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

Technical Considerations

Hydrogen and Analytical Tools Webinar Series

March 6, 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.
- 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!

CLEAN ENERGY SOLUTIONS CENTER
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An Initiative of the Clean Energy Ministerial

Webinar & Speaker Introductions

Presented by Holly Darrow, NREL

Agenda

- Overview of the Clean Energy Solutions Center
- Technical considerations and challenges of hydrogen production, storage, and transport
- H2A/H2A-Lite Demonstration and Overview
- Q&A

Webinar Speakers

Holly Darrow

Project Lead

National Renewable Energy Laboratory

Misho Penev

Hydrogen Researcher

National Renewable Energy Laboratory

Jamie Kee

Hydrogen Researcher

National Renewable Energy Laboratory

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An Initiative of the Clean Energy Ministerial

Clean Energy Solutions Center

Presented by Aaron Ng, CESC

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

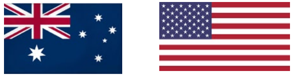
Many developing governments lack capacity to design and adopt policies and programs that support the deployment of clean energy technologies.

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.

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

isa INTERNATIONAL SOLAR ALLIANCE

Expert Connections Empower
Bankable Solar Projects

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

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Technical considerations and challenges of hydrogen production, storage, and transport

Presented by Jamie Kee, Michael (Misho) Penev

March 06, 2024

Outline

Introduction

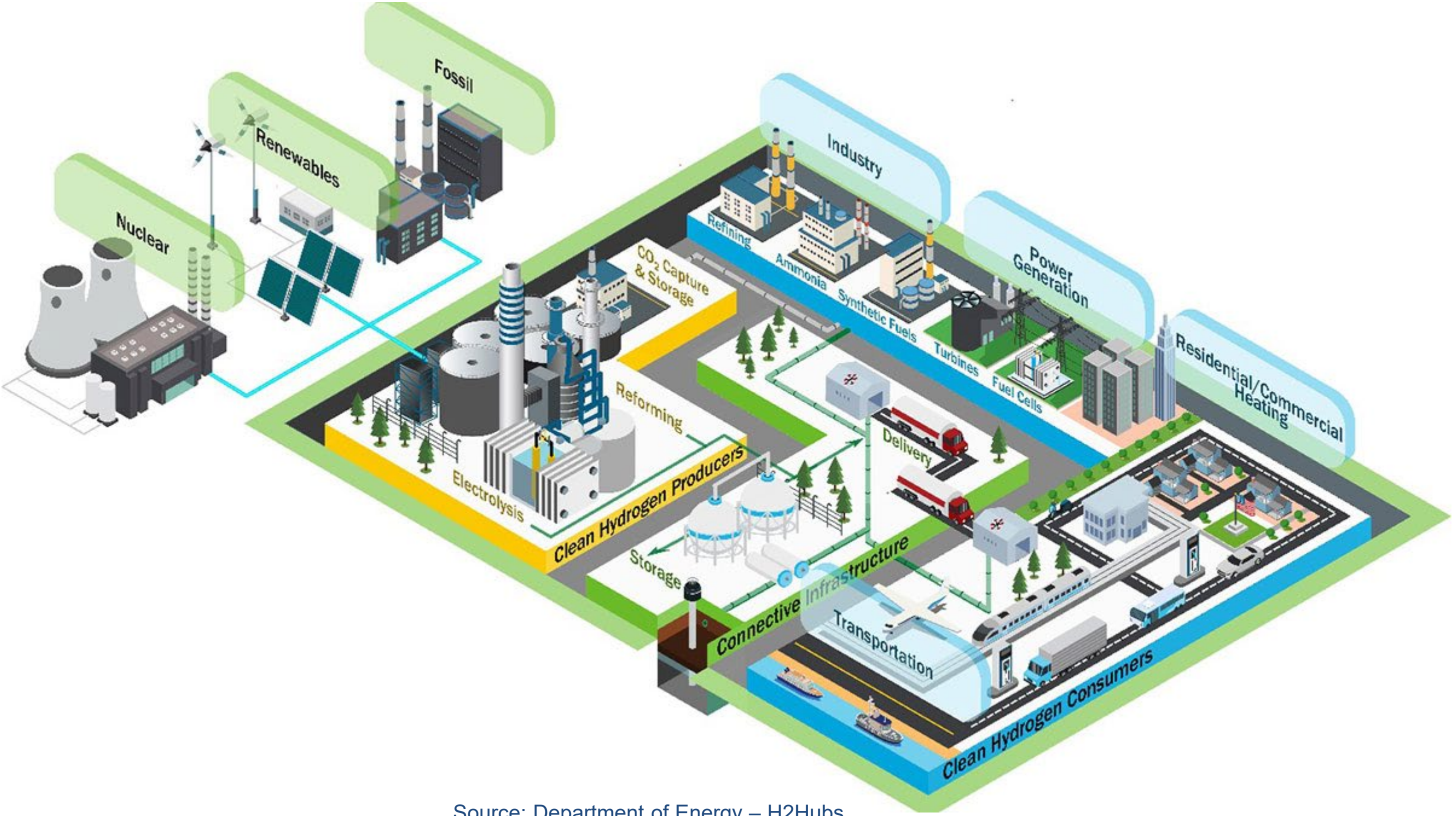
Production

Transportation of Hydrogen

Storage

H2A-Lite

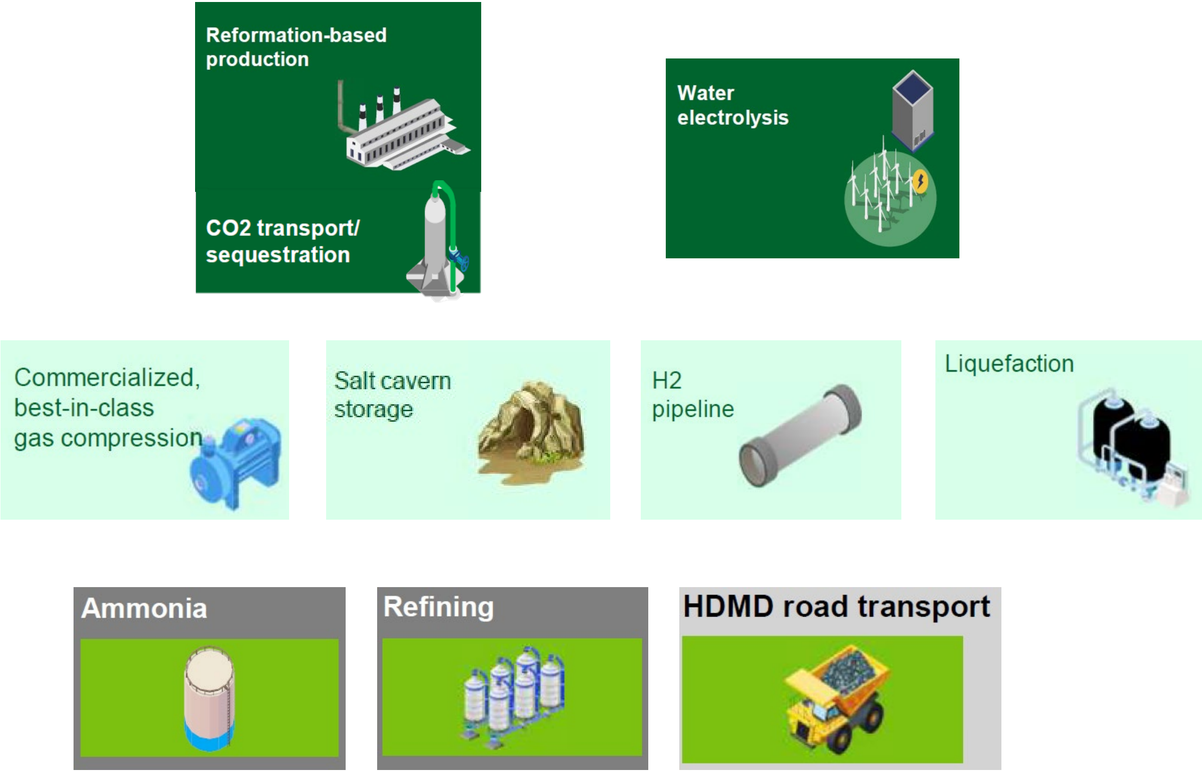
Hydrogen requires connective infrastructure



Source: Department of Energy – H2Hubs

The hydrogen value chain can be divided into 3 categories

- Upstream
  - Production
- Midstream
  - Transportation
  - Storage
- Downstream
  - End-use



Reformation-based production

CO2 transport/ sequestration

Water electrolysis

Commercialized, best-in-class gas compression

Salt cavern storage

H2 pipeline

Liquefaction

Ammonia

Refining

HDMD road transport

Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Outline

Introduction

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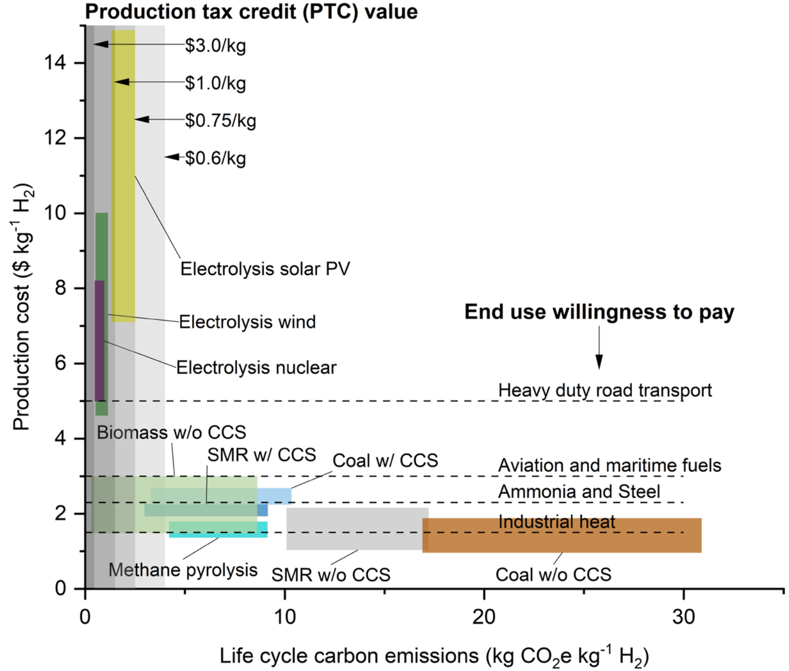
H2A-Lite

Carbon emissions from hydrogen production varies based on the feedstocks and production pathway

Quantifying life cycle carbon emissions is more descriptive than hydrogen colors

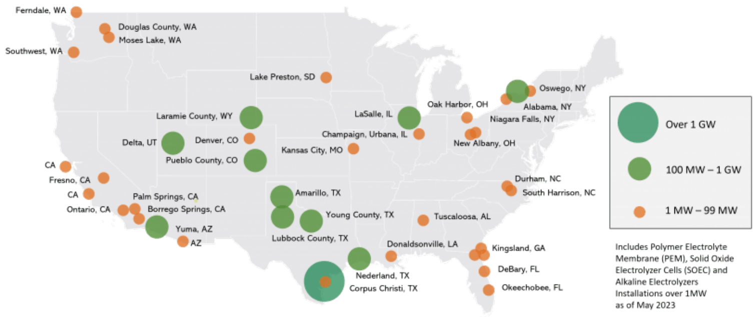
Color	Energy Source	Mode of Production
White	Natural geologic formations	Natural fracking
Green	Renewable energy	Water electrolysis
Yellow	Solar	Water electrolysis
No Color	Biomass	Gasification
Red	Nuclear	Catalytic splitting
Purple/Pink	Nuclear	Water electrolysis
Turquoise	Natural gas	Pyrolysis
Blue	Natural gas	Steam reforming + CCS
Gray	Natural gas	Steam reforming
Black/Brown	Coal (lignite and bituminous coal)	Gasification



Derived from: Parkinson, B., P. Balcombe, J.F. Spiers, A.D. Hawkes, and K. Hellgardt. 2018. “Levelized cost of CO2 mitigation from hydrogen production routes. *Energy & Environmental Science* 12: 19-40. https://pubs.rsc.org/en/content/articlelanding/2019/ee/c8ee02079e and https://www.nrel.gov/docs/fy22osti/82554.pdf.

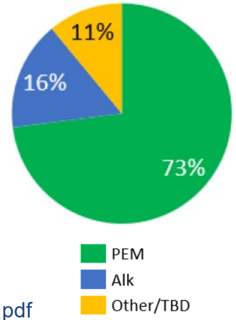
Electrolysis can produce clean hydrogen

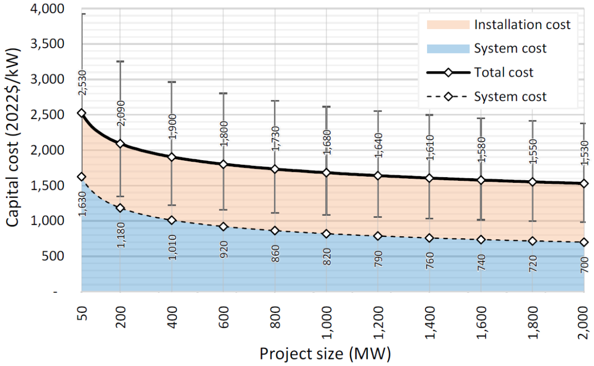
Technology	Applications	Degree of maturity	Advantages	Disadvantages
Alkaline Water Electrolysis (AWE)	Industrial applications (e.g., ammonia, refining, steel, chemicals)	Established technology; commercial stage	Cost-effective, mature technology No PGM[4] catalysts	Low current density Corrosive electrolyte
Proton Exchange Membrane (PEM)	Diverse use cases, including road transport Distributed hydrogen production Grid balancing	Increasing scale-up; commercial stage	Simple cell design and small footprint High current density Differential pressure operations High dynamic response	Scale-up constrained by PGM supply and PFAS[5] usage Less demonstration of long-term durability vs. AWE
Solid Oxide Electrolysis Cell (SOEC)	Low purity industrial use cases Co-location with high temperature steam	Laboratory / early commercial stage	Low electricity demand using steam (high efficiency) No PGM catalysts	Heat / steam source required Limited dynamic response Durability challenges with high-temperature operations



Includes Polymer Electrolyte Membrane (PEM), Solid Oxide Electrolyzer Cells (SOEC) and Alkaline Electrolyzers Installations over 1MW as of May 2023

Planned and existing PEM, SOEC, AWE electrolyzer installations above 1 MW in the United States as of May 2023



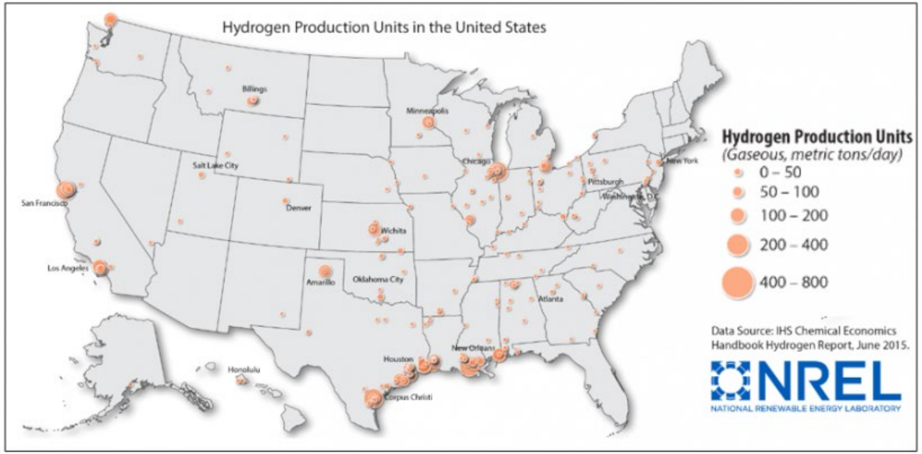


Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf
Arjona, V., DOE Hydrogen Program Record 23003, June 2023.
https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/24002-summary-electrolyzer-cost-data.pdf

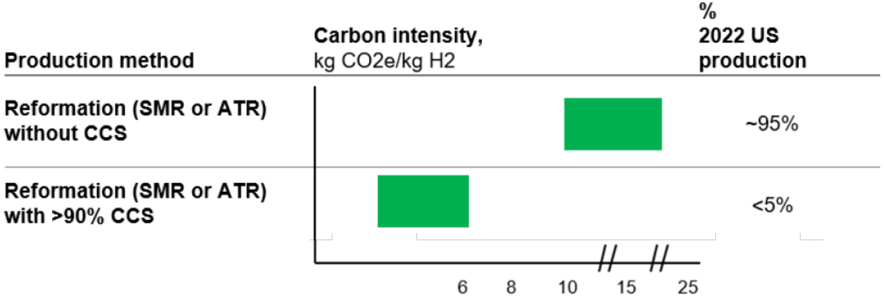
Natural gas reforming can create clean hydrogen with CCS

Natural gas reforming

- Majority of hydrogen produced today is from natural gas reforming
- Steam methane reforming (SMR) and auto-thermal reforming (ATR) both can currently produce hydrogen at scale
- Reforming products have high carbon intensity which can be mitigated with carbon capture and sequestration (CCS)
    - Point source capture technologies such as amine-based solvents



Source: https://www.energy.gov/eere/fuelcells/fact-month-may-2018-10-million-metric-tons-hydrogen-produced-annually-united-states



Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Outline

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H2A-Lite

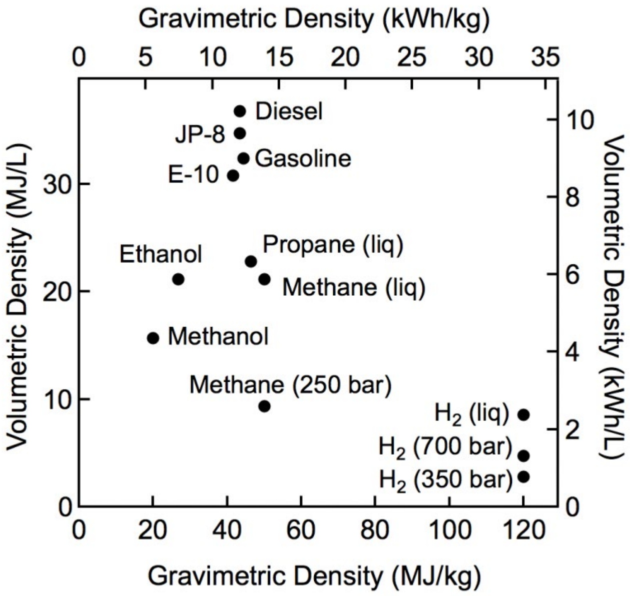
Prior to transportation, hydrogen must be compressed or liquified due to low volumetric density

Gas phase compression:

- Majority of hydrogen compressors today are mechanical compressors
  - Reciprocating, rotary, ion, centrifugal
  - Interstage cooling
- Non-mechanical alternatives exist
  - Electrochemical, metal hydride
- Operating the production method at higher pressure can reduce downstream compression

Liquefaction:

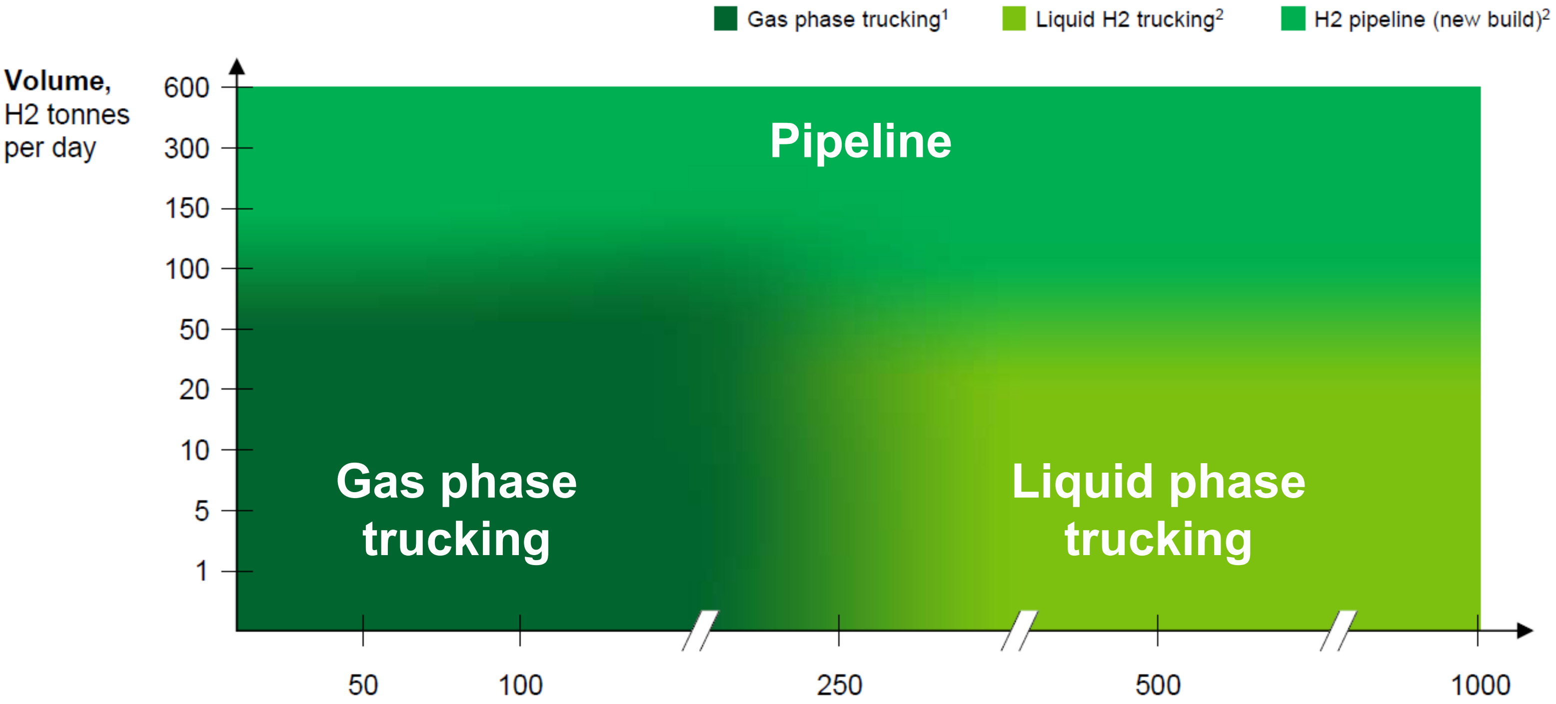
- A liquefier cools the hydrogen to cryogenic temperatures
- Hydrogen can be lost due to boil off/evaporation
- Relatively higher energy usage



Sources: https://www.energy.gov/eere/fuelcells/gaseous-hydrogen-compression
EERE. "Hydrogen Storage." https://www.energy.gov/eere/fuelcells/hydrogen-storage.

There are many options for hydrogen transportation, where the optimal pathway will depend on each case

Preferred hydrogen distribution method by volume and distance



Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Gaseous tube trailers can be economical for hydrogen transport for short distances and small volumes

Gaseous tube trailer transport

- Transport gas phase hydrogen in long cylinders stacked on a trailer
- Compressed to 300-500 bar
  - Requires gas phase compressors
  - Requires ~1 kWh/kg
- Low transport capacity
  - Up to 1000 kg H_2 per trailer
- Ideal for short distances and small volumes
- Low capital intensity and cost-effective operation at small scale
- Can take advantage of trailer swapping

https://www.energy.gov/eere/fuelcells/hydrogen-tube-trailers

Sources: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf
https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/9013_energy_requirements_for_hydrogen_gas_compression.pdf

Liquid tankers can be economical at larger capacities compared to gaseous tube trailers

Liquid tanker transport

- Cryogenic cooling to liquify H_2 followed by storage in cryogenic tanks
  - Requires a liquefier to cool below -253 ºC
  - Requires 10-13 kWh/kg
- Transport capacity up to 4000 kg H_2
- Can be ideal for larger volumes where pipes are not feasible
- Higher capital intensity than gas phase trucking
- Hydrogen can be lost due to boil off
- Low-temperature liquid transfer or vaporization to a gas from liquid trailers

https://www.energy.gov/eere/fuelcells/liquid-hydrogen-delivery

Sources: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf
https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/9013_energy_requirements_for_hydrogen_gas_compression.pdf

Pipelines can move large volumes over large distances to achieve economies of scale

Pipeline transport

- Compressed gas phase hydrogen
- Low cost of transport for high volume and long distance
  - Not common for low volumes
- Initial pipeline construction is time and capital intensive
- Require stable and credit-worthy offtakers who will demand significant volumes
- 1600 miles of H_2 pipelines in the U.S. today
- Can provide access to geologic storage

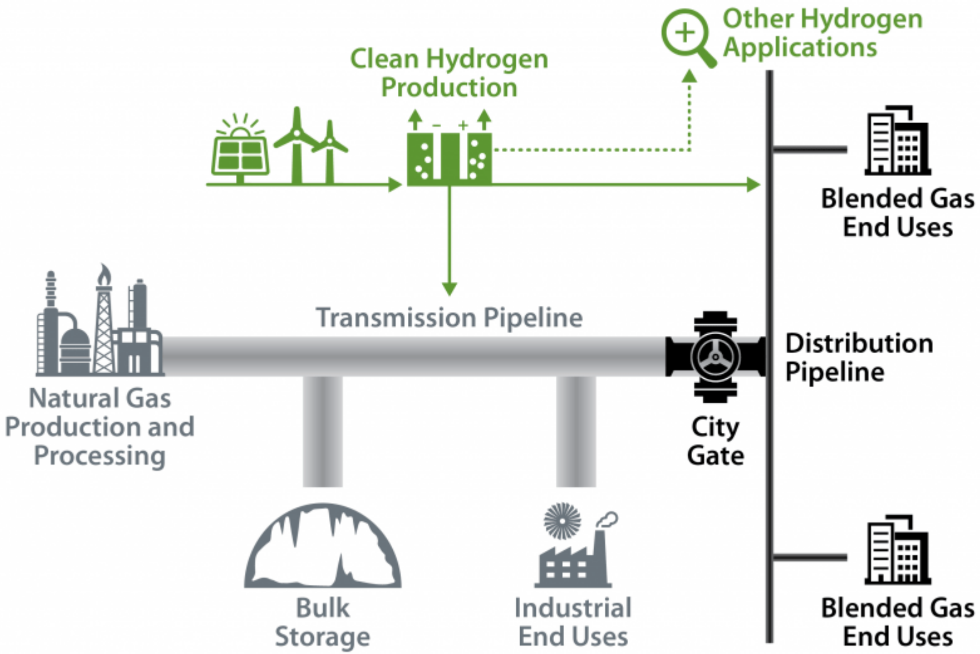
https://www.nrel.gov/news/program/2023/hydrogen-blending-as-a-pathway-toward-u.s.-decarbonization.html

Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Hydrogen may be blended into natural gas networks at certain blend ratios but may require modifications

Hydrogen blending in pipelines

- Compressed gas phase hydrogen
- Blending ratio may be limited without modifications
- Capital intensity can change with blending ratio
    - Modification to pipe and compressors



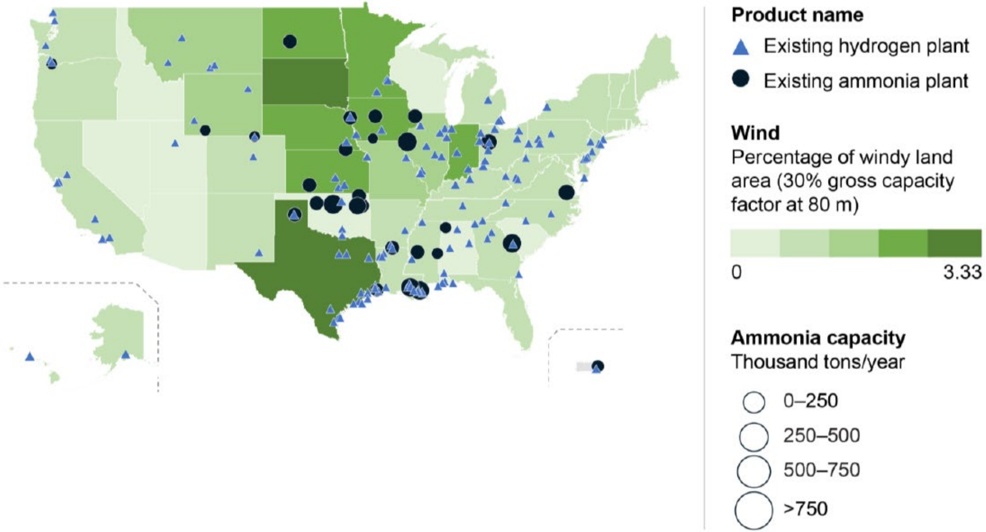
https://www.energy.gov/eere/fuelcells/hyblend-opportunities-hydrogen-blending-natural-gas-pipelines

Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Hydrogen can also be converted into other forms for transport

Novel hydrogen carriers

- Store hydrogen in some other chemical state rather than as free hydrogen molecules
- Convert the hydrogen into another chemical (such as ammonia)
- Reversibility may be costly
- Need to consider what the intended end use is
- Need to consider stability of stored state



Source: DOE. 2022. https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf

Outline

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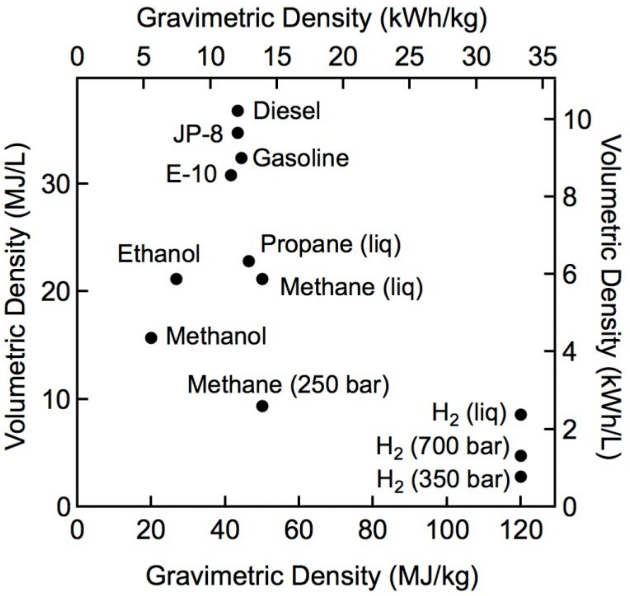
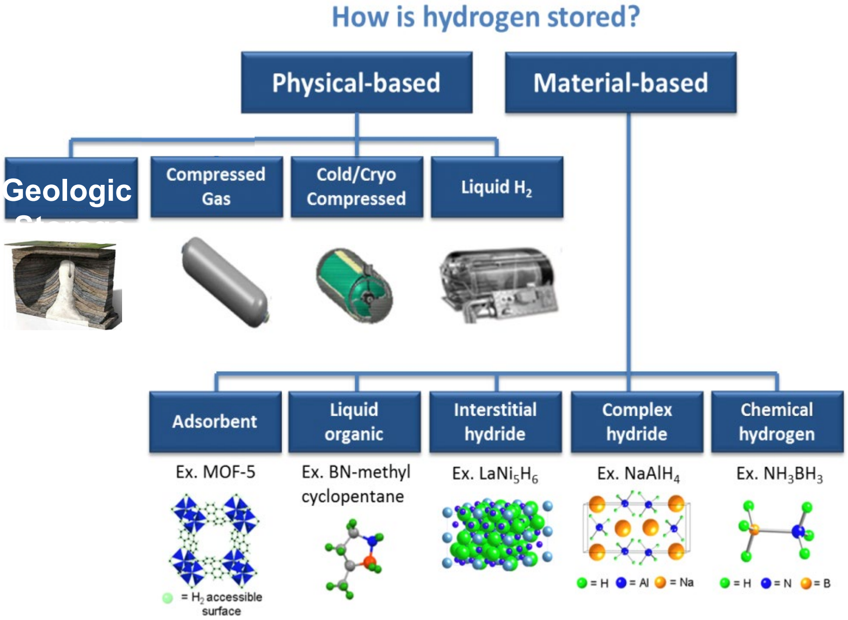
H2A-Lite

Storage

Hydrogen has high gravimetric density but low volumetric density



There are various options for hydrogen storage



Source: EERE. “Hydrogen Storage.” https://www.energy.gov/eere/fuelcells/hydrogen-storage.

Hydrogen can be stored as a compressed gas in a pressure vessel

Compressed gas tank storage

- Hydrogen gas is compressed at ambient temperature to 300-700 bar
- Storage capacity is limited due to the low volumetric density of hydrogen at room temperature
- High unit cost option, but lower total CapEx cost at smallest scales

https://www.iybssd2022.org/en/easac-commentary-on-hydrogen-and-synthetic-fuels/

Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Hydrogen can be stored as a liquid

Liquid H_2 tank storage

- Cryogenic cooling to liquefy hydrogen, followed by storage in insulated tanks
- Allows storage of large volumes of hydrogen, but requires large total CapEx investment (roughly 10x of compressed gas storage tanks)
- Hydrogen liquefaction uses >30% of the hydrogen energy content
- Liquid hydrogen may not be viable for long-term storage (>10 days) without boiloff mitigation

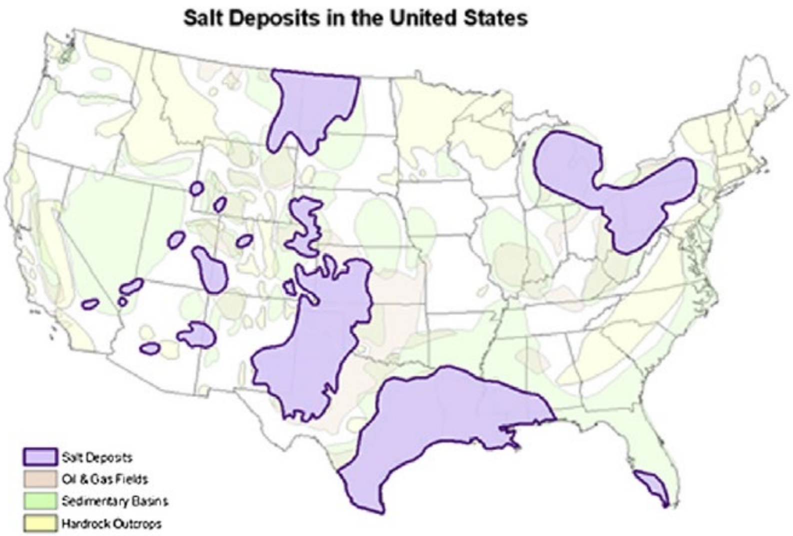
https://www.energy.gov/eere/fuelcells/liquid-hydrogen-delivery

Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Large volumes of hydrogen can be stored in salt caverns

Salt cavern storage

- Geologic formations created by salt deposits that can store gaseous hydrogen at elevated pressure (70-190 bar)
- Large-scale storage and low capital costs/kg, but also limited availability
  - Location dependent
- ~2000 salt caverns in North America with an average capacity of 10^5-10^6 m^3
- Competition with storage of other gases
- Storage CapEx costs expected to remain stable through 2030



Lord et al. Int. J. Hydrogen Energ. 39 (2014) 15570

Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Lined hard rock caverns are another geologic storage option for hydrogen

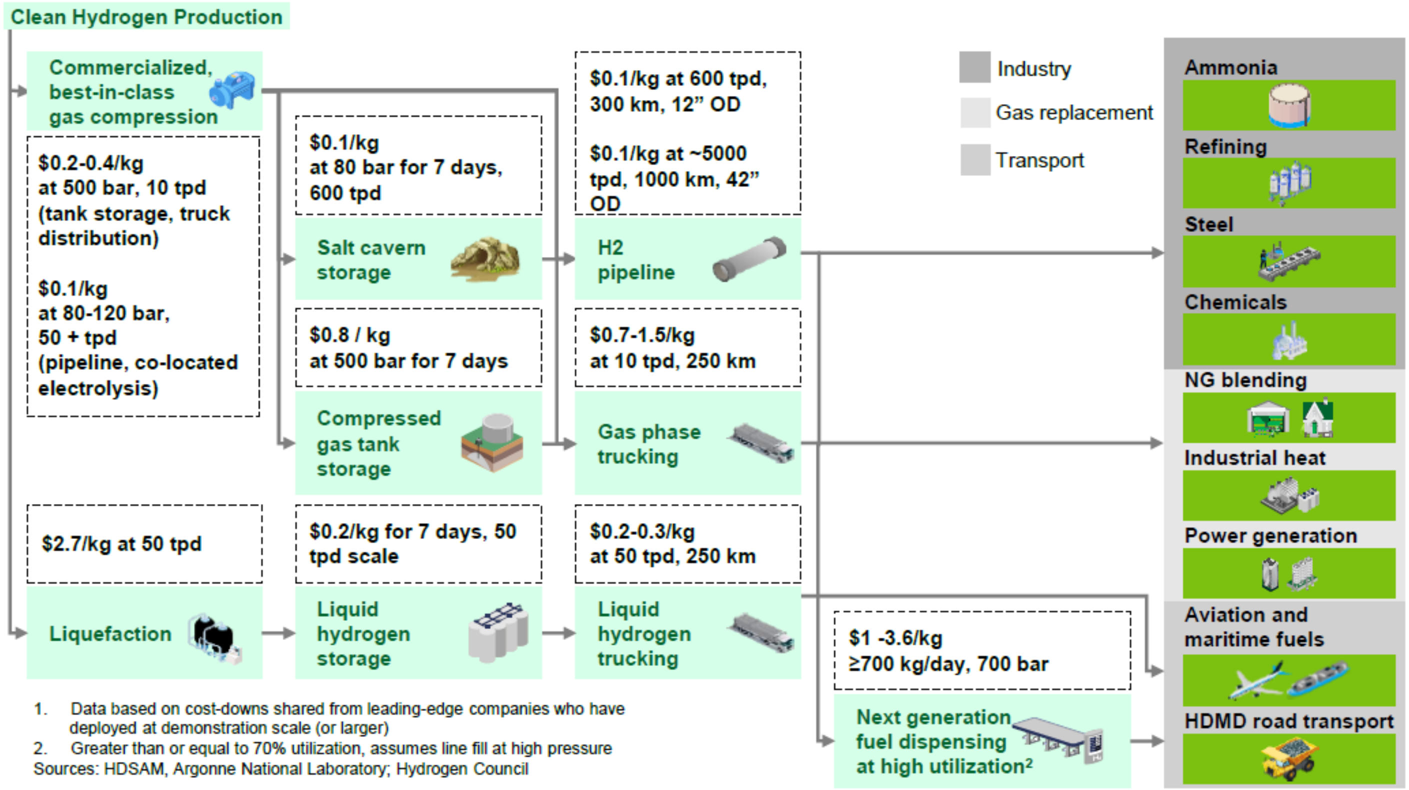
Lined hard rock cavern

- Underground cavern is surrounded by hard, low permeability rock, which can be lined to hold pressurized hydrogen
- Earlier stage technology than salt caverns with limited hydrogen demonstrations
- Store gaseous hydrogen at elevated pressure (similar to salt caverns)
- Storage CapEx costs expected to remain stable through 2030

Lord et al. Int. J. Hydrogen Energ. 39 (2014) 15570

Source: https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf

Understanding the entire value chain help understand what pathways are best suited for each application



Clean Hydrogen Production

Commercialized, best-in-class gas compression

$0.2-0.4/kg at 500 bar, 10 tpd (tank storage, truck distribution)

$0.1/kg at 80-120 bar, 50 + tpd (pipeline, co-located electrolysis)

$0.1/kg at 80 bar for 7 days, 600 tpd

Salt cavern storage

$0.8 / kg at 500 bar for 7 days

Compressed gas tank storage

$0.1/kg at 600 tpd, 300 km, 12" OD

$0.1/kg at ~5000 tpd, 1000 km, 42" OD

H2 pipeline

$0.7-1.5/kg at 10 tpd, 250 km

Gas phase trucking

$2.7/kg at 50 tpd

Liquefaction

$0.2/kg for 7 days, 50 tpd scale

Liquid hydrogen storage

$0.2-0.3/kg at 50 tpd, 250 km

Liquid hydrogen trucking

$1 -3.6/kg ≥700 kg/day, 700 bar

Next generation fuel dispensing at high utilization²

■ Industry
□ Gas replacement
□ Transport

Ammonia
Refining
Steel
Chemicals
NG blending
Industrial heat
Power generation
Aviation and maritime fuels
HDMD road transport

1. Data based on cost-downs shared from leading-edge companies who have deployed at demonstration scale (or larger)
2. Greater than or equal to 70% utilization, assumes line fill at high pressure

Sources: HDSAM, Argonne National Laboratory; Hydrogen Council

Q&A

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H2A/H2A-Lite Demonstration and Overview

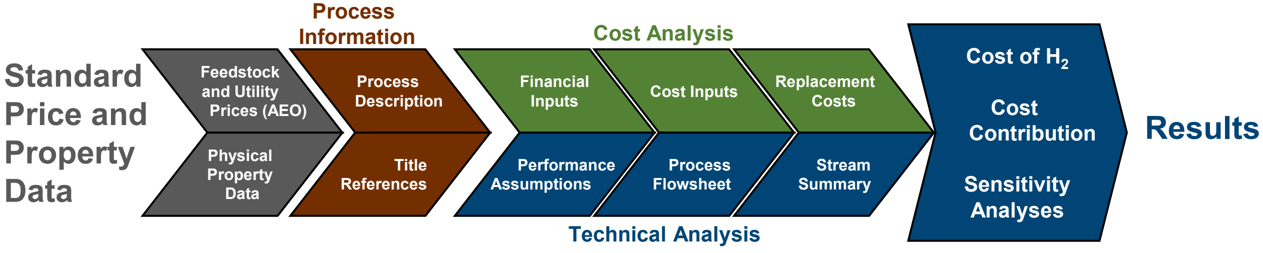
Presented by Misho Penev

March 06, 2024

Hydrogen Specific Model Suite

1. Overview H2A
2. H2A demonstration
3. Overview H2A-Lite
4. H2A-Lite demonstration

H2A (H2 Production Analysis Tool)



Standard Price and Property Data

Process Information

Feedstock and Utility Prices (AEO)

Physical Property Data

Process Description

Title References

Cost Analysis

Financial Inputs

Cost Inputs

Replacement Costs

Performance Assumptions

Process Flowsheet

Stream Summary

Technical Analysis

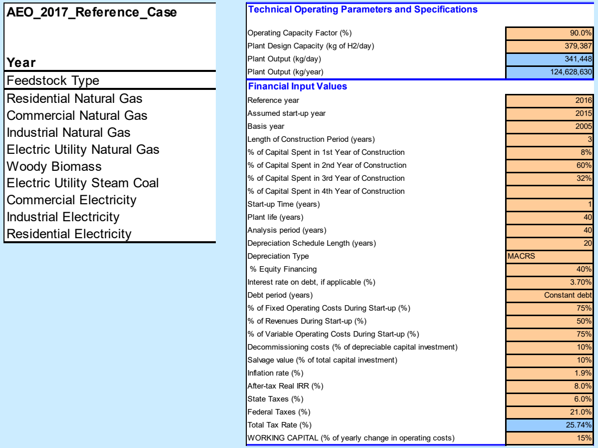
Cost of H_2

Cost Contribution

Sensitivity Analyses

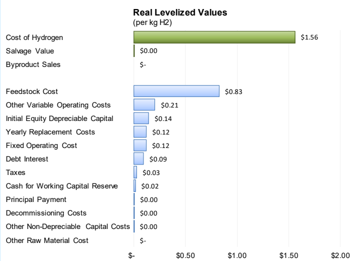
Results

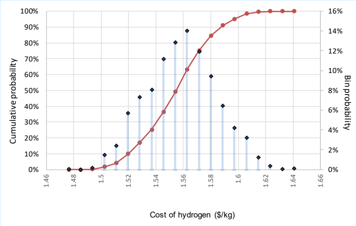
Spreadsheet Examples

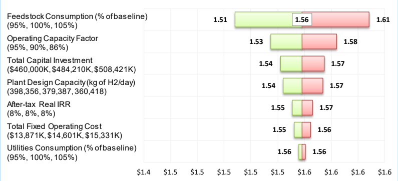


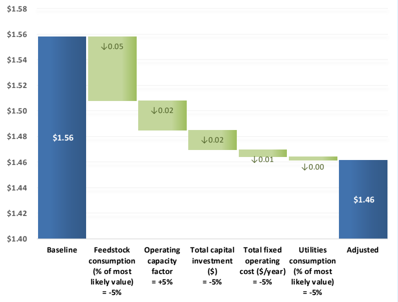
AEO_2017_Reference_Case
Year
Feedstock Type
Residential Natural Gas
Commercial Natural Gas
Industrial Natural Gas
Electric Utility Natural Gas
Woody Biomass
Electric Utility Steam Coal
Commercial Electricity
Industrial Electricity
Residential Electricity

Technical Operating Parameters and Specifications	
Operating Capacity Factor (%)	90.0%
Plant Design Capacity (kg of H2/day)	379,387
Plant Output (kg/day)	341,448
Plant Output (kg/year)	124,628,630
Financial Input Values	
Reference year	2016
Assumed start-up year	2015
Basis year	2005
Length of Construction Period (years)	3
% of Capital Spent in 1st Year of Construction	8%
% of Capital Spent in 2nd Year of Construction	60%
% of Capital Spent in 3rd Year of Construction	32%
% of Capital Spent in 4th Year of Construction	
Start-up Time (years)	1
Plant life (years)	40
Analysis period (years)	40
Depreciation Schedule Length (years)	20
Depreciation Type	MACRS
% Equity Financing	40%
Interest rate on debt, if applicable (%)	3.70%
Debt period (years)	Constant debt
% of Fixed Operating Costs During Start-up (%)	75%
% of Revenues During Start-up (%)	50%
% of Variable Operating Costs During Start-up (%)	75%
Decommissioning costs (% of depreciable capital investment)	10%
Salvage value (% of total capital investment)	10%
Inflation rate (%)	1.9%
After-tax Real IRR (%)	8.0%
State Taxes (%)	6.0%
Federal Taxes (%)	21.0%
Total Tax Rate (%)	25.74%
WORKING CAPITAL (% of yearly change in operating costs)	15%

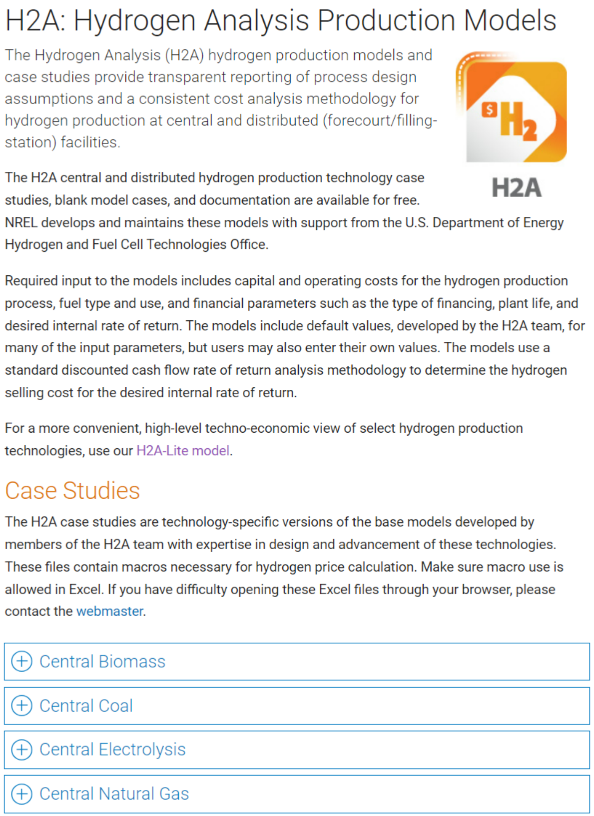








H2A: Where to Obtain



H2A: Hydrogen Analysis Production Models

The Hydrogen Analysis (H2A) hydrogen production models and case studies provide transparent reporting of process design assumptions and a consistent cost analysis methodology for hydrogen production at central and distributed (forecourt/filling-station) facilities.

The H2A central and distributed hydrogen production technology case studies, blank model cases, and documentation are available for free. NREL develops and maintains these models with support from the U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office.

Required input to the models includes capital and operating costs for the hydrogen production process, fuel type and use, and financial parameters such as the type of financing, plant life, and desired internal rate of return. The models include default values, developed by the H2A team, for many of the input parameters, but users may also enter their own values. The models use a standard discounted cash flow rate of return analysis methodology to determine the hydrogen selling cost for the desired internal rate of return.

For a more convenient, high-level techno-economic view of select hydrogen production technologies, use our H2A-Lite model.

Case Studies

The H2A case studies are technology-specific versions of the base models developed by members of the H2A team with expertise in design and advancement of these technologies. These files contain macros necessary for hydrogen price calculation. Make sure macro use is allowed in Excel. If you have difficulty opening these Excel files through your browser, please contact the webmaster.

⊕ Central Biomass

⊕ Central Coal

⊕ Central Electrolysis

⊕ Central Natural Gas

Free to download:
https://www.nrel.gov/hydrogen/h2a-production-models.html

Pre-populated central production technologies:
- Biomass gasification
- Coal gasification
- Electrolysis
- Natural gas SMR
- Natural gas SMR+CCS
- Natural gas ATR+CCS

Distributed production pathways:
- Electrolysis
- Ethanol reforming
- Natural gas SMR

Emerging technologies:
- Photo-electrochemical
- Solar thermochemical ferrite cycle

Hydrogen Specific Model Suite

1. Overview H2A
2. H2A demonstration
3. Overview H2A-Lite
4. H2A-Lite demonstration

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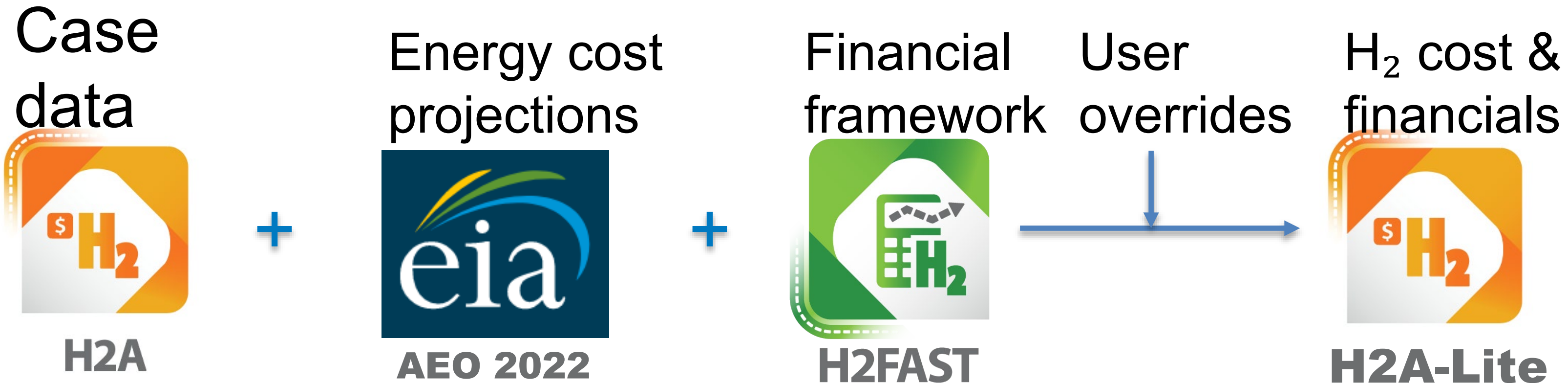
H2A-Lite: Overview

Based on Hydrogen Financial Analysis Scenario Tool (H2-FAST)

- Uses Generally Accepted Accounting Principles (GAAP) financial analysis
- Also compatible with International Financial Reporting Standards (IFRS)
- Articulates standard financial reports for duration of analysis
  - Income statements
  - Cash flow statements
  - Balance sheets
- Analysis performed on real 2020$ basis (for consistency with H2A –future methodology)



Case data

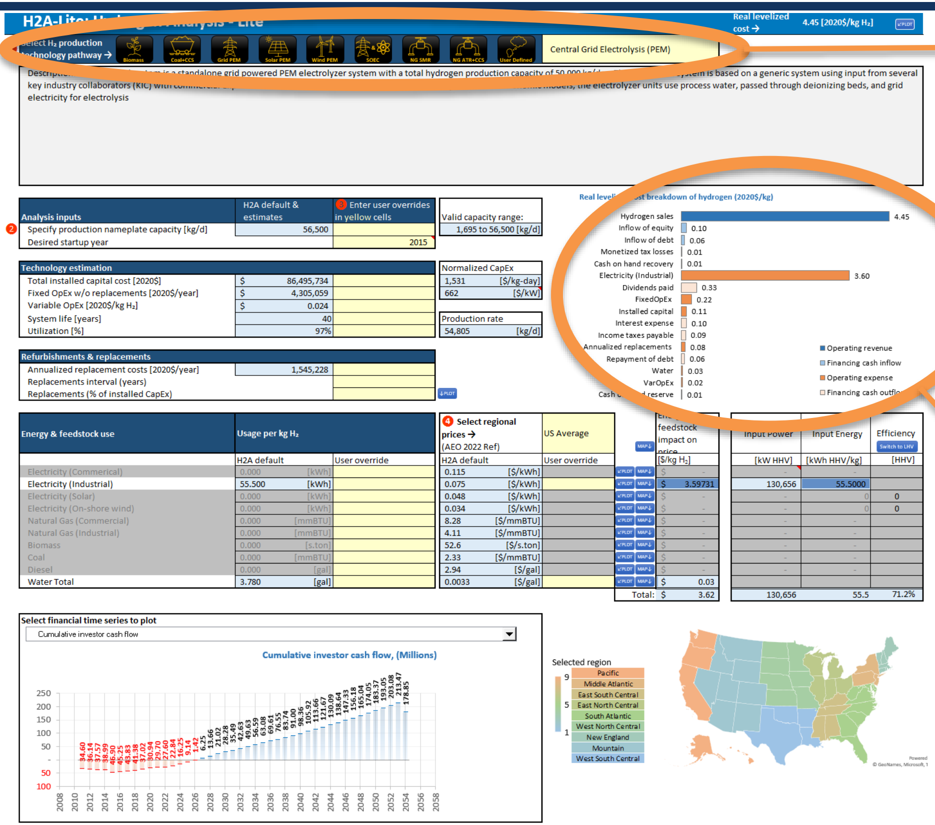
Energy cost projections

Financial framework

User overrides

H_2 cost & financials

H2A-Lite Layout



H2A-Lite: H[illegible]**Analysis - Lite**

Real levelized cost → 4.45 [2020$/kg H₂]

Select H₂ production technology pathway → Central Grid Electrolysis (PEM)

Descripti[illegible] is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/d[illegible]ystem is based on a generic system using input from several key industry collaborators (KIC) with commercial[illegible]models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis

Analysis inputs	H2A default & estimates	③ Enter user overrides in yellow cells
② Specify production nameplate capacity [kg/d]	56,500	
Desired startup year		2015

Valid capacity range:
1,695 to 56,500 [kg/d]

Technology estimation		
Total installed capital cost [2020$]	$ 86,495,734	
Fixed OpEx w/o replacements [2020$/year]	$ 4,305,059	
Variable OpEx [2020$/kg H₂]	$ 0.024	
System life [years]	40	
Utilization [%]	97%	

Normalized CapEx	
1,531	[$/kg-day]
662	[$/kW]

Production rate	
54,805	[kg/d]

Refurbishments & replacements		
Annualized replacement costs [2020$/year]	1,545,228	
Replacements interval (years)		
Replacements (% of installed CapEx)		

Real levelized cost breakdown of hydrogen (2020$/kg)

④ Select regional prices → (AEO 2022 Ref): US Average

Energy & feedstock use	Usage per kg H₂: H2A default		Usage per kg H₂: User override	Prices: H2A default		Prices: User override	Energy & feedstock impact on price [$/kg H₂]	Input Power [kW HHV]	Input Energy [kWh HHV/kg]	Efficiency [HHV]
Electricity (Commerical)	0.000	[kWh]		0.115	[$/kWh]		$ -	-	-	
Electricity (Industrial)	55.500	[kWh]		0.075	[$/kWh]		$ 3.59731	130,656	55.5000	
Electricity (Solar)	0.000	[kWh]		0.048	[$/kWh]		$ -	-	0	0
Electricity (On-shore wind)	0.000	[kWh]		0.034	[$/kWh]		$ -	-	0	0
Natural Gas (Commercial)	0.000	[mmBTU]		8.28	[$/mmBTU]		$ -	-	-	
Natural Gas (Industrial)	0.000	[mmBTU]		4.11	[$/mmBTU]		$ -	-	-	
Biomass	0.000	[s.ton]		52.6	[$/s.ton]		$ -	-	-	
Coal	0.000	[mmBTU]		2.33	[$/mmBTU]		$ -	-	-	
Diesel	0.000	[gal]		2.94	[$/gal]		$ -	-	-	
Water Total	3.780	[gal]		0.0033	[$/gal]		$ 0.03			
						Total:	$ 3.62	130,656	55.5	71.2%

Select financial time series to plot

Cumulative investor cash flow

Cumulative investor cash flow, (Millions)

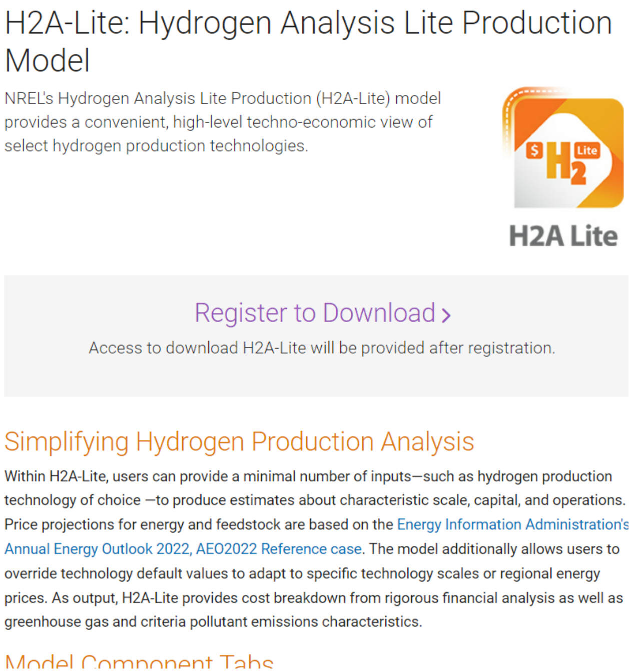
Central production pathways:

- Biomass gasification
- Coal gasification
- Electrolysis
- Natural gas SMR
- Natural gas SMR+CCS
- Natural gas ATR+CCS

Cost Breakdown

All yellow cells allow user overrides

H2A-Lite: Where to Obtain



H2A-Lite: Hydrogen Analysis Lite Production Model

NREL's Hydrogen Analysis Lite Production (H2A-Lite) model provides a convenient, high-level techno-economic view of select hydrogen production technologies.

Register to Download ›

Access to download H2A-Lite will be provided after registration.

Simplifying Hydrogen Production Analysis

Within H2A-Lite, users can provide a minimal number of inputs—such as hydrogen production technology of choice —to produce estimates about characteristic scale, capital, and operations. Price projections for energy and feedstock are based on the Energy Information Administration's Annual Energy Outlook 2022, AEO2022 Reference case. The model additionally allows users to override technology default values to adapt to specific technology scales or regional energy prices. As output, H2A-Lite provides cost breakdown from rigorous financial analysis as well as greenhouse gas and criteria pollutant emissions characteristics.

Model Component Tabs

Free to download:
https://www.nrel.gov/hydrogen/h2a-lite.html

Pre-populated central production technologies:
- Biomass gasification
- Coal gasification
- Electrolysis (grid, wind, solar, nuclear)
- Natural gas SMR
- Natural gas ATR+CCS

Thank you!

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Thank you!

Questions? Contact Expert@CleanEnergySolutions.org.

The next installment in this series will focus on hydrogen markets.

Register today!