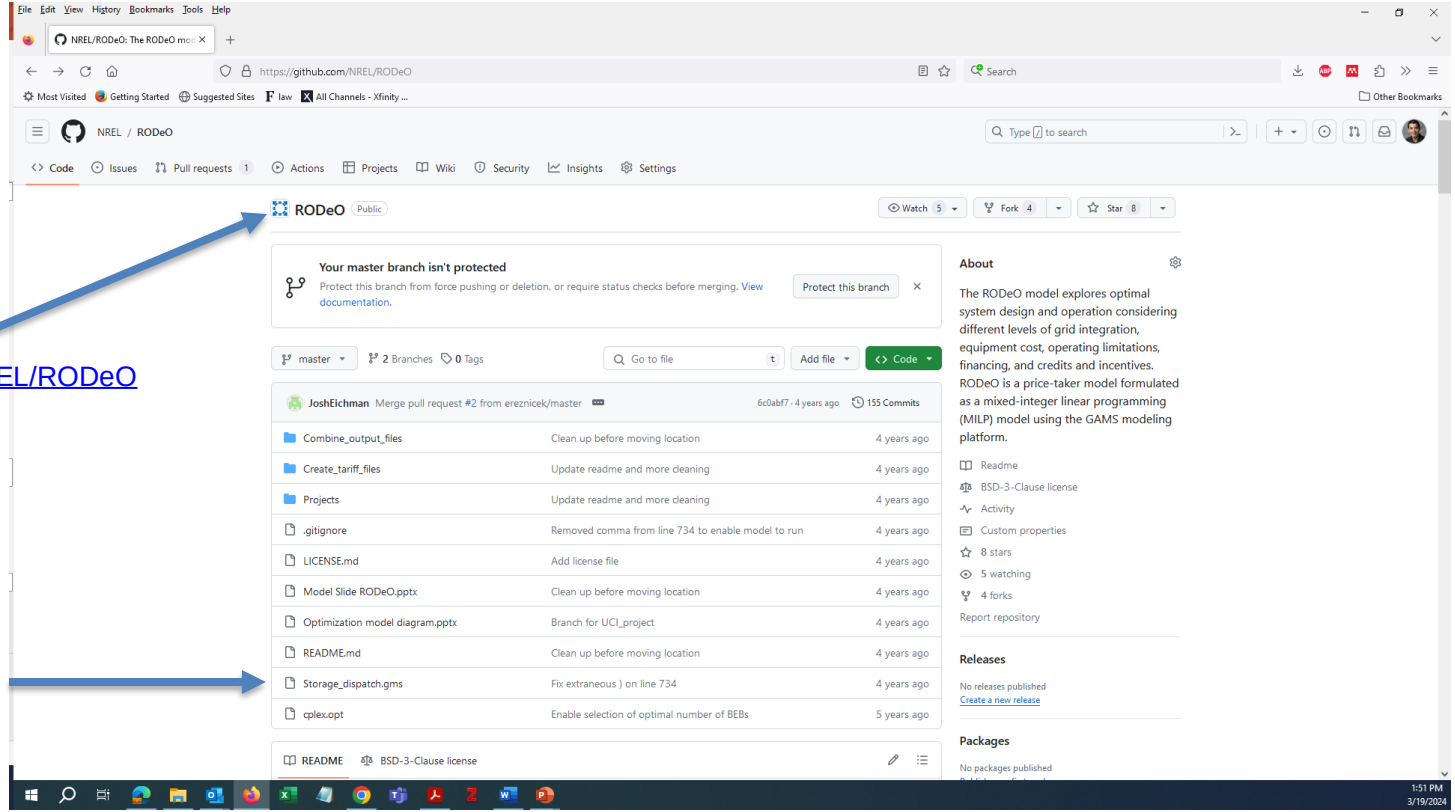
Applications

- Multi-market optimization
- Hydrogen business case assessment
- Wholesale market revenue comparison
- Retail rate optimization
- Solar PV + Storage
- Real-time optimization control of electrolyzer
- Vehicle fleet optimization

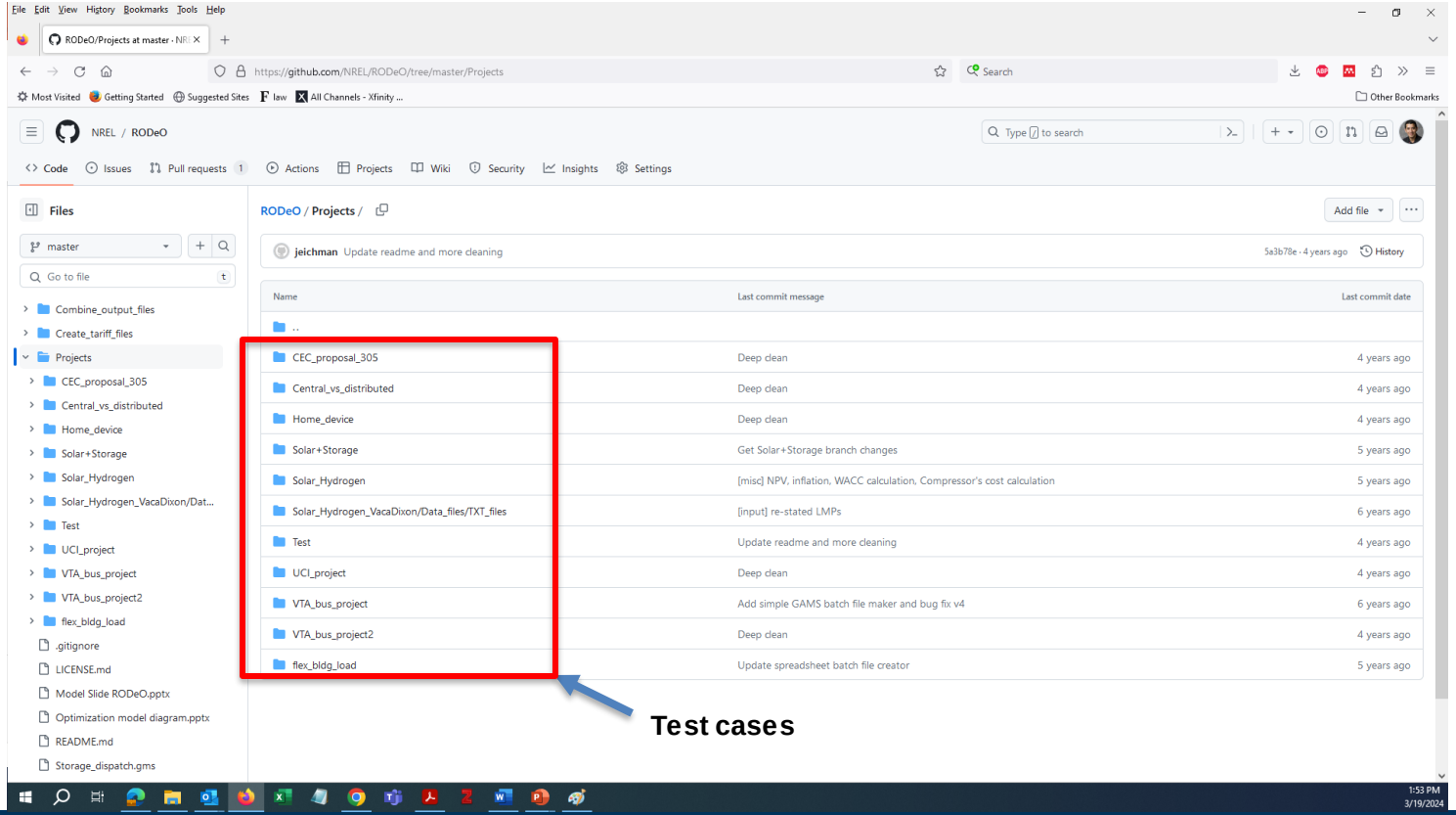
How to get RODeO™?

https://github.com/NREL/RODeO

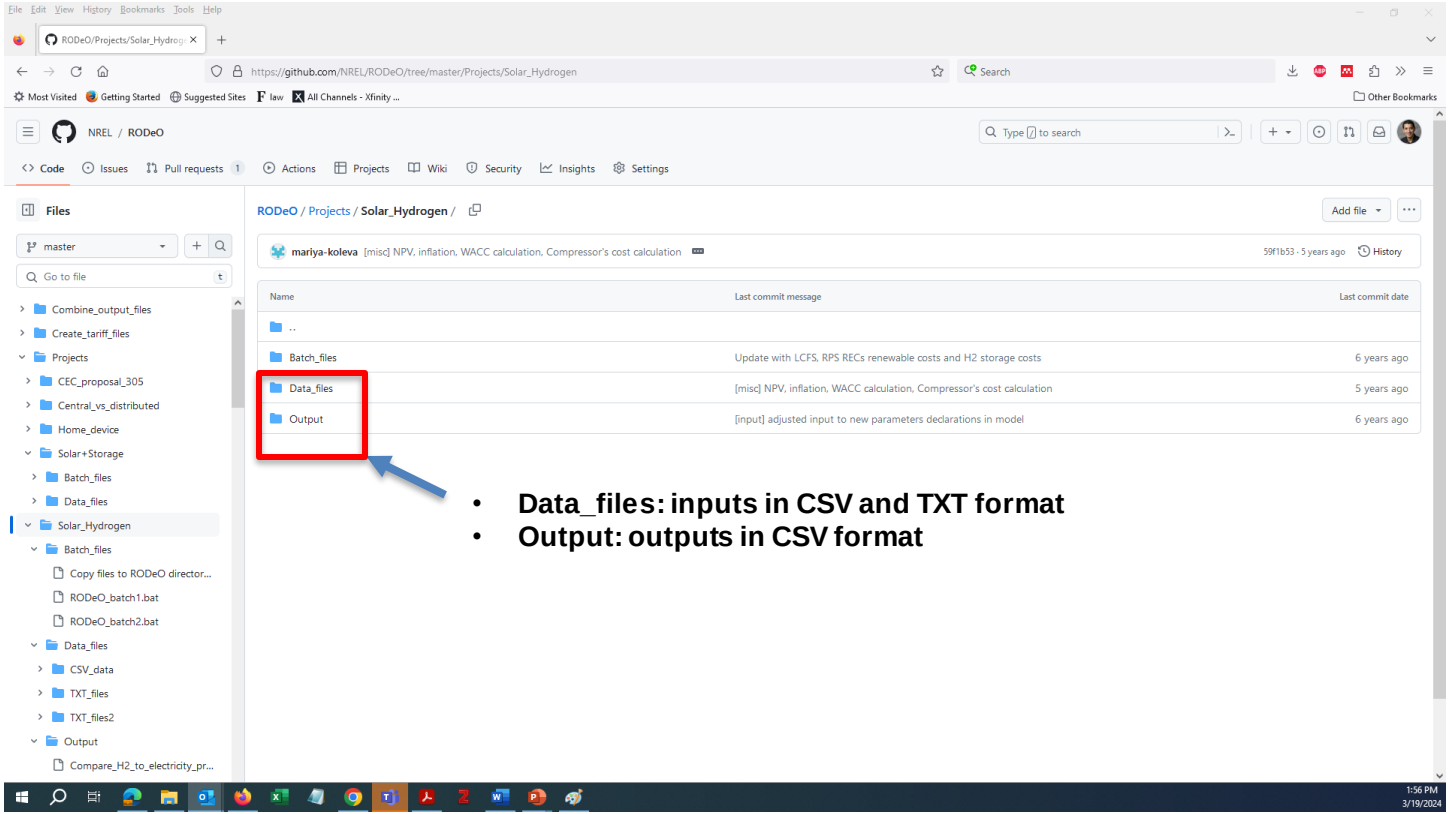
RODeO model



How to get RODeO™?

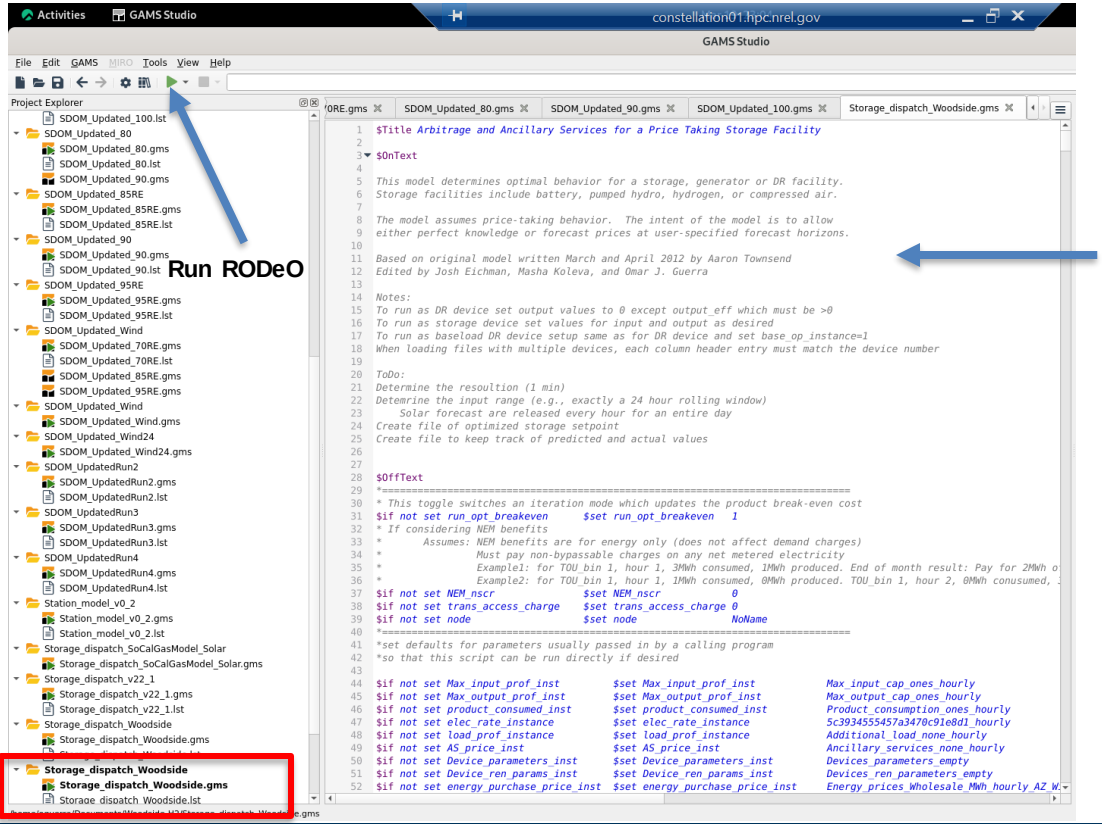


How to get RODeO™?



- **Data_files: inputs in CSV and TXT format**
- **Output: outputs in CSV format**

How to run RODeO™?



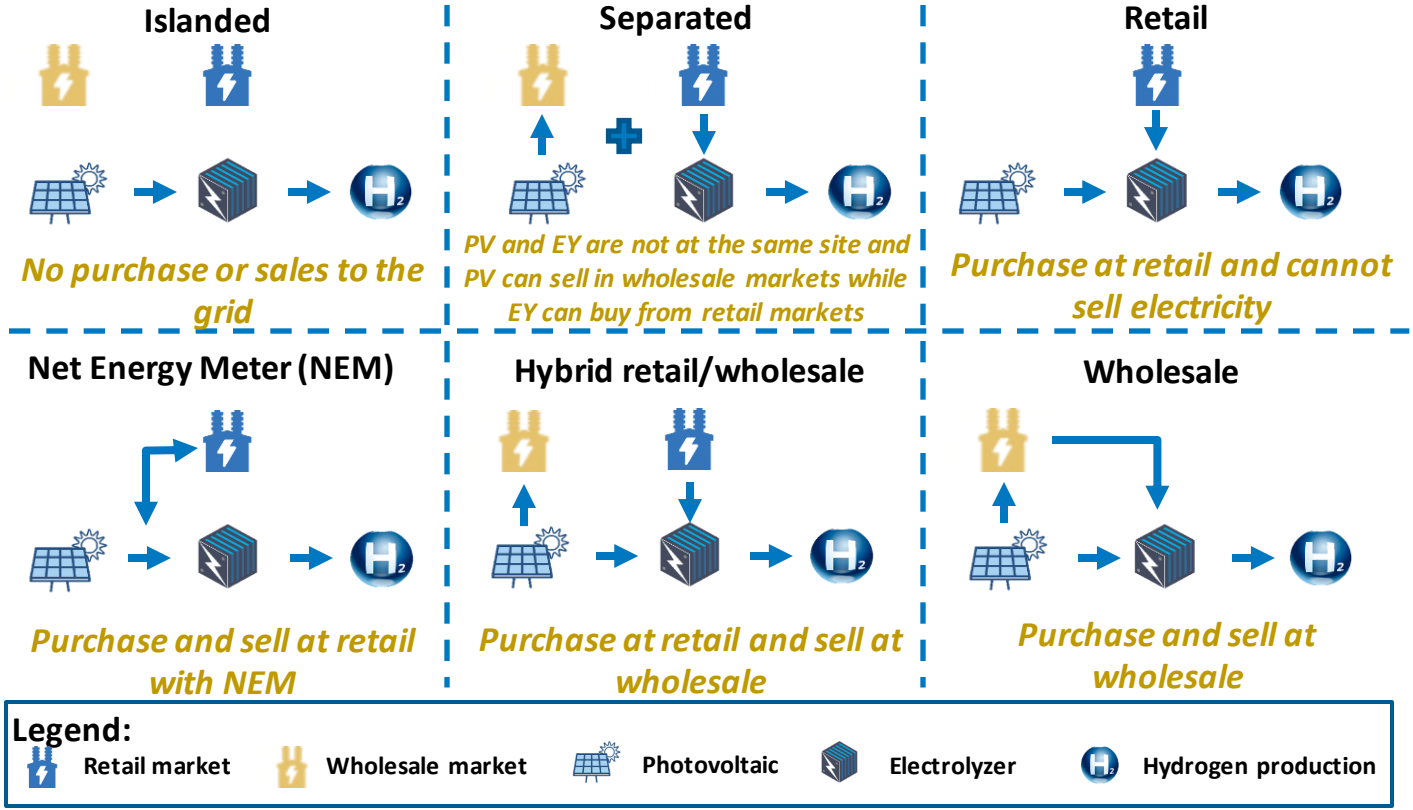
Run RODeO

Description of the model RODeO

Folder with the model and data

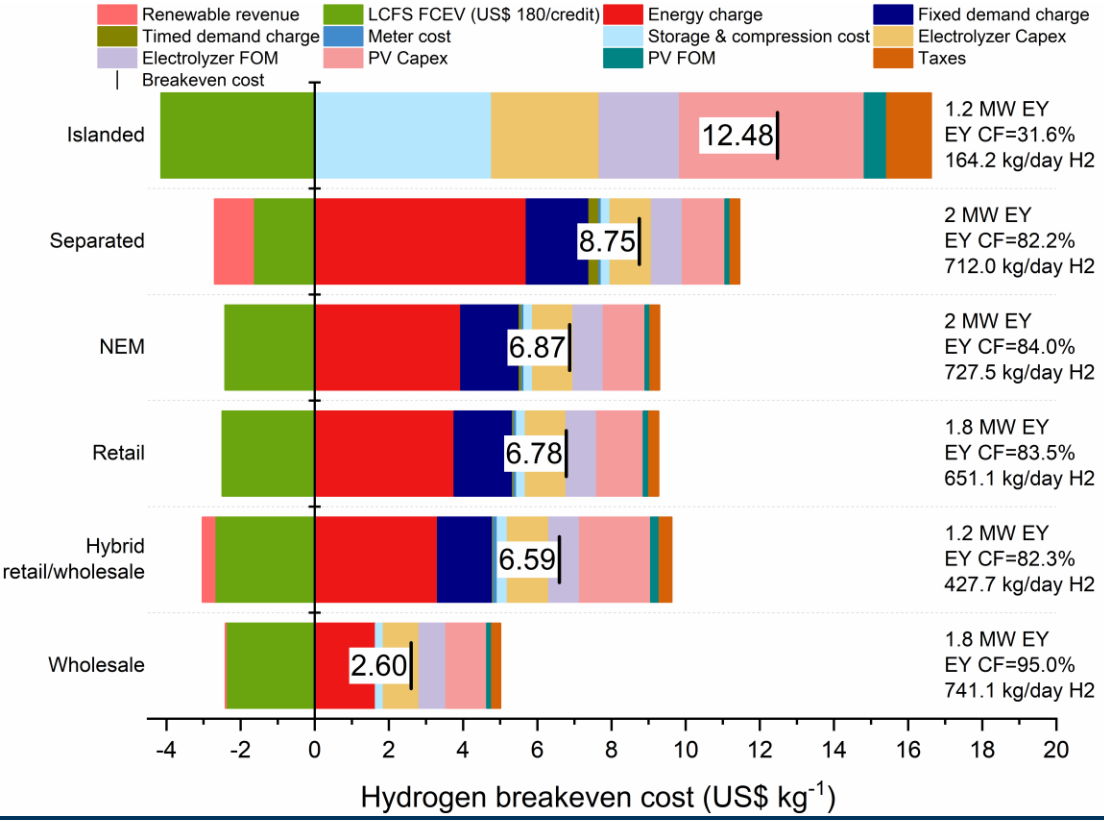
Image Source: Sam Booth, NREL

What does RODeO™ do?



Market configurations (analysis includes production, compression and storage)

What does RODeO™ provide?



Key Outputs

- RODeO can provide the hydrogen cost breakdown for each system configuration and scenario.
- RODeO helps to identify cost drivers and targets for clean hydrogen technologies.
- RODeO helps to identify optimal design and operation for hydrogen systems

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Thank you!

Omar Jose Guerra Fernandez | omarjose.guerrafernandez@nrel.gov

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Thank you!

Questions? Contact Expert@CleanEnergySolutions.org.

The next installment in this series will focus on international hydrogen landscapes.

Register today!