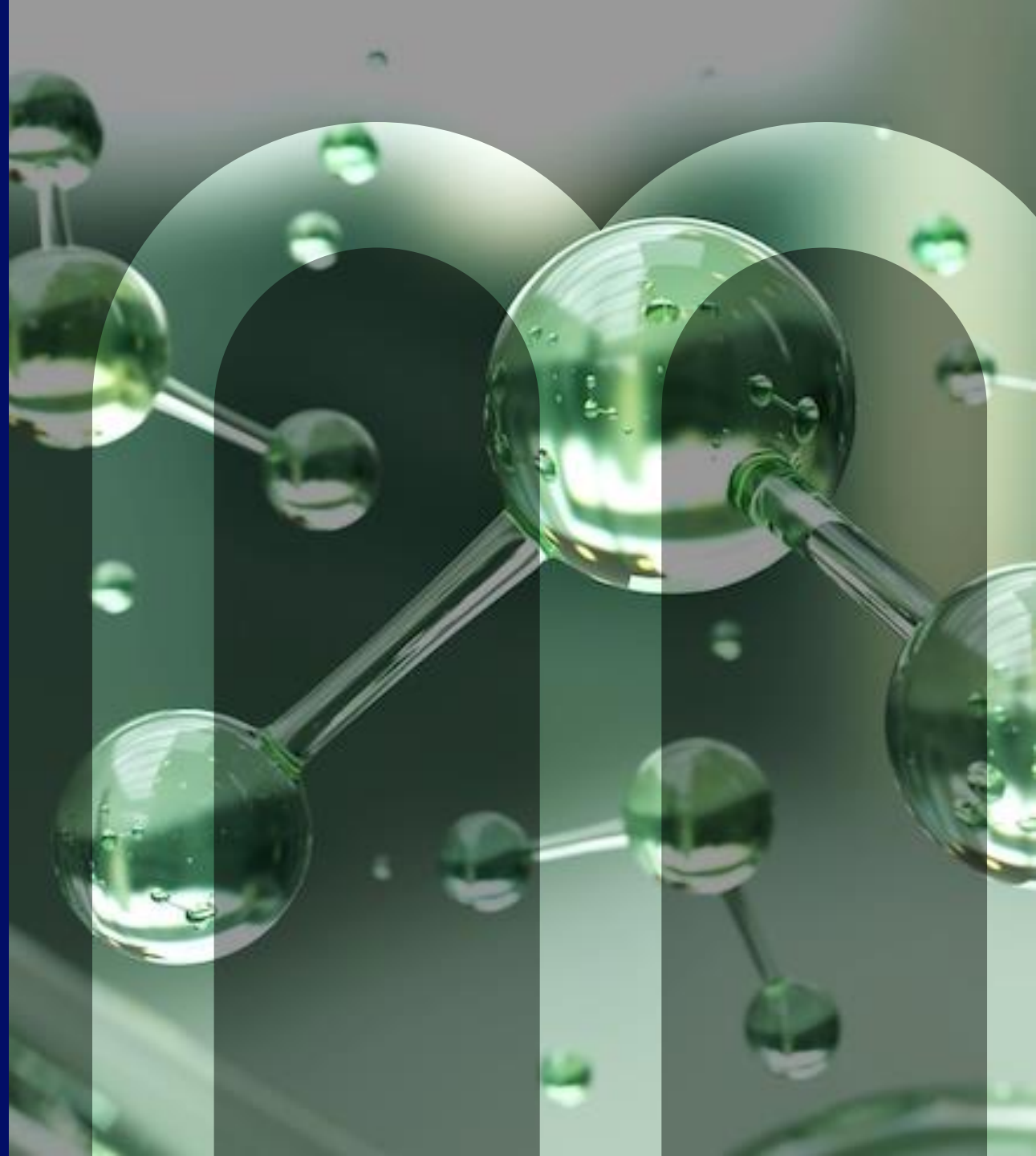
Exploring Brazil's Untapped Potential in the Hydrogen Market – Jan/24 update

Document for discussion

Rio de Janeiro, January 2024



CONTENT

Global hydrogen market overview

Opportunities for Brazil in the hydrogen market

By capitalizing on the fast-growing hydrogen market, companies now have the chance to establish themselves as the frontrunners in the decarbonization industry

Hydrogen is key for meeting global decarbonization targets	▪ Meeting decarbonization targets implies using clean feedstocks and fuels in hard-to-abate sectors, such as steel, fertilizers, aviation, shipping, cement and others ▪ Low-emission hydrogen has gained global adoption due to its versatile applications and its ability to substitute fossil fuels where electrification is not feasible ▪ Countries representing 80% of global GDP have implemented national strategies to foster the development of the low-emission hydrogen market – Governmental programs aim to drive its expansion by setting targets for supply and demand, as well as providing funding and tax credits. In the USA, IRA offers a tax credit of up to USD 3/kg
There is currently a fast-growing market with an extraordinary potential	▪ Scenarios show that the low carbon hydrogen market will grow to 225 Mt/year by 2050 (more than 2x the hydrogen market in 2020 of 88Mt/year), reaching a market size of USD 340-450 bn annually ▪ Projects are booming – There are 1400+ projects of low-emission hydrogen in concept, feasibility, FID, construction or in operation phases ▪ Investments announced have grown by 36% from May/23 to Oct/23, reaching a total of USD 570 bn with about 25% of these investments have been committed ▪ US and China may rise as major demand and supply centers of low-emission H_2, while EU, South Korea and Japan may be large importers of low-emission hydrogen from low-cost producing regions as Middle East, North Africa, Australia, and Latin America – Brazil can emerge as a leading exporter of green hydrogen, given its low energy cost
Now is the opportunity for companies to establish themselves as the emerging leaders in this industry, despite challenges	▪ Major players in the oil and gas and chemical sectors are actively developing projects for low-emission hydrogen production, while leading companies in the fertilizer and steel sectors are strategically positioning themselves as consumers of low-emission hydrogen ▪ Biggest challenge for the hydrogen market to develop is to become cost-competitive without subsidies, which could be reached as soon as 2030 with hydrogen in the USD 1-3/kg range by mainly reducing the electrolyzer CAPEX and the electricity cost

Source: team analysis

Hydrogen can decarbonize several activities

Energy Carrier
Hydrogen

- Renewable energy source
- Long term and large-scale energy storage
- Backup and off-grid

Source of energy

1

Enable **large-scale, efficient renewable energy** integration and **power generation**

Backbone of energy systems

2

Distribute energy across sectors & regions

Act as a **buffer** to Increase system resilience

3

Examples of end use

4 Decarbonize **transport**

- FCEV light duty
- FCEVs heavy duty, including long-haul trucks
- Rail
- Shipping
- Aviation

5 Decarbonize **industry energy** use

- Iron & Steel
- Cement
- Electric power
- High-temperature heat processes and oil refining & other processes

6 Serve as **feedstock using captured carbon**

- Steel (replace coke, NG)
- Fertilizer (Ammonia)
- Petrochemicals (Refinery)
- Synthetic hydrogen-based liquid fuels (e-methanol, ammonia, others)

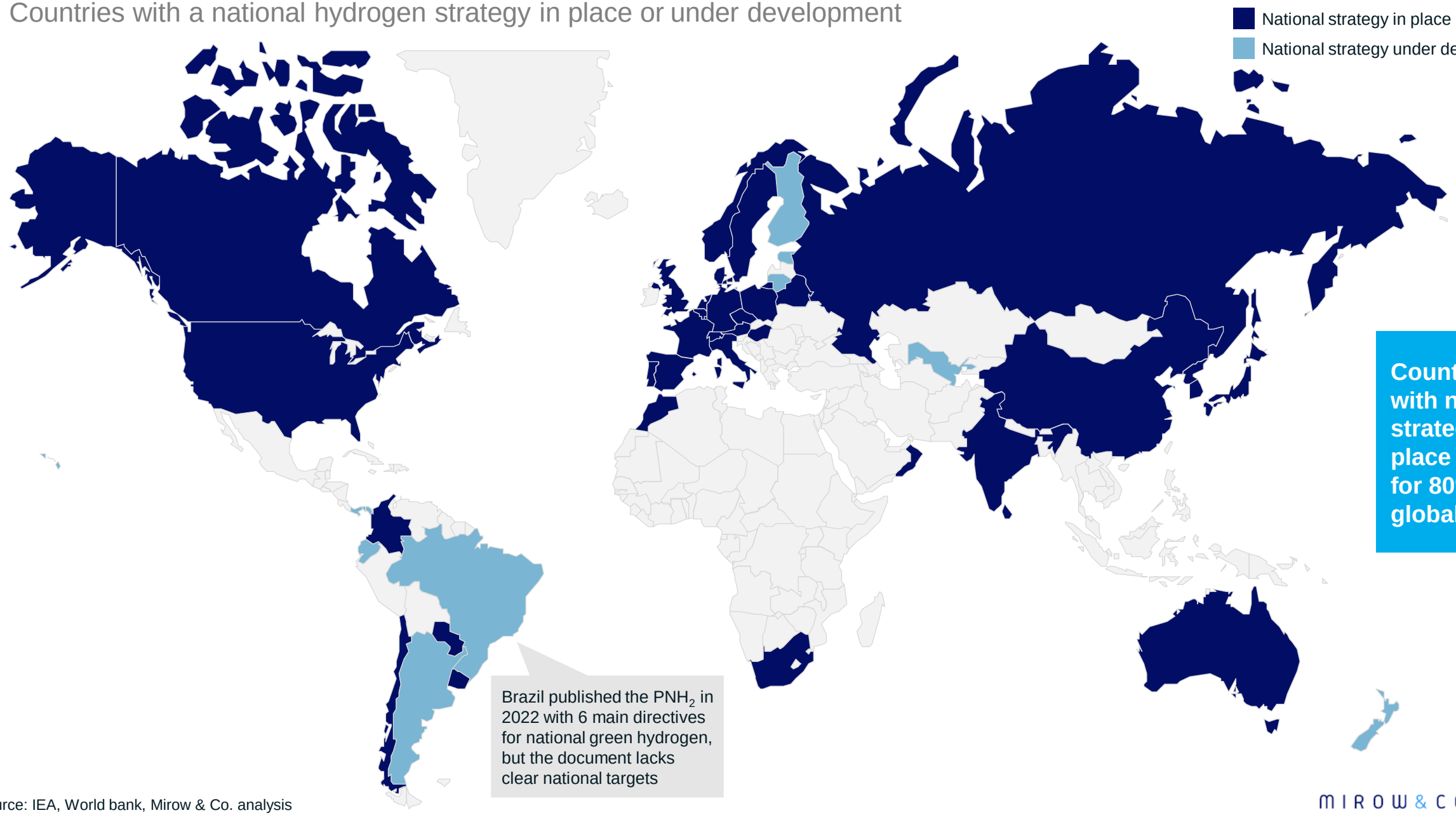
7 Decarbonize **buildings heating**

- Blending in current infrastructure
- 100% hydrogen
- Fuel cells and co-generation

Source: Hydrogen Council, Goldman Sachs Investment Research, IEA, team analysis

For this reason, there is a large global movement to boost the low-carbon hydrogen market…

Countries with a national hydrogen strategy in place or under development

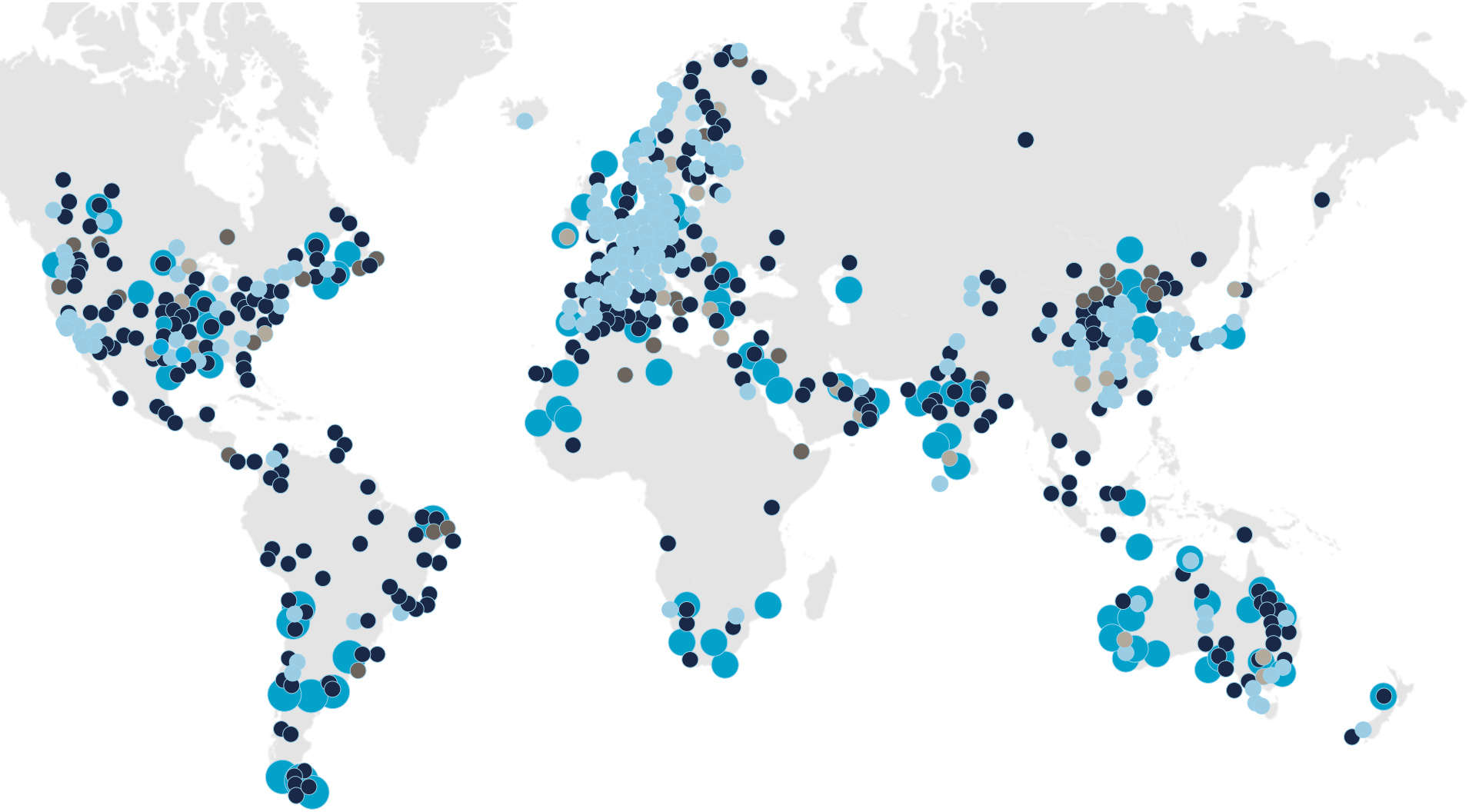


Countries with national strategy in place account for 80% of the global GDP

Source: IEA, World bank, Mirow & Co. analysis

… which is promoting a boom of projects around the globe

Number of low-carbon hydrogen projects worldwide[1] as of October 2023



1.418 projects[1]

1.046 in May 2023 (36% growth)

- **166 (+48% growth)**
  Giga-scale production
- **719**
  Large-scale industrial use
- **256**
  Mobility
- **144**
  Integrated H_2 economy
- **126**
  Infrastructure projects

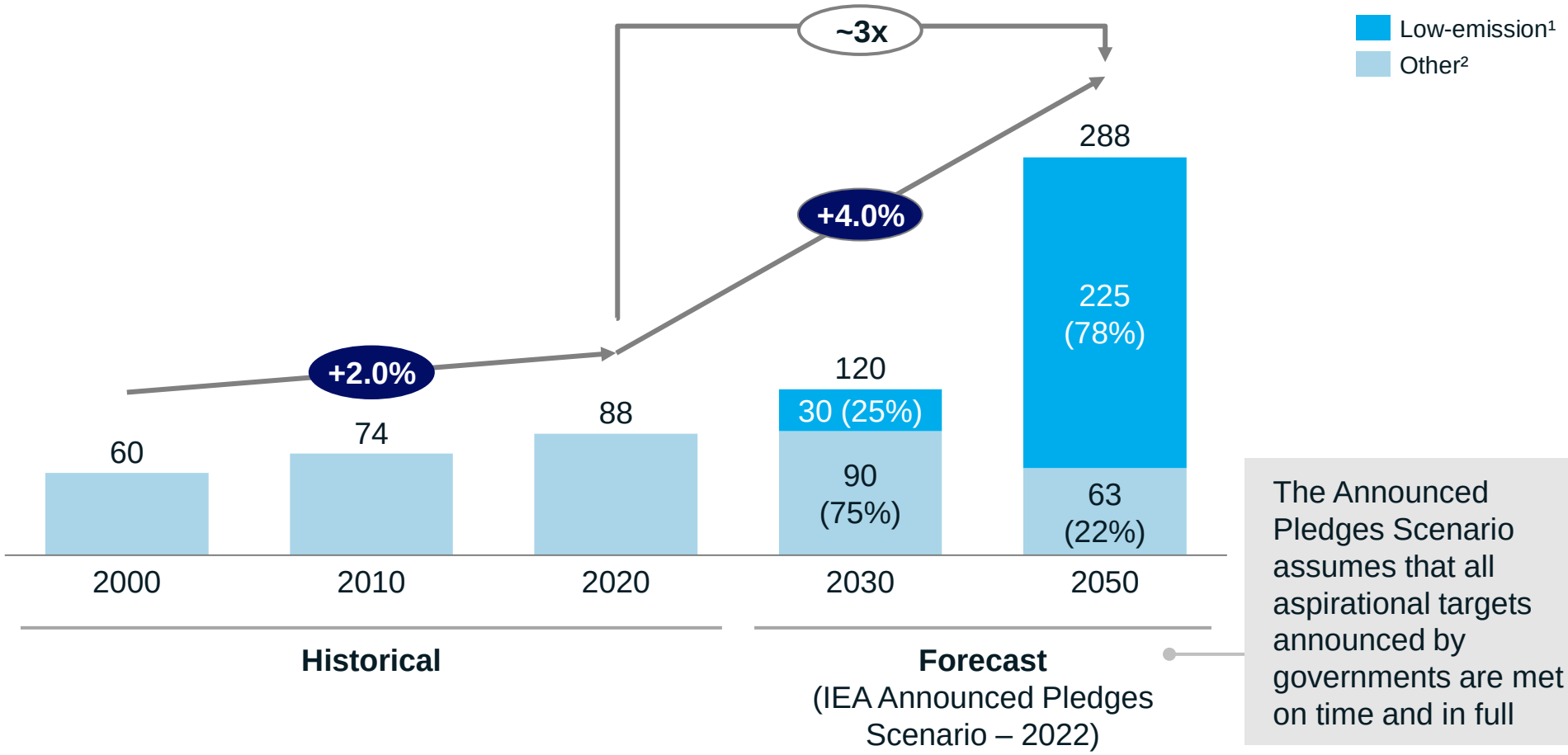
1. Project announcements below 1 MW excluded; includes 7 projects without specified type

Source: Hydrogen Council, team analysis

Global hydrogen demand has grown in a 2% CAGR for 20 years – Now, driven by the booming low-emission hydrogen market, it is set to triple by 2050

Global hydrogen demand, 2000-2050

Mt H_2



The Announced Pledges Scenario assumes that all aspirational targets announced by governments are met on time and in full

The demand for low-emission hydrogen is expected to increase rapidly in the coming years due to a focus on reducing greenhouse gas emissions, government incentives, and the declining cost of producing hydrogen, making it competitive with other energy sources

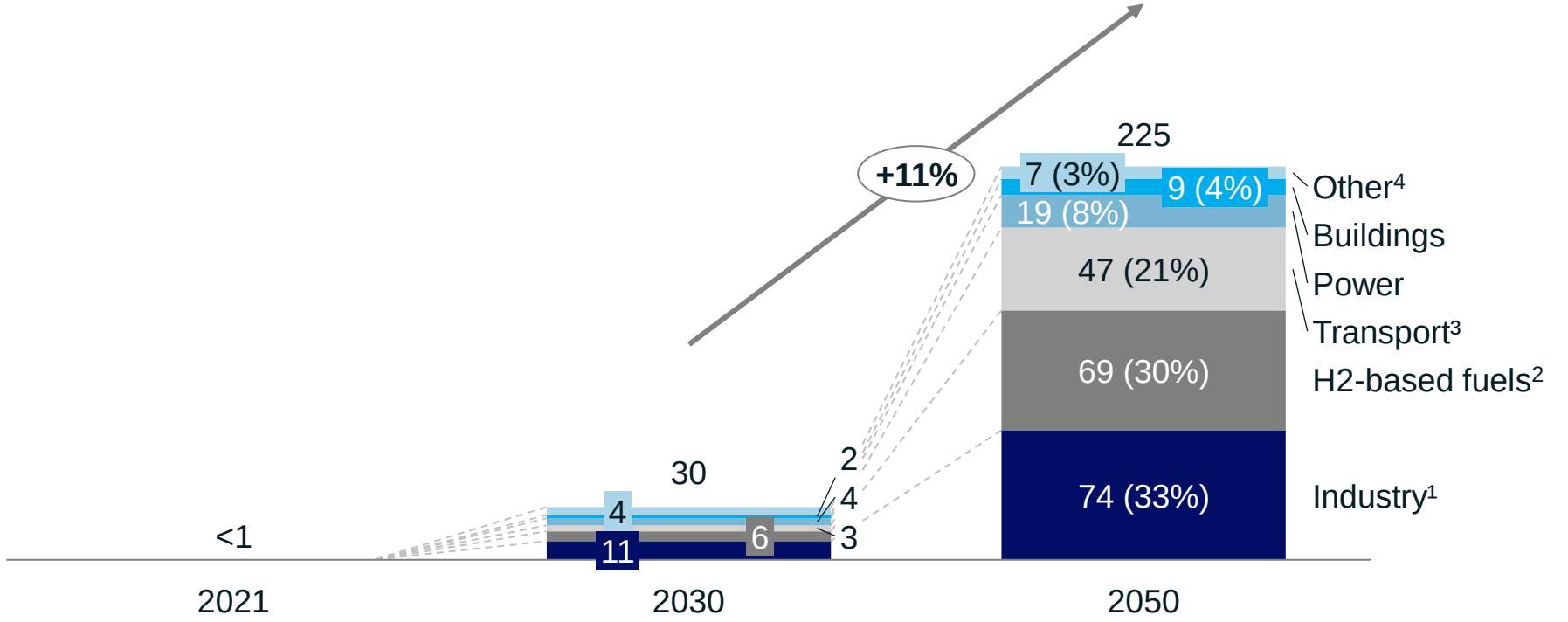
1. Includes mainly green and blue, and other types from clean sources;
2. High emission hydrogen, including grey, brown and black hydrogen

Source: IEA, team analysis

Low carbon hydrogen demand will grow mainly driven by the applications in the industry, hydrogen-based fuels and transportation, according to the announced pledges scenario

Global low-emission hydrogen demand by application area

Mt H_2/year



CAGR 2030-50

Other4	2%
Buildings	8%
Power	8%
Transport3	14%
H2-based fuels2	13%
Industry1	10%

% of low-emission H_2 from total	2021	2030	2050
	0.3%	24%	78%

Considering Announced Pledges Scenario, low-emission hydrogen demand could reach up to USD 340-450 bn globally[5] by 2050

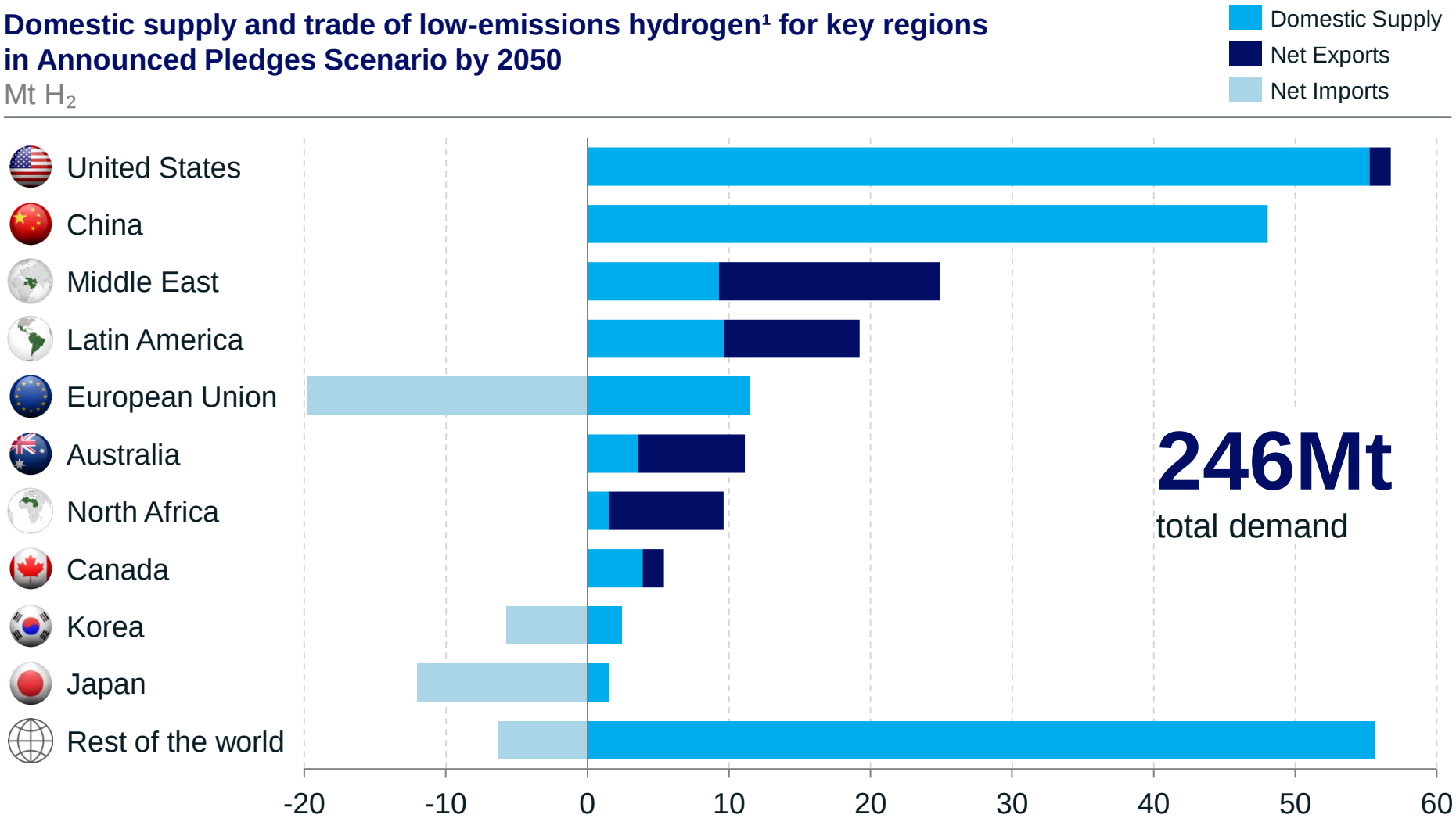
1. Mainly chemicals, iron & steel, and cement;
2. Ammonia, methanol and other synthetic hydrocarbons (gases and liquids) made from low-emissions hydrogen;
3. Mainly light-duty vehicles, heavy trucks, and aviation & shipping;
4. Mainly hydrogen used in refineries; 5. Price assumption of 1.5-2.0 USD/kg of low-emission hydrogen

Source: IEA, team analysis

China and US are expected to be the largest markets in low-emission hydrogen, representing 43% of the global demand and production

Domestic supply and trade of low-emissions hydrogen[1] for key regions in Announced Pledges Scenario by 2050

Mt H_2



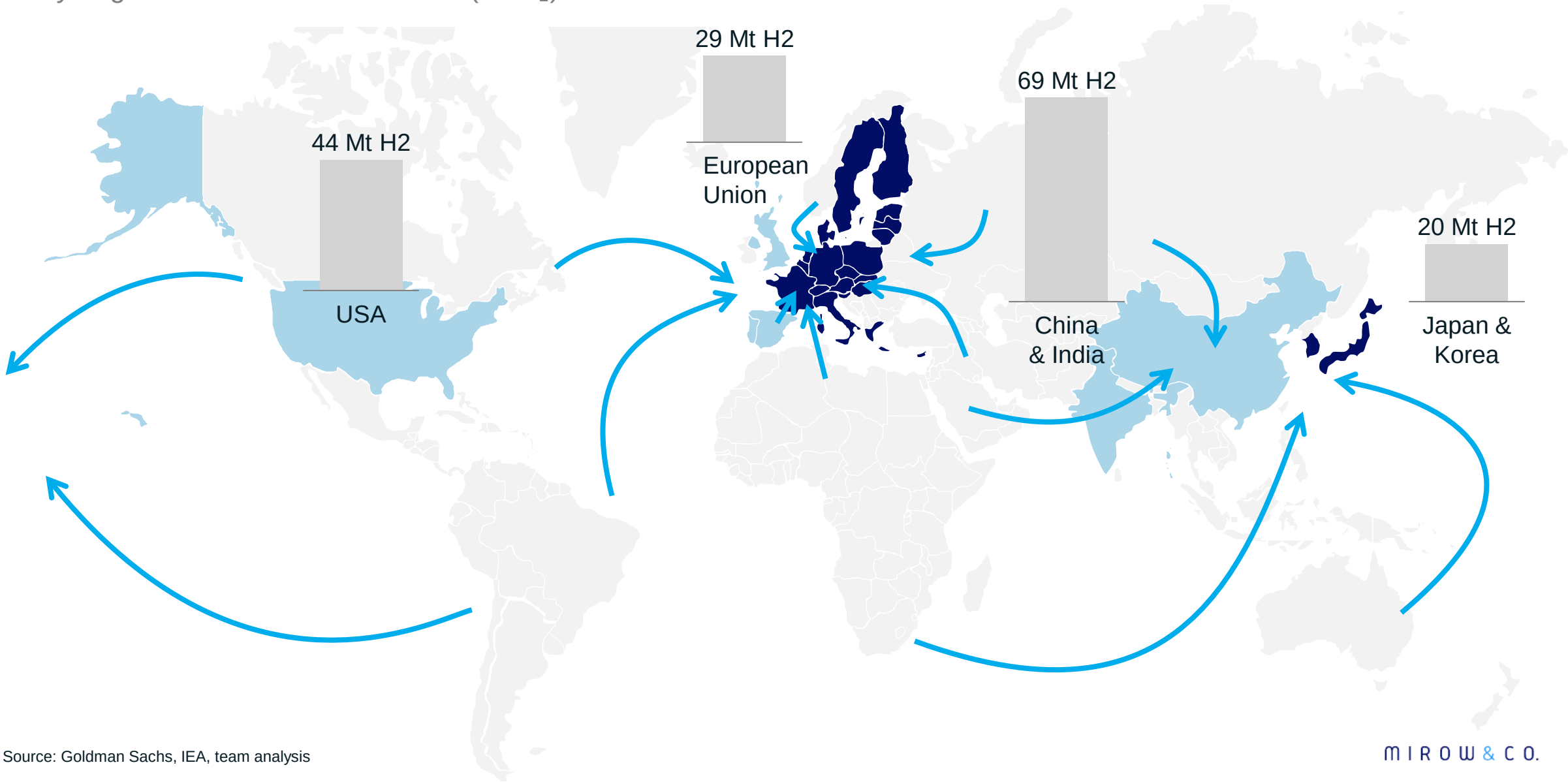
	Global demand share	Global production share
United States	23%	23%
China	20%	20%
Middle East	4%	10%
Latin America	4%	8%
European Union	13%	5%
Australia	1%	5%
North Africa	1%	4%
Canada	1%	2%
Korea	3%	1%
Japan	5%	1%
Rest of the world	25%	22%

1. Low-emission hydrogen includes hydrogen-based fuels as a means of exporting clean energy via its transformation to hydrogen

Source: IEA, team analysis

European Union, Japan and Korea are likely to be main importing markets of clean hydrogen by 2050

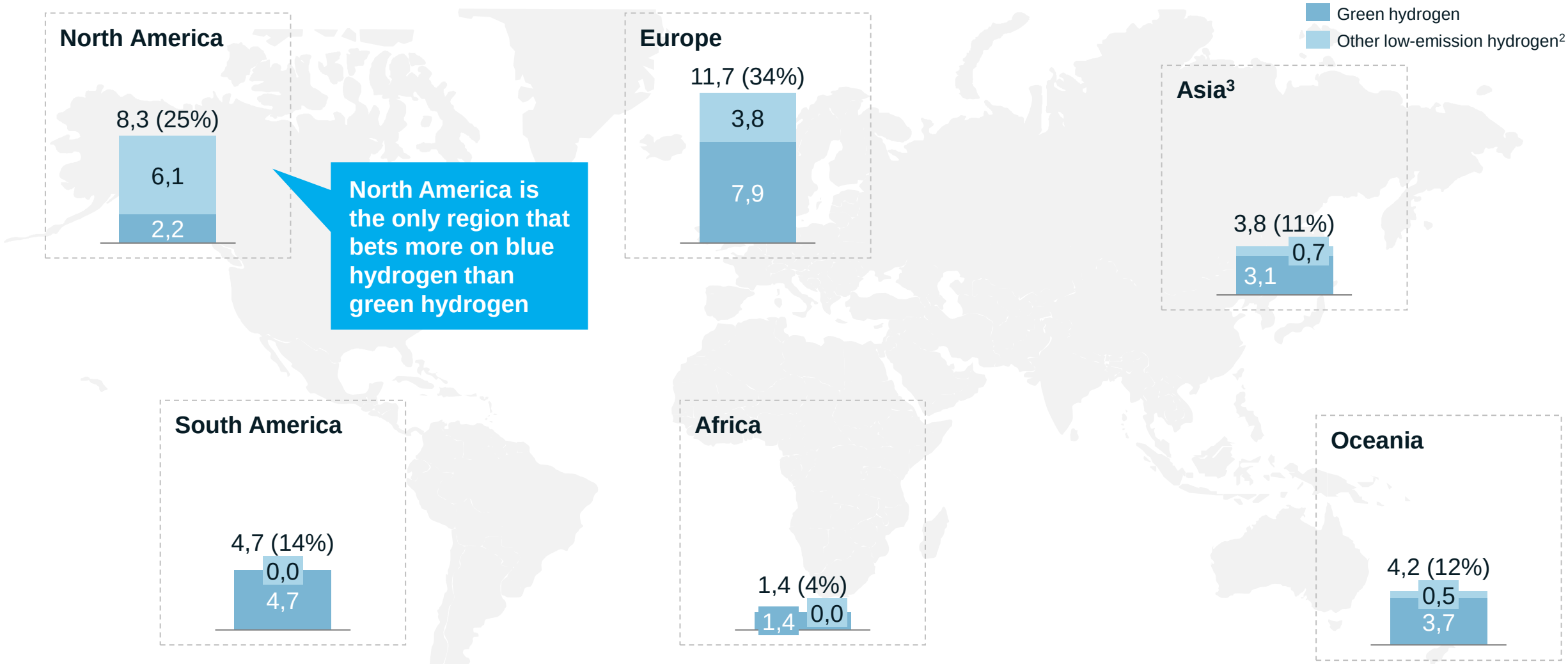
Hydrogen demand in main centers (Mt H_2)



Source: Goldman Sachs, IEA, team analysis

60% of the 34 Mt announced capacity of hydrogen projects is concentrated in Europe and North America, with the latter investing more in other low-emission hydrogen

Capacity of announced low emission hydrogen projects worldwide[1] in Mt H_2/year as of October 2022 (% of total)



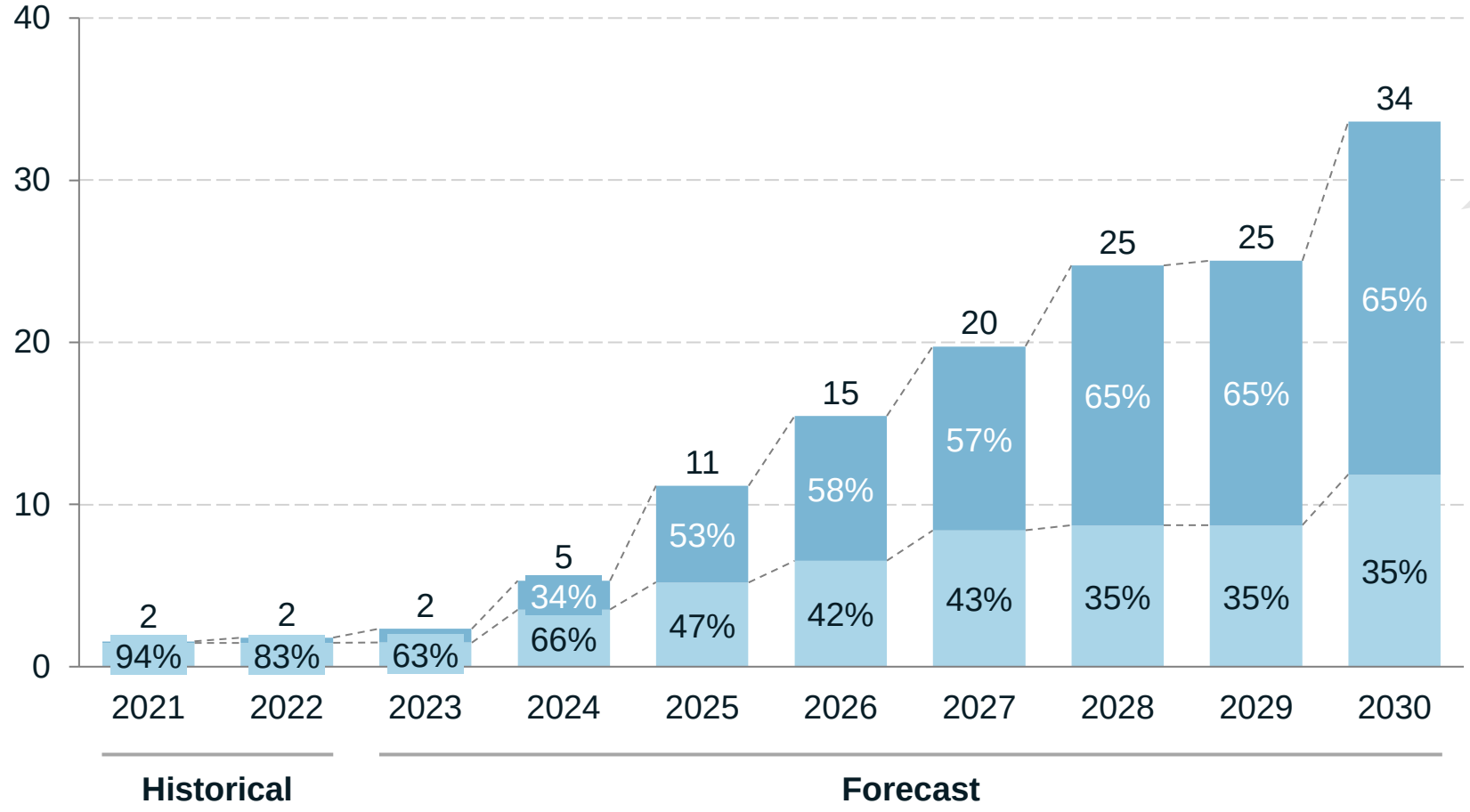
1. It was considered only projects in feasibility study, final investment decision, under construction or operational
2. Includes mainly blue hydrogen, and other types from clean sources
3. Considering middle east

Source: Hydrogen Council, IEA as of October 2022, team analysis

There are 34 Mt of low-emission hydrogen production projects mapped in this decade, most of them of green hydrogen and aligned with Announced Pledges Scenario (30 Mt by 2030)

Cumulative installed capacity of low emission hydrogen production as of October 2022
Mt, total planned projects announced[1]

CAGR
2023-2030



The production expected from new projects could meet the supply-demand level of Announce Pledges Scenario (30 Mt in 2030)

Green hydrogen **59%**

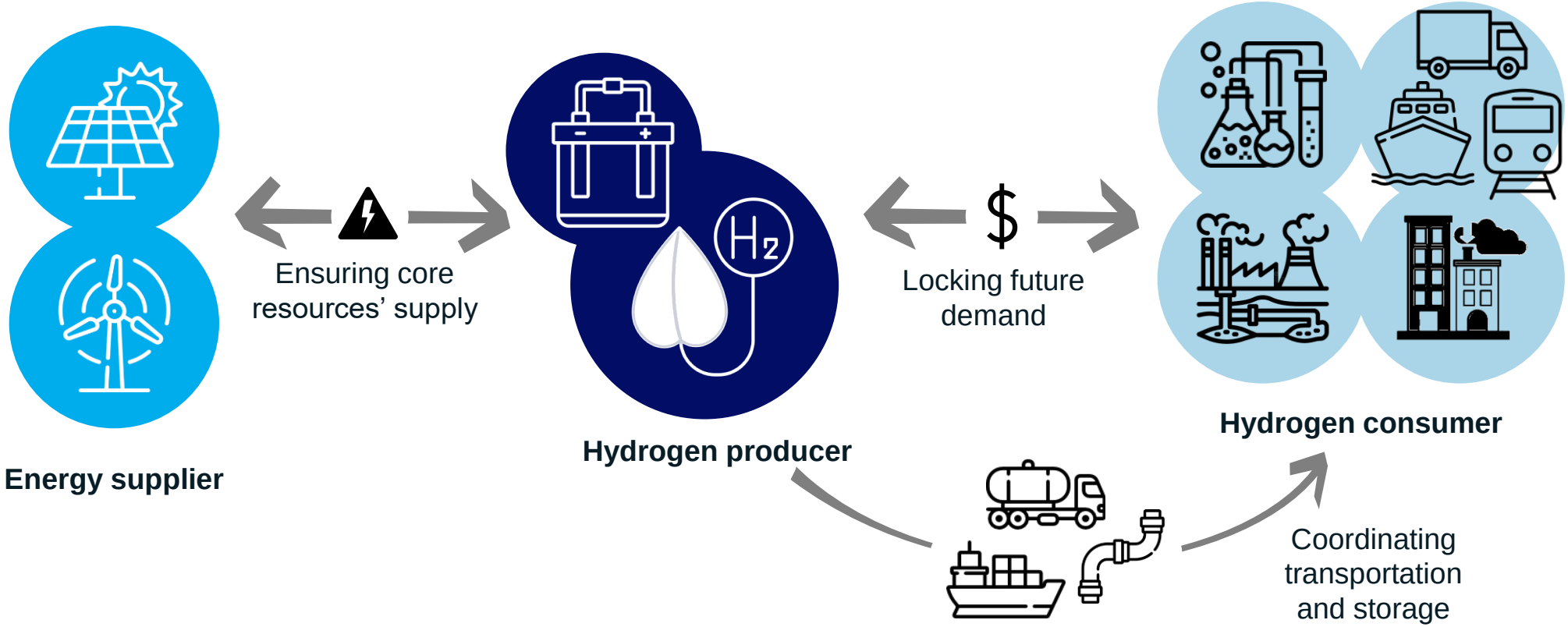
Other low-emission hydrogen[2] **35%**

1. Includes projects in feasibility, FID, construction, and operational phases
2. Includes mainly blue hydrogen, and other types from clean sources

Source: IEA as of October 2022, hydrogen council, team analysis

Current projects are typically designed end-to-end, with long-term contracts of hydrogen supply at cost-plus pricing

- Early **projects are designed end-to-end** to ensure both green energy supply and hydrogen purchase agreements
- Long-term **revenue contracts are key** for early hydrogen projects to **mitigate the risks** associated with the inexistence of a hydrogen merchant market



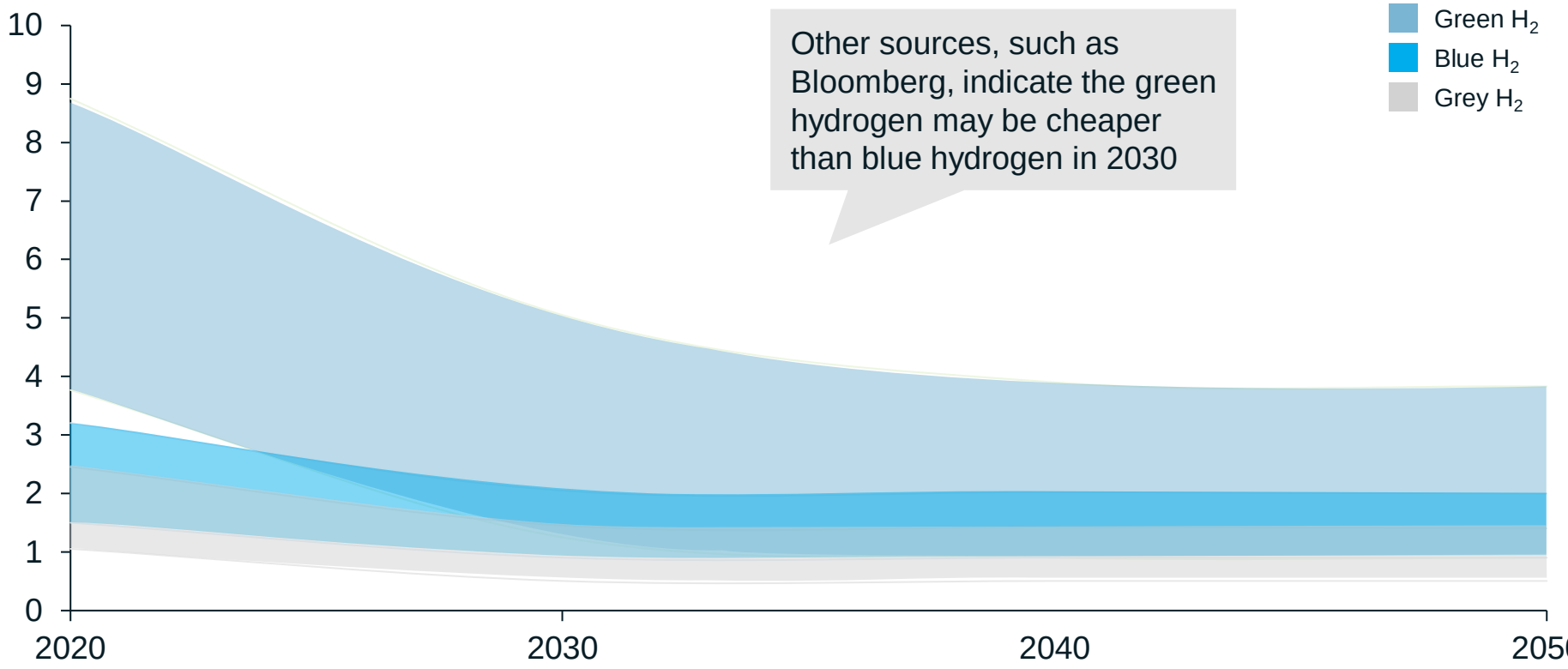
- There are **no spot prices for hydrogen** as there is no merchant market
- Until a benchmark price for hydrogen is adopted in the market, green and blue hydrogen contract prices may follow a **cost-plus pricing[1] logic**
- Typical stakeholders are **clean electricity generators** and **companies aiming at decarbonizing** their supply chain

1. Current contracts for the sale of grey hydrogen are often based on the actual price of feedstock (natural gas), plus other fixed and variable costs and a profit element
Source: Norton Rose Fulbright, S&P Global, team analysis

Green hydrogen may become more competitive versus other types, with lower-range price dropping from 3.8 to 0.9 USD/kg in the 2021-2050 period

Levelized cost of hydrogen (LCOH) production by technology per year in Net Zero Scenario[1]

USD/kg



Other sources, such as Bloomberg, indicate the green hydrogen may be cheaper than blue hydrogen in 2030

Lower-range cost

USD/kg

2020	2030	2050
3.8	1.3	0.9
1.5	0.9	0.9
1.0	0.5	0.5

Green H_2 median LCOH expected to drop from USD6.3/kg in 2021 to USD3.2/kg in 2030 and to USD2.4/kg in 2050

Carbon price (not considered in this analysis) could have significant impact on grey hydrogen competitiveness

1. Ranges of production cost estimates reflect regional variations in costs and renewable resource conditions

Source: IEA, team analysis

CONTENT

Global hydrogen market overview

Opportunities for Brazil in the hydrogen market

Brazil has the potential to become a major green hydrogen exporter globally

Brazil has a strong competitive edge in H2 production with low-cost renewable generation

- Brazil has a favorable combination of factors to produce low-cost renewable energy
  - High quality and availability of solar and wind resources (Brazil is top 10 in terms of installed capacity)
  - Well-disposed infrastructure and good geographic conditions, with over 175,000 kilometers of transmission lines close to potential production sites and consumption regions, and available low-cost land
- Energy cost in Brazil is currently ranging around 39 USD/MWh and may drop below 30 USD/MWh by 2030

As result, Brazil has one of the lowest hydrogen costs globally

- Thanks to this advantage, Brazil can produce green hydrogen at a tax-free FOB cost of 3.3 USD/kg, placing Brazil among the countries with lowest hydrogen costs
- Projected cost by 2030 is 1.7 USD/kg driven by reduction in energy costs, and electrolyzer's capex and efficiency
- The hot spots of hydrogen production in Brazil are the ports of Pecém, Açu, and Suape – among these, Pecém stands out as the primary port due to its shorter distance to Europe and a ZPE providing tax benefits

International market will drive demand as domestic consumption does not seem to be significant

- Most projects are focused on exports to Europe, where Brazilian H_2 might reach ~3.0 USD/kg (w/o taxes) in 2030
  - Other sources of energy and feedstock such as biomass and natural gas might prevail given their lower costs and no concrete regulation of emission control to enforce hydrogen use
  - Green hydrogen may rise in niche purposes such as fertilizer and steel production
- In the longer term, as hydrogen achieve cost parity with other fuels, hydrogen can be used in more applications such as mobility (trucks and trains)

A robust regulatory framework must be in place to make investments viable

- A regulatory framework providing stability for the business environment is essential to make investments viable, and it should include critical factors for Brazilian competitiveness in the global hydrogen market
  - Expand ZPE benefits to other export hubs
  - Ensure current tax/charges exemption for renewable generation and capex acquisition

Source: team analysis

Brazil has abundant availability of the main required feedstock for producing green, blue or moss hydrogen – the majority of the announced projects are primarily focused on the first one

Details in next slides

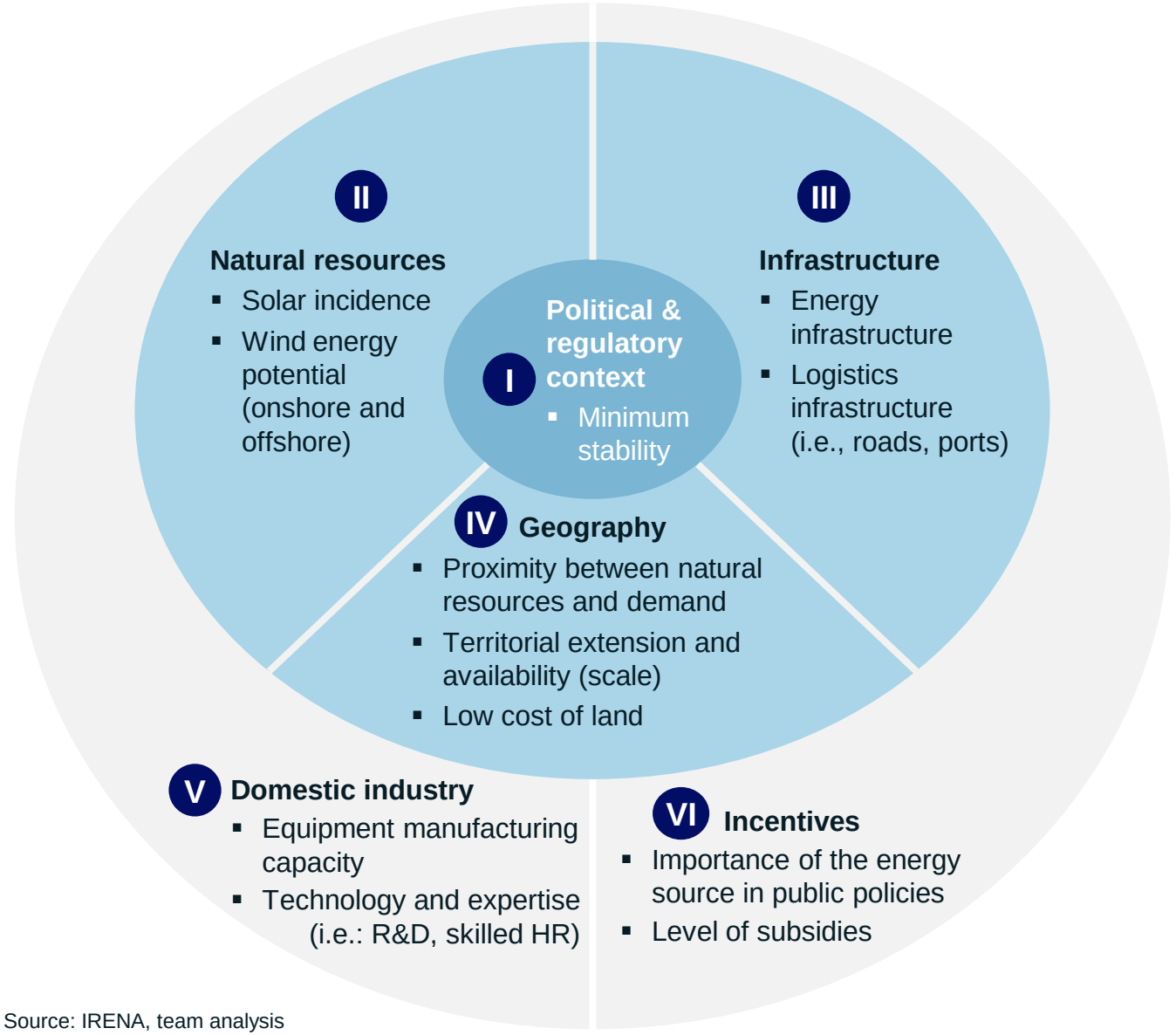
		Feedstock	Availability in Brazil	Announced projects
Green hydrogen	Electrolysis	Solar and wind electricity	Abundant specially in the Northeast	56
		Freshwater	Widely available in most regions – Long coast for desalination available as well	
Blue hydrogen	Steam reforming	Natural gas	Widely available	2
		Freshwater	Widely available in most regions – Long coast for desalination available as well	
	Auto thermal reforming	Natural gas	Widely available	
		Freshwater	Widely available in most regions – Long coast for desalination available as well	
Moss hydrogen	Catalytic reforming	Biomass	Widely available	0
		Critical metals (e.g., Rh, Ir, Pd, Pt)	Available at high cost	
	Gasification	Biomass	Widely available	
		Steam	Widely available	
	Anaerobic digestion	Biomass	Widely available	
		Enzymes	Natural appearance during the process	

In addition to the green hydrogen, experts support that Brazil could also be a relevant producer blue and moss hydrogen

Source: IRENA, team analysis

Brazil combines critical factors that provide competitive advantage in renewable generation

Key criteria for a renewable energy cost assessment



Minimum requirement | Core criteria | Additional advantages

Brazil meets key requirements to produce low-cost renewable energy

I Political & regulatory context
- Minimum stability met as a democratic and politically stable country ✓

II Natural resources
- High solar incidence in most regions ✓
- High onshore and offshore wind energy potential, specially in the Northeast ✓

III Infrastructure
- Existence of a National Interconnected System ✓
- Road access in most regions ✓
- Existence of large ports ✓

IV Geography
- Vast territorial extension, with available and low-cost land with solar and wind energy potential ✓

V Domestic industry
- Regional manufacture of key renewable energy production equipment ✓

VI Incentives
- Government policies and relevant subsidies offered by the government directed to clean energy generation ✓

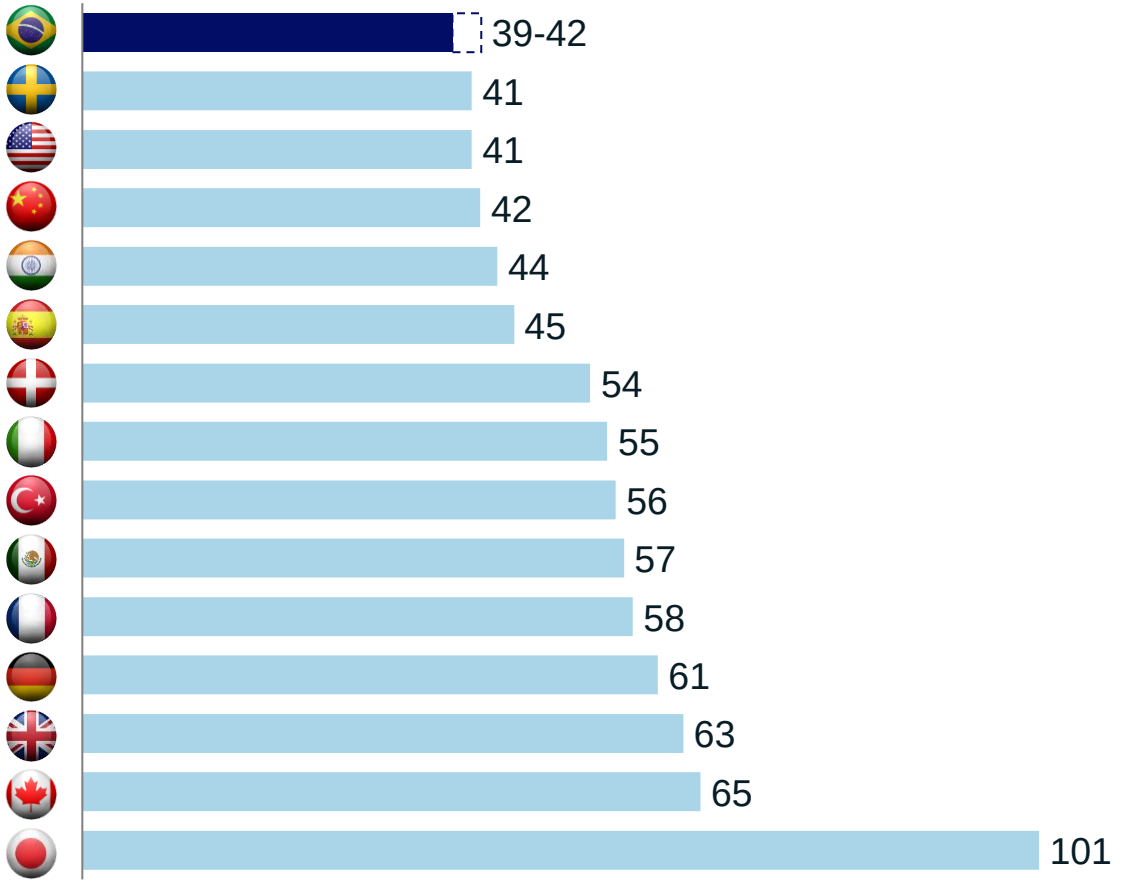
Source: IRENA, team analysis

Current Brazilian renewable energy cost is highly competitive in the international landscape

Lower limit (Brazil) | Upper limit (Brazil) | Average

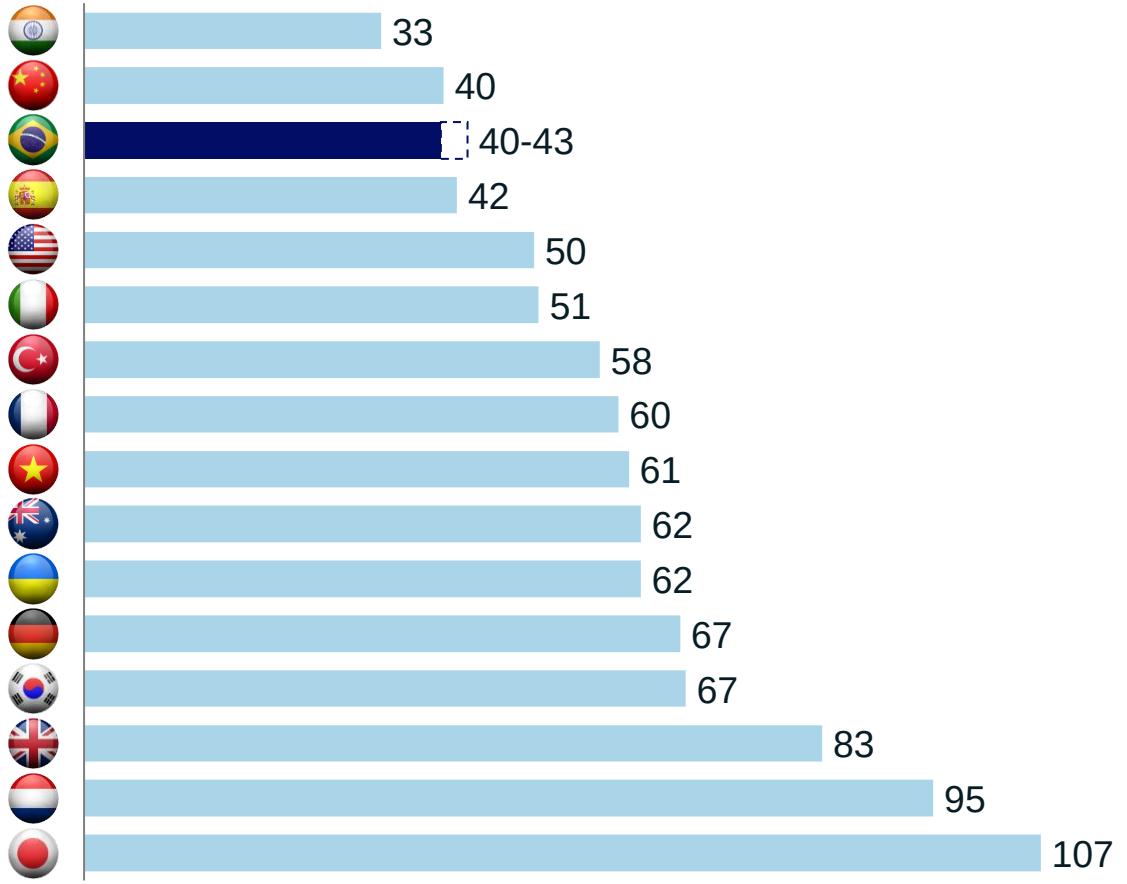
Levelized cost of wind energy for selected countries, 2023[1]

USD/MWh



Levelized cost of solar energy for selected countries, 2023[1]

USD/MWh

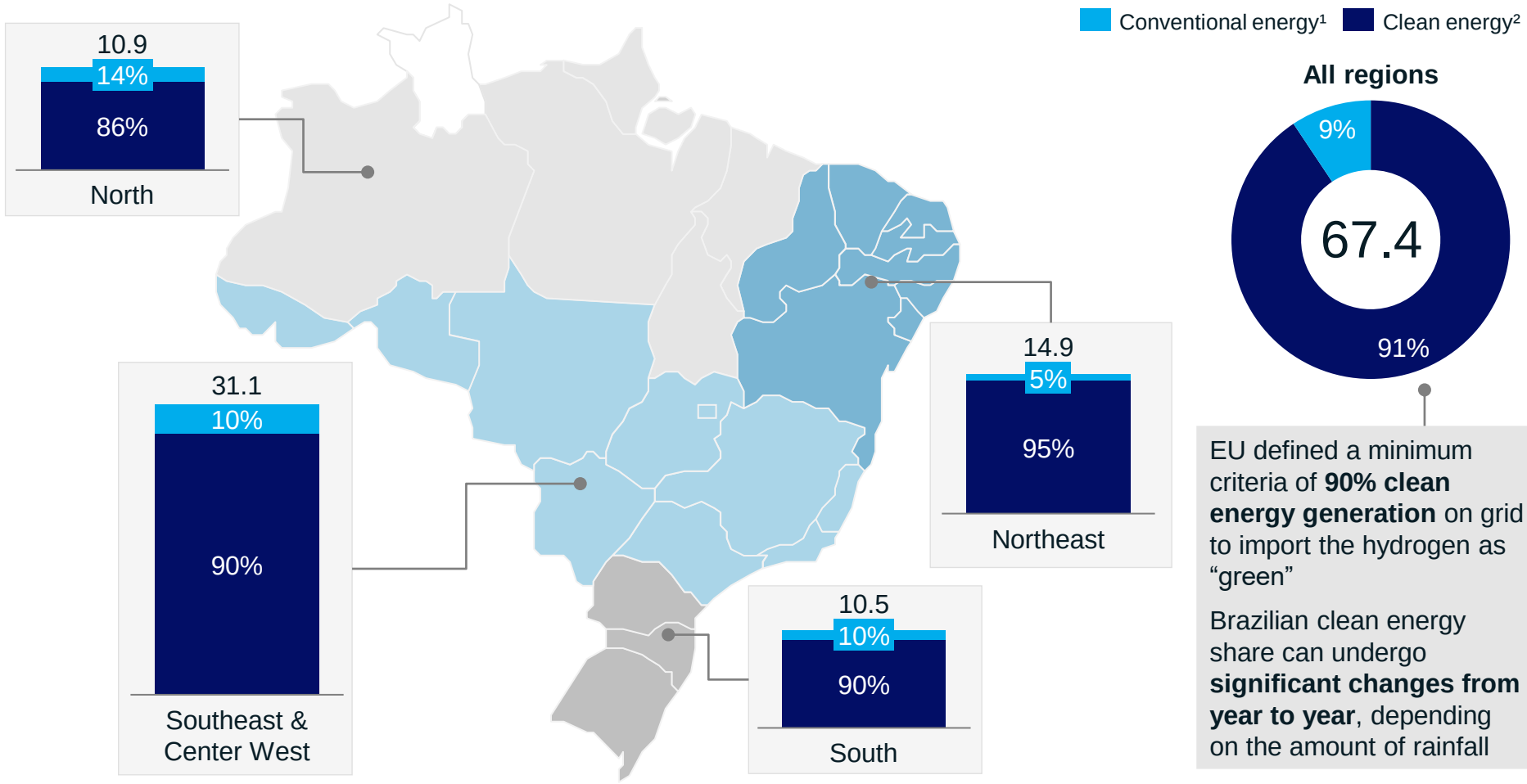


1. Brazil data was extracted from the Mirow model, considering self energy production (full operation) with 80% accuracy in the most attractive areas. Data for other countries originally refer to 2019 but were multiplied by a global energy cost reduction rate forecasted by BP between 2019 and 2023 (-25,5% for solar energy and -10,8% for wind energy)
Source: IRENA, BP, Mirow hydrogen model, team analysis

Brazil can take advantage of a clean electrical grid, making even on-grid projects viable – the Northeastern region is especially attractive

Brazilian energy generation, 2022

MWmed (000')



All regions

EU defined a minimum criteria of **90% clean energy generation** on grid to import the hydrogen as "green"

Brazilian clean energy share can undergo **significant changes from year to year**, depending on the amount of rainfall

Green hydrogen certification

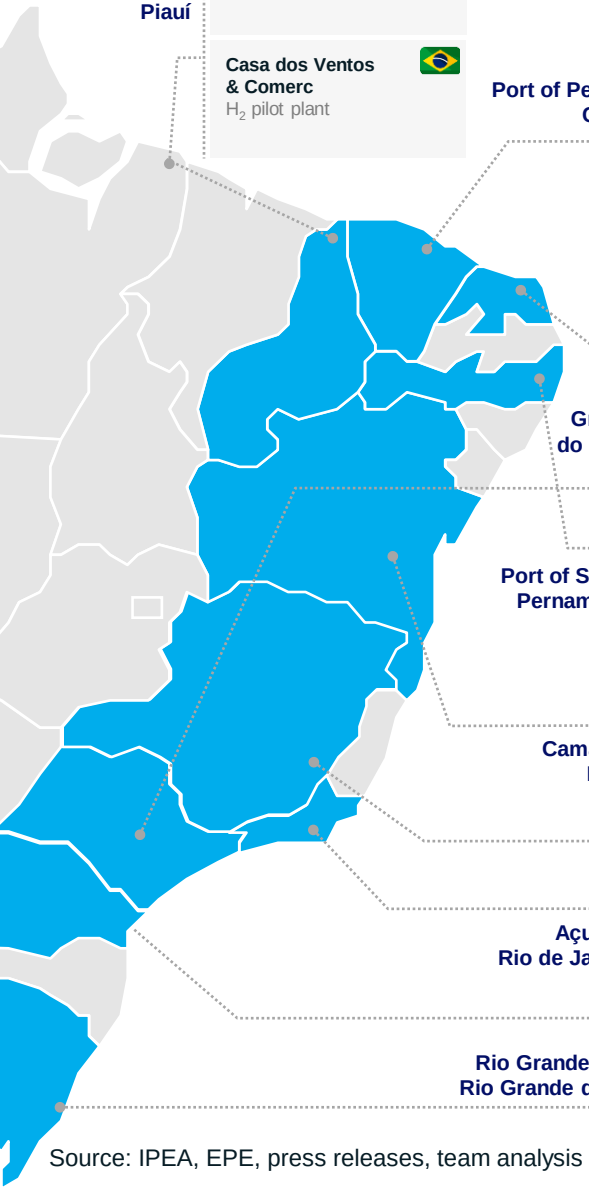
- **Very fragmented global market**
  - There are currently at least **8 voluntary certification schemes** around the world, which have fundamental differences among them
- In **Brazil**, CCEE published in Dec/22 a **Hydrogen Certification Manual**, based on the latest definitions of the European standards, which defines:
  - **Renewable H_2**: fully produced with renewable energy from PPA, self-production or a mix of them, on-grid or off-grid
  - **Partially renewable H_2**: produced with energy from the grid that exceeds the renewable energy PPA or self-production

1. It considers natural gas, coal, industrial waste, fuel oil, diesel oil and other multi-fuel
2. It considers wind, solar, biomass, nuclear and hydraulic

Source: ONS, CCEE, EPBR, team analysis

In Brazil, 40+ potential projects were identified mostly aiming the export market

NON-EXHAUSTIVE



Piauí

Green Energy Park & Solatio
20 GW H_2 project

Casa dos Ventos & Comerc
H_2 pilot plant

Port of Pecém, Ceará

EDP
USD 8 Mi in investment
200 t/year of H2
3 MW power capacity

Enegix Energy
USD 5.4 Bi in investment
615,000 t/year of H2
3.4 GW power capacity

AES Brasil
USD 2 Bi in investment
240 t/year of H2
2 GW power capacity

Fortescue Future Industries
USD 6 Bi in investment
300,000 t/year of H2
2.1GW power capacity

Linde (White Martins)
Memorandum signed for green hydrogen

MingYang
USD 1 Bi in investment (estimated)
Memorandum signed for green hydrogen among others

Neoenergia/Iberdrola
Memorandum to analyze the use of green hydrogen in public transport

Qair
USD 6.95 Bi in investment
296,000 t/year of H2
2.2 GW power capacity

Casa dos ventos & Comerc & THA
USD 6 Bi in investment
345,000 t/year of H2
2.4 GW power capacity

Transhydrogen Alliance
USD2 billion
500,000 t/year of H2

Engie
Memorandum signed for green hydrogen project

Enel
Memorandum signed for green hydrogen project

Eneva, Differential, Hytron
Memorandum signed for green hydrogen

+17 more projects with companies from **energy and petrochemical industries**

Rio Grande do Norte

Enterprize Energy
Memorandum signed for offshore wind and green hydrogen plant with ammonia production

Internacional Energias Renováveis
USD 3.2 billion in investment offshore wind solar and green hydrogen plant

Neoenergia/Iberdrola
Memorandum signed for green hydrogen

São Paulo

Shell
Up to 39 t/year of H_2

Port of Suape, Pernambuco

Linde group (White Martins)
156 t/year of green H2
1.6 MW power capacity

Qair
USD 3.8 Bi in investment
488,000 t/year of green H2
190,000t/year of blue H2
1 GW power capacity

Fortescue Future Industries
No further information

Casa dos Ventos
No further information

Neoenergia/Iberdrola
Memorandum signed for green hydrogen

CTG Brasil
Up to USD 9 Mi in investment

Voltalia
Memorandum signed for green hydrogen

Camaçari, Bahia

Unigel
USD 1.5 Bi in investment
100,000 t/year of green H2 240 MW power capacity

CGN Brazil Energy
14GW wind and solar power plant to supply energy for H_2 production

Uberaba, Minas Gerais

Atlas Agro
USD 850 Mi in investment
500,000t/year of ammonia

Açu Port Rio de Janeiro

Fortescue Future Industries
250,000 t/year of ammonia
300 MW power capacity

Shell
Up to USD 40 Mi in investment 10 MW power capacity in 2025 w/ expansion up to 100 MW in the future

Linde group (White Martins)
Memorandum signed for green hydrogen

Neoenergia e Prumo
Memorandum signed for green hydrogen

Rio Grande Port, Rio Grande do Sul

Neoenergia/Iberdrola
Memorandum signed for green hydrogen

Linde group (White Martins)
Memorandum signed for green hydrogen

Paraná

Engie
Memorandum signed for green hydrogen as part of project to produce globally 4 GW of green hydrogen by 2030

80%+ of the projects announced are in the northeast and **60%** of all the investment announced for Brazil is in Ceará

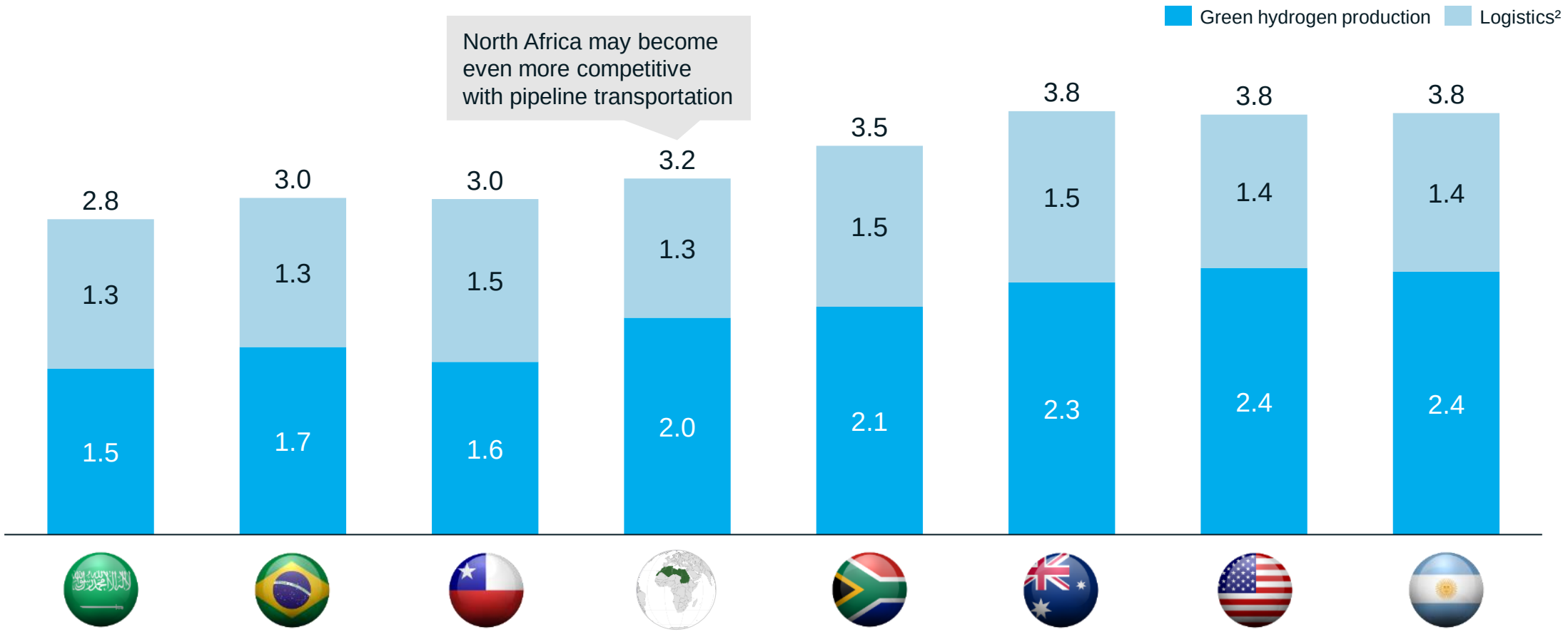
60%+ of the projects announced in Brazil are led by **energy companies** aiming to export

Source: IPEA, EPE, press releases, team analysis

As a result, Brazilian green hydrogen could become highly competitive in meeting the demands of the European import market

Levelized cost of green hydrogen in Rotterdam port, by selected exporting countries/regions, 2030[1]

US$/kgH2



1. Brazil data source is Mirow hydrogen model. For other countries, it was considered IEA data without taxes and subsidies
2. It includes conversion, storage, shipping (by cargo ship) and reconversion costs using ammonia as a carrier

Source: Searoutes, IEA, Goldman Sachs, Bloomberg, Mirow hydrogen model, team analysis

A variety of potential applications for green hydrogen could promote the development of a domestic market in Brazil; however, most won't be viable in the short term without incentives

		Rationale for green H2 application	Likelihood of adoption	Estimated time to breakeven	Main hydrogen-based product
Industry	Steel	▪ Steelmakers in Brazil can apply low-cost hydrogen to produce and export green steel products	Likely	Long term (+10 years)	▪ H2 gas
	Fertilizer	▪ Brazil can produce green fertilizers for agriculture, especially crops typically for exports	Likely	Medium term (5-10 years)	▪ Urea[1]
	Refining	▪ Replacement of gray hydrogen currently used in the hydrotreatment and hydrocracking processes in refineries	Possible	Medium term (5-10 years)	▪ H2 gas
	Gas pipes input	▪ Hydrogen can be blended in current natural gas infrastructure up to 15-20% without significant retrofit in the network ▪ Deeper understanding of impact on thermal power plants operation is needed	Possible	Long term (+10 years)	▪ H2 gas
	Power generation	▪ Brazilian energy matrix is already highly clean and other sources of energy are expected to be priority (wind, solar) ▪ Natural gas may also gain relevance	Very unlikely	Long term (+10 years)	▪ H2 gas
Mobility	Ships	▪ Renewable fuels are gaining importance as alternatives to reduce emissions in shipping and aviation, both driven by regulatory targets ▪ E-methanol and SAF, particularly from H2, are potential options	Likely	Medium term (5-10 years)	▪ E-methanol[2]
	Airplanes		Likely	Medium term (5-10 years)	▪ E-SAF
	Trucks	▪ Long-haul trucks and trains are hard to electrify due to expensive batteries and bio-fuels could not meet the full demand	Possible	Short term (up to 5 years)	▪ H2 gas
	Trains		Possible	Short term (up to 5 years)	▪ Ammonia
	Cars	▪ Electric cars are probably the mainstream technology for decarbonization, together with currently used ethanol	Unlikely	Medium term (5-10 years)	▪ H2 gas

1. And other nitrogen fertilizers produced from ammonia; 2. Ammonia and hydrogen gas are also potential fuels for ships
Source: expert interviews, team analysis

MIROW & CO.