Hydrogen Considerations Tree
Executive Deck

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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.

- **1. End-Use Application Considerations (1 hr)**
  - Energy Generation
  - Industrial and Chemical
  - Transport and Agriculture
- **2. Production and energy source Considerations (1 hr)**
  - Electrolysis Technological Advancements
  - Feedstock
  - Energy Sources: Renewable, Nuclear, Fossil
- **3. Infrastructure Considerations (1 hr)**
  - Production and Conversion
  - Storage and Distribution
  - Clusters or hubs
- **4. Costs and Economic Viability Considerations (1 hr)**
  - Capital Expenditure/ Operating expenditure Viability
  - Markets
  - Technology Availability
- **5. Environmental Considerations (1 hr)**
  - Greenhouse Gases & Life Cycle Assessments
  - Local/Regional/ Country-Level Environmental Impacts
  - Resource competition
- **6. Social Considerations (1 hr)**
  - Stakeholder Engagement
  - Workforce Opportunities
  - Health and Safety
- **7. Policy and Regulatory Considerations (1 hr)**
  - Policy and regulatory framework
  - Incentives and Enabling Conditions
  - Standards and Certifications
- **8. Considerations Tree Exercises (1-2 hrs)**
  - Case Study: Large-scale wind powered hydrogen & ammonia project
  - SWOT Analysis (Strengths, Weaknesses, Opportunities, Threats)

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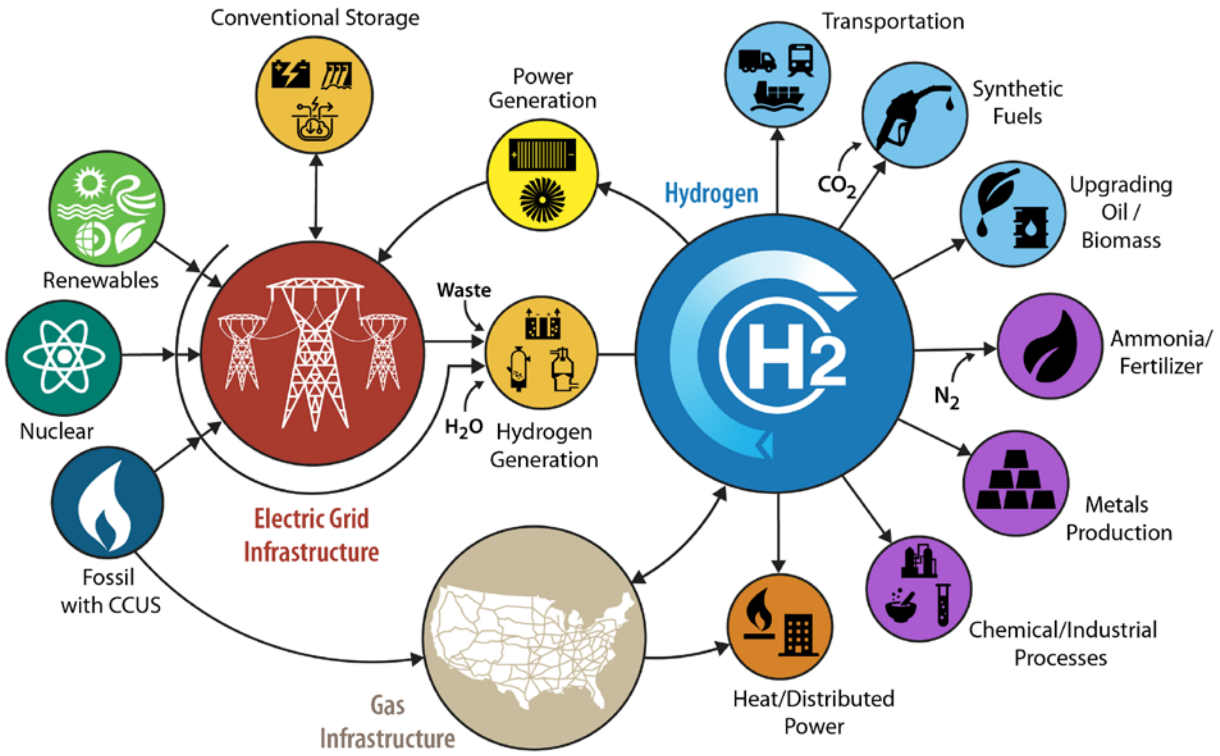
Hydrogen is a versatile energy carrier.

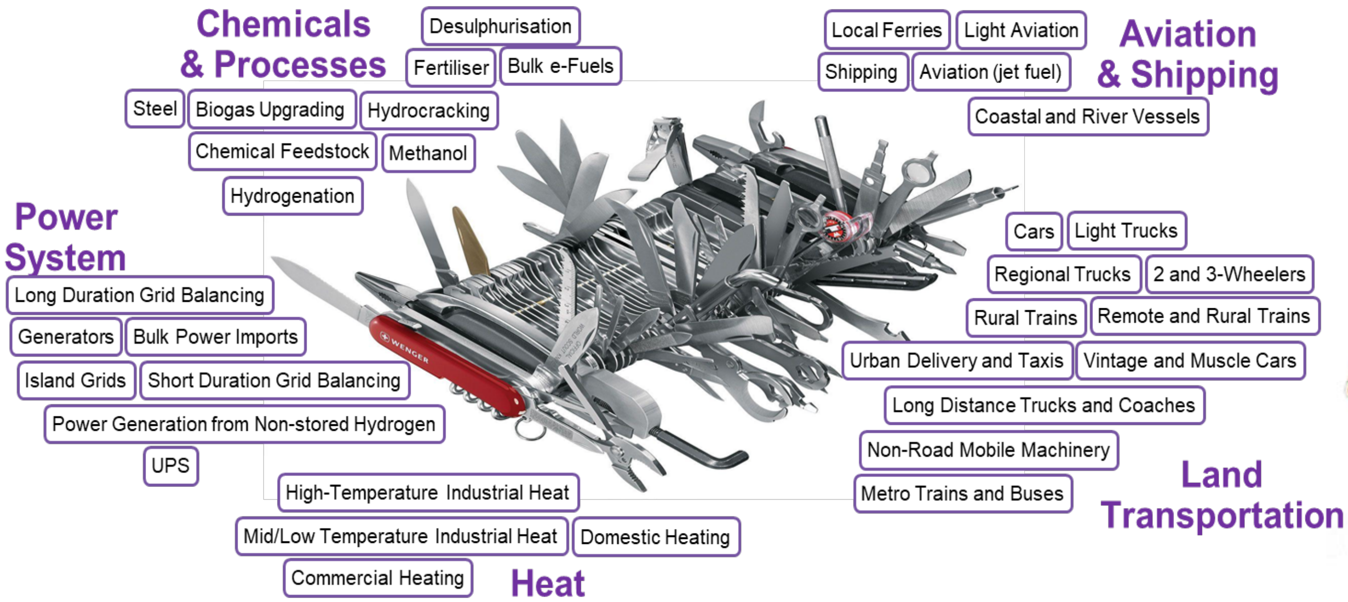
- Hydrogen can be produced via **electrolysis** using electricity from renewable energy (e.g. wind and solar), hydropower, or nuclear energy, it can be found naturally in **geologic reserves**, produced from **gasification** of biomass, or other more conventional production pathways (e.g. **steam methane reformation** from natural gas)
- Electrolysis of water using 100% renewable energy produces **zero direct carbon emissions**
- Hydrogen can be used in different sectors of the economy. For example, the transport sector, **refineries**, **fertilizer** production, **chemical** production, **steel**, **cement kilns**, and other industrial applications.



Source: DOE Hydrogen and Fuel Cell Technologies Office. H2@Scale. https://www.energy.gov/eere/fuelcells/h2scale.

Hydrogen – Climate's Swiss Army Knife?

You can do almost anything with a Swiss Army Knife…



Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 5.0, 2023.Concept credit: Adrian Hiel, Energy Cities. Image: Wenger (concept credit: Paul Martin). *CC-BY 4.0*

But would you build your house with one?

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Greenhouse gas emissions from hydrogen production varies based on the energy sources and production pathway.

How the world currently refers to hydrogen:

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

How we should be looking at hydrogen:

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.

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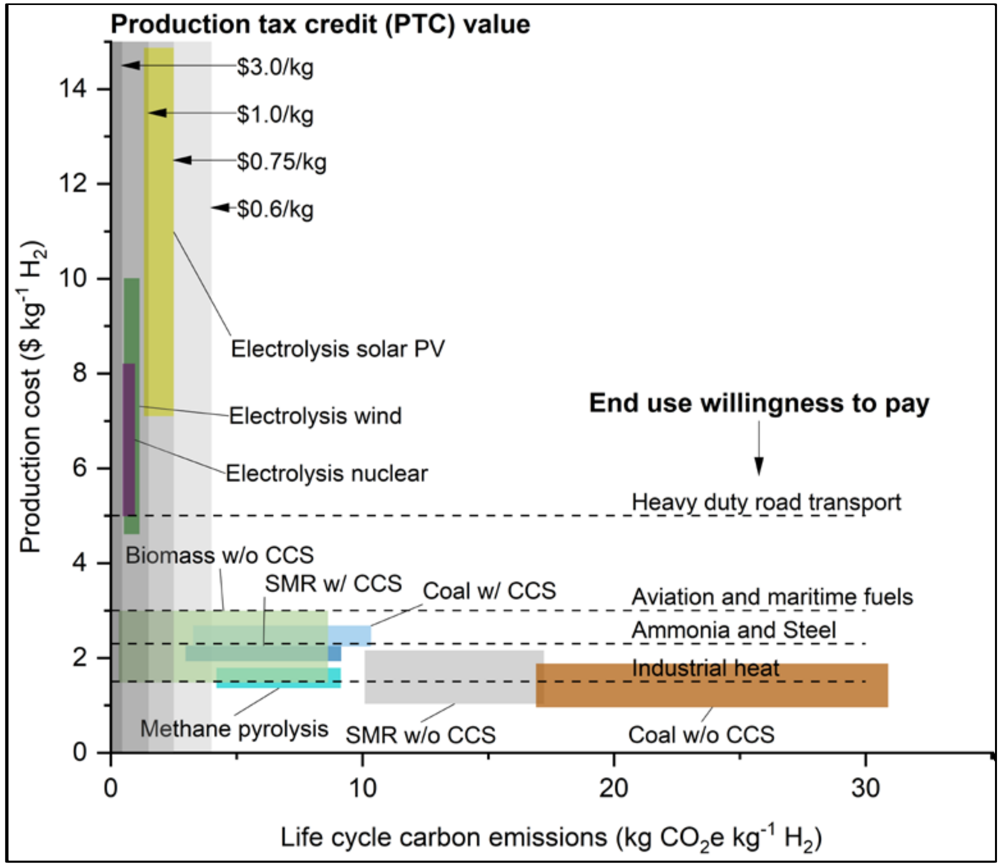

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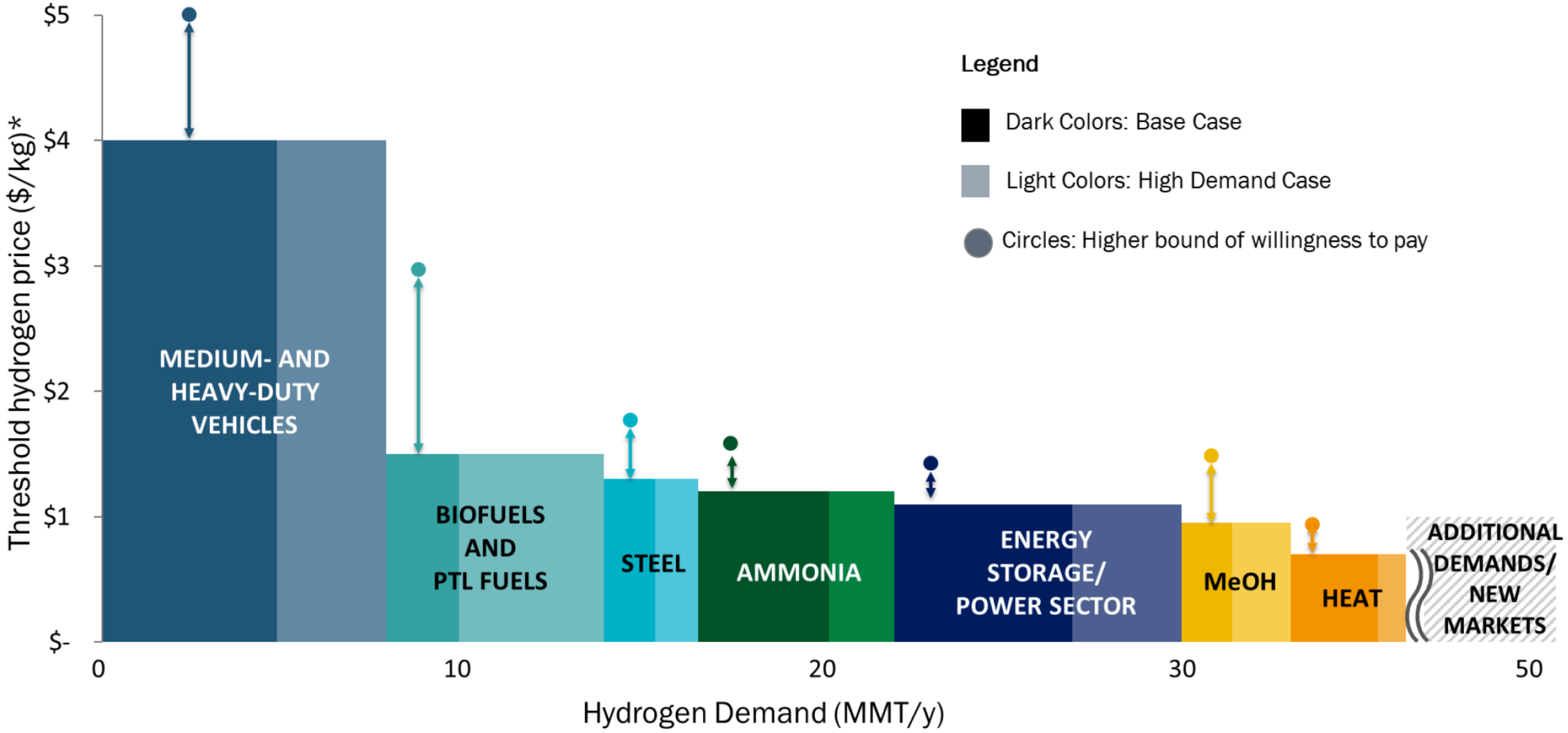
Demand and willingness to pay varies with end use.

Willingness to pay, or price cap, for clean hydrogen in various current and emerging sectors (including production, delivery, and on-site conditioning, such as additional compression, storage, cooling, and/or dispensing).



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

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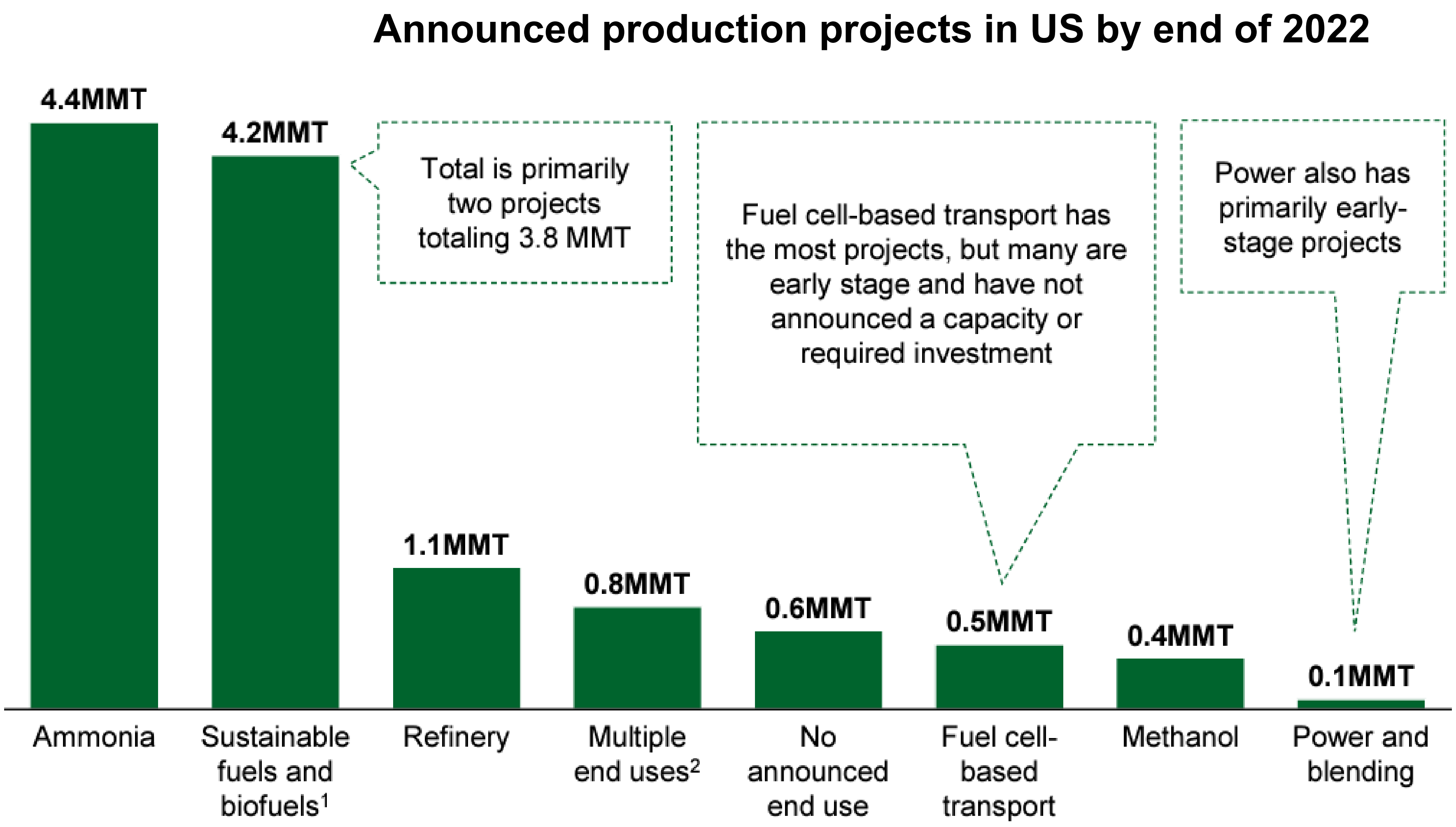
Most clean hydrogen projects today (US example) are focused on ammonia and sustainable fuel production.



1 Includes sustainable fuels and biofuels and fuel-cell based transport

2 Represents production capacity that is targeting more than one of the other end use sectors

Source: McKinsey Hydrogen Insights P&I tracker & Electrolyzer supply tracker as of the end of 2022

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

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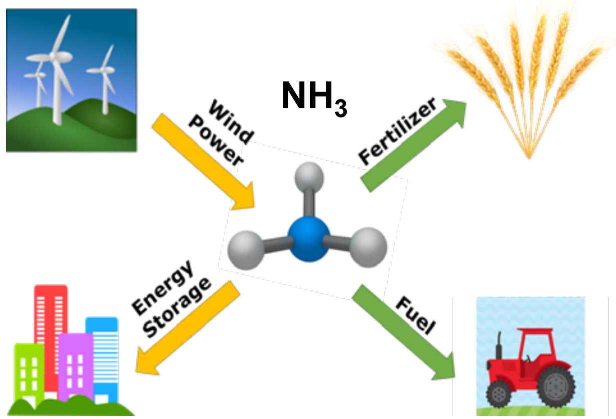
Green ammonia offers near-term opportunities for the deployment of clean hydrogen.

- **Key opportunity:**
  - High energy intensity and hydrogen content
  - Liquification at near room temperature (20^{o}C at 7.5 bar)
  - Already produced large-scale and traded globally
  - Near-term domestic market and existing infrastructure
  - Energy security, especially where ammonia is imported
  - Can be used directly in some applications (e.g. fertilizers, power generation, maritime fuel)
  - High economic opportunity for domestic use versus export

- **Co-located systems – multiple benefits:**
  - Desalination plant
  - Renewable energy generation
  - Hydrogen production
  - Ammonia production

- **Key considerations:**
  - Low TRL of dynamic operation and cracking (NH_3 as energy carrier)
  - Not yet competitive with conventional sources
  - Toxic and corrosive gas



Source: UMN, Michael Reese and Jennifer King (NREL)

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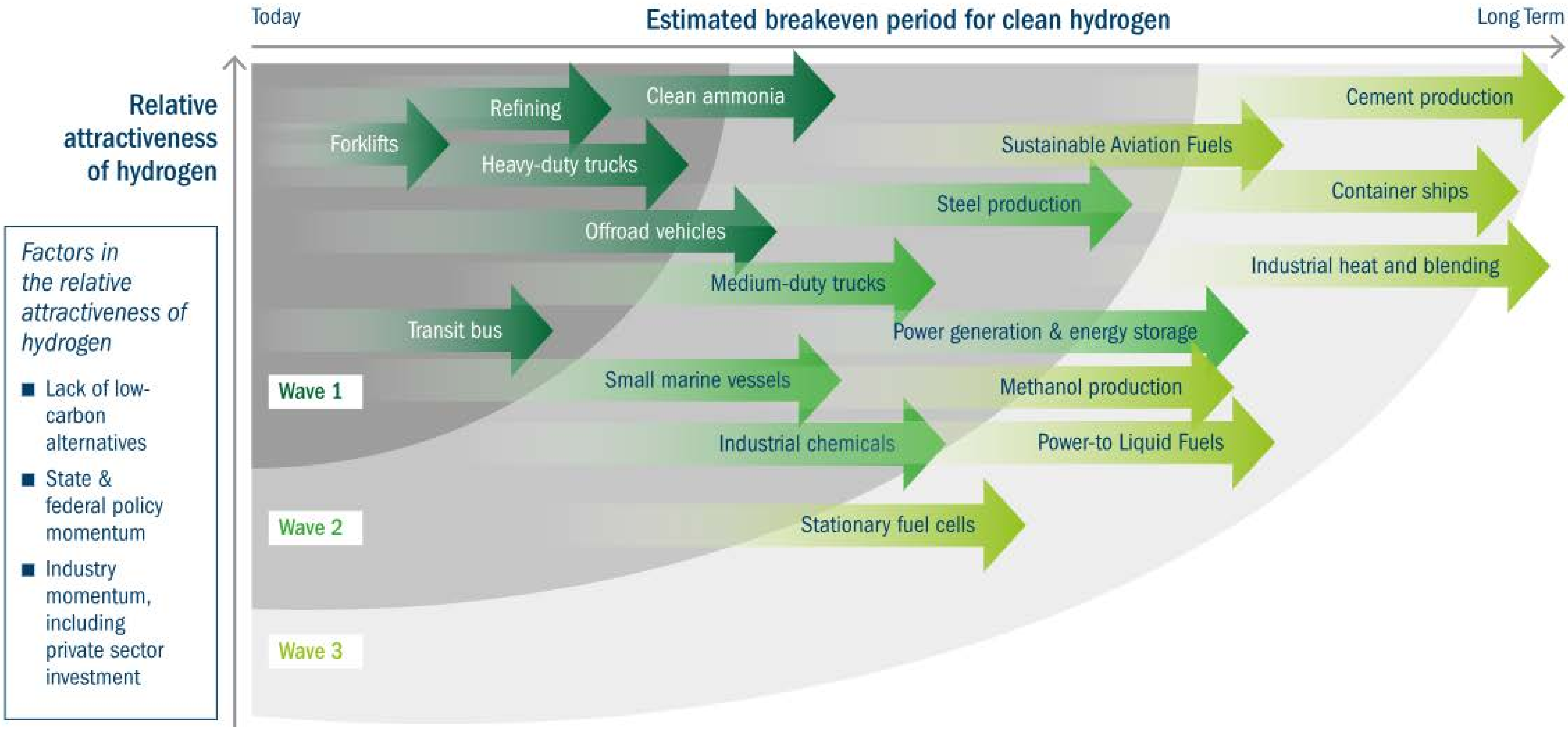
As production costs of low-carbon hydrogen decrease and alternative low-carbon options become limited, its competitiveness will expand across various applications.



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

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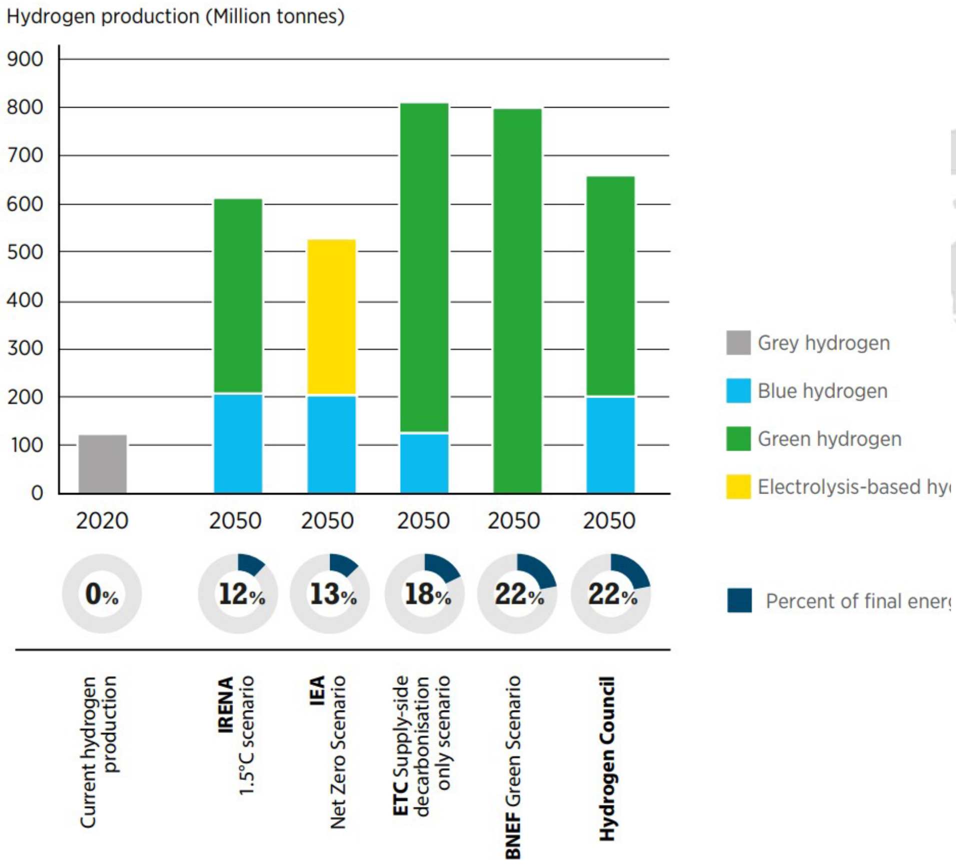
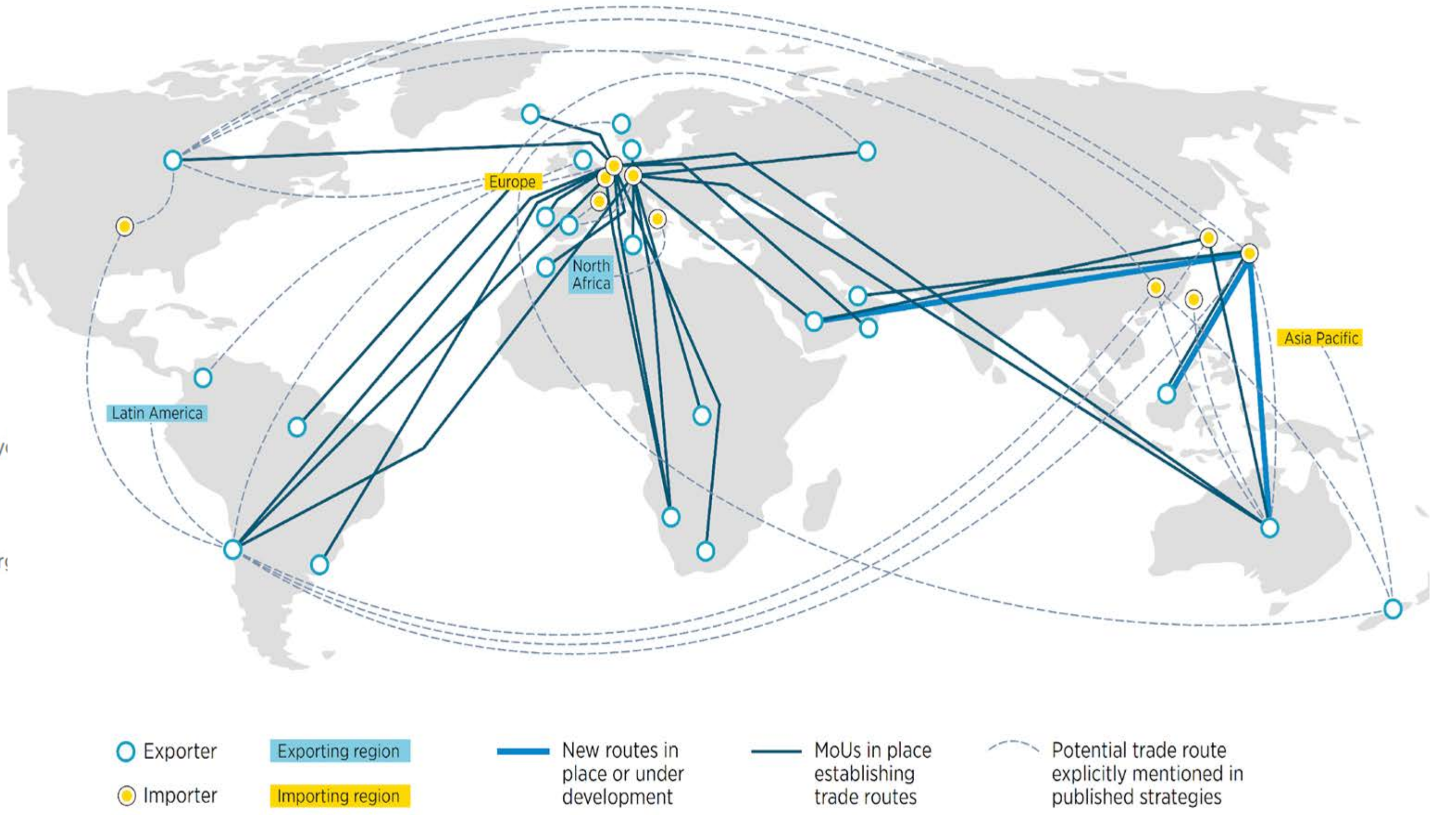
Global hydrogen markets are growing, but still uncertain in many cases.



Source: https://www.irena.org/Digital-Report/Geopolitics-of-the-Energy-Transformation#page-1

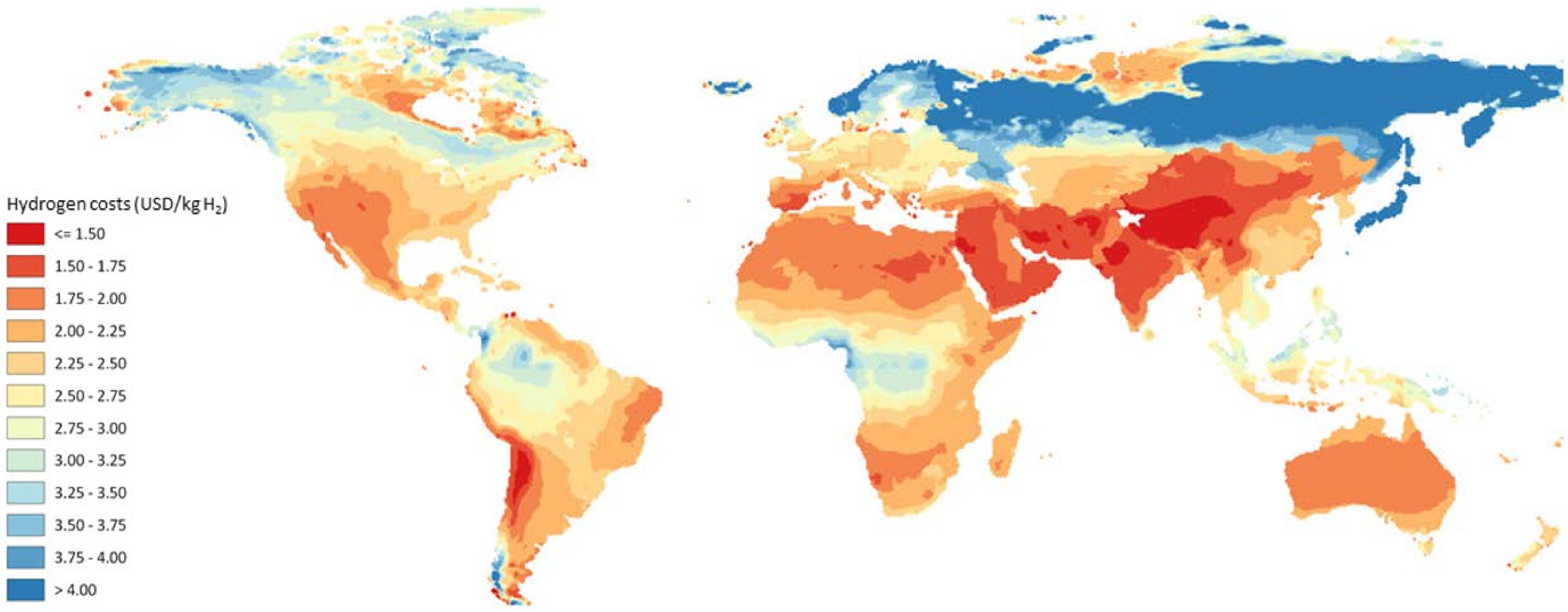
An expanding network of hydrogen trade routes, plans, and agreements



Source: IRENA. 2022. *Geopolitics of the Energy Transformation: The Hydrogen Factor.* https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen.

Low-carbon hydrogen production from solar and wind electrolysis is expected to be competitive with traditional production methods by 2030 or earlier.

Hydrogen costs from solar and wind electrolysis by 2030



Source: IEA. *Global Hydrogen Review 2021.* https://iea.blob.core.windows.net/assets/5bd46d7b-906a-4429-abda-e9c507a62341/GlobalHydrogenReview2021.pdf. Based on Copernicus Climate Change Service and hourly solar data from Renewables.ninja.

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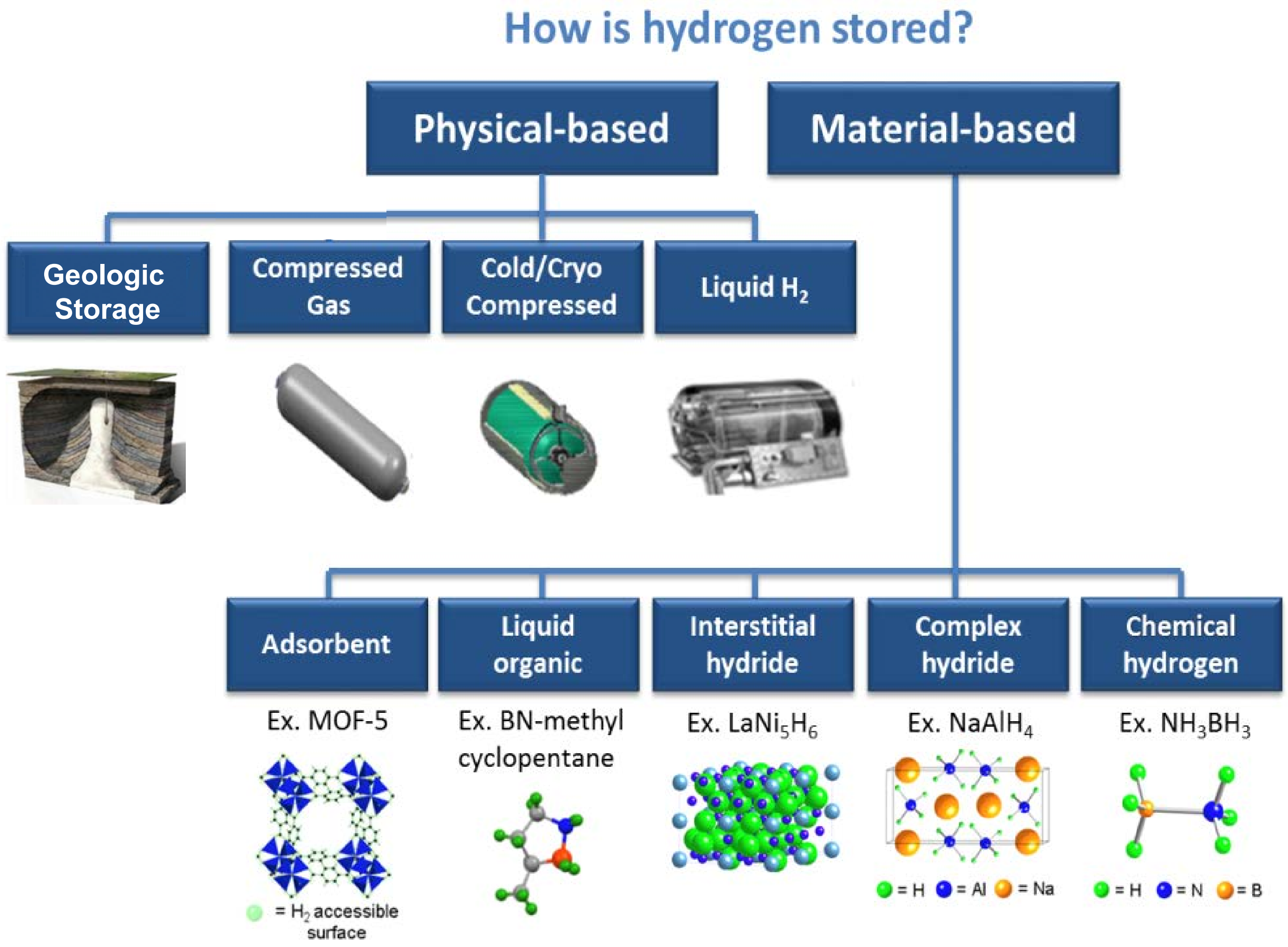
There are various options for hydrogen storage and conversion.



Challenges in Storage:

- Low energy density = **high volume**
- **Leakage** due to small molecular size and **embrittlement** of metal
- **Limited availability** of geological storage sites
- **Additional cost** and **low efficiency** of conversion and reconversion to electricity or hydrogen-based fuels

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

Cost Contribution of Infrastructure

Tube-Trailer Truck Delivery
Short Distance

Total delivery cost \$3 : \$5 / kg_{H2}

Liquid Hydrogen Truck Delivery
Medium Distance

Total T&D cost \$3 : \$4 / kg_{H2}

Pipeline Delivery
Long Distance

Total delivery cost \$0.5 : \$1 / kg_{H2}

Shipped as Ammonia
International Export

Costs vary with distance
***Can also be shipped as e-methanol or liquid organic hydrogen carriers (LOHC)**

Increasing Transport Distance

Source: Elgowainy, A., Technoeconomic analysis of hydrogen delivery and Dispensing infrastructure, ANL, 2022

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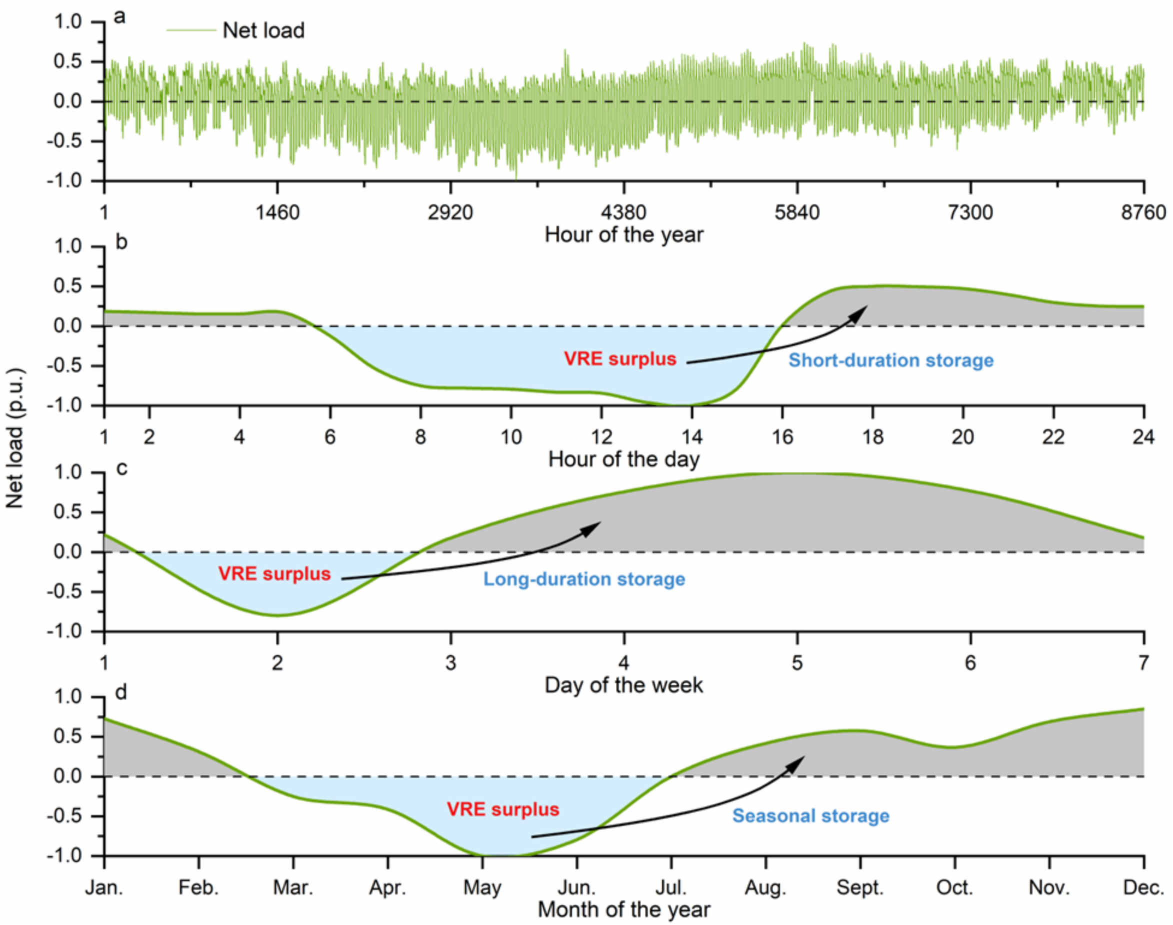
Seasonal energy storage for the power sector is a potential future application for clean hydrogen, especially with high integration of variable renewable energy.

Multi-scale energy storage needs for 95% carbon-free CAISO power system
(28.4% wind and 51.5% solar PV energy share)



Definitions:

- **Net load**: electricity demand minus variable renewable energy (VRE), e.g., wind plus solar PV power, availability.
- **Short-duration storage**: up to 10 hours of discharge duration at rated power before the energy capacity is depleted (typically lithium-ion batteries)
- **Long-duration energy storage**: discharge duration >10 hours and <100 hours (e.g. compressed air energy storage (CAES), pumped hydro storage (PHS), flow batteries)
- **Seasonal energy storage**: discharge duration >100 hours (e.g. hydrogen, methanol, etc.)

Ref : Guerra, O. J. Beyond short-duration energy storage. Nature Energy 6, 460–461 (2021).

Useful Tools for Economic Analysis of Hydrogen Projects

Hydrogen Production Cost Calculator

Electrolyser Efficiency (0.75):

0.75

Average Wholesale Price (24h) ($/MWh):

40

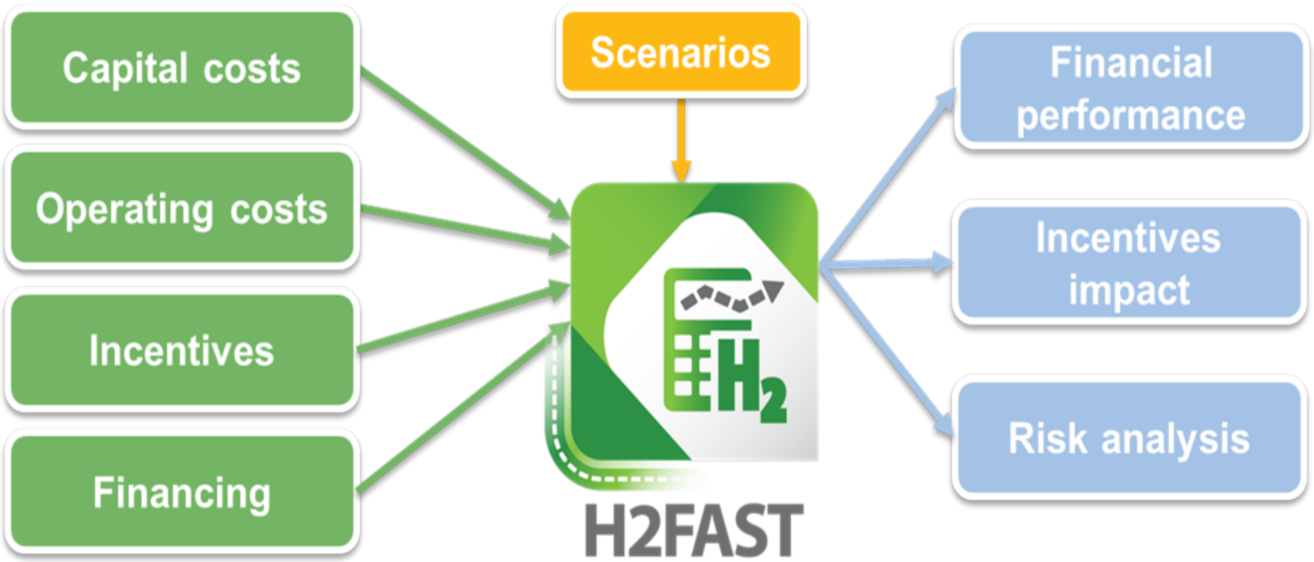
Average Wholesale Price (Off-peak) ($/MWh):

30

Calculate Cost

Average H2 production cost (24h): $1.78/kg
Average H2 production cost (Off-peak): $1.33/kg

Source: https://sustainabilityinfo.com/energy/green-hydrogen-production-cost-calculator/



https://www.nrel.gov/hydrogen/h2fast.html
https://www.nrel.gov/hydrogen/h2a-lite.html
https://www.nrel.gov/hydrogen/h2a-production-models.html

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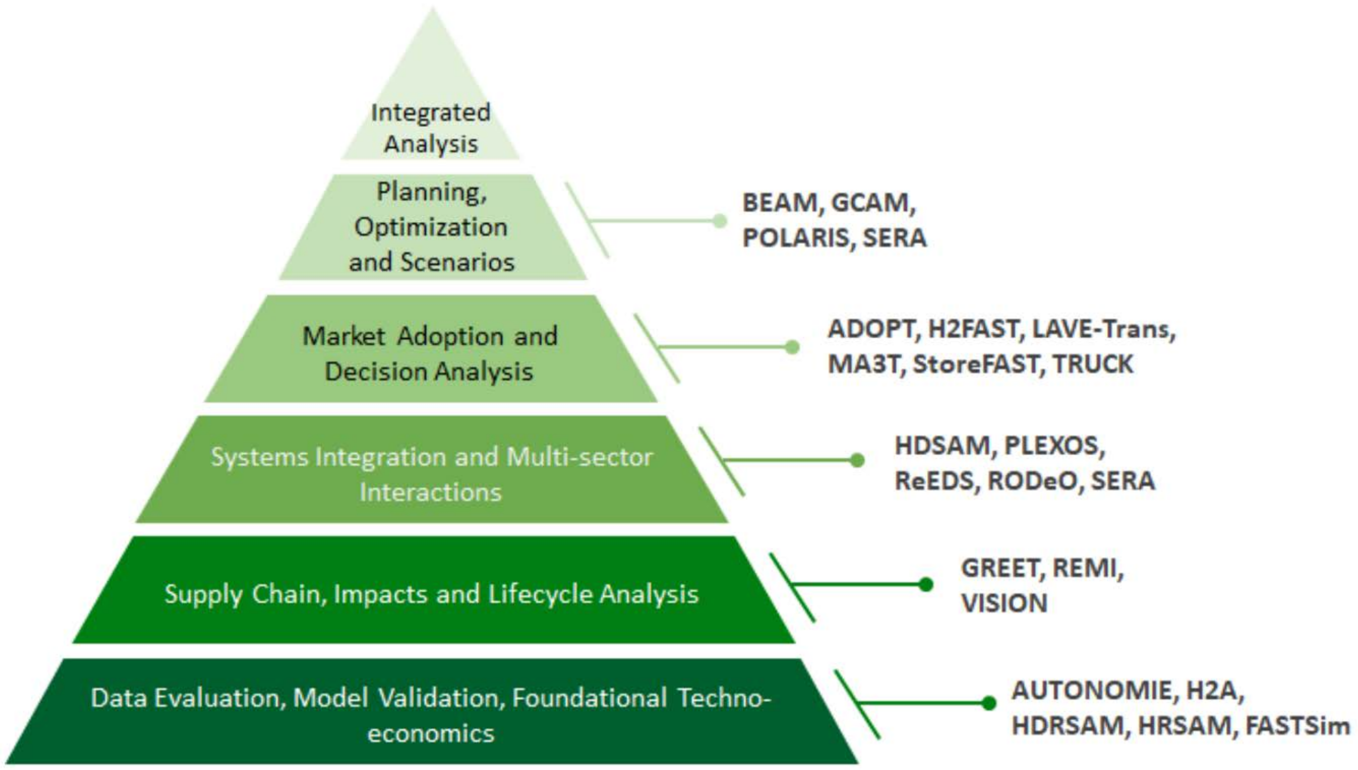
Tools Spotlight: supporting decision making

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.

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

1. End Use Application Considerations

Hydrogen decision-making requires a thorough review of end-use applications and considerations.

1

- **Analysis of alternatives:**
  - Is there a specific motivation to select hydrogen or e-fuels, versus electrification, biofuels, or other alternatives?
- **Transport:**
  - Do you have heavy or long-distance transport fleets?
  - Is it for fleets or personal use vehicles?
  - Are you interested in decarbonizing shipping, aviation, or other specialty and hard-to-abate transport applications?
- **Industrial:**
  - Are there industrial clusters near renewable energy sources?
  - Are there premiums or incentives? (e.g. for green steel)
  - Is this to support scope 3 emissions accounting? (e.g. concrete)
- **Chemical industry:**
  - Is there proximity to an ammonia market or port?
- **Agriculture:**
  - Is there proximity to agricultural regions or clusters?

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Key Takeaways - End Use Considerations

1

- Hydrogen and its alternatives have limited niche applications that can compete with near-term market alternatives, and are best suited to decarbonizing hard-to-abate sectors (e.g., aviation, shipping, long-distance cargo transport, steel, industrial kilns, forklifts, agriculture).

- Evaluation of alternatives for end uses can help ensure market viability - for example, evaluating electrification options first.

- Proximity and access to end users is critical to justify investment and development of hydrogen projects, especially when clusters of end-users can help to reduce infrastructure (storage, transport, and distribution) requirements and reduce risk associated with off-taker agreements.

- Economic opportunity for domestic use of hydrogen and its derivatives, versus export only.

Knowledge Check

1

What critical role is low-carbon hydrogen expected to play in the near future in helping to reduce global GHG emissions?

A) Fueling long-distance space travel

B) Powering personal electric vehicles

C) Producing fertilizer for farmers

D) Heating homes in the winter

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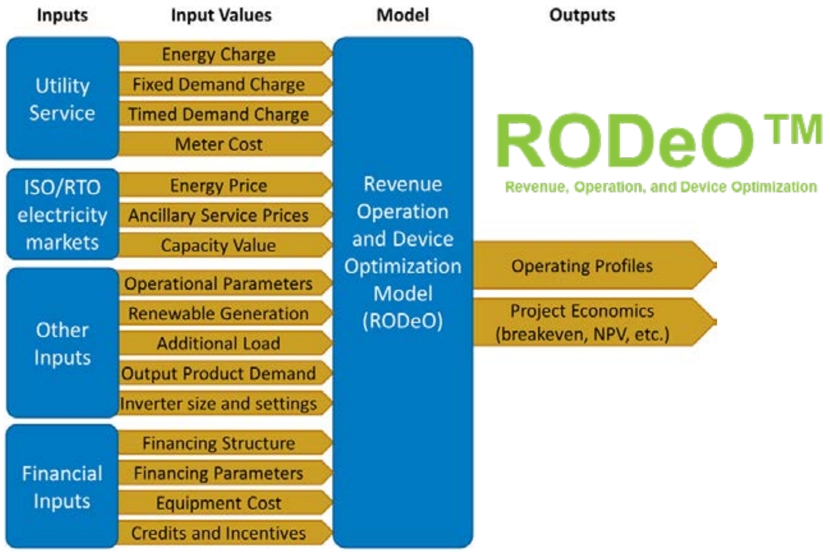
2. Production and Energy Source Considerations

Hydrogen markets require reliable energy sources and technology readiness.

- **Energy Source:**
  - Is there high local availability and quality of renewable energy?
  - Are the costs of power generation ($/MWh) competitive?
  - Is climate change a concern for sources? (e.g., hydropower)
  - Are there specific renewable targets?
  - What is the risk of stranded assets?

- **Technological Advancements:**
  - Is there opportunity to scale up electrolyzers and associated PtX synthesis units (modular growth)?
  - Have there been advances in production technologies?
  - What is the technology readiness level (TRL)?
  - What is the efficiency of production technologies and catalysts?

- **Feedstock availability, sustainability, and supply chain risks:**
  - Is there a sustainable supply of water and feedstock?
  - Is there a good quality and sustainable source of CO_2 for e-fuels?
  - Are there supply chain limitations regarding critical minerals, e.g. platinum for PEM electrolyzers?
  - What is the carbon capture and storage potential for “blue hydrogen”



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Key Takeaways - Production and Energy Source Considerations

- Hydrogen is a flexible and potentially zero carbon emission energy carrier, depending on the production pathway, transport, storage and end use considerations.
- Although color nominations have been used to characterize hydrogen, quantitative metrics, e.g., lifecycle carbon footprint, are more appropriate, particularly in the context of international hydrogen markets.
- There are many alternative sources of low-emission hydrogen, and it is uncertain which of these technologies will dominate in long-term markets, and their respective impacts on the value chain (e.g. critical minerals).
- Availability, quality, reliability and sustainability of energy sources is critical for project viability.

Knowledge Check

What production pathway for hydrogen has the lowest life-cycle carbon emissions in kg of CO_2/kg H_2?

A) Renewable powered electrolysis
B) Steam methane reformation with CCS
C) Grid-driven electrolysis
D) Coal gasification with CCS

3. Infrastructure Considerations

Hydrogen decision-making requires a thorough review of infrastructure considerations.

3

- **Hydrogen/Derivative Production**
  - What infrastructure are available for renewable energy electricity generation (e.g. substations, transmission)?
  - Is there opportunity for co-located infrastructure (e.g. desalination plant)?

- **Storage:**
  - What are the storage opportunities in the area (underground, above ground, compressed, cryogenic, ports)?
  - Has storage feasibility, safety, and capacity been considered?

- **Transportation and Distribution:**
  - Are exclusive pipelines available to transport pure H_2?
  - What is the material adequacy of existing pipelines for natural gas blending?
  - Refueling stations, transportation corridors?

- **End-use:**
  - What is the proximity to clusters or potential hubs?
  - Are there industrial/chemical sectors, port, trucking operations, mining, forklift fleets nearby that could utilize existing infrastructure?
  - What is the potential for retrofitting existing production facilities (e.g. ammonia, steel)?

SERA

Photo by Dennis Schroeder, NREL 40080

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Key Takeaways - Infrastructure Considerations

- The development of a hydrogen infrastructure is costly and critical to achieve large-scale deployment of hydrogen technologies, this involves decision-making across different levels, e.g., from supply chain to process design, integration, and operations.
- Utilizing existing infrastructure, where available, can significantly reduce project CAPEX
- Centralized (Hubs) provide an opportunity to optimize and minimize required infrastructure for storage and transport of hydrogen and its derivatives

Knowledge Check

If the closest market offtaker is 15,000 km (>9,000 miles) away from the production source, what is most likely the best transport format for hydrogen?

A) Compressed gas in tubes

B) Cryogenic liquid in trucks

C) Shipped as ammonia

D) Gas pipeline

4. Costs and Economic Viability Considerations

Hydrogen decision-making requires review of costs and economic viability considerations.

4

- **Capital Costs:**
  - How much new infrastructure development is required?
  - What is the cost of necessary upgrades?
  - How expensive is it to purchase land?
  - Has the high capital cost of hydrogen production facilities been considered?
  - How high is the discount rate being required by the investor(s)?
- **Operational Costs:**
  - How competitive is local energy supply?
  - How available and costly is local maintenance support?
  - What is the cost of feedstock for hydrogen production?
  - What is the cost of land leasing
  - What is the cost of project insurance?
- **Economic viability:**
  - Have potential revenue streams been accurately analyzed?
  - What are available financing options?
  - Are there investment and tax incentives available?
- **Market Demand:**
  - Is there an existing market for clean hydrogen and its derivatives?
  - Does domestic demand make more economic sense than international export?
  - How likely are changes in market applications, e.g. transportation, industry, power generation, storage, agriculture, energy carrier?
- **Market dynamics:**
  - How strict are regulatory or certification requirements in target markets and are they becoming stricter over time?
  - How reliable are pricing projections for products?
  - What are the supply chain risks and considerations?
  - How to mitigate price risk over time?

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Key Takeaways - Cost and Economic Considerations

- Hydrogen production costs should be evaluated in the context of the end use application being considered, e.g., the end use willingness to pay varies significant across different applications (e.g., heavy-duty transportation versus industrial heat).

- Hydrogen storage and transportation is significantly more expensive than other energy carriers. Thus, these costs should be carefully considered when designing hydrogen projects to minimize the need for extensive storage and transport infrastructure.

Knowledge Check

4

What is likely a more economically viable project in the near term?

A) Hydrogen produced from biomass gasification in India and shipped to Japan as compressed gas

B) Hydrogen produced from wind-powered electrolysis in La Guajira, Colombia and synthesized to produce ammonia for utilization by a cluster of local farmers

C) Hydrogen produced from nuclear-powered electrolysis in Argentina and shipped to Japan as ammonia

D) Hydrogen produced from steam methane reformation + geologic CCS and used for local taxi fleets

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5. Environmental Impacts and Sustainability Considerations

Hydrogen decision-making requires review of environmental considerations.

- **Carbon Emissions:**
  - How confident are calculated reductions in carbon emissions and air pollutants?
  - Is there 3rd party verification of carbon capture, utilization, and storage?
  - What is the potential for leakage (GWP of hydrogen >10 x CO2)?
- **Life Cycle Analysis:**
  - Have environmental impacts of the hydrogen LCA been considered?
- **Land Use and Access:**
  - Is there enough land available for infrastructure?
  - Is there a need for resource extraction and land disruption?
  - Is there potential to use a brownfield versus greenfield site?
- **Water Usage:**
  - Have water requirements for hydrogen production been considered?
  - What are the potential impacts on ecosystems and local communities?
- **Waste:**
  - Is there a waste disposal plan in place?
  - How is brine and other discharge being managed?
  - Is there any hazardous waste being generated?
- **Sustainability:**
  - Are renewable energy resources being utilized where possible?
  - What is the resource depletion risk?

Photo from Getty Images 508752705

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Key Takeaways - Environmental Considerations:

- Hydrogen environmental benefits depend on the application and available alternatives, with reduction of fugitive methane and hydrogen emissions playing a critical role in achieving those environmental benefits.

- Decarbonization of hydrogen production is a priority for ensuring that hydrogen plays a significant role in energy transitions.

- Hydrogen projects can have significant impacts on land and water resources, which should be reduced and managed where possible.

Knowledge Check

5

Which hydrogen pathway is likely to yield the greatest reduction in GHG emissions?

A) A coal gasification plant with CCS for local power generation from H_2 to replace natural gas generation

B) Biomass gasification with CCS for utilization in hydrogen fuel cell taxis in a market 5,000 miles away

C) Solar powered electrolysis used to generate e-kerosene for a local airport

D) Wind powered electrolysis to fuel a national fleet of long-distance cargo trucks

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6. Social Considerations

Hydrogen decision-making requires review of social considerations.

- **Land use and access:**
  - What ownership models have been considered (leasing versus purchasing of land)?
  - Does the project have right-of-way or any access bottlenecks?
- **Stakeholder engagement**
  - What is the local perception of the project?
  - Have local workforce opportunities been identified and supported?
  - What are the value chain (manufacturing, infrastructure, construction, indirect jobs) & supply chain risks?
- **Social justice:**
  - Are the projects investing in human capital in local communities?
  - What are the proposed community development programs?
  - Does the project help to support poverty reduction?
- **Water usage:**
  - Is there water competition with agriculture, human consumption, or productive uses?
  - Does the project contribute to fresh water supply with a desalinization plant?
  - What are the potential impacts on ecosystems and local communities with water use?
- **Human health and safety:**
  - Have human safety risks due to dangerous and hazardous gases been mitigated?
- **Regulatory framework for successful stakeholder engagement:**
  - Are there existing regulations for prior consultation process and stakeholder engagement?
- **Data availability:**
  - Are there vulnerable communities in the project area?
  - Are socioeconomic data available to inform project decisions?
  - Are data available or being collected to monitor health concerns?

Source: United Nations Sustainable Development Goals. https://sdgs.un.org/goals

Image from Getty Images 1314214863

Key Takeaways - Social Considerations

- Early-stage community engagement and planning is critical to mitigate/avoid potential social barriers/issues and any health and safety risks.

- Lessons learned from power and industrial sectors should be considered for deploying hydrogen projects and associated workforce development opportunities in a just and equitable way, with emphasis on gender equity and supporting underserved communities.

Knowledge Check

6

What poses the greatest safety risk to a neighboring community?

A) Storage of compressed hydrogen gas in above ground tanks

B) Discharge of brine from a desalinization plant

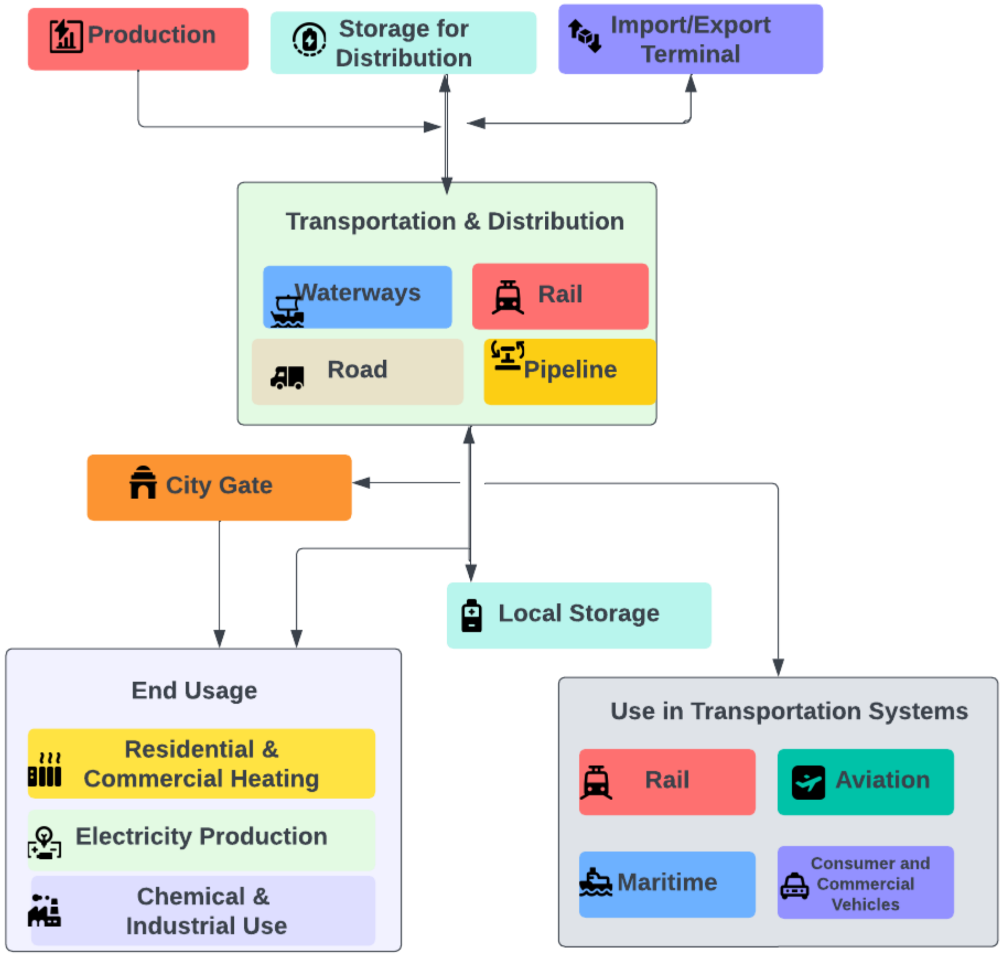
C) Storage of cryogenically liquified hydrogen in above ground tanks

D) Transport of ammonia in shipping tankers

7. Policy and Regulatory Considerations

Hydrogen decision-making requires review of policy and regulatory considerations.

- **Policy landscape and regulatory frameworks:**
  - Is there a regulatory framework for production, storage, transportation?
  - Are there emissions reduction targets that can drive greater adoption?
- **Incentives and Support Programs:**
  - Are there government incentives or subsidies available for hydrogen?
  - Are there any other forms of support or incubator programs?
  - Is there a carbon market or pricing mechanisms available?
- **Regulations:**
  - Are safety standards developed for hydrogen and its derivatives?
  - Are there national and/or international certification schemes in place?
- **Safety and Handling:**
  - Are there safety requirements for handling, storing, distribution and operation of hydrogen and its derivatives?
  - Does the project count on regular safety training programs?
  - Does the project have an emergency response plan?
- **International Collaboration:**
  - Are international cooperation mechanisms: partnerships, trade agreements, global initiatives (e.g. IPHE) supporting the project(s)?
  - Is there established standardization to enable cross-border trade and deployment of clean hydrogen?



Source: Baird, Austin R., Brian D. Ehrhart, Austin M. Glover, and Chris B. Lafleur. 2021. *Federal Oversight of Hydrogen Systems*. SAND2021-2955. Albuquerque, NM: Sandia National Laboratory. https://energy.sandia.gov/wp-content/uploads/2021/03/H2-Regulatory-Map-Report_SAND2021-2955.pdf.

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Key Takeaways - Regulatory and Policy Considerations

- While policies may be in place for fuels or derivatives with existing and established markets (e.g. ammonia), regulatory frameworks for hydrogen are still nascent in most markets.

- Global certification schemes are a priority for the development of an international hydrogen market.

- Policies and regulations are needed across sectors, for all derivatives or products, and for all phases of production, distribution and delivery.

Knowledge Check

7

What of the following regulatory mechanisms are recommended for the development of a hydrogen market?

A) Health and safety standards

B) Regulation for transport, storage, and delivery

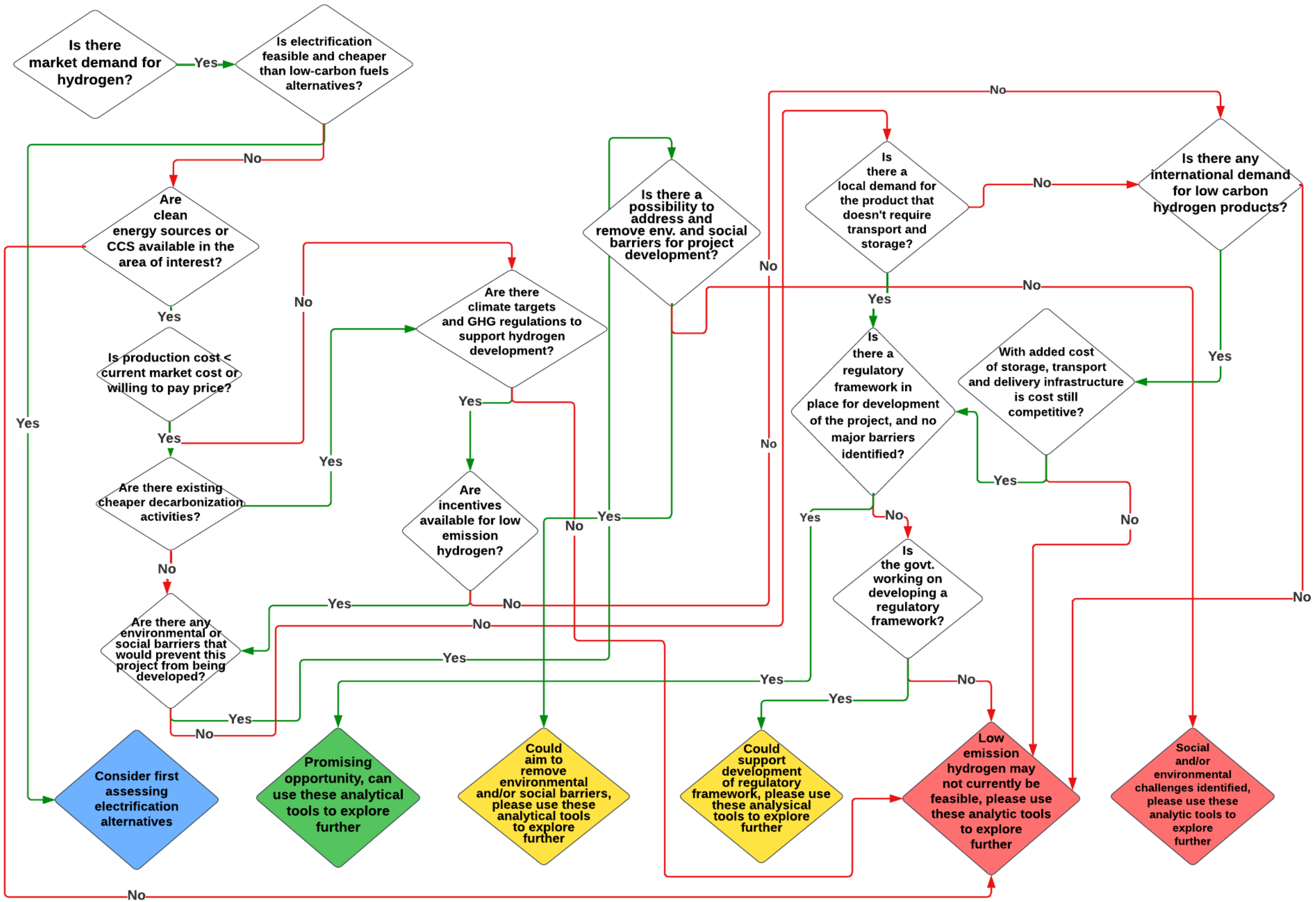
C) Tax or market incentives for early adopters

D) Certification schemes for low-emission hydrogen

8. Synthesis Exercises

Navigating Hydrogen Considerations Tree Flow Chart for Potential Projects

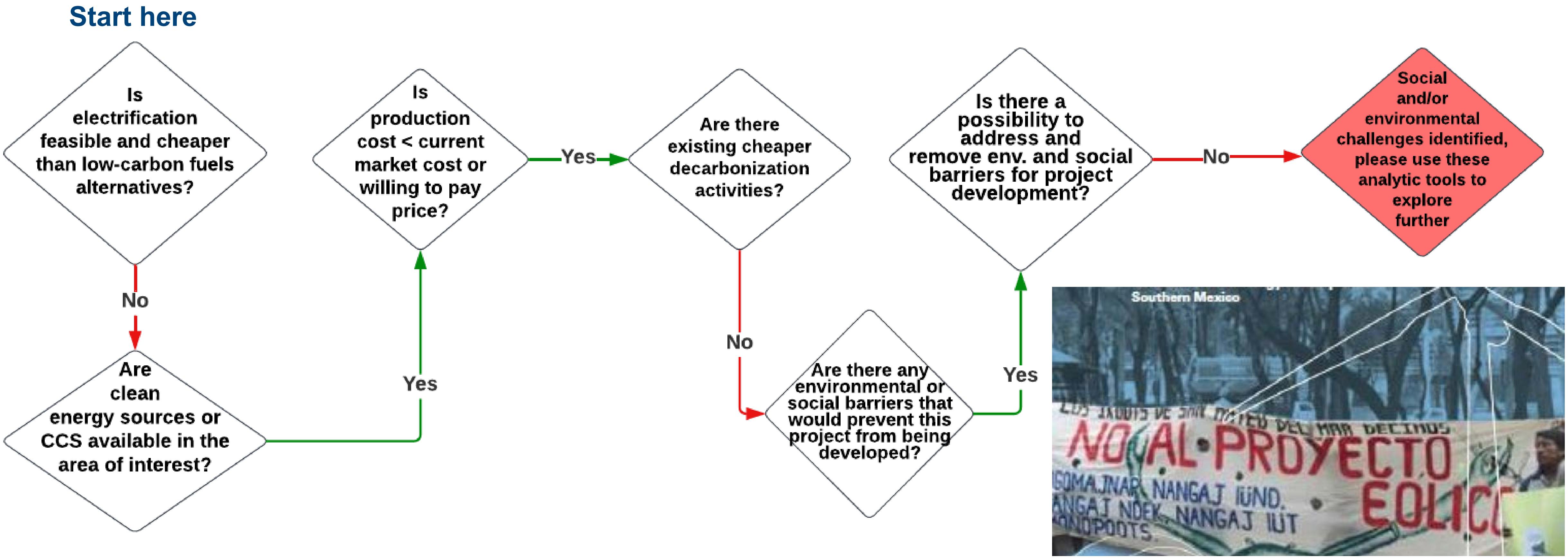
Start Here:



Note: This flow chart is intended to provide a very <u>high-level overview </u>of considerations and questions, to be used for qualitative discussion purposes.

It should <u>not</u> be used to make investment decisions.

Significant Barrier(s) Identified



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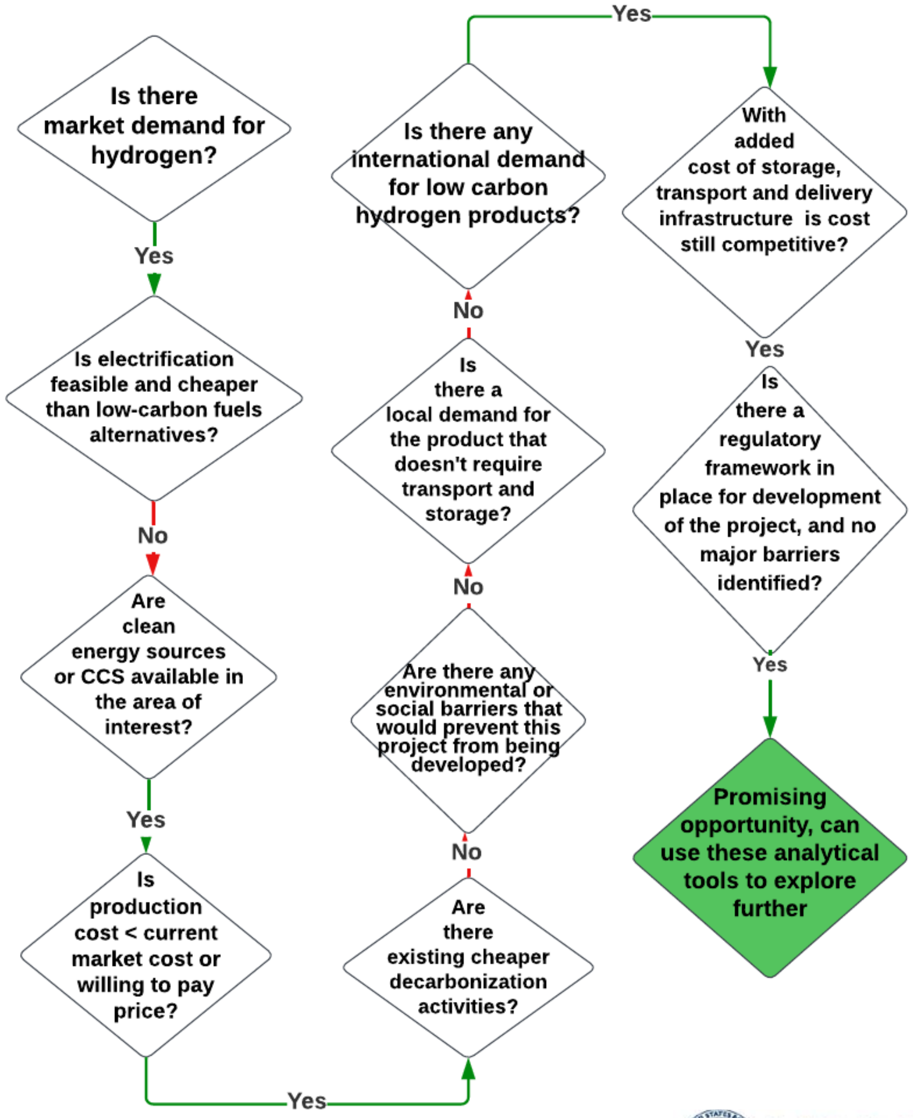
Promising Opportunity to Explore Further

Start here



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Group Exercise - Synthesis Activity Overview

Image from Getty Images 1395775131

Overview: This role-playing activity allows participants to actively engage in the decision-making process and understand the potential benefits, challenges, and trade-offs associated with hydrogen technologies and projects. Participants will explore potential projects from different stakeholder perspectives and apply knowledge gained during the capacity-building program.

Instructions:

- The participants will be presented with background information on a large-scale hydrogen and ammonia project that is being proposed to the policymaker.
- The participants will take on different stakeholder roles to evaluate the proposed project utilizing the knowledge gained during the seven different considerations modules to critically assess the project from different considerations and perspectives.
- In the end, a decision will be made by the policymaker on whether to permit the project, based on the stakeholder engagement, and the policymaker will present their decision and justification.

Outcome: There are no right or wrong results from this exercise; more important is that participants are able to apply the different considerations learned during the training program and critically assess the projects from different perspectives and value considerations to draw a conclusion on whether the potential benefits from the project outweigh the costs.

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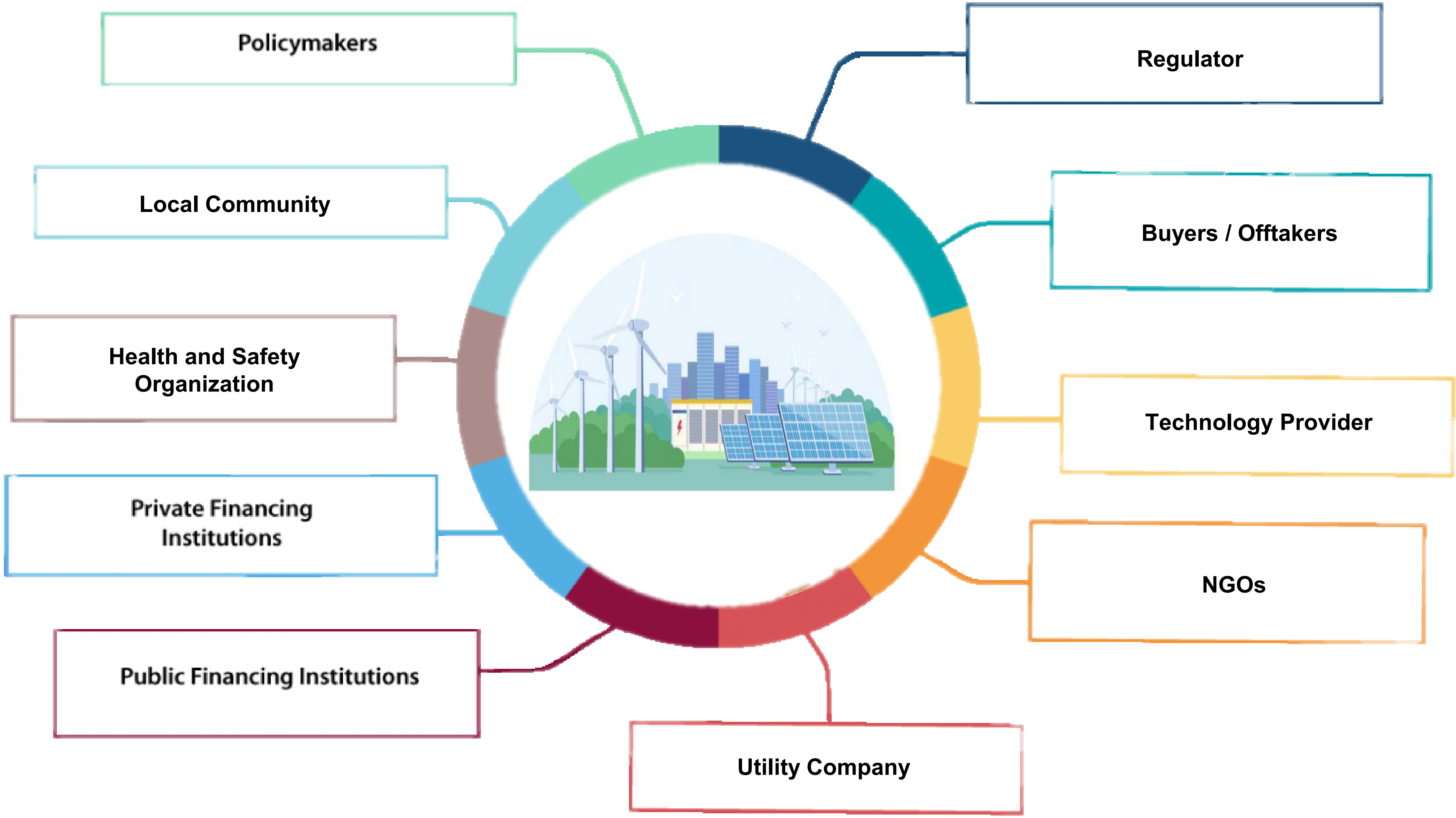
Stakeholders

8



Group Exercise – SWOT Analysis

SWOT Analysis - Large-scale hydrogen and green ammonia project

STRENGTHS

- Low-cost, low-carbon electricity or feedstock?
- Located close to reliable demand or cluster of users?
- Weak customer pricing power?
- Offtake agreements with credit worthy counterparty?
- Existing infrastructure that can be utilized?
- Dependable supply chain?
- High capacity factor renewable energy resource? If not, tradeoffs in a lower capacity factor system?
- Confirmed potential offtakers and long-term purchase agreement?
- Multiple financing options?

WEAKNESSES

- Technology readiness level (TRL) and scalability?
- Trained labor force?
- Clear rules, regulations, and safety protocols?
- Sufficient insurance coverage?
- Distance to demand. Size of demand.
- Robust operations risk management plan
- Who is the major beneficiary, developer or community?
- Supply chain vulnerability. Pricing power of suppliers?
- Existing infrastructure?

OPPORTUNITIES

- Operating in a market with few competitors, limited alternatives, or otherwise difficult to bring-to-market solutions.
- Access to low-cost bulk storage (e.g., geologic) and diverse set of customers to scale.
- Availability of public incentives or attractive financing
- Are there additional benefits that the project can provide (e.g., desalination of water, employment)?
- Opportunity to reduce ammonia imports or access international ammonia markets
- Expansion of agricultural activates
- Creation of technical and non-technical jobs
- Decarbonization of an existing hydrogen use
- Energy security of offtakers

THREATS

- Risk of just one offtaker
- Probability of major natural disasters or environmental, social, or health and safety impacts
- Probability of electricity supply disruption
- Target for cyber security threats?
- High cost of procurement (or time)
- Evolving or unclear regulations (environmental, social)
- Interest rate environment
- Development of alternative, emerging technologies
- Hydrogen leakage and potential catastrophic events

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Thank you!

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