Hydrogen and Energy 101: Role of CCUS

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Outline of Presentation

- Production and Uses of H_2
- Integration of Fossil Energy into the H_2 Economy
- H_2 as a Solution to a Carbon-Neutral Economy
- Brief Look at the H_2 Economy
- Health/Safety Aspects of H_2
- Global CCS Projects
- Challenges in Scaling up the H_2 Economy
- Concluding Remarks

Production and Uses of Hydrogen

- H_2 economy is big news today, but challenges to produce, use and store H_2. Significant increase in H_2 use by 2050 - countries transition toward a low-carbon economy. Fossil fuels (mostly natural gas) will remain primary source of H_2 by 2050
- ~ 70% of global CO_2 production is from Steam Methane Reforming (SMR) of natural gas
- Main uses of H_2 : Ammonia (NH_3) production for fertilizers; as a chemical feedstock and catalyst; in petrochemical and refinery processing. Secondary uses: As mixture of gases for methanol and steel production. Current share from renewables and fossil fuel plants with CCUS is very low (< 0.7%)
- Price of H_2 varies between regions, end uses and H_2 transportation

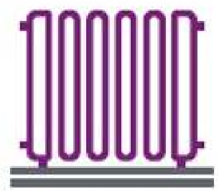
Hydrogen production: what colour?

	Commonly used term	Process	Carbon output
	"Grey" hydrogen	• Fossil fuel-to-hydrogen conversion • Electrolysis based on high-carbon electricity	• Fossil CO_2 is emitted
"CLEAN/LOW-CARBON"	"Blue" hydrogen	• Fossil fuel-to-hydrogen conversion with CCS	• Fossil CO_2 is captured and stored
"CLEAN/LOW-CARBON"		• Methane pyrolysis	• No CO_2 is emitted, solid carbon is produced
"CLEAN/LOW-CARBON"	"Green" hydrogen	• Sustainable biomass-to-hydrogen conversion	• Biogenic CO_2 is emitted
"CLEAN/LOW-CARBON"		• Water-splitting (electrolysis/photoelectrocatalytic) based on renewable electricity	• No CO_2 is emitted
"CLEAN/LOW-CARBON"	Carbon negative hydrogen	• Sustainable biomass-to hydrogen-conversion with CCS	• Biogenic CO_2 is captured and stored
"CLEAN/LOW-CARBON"		• Biomass pyrolysis	• No biogenic CO_2 is emitted, solid carbon is produced

REF: IOGP Fact Sheet, 2020 - H2 Scaling up hydrogen in Europe

Hydrogen applications

As a feedstock in the **chemical, refining and steel industry**, and as low-carbon fuel in energy-intensive processes



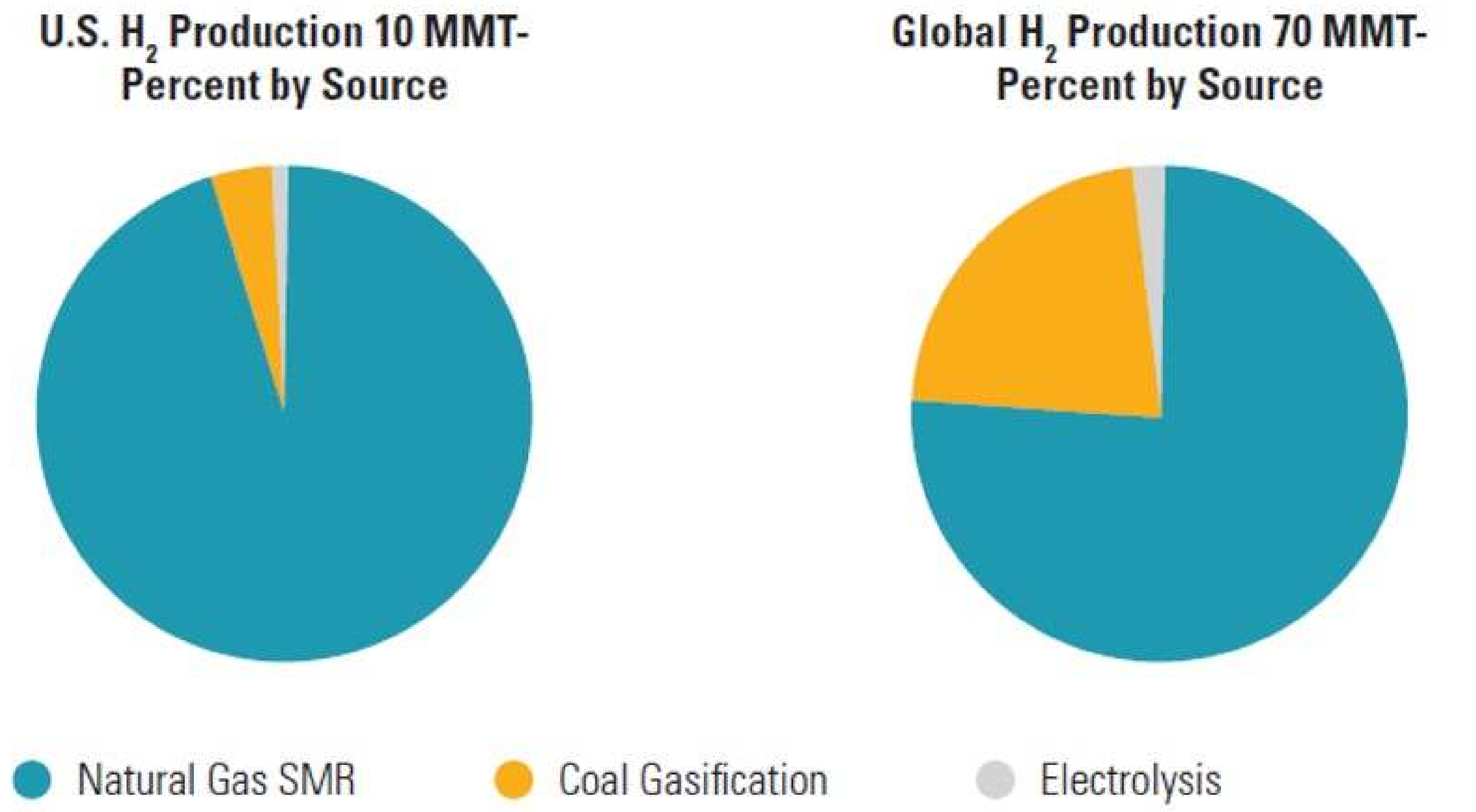
Used into the gas grid to decarbonise **residential and commercial heating**

In **passenger cars**, as well as **heavy** and **long-haul road** and **maritime transport**

In the **power sector**, supporting the transition towards net-zero emissions

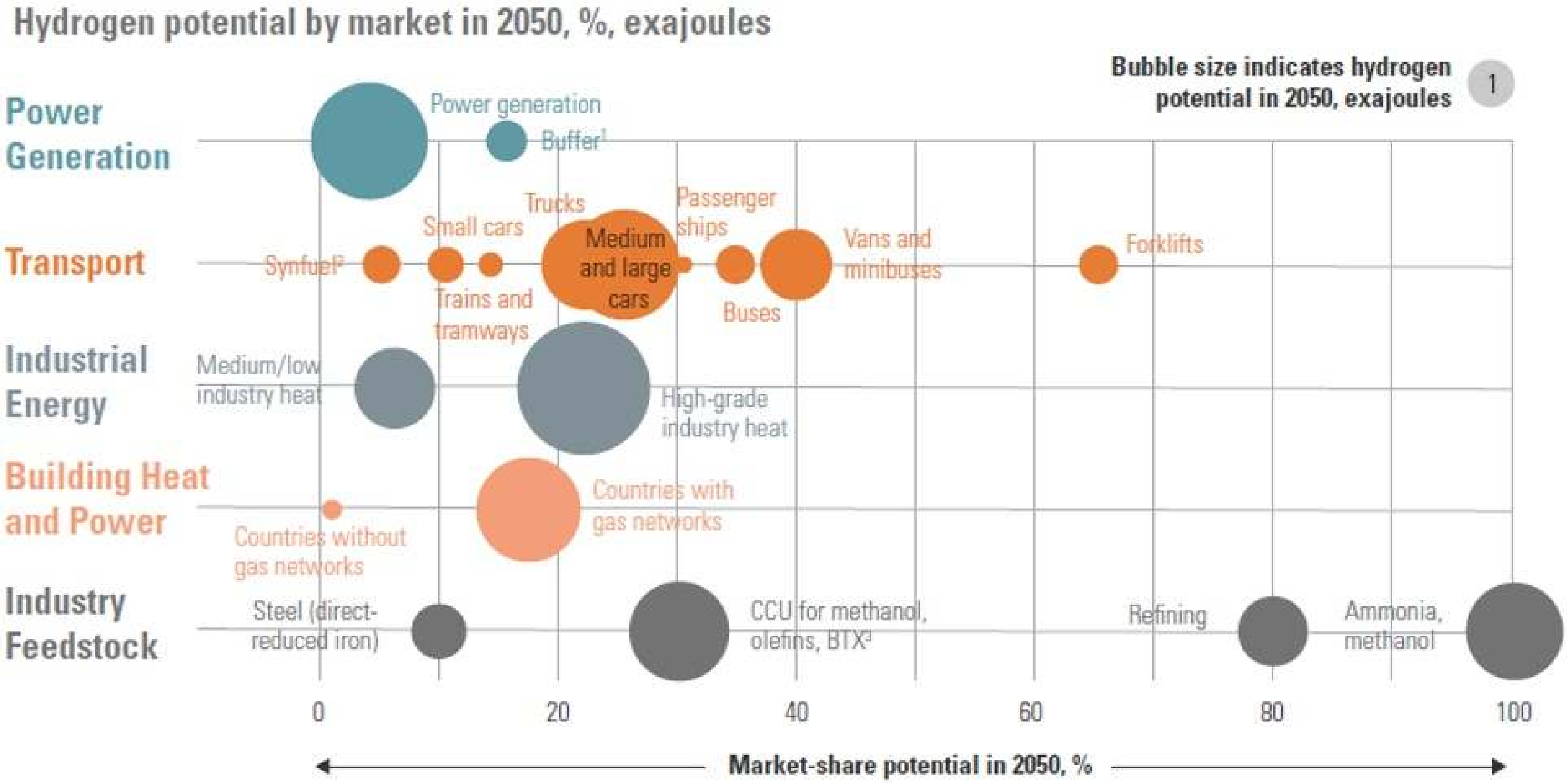
REF: IOGP Fact Sheet, 2020 – H2 Scaling up hydrogen in Europe

Figure 3. U.S. and Global Production of Hydrogen



REF: Hydrogen Strategy: Enabling A Low-Carbon Economy, USDOE, July 2020

Figure 8. Global Potential for Future Use of Hydrogen



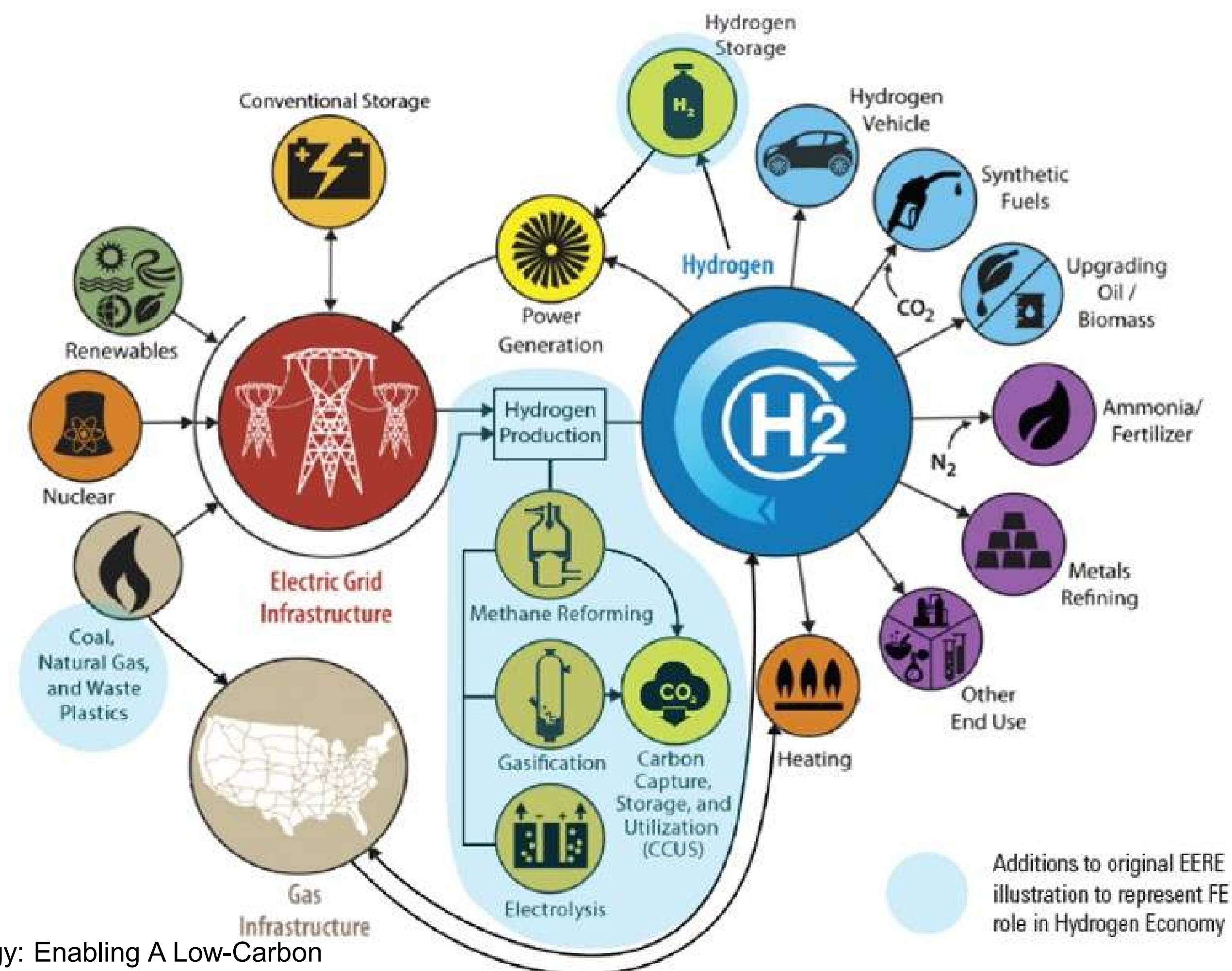
[1] % of total annual growth in hydrogen and variable renewable-power demand.

[2] For aviation and freight ships.

[3] Carbon capture and utilization; % of total methanol, olefin, and benzene, toluene, and xylene (BTX) production using olefins and captured carbon.

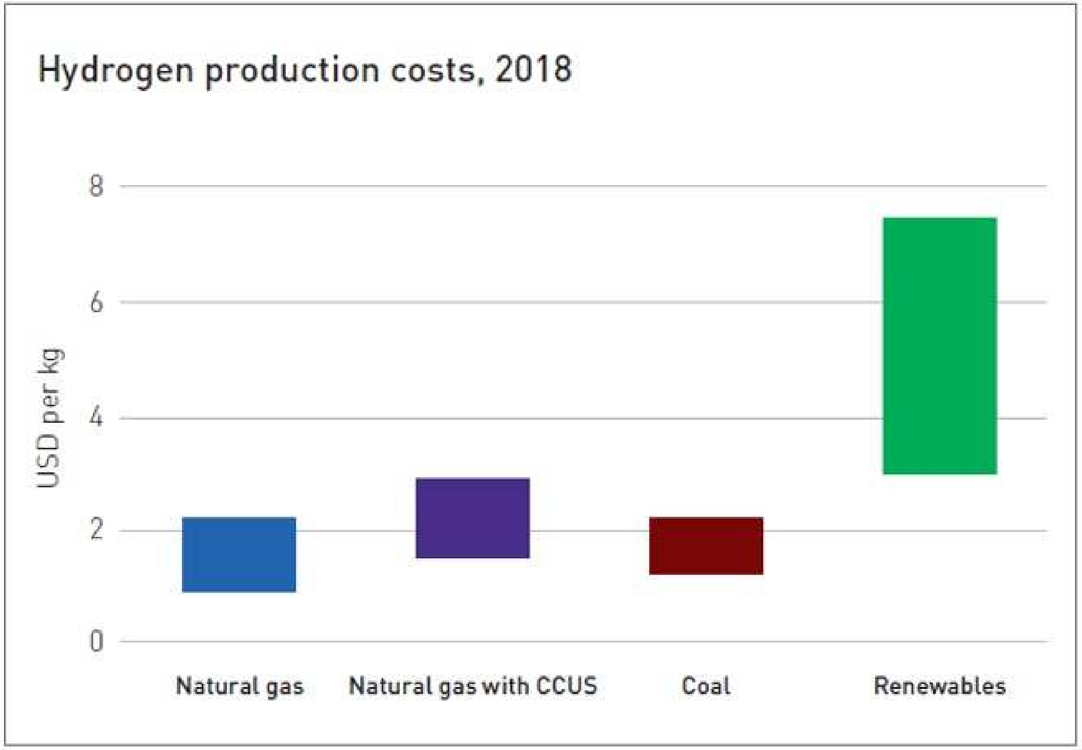
REF: Hydrogen Strategy: Enabling A Low-Carbon Economy, USDOE, July 2020

Figure 1. Integration of Fossil Energy into the Hydrogen Economy[4]



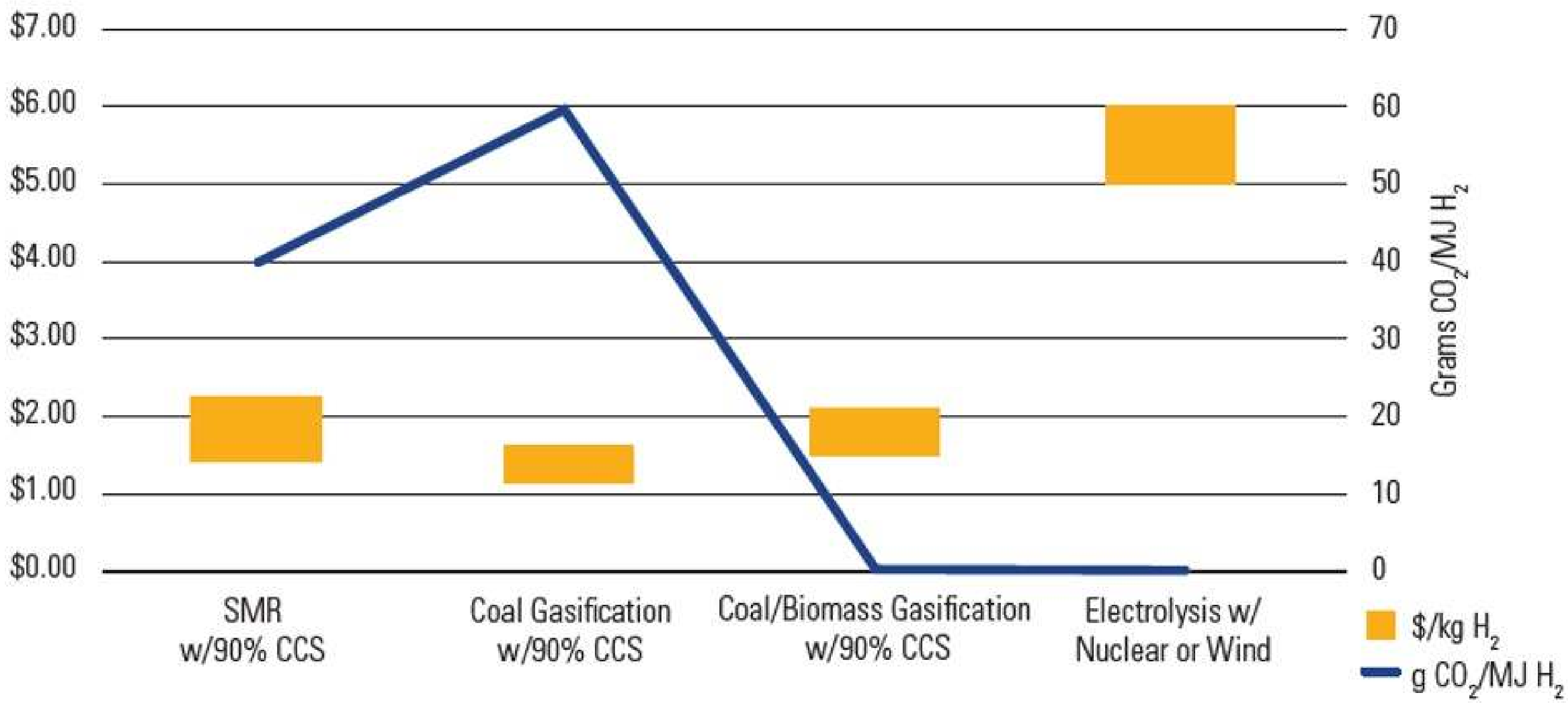
REF: Hydrogen Strategy: Enabling A Low-Carbon Economy, USDOE, July 2020

The potential of CCS applied to hydrogen production



Source: IEA (2019)

Figure 4. Current Cost of Hydrogen Production and CO_2 Intensity

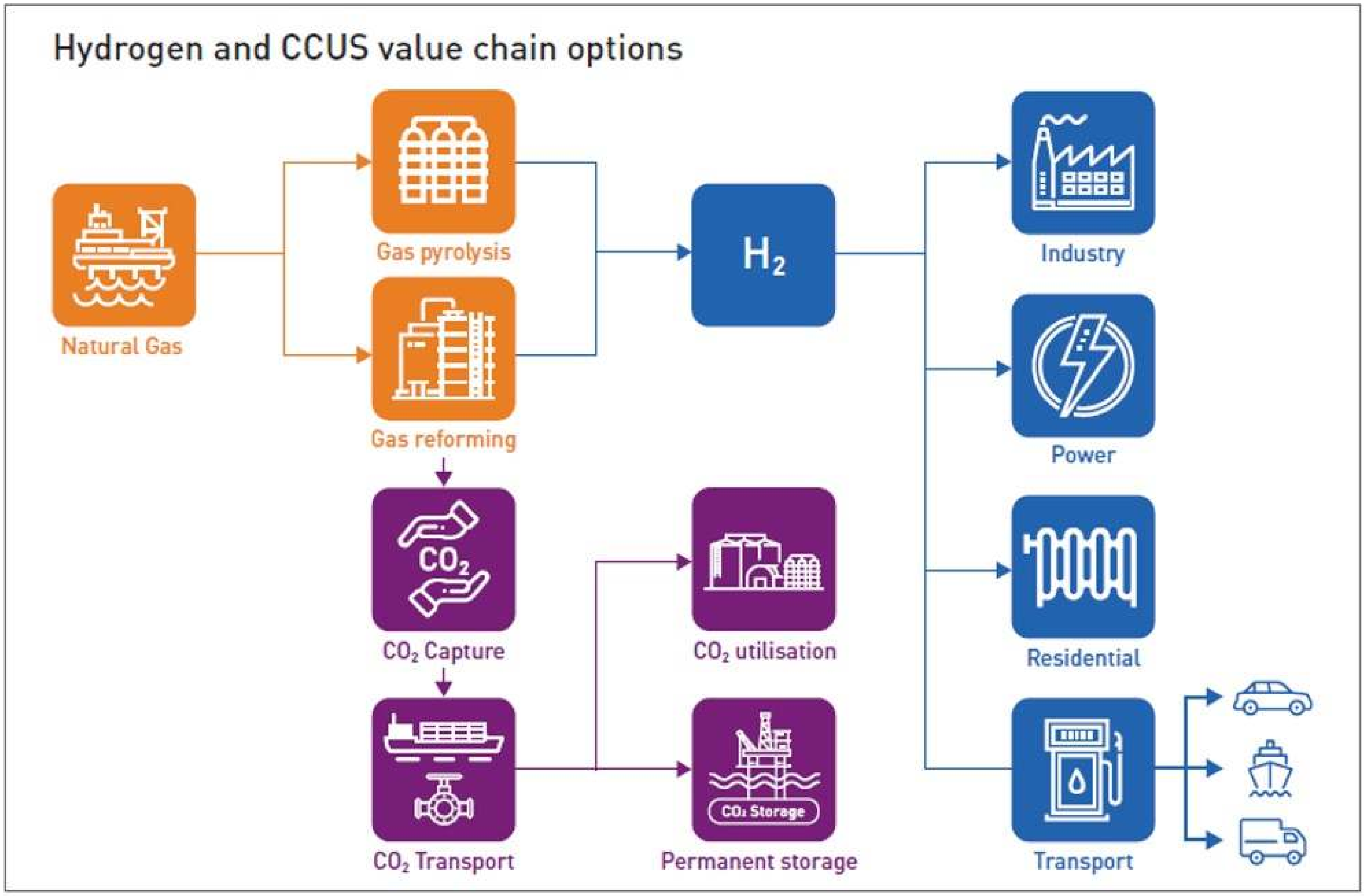


(Source: IEA Roadmap for Hydrogen and Fuel Cell and DOE Baseline Studies)

Hydrogen Strategy: Enabling a Low-Carbon Economy, USDOE, July 2020

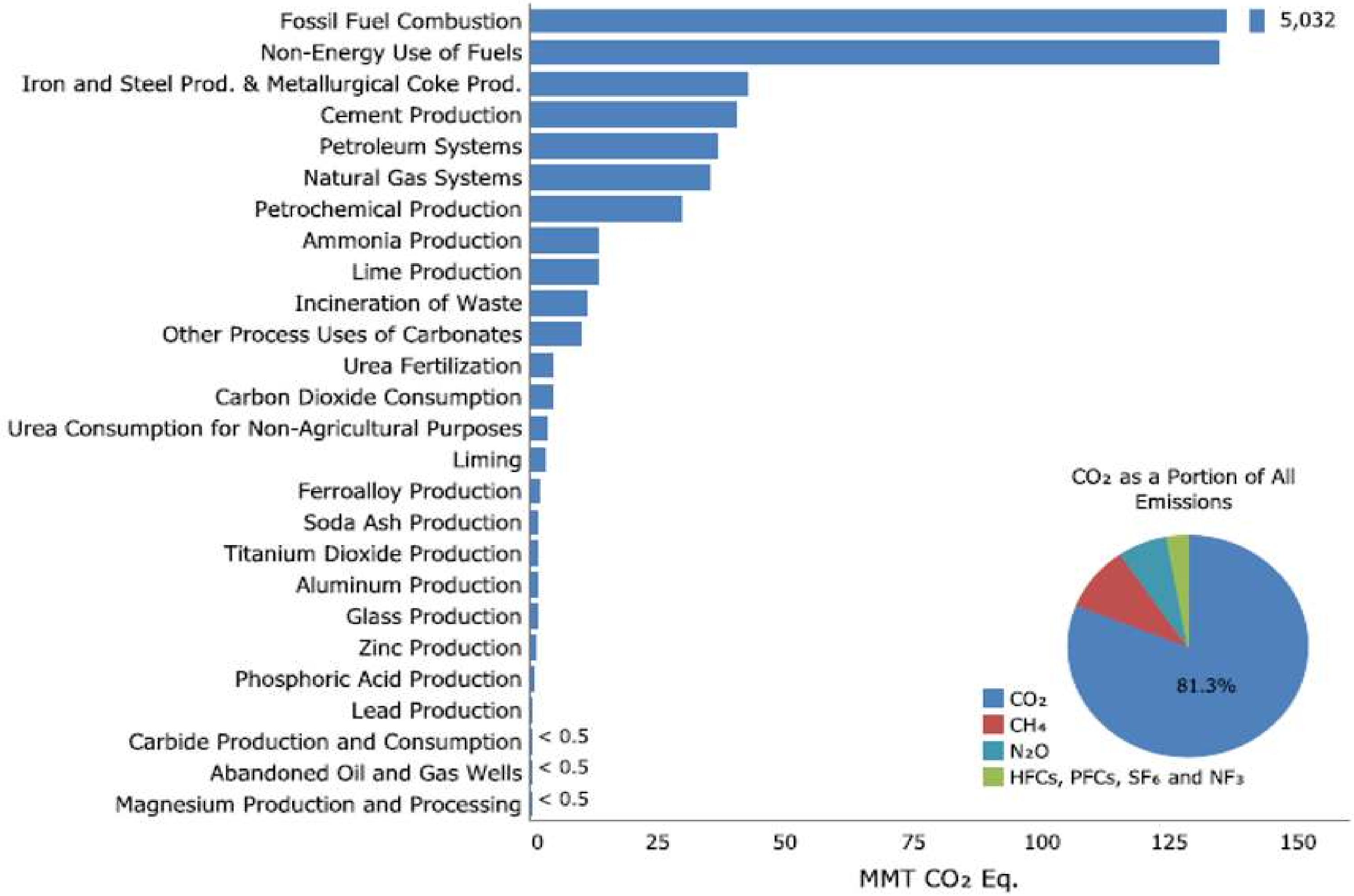
H_2 as Part of Solution to a CO_2 -Neutral Energy Supply

- H_2 is not an energy source but an energy carrier - key reason why H_2 might outcompete electricity in some situations. Since H_2 combustion produces H_2O but no CO_2 – ideal for producing CO_2 – neutral energy (like electricity)
- H_2 can be stored (in tanks and underground) and transported in a stable way (can use existing gas pipeline network)
- H_2 can be combined with carbon and nitrogen to make hydrogen-based fuels (easier to handle), and used as feedstock in industry, reducing emissions
- Can reduce high CO_2 intensity upstream by replacing fossil fuels with renewables or nuclear as initial energy input, or equip fossil fuel plants with CCUS
- "Carbon Neutral" refers to GHG reduction (Kyoto Protocol, 1997 – carbon offset credit) and "Net Zero Carbon" aims to limit global carbon emissions to reach net zero by 2050 (limits surface temperature rise to 1.5^0 C – Paris Agreement)



REF: IOGP Fact Sheet, 2020 – H2 Scaling up hydrogen in Europe

Figure ES-5: 2018 Sources of CO_2 Emissions (MMT CO_2 Eq.)



REF: EPA 430-R-20-02 – Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 - 2018

Brief Look at the H_2 Economy

- Deploying clean H_2 could reduce ~ 34% of GHG emissions from fossil fuels by 2050.
- A scaled-up H_2 industry can lower cost of renewable H_2 to $ 2/kg in 2030 and to $ 1/kg in 2050 (compared to current cost of $ 7.50/kg for green and $ 2.40/kg for blue H_2). Costs could be ~ 25% lower in U.S., Brazil, Australia, Scandinavia, Middle East with good renewable and H_2 geologic storage resources and ~ 50 – 70% higher in Japan and Korea
- Steel industry – likely benefactor of H_2 economy (~ 9% of global carbon emissions) by using H_2 instead of fossil fuels for half of global output by 2050
- Home heating and cooking – another benefactor by blending 5-20% with natural gas for transport through existing pipelines. Similar analog to switch use of *town gas (H2/CO mix) to natural gas* for heating/cooking in major cities in the 1960s
- H_2 will play a bigger role in transportation (near term mainly for trucks/buses/long-haul transport rather than for cars/motorcycles)

Physical Properties of Hydrogen/Health and Safety Risks

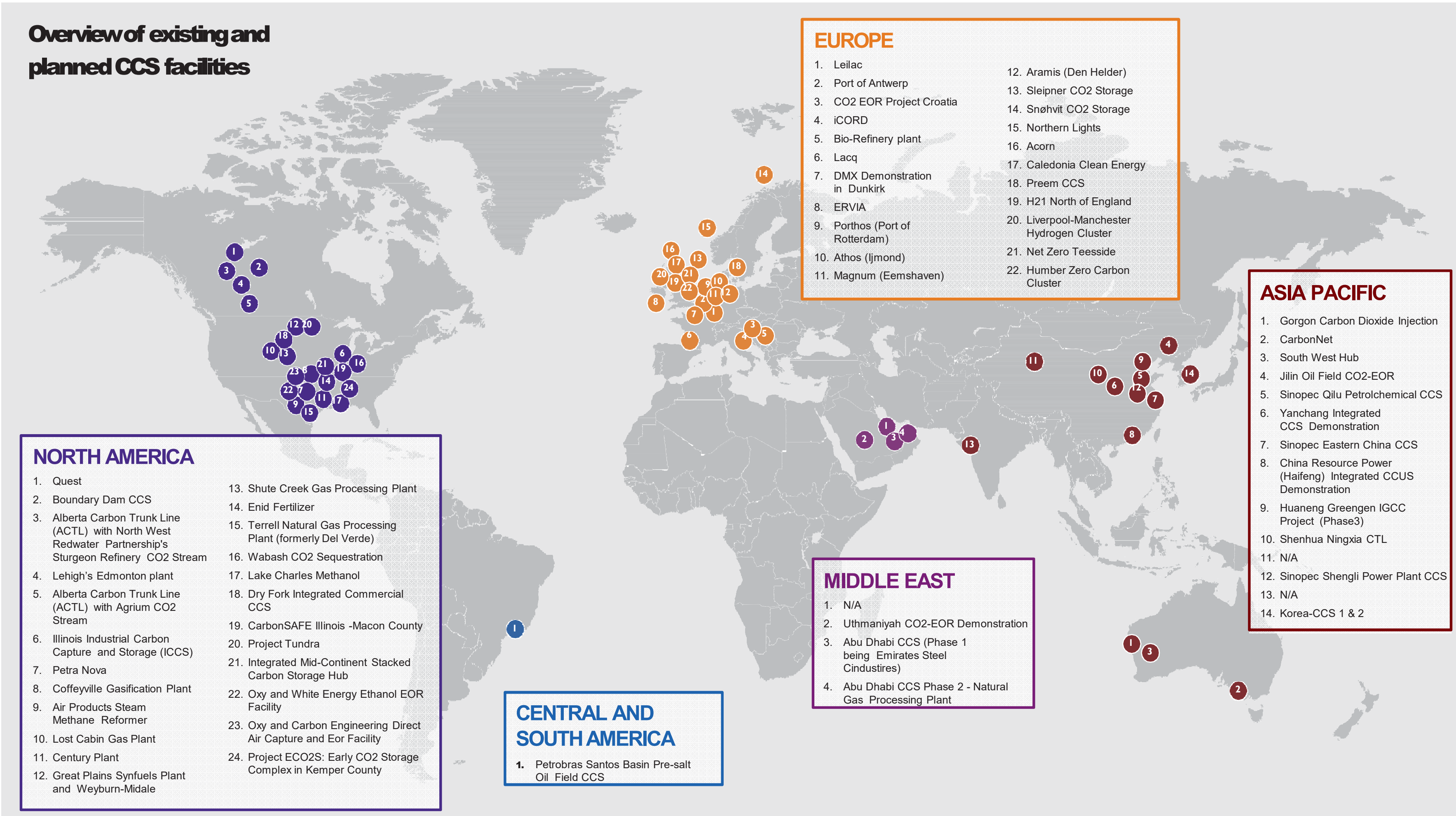
- H_2 has more energy/unit of mass compared to natural gas or gasoline (attractive as transport fuel), however has low energy density/unit of volume. Need larger H_2 volumes to meet identical energy demands as other fuels. Use larger or faster-flowing pipelines and larger storage tanks.
- H_2 can be compressed, liquified, or transformed into H_2-based fuels with a higher energy density, but this (and subsequent re-conversion) uses some energy
- H_2 handling requires special equipment and procedures. Diffuses into some materials (iron and steel pipes and through sealings and connections) more easily than natural gas.
- H_2 is a non-toxic gas, but highly flammable due to its high flame velocity, broad ignition range and low ignition energy. H_2 flame not visible to the naked eye and since it is colorless and odorless difficult to detect fires and leaks. Adequate ventilation and leak detection and special flame detectors are required - widespread use would bring new challenges that will have to be addressed.
- Health and safety considerations of H_2 -based fuels and feedstocks are familiar in the energy sector - exceptions are NH3 and liquid organic hydrogen carriers (LOHCs)
- NH3 raises more health and safety concerns than H_2 and will require professionally trained operators. It is highly toxic, flammable, corrosive and escapes from leaks in gaseous form. However, unlike H_2 it has a pungent smell and can be easily detected

Geological storage of H_2

- Geological storage best option for large-scale/ long-term storage and tanks for short-term/ small-scale storage
- Possible storage sites: Salt caverns, depleted O&G reservoirs and deep saline aquifers
- Salt caverns used for H_2 storage in UK since 1970s and in US since 1980s (with largest H_2 storage facility – 10-20 ktH2) and likely the lowest-cost option
- Depleted O&G reservoirs have larger capacity, but are more permeable and require contaminants removal prior to use in fuel cells
- Aquifers have least amount of experience. Both depleted O&G and aquifers have natural barriers that can provide containment. If can overcome challenges, may be best for large scale H_2 storage

International Association of Oil & Gas Producers

Global CCS projects



Overview of existing and planned CCS facilities

NORTH AMERICA

1. Quest
2. Boundary Dam CCS
3. Alberta Carbon Trunk Line (ACTL) with North West Redwater Partnership's Sturgeon Refinery CO2 Stream
4. Lehigh's Edmonton plant
5. Alberta Carbon Trunk Line (ACTL) with Agrium CO2 Stream
6. Illinois Industrial Carbon Capture and Storage (ICCS)
7. Petra Nova
8. Coffeyville Gasification Plant
9. Air Products Steam Methane Reformer
10. Lost Cabin Gas Plant
11. Century Plant
12. Great Plains Synfuels Plant and Weyburn-Midale
13. Shute Creek Gas Processing Plant
14. Enid Fertilizer
15. Terrell Natural Gas Processing Plant (formerly Del Verde)
16. Wabash CO2 Sequestration
17. Lake Charles Methanol
18. Dry Fork Integrated Commercial CCS
19. CarbonSAFE Illinois -Macon County
20. Project Tundra
21. Integrated Mid-Continent Stacked Carbon Storage Hub
22. Oxy and White Energy Ethanol EOR Facility
23. Oxy and Carbon Engineering Direct Air Capture and Eor Facility
24. Project ECO2S: Early CO2 Storage Complex in Kemper County

CENTRAL AND SOUTH AMERICA

1. Petrobras Santos Basin Pre-salt Oil Field CCS

EUROPE

1. Leilac
2. Port of Antwerp
3. CO2 EOR Project Croatia
4. iCORD
5. Bio-Refinery plant
6. Lacq
7. DMX Demonstration in Dunkirk
8. ERVIA
9. Porthos (Port of Rotterdam)
10. Athos (Ijmond)
11. Magnum (Eemshaven)
12. Aramis (Den Helder)
13. Sleipner CO2 Storage
14. Snøhvit CO2 Storage
15. Northern Lights
16. Acorn
17. Caledonia Clean Energy
18. Preem CCS
19. H21 North of England
20. Liverpool-Manchester Hydrogen Cluster
21. Net Zero Teesside
22. Humber Zero Carbon Cluster

MIDDLE EAST

1. N/A
2. Uthmaniyah CO2-EOR Demonstration
3. Abu Dhabi CCS (Phase 1 being Emirates Steel Cindustries)
4. Abu Dhabi CCS Phase 2 - Natural Gas Processing Plant

ASIA PACIFIC

1. Gorgon Carbon Dioxide Injection
2. CarbonNet
3. South West Hub
4. Jilin Oil Field CO2-EOR
5. Sinopec Qilu Petrolchemical CCS
6. Yanchang Integrated CCS Demonstration
7. Sinopec Eastern China CCS
8. China Resource Power (Haifeng) Integrated CCUS Demonstration
9. Huaneng Greengen IGCC Project (Phase3)
10. Shenhua Ningxia CTL
11. N/A
12. Sinopec Shengli Power Plant CCS
13. N/A
14. Korea-CCS 1 & 2

Courtesy: Shell Quest Canada

TABLE 26 | ACTUAL FEED, CAPEX AND OPEX COSTS AND REVENUE FOR SHELL QUEST

[Source: Shell, 2016a and **Shell, 2017m]**

PROJECT PHASE		MILLIONS OF DOLLARS, CANADIAN ($)
COSTS		
FEED		139.4
CAPEX	Labour and commissioning	147.9
	Tie-ins	37.1
	Capture	437.5
	Transporation	127.4
	Storage	40.4
Total CAPEX		790.3
Total CAPEX + FEED		929.7
Annual OPEX	2016 (Actual)	30.2
	2018 (Estimate)	35
REVENUE		
Government Grants		
Alberta	2012-2014[†††††]	298
	2015	149
	2016 and beyond	298
Canada	2009-2014	108
	2015	12
Total Grants		865
CO_2 Credits	2016 (Actual)	3.3
Total REVENUE	To end of 2016 (Actual)	600.1

Top Clean Energy Developments of 2020

- **Coal is on its way out:** (1) US power companies retiring > 12 coal plants in US (~ 26 gigawatts), (2) in Europe coal plants retirements outpaced new plant commissioning, (3) global coal consumption down - COVID-19
- **Gas also in decline:** As utilities retire coal plants, also not replacing coal with gas
- **China and carbon neutrality:** Per Paris Accord, will achieve peak CO2 emissions before 2030 and carbon neutrality by 2060 (by adopting more vigorous policies/measures)
- **Green Deals - carbon-free electricity goes mainstream:** (1) S&P Global Clean Energy index up 37% (in last 2 years), (2) EU stimulus package set aside 25% for clean energy technologies, (3) Biden administration proposed a carbon-free power sector by 2035
- **Big banks make climate commitments:** To reduce carbon intensity of entire portfolios over time
- **Financial Institutions and shipping decarbonization:** Poseidon Principles – finance initiative to decarbonize the maritime sector ($ 140 billion in loans - ~ 30% of global ship finance portfolio)

(SOURCE: Laurie Stone/RMI/Energy Post – Jan 4, 2021)

Top Clean Energy Developments of 2020 (Continued)

- **Green H2 taking off:** Coalition of global companies to scale up and increase green H2 production 50-fold in next 6 years (decarbonize steel industry)
- **US rejoins Paris Agreement:** many states/local ballot measures passed
- **Bans on gas vehicles are growing -** France/Canada/U.K. and dozen others to ban gas vehicles within 2 decades. California has goal to ban IC engine vehicles by 2035
- **Renewed focus on methane emissions:** EU has adopted methane strategy (and major O&G majors have joined)
- **Racial justice enters climate activism discussion:** Most affected by climate change potentially are poor and marginalized communities

Concluding Remarks

- H_2 will play an important role for future energy needs globally
- CCUS will also play a bigger role in enabling transition to a low carbon economy
- Major challenges to massively scale-up the H_2 economy: government policies and financial incentives/subsidies; global cooperation; buildup of infrastructure and commercial markets/hubs; technology challenges – transportation, potential use of existing gas pipeline networks, blending H_2, and decarbonizing major industry sectors – steel, cement etc.
- Industrial-scale production of low-carbon H_2 possible with today's technology with ability for substantial near-term emission reductions
- O&G industry with its unique skills, resources and experience can play a major role in this energy mix transition