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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
- Health/Safety Aspects of H_2
- Geologic Storage of H_2
- Global CCS Projects
- Top Clean Energy Developments
- Concluding Remarks

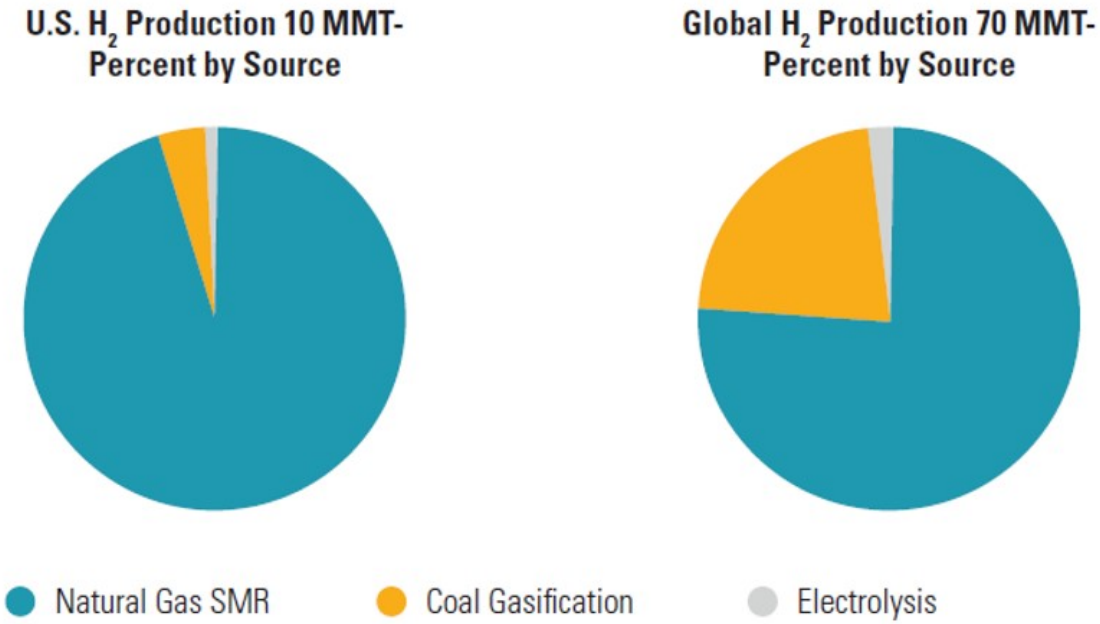
Hydrogen production: what colour?

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

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

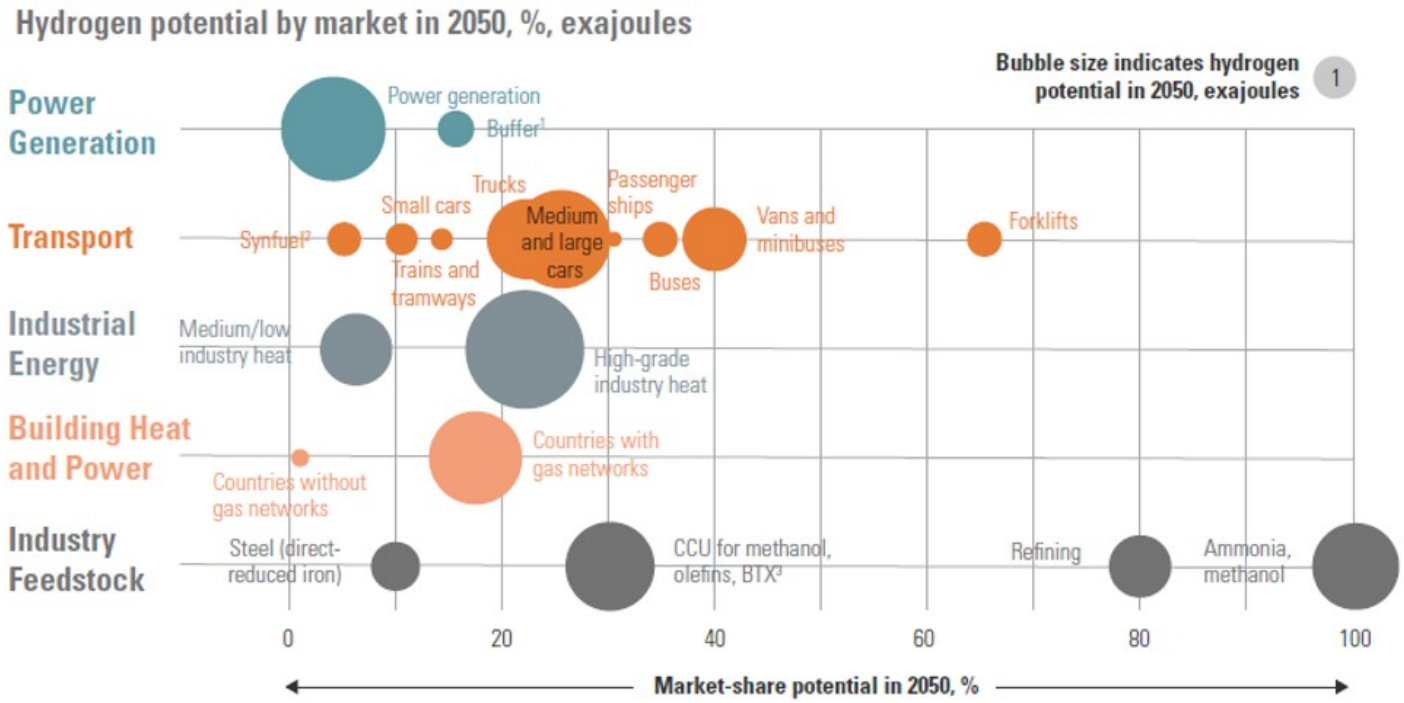
- REF: Hydrogen Strategy: Enabling A Low-Carbon Economy, USDOE, July 2020

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



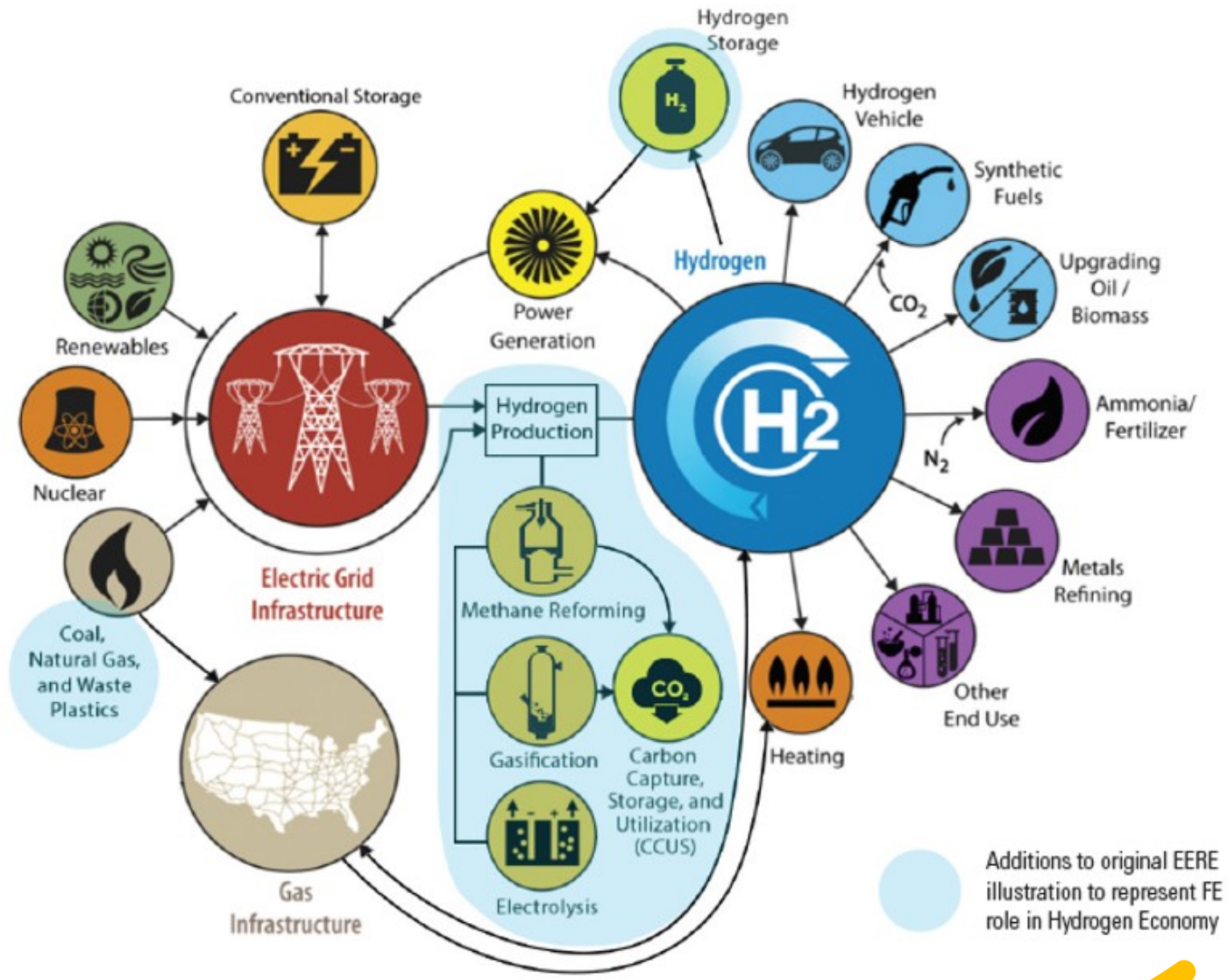
[1] % of total annual growth in hydrogen and variable renewable-power demand.

[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.

- Integration of Fossil Energy into the Hydrogen Economy

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



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

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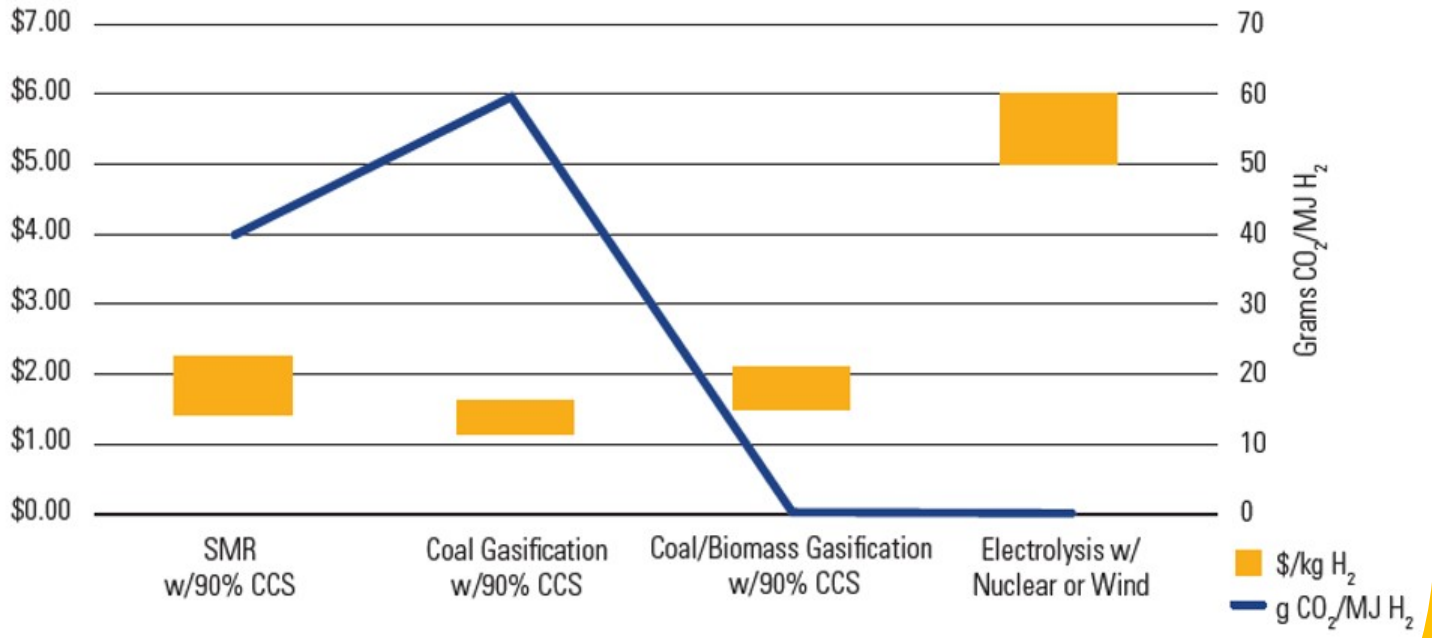
Figure 4. Current Cost of Hydrogen Production and CO_2 Intensity



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

• Brief Look at the H_2 Economy

- Deploying clean H_2 could reduce ~ 34% of GHG emissions from fossil fuels by 2050
- Scaled-up H_2 industry can lower cost of renewable H_2 ($ 2/kg -2030 and $ 1/kg -2050 (current cost - $ 7.50/kg for green and $ 2.40/kg for blue H_2).
- Steel industry – likely benefactor of H_2 economy (~ 9% of global carbon emissions)
- Home heating and cooking – another benefactor by blending 5-20% with natural gas for transport through existing pipelines
- H_2 will play a bigger role in transportation

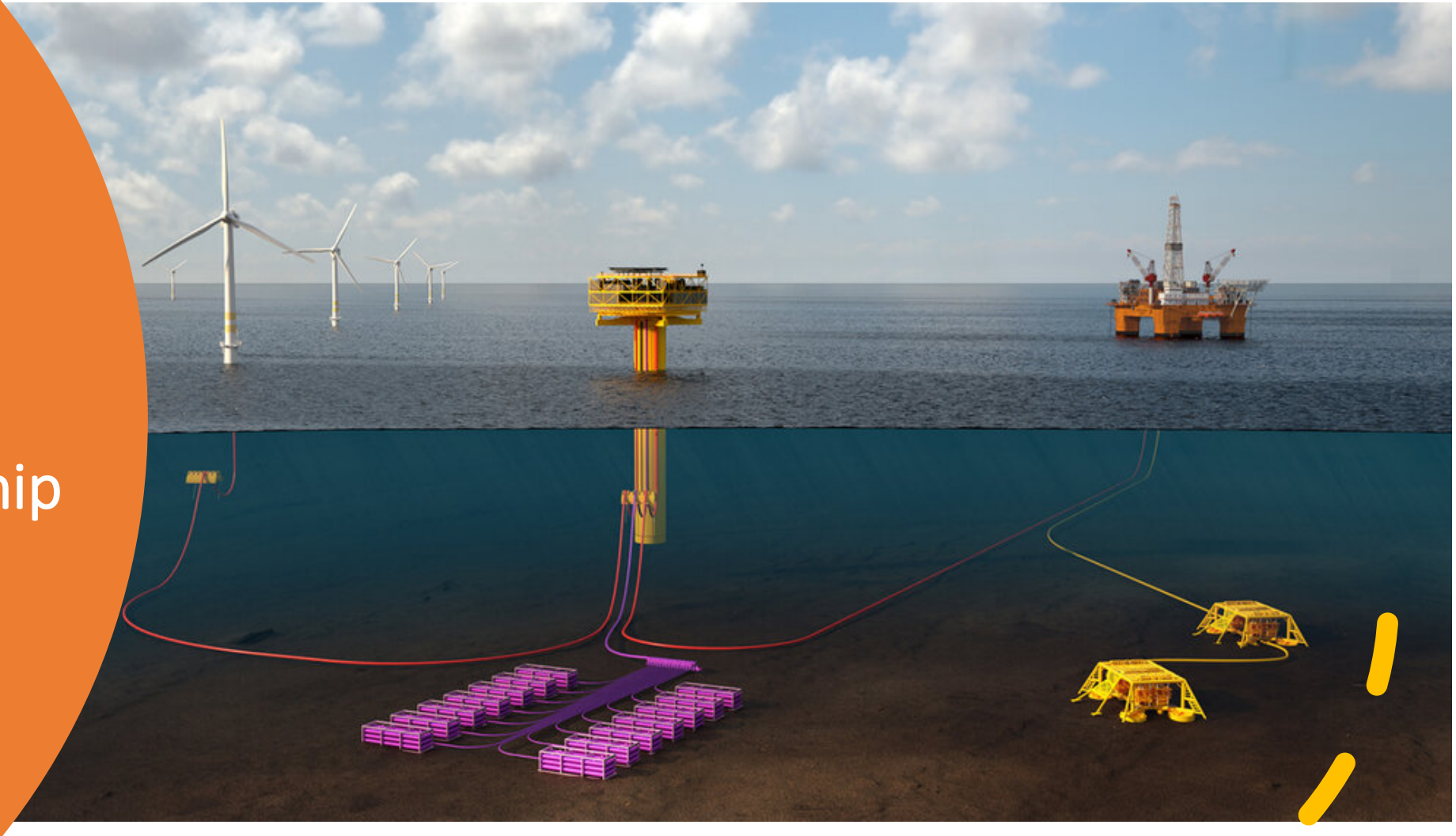
Health and Safety Aspects of H_2

- 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 (Requires larger H_2 volumes to meet identical energy demands as other fuels)
- H_2 can be compressed, liquified, or transformed into H_2-based fuels with a higher energy density (but subsequent re-conversion uses some energy)
- H_2 handling requires special equipment and procedures – widespread use would bring new challenges. Requires adequate ventilation, leak detection and special flame detectors
- Health and safety considerations of H_2 -based fuels and feedstocks are familiar in the energy sector - exceptions are NH_3 and liquid organic hydrogen carriers (LOHCs)
- NH_3 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

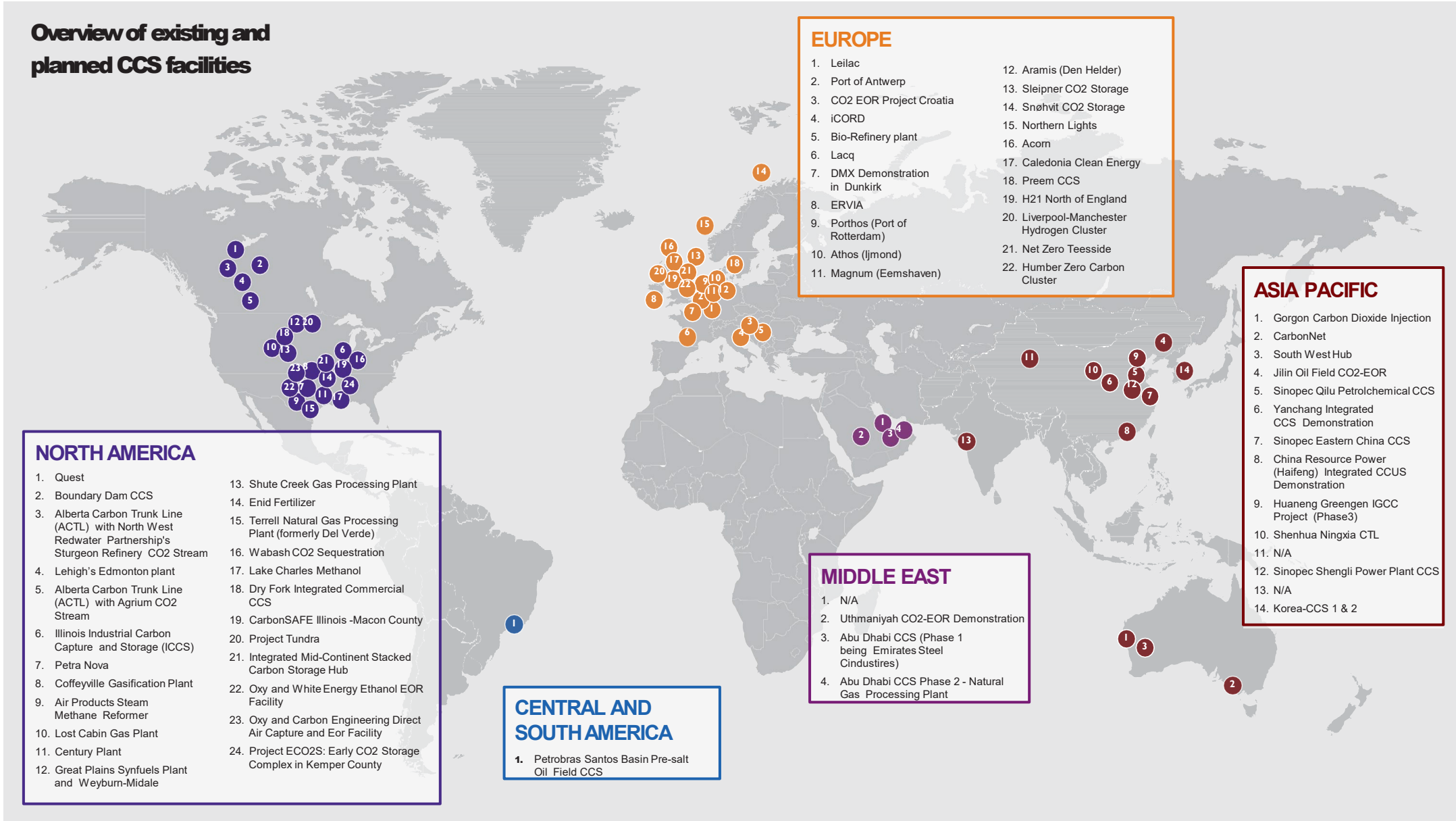
Geological Storage of H_2

- 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 and US since 1980s (Beaumont, TX, Delta, UT – hub and spoke model) - likely the lowest-cost option
- Depleted O&G reservoirs - Larger capacity, and more permeable. Will require contaminants removal prior to use in fuel cells (Greensand DK)
- Aquifers have least amount of experience. Both depleted O&G and aquifers have natural barriers that can provide containment. If can overcome challenges, attractive for large scale H_2 storage

Offshore Hydrogen Storage (Courtesy Technip FMC – Deep Purple)



Global CCS projects



Courtesy: Shell Quest Canada

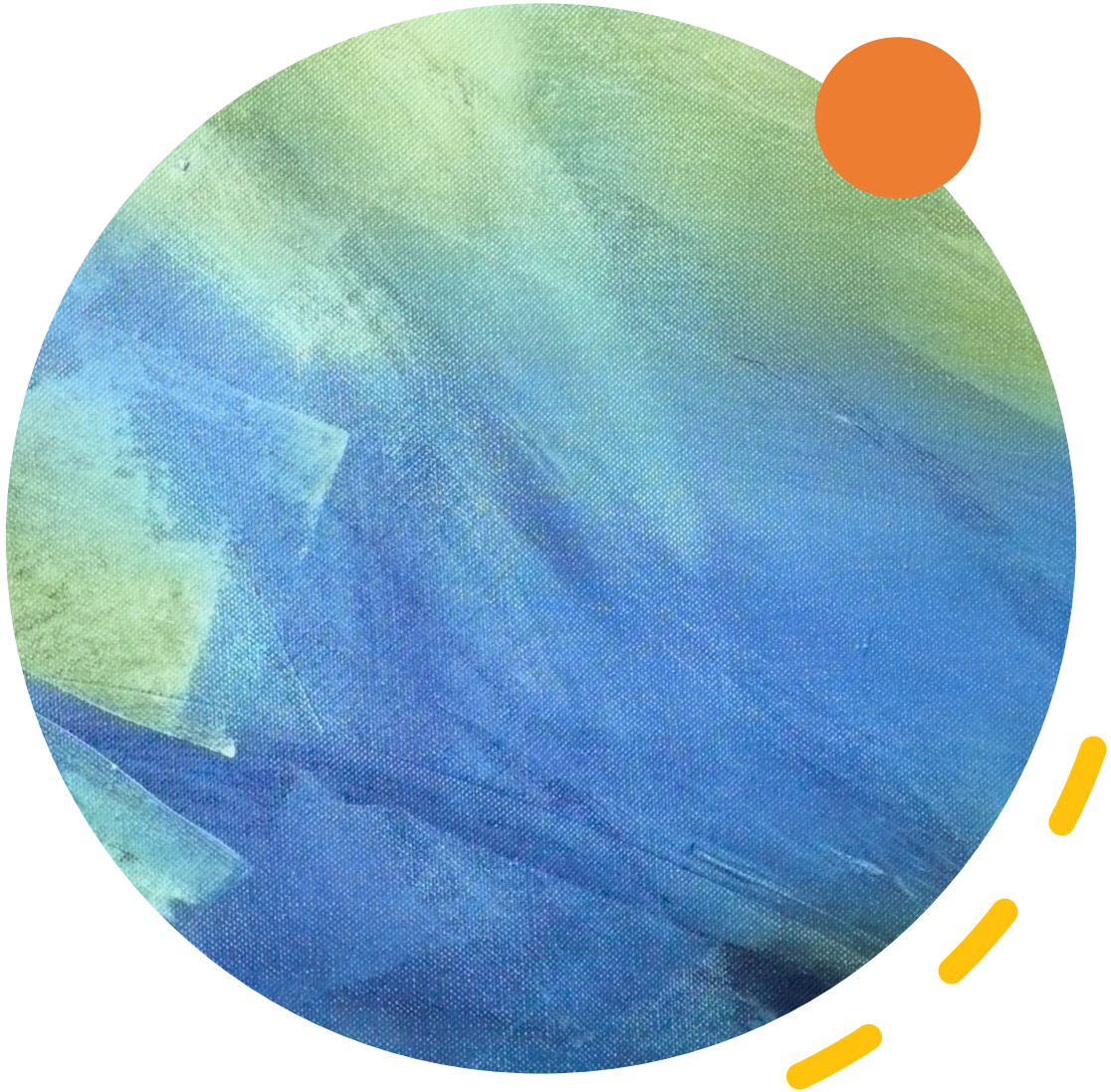
Top Clean Energy Developments of 2020/2021

- **Coal is on its way out:** (1) US and EU coal plants retirements outpaced new plants, (2) global coal consumption down
- **Gas also in decline:** Utilities not replacing coal with gas
- **China and carbon neutrality:** Plans to be carbon neutral by 2060 (will adopt 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

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

Top Clean Energy Developments of 2020/2021 (Continued)

- Green H_2 taking off
- Increase in Blue H_2 projects in US and globally
- US rejoins Paris Agreement – CATCH Act – 45Q changes
- Bans on gas vehicles are growing
- Renewed focus on methane emissions
- Racial justice enters climate activism discussion



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; global cooperation; buildup of infrastructure and commercial markets/hubs; technology challenges – transportation, potential use/blending of existing gas pipeline networks, 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