A Global Hydrogen Future

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Opening Session

A Global Hydrogen Future

Keynote Addresses

Ernest J. Moniz – EFI - Chairman & CEO

Fahad Alajlan – KAPSARC - President

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A Global Hydrogen Future

The Climate Change Context

Jonathan Pershing – The Hewlett Foundation

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The Climate Change Context

EFI – KAPSARC Hydrogen Workshop
October, 2022

Jonathan Pershing

WILLIAM + FLORA
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Foundation

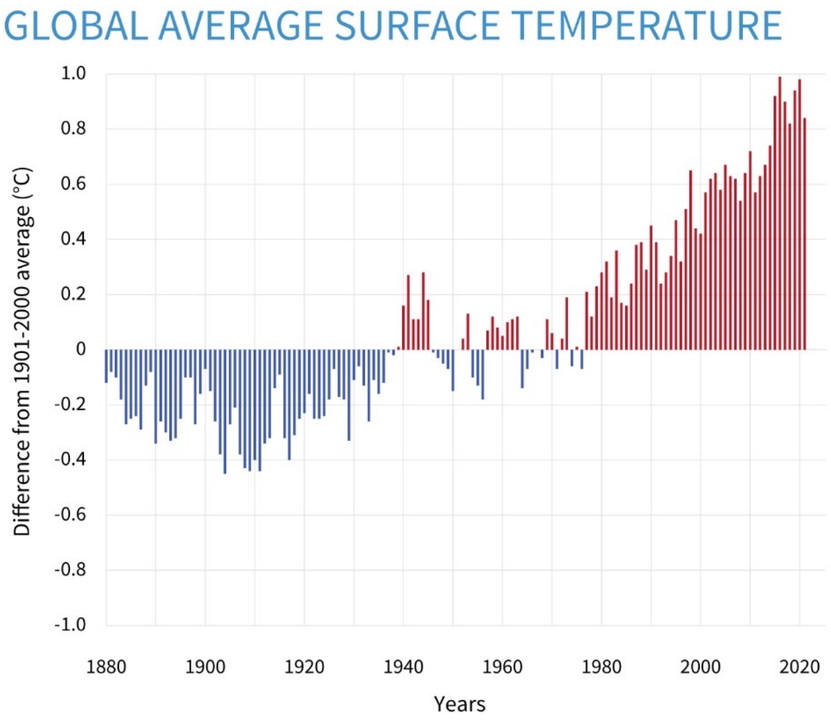
The Paris Agreement (2015)

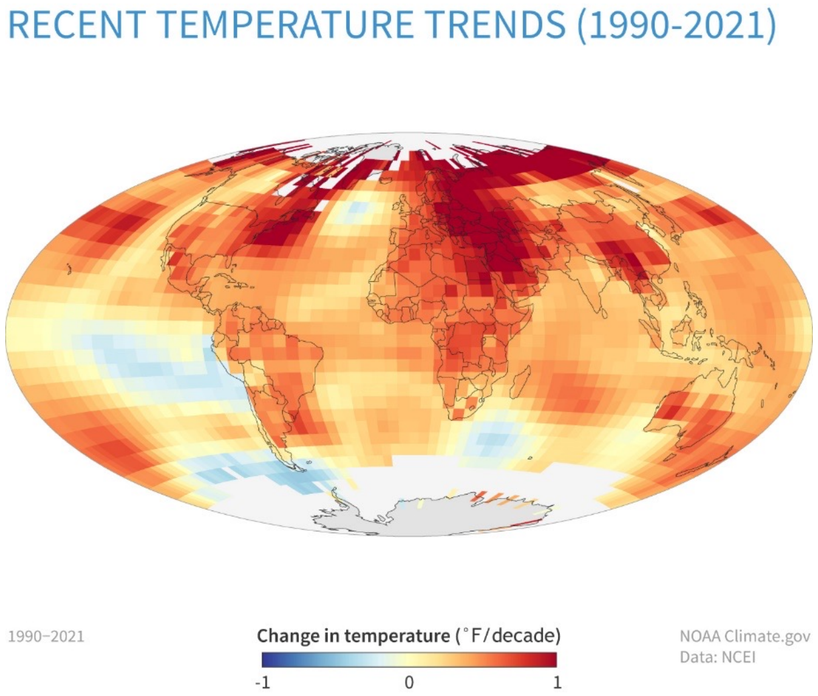
"Aims to strengthen the global response to the threat of climate change by holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels."

(Paris Agreement, Article 2)

194 Parties, entered into force in November 2016

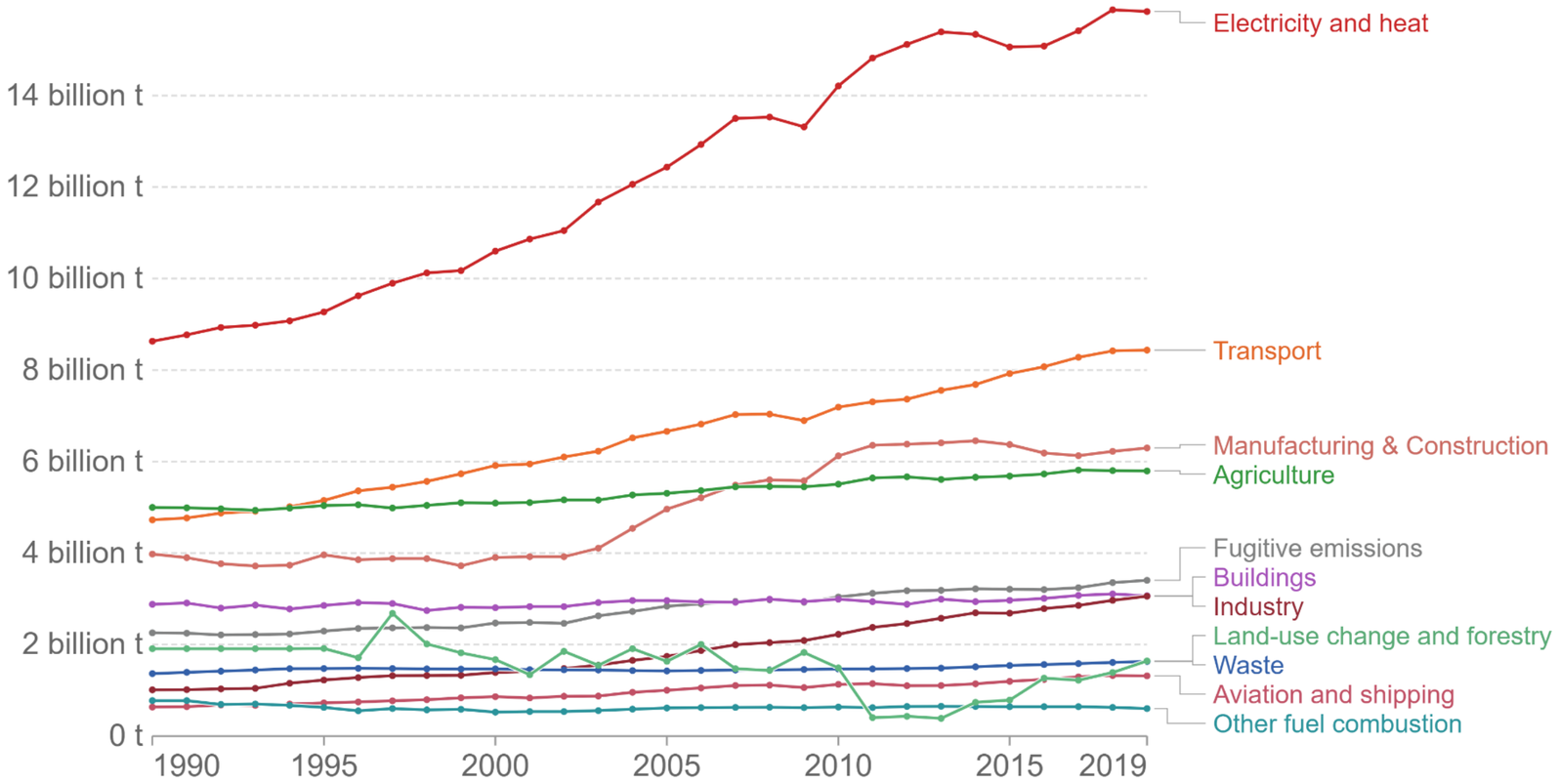
Trends in global temperature





Source: NOAA, [Climate Change: Global Temperature | NOAA Climate.gov]

Trends in global greenhouse gas emissions 1990 - 2019



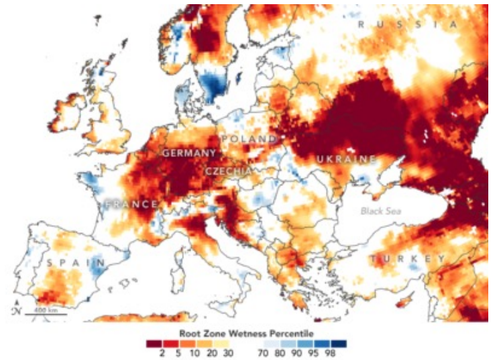
Source: Our World in Data based on Climate Analysis Indicators Tool (CAIT).
Note: Greenhouse gases are weighted by their global warming potential value (GWP100). GWP100 measures the relative warming impact of one molecule of a greenhouse gas, relative to carbon dioxide, over 100 years.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

Climate Impacts Today: 1.1°C

Surface air temperatures across the planet, on July 13, 2022, ranging from less than zero degrees Celsius (dark blue) to greater than 45 degrees Celsius (black). Joshua Stevens/GEOS-5/NASA GSFC/VIIRS/Suomi National Polar-orbiting Partnership

Pakistan, 33 million displaced, climate likely increased severity by about 50%

Increased sea surface temperatures of about 1°C led to intensification of storm (from Cat 2 to Cat 5)



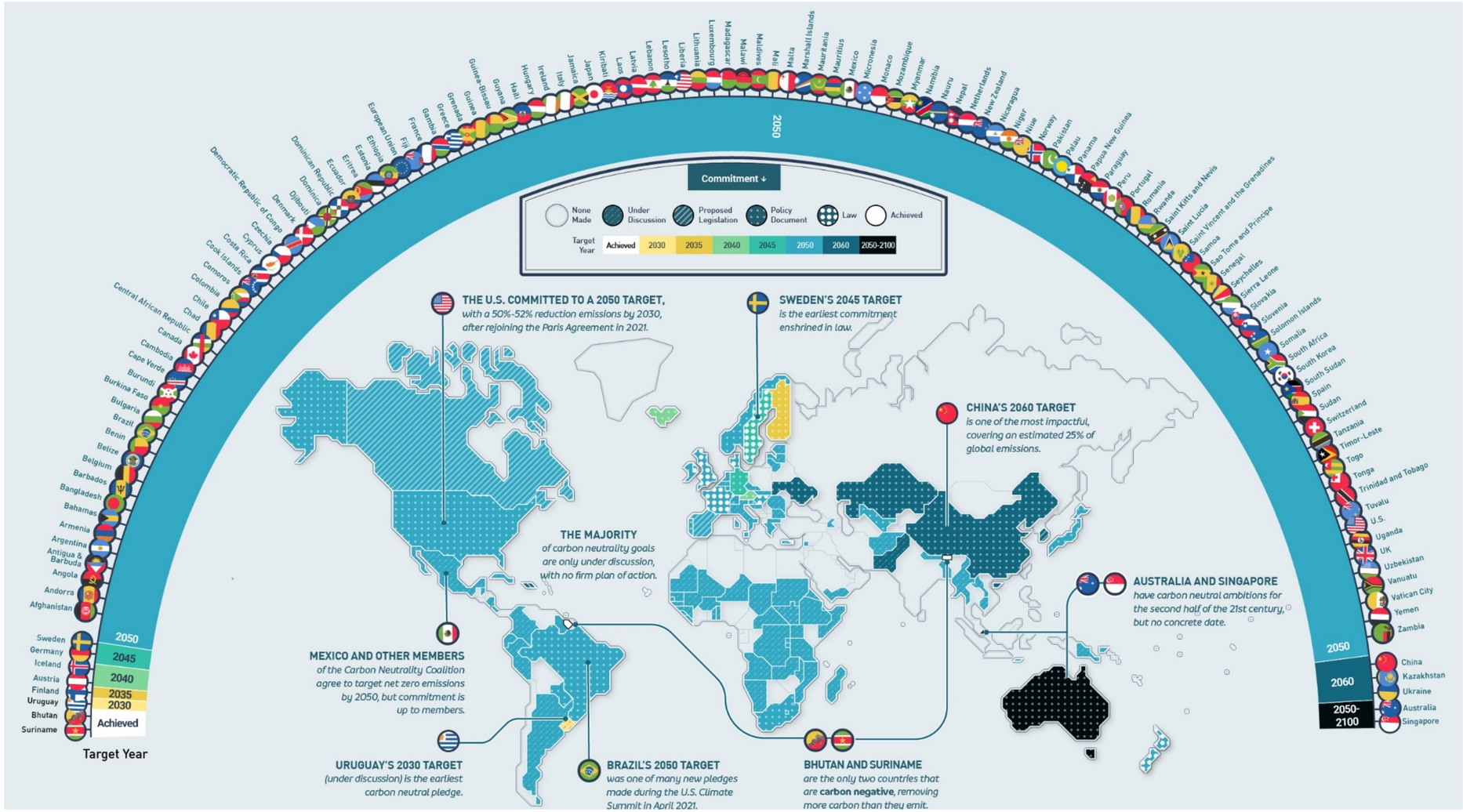
European drought worst in at least 250 years; maize production dropped 20-40 percent

Reductions Needed to Meet Paris Temperature Goal

According to the IPC's 6th Assessment Report, released in April 2022, limiting warming to around 1.5°C (2.7°F) requires global greenhouse gas emissions to peak before 2025 at the latest, and be reduced by 43% by 2030.

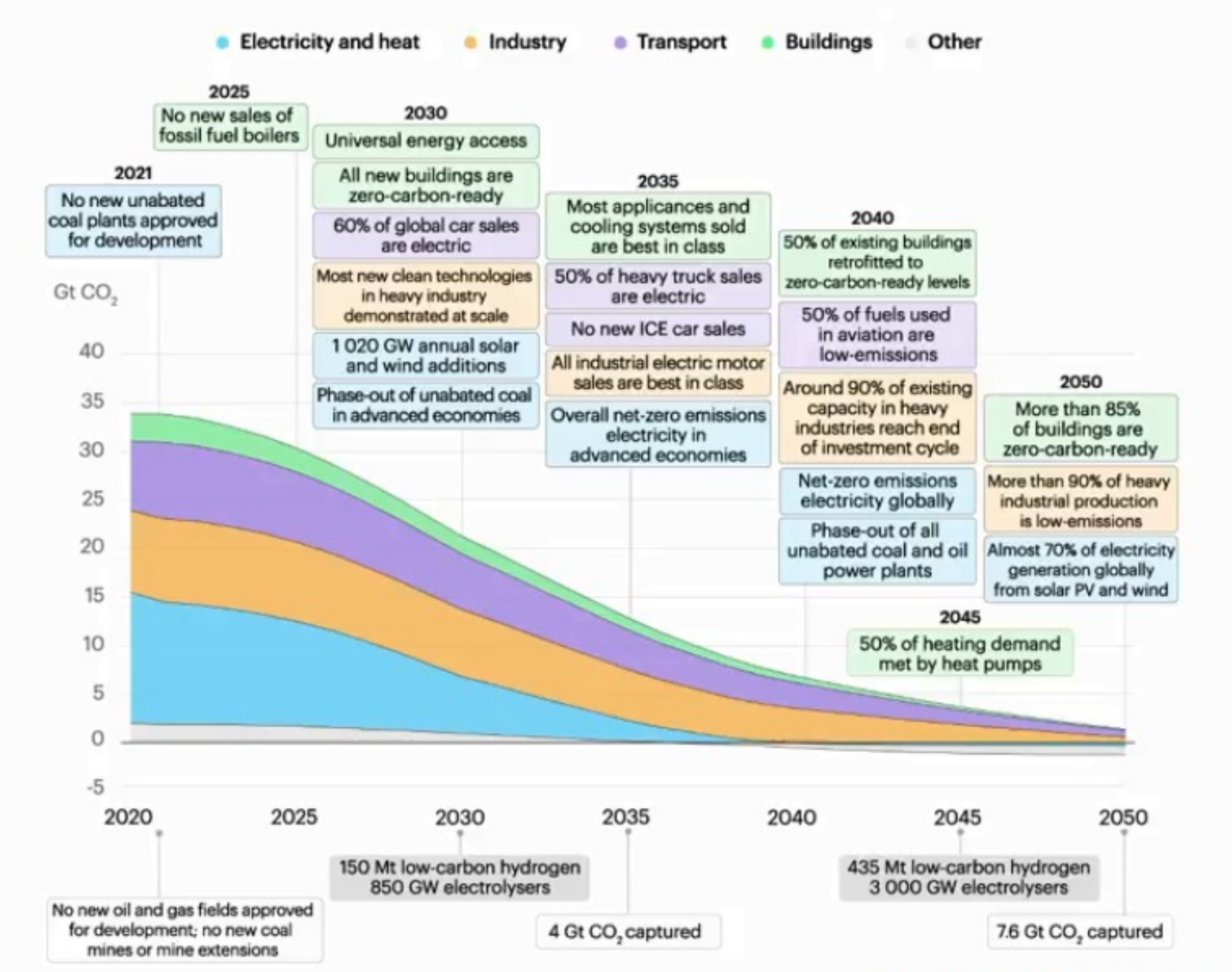
Net Zero Pledges

(As of July 2022)



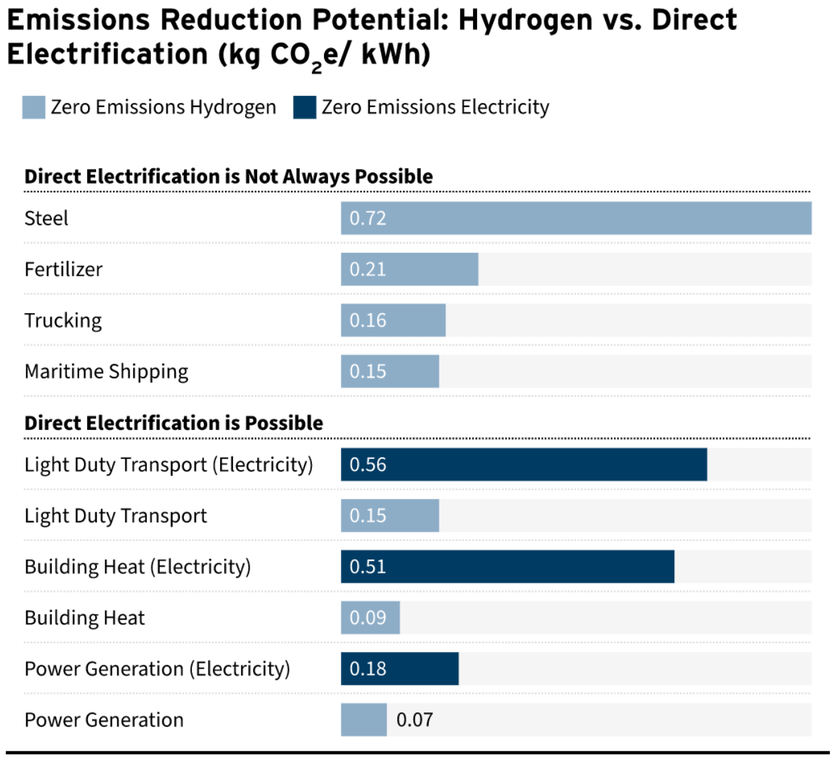
Source: [Race to Net Zero: Carbon Neutral Goals by Country - Full Size (visualcapitalist.com)]

A Net Zero by 2050 Scenario

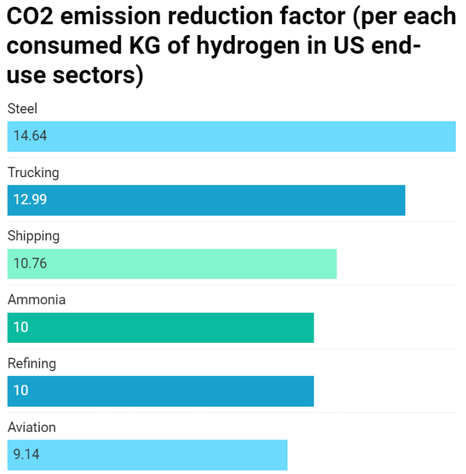


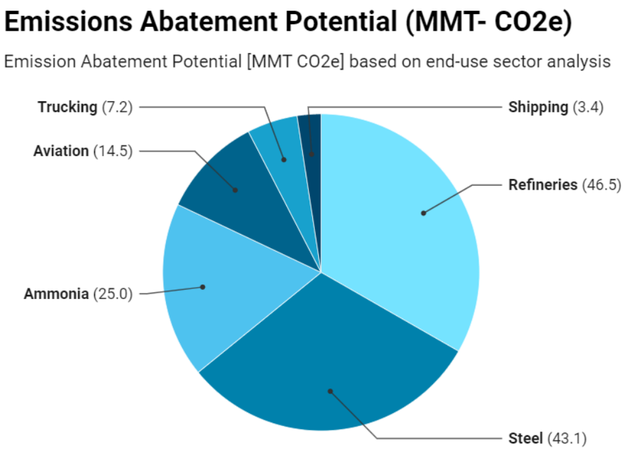
Source: IEA, [Net Zero by 2050 - A Roadmap for the Global Energy Sector (windows.net)]

Hydrogen is a key part of the solution – but not equally in all sectors



Source: RMI, [Hydrogen Reality Check: We Need Hydrogen — But Not for Everything - RMI]





Source: RMI, [Policy Memo: Clean Hydrogen Abatement - RMI]

Implications of getting to net zero by 2050

- Investment shifts: massive new investment in electricity and clean energy infrastructure (including for grid, EV charging, hydrogen, DAC and CO2 pipelines). Fossil investment down sharply. Overall GDP up.
- Employment shifts: decrease in oil and gas, increase in renewable energy. Major increases in some manufacturing sectors (solar PV, batteries as well as building efficiency improvements)
- Geographic advantages change: countries with critical minerals, or zero-emissions industrial energy capacity have significant advantages in new global zero-emission marketplace
- The transition could be disruptive without policy and planning to help manage the volatility and transition risk.

Implications of getting to net zero by 2050

BUT:

Inaction on climate change (and a temperature increase of about 3°C) could cost $178 trillion by 2070, while the global economy could gain $43 trillion over that same period by accelerating the transition to net zero.

Source, Deloitte, 2022 “Global Turning Point Report”, The turning point A Global Summary (deloitte.com)

A Global Hydrogen Future

Panel Discussion - Global Hydrogen Overview

Moderator: Melanie Kenderdine

Participants: Adam Sieminski, Martin Wilhelm and Han Phoumin

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The Role of Hydrogen in a Climate Challenged World

…Sustainability, Access, and Security

Energy Futures Initiative / KAPSARC Workshop

11 October 2022

Adam Sieminski

Senior Advisor

King Abdullah Petroleum Studies and Research Center

KAPSARC

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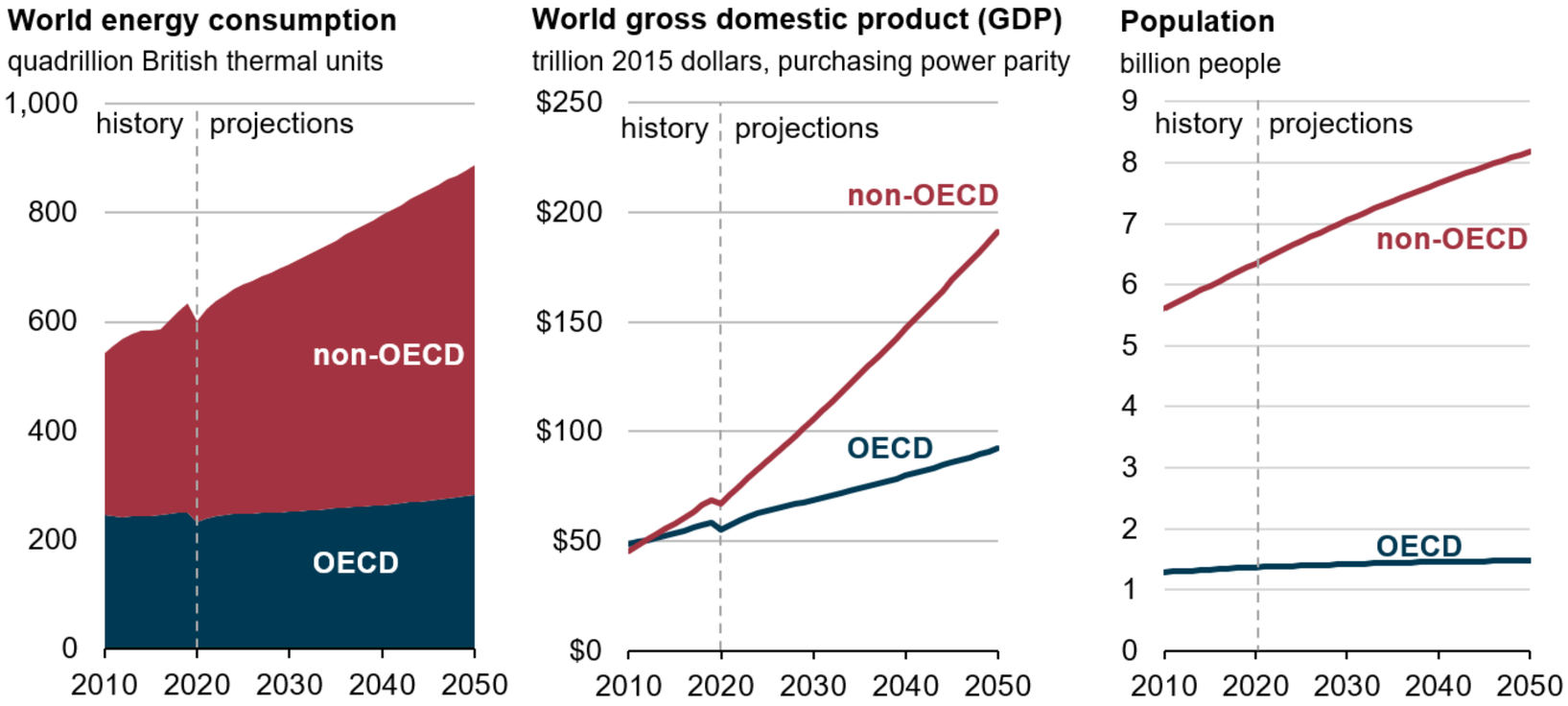
Global energy use increases nearly 50% by 2050, driven by non-OECD economic growth and population in the Energy Information Administration reference case

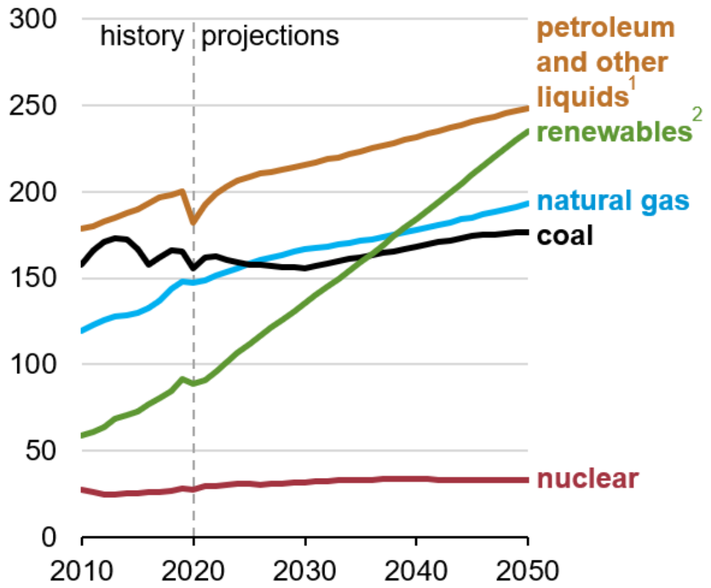


Source: Energy Information Administration, IEO 2021

Liquid fuels remain the largest source of primary energy in the EIA's reference case, but renewables use grows to nearly the same level

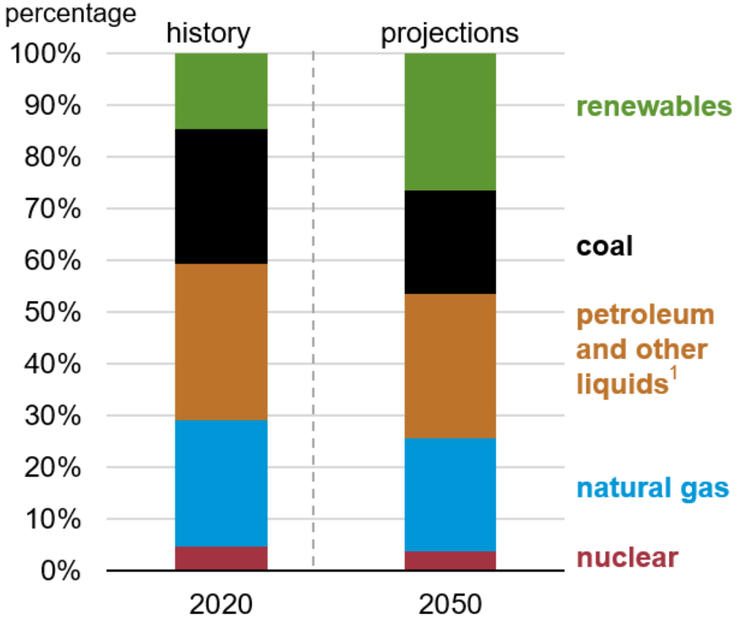
Primary energy consumption by energy source, world

quadrillion British thermal units



Share of primary energy consumption by source, world

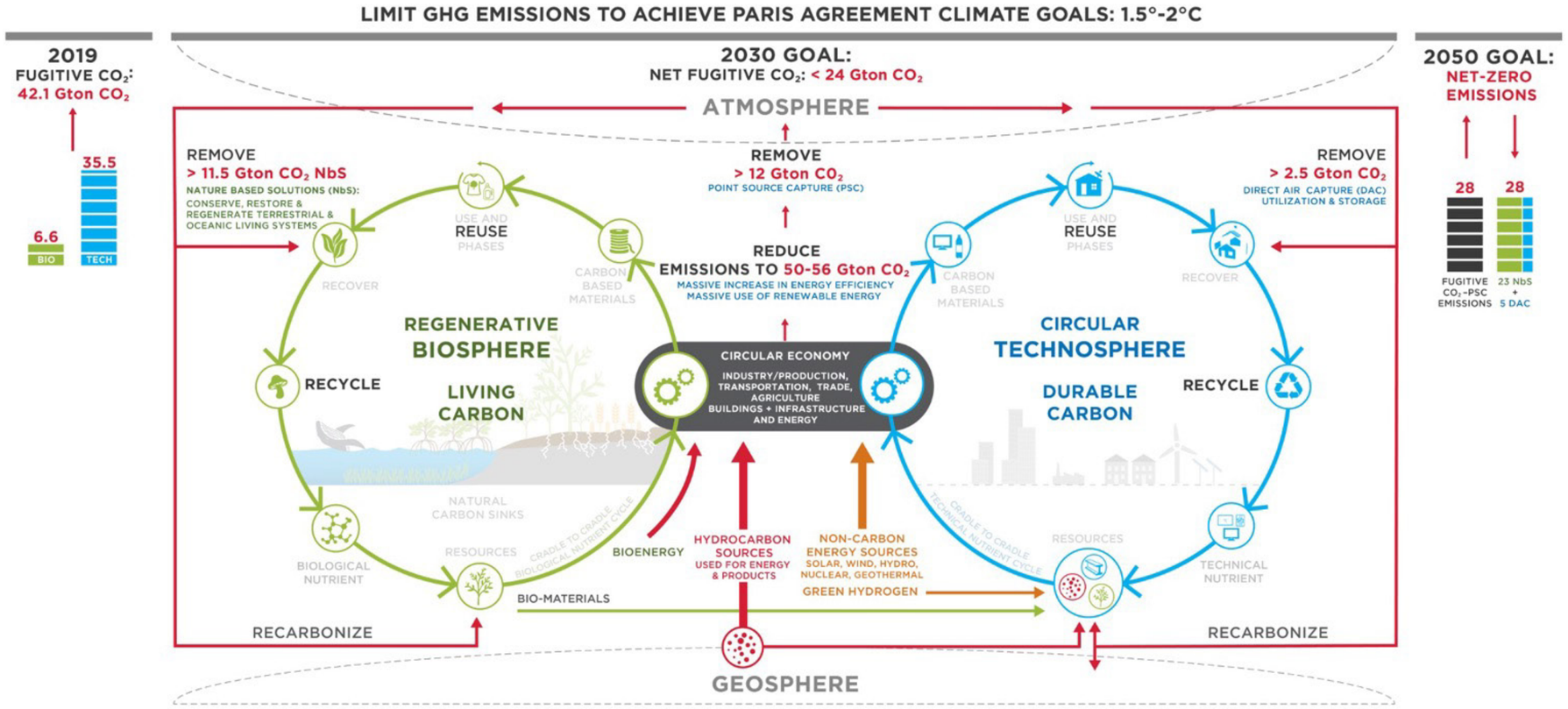
percentage



[1] Includes biofuels
[2] Electricity generation from renewable sources is converted to Btu at a rate of 8,124 Btu/kWh

Source: Energy Information Administration, IEO 2021

Applying circular economy concepts to carbon flows- emissions are the problem
…living carbon, durable carbon, and fugitive carbon



Source: Copyright McDonough Innovation, used with permission

Narrow focus on only reducing fossil fuels will result in significant, undesirable socio-economic consequences for both consumers and producers

No practical solutions for hard to abate sectors

- Few cost-efficient emissions reduction solutions for energy-intensive sectors such as aviation, shipping, heavy-duty trucking, cement, metals smelting

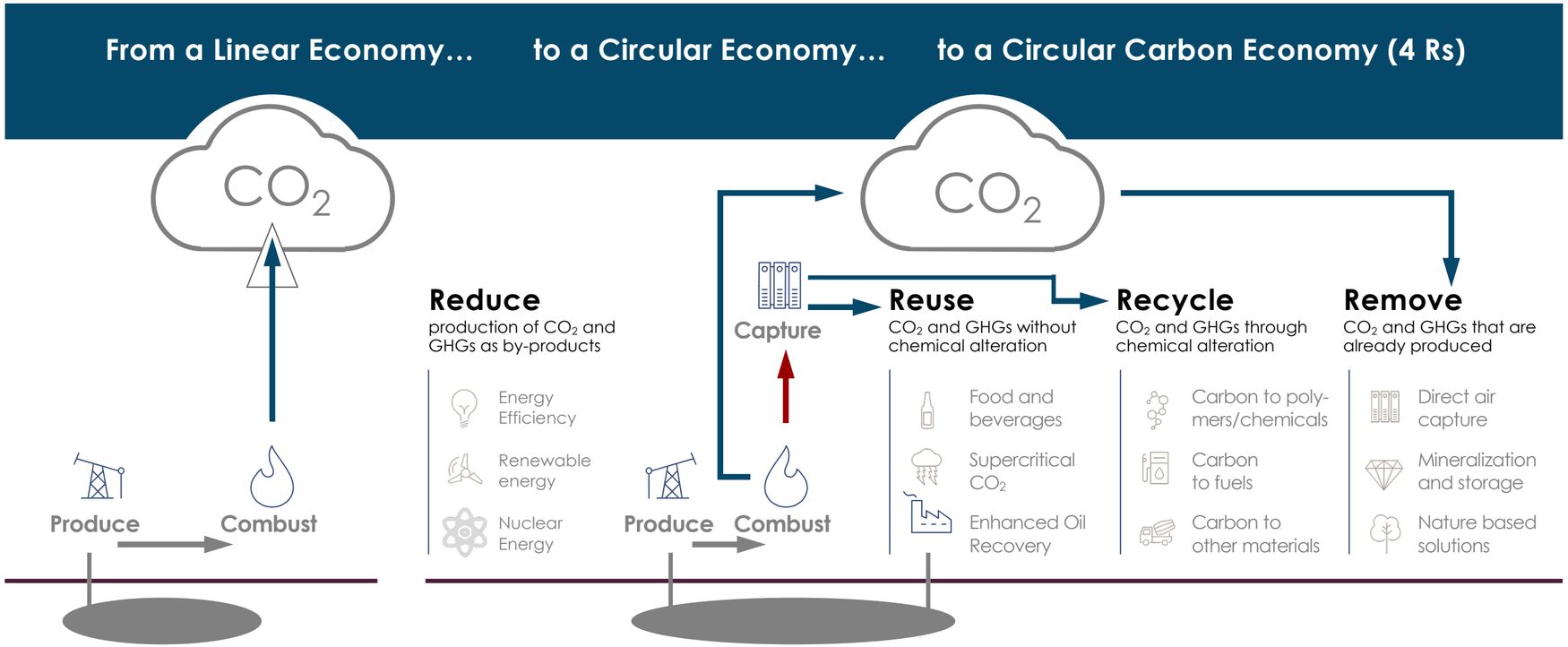
Reduced energy access and reliability

- Major negative impact on consumers access to “affordable, reliable, sustainable, and modern energy for all” – UN Sustainable Development Goal (SDG) 7
- Deterioration of energy availability as a result of depending heavily on intermittent sources

Inefficient utilization of costly existing infrastructure

- Significant cost and time in premature switching to new energy sources
- Inadequate utilization of infrastructure investments already committed

A holistic approach, that utilizes all available levers to address CO_2 emissions – with climate protection and economic growth



The circular carbon economy sustainability framework implementation can work in many countries based on each nation's unique circumstances

Technology

- **Prioritize solutions** based on abatement potential, cost, and maturity
- Advance CCE technologies with sustained **R&D and pilot projects**

Policy

- **Provide mechanisms for enabling** deployment of underutilized and new CCE technologies
- Develop **robust measurement, reporting, and verification** systems

Markets

- Establish **carbon hubs** that create a market for carbon leading to innovative products
- Look for ways to make carbon a **value-added** product not an economic burden

Key ongoing energy sustainability initiatives in Saudi Arabia
...advancing technologies with sustained R&D and pilot projects

Energy efficiency
Launched the **Saudi Energy Efficiency Program** to improve energy efficiency in the **buildings, transportation and industrial sectors**

Enhanced Oil Recovery
Aramco capturing CO_2 in **the Hawiyah gas plant** and using it **for Enhanced Oil Recovery** in Uthmaniyah

CO_2 to chemicals
SABIC planning to scale up by 2030 **capture of CO_2 from the ethylene glycol** process and then using it in the **production of methanol and fertilizer**

Nature-Based Solutions
Saudi Aramco plan to plant ~46M trees by 2030
Protecting and restoring mangroves in KSA and abroad

Liquid fuel displacement
Transform KSA's **energy mix** by converting up to **50% of liquid to gas and renewable energy** by 2030 **displacing ~1mbpd**

CO_2 for industries
SABIC currently capturing and selling **liquid CO_2** for **water desalination, food & beverages, and meat refrigeration and conservation**

E-fuels
Plan for pilot by 2023 of **large-scale green e-fuels production facility** that will **utilize green energy from NEOM**

Direct Air Capture
Saudi Aramco exploring pilot project

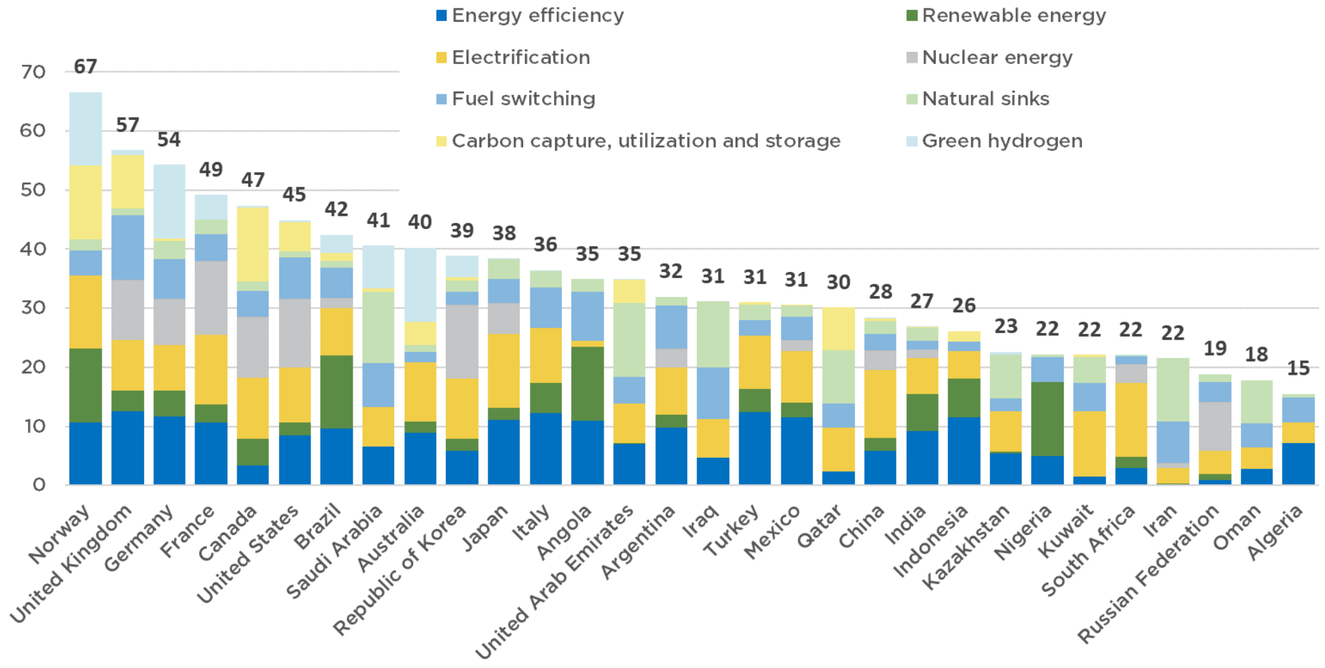
NEOM Green Hydrogen
Invested in a **5B$ Hydrogen plant in NEOM by 2024** with dedicated **wind and solar power to produce green hydrogen**

Saudi Green Initiative
- **National target set to reach net zero greenhouse gas (GHG) emissions by 2060**
- **Saudi Aramco and Sabic target net zero GHG emissions from wholly-owned operations (Scope 1&2) by 2050**
- **Nationally Determined Contribution (NDC) raised to 270 million tonnes of CO2e emissions per year by 2030**
- **Kingdom joins the Global Methane Pledge to reduce global CH4 emissions by 30% from 2020 levels by 2030**
- **Saudi Arabia pledges to plant 10 billion trees across the nation and rehabilitate 40 million hectares of land**

CCE Index - Carbon circularity performance scores for 2021
...developing robust measurement, reporting, and verification systems

CCE Performance Score

- Energy Efficiency
- Renewable Energy
- Electrification
- Nuclear Energy
- Fuel Switching
- Natural Sinks
- CCUS
- Clean Hydrogen



Source: Luomi, Yilmaz, Alshehri; KAPSARC 2021

A new international forum established in 2021 formalized in 2022 to develop long-term strategies to reach global net-zero emissions with continuing use of hydrocarbons

Net-Zero Producers Forum – U.S. Climate Summit, April 2021

Canada, Norway, Qatar, Saudi Arabia, United Arab Emirates, and the United States, collectively representing almost 50% of global oil and gas production, have established a new international forum dedicated to reaching global net-zero emissions

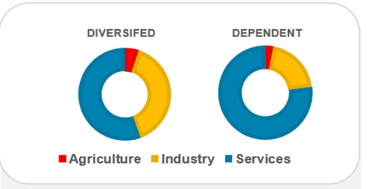
Develop Pragmatic Net-Zero Emission Strategies

Develop methane abatement strategies

Circular Carbon Economy

Advance the Circular Carbon Economy approach of valuing all solutions

Develop and deploy clean-energy and carbon capture and storage technologies

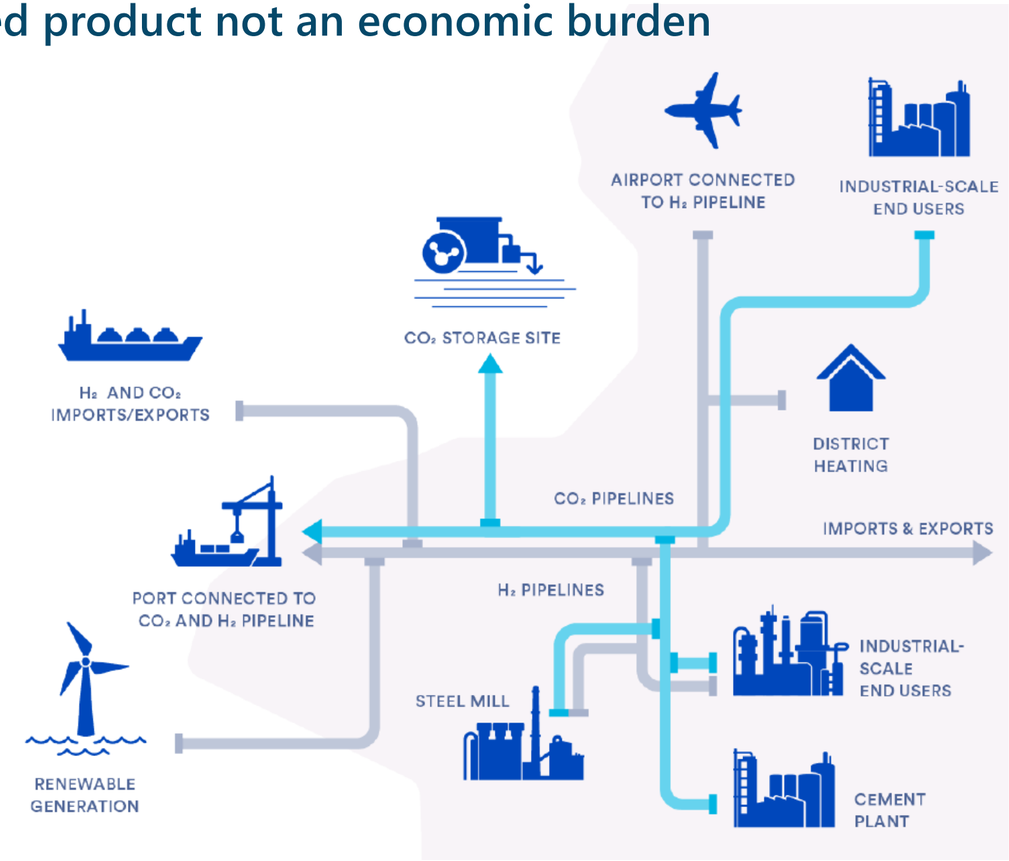


Diversify away from over-reliance on hydrocarbon revenues

Deep decarbonization hubs
...making carbon a value-added product not an economic burden

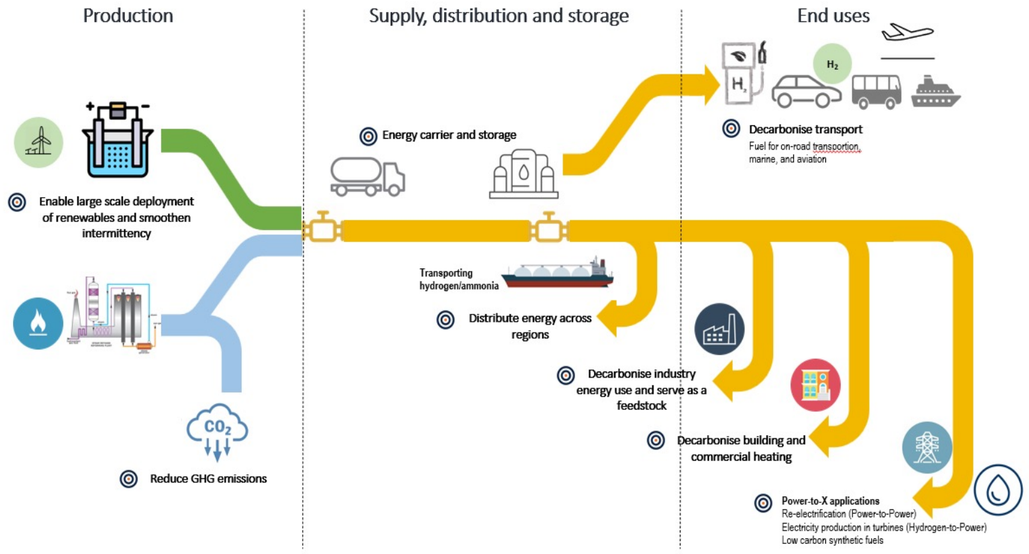
- **Reduce financial costs and risks** with no-regrets infrastructure
- **Increase economic efficiency** and enable greater innovation through shared infrastructure
- **Facilitate deeper emissions reductions** in areas of high concentration
- **Enable faster coordination uptake** because it is more effective to build large infrastructure facilities rather than multiple smaller ones

Source: Clean Air Task Force



Hydrogen: A potential energy carrier to accelerate the transition

- **Hydrogen can complement electrification in meeting goals under the Paris Agreement**
- **Hydrogen is very versatile, however it is best used for hard-to-abate sectors**
- **Under the CCE framework, hydrogen can enable all four carbon mitigation options**
  - **Reduce:** substituting high-carbon fuels with clean hydrogen can reduce carbon emissions entering the system
  - **Recycle:** using hydrogen with CO2 to create synthetic fuels can directly replace conventional fossil fuels
  - **Reuse:** CO2 from blue hydrogen production can be used for CO_2-EOR
  - **Remove:** the production of hydrogen from biomass with CCS removes CO_2 from the system and allows for negative emissions



Source: KAPSARC, Hasan and Shabaneh, 2022

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Thank You

EFI-KAPSARC Joint Workshop titled “A Global Hydrogen Future,” held on Oct 11, 2022.

Potential Hydrogen as Game Changer in ASEAN & EAS’s Decarbonisation Pathways

Han Phoumin, Ph.D
Senior Energy Economist

Economic Research Institute for ASEAN and East Asia

Overview

- ASEAN & EAS region currently faces paramount challenges in matching its energy demand with sustainable energy supply given the transition to a lower carbon economy, and net zero emission by 2050
- The current region's energy system is dominated by fossil fuel with almost 80% share of combined coal, oil and natural gas;
- In response to the climate commitments of COP21, the region will need to balance b/t economic growth, energy affordability, availability and environment.
- The ASEAN & EAS region's energy reality and transition to cleaner energy system will need to consider clean use of fossil fuel, Res, and other new energy such as hydrogen.
- Thus, the role of hydrogen could help decarbonize the emission as its presence will also an enable of accelerating NRE to its full potentials.
- Countries have started concrete plan/roadmap in the value chain of hydrogen, hydrogen share target, and policy supports are progressing.

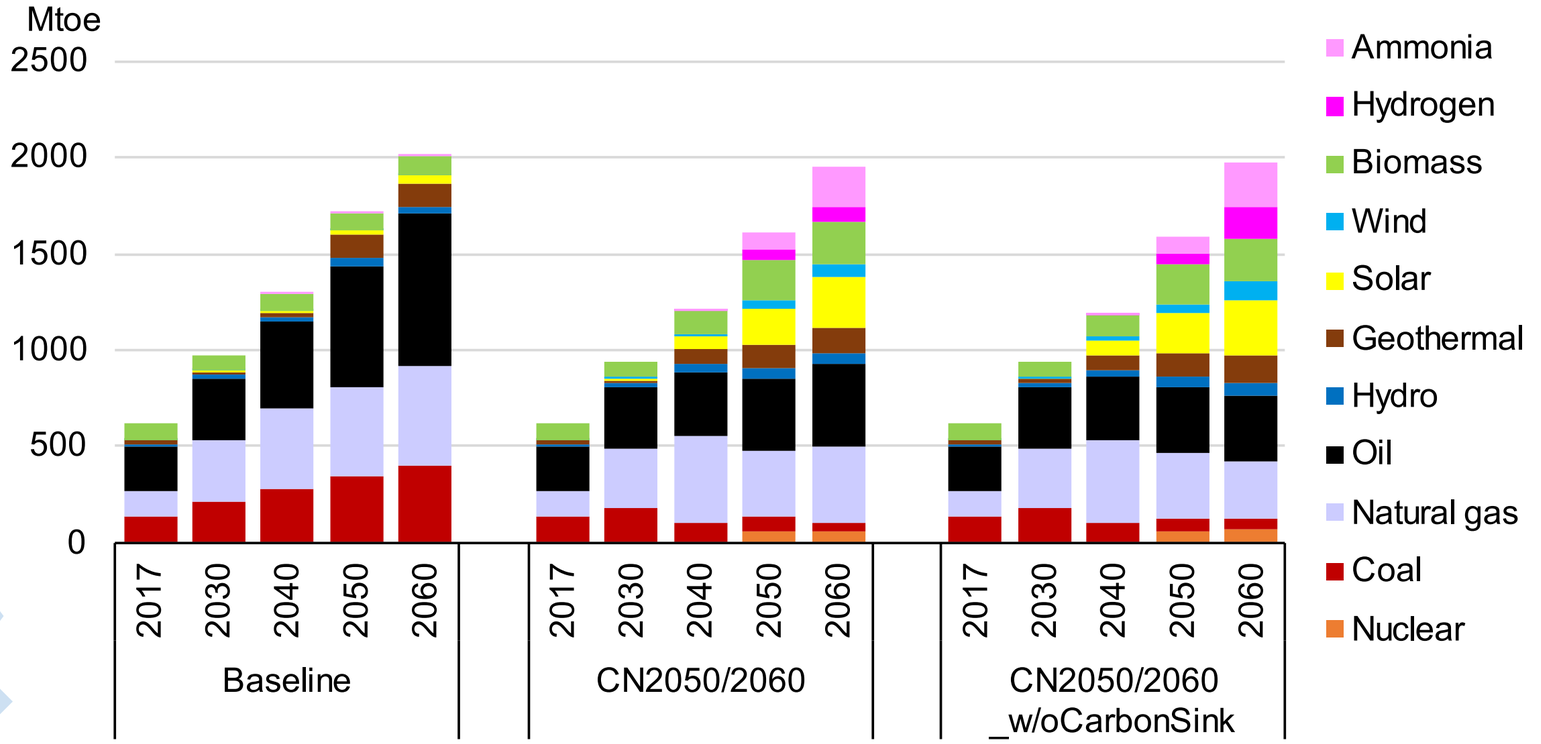
Hydrogen Development and Up-taking in EAS region

- China is expected to invest $2 billion in hydrogen industries in the next few years. China planned to put in place 300 hydrogen fueling stations in 2025 and scale up to 1,000 hydrogen fueling stations by 2030.
- Japan is actively promoting the global adoption of hydrogen for vehicles, power plants and other potential uses. The Sixth Strategic Energy Plan targets for energy produced from hydrogen and/or ammonia sources at 1% of Japan's total power generation by fiscal year 2030. More concrete projects are being constructed.
- South Korea’s New Deal focuses on hydrogen economy and promote all investment along value chain of the hydrogen with clear targets in all industries including the FCEVs, power generation and expanding to the entire energy system.
- Australia Govt’s National Hydrogen Strategy sets a vision for commercial renewable hydrogen export by 2030, with an estimated demand for export of 3 million tonnes each year by 2040, worth up to $ 10 billion each year by that time.
- Brunei Darussalam is taking lead in the region’s hydrogen supply chain as it has supplied the liquefied hydrogen from Muara port to Japan in late 2019. Many other ASEAN will follow the introduction and adoption of hydrogen into the future energy mix.
- In the energy transition, hydrogen and ammonia co-combustion with coal & natural-fired power plants are highly in the policy agenda. Future 100% of hydrogen power generation is also recommended.

Hydrogen plays Crucial Role in Decarbonization Pathways in the region

- A wide range of technologies, including renewables, nuclear, CCS and import of hydrogen and ammonia, are necessary for deep decarbonization.
- Zero emission energies together contribute to 56% of primary energy in 2060 in the *CN2050/2060,* and 65% in the *CN2050/2060_w/oCarbonSink*.

Primary energy supply in ASEAN



Fossil fuels include non-energy use. CO_2 from fossil fuel combustion in 2060 in CN2050/2060 is offset by NETs and natural carbon sink.

1 NETs = Negative Emissions Technologies

Key regulatory and investment for promoting hydrogen in EAS region

Major policy reforms are needed to ensure that clean fuels such as hydrogen and renewables and clean technologies will gradually replace traditional fuels and technologies:

(i) Develop a clear strategy/road map to promote hydrogen use in transport; power generation; and other sectors where emissions are hard to abate.

(ii) The policies to enable economies of scale in cost-competitive production of hydrogen to induce investors to consider electrolyser manufacturing; improvements in electrolyser efficiency, operation, and maintenance; and the use of low-cost renewable power.

(iii) PPP partnership to build awareness of hydrogen society, and ensure that the public is willing to pay for them.

(iv) Financing mechanisms such as banks must create favourable conditions to finance facilities such as electrolysers, and all form of the hydrogen productions including the Steam Methane Reforming (SMR).

Thank you! And some related publications for references of my talks

sustainability

MDPI

Article

Potential Renewable Hydrogen from Curtailed Electricity to Decarbonize ASEAN's Emissions: Policy Implications

Han Phoumin [1,*], Fukunari Kimura [1,2] and Jun Arima [1,3]

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* Correspondence: han.phoumin@eria.org

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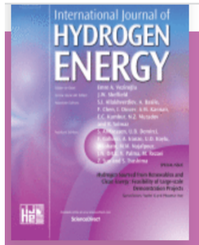

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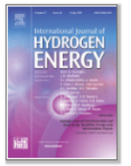
Hydrogen Sourced from Renewables and Clean Energy: Feasibility of Large-scale Demonstration Projects

Edited by Yanfei Li, Phoumin Han
Volume 47, Issue 58,
Pages 24255-24668 (8 July 2022)

ELSEVIER

International Journal of Hydrogen Energy

Volume 47, Issue 58, 8 July 2022, Pages 24548-24557



Curtailed electricity and hydrogen in Association of Southeast Asian Nations and East Asia Summit: Perspectives form an economic and environmental analysis

Youngho Chang [a], Han Phoumin [b]

Show more

A Global Hydrogen Future Break

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EFI's Action Plan for U.S. Hydrogen Market Formation

Alex Kizer, ***SVP of Research***

EFI's Clean Hydrogen Portfolio

Project Objectives

- Animate **capital investment** in hydrogen through policy recommendations
- Inform **infrastructure package implementation** for hydrogen, especially for the regional hubs
- Provide **thought leadership** for new coalitions and pathways for market formation

Project Workstreams and Objectives

Views from Industry, Innovators, and Investors Report (Sep 2021)

- Provide a snapshot of the clean hydrogen investment environment
- Describe investors' market outlook, investment rationale, and business models
- Articulate investors' priority factors (enablers and deterrents) driving business decisions

Regional Workshops and Reports

Ohio River Valley
(Jul/Sep 2021)

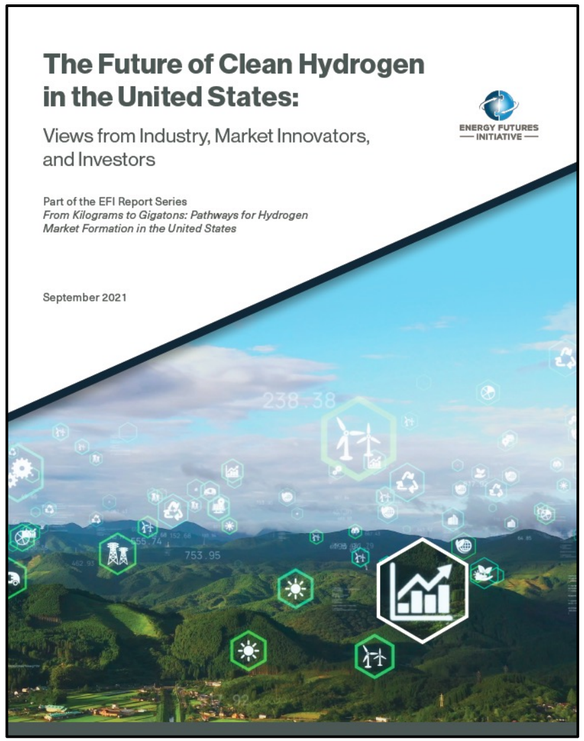
Carolinas
(Oct/Dec 2021)

Gulf Coast
(Jun/Sep 2022)

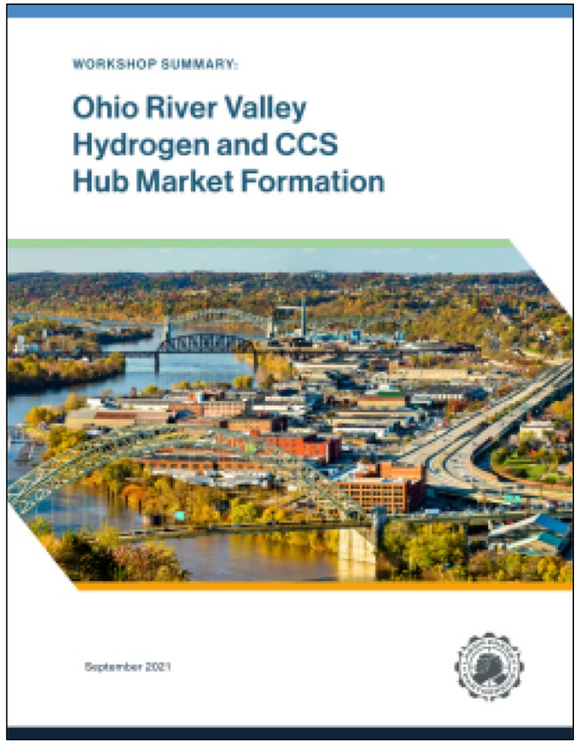
Policy Action Plan (Nov 2022)

- Profile U.S. capabilities, resources, and interests in clean hydrogen
- Identify key ingredients of successful hydrogen hubs at a regional level
- Develop a reusable framework that helps DOE program hub funding
- Describe policy and regulatory needs for both hubs and broader market formation

Building EFI's voice in clean hydrogen while engaging policymakers



Sep 2021



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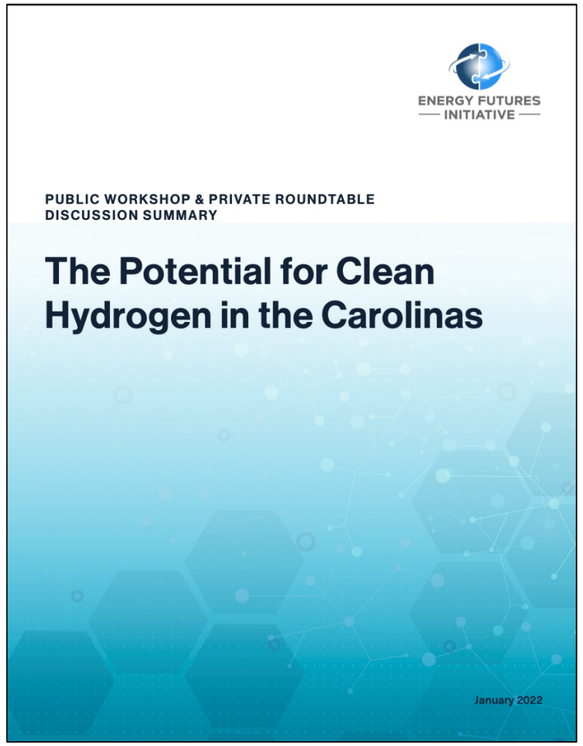
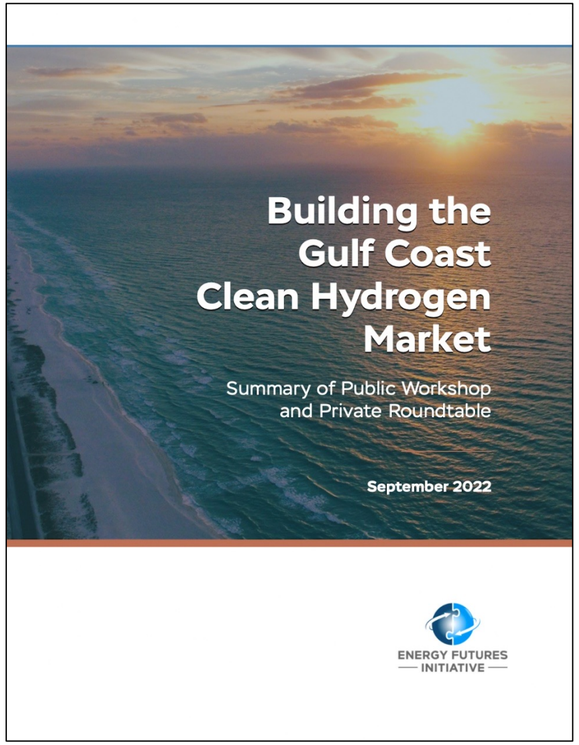


Jan 2022



Sep 2022

The existing U.S. hydrogen value chain

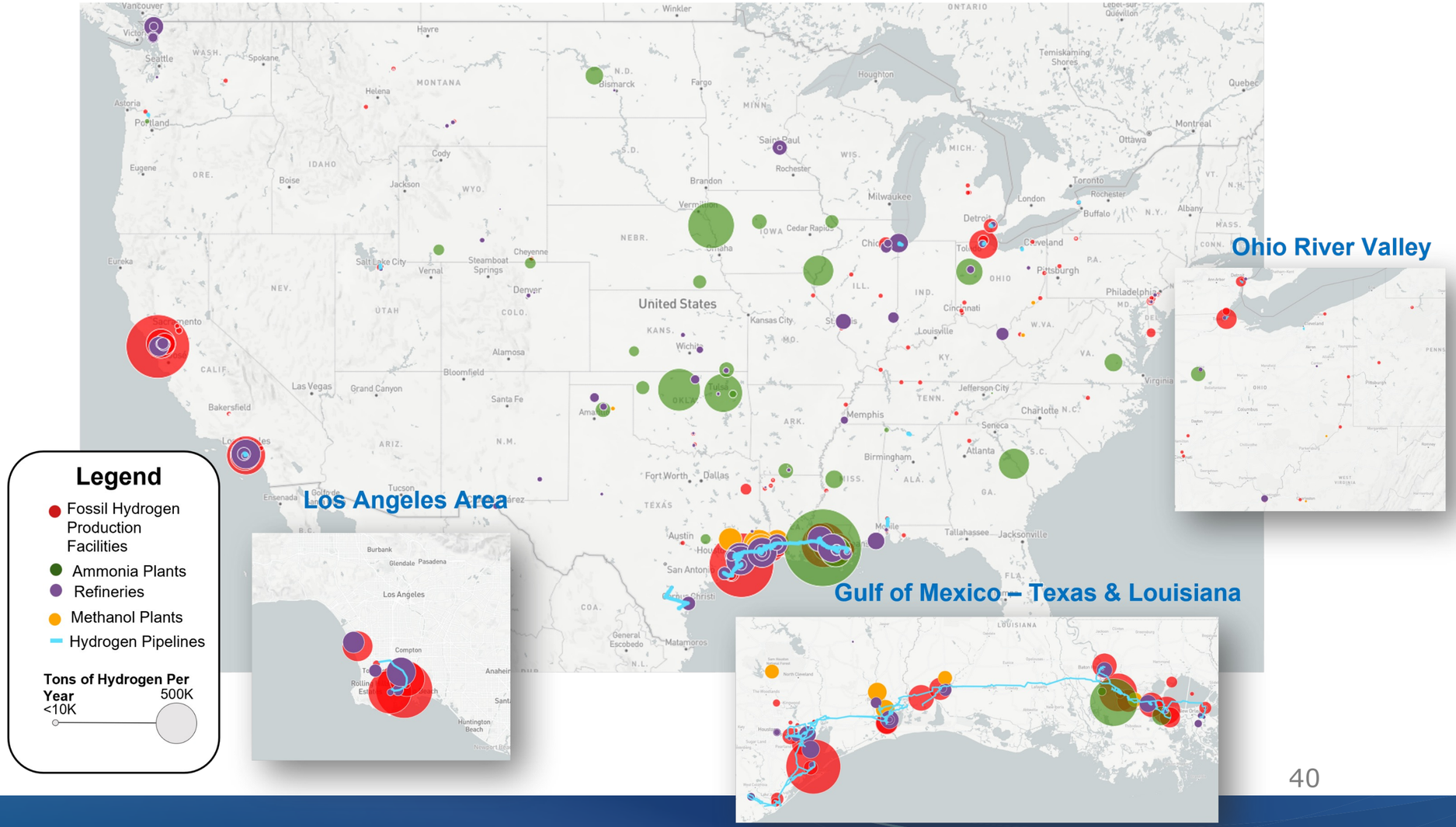
11.5 Mt of hydrogen produced annually

25 operating hydrogen pipelines

1,600 miles of hydrogen pipelines

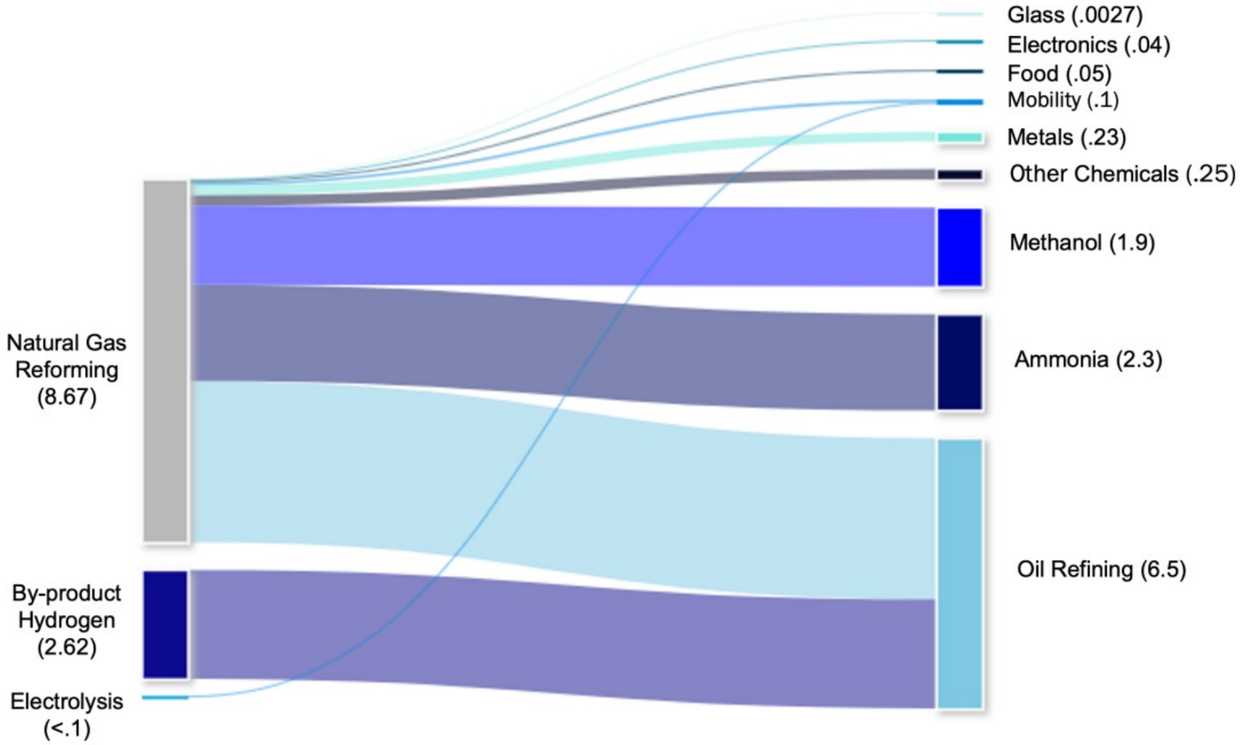
94% of demand is from refineries, ammonia plants, and methanol plants

Current U.S. Hydrogen Production Facilities, Pipelines, and End Users

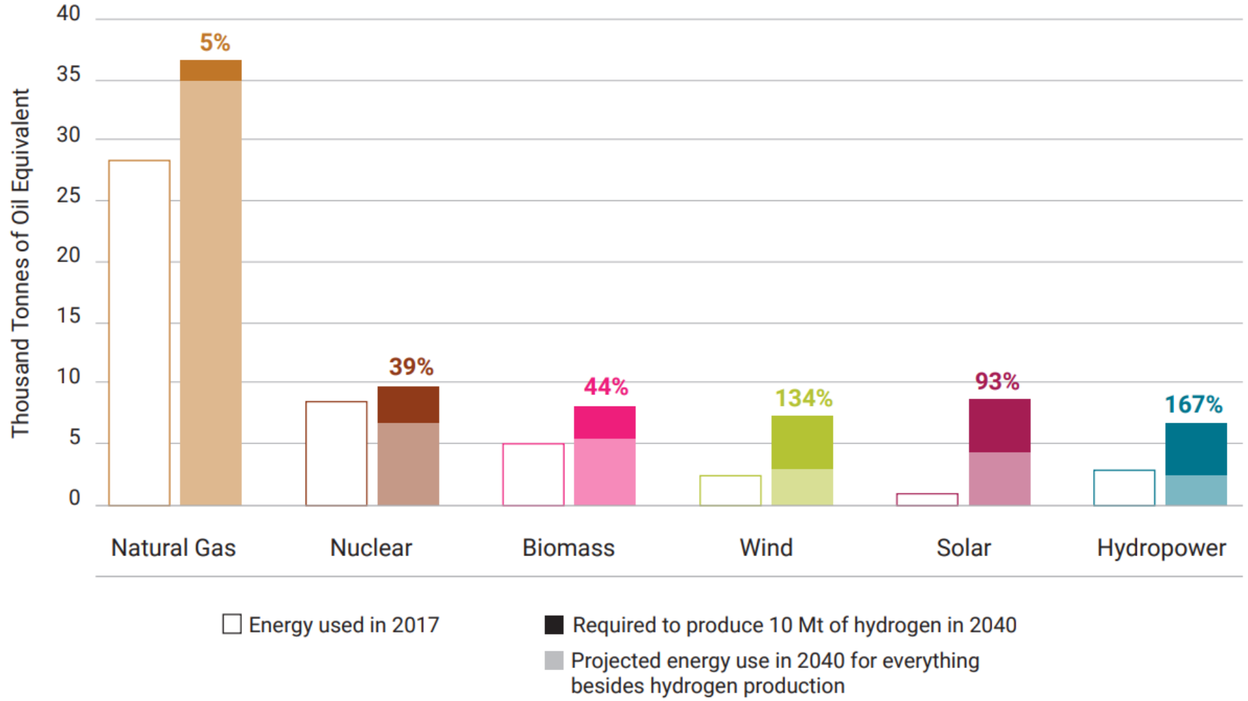


The current market will require scaling up multiple production pathways to meet future demand

Current Hydrogen Supply and Demand Balance in the United States, Roughly



Estimated Energy Requirements to Produce 10 Mt of Hydrogen, by Resource Type

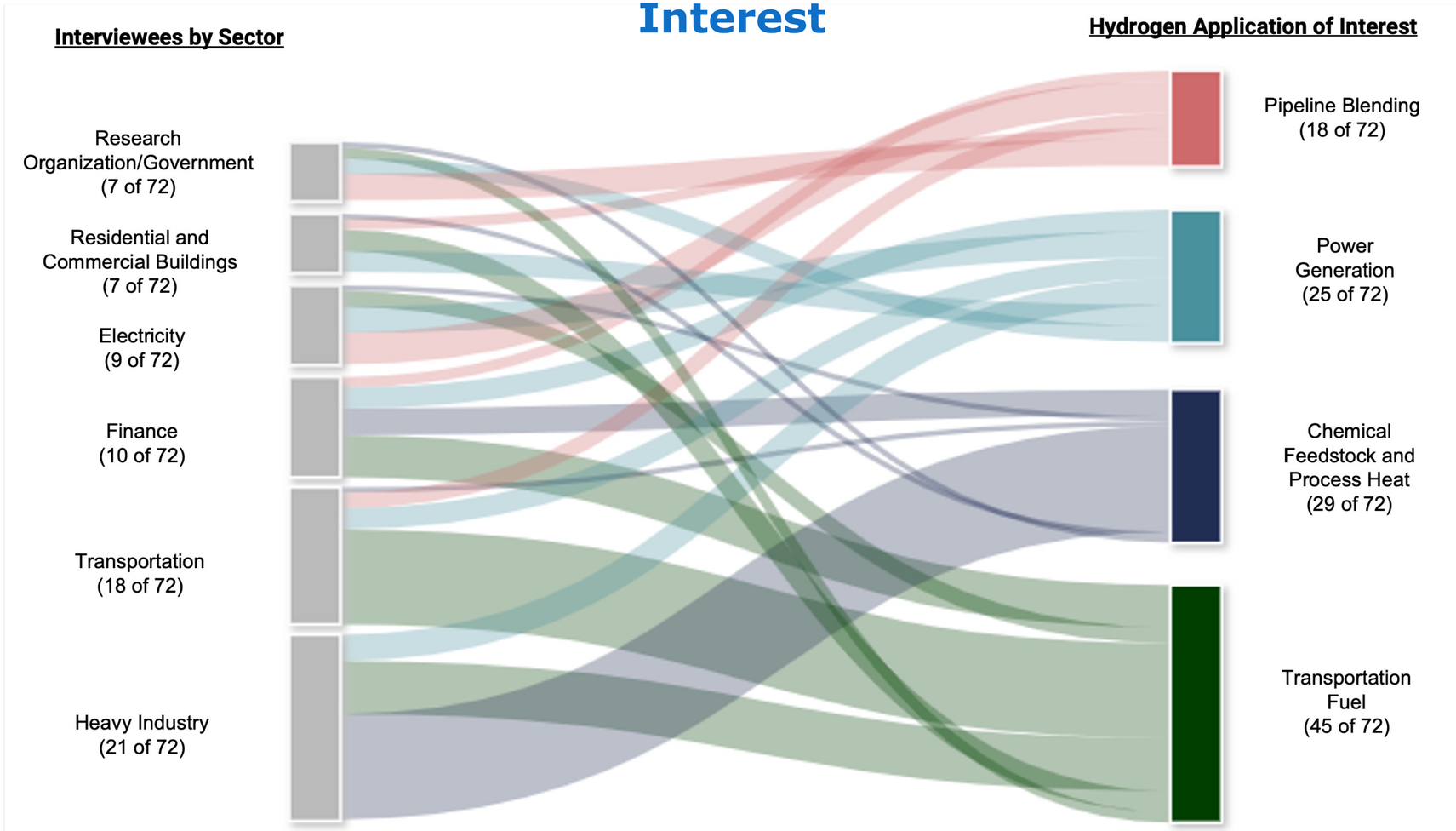


Data are from NREL and the Alternative Fuels Data Center.

While there is a diverse set of companies exploring clean hydrogen today…

- Companies are exploring beyond their own sectors.
- Many firms have multi-pronged approaches to hydrogen market participation.
- Interest in transportation fuel dominated.

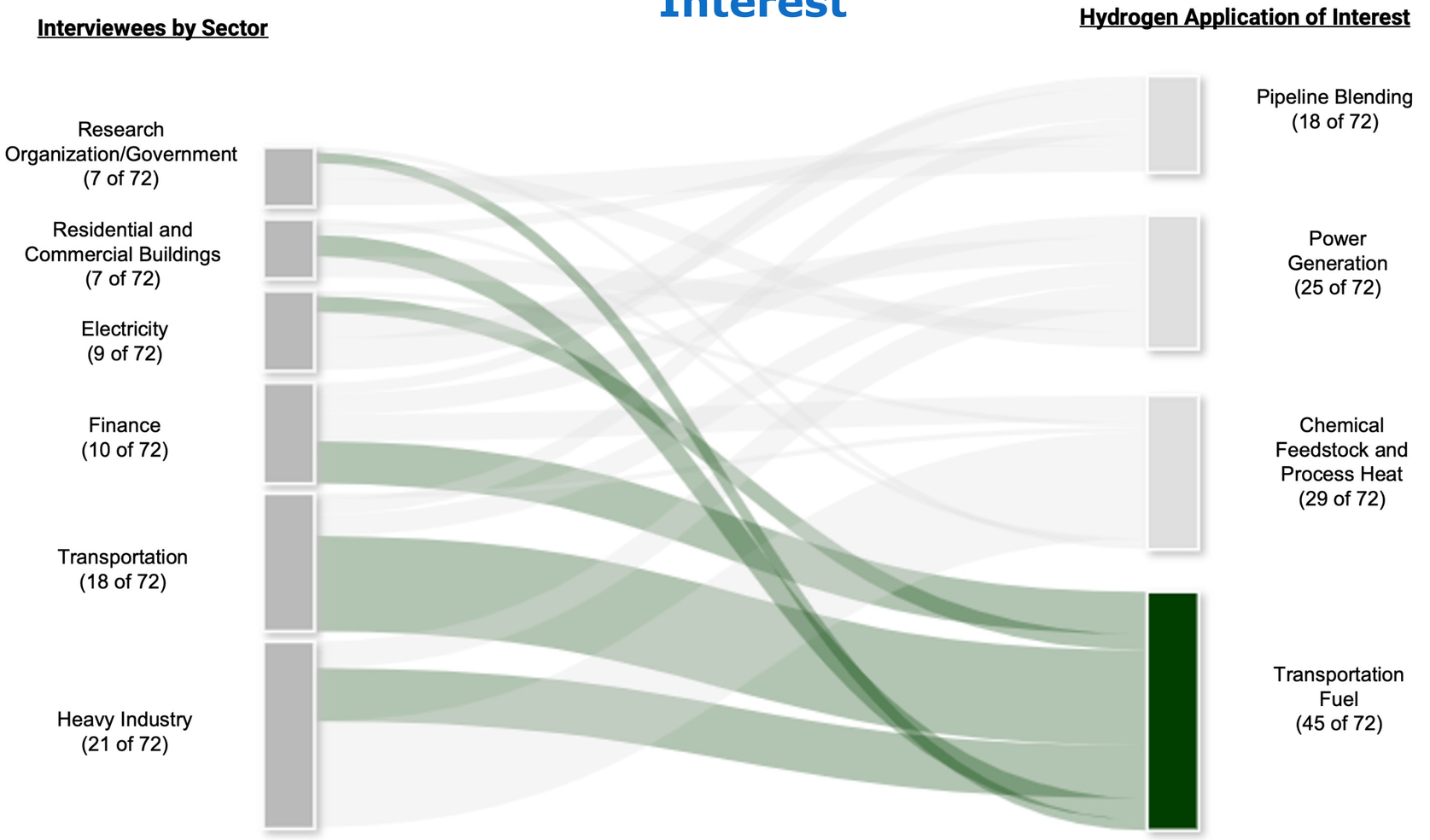
Stakeholders Interviewed and Hydrogen Applications of Interest



…they are focused on small-scale, commercial applications today

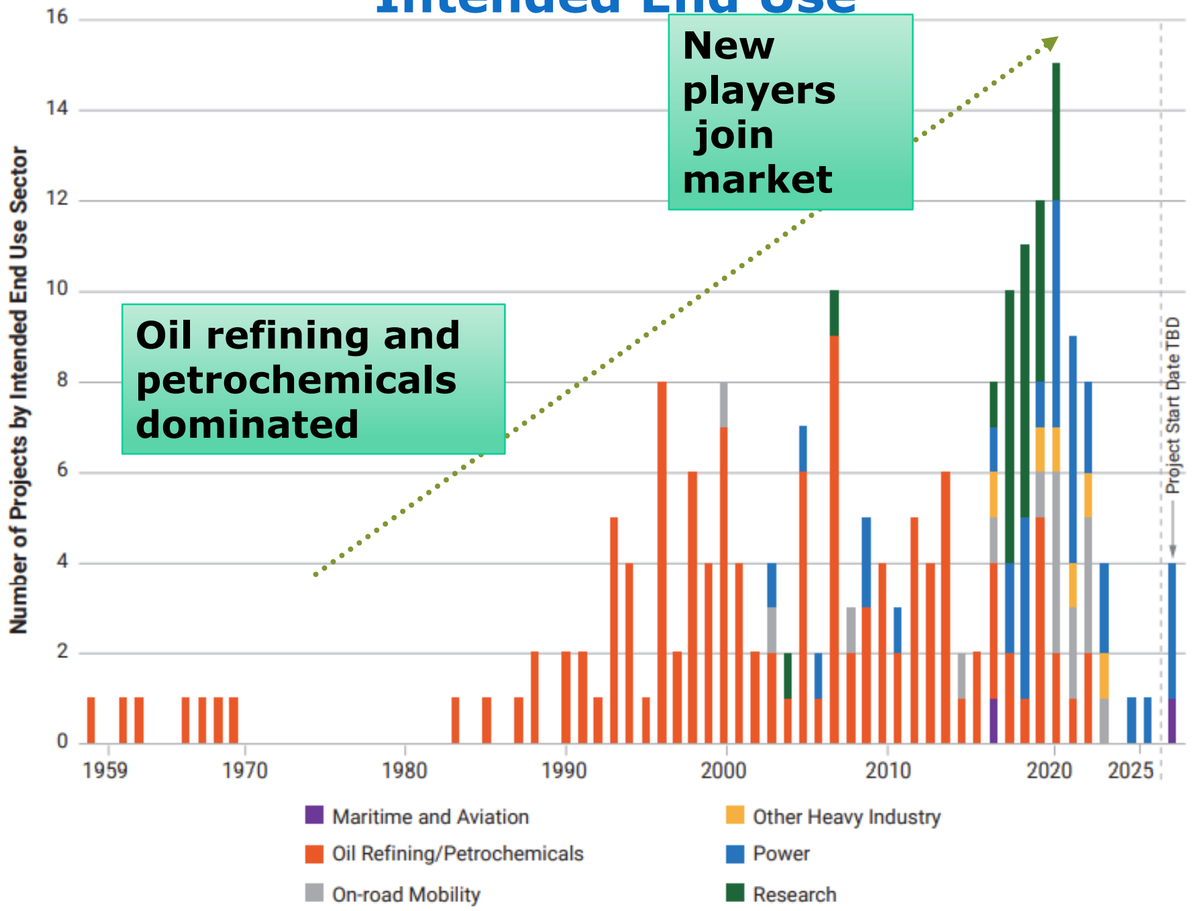
- Existing **policy** is most supportive of hydrogen in transportation sector.
- Light- and medium-duty vehicles and forklifts are **commercially** available.
- Vehicle **fleets** are an attractive application of hydrogen.
- Easier to **experiment** in transportation sector than other end uses.

Stakeholders Interviewed and Hydrogen Applications of Interest

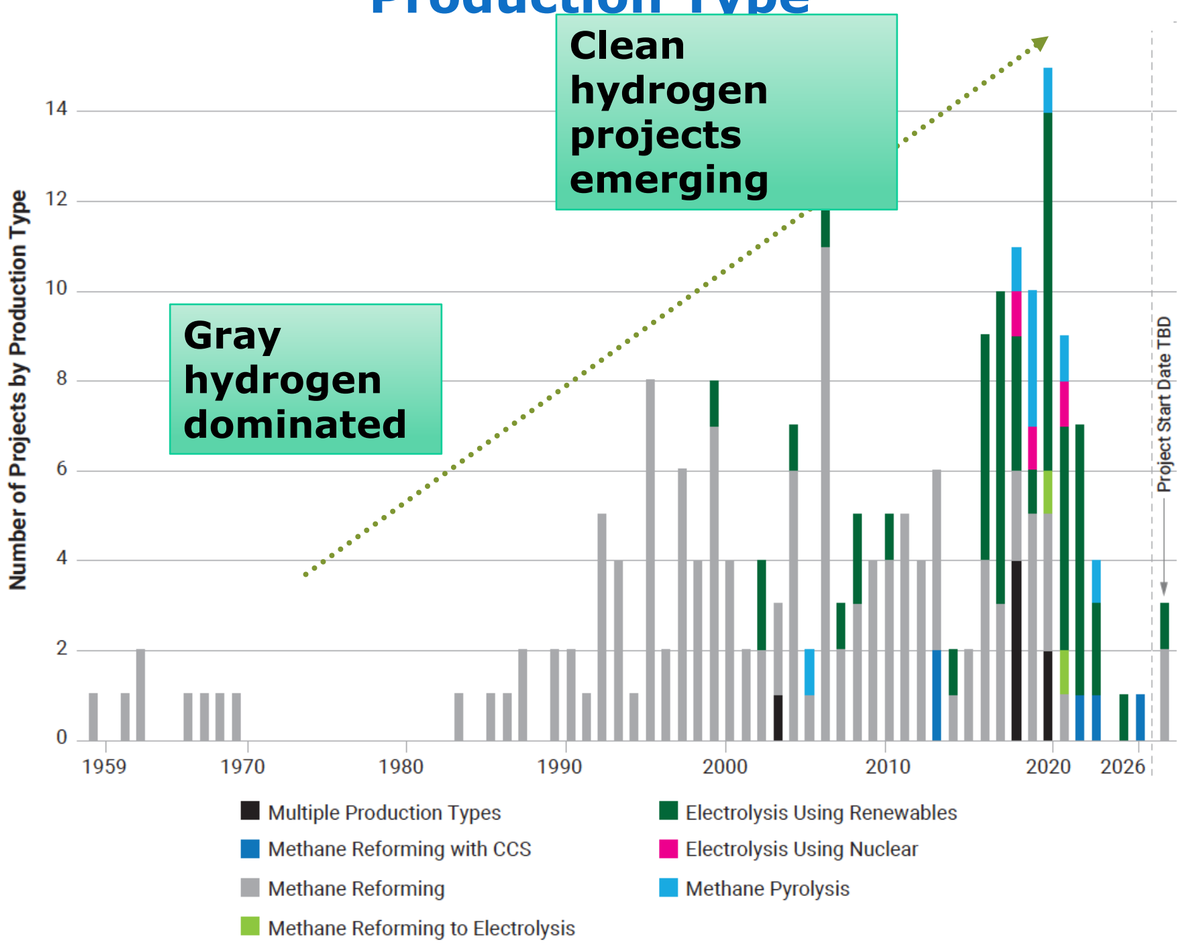


Non-traditional projects from non-traditional firms

Number of U.S. Hydrogen Projects by Intended End Use



Number of U.S. Hydrogen Projects by Production Type

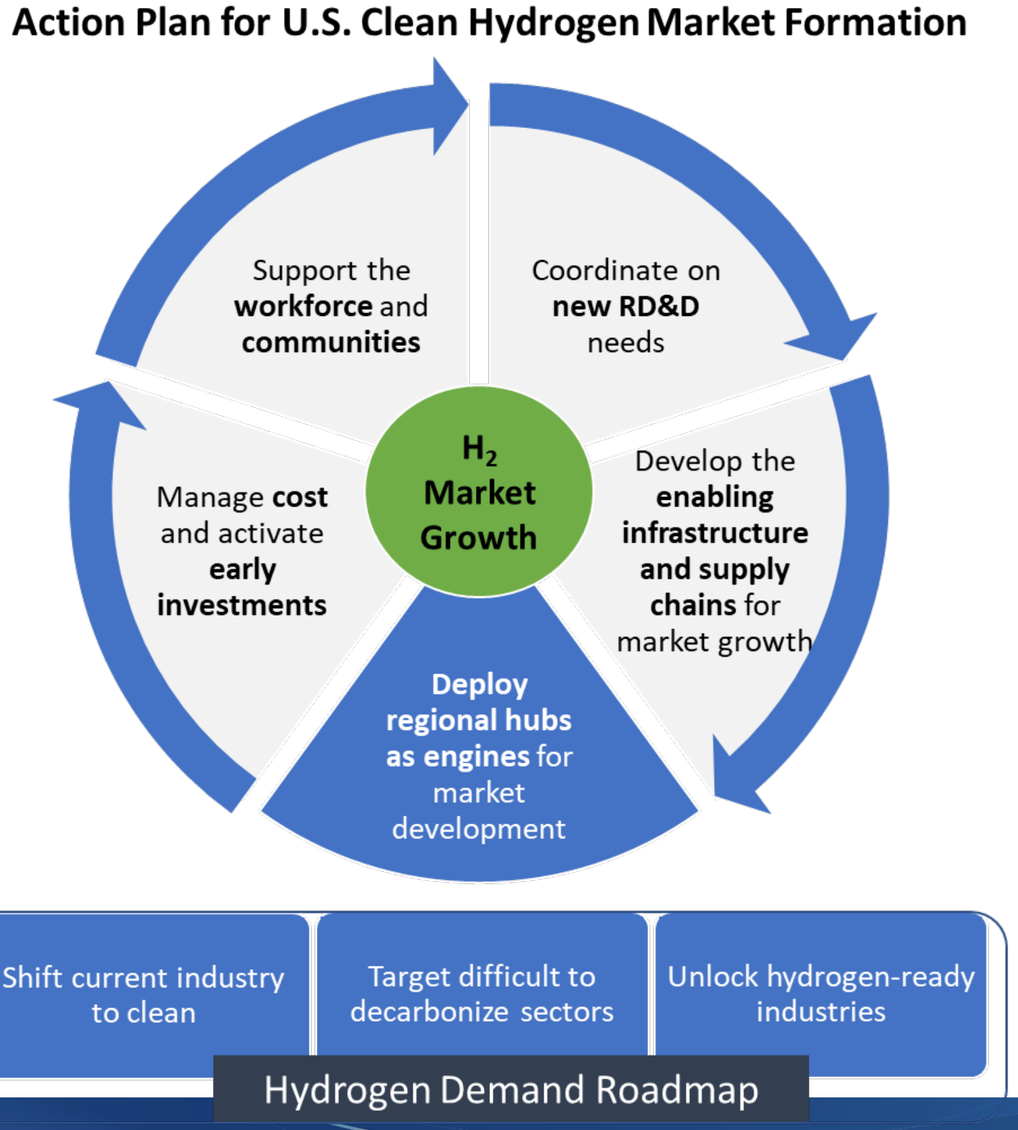


** Data based on publicly announced projects before September 2021*

Develop a new "Action Plan" for U.S. Hydrogen Market Formation

Unique Contributions of Action Plan

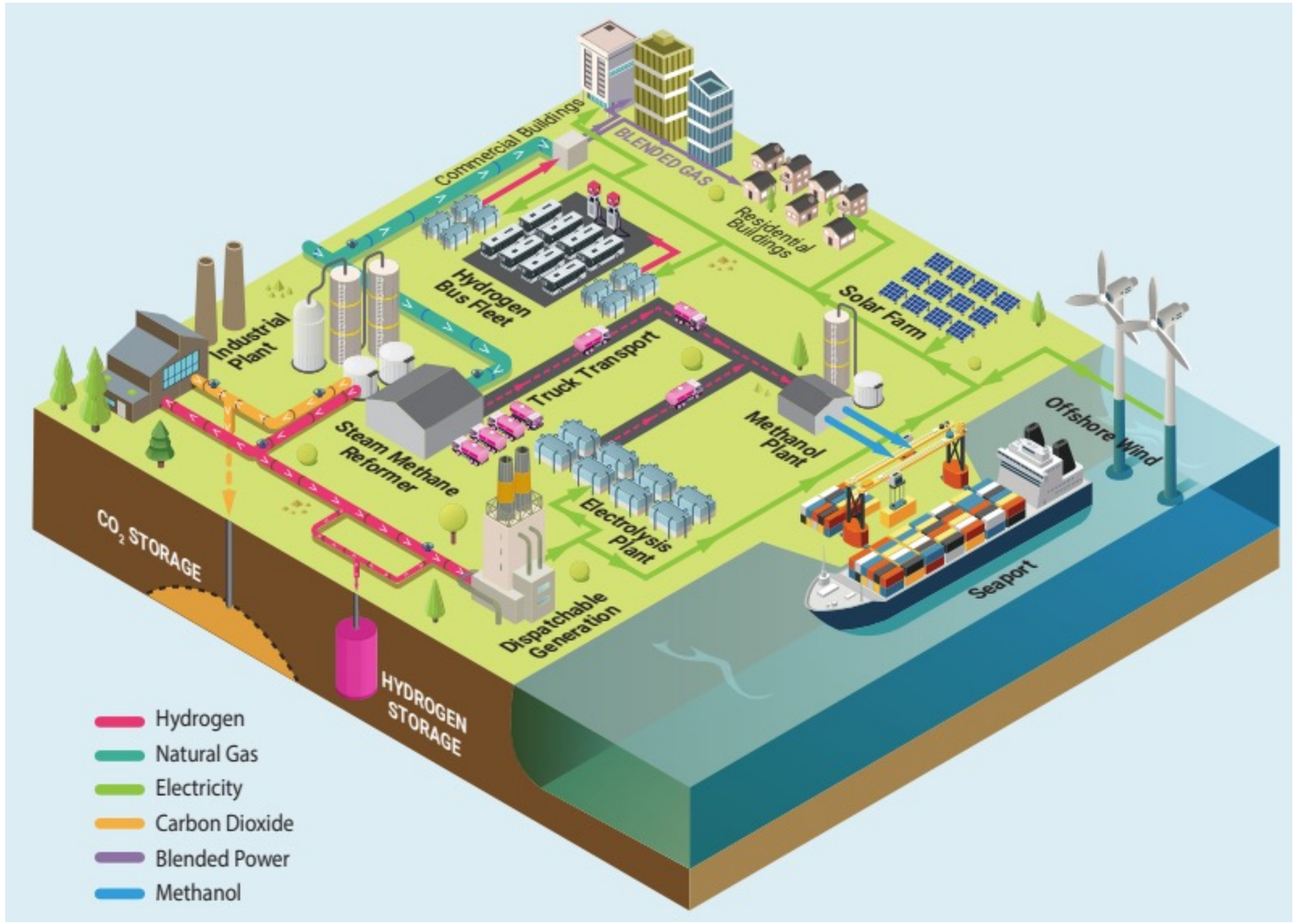
- New data collected on U.S. clean hydrogen project and industry trends. New website to host this data for public consumption
- New analysis of the IRA's potential impact on clean hydrogen costs
- Recommendations for how to jumpstart clean hydrogen demand to rapidly reduce U.S. emissions
- Recommendations for how DOE and regional hubs can maximize potential



Regional hubs are a major focus for investors

- IIJA's $8 billion for regional clean hydrogen hubs, combined with IRA incentives, could be gamechangers for clean hydrogen production investment
- Regional hubs can take advantage of IRA's support across the entire clean H2 value chain (see figure)
- In the IRA, the new hydrogen PTC and expanded 45Q appear to be the most signficant new developments for clean hydrogen

IRA incentives cover clean hydrogen value chain

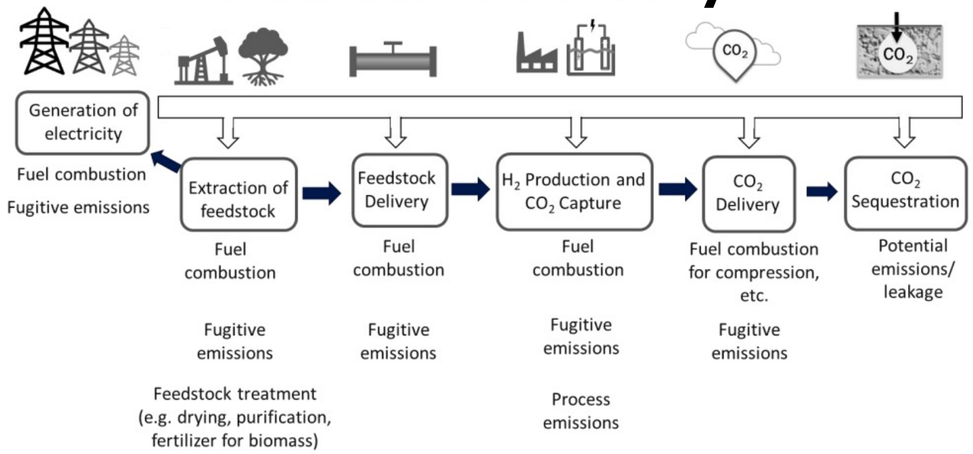


Definitions of “clean” hydrogen vary by policy

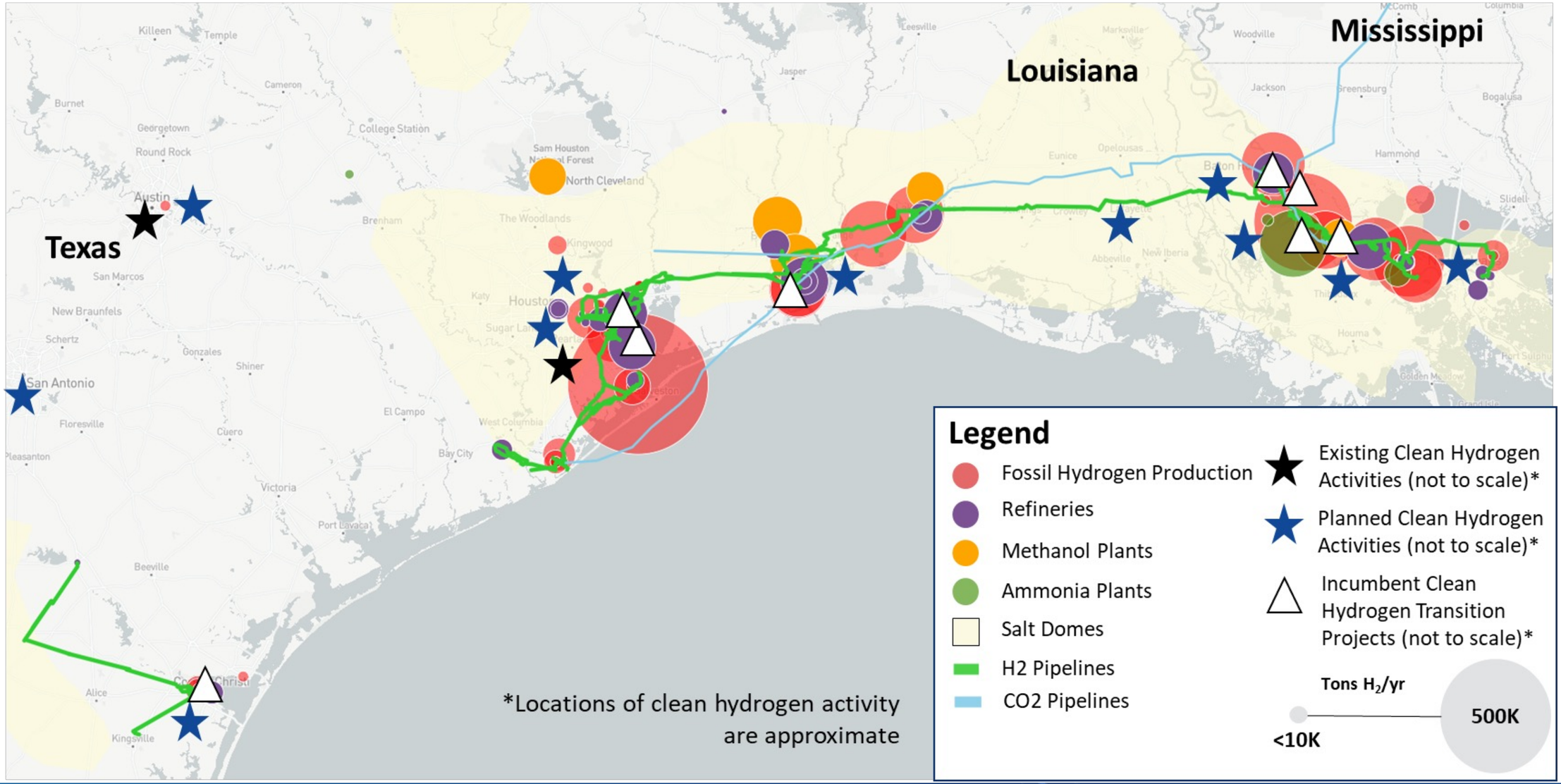
- The term “clean hydrogen” is used often without specific definition
- Most definitions, however, account for lifecycle emissions, thus favoring cleaner production pathways
- U.S. policy and recent guidance by DOE provides a useful framework though additional clarification will be needed

DOE’s Hydrogen Shot Initiative--LCA	1.2 kg CO2e/kg H2
Infrastructure Investment and Jobs Act (IIJA)--Production	2.0 kg CO2e/kg H2
Inflation Reduction Act (IRA)--LCA	4.0 kg CO2e/kg H2

DOE LCA Boundary



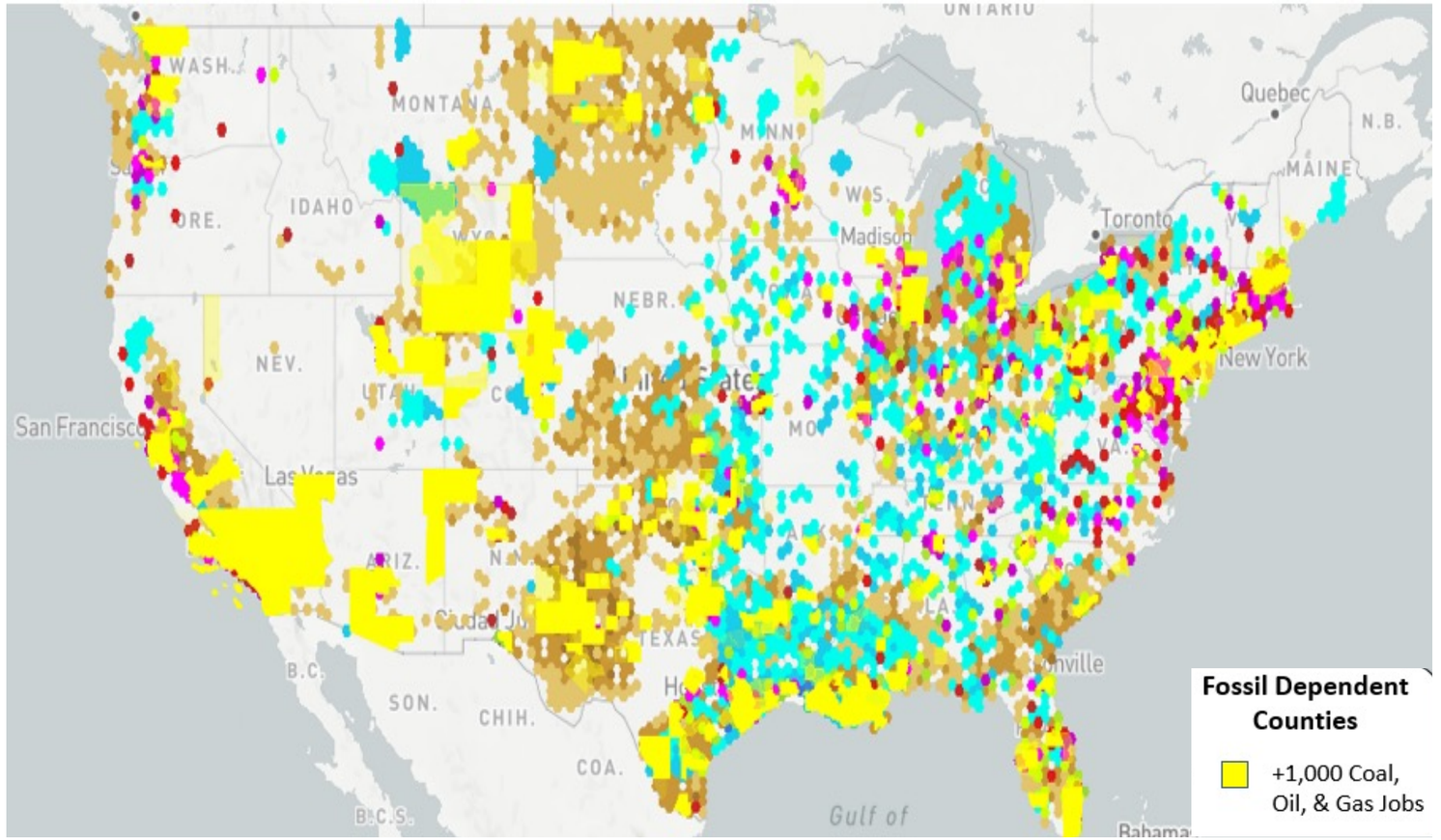
Existing Hydrocarbon and Proposed Clean Hydrogen Projects Provide Robust Base for Hub Development in Key Regions (U.S. Gulf Coast shown)



We're analyzing the potential impact of clean hydrogen on fossil-dependent communities

- **New jobs in a well-functioning hydrogen economy leverage many of the skills workers in at-risk sectors possess**
- **Six industries** that are particularly vulnerable to the energy transition:
  - coal mining,
  - oil and gas extraction,
  - pipeline transportation,
  - natural gas distribution,
  - petroleum,
  - coal products and manufacturing, and
  - electric power, generation, transmission, and distribution.

EFI Analysis of Regional U.S. capabilities and fossil-dependent communities



A Global Hydrogen Future

Arlington, Virginia – T. Mason Hamilton, Special Assistant to the Secretary General

Global Hydrogen Outlook: Middle East and North Africa

EFI – KAPSARC: Global Hydrogen Future

The International Energy Forum

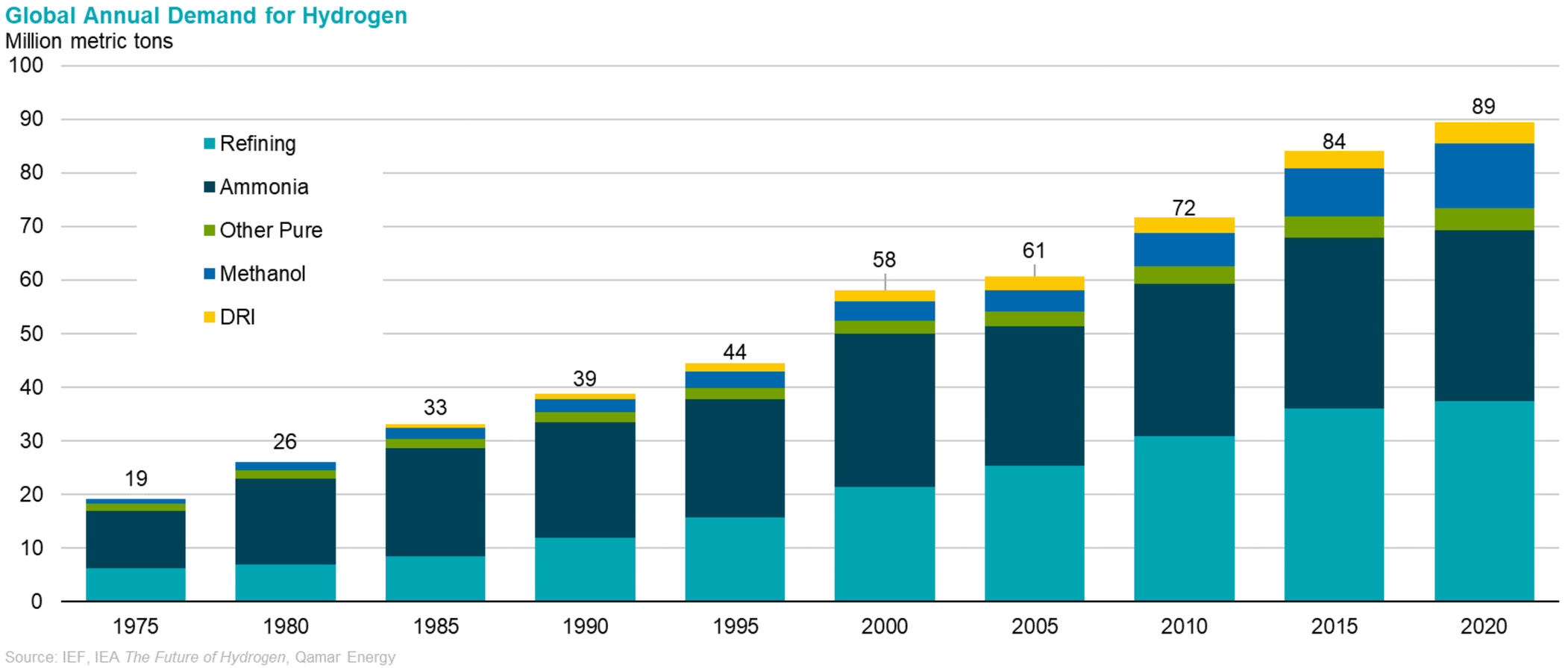
Key Takeaways

- Hydrogen market is poised for growth, but massive investments are needed as well as stable conditions required to make investment decisions
- After investment, energy intensity and “The Rainbow” are two key obstacles for hydrogen market development
- MENA region’s comparative advantages in hydrogen are numerous and obvious
- MENA hydrogen market will need to start local then go global
- Key opportunity: Increasing hydrogen use in MENA steel sector
- Reduce vulnerability: Increasing hydrogen use in MENA fertilizer sector
- MENA will play key role in establishing hydrogen market norms and data
- Avoid hydrogen-hype in today’s energy crisis

IEF Report: Hydrogen Market Pathways, Scaling-Up the Hydrogen Market

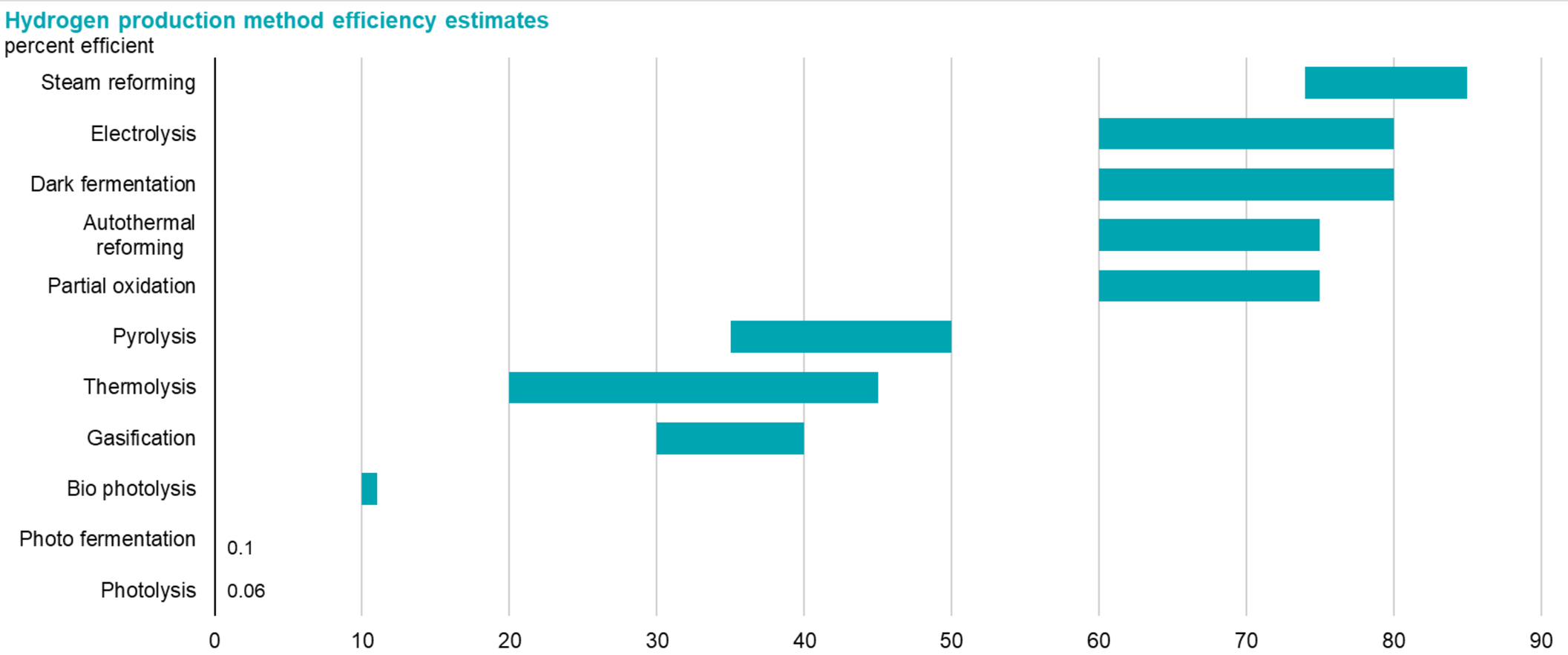
- Released June 2022
- In collaboration with:
  - Intercontinental Exchange (ICE)
  - Anne-Sophie Corbeau (Columbia University SIPA)
- Preceded by two virtual workshops with global panel of experts and industry leaders
- Focused on “What would the market mechanisms for hydrogen look like?”

Current market for hydrogen estimated around 90-100 million mt, refining and ammonia being the two largest sectors.



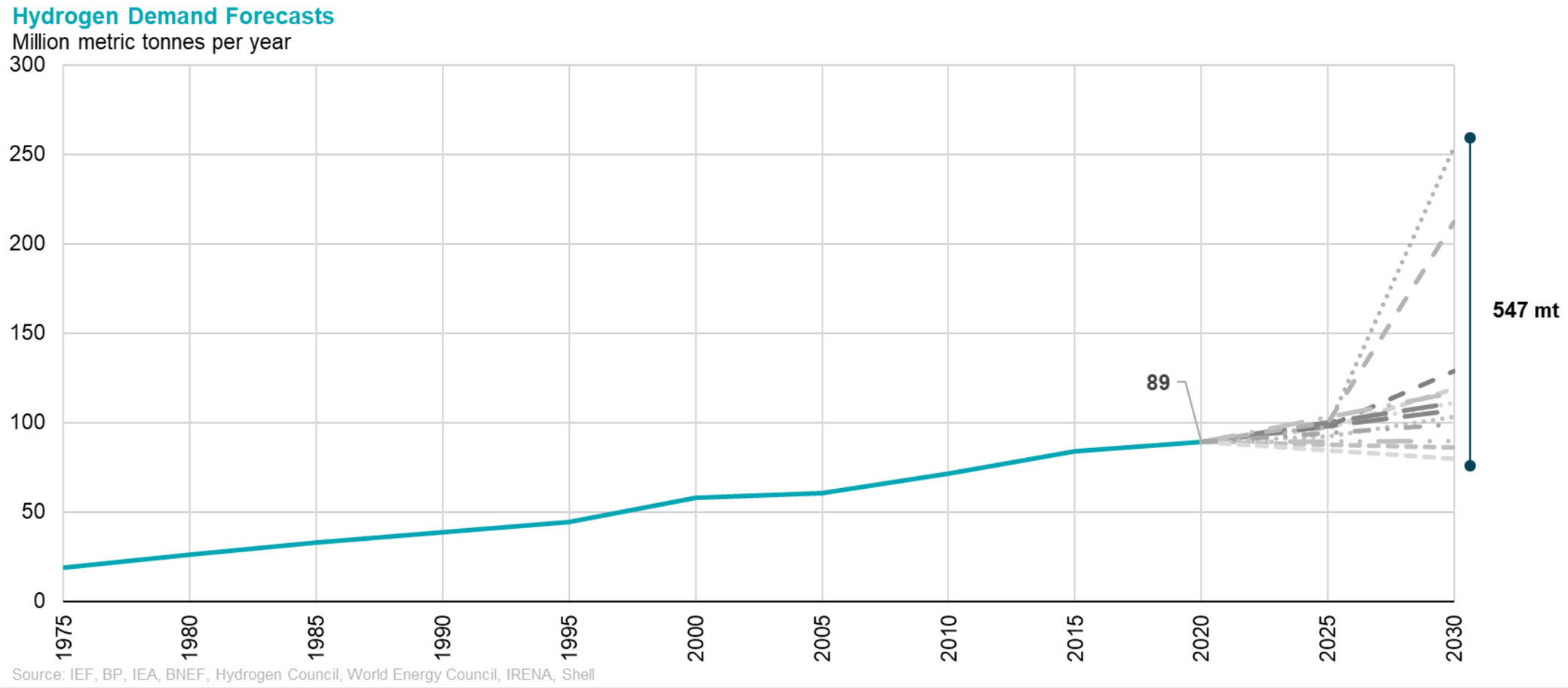
Source: IEF, IEA *The Future of Hydrogen*, Qamar Energy

Hydrogen production technologies continue to advance and increase in efficiency – especially various electrolysis technologies



Source: IEF, *Kumar & Himabindu MSEI (2019)*

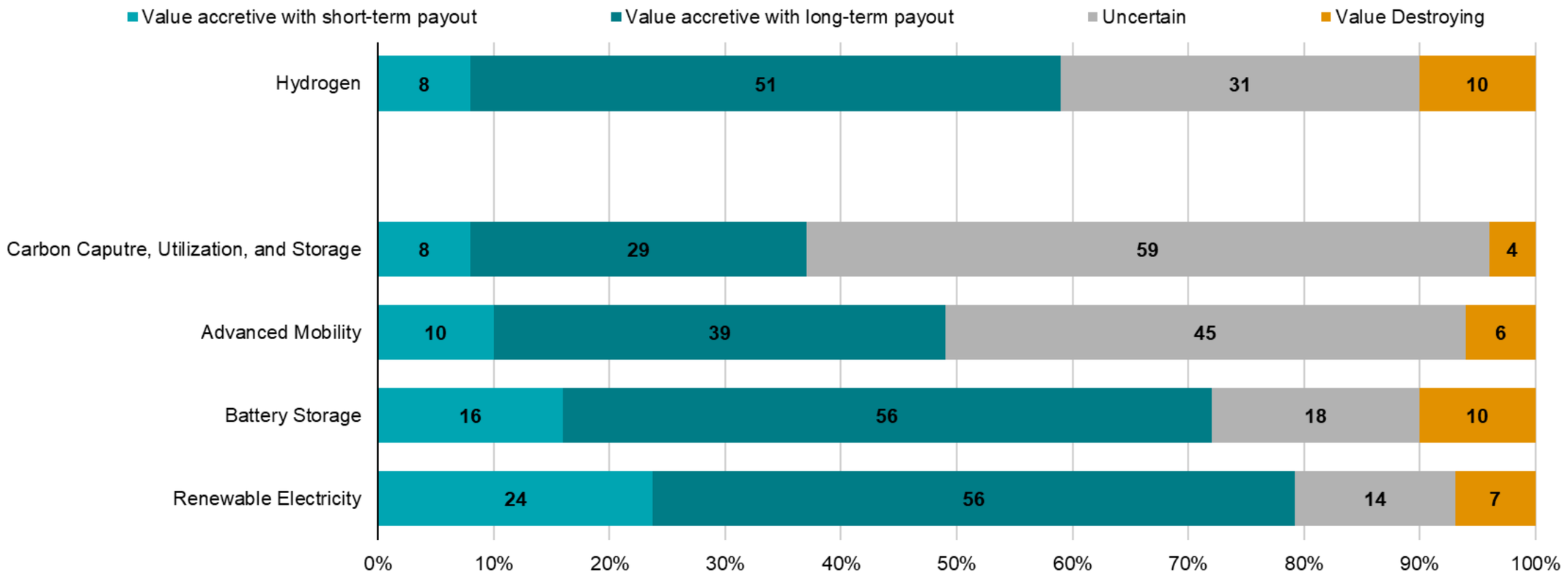
Short-term forecasts for hydrogen demand growth vary widely, with most showing status quo growth rates out to 2030



Hydrogen has perceived accreditive value, but confidence still needed for investment decisions

Q: How would you rate the perceived value of the following low-carbon energy investments for oil and gas companies?

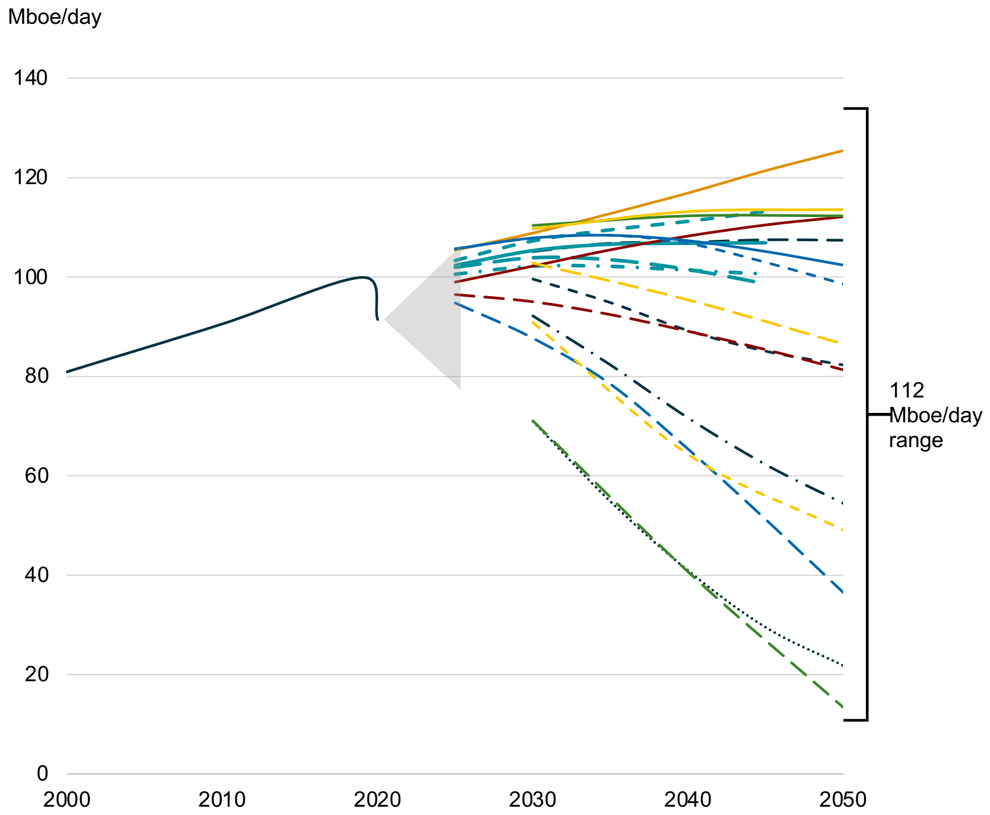
Investor response (percent of total)



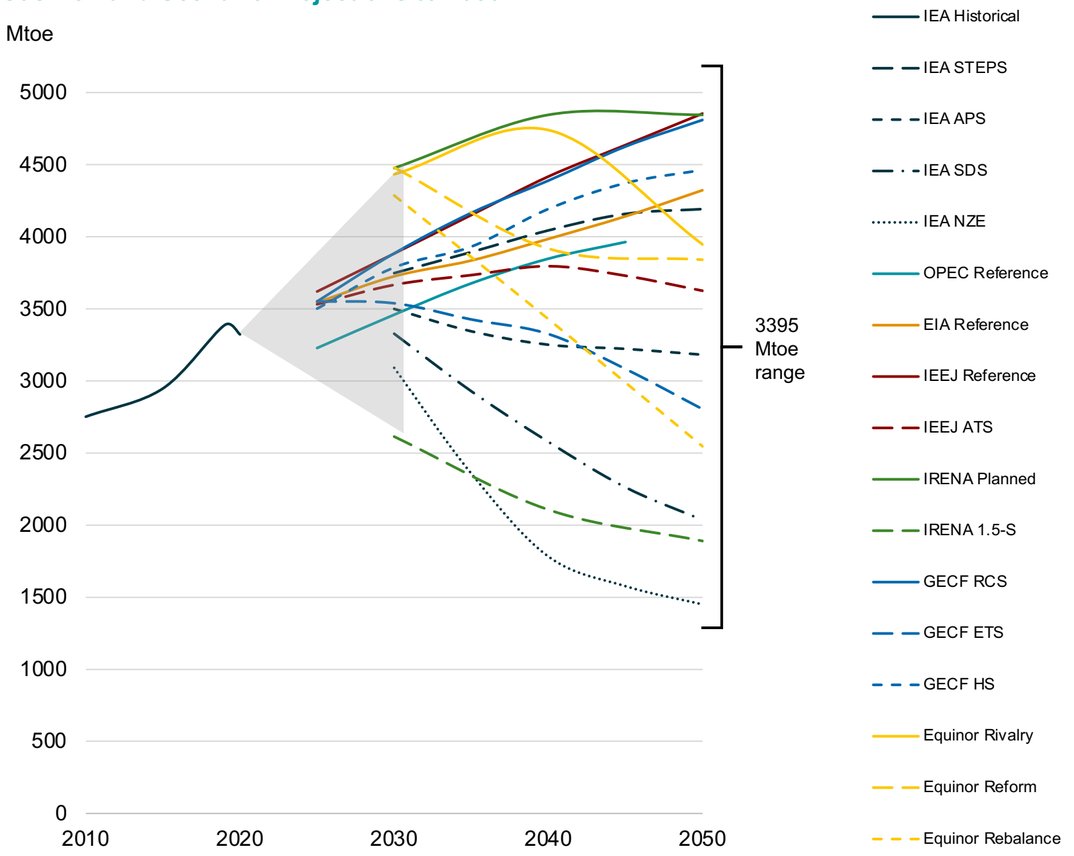
Source: IEF, BCG, *BCG CEI Oil & Gas Investor Survey, 2021*

Unprecedented uncertainty in markets and policies can deter much needed investment

Liquids Demand Scenario Projections to 2050

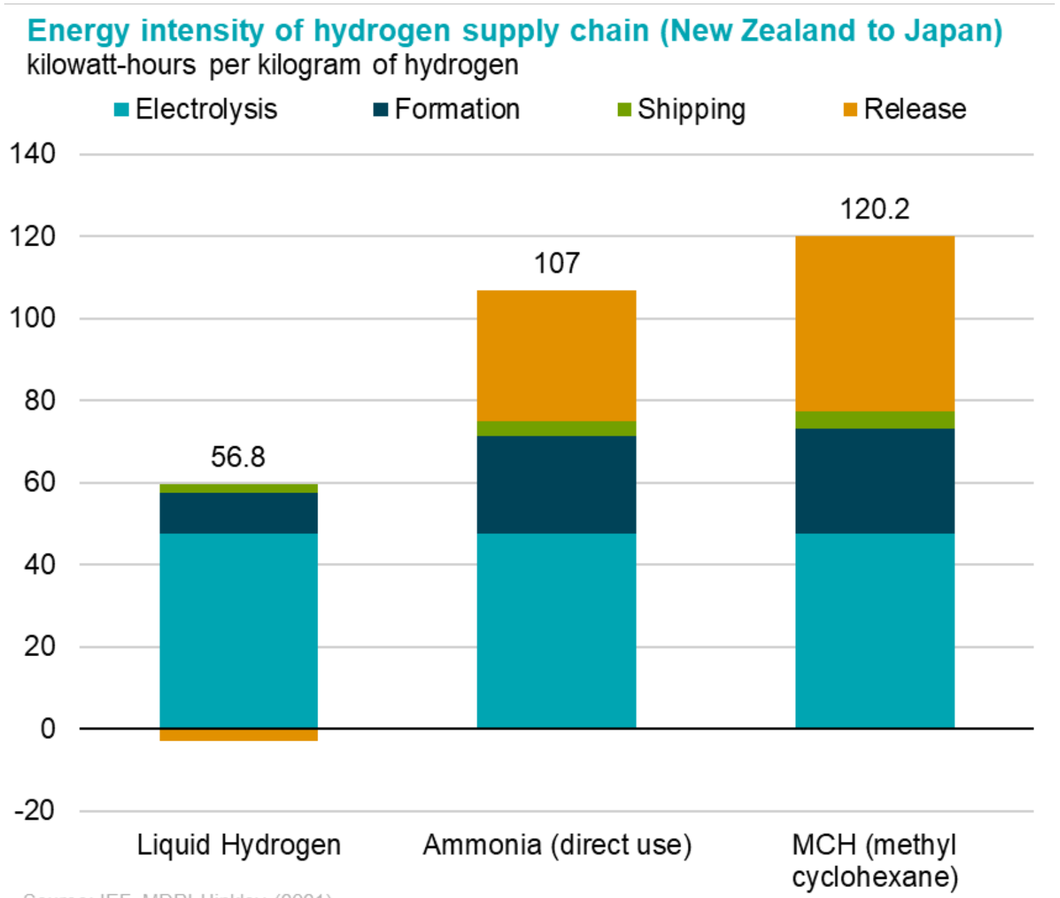


Gas Demand Scenario Projections to 2050

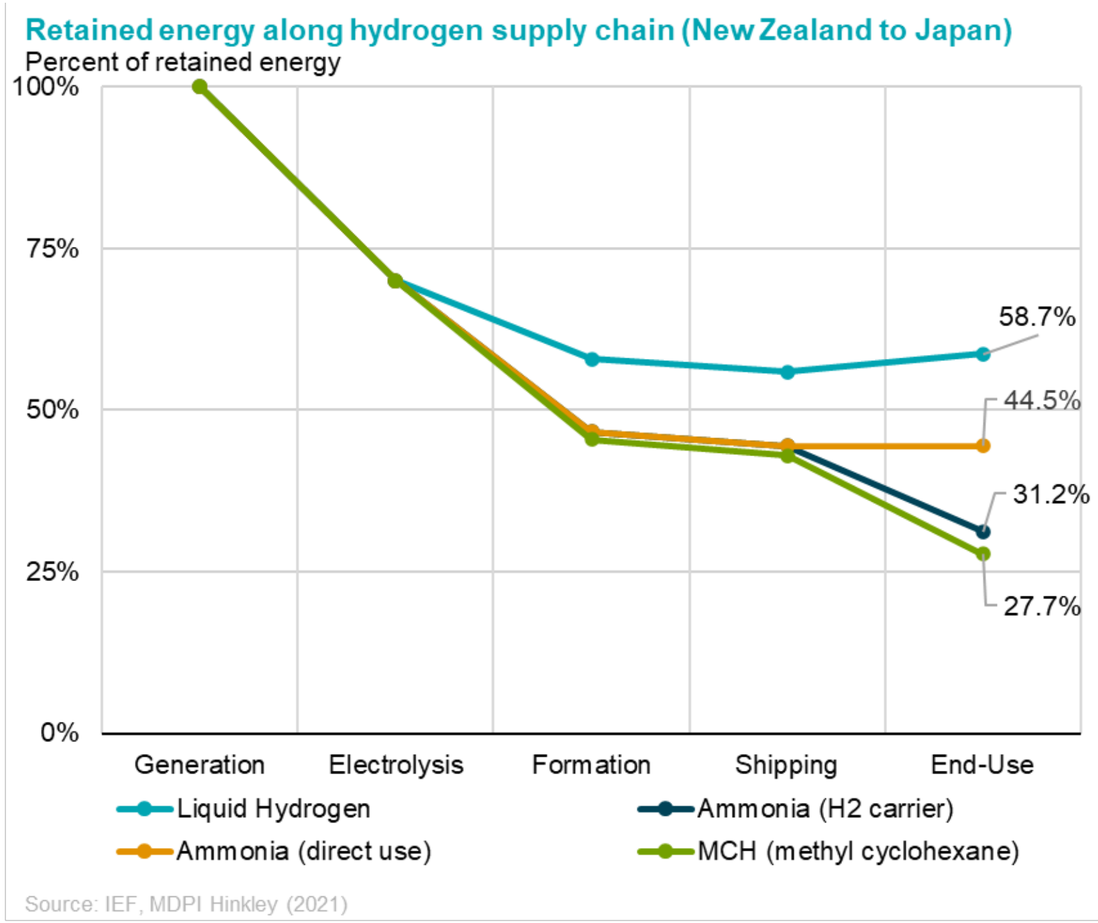


Source: IEF-RFF Outlooks Comparison Report 12th IEA-IEF-OPEC Symposium on Energy

Long distance transportation of hydrogen pose energy intensity challenges



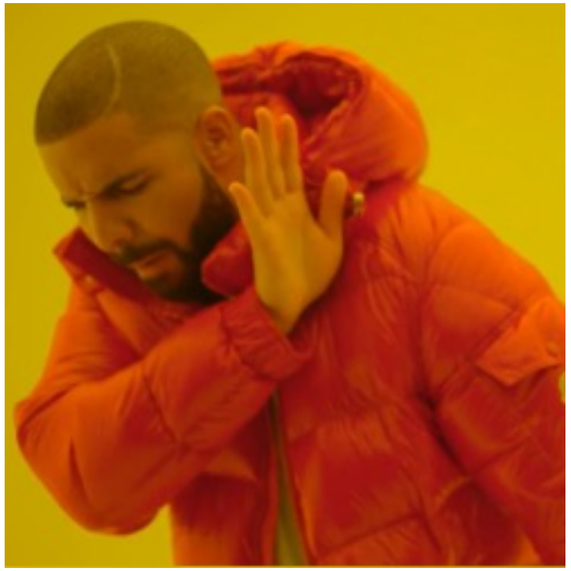
Source: IEF, MDPI Hinkley (2021)

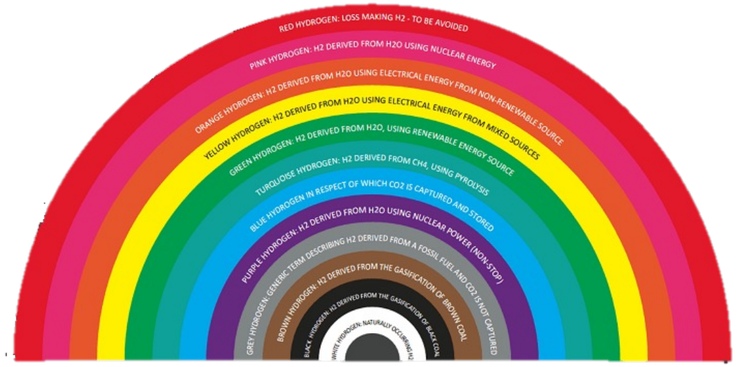


Source: IEF, MDPI Hinkley (2021)

Reject the Rainbow

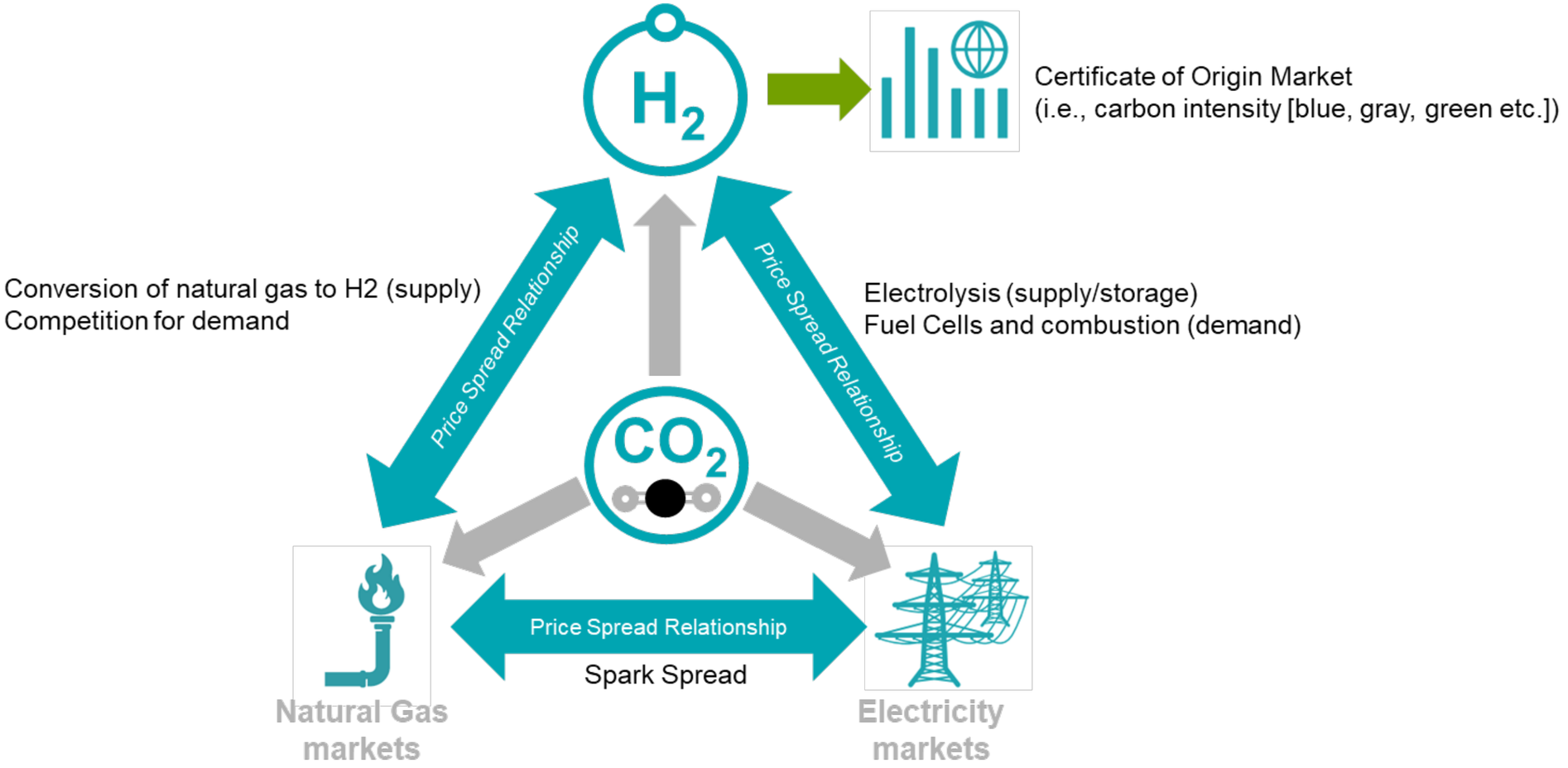
- Establishing a tradeable Hydrogen market requires standardization
- Price formation of various colors of hydrogen delays and impedes market development
- Colors only convey production emissions, not full cycle





Emissions Intensity of

Hydrogen can play a unique role in financial risk management during transition

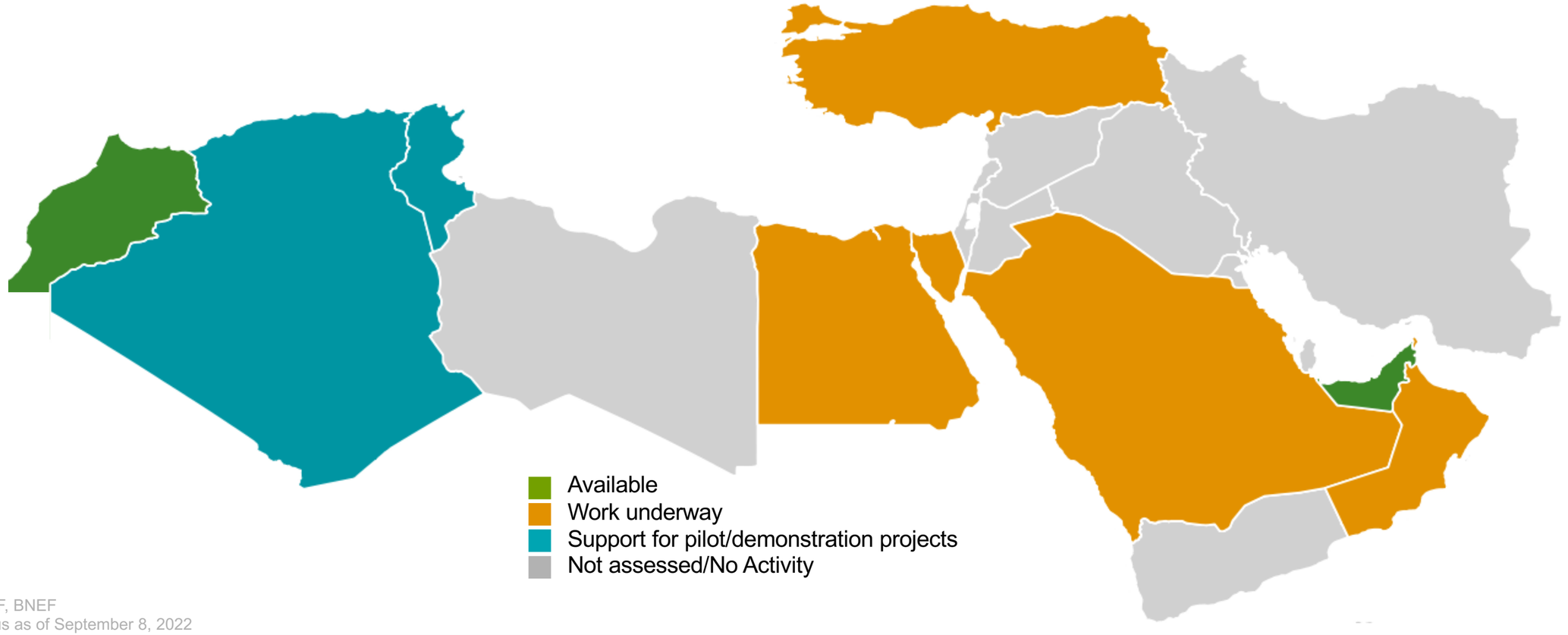


Stating the Obvious: MENA region's many hydrogen comparative advantages

- Massive renewable energy potential
  - High-capacity factors for solar and wind
  - Low clean hydrogen production costs
  - Little to no NIMBY issues
- Ample natural gas supplies + favorable CCS geology
- Long established energy trade patterns and business connections
- Central location – between major importers Europe and Asia
- Established domestic hydrogen consuming industries
- Multiple State-Owned Enterprises
  - Deep pockets in a capital-intensive industry
  - Comfort and experience with mega-projects

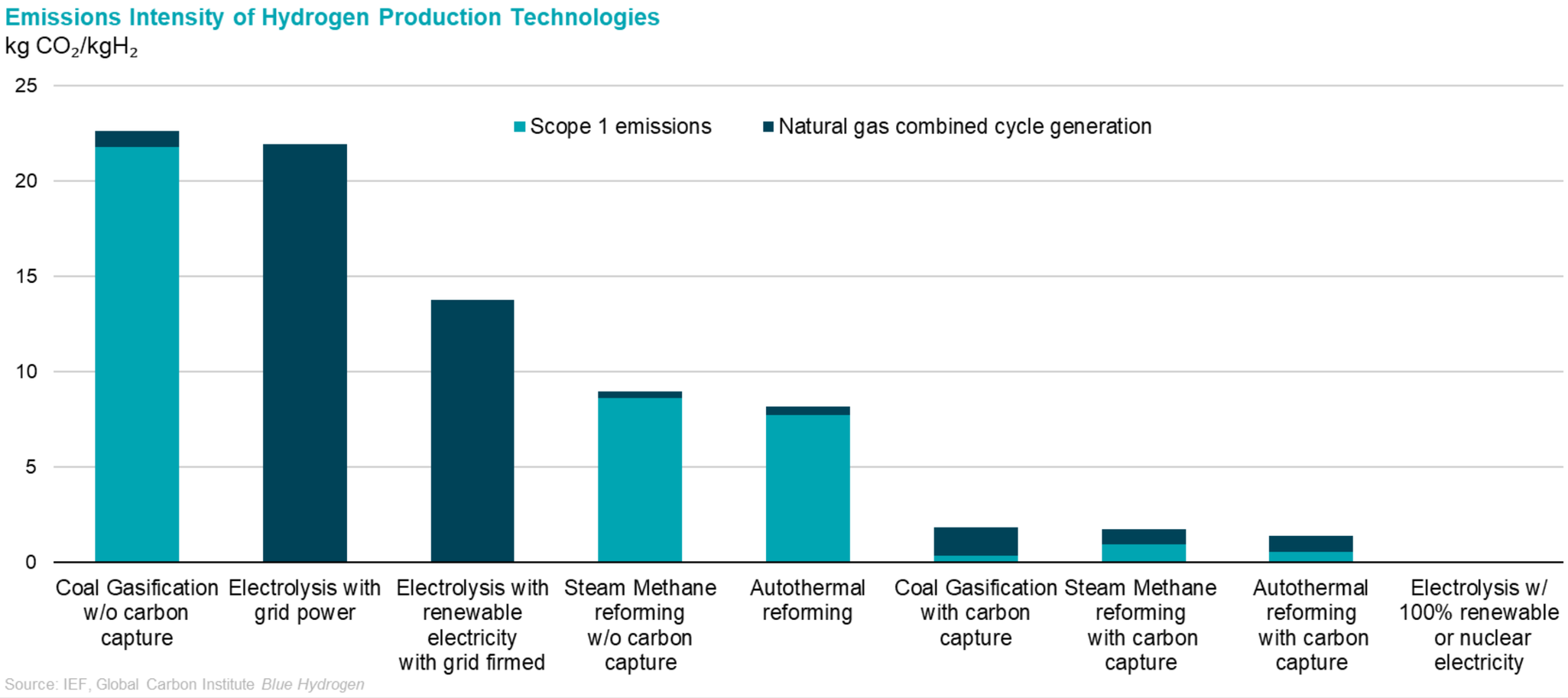
The MENA region is moving forward on Hydrogen strategies and policies

National Hydrogen Strategy Status - MENA



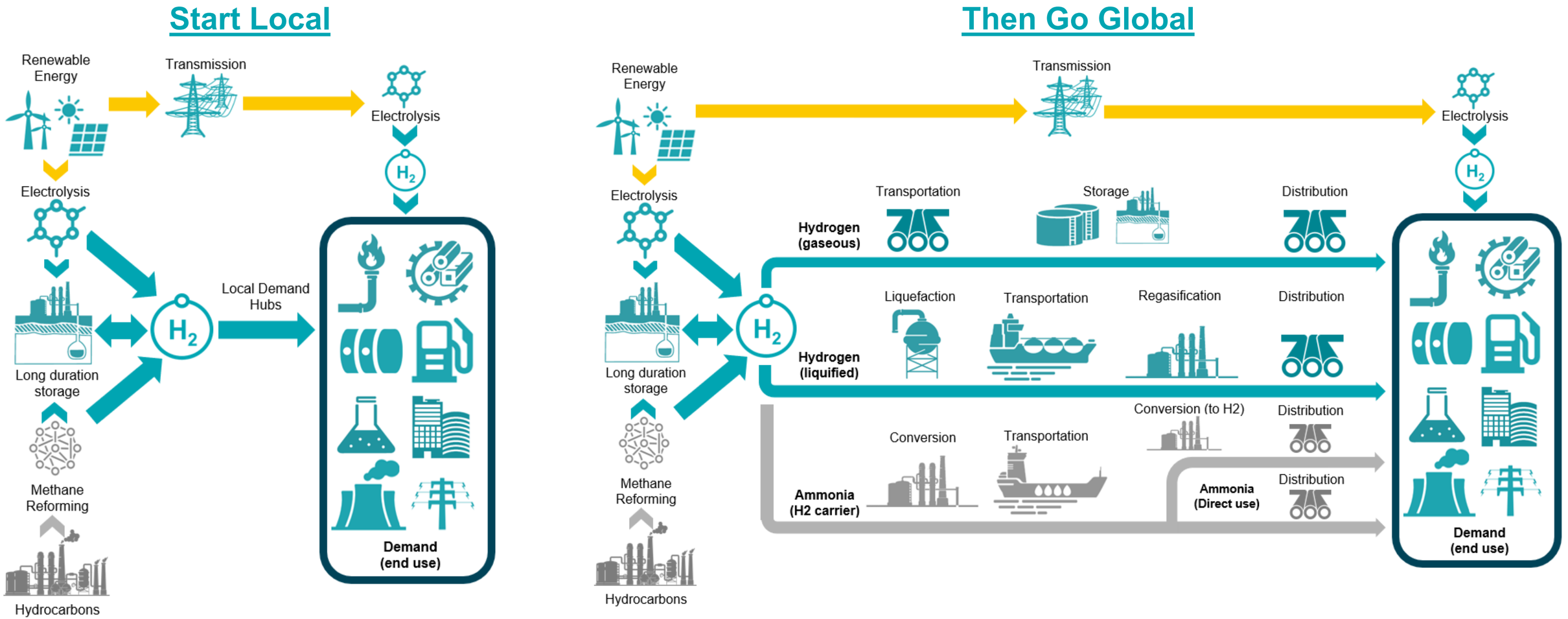
Source: IEF, BNEF
Note: Status as of September 8, 2022

MENA region has massive comparative advantages in multiple low emissions intensive means of production



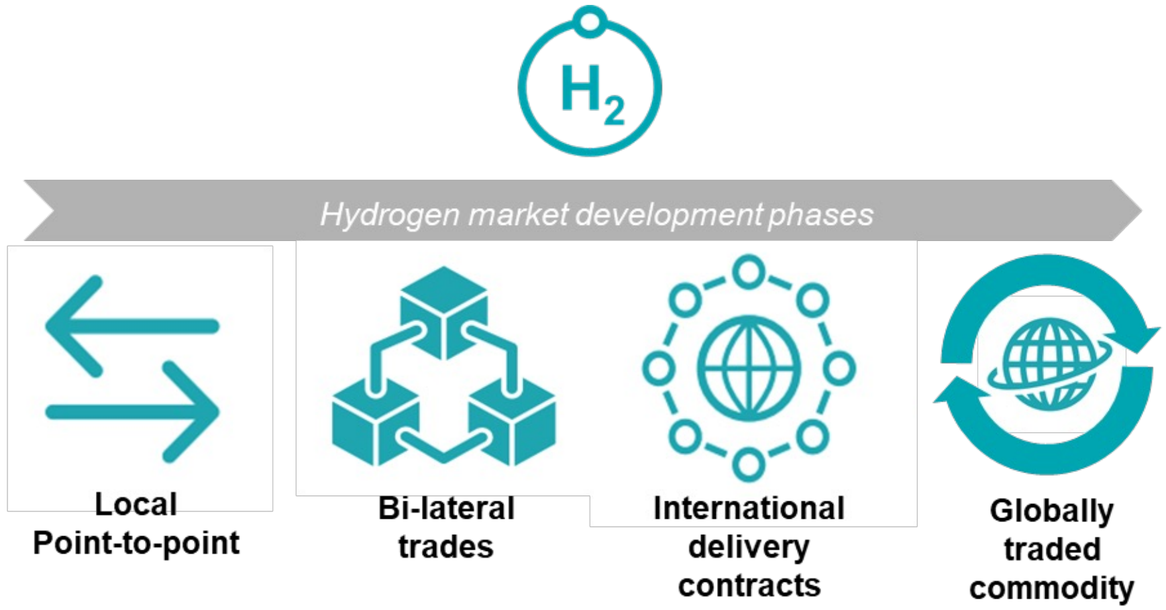
Source: IEF, Global Carbon Institute *Blue Hydrogen*

Before Exports: Establishing local supply/demand hubs is key to unlocking investment needed for global supply chain

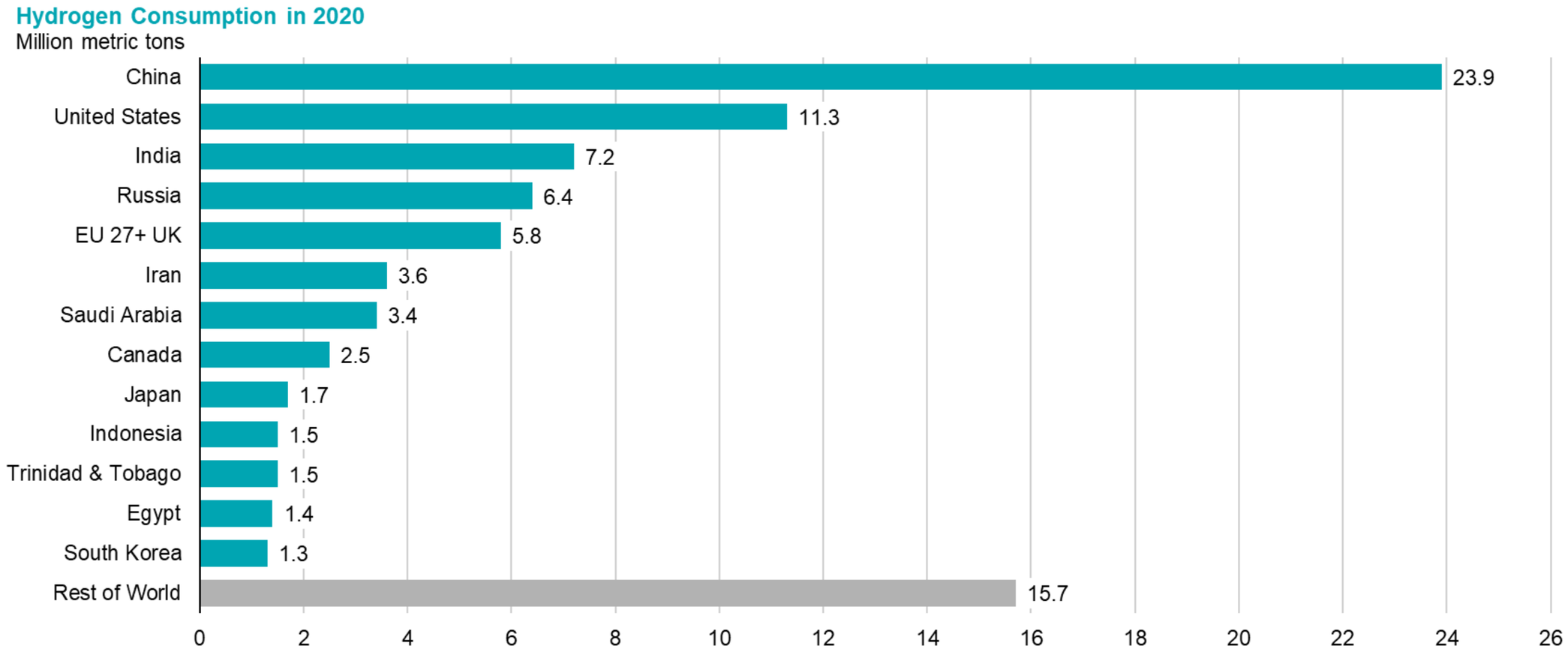


Hydrogen will need to progress from an isolated/closed market to a more widely traded commodity

- Hubs will represent first hydrogen demand centers
- Isolated, bi-lateral trades, “merchant” hydrogen
- Sectoral trade
- International point-to-point trade
  - Anchored by long-term contracts
- Hydrogen will be bought and sold in many forms (gaseous, liquid, ammonia, etc.)

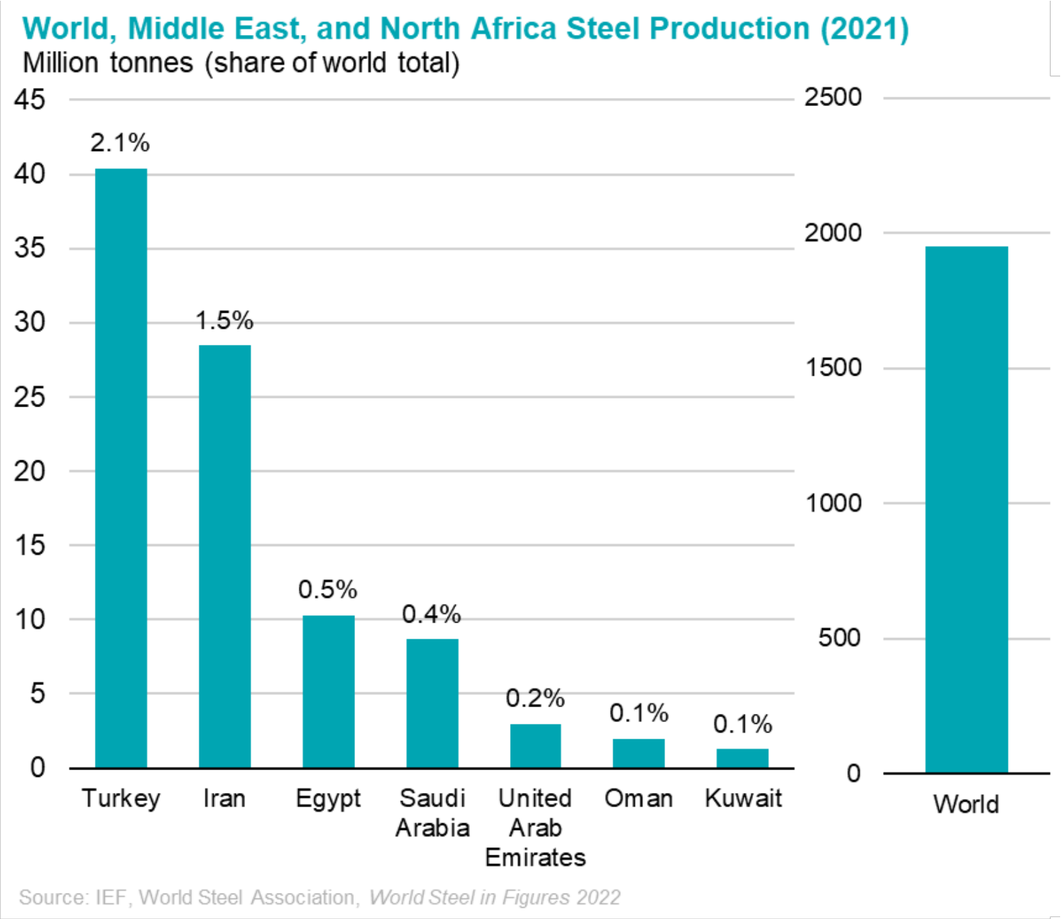


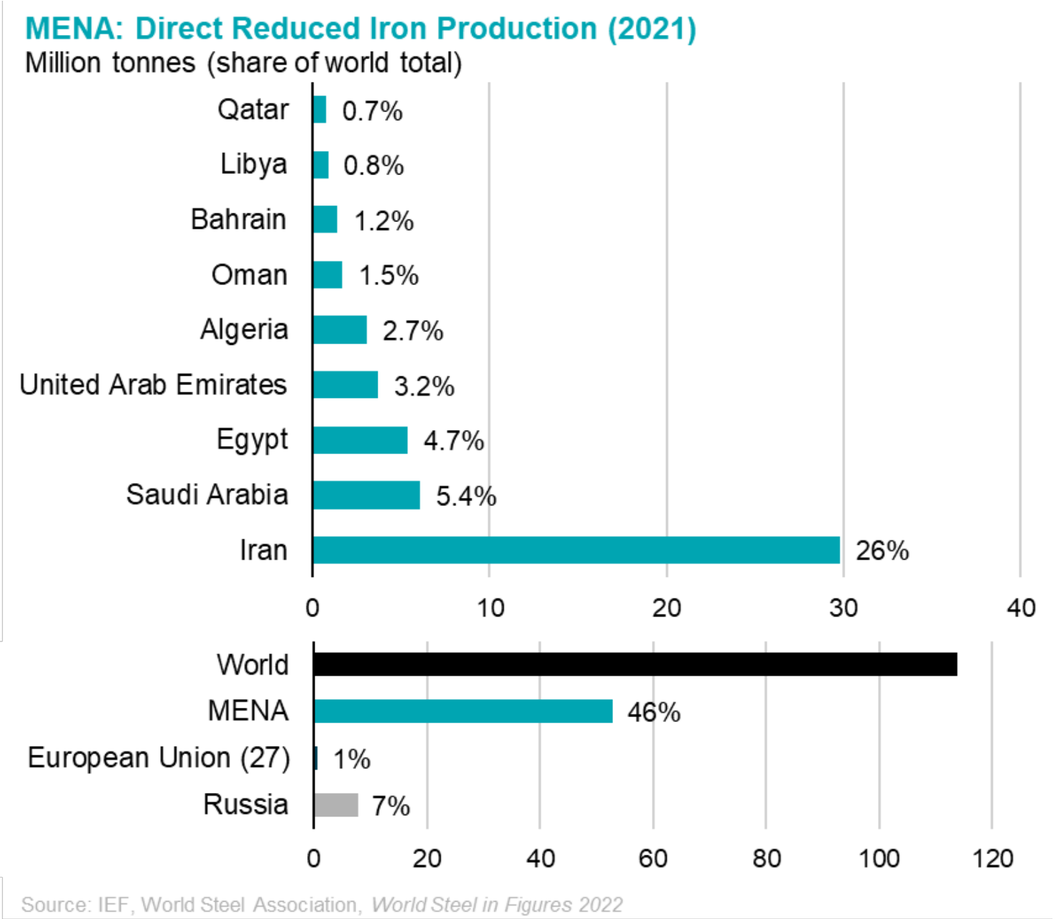
Several MENA countries already rank as the largest consumers of hydrogen



Source: IEF, IRENA *Geopolitics of the Energy Transformation: The Hydrogen Factor*

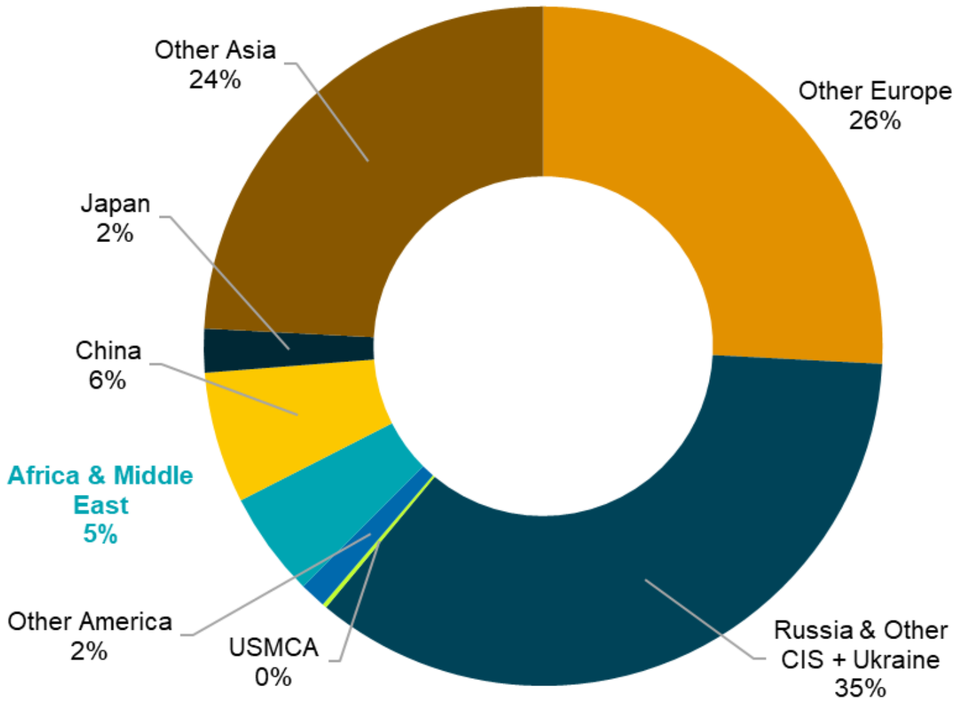
Strength: Although not a large steel producer, MENA region is a leader in DRI production





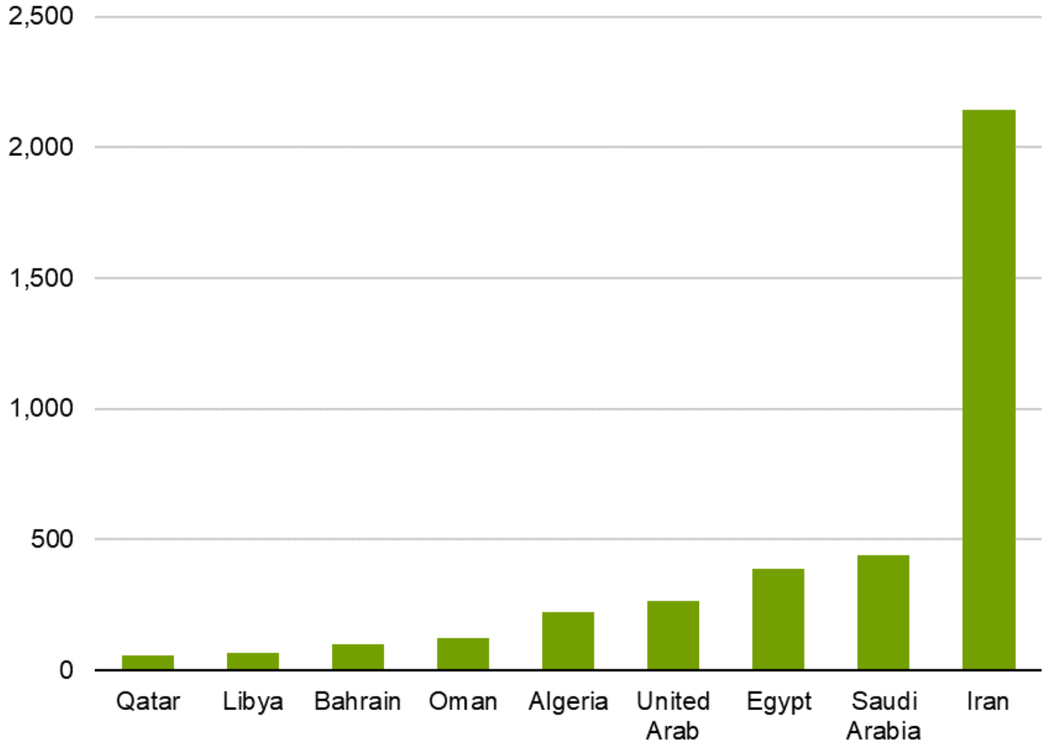
Hydrogen & DRI present large opportunity for MENA "green steel" leadership

EU (27) Steel import sources (2021)
percent of total



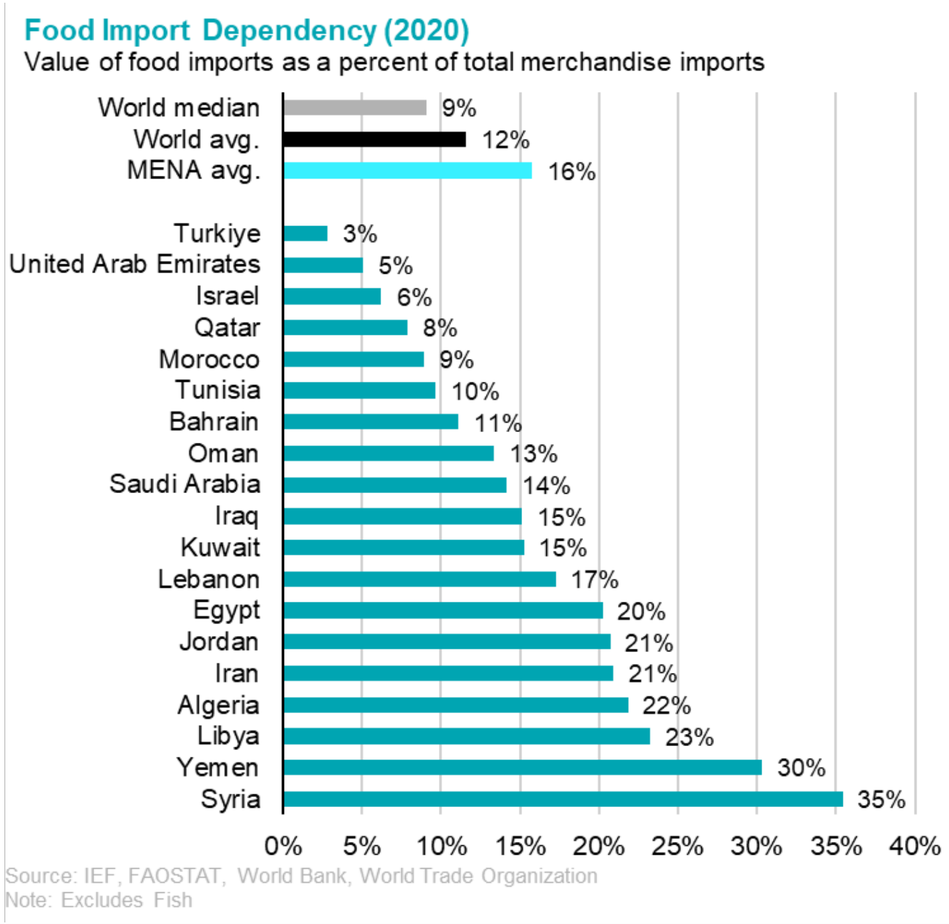
Source: IEF, World Steel Association, *World Steel in Figures 2022*

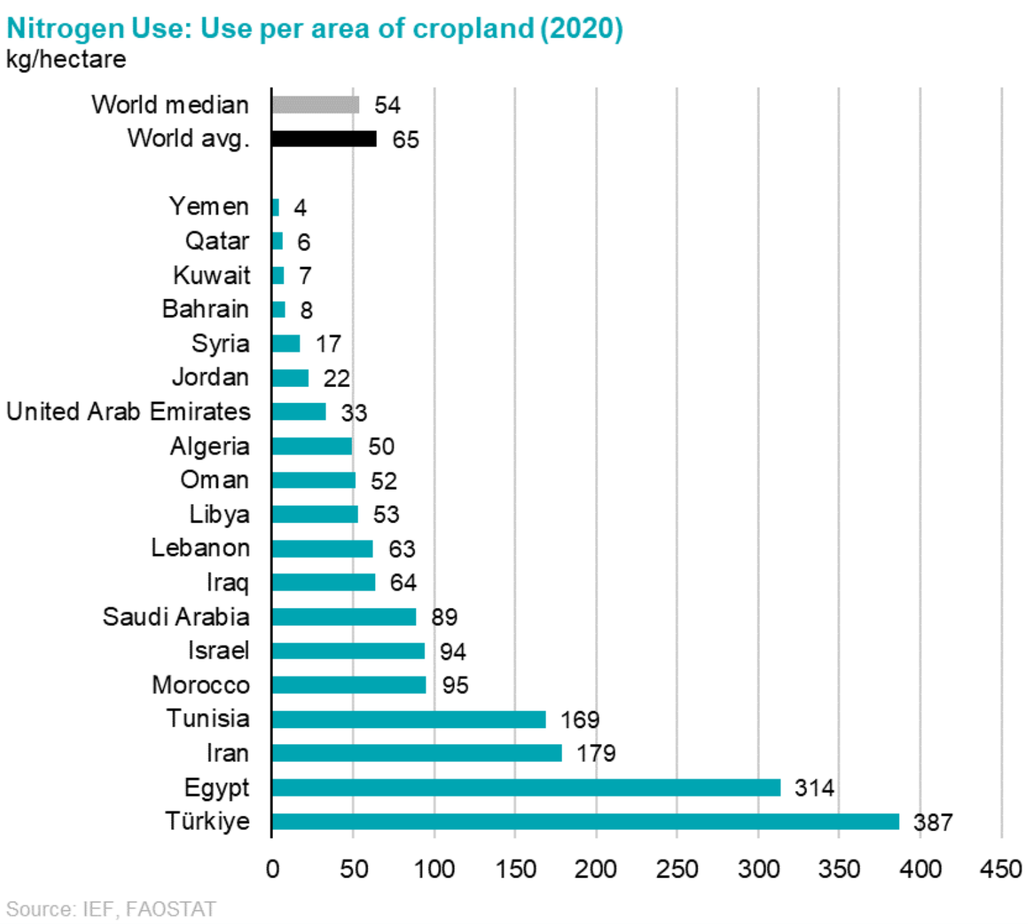
MENA: Estimated Hydrogen supply required for 100% green DRI production
thousand tons



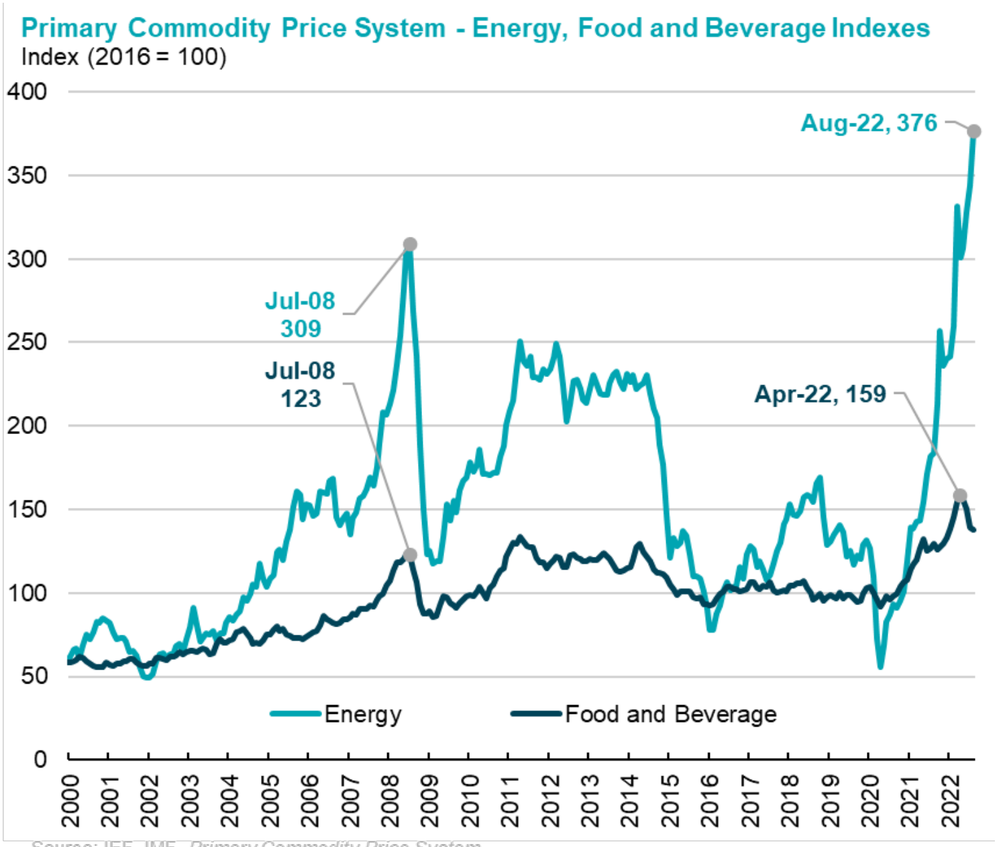
Source: IEF, World Steel Association, Habib & Ouki (2021)
Note: Estimates based on ~71.9kg of hydrogen per DRI ton

Weakness: MENA region is both food import dependent and an intensive user of fertilizers

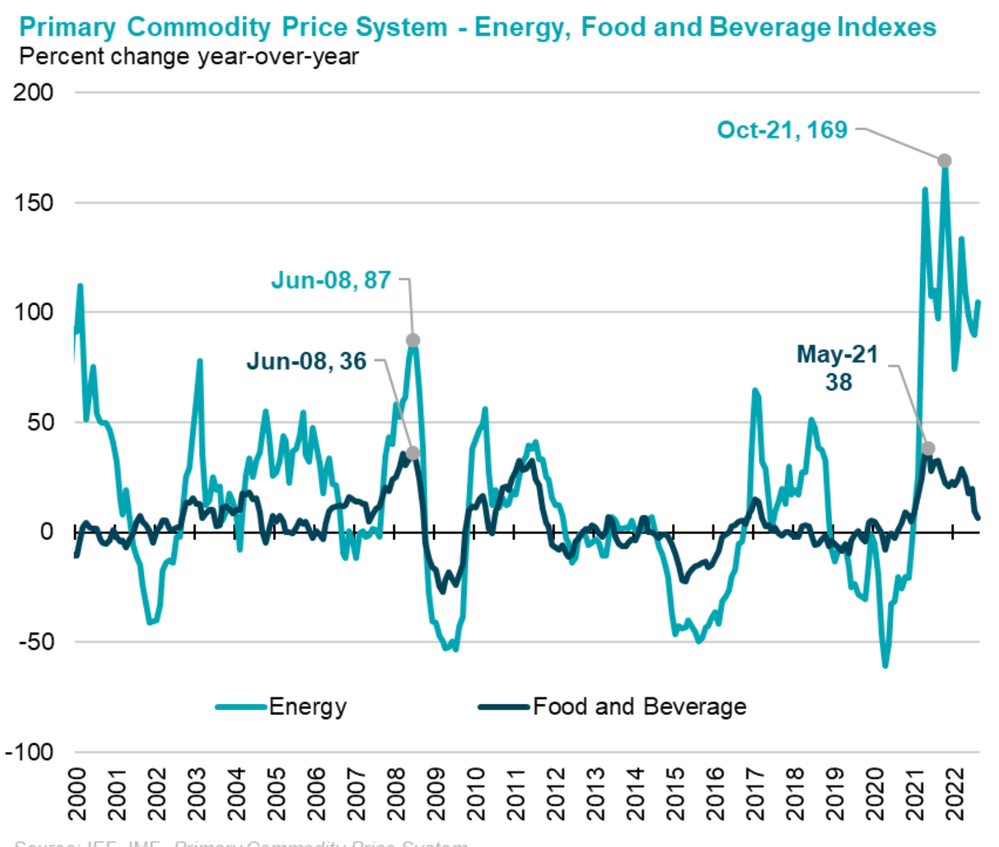




Rising energy prices have helped to offset increased food prices in some MENA countries, but not all

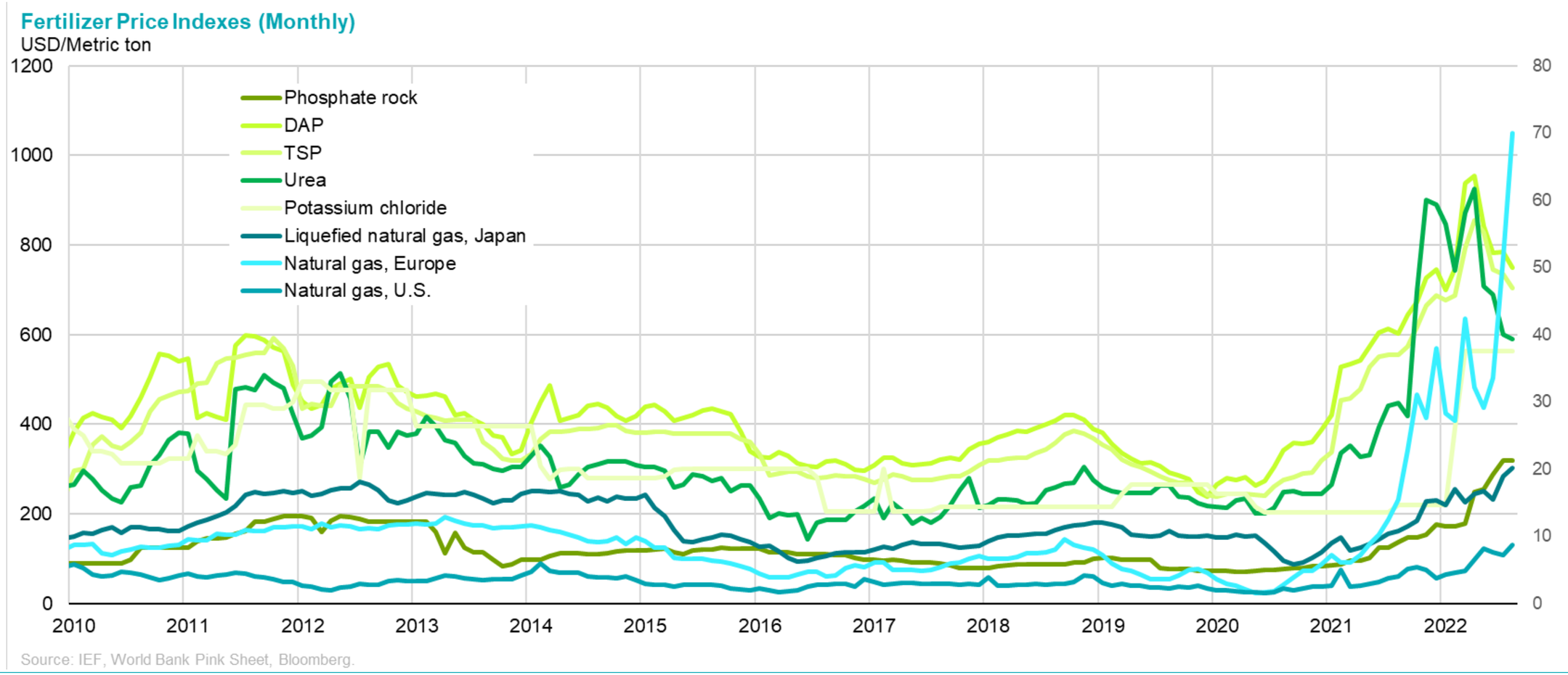


Source: IEF, IMF, *Primary Commodity Price System*
Note: Index includes global benchmark prices for Crude oil, Natural gas, Coal, Propane, Coffee, Tea, Cereals, Meats, Sugars and other foods.



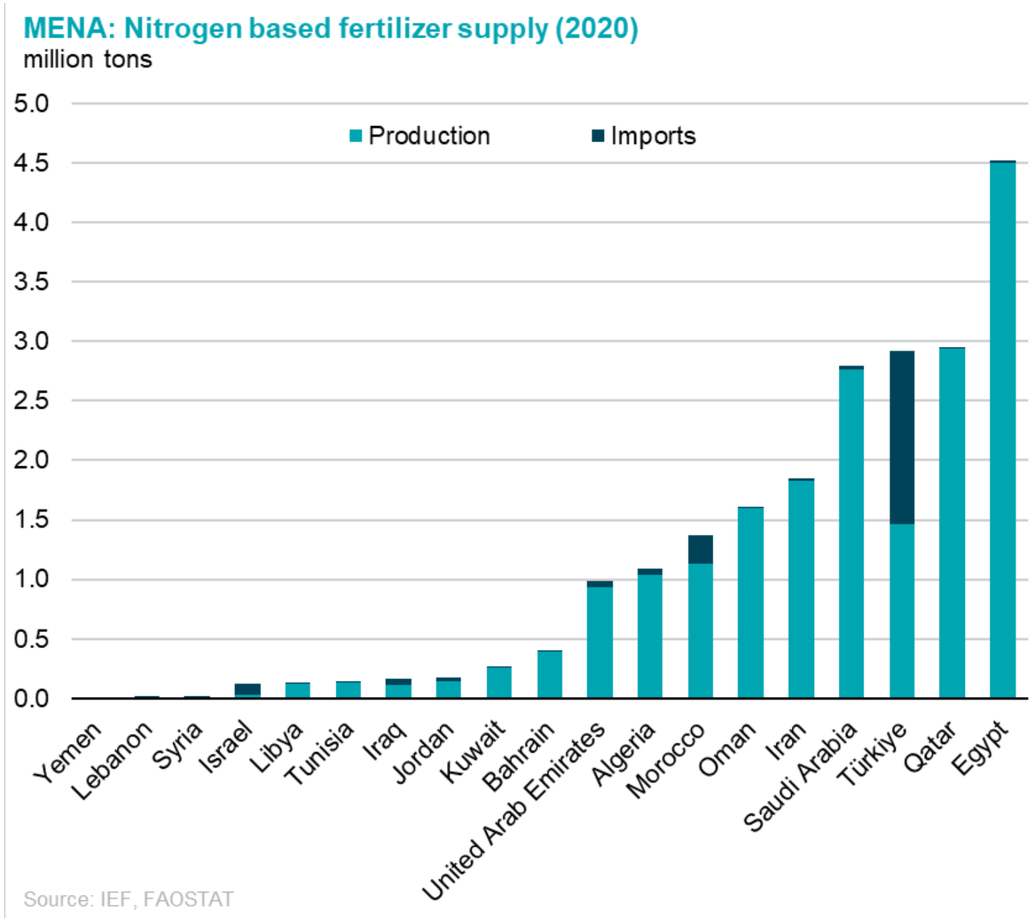
Source: IEF, IMF, *Primary Commodity Price System*
Note: Index includes global benchmark prices for Crude oil, Natural gas, Coal, Propane, Coffee, Tea, Cereals, Meats, Sugars and other foods.

Ammonia connection (NH3) means that high natural gas prices result in high fertilizer prices

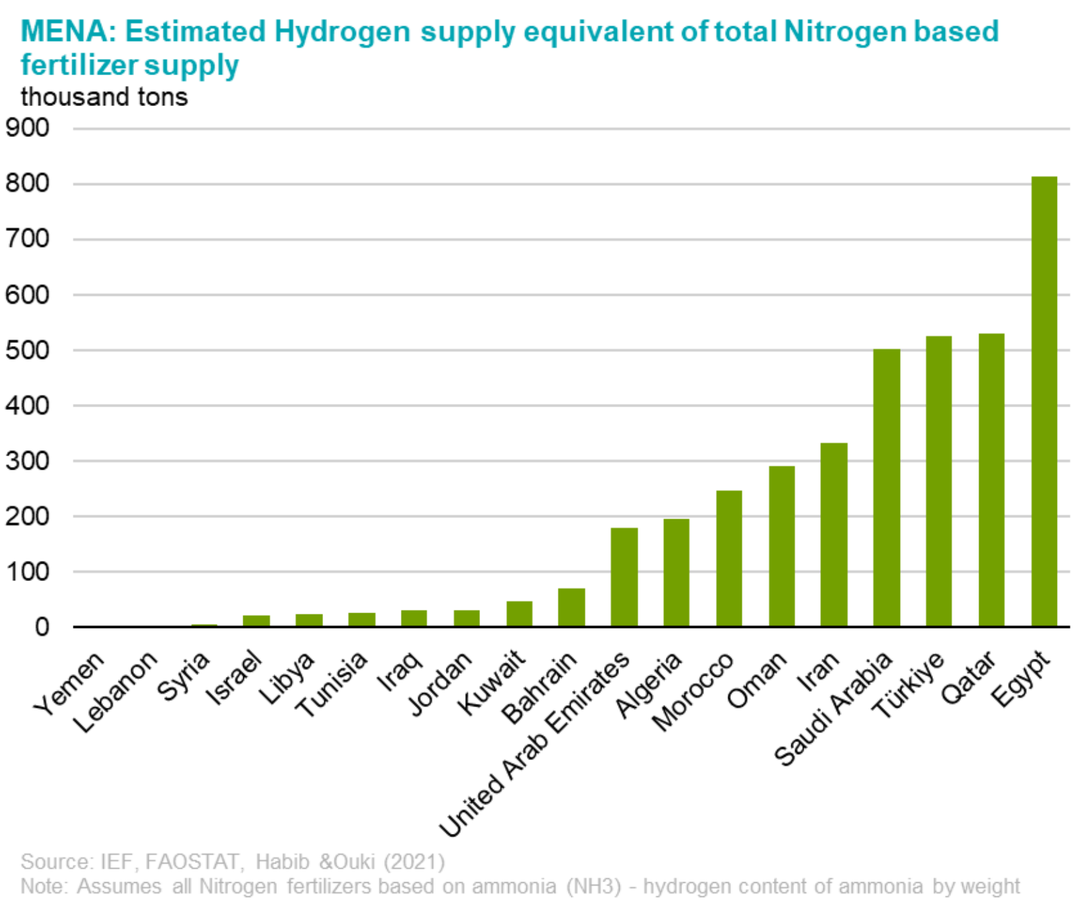


Source: IEF, World Bank Pink Sheet, Bloomberg.

Expanding clean hydrogen use in MENA fertilizer sector may both decarbonize and reduce vulnerability to food and fertilizer price shocks

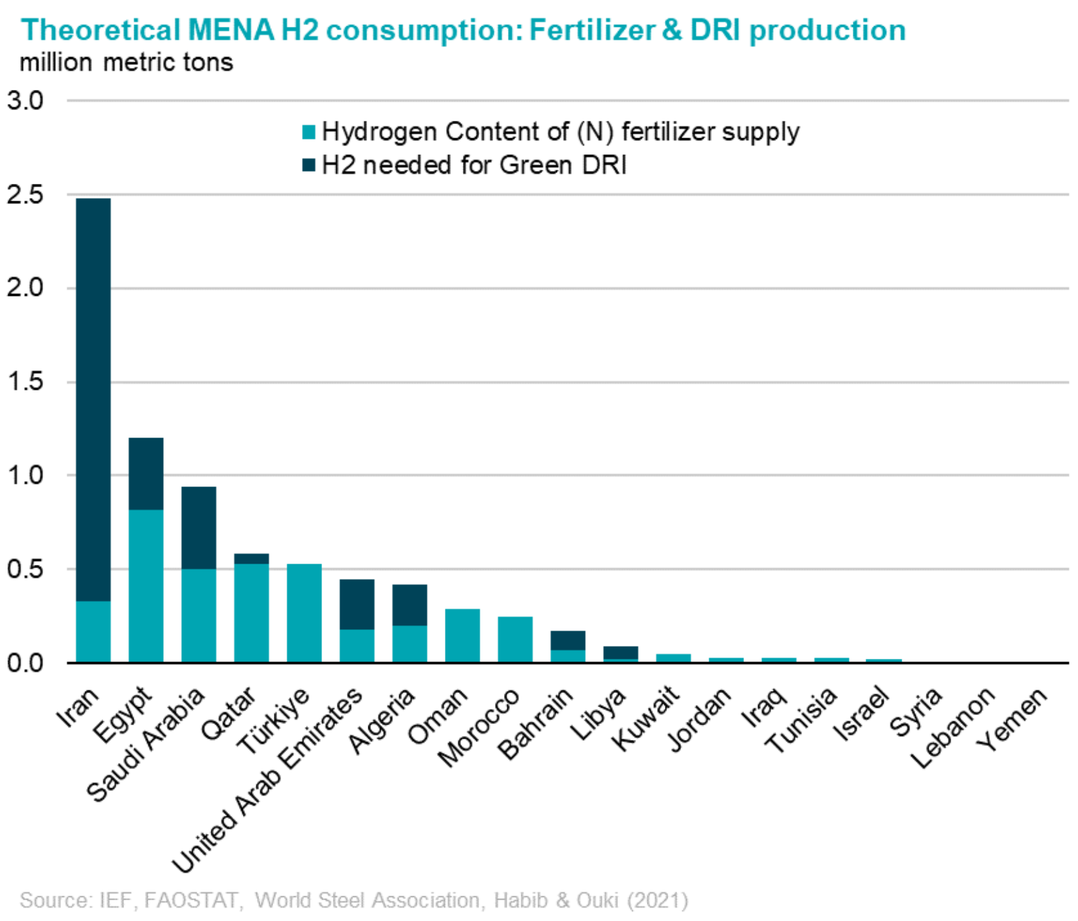


Source: IEF, FAOSTAT

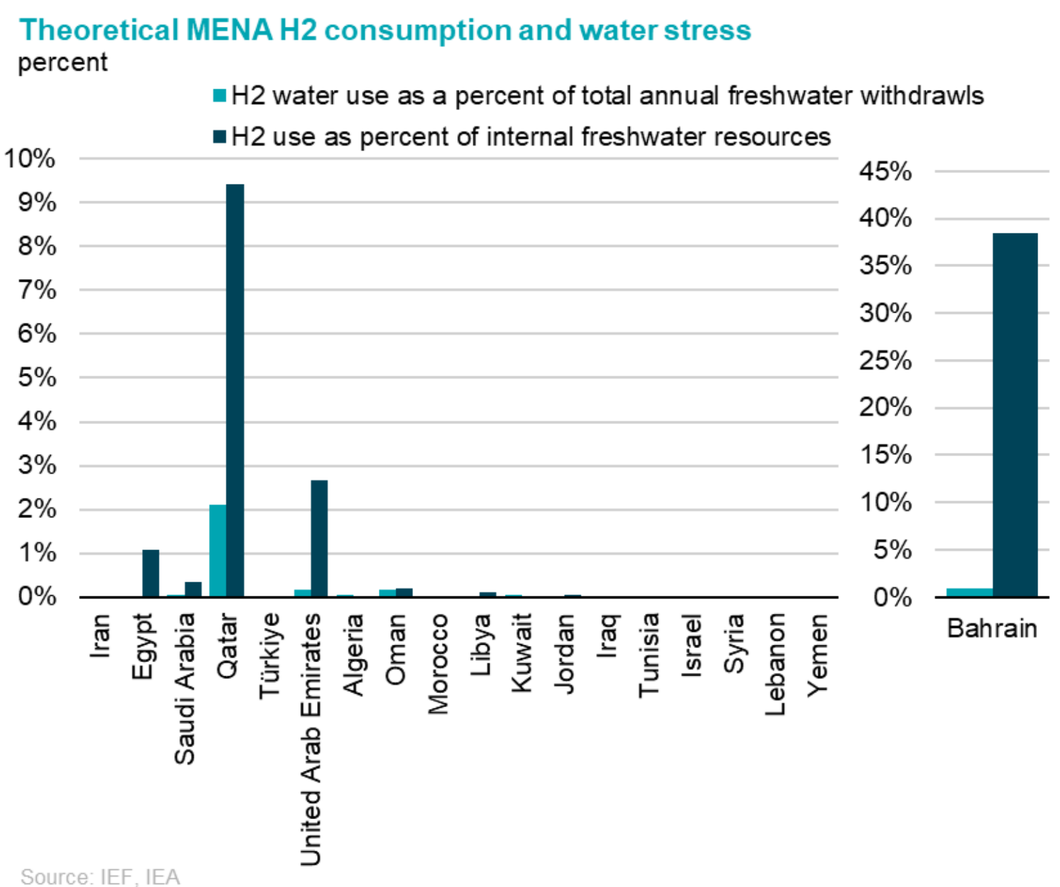


Source: IEF, FAOSTAT, Habib &Ouki (2021)
Note: Assumes all Nitrogen fertilizers based on ammonia (NH3) - hydrogen content of ammonia by weight

In a water stressed region, water used for hydrogen production (electrolyzer) would pose a challenge for only a few countries – for now

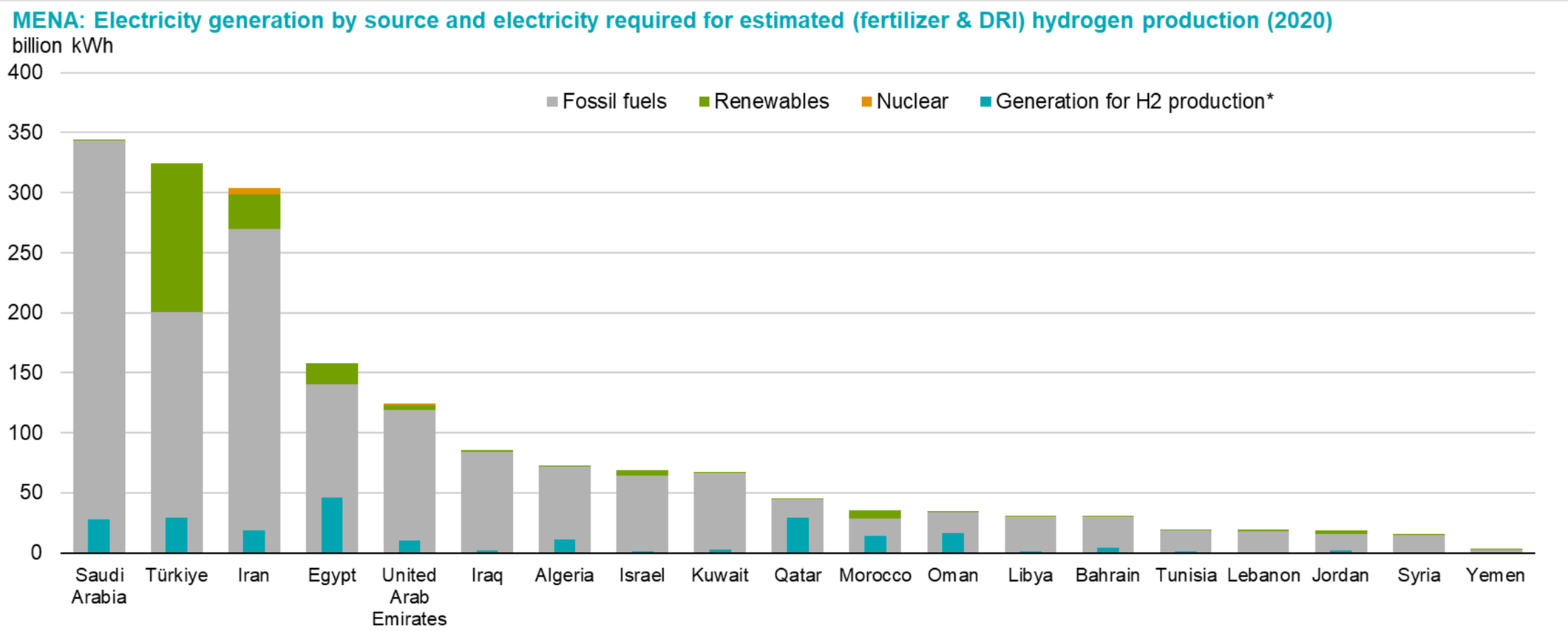


Source: IEF, FAOSTAT, World Steel Association, Habib & Ouki (2021)



Source: IEF, IEA
Note: Based on IEA 9 liters per kg of H2

Hydrogen production from renewable electricity would require significant expansion of capacity



Source: IEF, U.S. Energy Information Administration, IRENA, Habib & Ouki (2021)
Note: Estimated supply of hydrogen needed for 100% of nitrogen based fertilizer and DRI production. Production assumes PEM electrolyzer at 70% efficiency.

Hydrogen market development keys to success: MENA region and beyond

- Standardization
  - Definitions, carbon intensity, unit of measure/trade

- Statistics
  - Accurate, open, transparent data

- Transparency in pricing and contracts
  - Establish contractual norms
  - Provide data for financial models

- International Partnerships and coordination

MENA role in setting contractual norms and precedents is proven: Crude oil, LPG, LNG

Pen and Sword: Working together on hydrogen

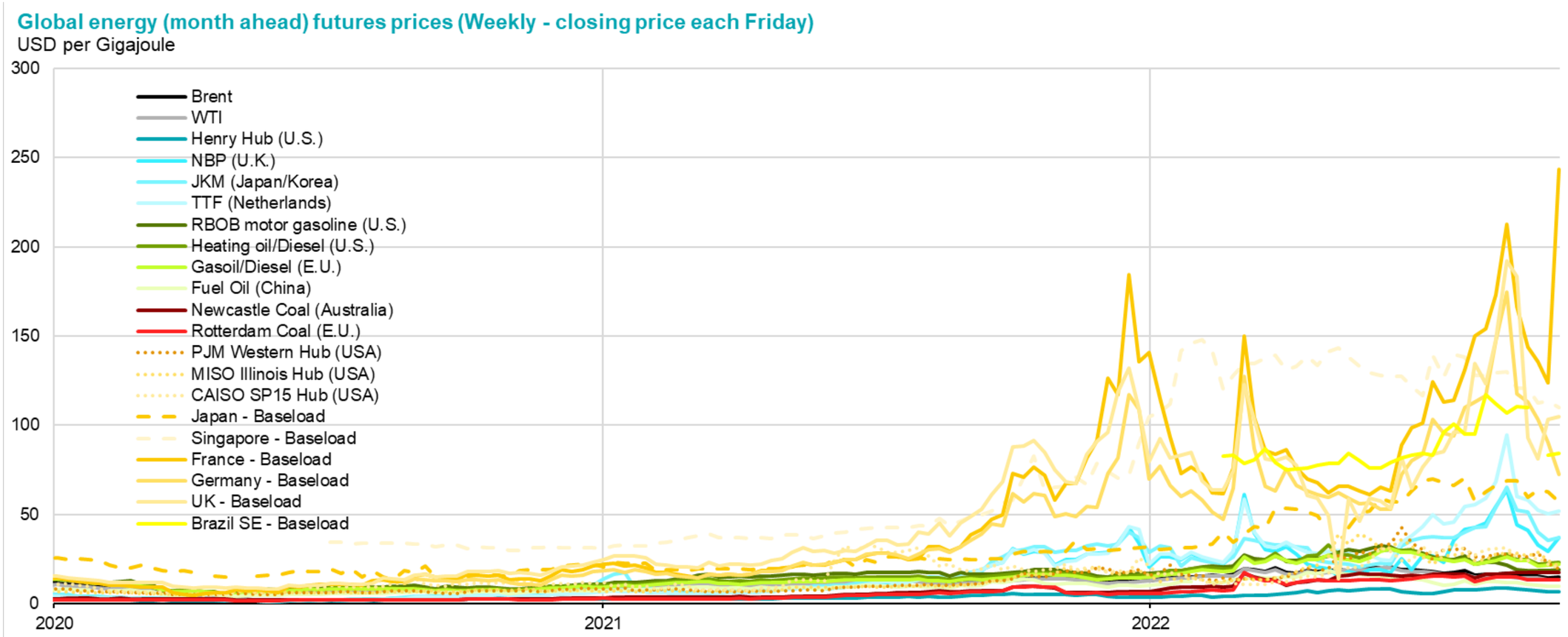
<

- Russian invasion of Ukraine
- Disruption of energy supplies to Europe
- High oil and natural gas prices
- Energy security now top priority for policy makers

- Time for hard policy choices has arrived
- Long debated policies becoming finalized
- Rules and regulations progressing
- Time to sign H2 offtake contracts

The English words "The pen is mightier than the sword" were first written by novelist and playwright Edward Bulwer-Lytton in 1839, in his historical play Cardinal Richelieu.

Hydrogen requires energy to produce, store, transport, and in some cases use – this poses major challenges in our energy short world



Source: IEF, Bloomberg.
Note: Btu conversions based on EIA AEO 2021 Table 71, Coal conversion based on 6,000kcal/kg

INTERNATIONAL ENERGY FORUM

Thank you

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A Global Hydrogen Future

The Hydrogen Value Chain

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EFI-KAPSARC Workshop – A Global Hydrogen Future

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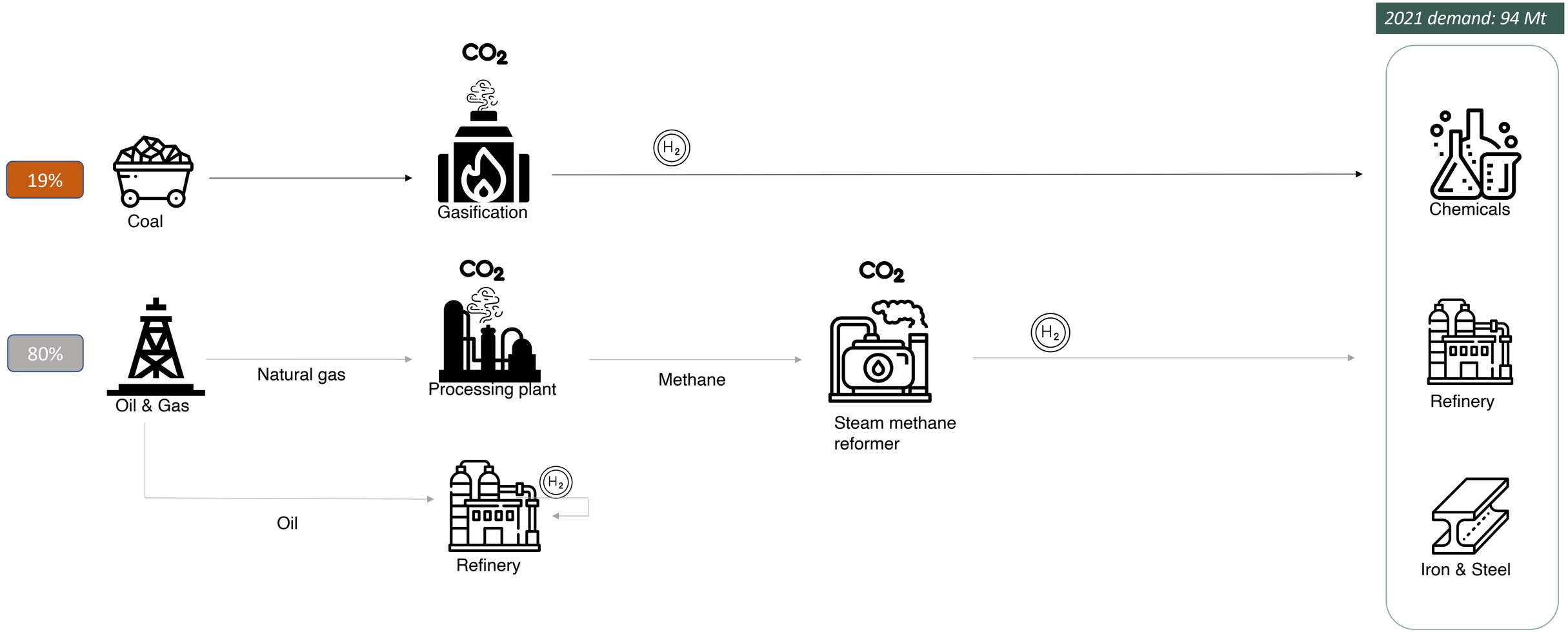
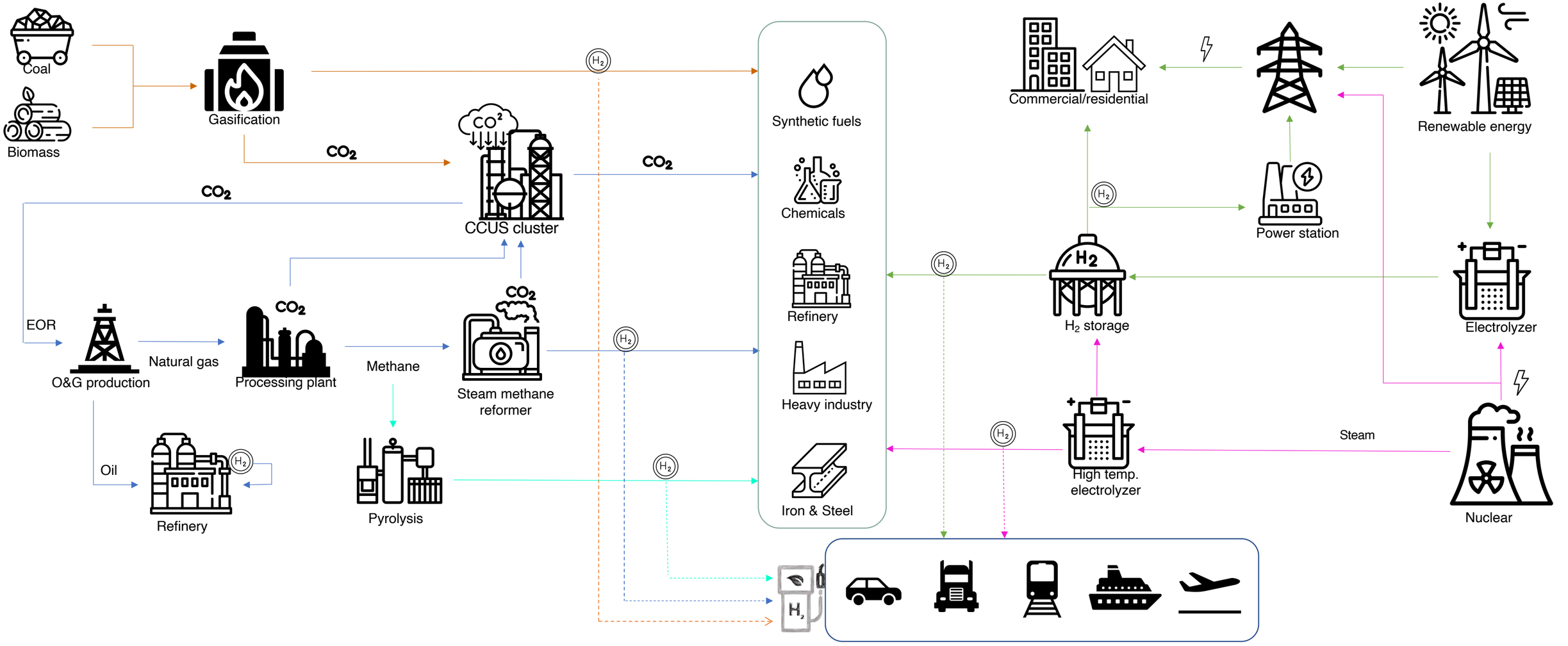
The hydrogen value chain as we know it



Source: KAPSARC, IEA

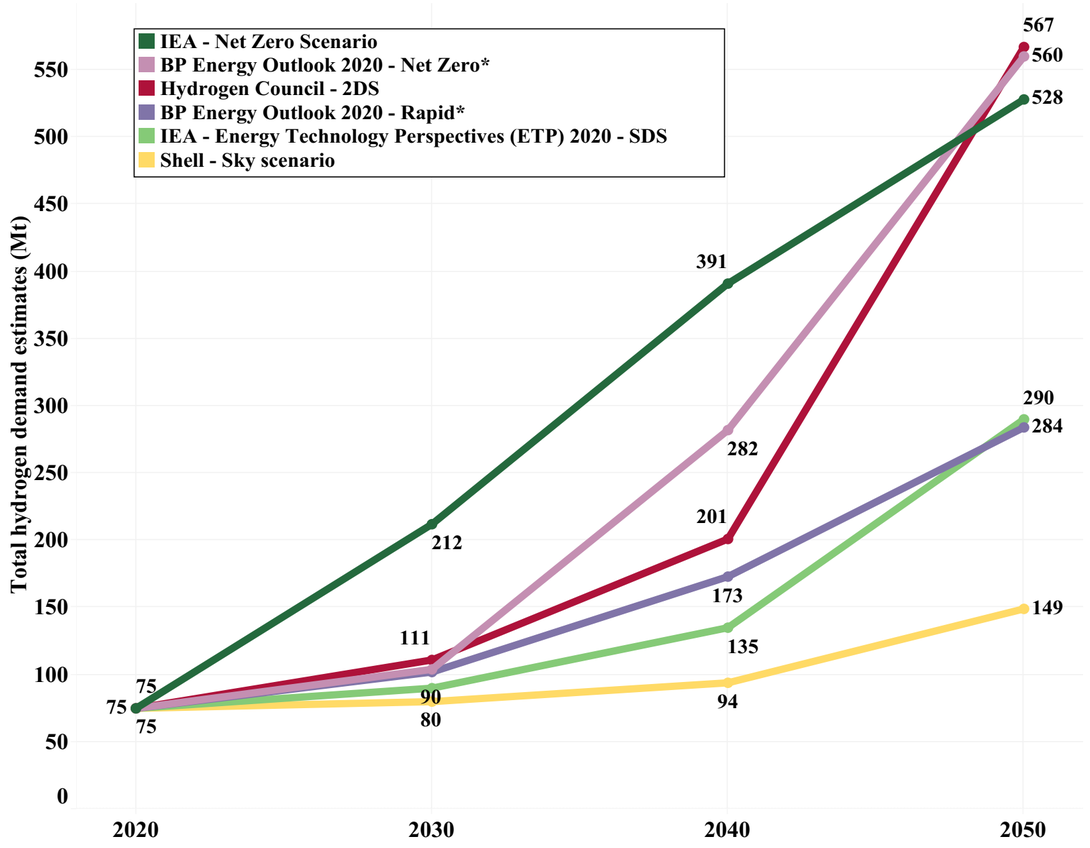
Hydrogen value chain of the future



Source: KAPSARC

Uncertainty in future hydrogen demand

- Hard-to-electrify industries are the most primed to explore the adoption of hydrogen
- Investment cases for hydrogen in most sectors are still evolving
- Supportive policies and regulatory frameworks are needed to encourage investments
- Role of governments will be essential to overcome the cost challenges

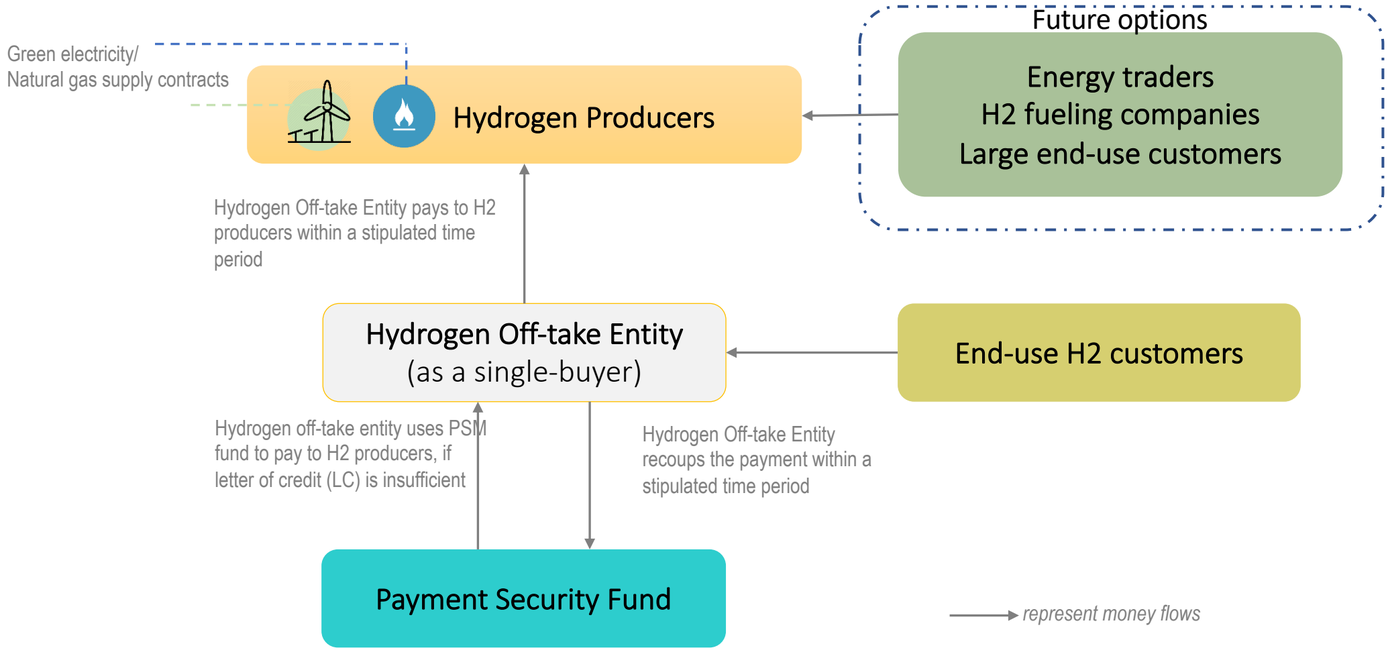


Source: Jan Braun, KAPSARC, IEA, Shell, BP, Hydrogen Council

De-risking the hydrogen value chain

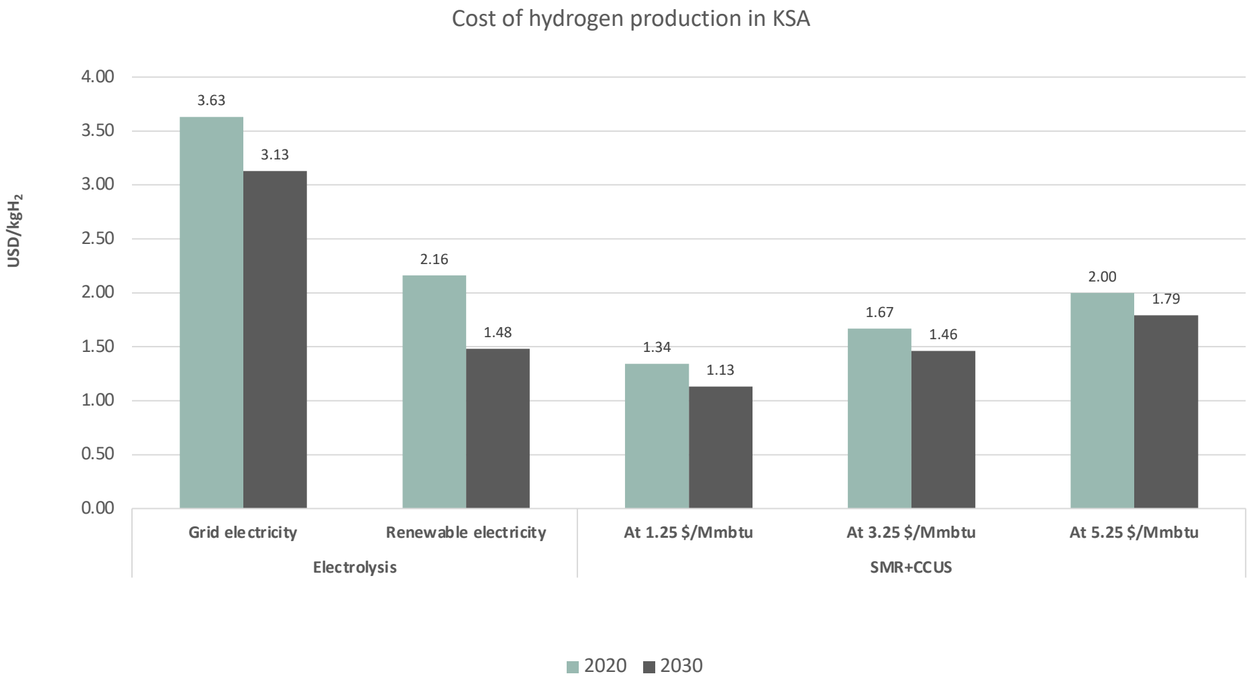
- The LNG and renewable electricity sector will be an important reference point in establishing a sound business model for hydrogen:
  - Long-term contracts
  - Take-or-pay
  - Oil/gas indexation
  - Cost-plus model
  - Price review clause

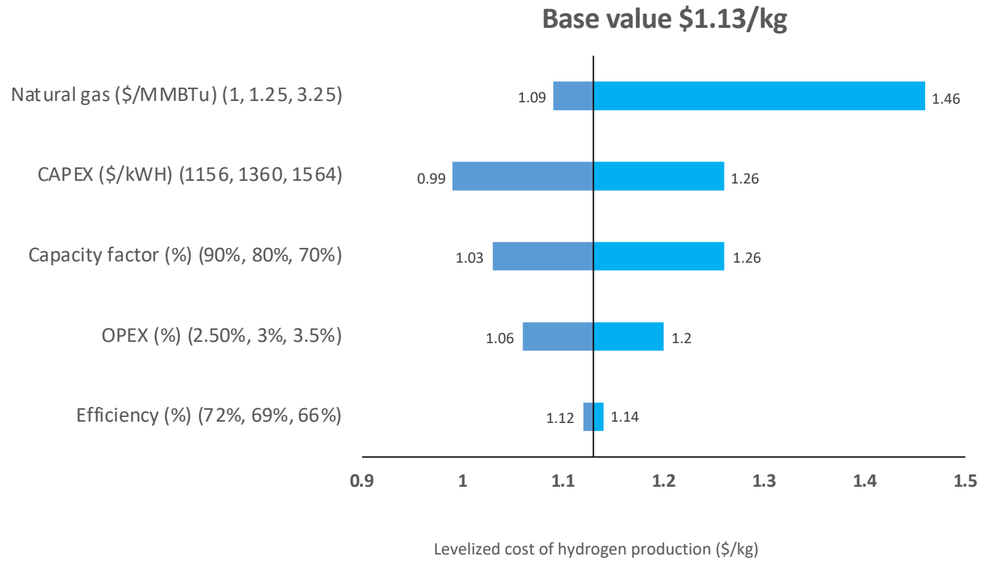
- For some hydrogen use cases, a centralized hydrogen procurement entity may be preferred initially

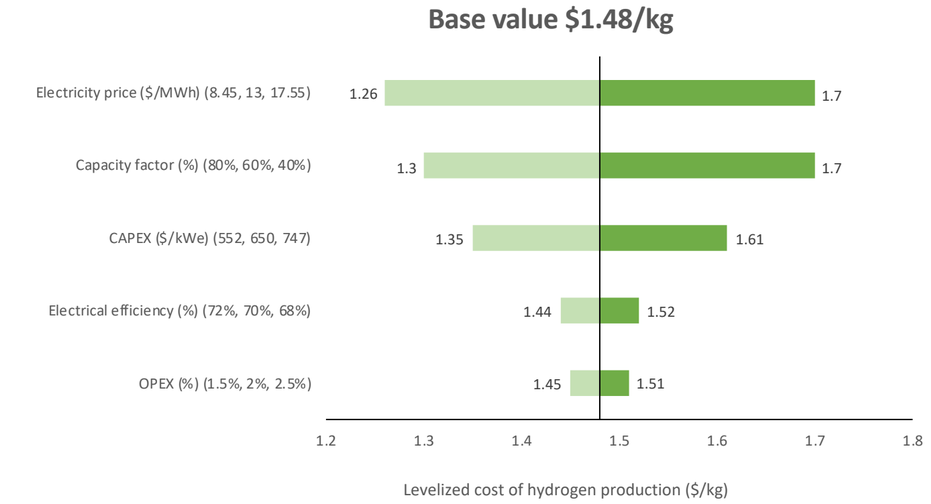


Source: Hasan 2022 (KAPSARC)

Scaling up the value chain



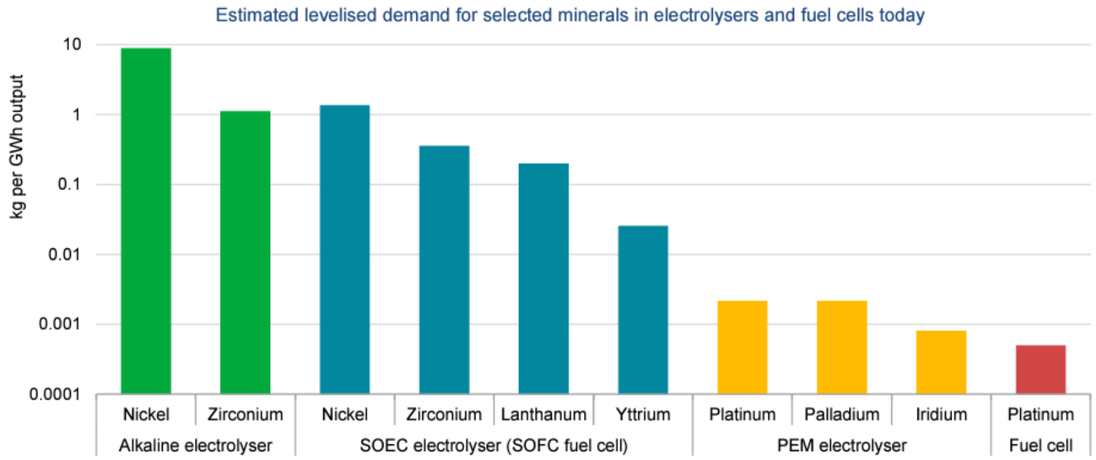


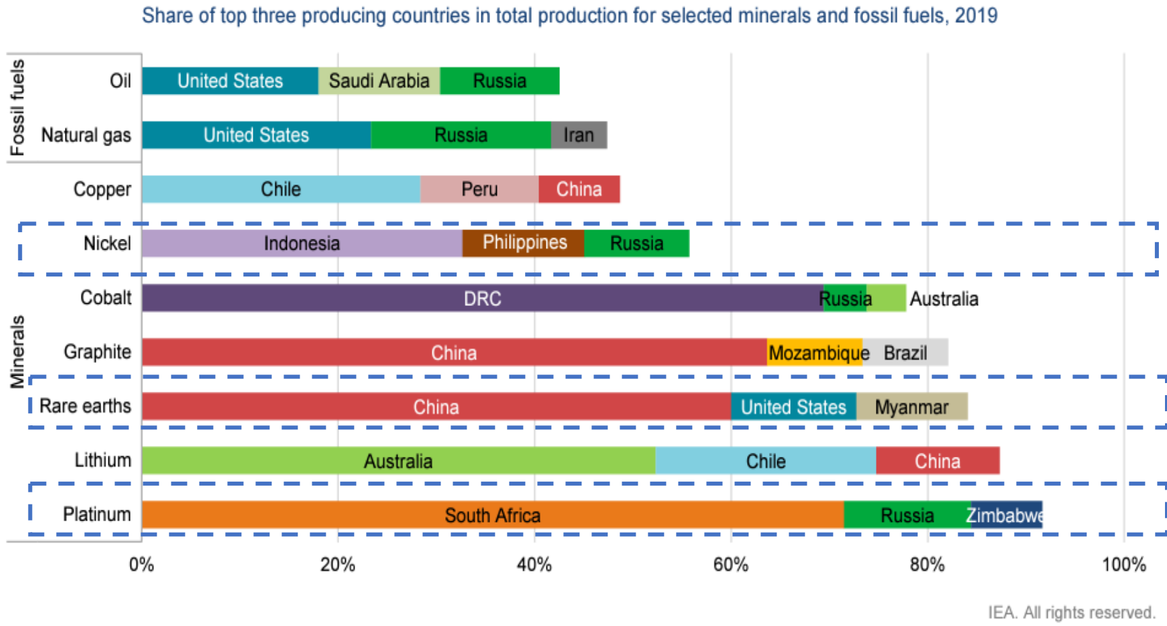


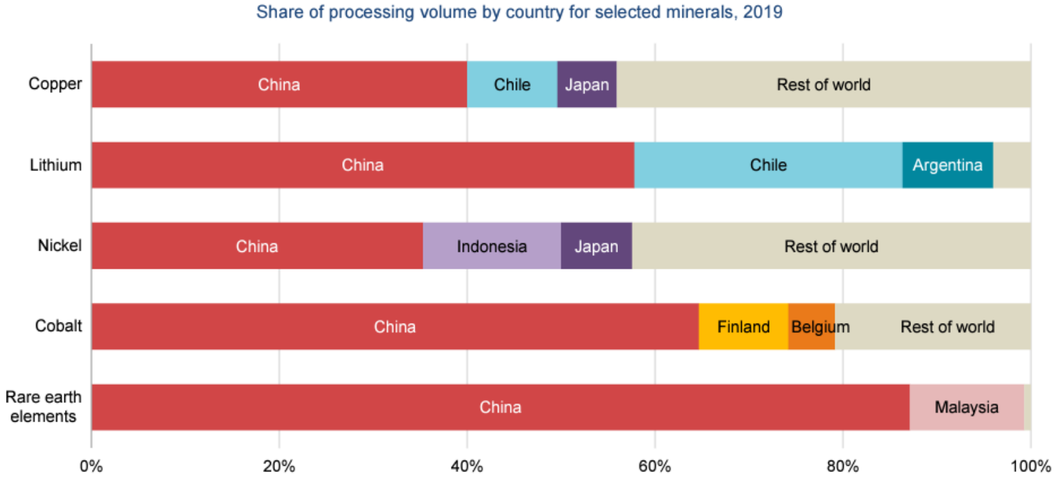
- Scaling up production is key to reducing CAPEX
- After the 2030s, NPVs become less sensitive to CAPEX for green H_2.
- Variable costs, electrolyzer capacity factors, and carbon storage capacities vary across geographies

Source: Shahid and Shabaneh 2022 (KAPSARC)

Critical minerals: technology risk?







Source: IEA

- Some low-carbon hydrogen pathways are critical-mineral intensive
- Price volatility and risk exposure of certain key raw materials

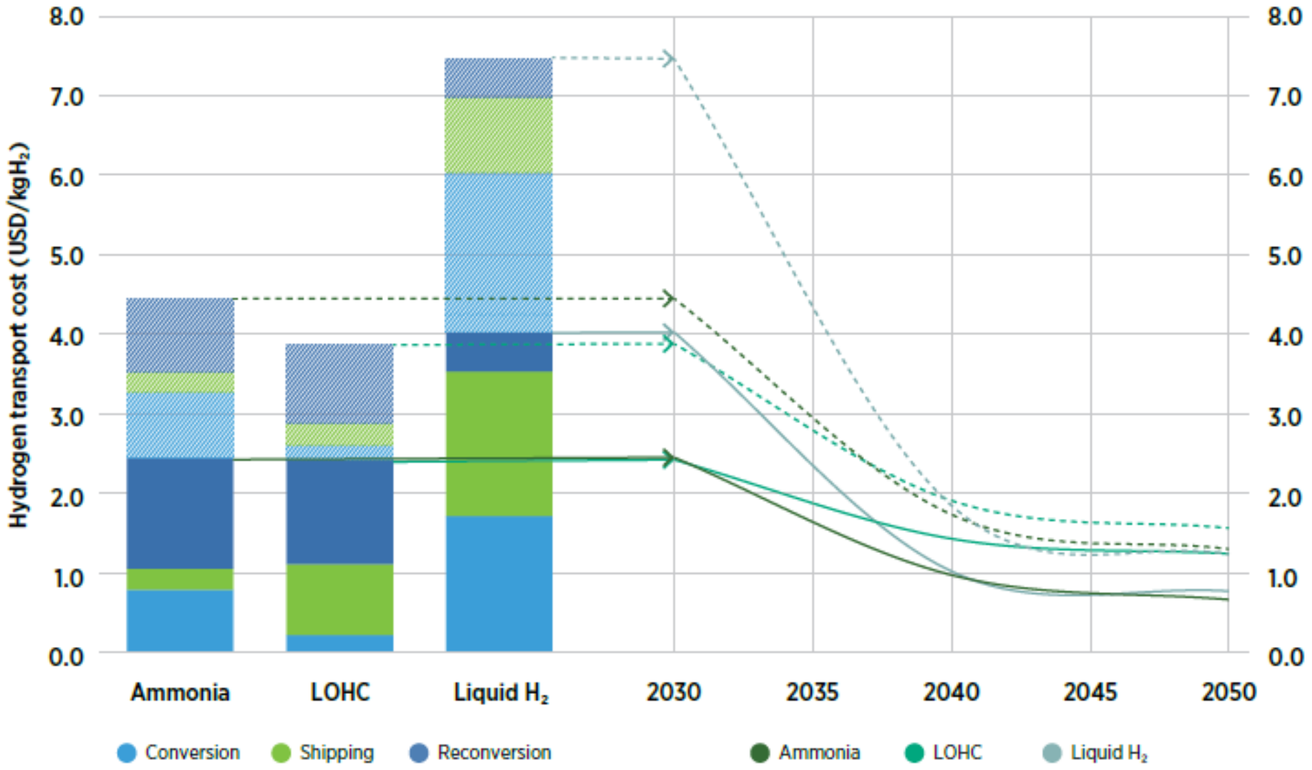
Assuming a 40% capacity factor for electrolyzer:

1 Mt of green H_2 → 15 GW electrolyzer capacity
20 GW Renewable capacity

Next stage: hydrogen transportation

- Hydrogen's low volumetric energy density poses one of the biggest challenges for storage and distribution
- Cost of the pipeline scales linearly with distance; investment costs much lower for repurposed pipelines.
- Beyond pipelines, ammonia and LOHC are the most attractive carrier, but reconversion has a high energy penalty
- End-use will dictate the form hydrogen shipped

Transport cost breakdown by hydrogen carrier for 2030 (left) and evolution toward 2050



Source: IRENA (2022) Technology Review of Hydrogen Carriers.

H_2 Certification: Harmonization or mutual recognition?

- Certification schemes attempt to reflect the regulatory framework of a national market
- Having harmonized standards and certification schemes is essential but challenging
- Mutual recognition of certification may be easier to achieve than harmonization

Sustainability criteria for hydrogen/RFNBOs	Schemes							Funding Programme	Regulations		
Regulation/standard	ISCC PLUS	CertifHy	dena Biogas-register	TÜV Süd CMS 70	China Hydrogen Alliance's Standard[1]	Certification Scheme (Japan)[2,3]	Zero Carbon Certification Scheme	H2Global	LCFS	RED II	RTFO
Market	EU	EU	DE	DE	CN	JP	AU	DE	US/CA	EU	UK
Purpose	v	v	r	v	n/a	v	v	r	r	r	r
Renewable electricity	+	+	+	+	+	+	+	+	+	+	+
Tracking models	MB	B&C	MB	MB; B&C	n/a	B&C	MB	MB	B&C[4]	MB	MB
GHG emissions	Well-to-Wheel	Well-to-Gate	According to demand	Well-to-Wheel	Well-to-Wheel	Well-to-Gate	Well-to-Gate	Well-to-Wheel	Well-to-Wheel	Well-to-Wheel	Well-to-Wheel[5]
Eligible carbon sources	+	tbu	+	Out of Scope	Out of Scope	n/a	+	tbu	+	Pending Delegated Act	+
Land use	+	-	-	-	-	-	-	+	+	-	-[6]

Source: dena and WEC Germany

44th IAEE INTERNATIONAL CONFERENCE
Riyadh, Saudi Arabia
4-9 February 2023

Pathways to a Clean, Stable and Sustainable Energy Future

Thank you

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A Global Hydrogen Future
Lunch Break

A Global Hydrogen Future
Breakout Sessions

1. Global Hydrogen Policy and Regulatory Review
2. Financing a Hydrogen Future
3. Developing a Global Hydrogen Market

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A Global Hydrogen Future Break

A Global Hydrogen Future

Panel Discussion - Global Hydrogen Overview

Moderator: Rick Westerdale

Participants: Ken Medlock, Peter Fazio and Jane Nakano

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A Global Hydrogen Future
Closing Session

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