Industrial Flexibility and Hydrogen

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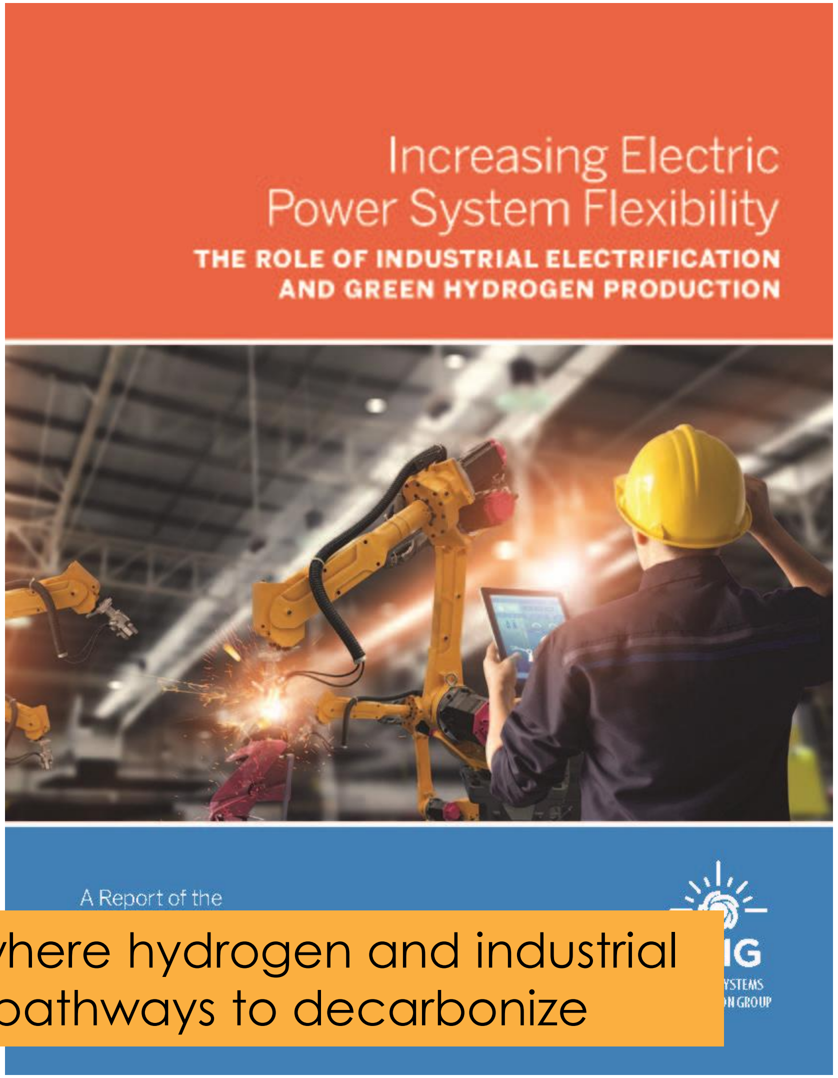
NARUC Electrification and Load Forecasting Training

June 1, 2023

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

ESIG Flexibility Task Force Report (early 2022)

- Increasing deployment of renewable resources around the world envisioned to decarbonize power systems
  - Reducing availability of traditional sources of flexibility while increasing value of flexibility
  - Increased electrification of energy system to take advantage of clean renewables
- Newly electrified resources have the potential to provide significant flexibility
  - Examined from the context of 70%+ renewable energy, where flexibility is increasingly important
  - Oversupply conditions may result in abundant low cost renewables available
  - Deficits in energy requires long duration storage, clean firm power or some other means of ensuring resilience



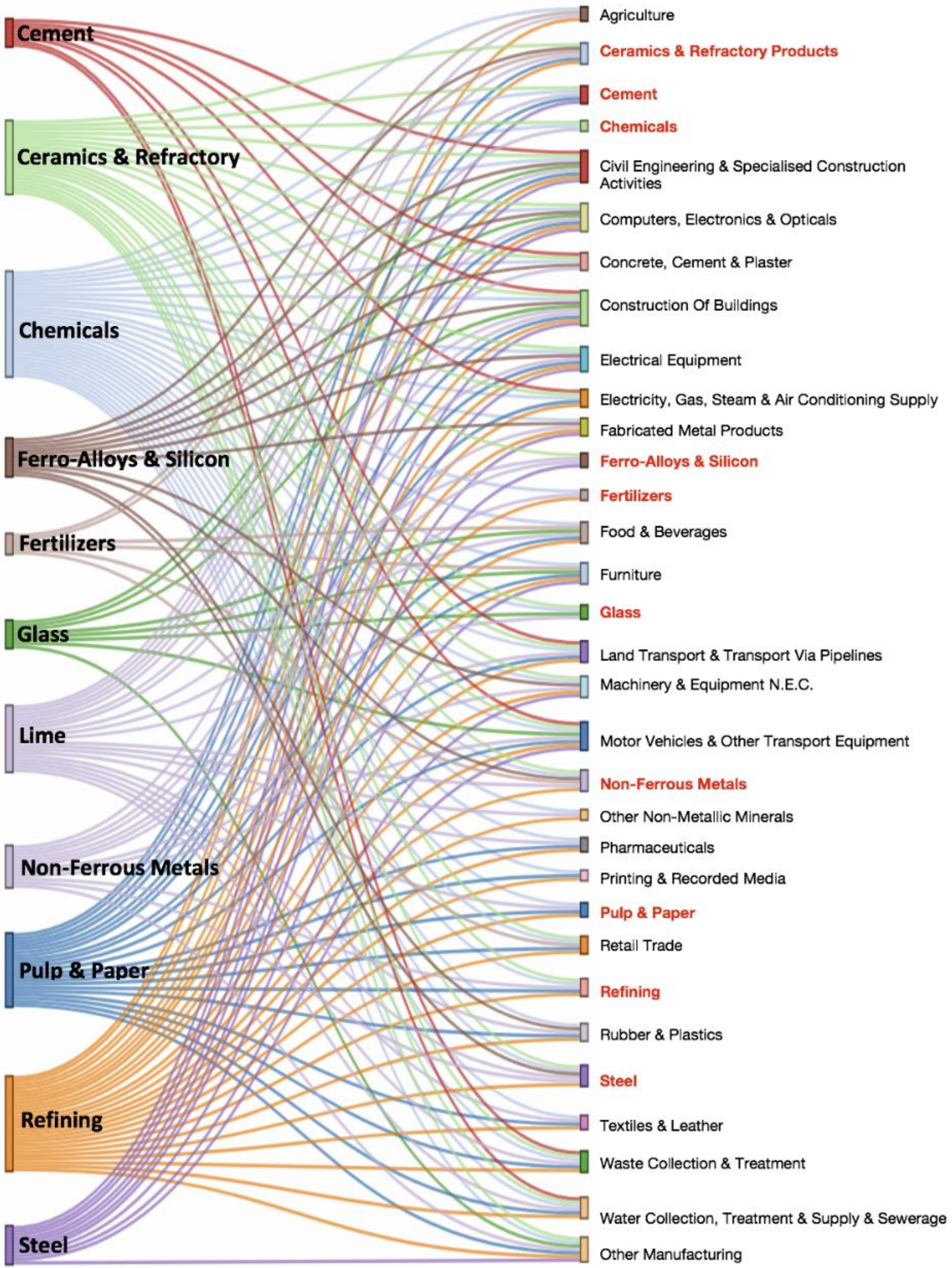
Focus is more on how we will plan and operate power systems where hydrogen and industrial electrification are major contributors of flexibility, less on the pathways to decarbonize

https://www.esig.energy/wp-content/uploads/2022/01/ESIG-Industrial-Elec-Hydrogen-report-2022.pdf

Industrial Electrification and Power System Flexibility

- Energy-intensive industries (EIIs) are the foundations of the broader economy and enable a vast amount of other industrial activity.
  - Account for over one-third of all energy use
  - link to all other economic sectors, are themselves extensively interlinked, and are deeply connected within the broader energy system
  - EEIs are often very carbon-intensive, and can be harder to decarbonize than other sectors such as the power sector
- Shift towards increased electricity use in the industrial sector expected in the near to medium term.

Source: Wyns, Khandekar, and Robson (2018)

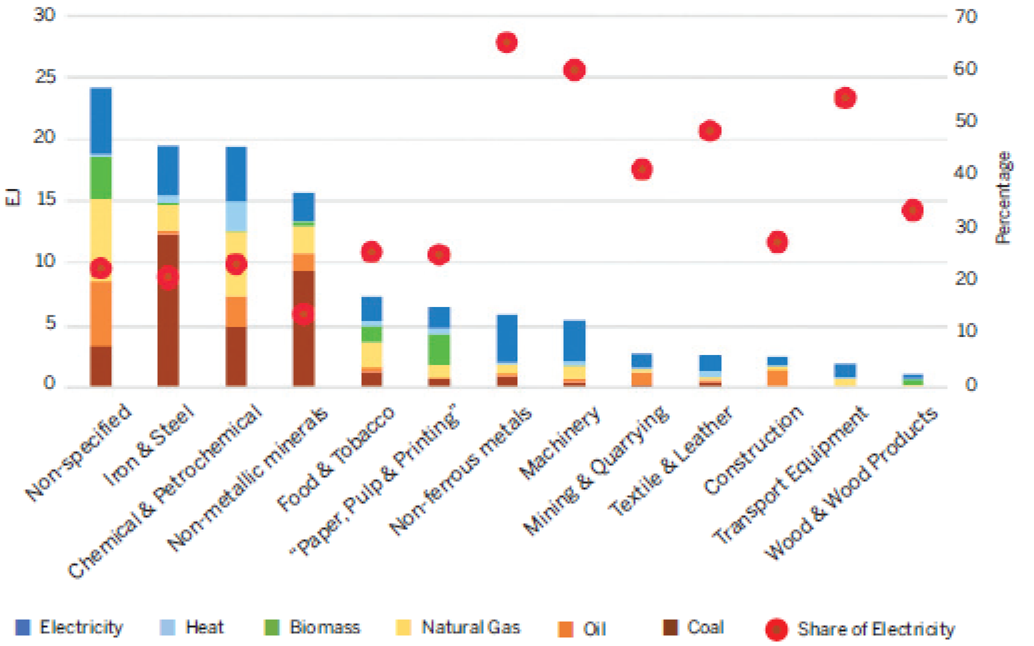


Industrial Electrification

- Wide range in how electricity is used in Energy Intensive Industries (EIIs) today – 14% (e.g., ceramics) to 65% (aluminum)
  - Some EEIs have clear path – others require technology development (e.g., lower temp can be quickly transitioned, but more work for >1000°C (e.g., cement/glass)
  - Process electrification, e.g., use of secondary steel produced in electric arc furnaces, is an area of focus
  - Other processes may need greater technology development into 2030s, and link to hydrogen
- Flexibility as a demand resource – direct control or price-based
  - Possible for some processes such as smelting to provide flexibility to shift some demand
  - Grid services are also possible from EEIs
  - Greater share of EEI coming from electricity will result in significant increase in electricity demand (e.g., EU shows 4x)
- Barriers like those associated with efficiency (equipment costs, policy) but with additional of technology development needed in some areas
  - Also need to determine economics if providing flexibility
  - Potential competitive disadvantage if not well designed

FIGURE 1

Source of Energy and the Proportion of Total Energy Demand Represented by Electricity, by Industry



The energy demand for each industry is on the left axis and represented by the colored bars, which indicate the source of energy used in those industries in exajoules (EJ). (One exajoule is 10^{18} joules, or 277.77 terawatt-hours (TWh)). Note that this is the amount of final energy consumption from each source and not electrical energy.) The share of total energy demand that is provided by electricity is on the right axis, represented by the red dots. Each dot shows the current use of electricity as a percentage of total energy; for example, for chemical industries, electrical energy provides approximately 20 percent of total energy use, whereas for machinery it provides a little more than 60 percent.

Source: Wei, McMillan, and de la Rue du Can (2019).

Role of Hydrogen Production in Grid Decarbonization and Flexibility

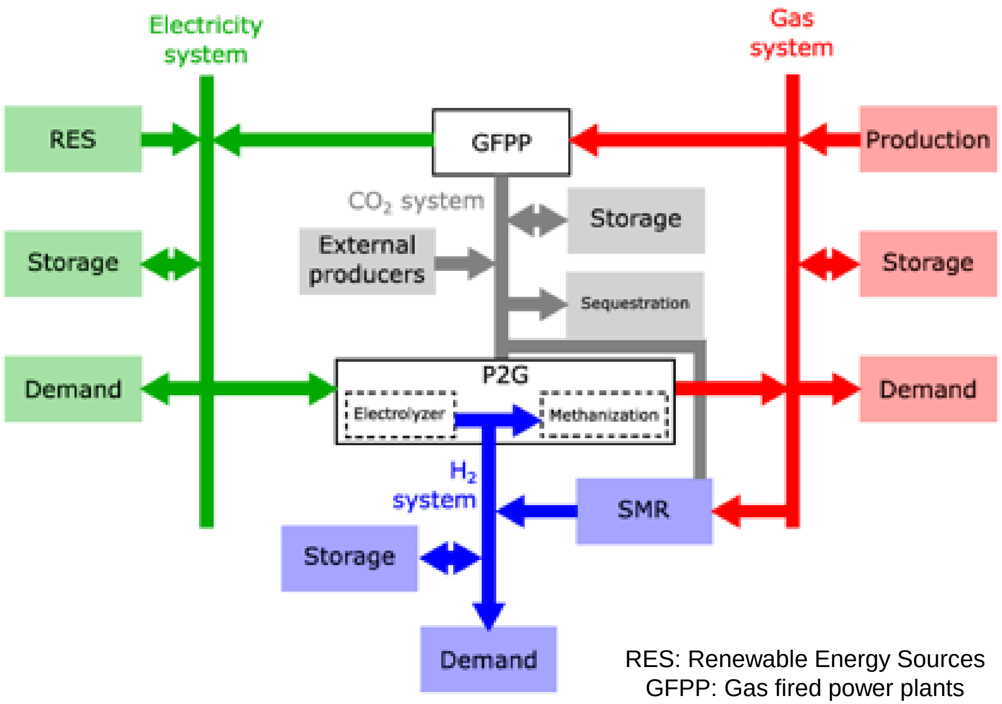
- Hydrogen has the potential to electrify end uses and/or provide grid flexibility as the power system decarbonizes
- Demand and supply side roles possible
  - Electrolyzers as flexible loads, providing grid services or shifting energy across days/weeks
  - Hydrogen fuel cells or hydrogen powered CTs could support ‘dunkelflaute’ conditions
  - Hydrogen, electricity and gas system all interlinked with one- and two-way flows possible
  - Most studies show a limited use of for electricity production - IEA’s net-zero-by-2050 scenarios show 2 percent by 2050 – but there could be a role in certain regions and depending on costs/performance

New York to test green hydrogen at Long Island power plant

Published July 12, 2021

EU Makes a New Bet on Green Hydrogen

Aug. 5, 2019

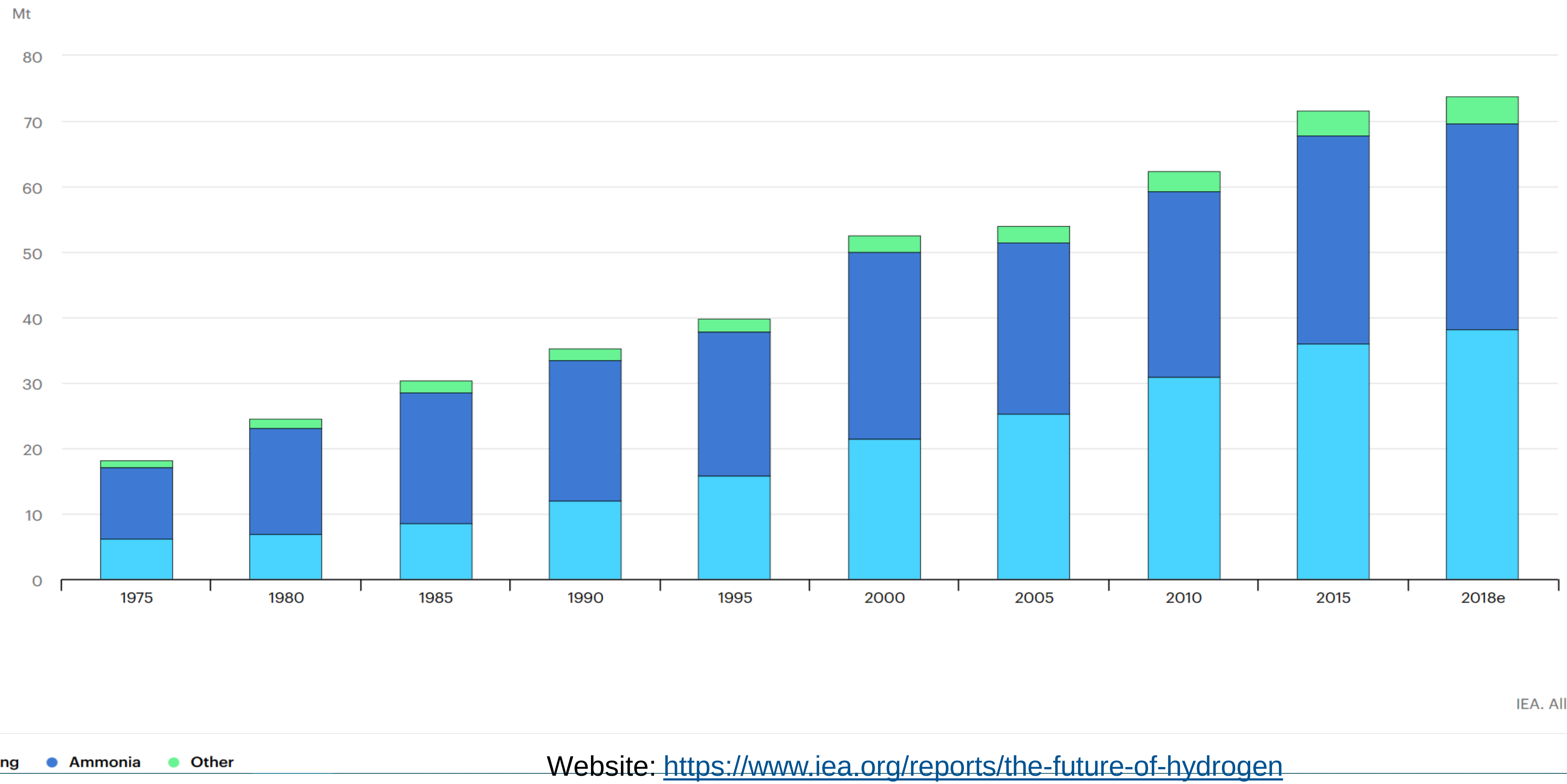


RES: Renewable Energy Sources
GFPP: Gas fired power plants
SMR: Steam Methane Reformer

Source: Belderbos (2019).

Worldwide pure H2 demand 1975-2018

Global demand for pure hydrogen, 1975-2018



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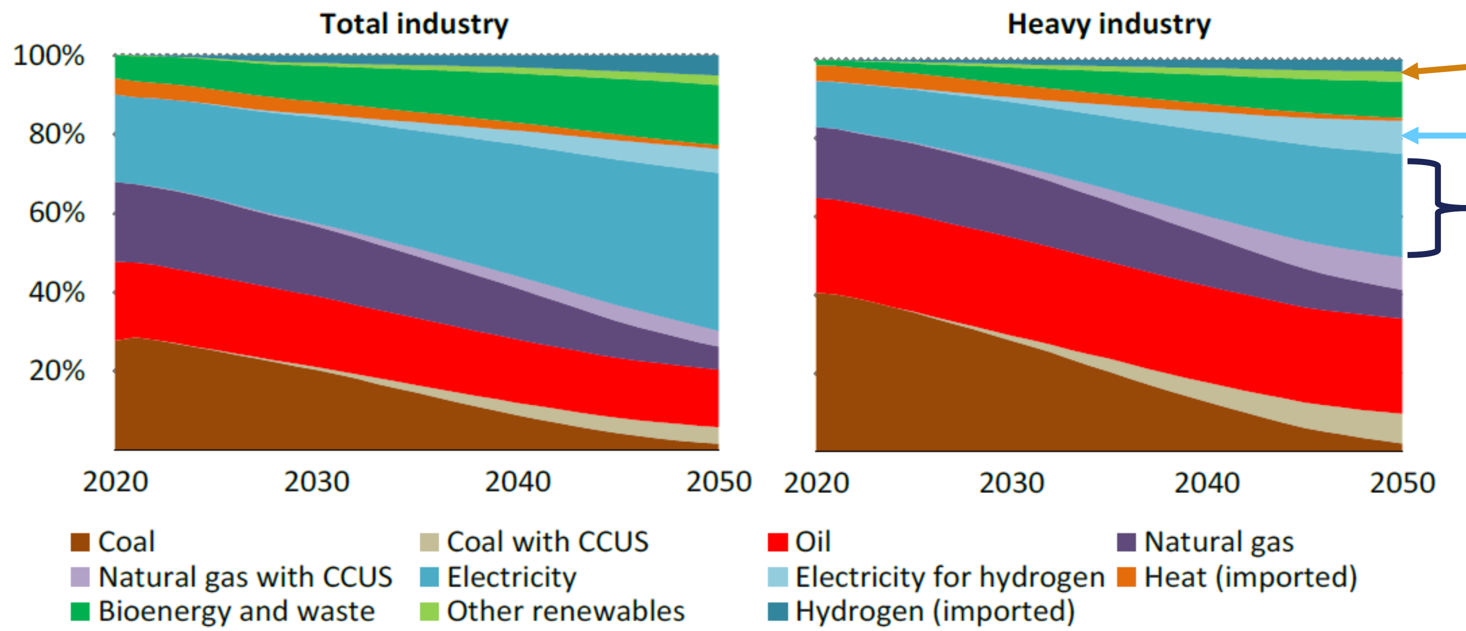
Website: https://www.iea.org/reports/the-future-of-hydrogen

H2 for industry – starting point for H2 development

Figure 3.18 ▷ Global final industrial energy demand by fuel in the NZE



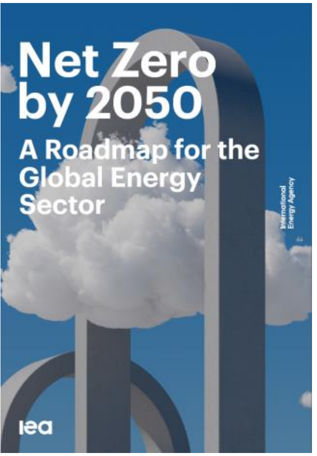
Hydrogen (imported)

Electricity for H_2

electrification

Fossil fuel use in industry is halved by 2050, replaced primarily by electricity and bioenergy

Notes: Industrial energy consumption includes chemical feedstock and energy consumed in blast furnaces and coke ovens. Hydrogen refers to imported hydrogen and excludes captive hydrogen generation. Electricity for hydrogen refers to electricity used in the production of captive hydrogen via electrolysis.



Projected industrial final energy demand by fuel through 2050 in the NZE scenario. 'Captive hydrogen' refers to hydrogen consumed on the same site where produced. NZE = Net zero emissions (by 2050)

Carbon-Free Energy for Manufacturing and Industry

ESIG

Slide borrowed from Clifford Ho, SNL

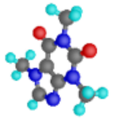
Energy StorM Workshop Intro

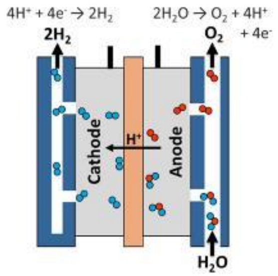
Make → Move → Store → Use

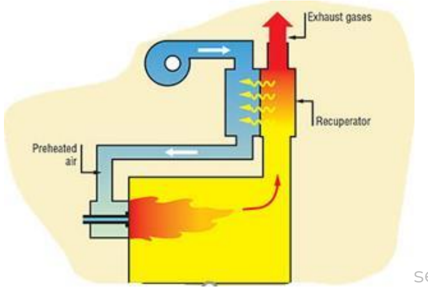
Electrical

Thermal

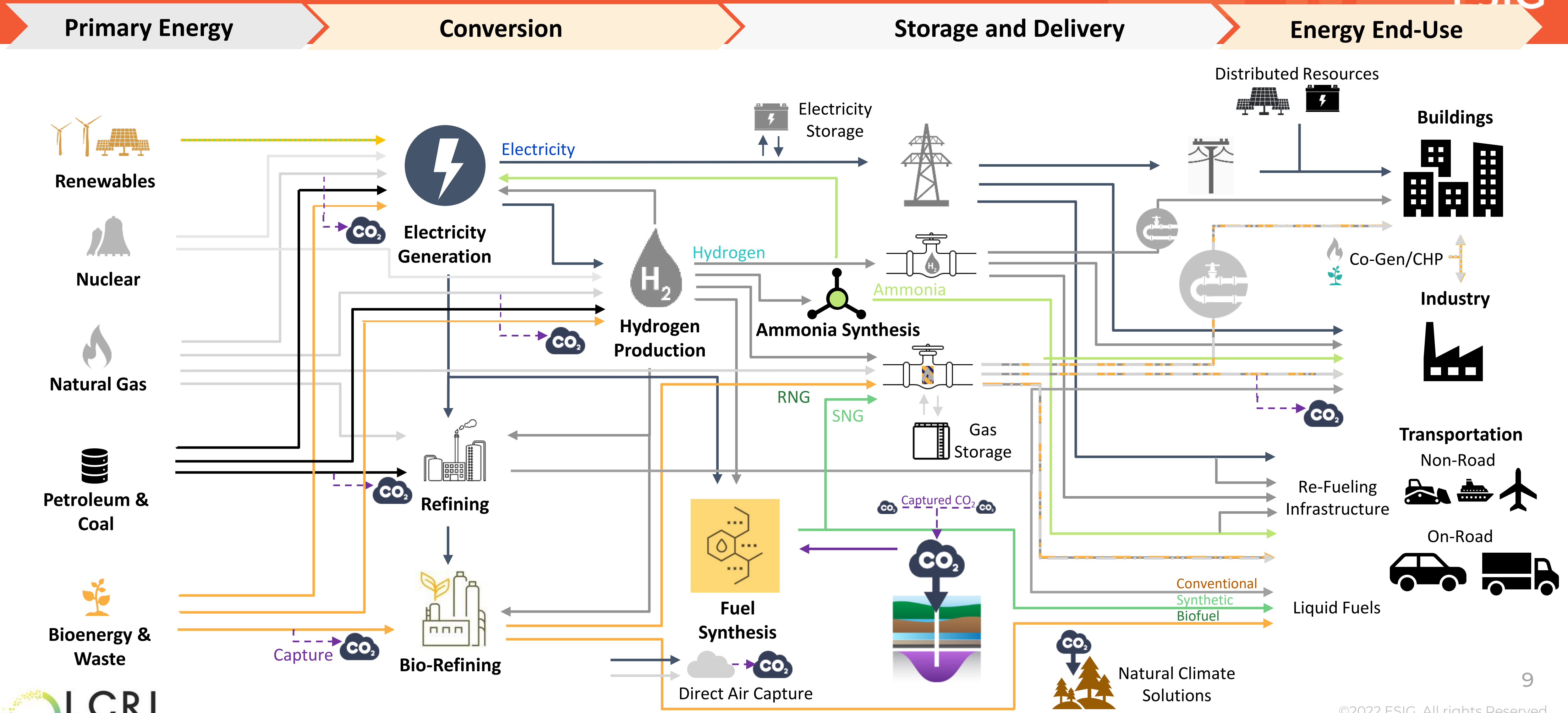
Chemical







Economy-Wide Low-Carbon Energy Pathways



Flexibility from hydrogen

- Initially expected as a source of demand side
  - Production of hydrogen through electrolyzers with clean electricity
  - Use in other industries as a feedstock to decarbonize there
  - Pockets may develop with unidirectional flexibility to make use of renewables and then be used from system side at other times

- Fuels can be produced away from where they are needed and transported
  - Requires consistent accounting of carbon costs/emissions
  - Could produce in places with high wind/solar potential (e.g. MENA, Australia, etc.)
  - Imported into places with less resources but suitable H_2 networks
    - US – currently has 1, 600 miles of hydrogen pipelines, 320,000 circuit miles of gas transmission
  - Will also impact markets – price formation, energy, capacity, etc.

ENTSO-E has formulated recommendations for policymakers on:

› **The new roles of hydrogen**
Hydrogen is a tool for reaching decarbonisation targets and not an end in itself

› **Where we are now and the next steps towards bigger hydrogen**
The business case to use hydrogen in an electricity system operation support function does not currently exist

› **Planning and operating hydrogen in 'one system of systems'**
A unified system perspective (one system view) is necessary

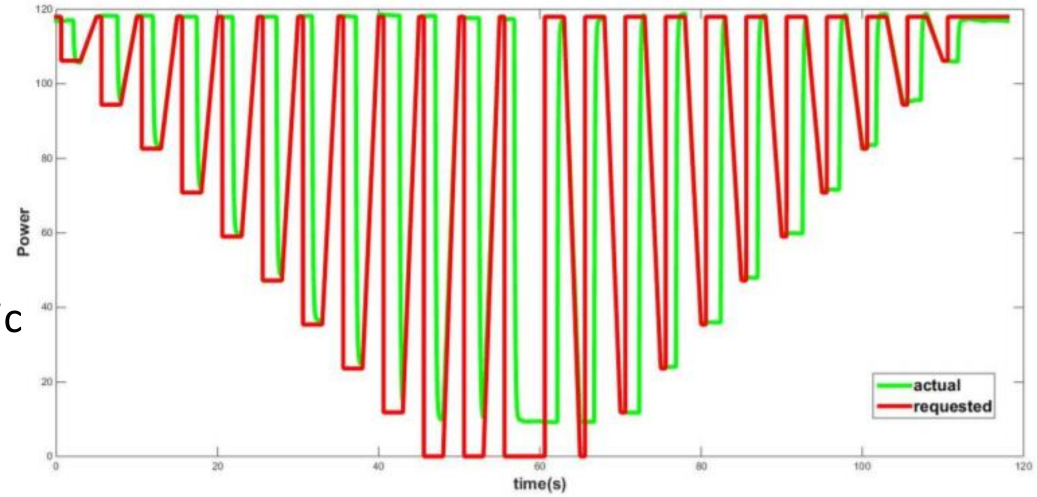
ENTSO-E, Nov 2021 (link)

Green hydrogen now cheaper than blue in Middle East, but still way more expensive in Europe

RECHARGE
Global news and intelligence for the Energy Transition

Provision of Flexibility from EIIs and Hydrogen

- As Demand Response
  - Shift energy form low cost hours to high demand
  - Could be dispatchable or price based demand
  - Will need to consider long durations and shifting over weeks/months
- By Providing Grid Services
  - Frequency regulation (continuously needed) from variable frequency drives, induction furnaces, electrolysis
  - Event based reserves (spin, contingency, etc.) from electrolysis, electric arc furnaces, mechanical pulp production, and cement milling
- Ability to provide services will vary
  - Processes used in specific industry will impact on EII ability
  - Different types of electrolyzers can provide services differently, with some having very quick response (e.g. polymer electrolyte membrane)
  - Presence of electric and hydrogen grids will drive how electrolyzers provide services, while possibility of using power plants (combustion turbines/fuel cells) is also there



INL & NREL testing of a 120kW electrolyzer

Source:
https://www.energy.gov/sites/prod/files/2017/06/f34/fcto_may_2017_h2_scale_wkshp_hovsapian.pdf

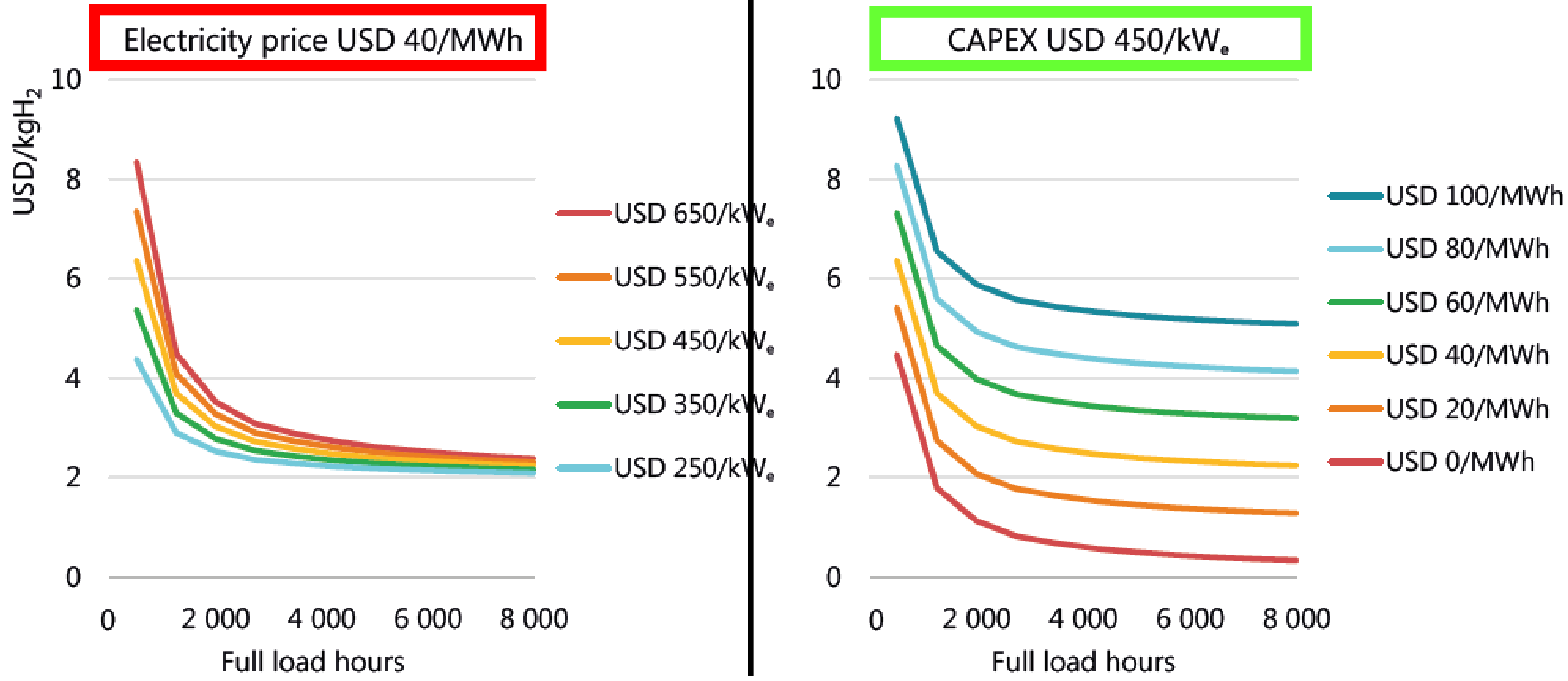
Hydrogen Production Costs – important factors

Important dependencies:

1) Investment cost
2) Full Load Hours (FLH)
3) Cost input electric energy
4) Efficiency electrolyzers & BOP/BOS
5) Discount rate (WACC)

1 \$/kg ≃ 25 $\$/MWh_{prim, HHV}$
1 \$/kg ≃ 30 $\$/MWh_{prim, LHV}$

Figure 12. Future levelised cost of hydrogen production by operating hour for different electrolyser investment costs (left) and electricity costs (right)



Notes: MWh = megawatt hour. Based on an electrolyser efficiency of 69% (LHV) and a discount rate of 8%.

Source: IEA 2019. All rights reserved.

With increasing full load hours, the impact of CAPEX on hydrogen costs declines and the electricity becomes the main cost component for water electrolysis.

Hydrogen Characteristics and Grid Services

Range of different technologies available with different potential characteristics for power system

Electrolyzers may be quick responding and could provide grid services

Will also need to have storage and/or connection to a hydrogen grid

Some technologies may be reversible

Gas turbines may be fitted to be powered by hydrogen

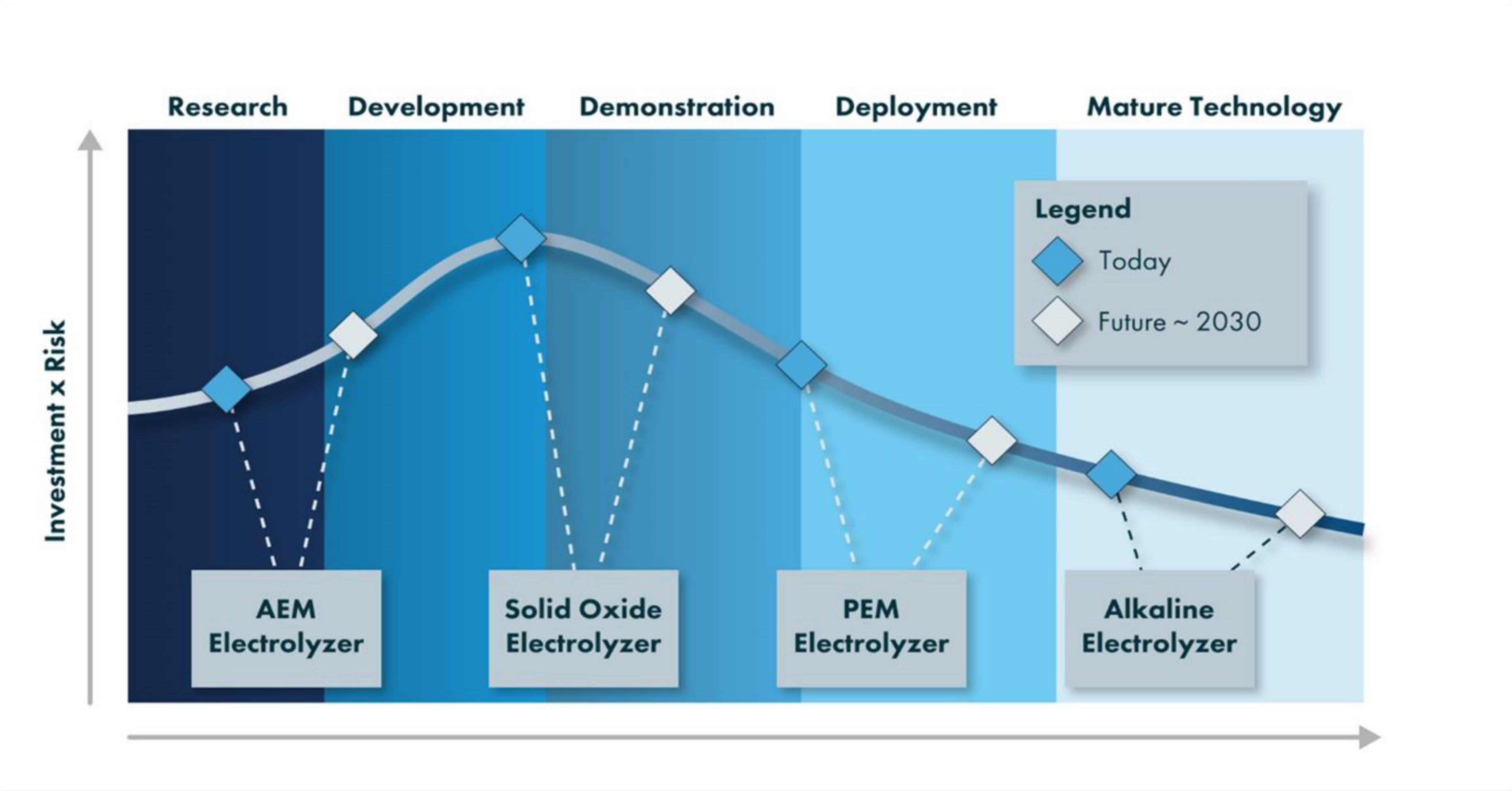
Technical and Economic Parameters for Different Types of Electrolyzers under Development

	Alkaline Electrolyzer			PEM Electrolyzer			SOEC Electrolyzer		
	Today	2030	Long Term	Today	2030	Long Term	Today	2030	Long Term
Electrical efficiency (%, LHV)	63–70	65–71	70–80	56–60	63–68	67–74	74–81	77–84	77–90
Operating pressure (bar)	1–30			30–80			1		
Operating temperature (°C)	60–80			50–80			650–1,000		
Stack lifetime (operating hours)	60,000–90,000	90,000–100,000	100,000–150,000	30,000–90,000	60,000–90,000	100,00–150,000	10,000–30,000	40,000–60,000	75,000–100,000
Load range (%, relative to nominal load)	10–110			0–160			20–100		
Plant footprint (m^2/kW_e)	0.095			0.048					
CAPEX (USD/kW_e)	500–1,400	400–850	200–700	1,100–1,800	650–1,500	200–900	2,800–5,600	800–2,800	500–1,000

Note: LHV = lower heating value; m^2/kW_e = square meter per kilowatt electrical. No projections made for future operating pressure and temperature or load range characteristics. For SOEC, electrical efficiency does not include the energy for steam generation. CAPEX represents system costs, including power electronics, gas conditioning, and balance of plant. CAPEX ranges reflect different system sizes and uncertainties in future estimates.

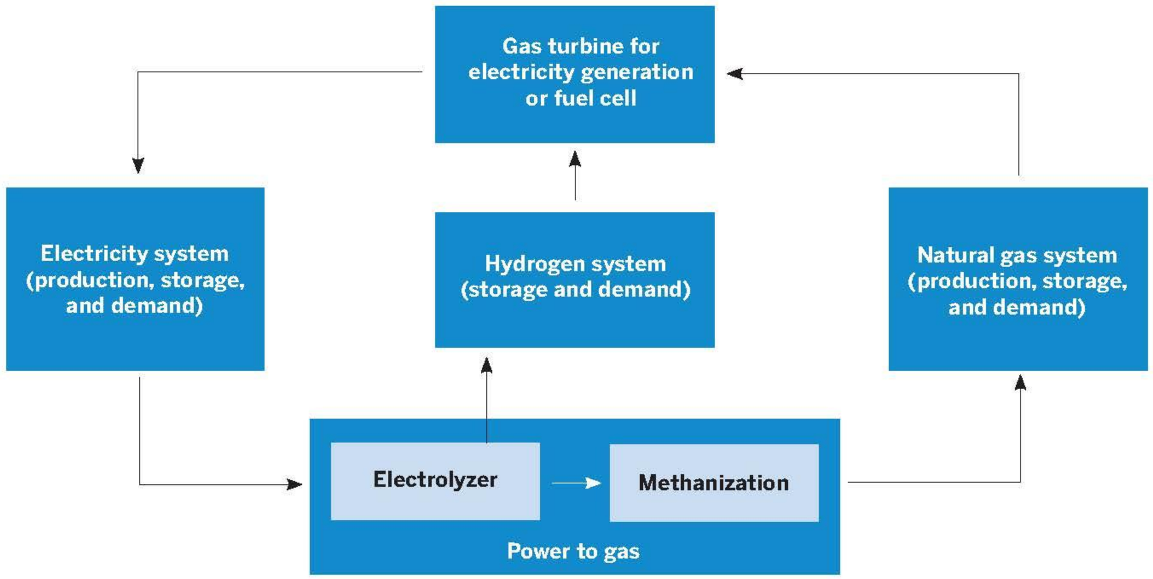
Source: International Energy Agency (2019), The Future of Hydrogen: Seizing Today's Opportunities. All rights reserved.

Status of Major Technology Types



Power to Gas System

The Main Elements of a Power-to-Gas System



Notes: The colors have no relationship to the conventional colors typically assigned to hydrogen. This figure is simplified to provide general context and as such misses some more detailed aspects of the system, including CO_2 streams to and from the gas system and steam methane reformers, and other technologies that are likely to accompany these systems such as carbon capture, utilization, and storage and direct air capture. While important in the overall context, they are less relevant to the interactions between green hydrogen, the electric power system, and the gas system that is the focus of this report. See Belderbos (2019) for a more detailed example of the full interactions.

Source: Energy Systems Integration Group.

Power to gas is one potential means to produce hydrogen and use it for other applications

- Could go to industrial processes with some storage needed also
- Could be methanized and injected into the natural gas network

Some portion of this may be used to produce electricity through gas turbines or fuel cells

- Typically very small amount of total energy envisioned (e.g., 5% of global energy in IEA study)
- But this could be an important energy resource for periods of low wind/solar

Costs of two-way coupling could be very challenging – lower reductions for fuel cells

Hydrogen can also be more valuable in other systems that are harder to decarbonize than electricity

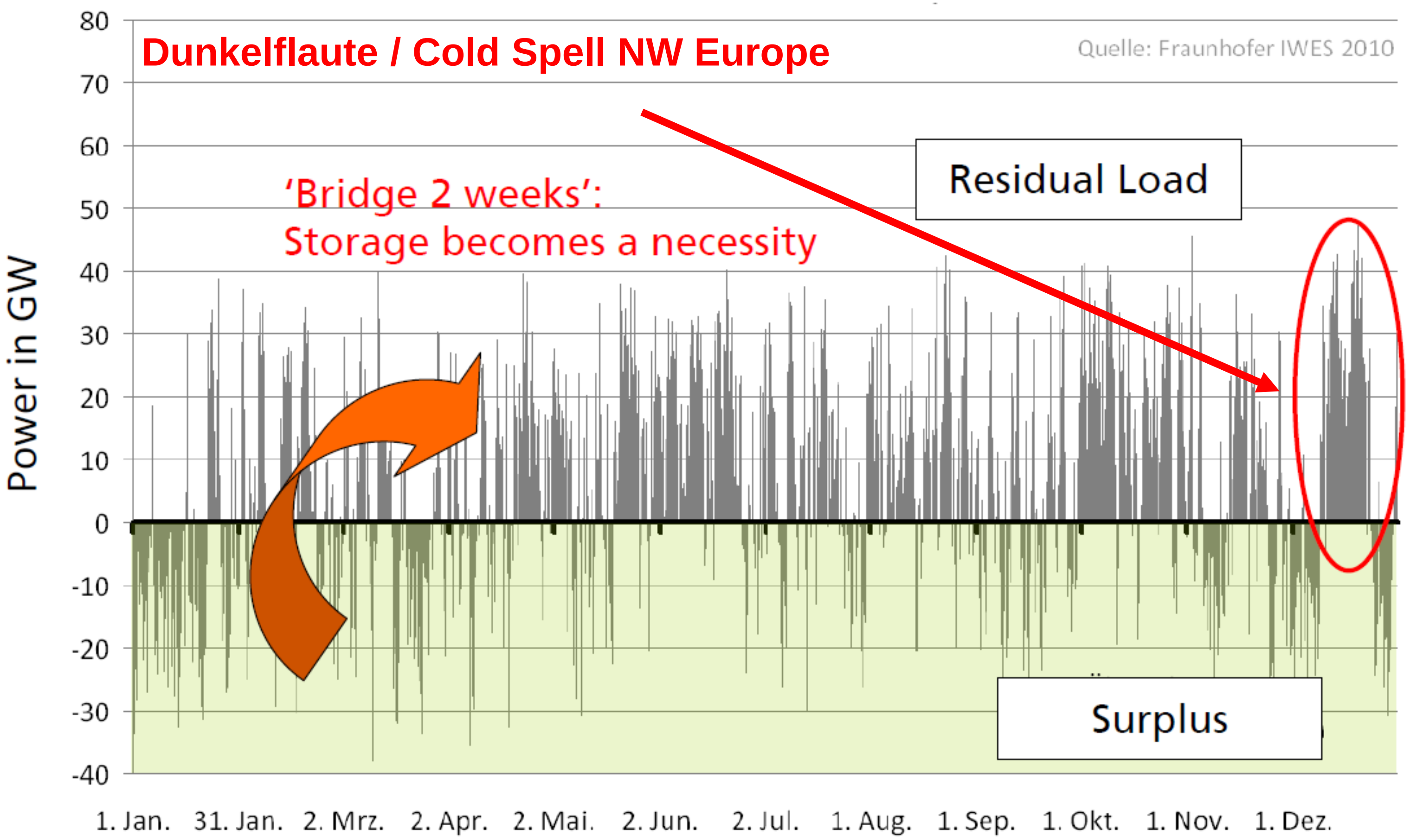
Long-Term Storage - Power to 'Gas' (H2 & CH4)

ESIG

From William d'Haeseleer, ESIG Tutorial on Hydrogen, March 2022

Energy scenario of the German govt. for 2050 (80% RES)

80% renewables in annual electrical <u>energy</u> share



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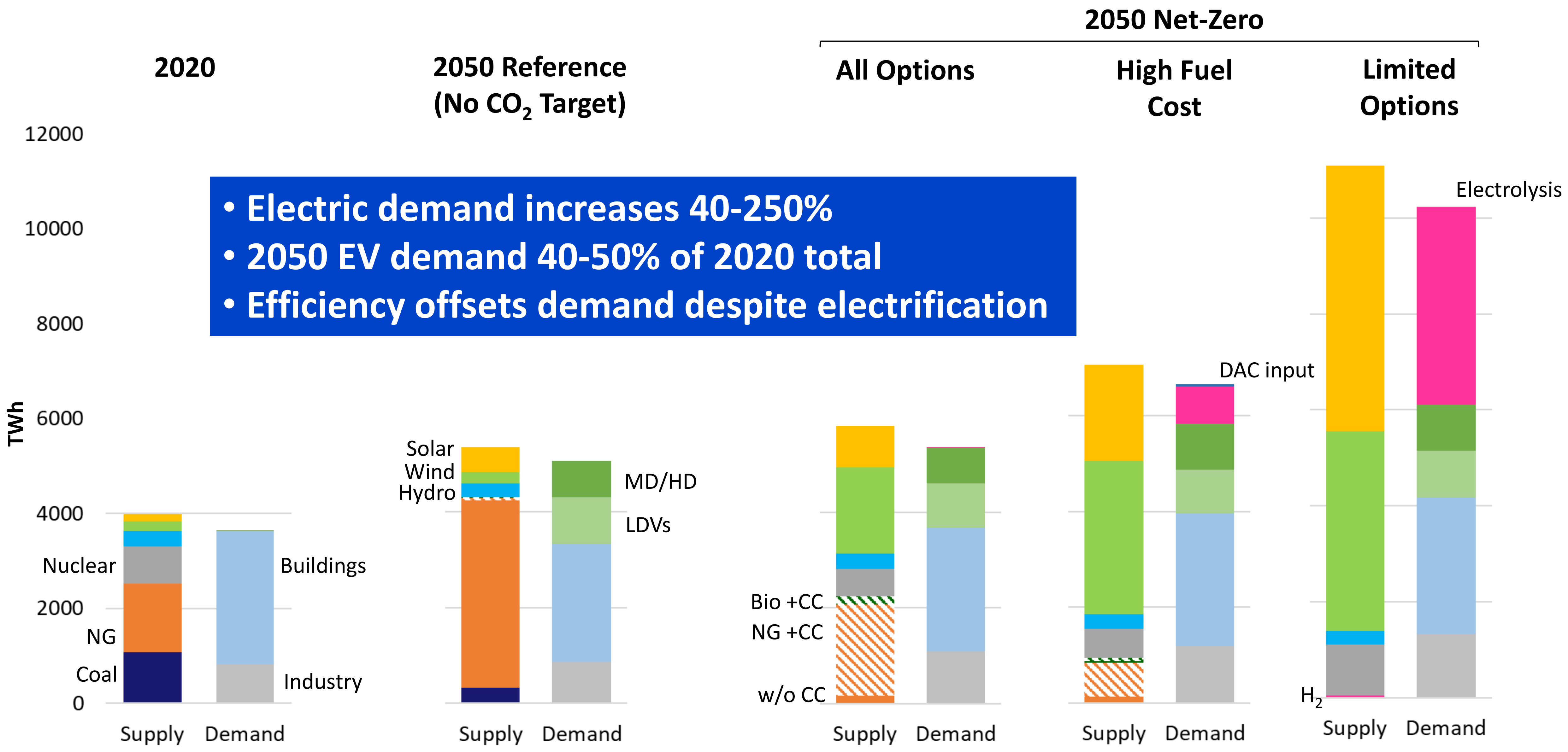
EPRI Analysis of U.S. Economy Decarbonization Targets

Recent EPRI analyses of technology deployments to meet U.S. 2030 (50%) and 2050 (Net-Zero) emission reduction targets show drastic changes required for energy systems and end uses.

2050 Net-Zero: Electricity Supply and Demand

- Electric demand increases 40-250%
- 2050 EV demand 40-50% of 2020 total
- Efficiency offsets demand despite electrification



Recent results (from EPRI)

Recent US-REGEN scenarios

At ~70% variable renewables and fossil generation becomes unavailable hydrogen-fired power generation and energy-storage discharge provide up to 9% of the total electricity supply for end uses in the United States.

At 100% renewables, hydrogen-fired generation and energy-storage discharge constitutes up to 20% of total electricity supply for end uses

LCRI LOW-CARBON RESOURCES INITIATIVE EPRI GTI ENERGY

TECHNOLOGY BRIEF

MODELING THE FLEXIBLE OPERATION OF ELECTROLYZERS FOR HYDROGEN PRODUCTION IN A LOW-CARBON ENERGY SYSTEM

Important Considerations

THE RESEARCH FRAMING

In a future low carbon energy system, flexible assets such as electrolyzers could be deployed to increase the uptake of variable renewable energy (VRE) on the grid and to utilize available renewable energy sources more efficiently. An understanding of the technical and economic factors with VRE use and hydrogen production in electrolyzers need to align across electricity supply, hydrogen production, and hydrogen offtake/use.

THE VALUE

Hydrogen's role in the changing energy landscape is yet to be determined and could vary significantly across investors, utilities, vendors, and end users. Modeling electrolyzers, especially at a systems scale, is crucial to understanding how they can be optimized for overall hydrogen production.

LCRI'S FOCUS

Research is needed to investigate the effect of variations in temporal and spatial resolutions of variables (O&M costs and electrical current availabilty) on the total hydrogen production in electrolyzers. This would help stakeholders make best use of their available assets while minimizing the cost of hydrogen production from electrolyzers.

Published March 10 and is free to the public

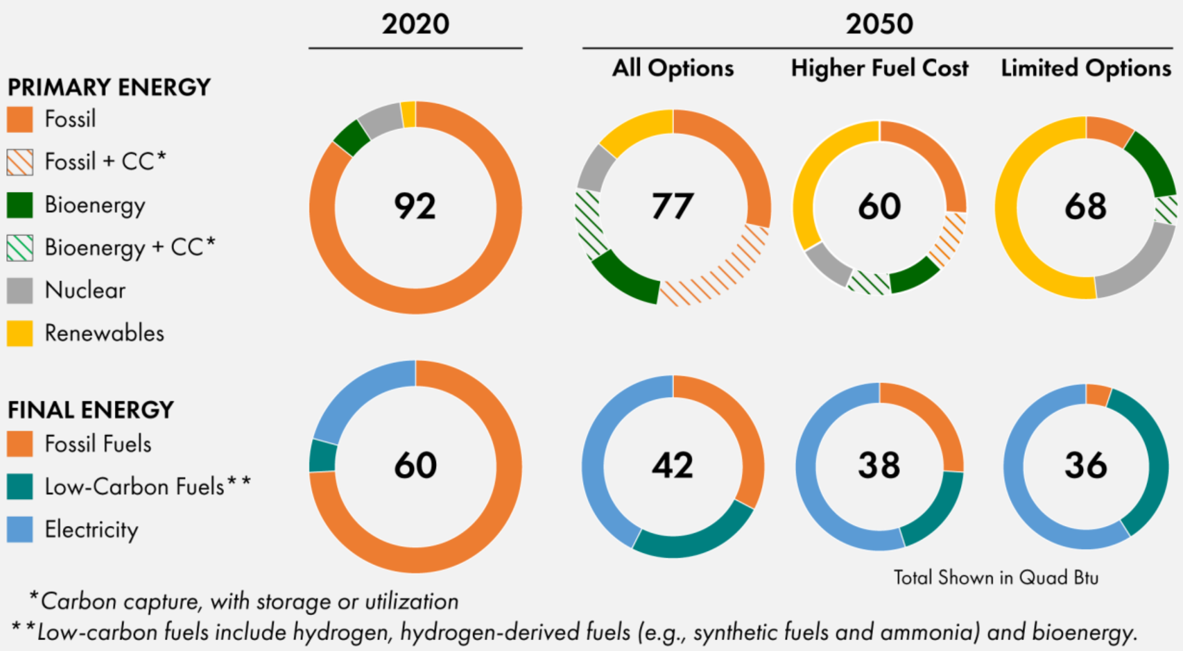
See [Modeling the Flexible Operation of Electrolyzers for Hydrogen Production in a Low-Carbon Energy System: Important Considerations]

Considerations when Modeling Electrolyzers

- Technology specific parameters such as efficiency, hydrogen production, operating temperature, min/max current density, etc.
- Desired operational profile
- Availability of low-cost electricity and water
- Proximity to offtake

Forthcoming ESIG activity on the topic

- Describe the modeling needed to evaluate the role hydrogen and other sources of industrial electrification in providing flexibility
- The end goal is not to make specific recommendations on technology choices or what the end state will look like, but rather understand the current capabilities and gaps
- The general evaluation framework for the current and evolving state of the industry can be updated as newer information and experience becomes available.
- Studies from IEA, NREL, EPRI, Princeton, etc. all lay out different pathways
- Focus on futures with very high levels of renewable generation and electrification to meet decarbonization goals



From lcri-netzero.epri.com – Net-Zero 2050

THANK YOU

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