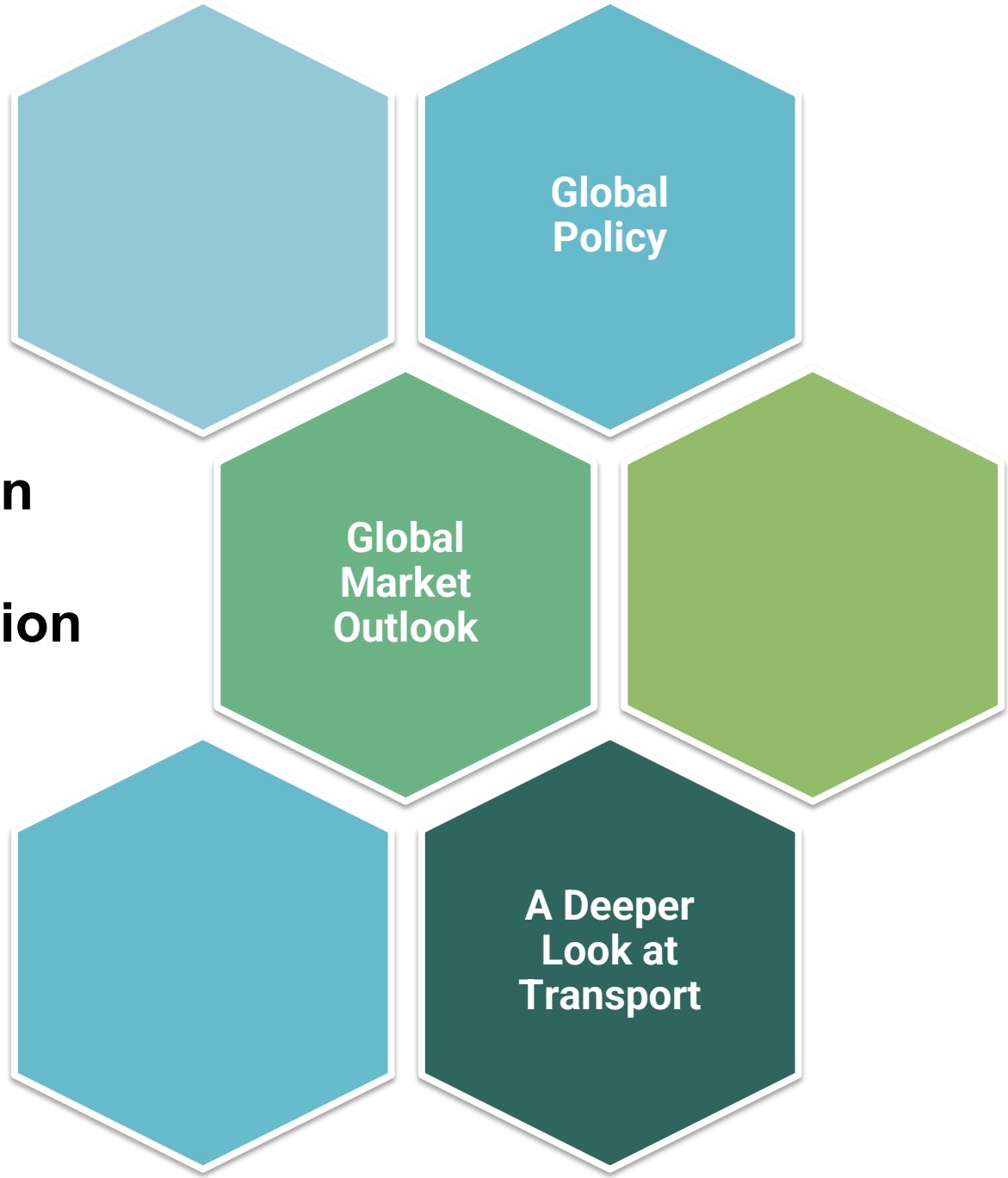
Outlook for Hydrogen

July 2022

transportenergy strategies

Prepared for Transport Energy Outlook Members

Topics Covered in This Presentation



Policy

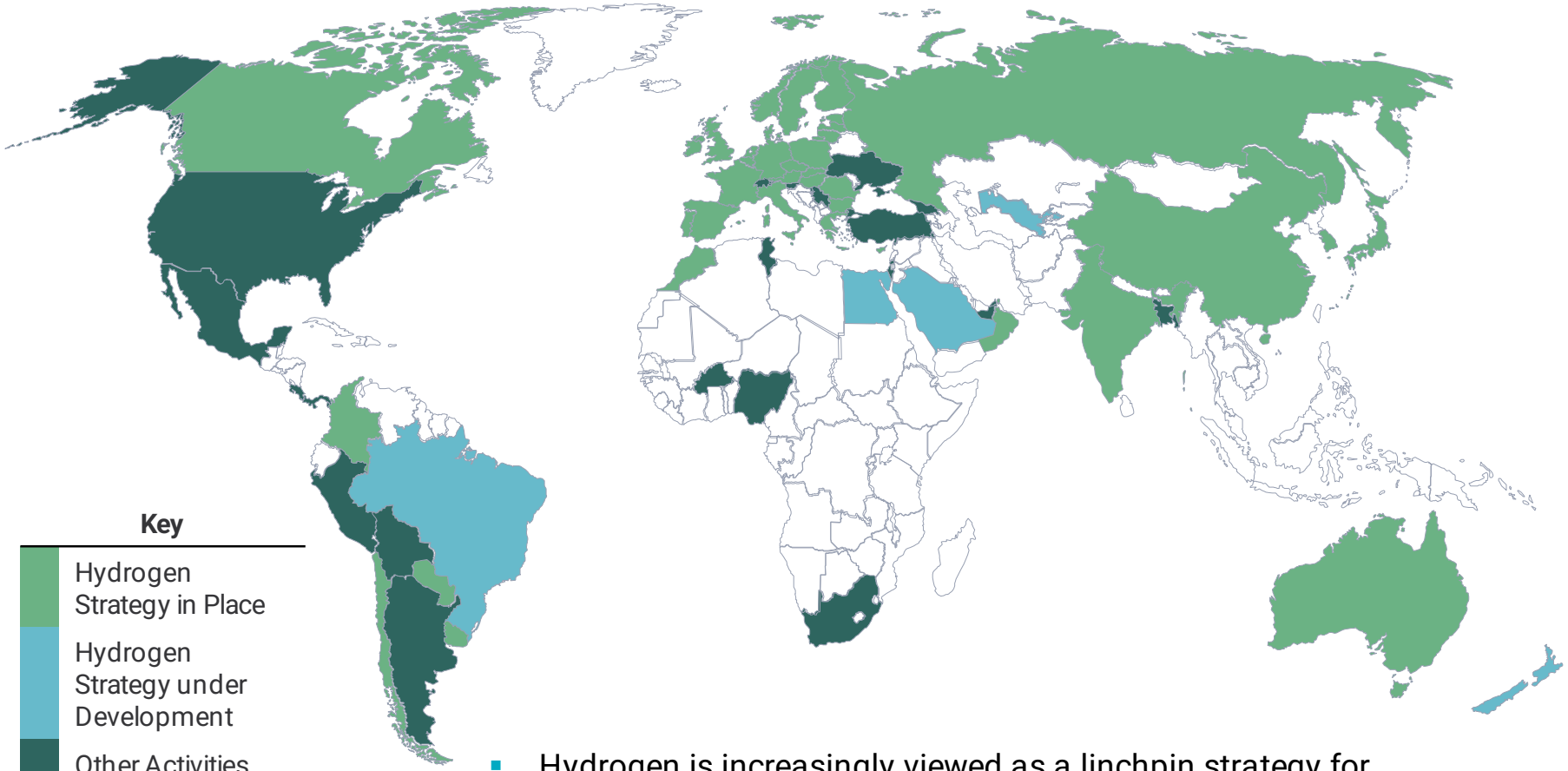
Key Points from the Analysis

- By the end of 2021 about 40 countries (including the EU-27) had developed national hydrogen strategies, and four other countries plan to finalize and release their strategies this year.
- Much of the production under these targets is expected to come from green hydrogen, through electrolysis, and blue hydrogen with the use of carbon capture use and storage (CCUS).
- Only nine countries are pursuing solely green hydrogen routes at the moment. Most are pursuing a mix of blue and green hydrogen.
- Sectoral priorities for some countries focus on hydrogen for chemical feedstocks, refining and, overwhelmingly, for the medium and heavy-duty (MHDV) trucking fleet.
- The EU has been the most aggressive at setting policies to scale up hydrogen, particularly through the Fit for 55 legislative package.
- Scaling up hydrogen may depend on tough carbon taxation policies which are not widespread in many countries right now.

At Least 40 Countries Have Released Hydrogen Strategies

Strategies are not binding, but set a direction for the future

Global Governments Supporting Hydrogen



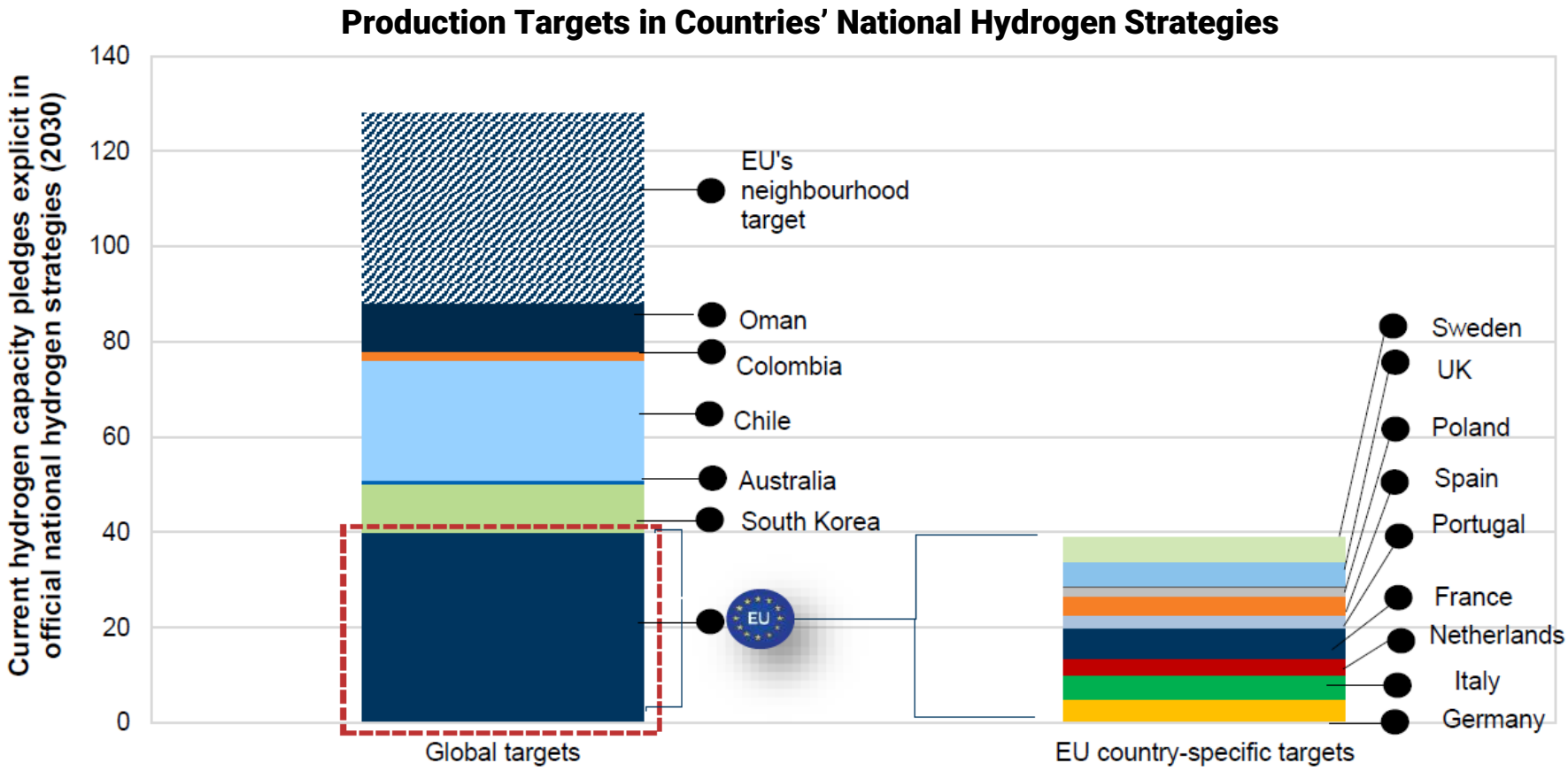
Key

- Hydrogen Strategy in Place
- Hydrogen Strategy under Development
- Other Activities Underway to Support Hydrogen Scale Up

- Hydrogen is increasingly viewed as a linchpin strategy for decarbonization, including in difficult transport sectors such as heavy-duty trucking, marine and even aviation.
- Some countries do set goals or targets (not mandates) for hydrogen in light-(LDVs) and heavy-duty vehicles (HDVs).

Source: Compiled by Transport Energy Strategies citing numerous sources , April 2022

Hydrogen Production to Triple by 2030 under Strategies



Source: Goldman Sachs, February 2022

- Targets represent approximately 130 gigawatts (GW) of capacity that countries are targeting to have in place by 2030.
- Much of the production under these targets is expected to come from green hydrogen, through electrolysis, and blue hydrogen with the use of carbon capture use and storage (CCUS).

Breaking Down H2 Strategies in Select Countries

Category	Asia			Europe					LAC	North America
	Australia	Japan	South Korea	EU	France	Germany	Norway	Spain	Chile	Canada
Contains timeline for market development with targets	◎	◎	◎	◎	“	◎		◎	◎	◎
Contains cost targets	“	◎	◎						“	“
Strategy includes measures to support H2 development:										
Direct investments	◎	◎	◎	◎	◎	◎	◎	“	“	“
Other financial mechanisms	◎	“	◎	◎	◎	◎	◎	“	“	“
Policy measures	◎	“	◎	◎	“	◎	“	◎	◎	“
Standardization	◎	◎	◎	“	“	◎	◎	◎	“	◎
R&D	◎	◎	◎	“	◎	◎	◎	◎	“	◎
International strategy	◎	◎	“	“	“	◎	“	◎	“	“
Import/Export/Self-Reliance	Export & Self-Reliance	Import	Import/ Export		Export	Import/ Export	Self-Reliance	Export & Self-Reliance	Export & Self-Reliance	Export & Self-Reliance

Source: Compiled and adapted by Transport Energy Strategies citing data from the World Energy Council, April 2022

Key: ◎ Detailed discussion “ Mentioned in strategy

Where Is the H2 Going?

Category	Asia			Europe					LAC	North America
	Australia	Japan	South Korea	EU	France	Germany	Norway	Spain	Chile	Canada
Sectoral Priorities										
Heating	↑	↑	↓	↓	↓	↓	↓	↓	↑	↑
Industry:										
Iron and steel	Long term priority	↓	↓	Long term priority	↑	↑	↓	↓	No mention	↑
Chemical feedstock	↑	↓	No mention	↑	↑	↑	↑	↑	↑	↑
Refining	No mention	↓	No mention	↑	↑	↑	↓	↑	↑	↑
Other	No mention	No mention	No mention	No mention	↑	↓	No mention	↓	No mention	↑
Power:										
Power generation	↓	↑	↑	↓	No mention	No mention	No mention	No mention	No mention	↓
Backup	↓	↓	↓	↓	No mention	No mention	No mention	↓	No mention	↓
Transport:										
Passenger vehicles	↓	↑	↑	↓	↓	↓	↓	↓	Long term priority	↑
Medium & heavy duty	↑	Long term priority	↑	↑	↑	↑	↑	↑	↑	↑
Buses	↓	↓	↓	↑	↑	↑	No mention	↓	No mention	Long term priority
Rail	Long term priority	↓	↓	Long term priority	↓	Long term priority	↑	↓	Long term priority	Long term priority
Maritime	Long term priority	↓	↓	Long term priority	↓	Long term priority	↑	↓	Long term priority	Long term priority
Aviation	↓	↓	No mention	Long term priority	↑	Long term priority	↓	↓	Long term priority	Long term priority

Source: Compiled and adapted by Transport Energy Strategies citing data from the World Energy Council, April 2022

Key: ↑ Immediate priority ↓ Lower priority

- Chemical feedstocks
- Refining

In Transport:

- Medium & heavy-duty hands down
- Buses

Low priority:

- Aviation
- Maritime
- Passenger cars (most countries)
- Power generation

Comparing Transport Targets in Select Hydrogen Strategies

Country	Transport Target								
	FCEVs	Year	Buses	Year	MHDV	Year	HRSs	Year	Other Targets
Colombia	1,500-2,000	N/A	-	-	1,000-1,500	N/A	50-100	N/A	-
Czech Republic	45,000	2030	900	2030	4,000	2030	-	-	-
France	5,000 20,000-50,000	2023 2028	-	-	200 800-2,000	2023 2028	100 400-1,000	2023 2028	-
Germany	-	-	-	-	-	-	400	2025	-
Hungary	4,800	2030					20	2030	
Japan	200,000 800,000	2025 2030	1,200	2030	-	-	320 900	2025 2030	10,000 forklifts (2030)
Korea	81,000 100,000 2.9 million	2022 2025 2040	40,000	2040	30,000	2040	310 1,200	2022 2040	80,000 taxis (2040)
Netherlands	15,000 300,000	2025 2030	-	-	3,000	2025	50	2025	-
Poland	-	-	100-250 2,000	2025 2030	-	-	32	2030	-
Portugal	-	-	-	-	-	-	50-100	2030	▪ 1-5% total final energy consumption in road transport by 2030 ▪ 3-5% total final energy consumption in maritime transport by 2030
Spain	5,000-7,500	2030	150-200	2030	-	-	100-150	2030	-

Source: Compiled and adapted by Transport Energy Strategies citing data from the countries' hydrogen strategies, April 2022

Recent Policymaking in the EU – It's A Lot!

- **Fit for 55 Hydrogen measures:**
  - A 50% renewable hydrogen target by 2030 for all hydrogen used in industry, which could lead to 90 TWh/year of hydrogen demand by 2030.
  - A 1.1% per annum increase of renewable energy sources share in the heating & cooling sector of which green hydrogen could participate.
  - A 2.6% share of final energy demand in transport target for renewable fuels of non-biological origin (RFNBOs) and a minimum of 0.7% of synthetic kerosene in final energy demand in aviation, which could lead to 87 TWh/year of hydrogen demand by 2030 (of which 7 TWh/year in aviation).
  - A 6% GHG emissions intensity reduction target for onboard fuels of by 2030 for the maritime sector, non-fuel specific, which could correspond with a hydrogen demand of 29 TWh/year.
- **To reach these targets the EU Commission is revising existing legislation and proposing new policies:**
  - Revising the EU Emission Trading System, particularly to allow for and require aviation and maritime fuels (of which hydrogen could be one fuel type) to participate.
  - Amending the Energy Taxation Directive so that carbon-intensive fuels are taxed more, while preferential tax rates for renewable and low-carbon hydrogen are expected to incentivize their use, especially in maritime and aviation.
  - Revising the RED with a higher renewable energy share (RES) target of 40% by 2030, including a 50% renewable hydrogen consumption in industry by 2030 target.
  - The Commission is developing new policies under ReFuelEU Aviation, FuelEU Maritime and a carbon border adjustment mechanism that will impact hydrogen.
  - The Commission released a Decarbonized Gas package of legislation in December 2021, to, among other things introduce a European Network of Network Operators for Hydrogen to ensure sound management of the EU hydrogen network and facilitate the trade and supply of hydrogen across EU borders.

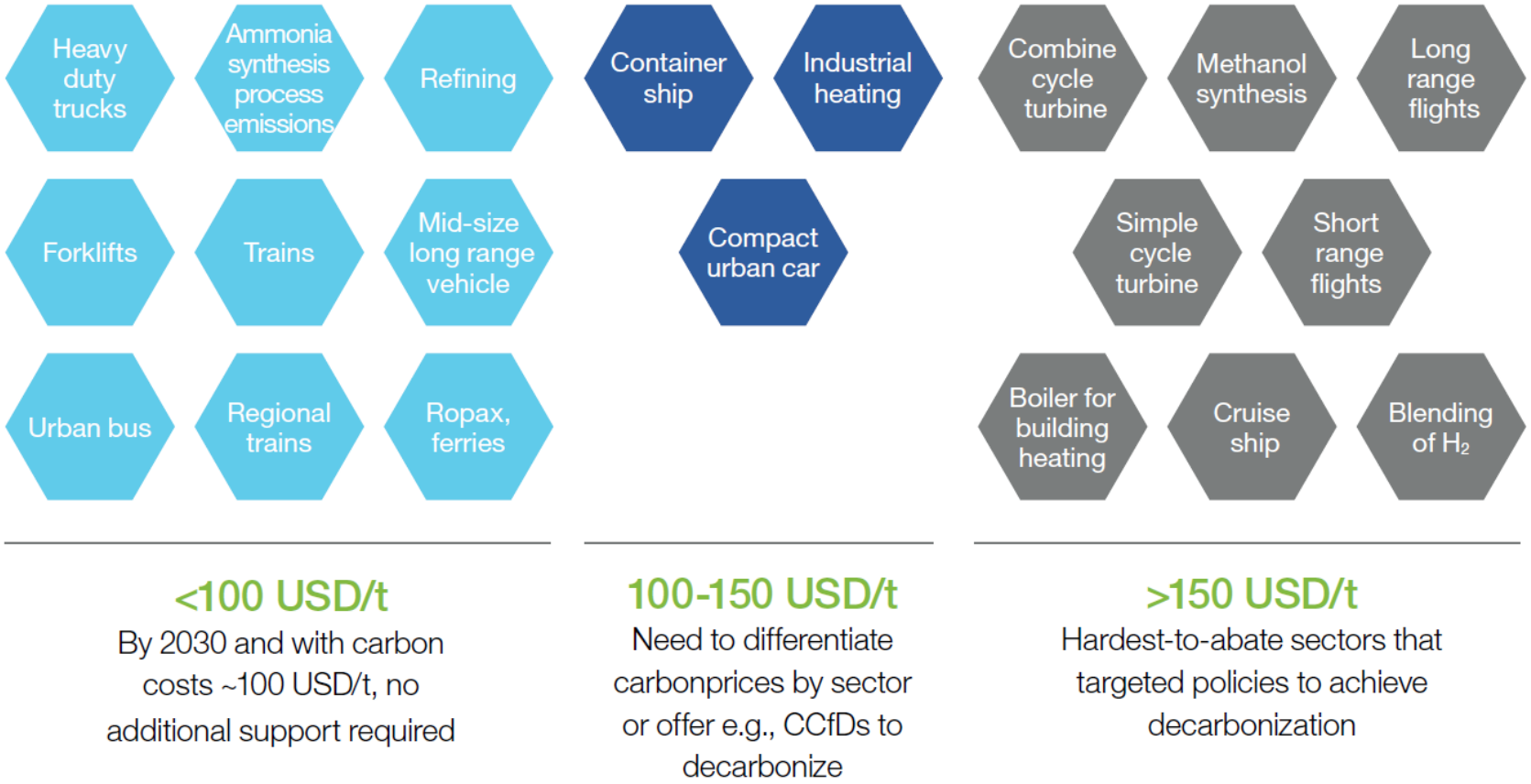
U.S. Policymaking by Comparison Is Not Far Reaching

Covers	Brief Summary	Lead Agency	Funding Level
Grants for alternative fueling infrastructure	Grant program for publicly accessible electric vehicle charging infrastructure, hydrogen fueling infrastructure, propane fueling infrastructure (for MD and HD vehicles only), and natural gas fueling infrastructure. Priority to rural areas, low- and moderate-income neighborhoods, and communities with low rate of private parking. Grants of up to $15 million will be made available.	DOT	$2.5 billion
Carbon Reduction Program	Carbon reduction program to reduce transportation emissions. Eligible projects include efforts to reduce the environmental and community impacts of freight movement, as well as projects to support deployment of alternative fuel vehicles and reduce transportation emissions at port facilities.	DOT	N/A
Clean Hydrogen Program	Creates a new program to advance research and development to demonstrate and commercialize the use of clean hydrogen in the transportation, utility, industrial, commercial, and residential sectors and demonstrate a standard of clean hydrogen production in the transportation, utility, industrial, commercial, and residential sectors by 2040. Activities to include setting technology cost goals, production of clean energy from diverse energy sources that include renewable energy resources, including biomass, and the use of clean hydrogen in various sectors, including transport.	DOE	$8 billion
Additional clean hydrogen programs	Would, among other things, create regional hydrogen hubs, a national clean hydrogen roadmap, clean hydrogen manufacturing initiative and a clean hydrogen electrolysis program.	DOE	$1 billion
Clean School Bus Program	Funding for zero and low emissions school buses.	EPA	$2.5 billion

Source: Transport Energy Strategies citing provisions of the IIJA, November 2021

What's Missing: Carbon Pricing

Only about 25% of GHG emissions are currently covered by current carbon pricing schemes



1. Assumption of average production cost for low carbon and renewable hydrogen of 1.9 USD/kg in 2030

Source: McKinsey & Company analysis

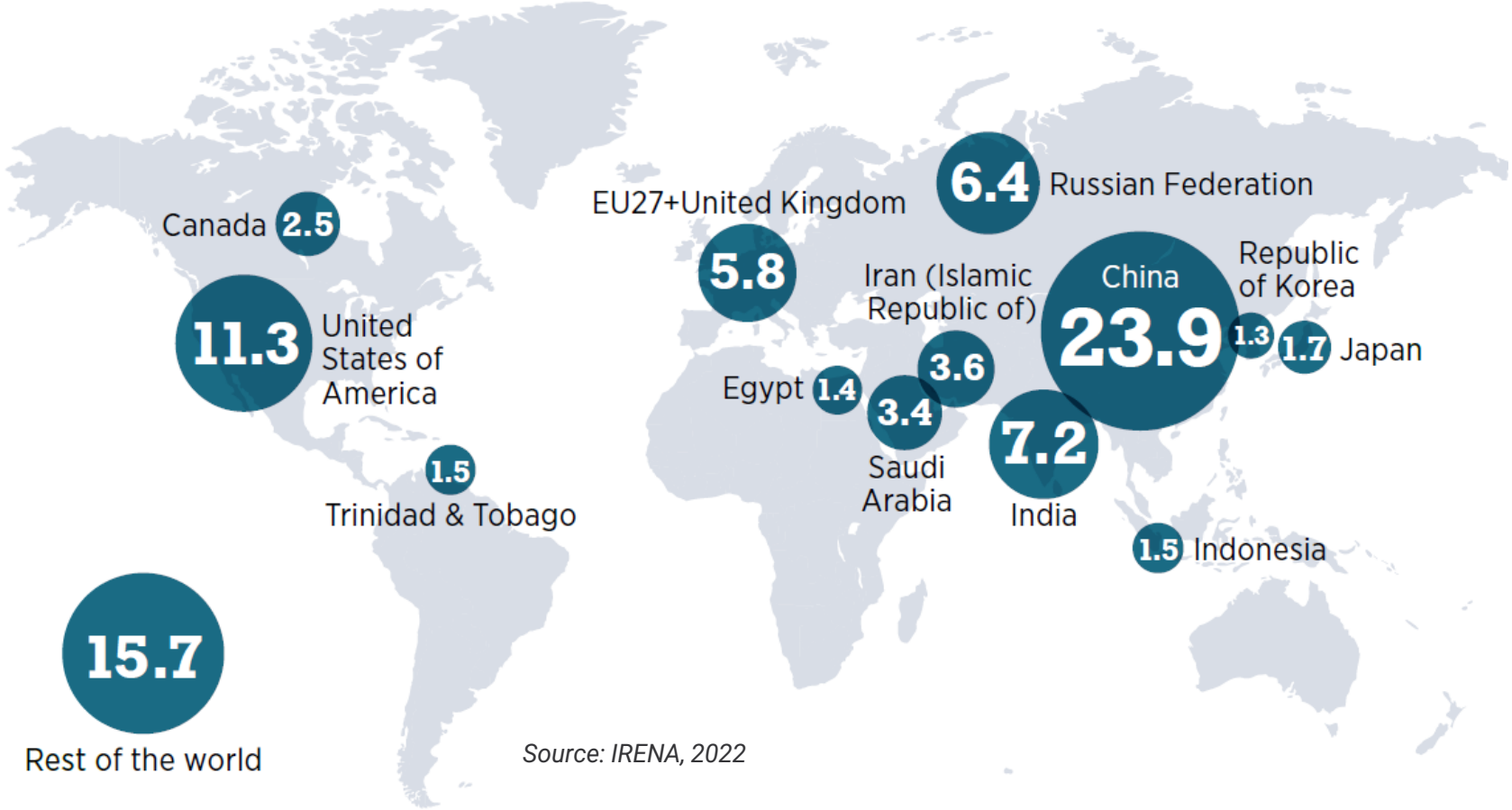
Only the UK, Sweden and Lichtenstein have carbon pricing that is at or over the USD 100/ton range

Market

Key Points from the Analysis

- Demand scenarios from the Hydrogen Council, IEA and Goldman Sachs point to a potential clean hydrogen (both blue and green) of around 500-600 MT by 2050.
- Most of this is expected to come from green hydrogen, necessitating a massive expansion of electrolyzer and renewables capacity.
- All three organizations expect that mobility will be the largest-consuming sector. This includes road transport (especially heavy-duty trucking), marine and aviation.
- Overall, IEA projects hydrogen and hydrogen-based fuels meet 10% of global final energy demand in 2050, while the Hydrogen Council projects 22%.
- Electrolyzer capacity projections in the three analyses range from 1-4 terawatts (TW) required by 2050 and 4.5-6.5 TW in renewables expansion.
- Underpinning these analyses is the assumption that there will be stronger, tougher prices on carbon that are over USD 100/ton. As noted in last month's report, such a price only exists in three countries right now.

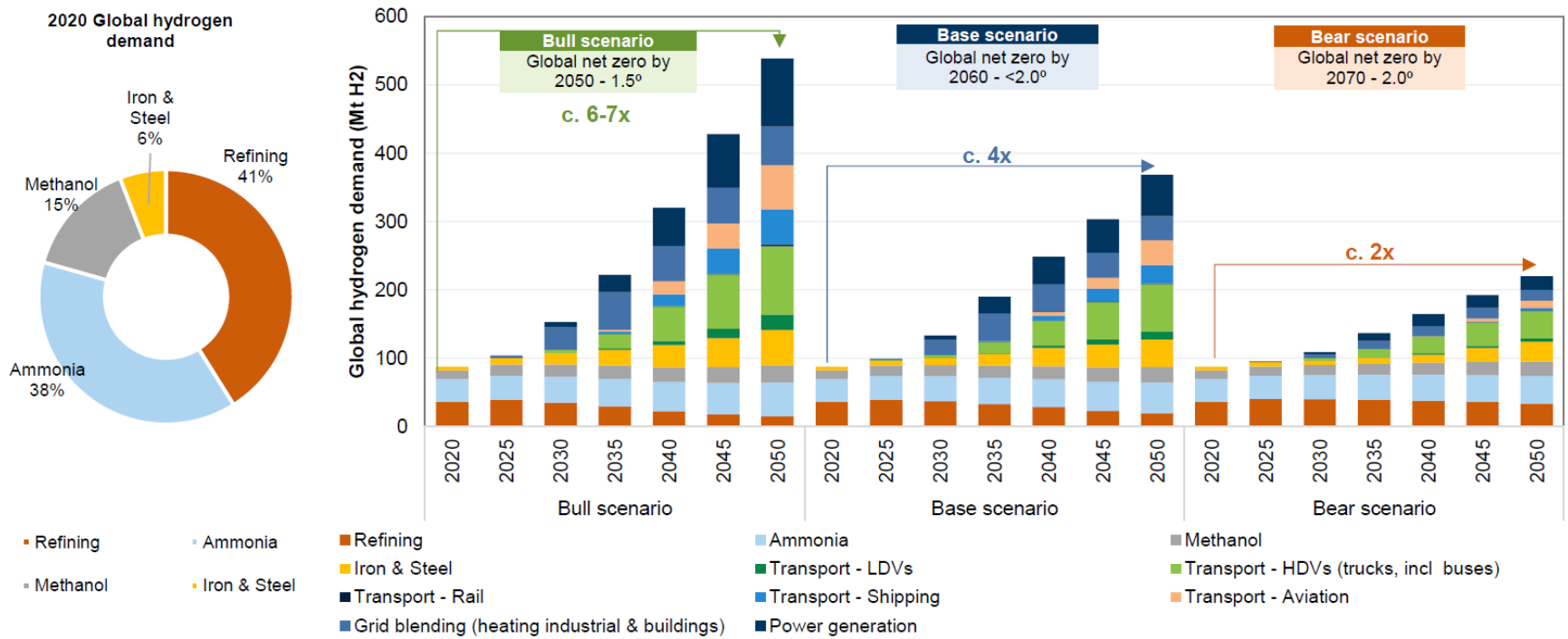
Hydrogen Consumption, 2020 (Million Tons/Year)



- Today, hydrogen used mainly as a feedstock for petrochemicals, refining, fertilizer and methanol industries.
- Around 120 million tons of hydrogen is produced globally
- China is the world's largest producer and consumer of hydrogen, and accounts for nearly one-third of dedicated global production.

A View: Hydrogen Demand Scenarios

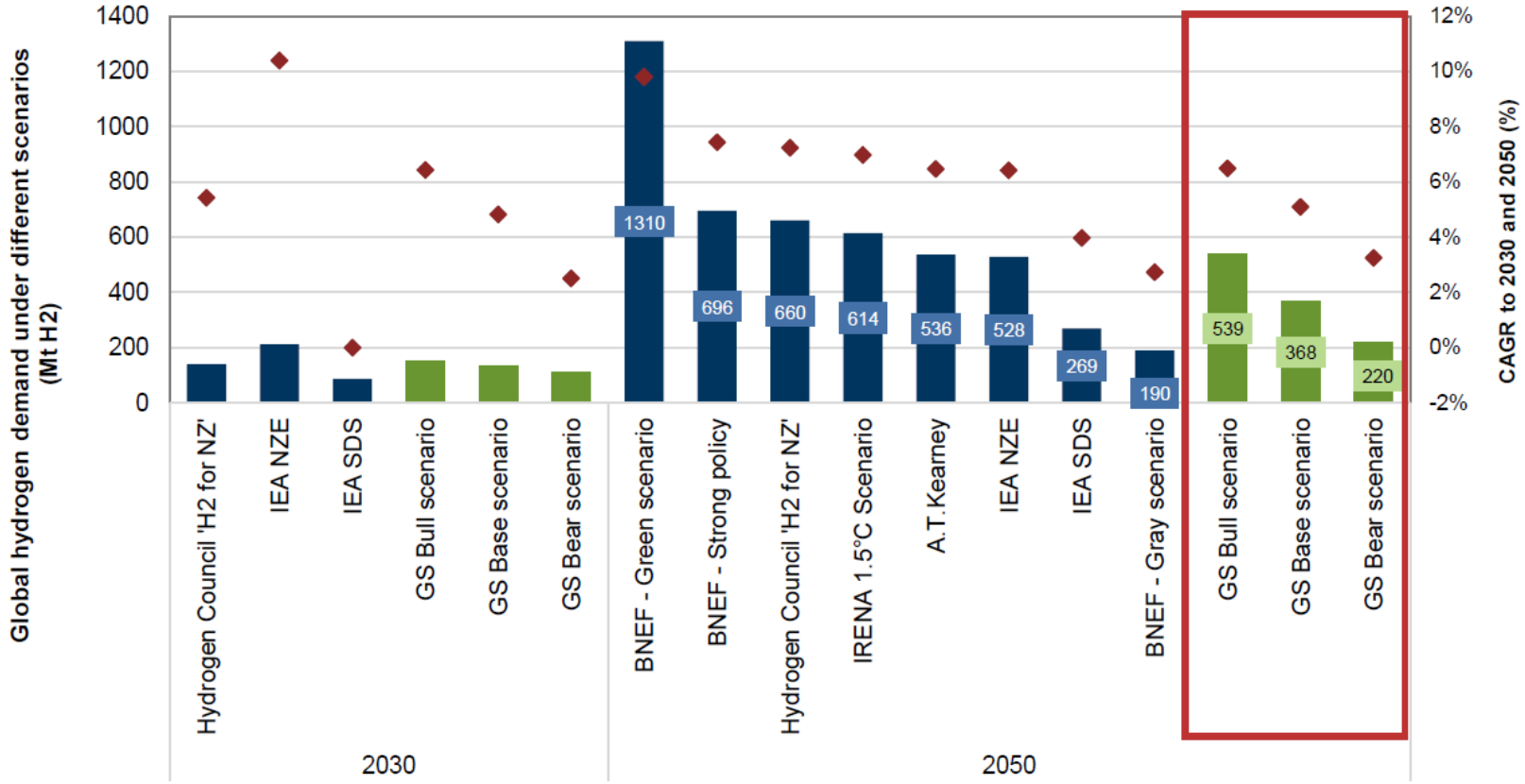
Global hydrogen demand for the three scenarios, split by industry (Mt H2)



Source: Goldman Sachs Global Investment Research

- Under all three Goldman scenarios global hydrogen demand increases at least two-fold on the path to net-zero, from two-fold in the bear scenario to seven-fold in the bull scenario.
- Blue and green hydrogen take off under its bull scenario, grow more modestly under the base scenario and grow much more slowly in its bear scenario.
- Green hydrogen takes 60% of the growth; blue hydrogen, 40%.

Other Views: Potential Hydrogen Demand through 2050

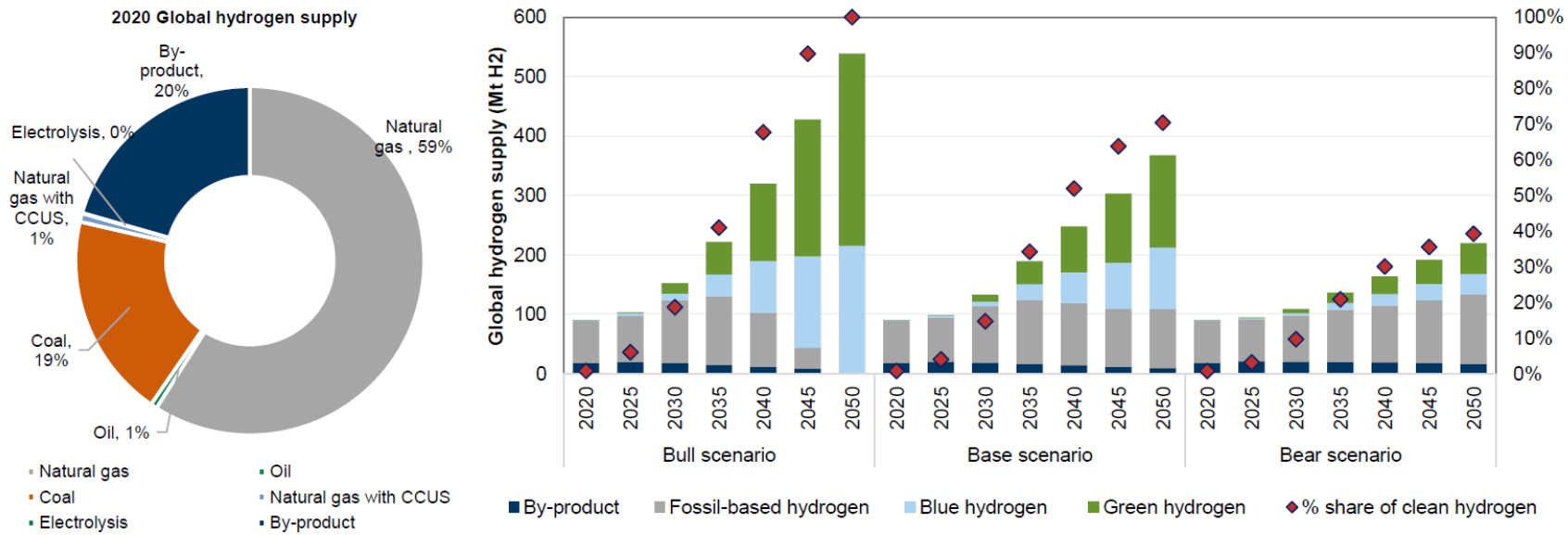


Source: BNEF, IEA, Hydrogen Council, AT Kearney, Goldman Sachs Global Investment Research

- Under all three Goldman Sachs (GS) scenarios global hydrogen demand increases at least 2-fold on the path to net-zero, from 2-fold in the bear scenario to 7-fold in the bull scenario.
- Up to US$5 trillion in investments required through 2050 to develop the supply chain and market.
- MENA, Latin America, Australia and Iberia could emerge as key clean hydrogen exporting regions.

Global Hydrogen Supply by Source

Global hydrogen supply by source



Source: IEA (2020), Goldman Sachs Global Investment Research

- With respect to the bull scenario, the findings are similar to IEA's NZS: major growth in road transport, power generation, shipping and aviation. Refining usage declines, but not as dramatically as in IEA's scenario.
- My view is that the current economic and geopolitical environment may complicate efforts to invest in and expand hydrogen supply – the base or even bear scenario may be more likely than the bull.
- Another complicating factor: The analyses assume tough carbon pricing that does not exist globally right at now (US$100/ton).

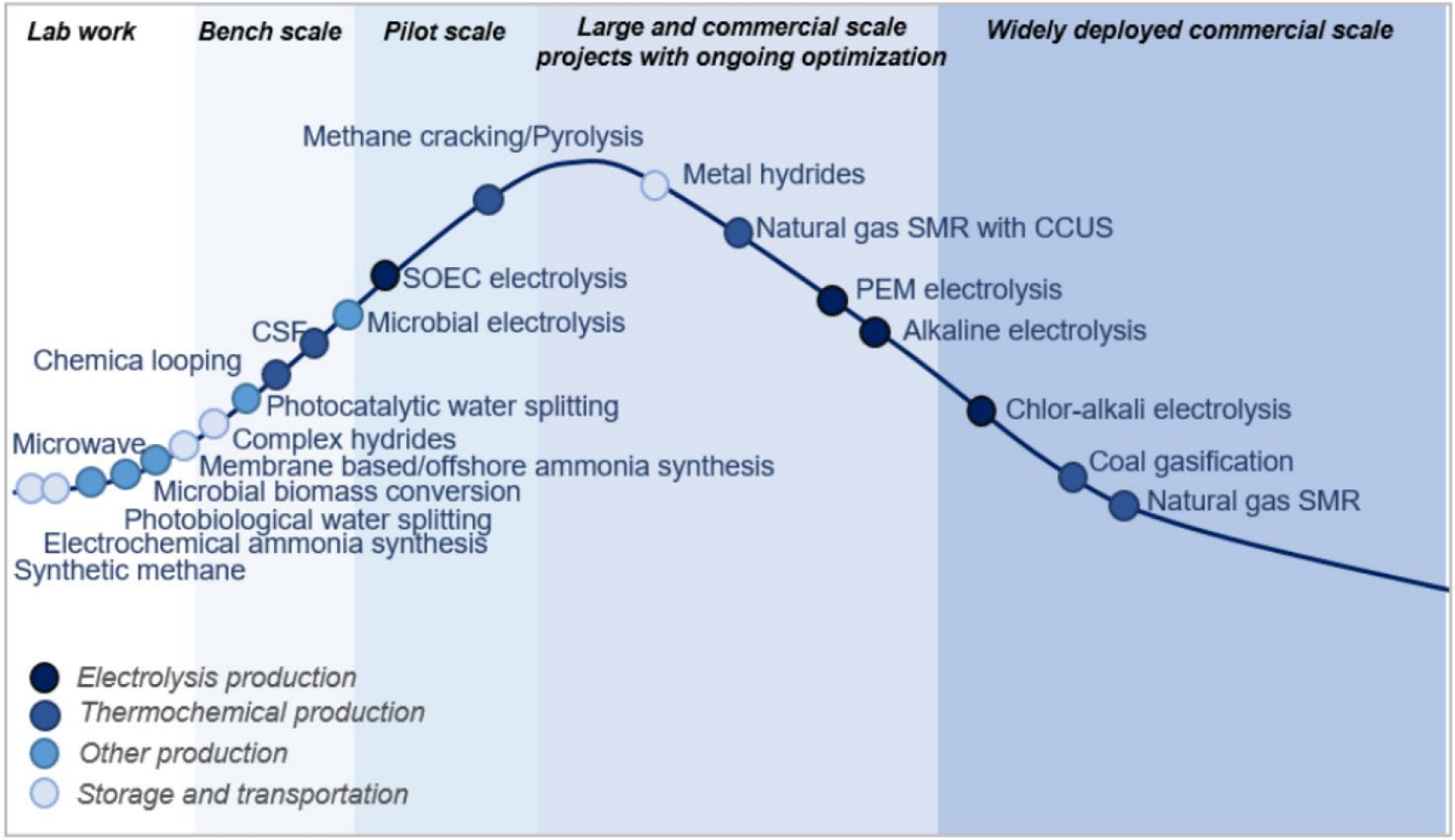
Addressable Markets and Their Competition

			Key competing de-carbonization technologies			Potential role for hydrogen	GS global hydrogen demand models – Hydrogen potential demand in 2050		
	End-use market	% of global CO2 emissions (direct, 2019)	Bioenergy	Electrification (renewable power & storage)	Carbon Capture	Hydrogen stage of development	GS Bull case	GS Base case	GS Bear case
	Refining	1.3 GtCO2, c. 3%	●	◐	◐	●	15 MtH2	19 MtH2	33 MtH2
	Primary chemicals	0.9 GtCO2, c. 3%	◐	◐	◔	◔	74 MtH2	68 MtH2	62 MtH2
	Iron & Steel	2.6 GtCO2, c. 7%	○	◐	◐	◐	52 MtH2	40 MtH2	29 MtH2
	Road transport Light-duty vehicles *(LDVs)*	3.9 GtCO2, c. 10%	●	●	○	◔	22 MtH2	12 MtH2	5 MtH2
	Road transport Heavy-duty vehicles *(HDVs, incl. trucks and buses)*	2.3 GtCO2, c. 6%	●	◔	○	◔	100 MtH2	68 MtH2	40 MtH2
	Rail	0.2 GtCO2, <1%	◔	●	○	◔	3 MtH2	2 MtH2	1 MtH2
	Shipping	0.9 GtCO2, c.2%	◔	◕	○	◕	52 MtH2	27 MtH2	4 MtH2
	Aviation	1.0 GtCO2, c.3%	◔	◕	○	◕	64 MtH2	36 MtH2	10 MtH2
	Power generation	13.8 GtCO2, c.36%	●	●	◔	◐	100 MtH2	60 MtH2	20 MtH2
	Buildings *(incl. space and water heating)*	3.5 GtCO2, c.9%	●	●	○	◐	56 MtH2	35 MtH2	16 MtH2

Source: Goldman Sachs Global Investment Research

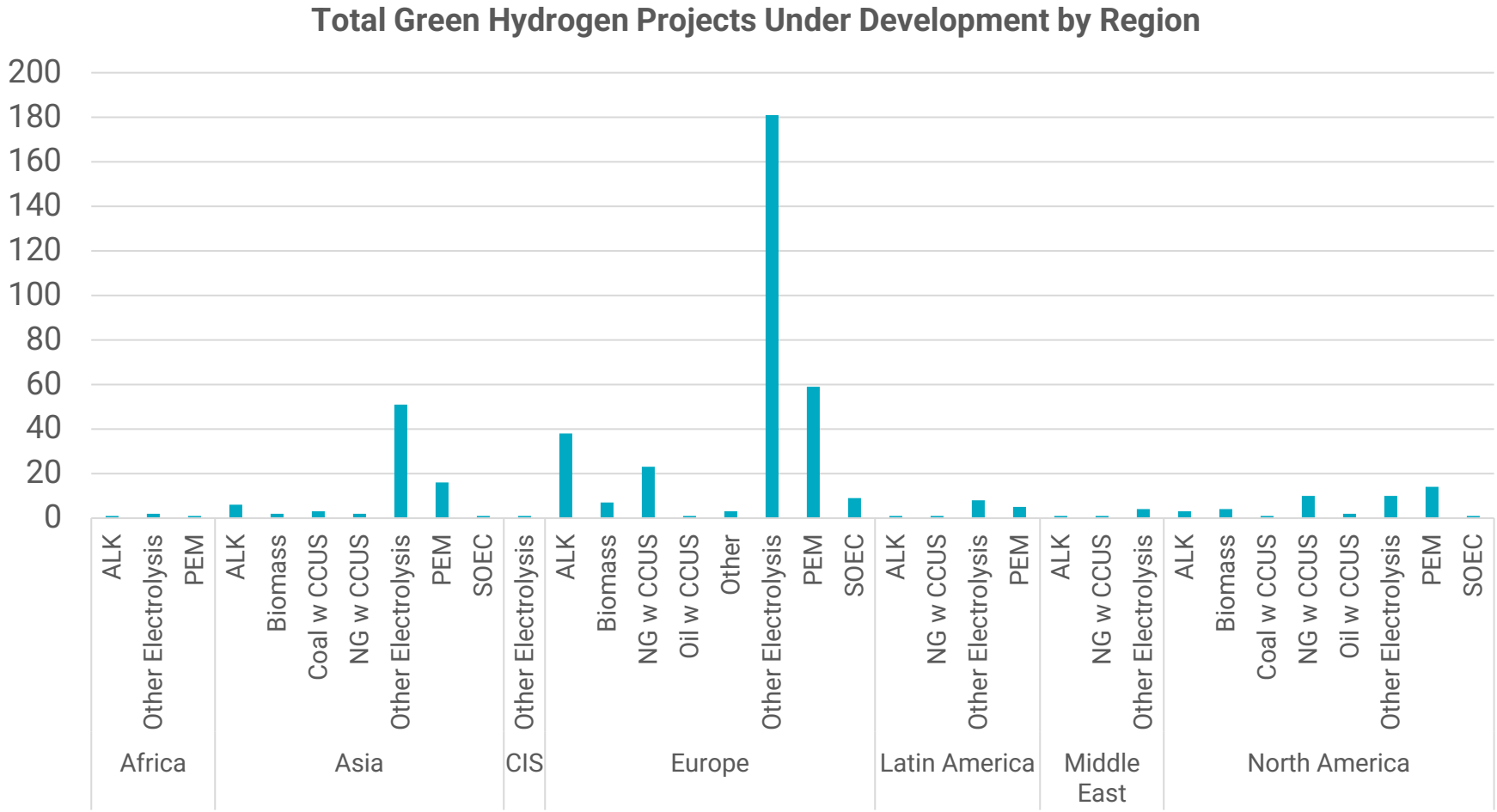
How Close Are H2 Technologies to Commercialization?

Electrolysis projects shifting from commercial scale projects to widely deployed



Source: Goldman Sachs, March 2022

Green Hydrogen Projects Exploding Globally

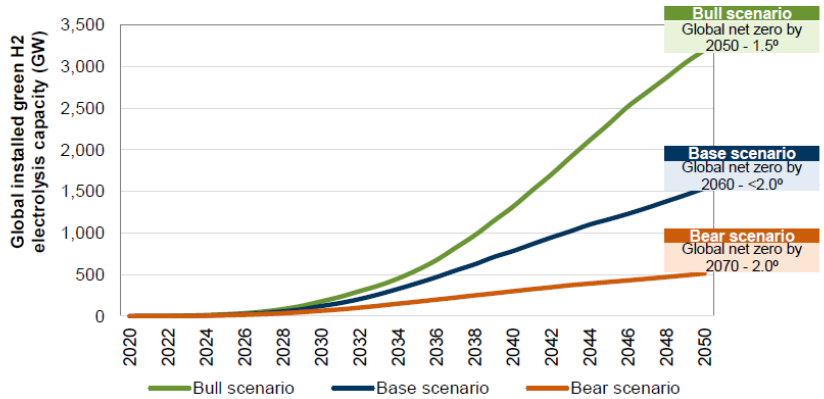


- More than 90% of these projects, if constructed, would be scheduled to come online before 2030.
- A whopping 87% of projects are green hydrogen projects that will use PEM, SOEC, alkaline or other electrolysis technology for production.
- Most of these projects will use on-shore and off-shore wind, solar and hydropower as the renewable energy source.

Source: Compiled by Transport Energy Strategies citing data from IEA, October 2021

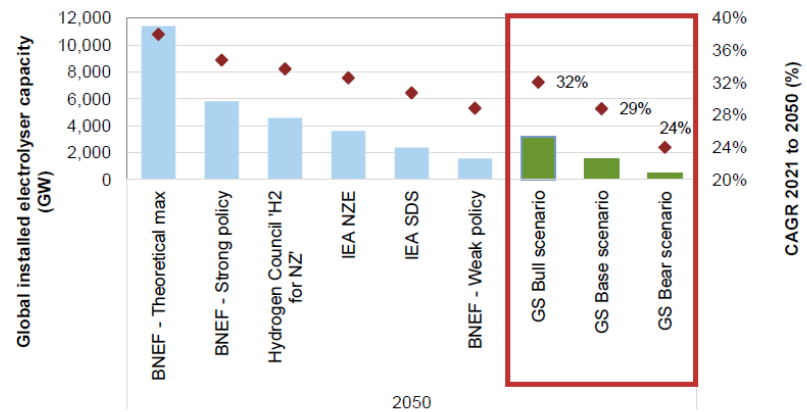
Electrolyzer Outlook

Global installed electrolyzer capacity based on our GS global hydrogen demand models (GW)



Source: Goldman Sachs Global Investment Research

Global installed electrolyzer capacity under various scenarios and vs GS global hydrogen models (GW)



Source: BNEF, Hydrogen Council, IEA, Goldman Sachs Global Investment Research

- The Bank estimates that 65 and 180 GW of electrolyzer capacity will need to be installed by 2030 and 500-3,200 GW by 2050 under the three scenarios.
- With the industry likely to experience substantial growth, the bank projects that the cost of these electrolyzer units (in US$/kW) has the potential to decrease by 50%-65% by 2030 for alkaline and PEM electrolysis systems, respectively.
- Longer term, the cost of alkaline and PEM electrolyzers is likely to converge to around US$300-400/kW (2030E), with PEM enjoying a higher learning rate compared to alkaline given its higher starting point and earlier stage of development.
- Goldman Sach's bull scenario aligns with IEA's NZS, and both are slightly lower than the Hydrogen Council's projections.

A Deeper Look at Transport

Key Points from the Analysis

- FCEV stocks had been growing by about 70% annually from 2017 to 2020 but declined 15% in 2021 with the impact of pandemic. There are 40,000 FCEVs on the road as of June 2021.
- South Korea, the U.S., China and Japan are the primary markets responsible for a sixfold increase in FCEV sales in four years.
- Not one country with an applicable strategy is even close to meeting its targets, and South Korea will miss its 81,000 FCEV target for this year.
- There seems to be some coalescence around battery electric vehicles (BEVs) as a preferred mode for decarbonizing the light-duty and light commercial vans (LCV) fleets, and hydrogen FCEVs for the HDV fleet.
- Aviation and shipping are projected to account for 110 Mt of hydrogen demand by 2050, according to the Hydrogen Council. Compare that to Goldman Sachs' Bull scenario which is closer to 130 Mt with its Base Scenario at 70 Mt.
- The Hydrogen Council and Goldman Sachs see an interim period where biofuels, SAF and other alternative fuels will play a key role. The time horizon, however, is much longer in the bank's projections.

National Strategy FCEV Targets v. FCEV Sales

Country	Transport Targets in National Strategy	Sales (Thousand Units)				
		2017	2018	2019	2020	Through June 2021
China	• 50,000 FCEVs by 2025	-	1.79	6.18	8.44	8.44
Europe	• 3.7 million FCEVs, 500,000 light-duty commercial vehicles, 45,000 trucks and buses by 2030	1.19	1.42	2.18	2.67	3.08
Japan	• 200,000 fuel cell electric vehicles (FCEVs) (2025) • 800,000 FCEVs (2030) • 1,200 fuel cell (FC) buses (2030) • 10,000 FC forklifts (2030)	2.30	2.93	3.63	4.20	5.60
South Korea	• 2.9 million FC cars domestic, 3.3 million FC cars exported (2040), 100,000 units by 2025, 81,000 units by 2022 • 80,000 FC taxis (2040) • 40,000 FC buses (2040) • 30,000 FC trucks (2040)	-	0.90	5.08	10.09	14.56
U.S.	• No strategy in place	3.35	5.90	8.04	9.25	11.12
Rest of World	N/A	-	-	-	0.15	0.34

Source: Compiled by Transport Energy Strategies citing data from IEA, countries' national strategies, May 2022

FCEV Model Availability

Company	Target	Year	Vehicle Category
BMW	Limited-series fuel cell SUV release	2022	LDV
Jaguar Land Rover	Prototype testing of fuel cell SUV	2021-2022	LDV
Great Wall Motor	Fuel cell SUV release	2021	LDV
Toyota	Deployment of 600 FCEV taxis in greater Paris region	2024	LDV
Riversimple	Production target of 5,000 fuel cell coupes/yr	2023	LDV
Riversimple	Light goods vehicle model release	2023	Light commercial van (LCV)
Stellantis	Fuel cell van models release	2021	LCV
Renault & Plug Power	Light commercial vehicle models release	2021	LCV
Symbio and Safra	Availability of 1,500 buses	2021	Bus
Symbio and Safra	Construction of largest EU fuel cell plant (60,000 units/yr)	-	Bus
H2Bus Consortium	Deployment of 600 fuel cell buses	2023	Bus
Daimler	Testing of GenH2 truck with liquid hydrogen onboard storage	2021	Truck
Air Products & Cummins	Conversion of ~2 000-truck fleet to hydrogen fuel cells	2022+	Truck
Nikola	Purchase order of up to 800 fuel cell trucks to US Anheuser -Busch	2023+	Truck
MAN	Deployment of hydrogen fuel cell demonstration fleet	2024	Truck
Hyzon	Purchase orders for 1 500 fuel cell trucks to Hiringa Energy in New Zealand; 20 to Jan Baaker and Millenaar & van Schaik in the Netherlands; and 70 to JuVE/MPREIS in Austria	2024	Truck
Hyundai	Purchase order of 1,600 fuel cell trucks to Switzerland	2025	Truck
Volvo & Daimler	Large-scale series production of fuel cell trucks	2025+	Truck

Source: Compiled by Transport Energy Strategies, May 2022 citing data from the International Energy Agency

Model availability is one among many issues impacting FCEV sales. There are only two passenger car FCEVs on the market in the world right now: Toyota Mirai and Hyundai NEXO.

Hydrogen Refueling Stations (HRS)

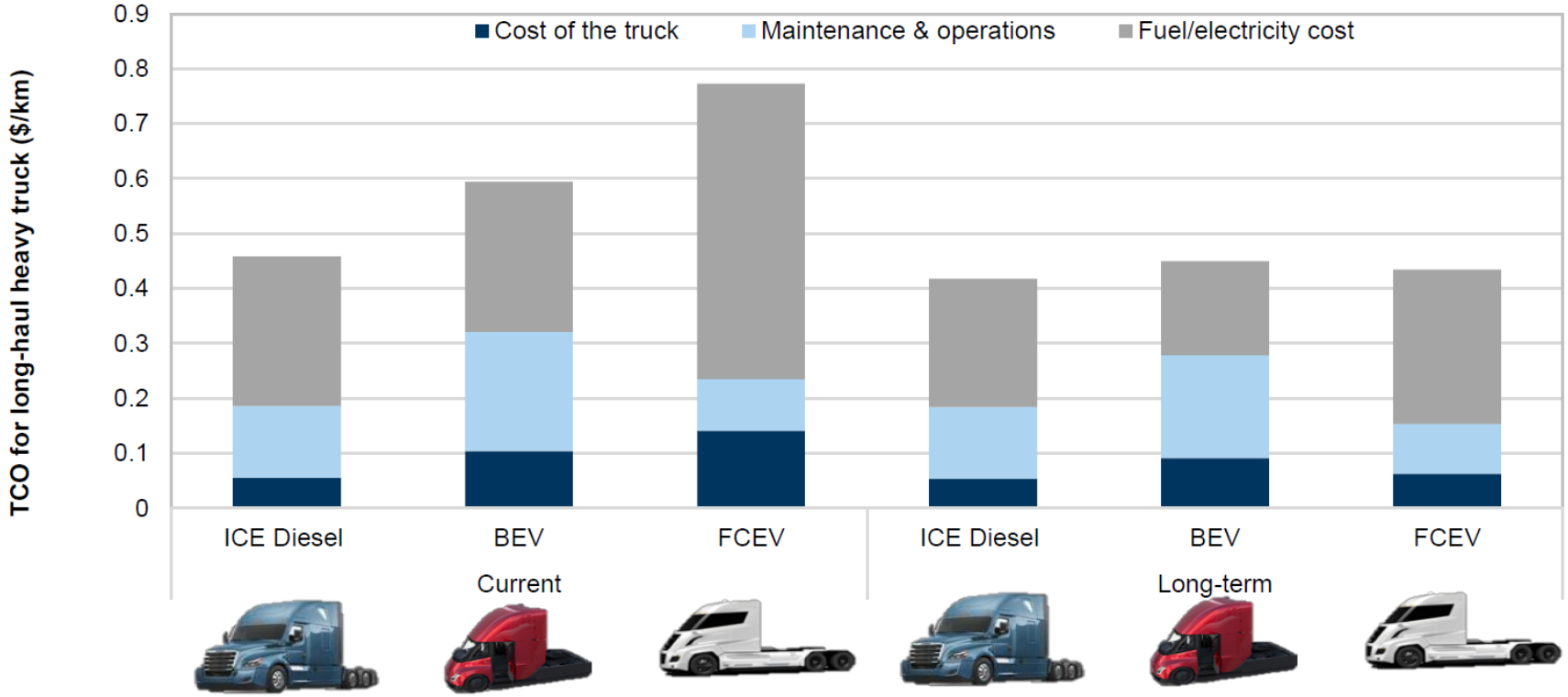
Country	National Hydrogen Strategy HRS Target	Total Stations	Public Stations
Japan	• 320 (2025) • 900 (2030)	137	137
Germany	• 400 (2025)	90	90
China	• No specific target set	85	66
U.S.	• No specific target set	63	46
South Korea	• 310 (2022) • 1,200 (2040)	52	N/A
France	• 100 (2023) • 400-1,000 (2028)	38	28
UK	• No specific target set	13	10

Source: Compiled by Transport Energy Strategies, May 2022 citing data from AFC TCP, countries' national hydrogen strategies

- There were a total of 540 hydrogen refueling stations, both public and nonpublic, installed around the world by the end of 2020.
- At the end of 2020, Asia had the highest number of stations, with a total of 278, followed by Europe with 190 and North America with 68.

Total Cost of Ownership (TCO) Comparisons for HDVs

Long-term, FCEV TCO projected to be on par with diesel

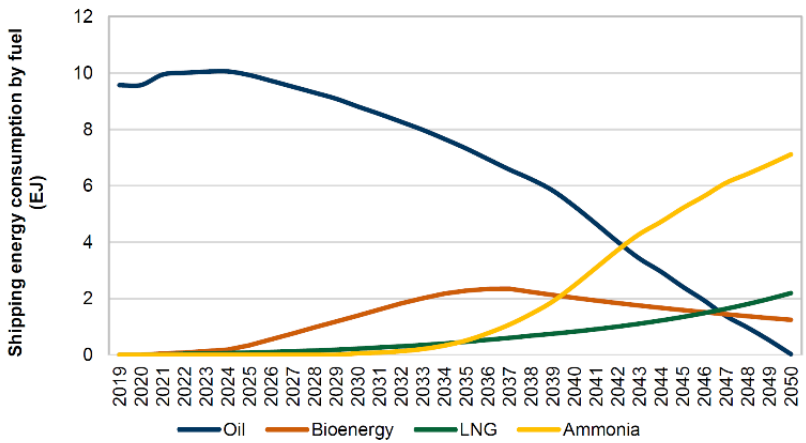


Source: Company data, Goldman Sachs Global Investment Research

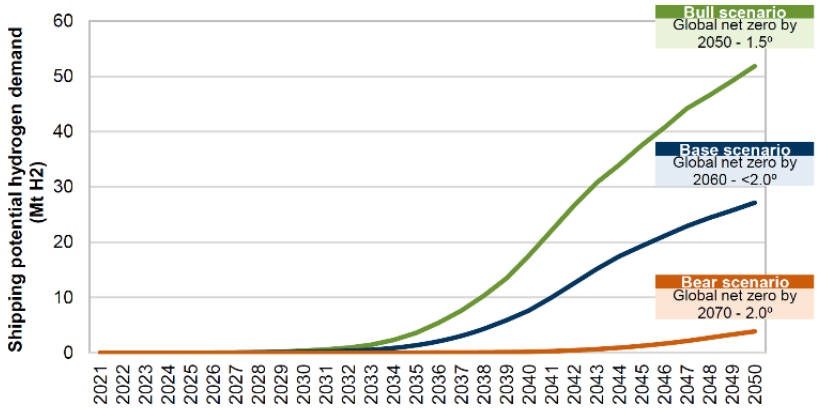
What about fuel costs? In the Goldman Sachs study, the authors found that US$4-4.5/kgH2 would be sufficient for cost parity with diesel (normalized diesel prices), while at current FCEV costs a hydrogen price of US$3-3.5/kg H2 would be needed for cost parity, well below the $8-12/kgH2 at the pump currently.

There Is No Silver Bullet for Aviation and Maritime

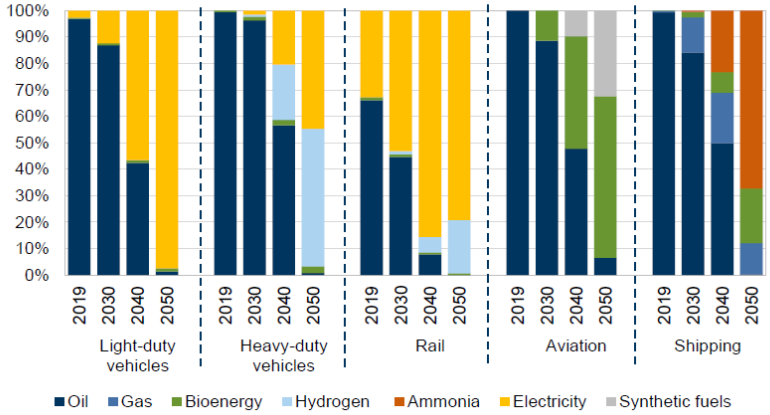
Shipping energy consumption by fuel (EJ)



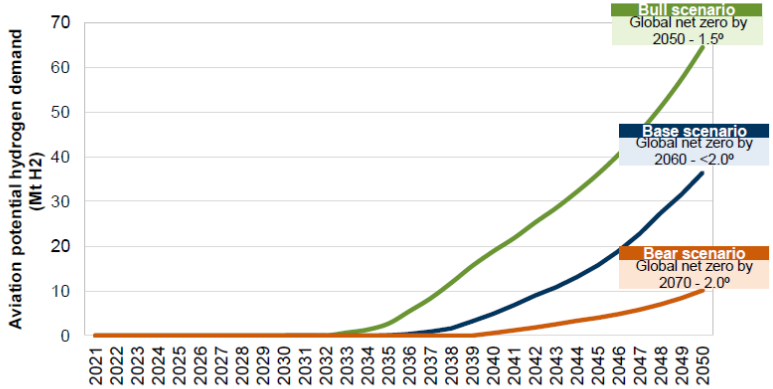
Potential H2 demand for the shipping industry (Mt H2 pa)



Energy mix evolution for the transport sector by mode, under our GS 1.5 net zero by 2050 scenario (%)



Aviation potential hydrogen demand (Mt H2 pa) under the three GS global hydrogen scenarios



Source: Goldman Sachs, February 2022

TAMMY KLEIN
FOUNDER & CEO
+1.703.625.1072 (M)
TAMMY@TRANSPORTENERGYSTRATEGIES.COM

transportenergy strategies