HEC Hydrogen Sessions

Producing Hydrogen with Carbon Capture, Use and Sequestration

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Hydrogen Energy Center

HEC is a nonprofit professional society focused on accelerating the hydrogen as an enabling solution for renewable energy

HEC provides public forums, conducts research and implements projects focused on accelerating the clean energy future

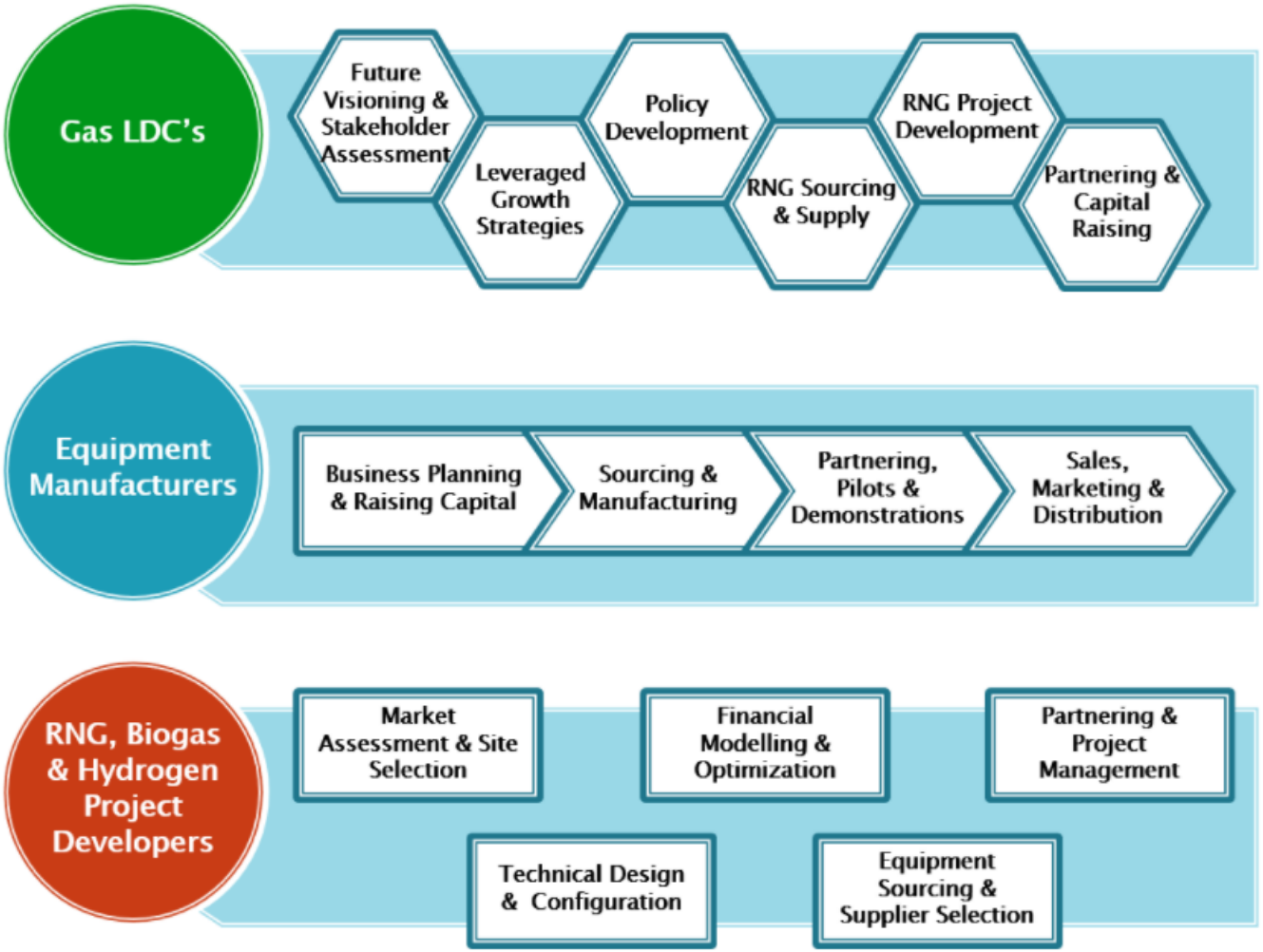
Consider supporting this important effort by becoming a member:

- Influence the course of renewable hydrogen energy technology and policy.
- Be a part of projects that really build hydrogen solutions.
- Have full access to white papers, technical reports, and meeting minutes from our projects and from other organizations.
- Immerse yourself in the hydrogen "goings-on" by connecting with developments & networking with people who are collectively driving the hydrogen "bus".

Upcoming Hydrogen Sessions

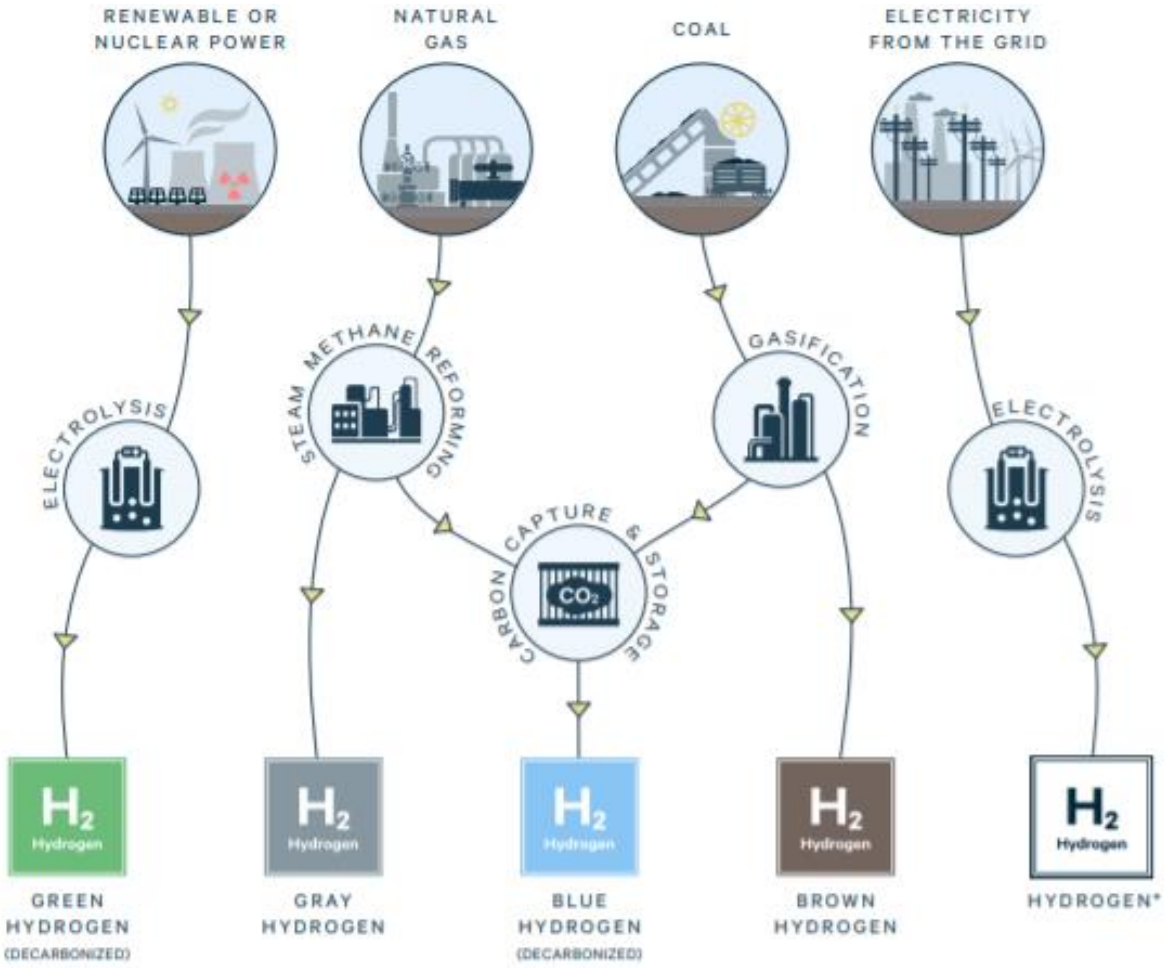
- July 2, 2021 Wind to Hydrogen

Velerity Services

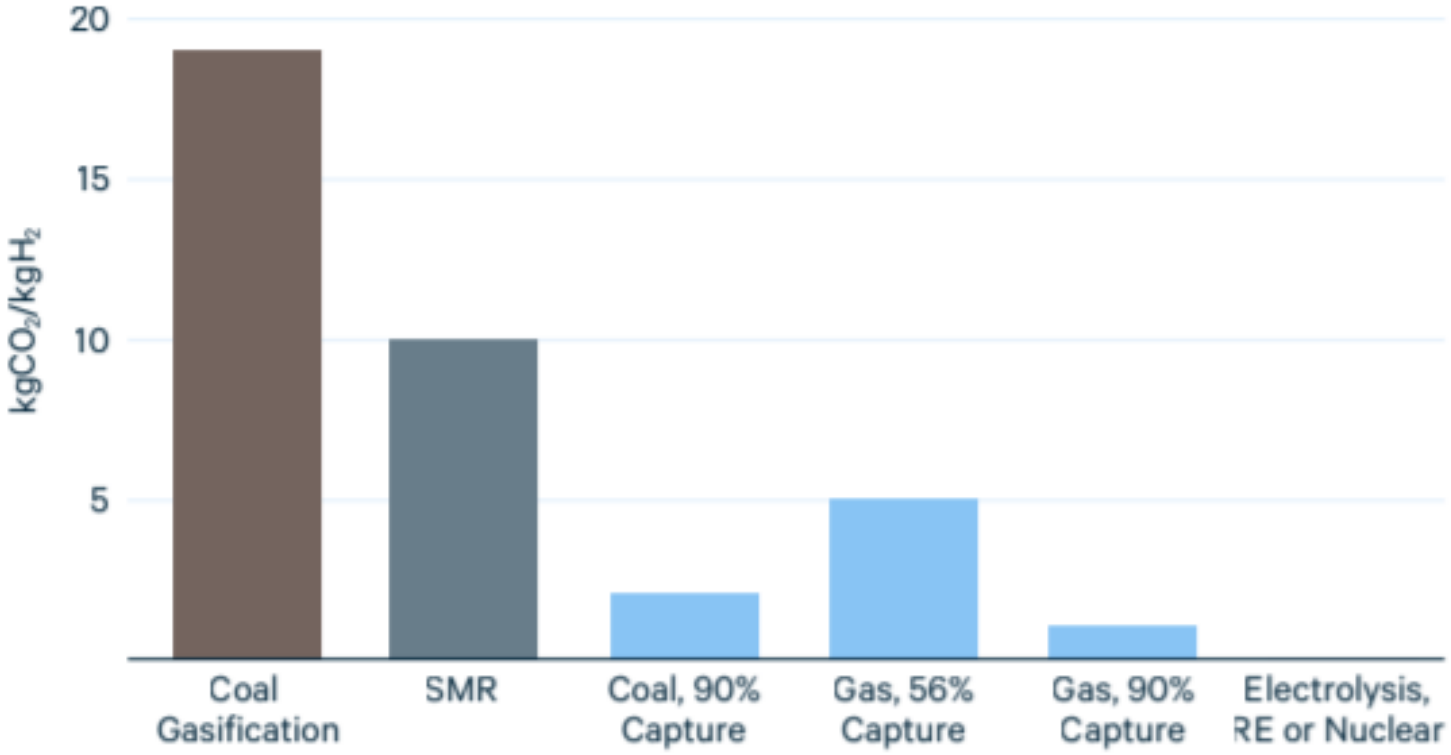


Velerity – Illustrative Clients

Hydrogen Production Pathways

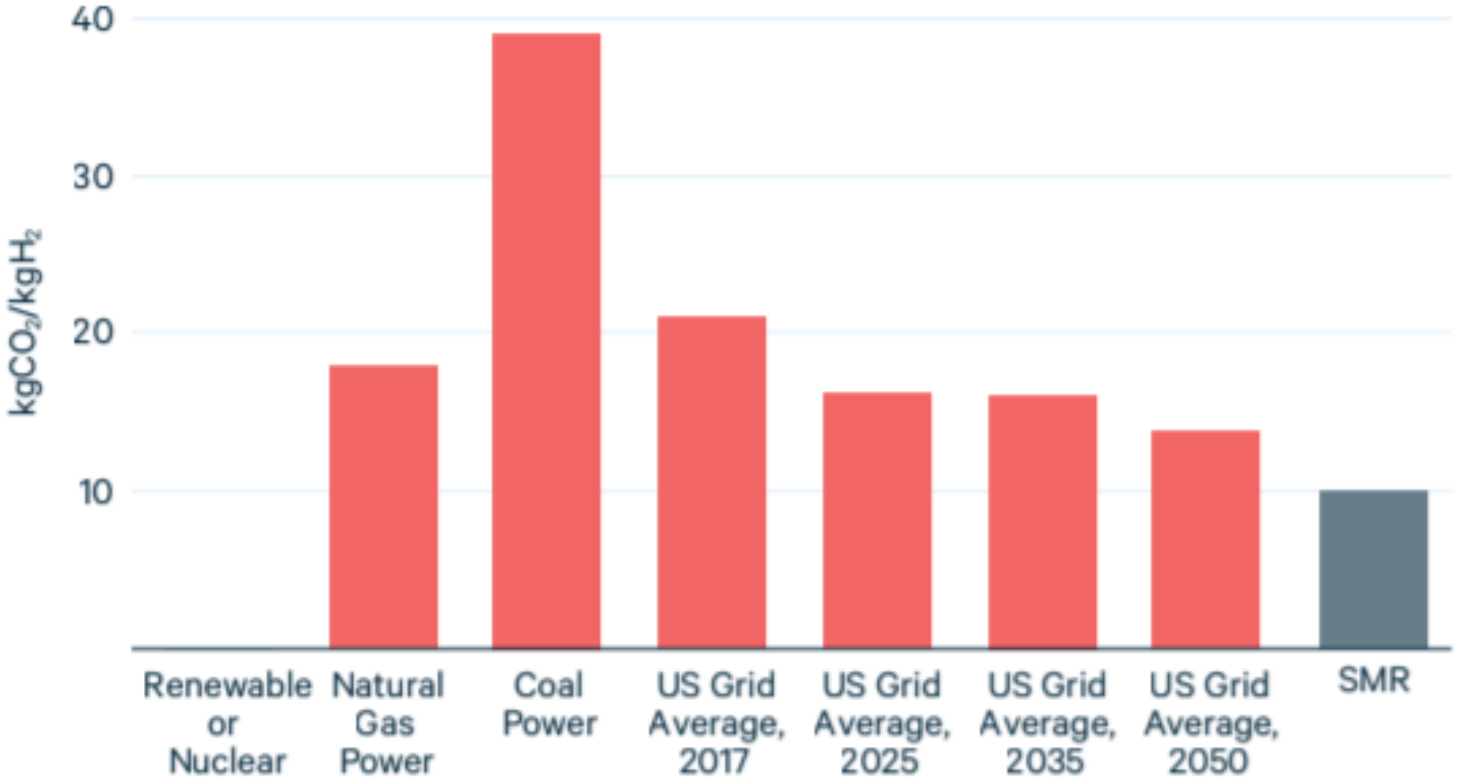


CO2 emissions by production pathway



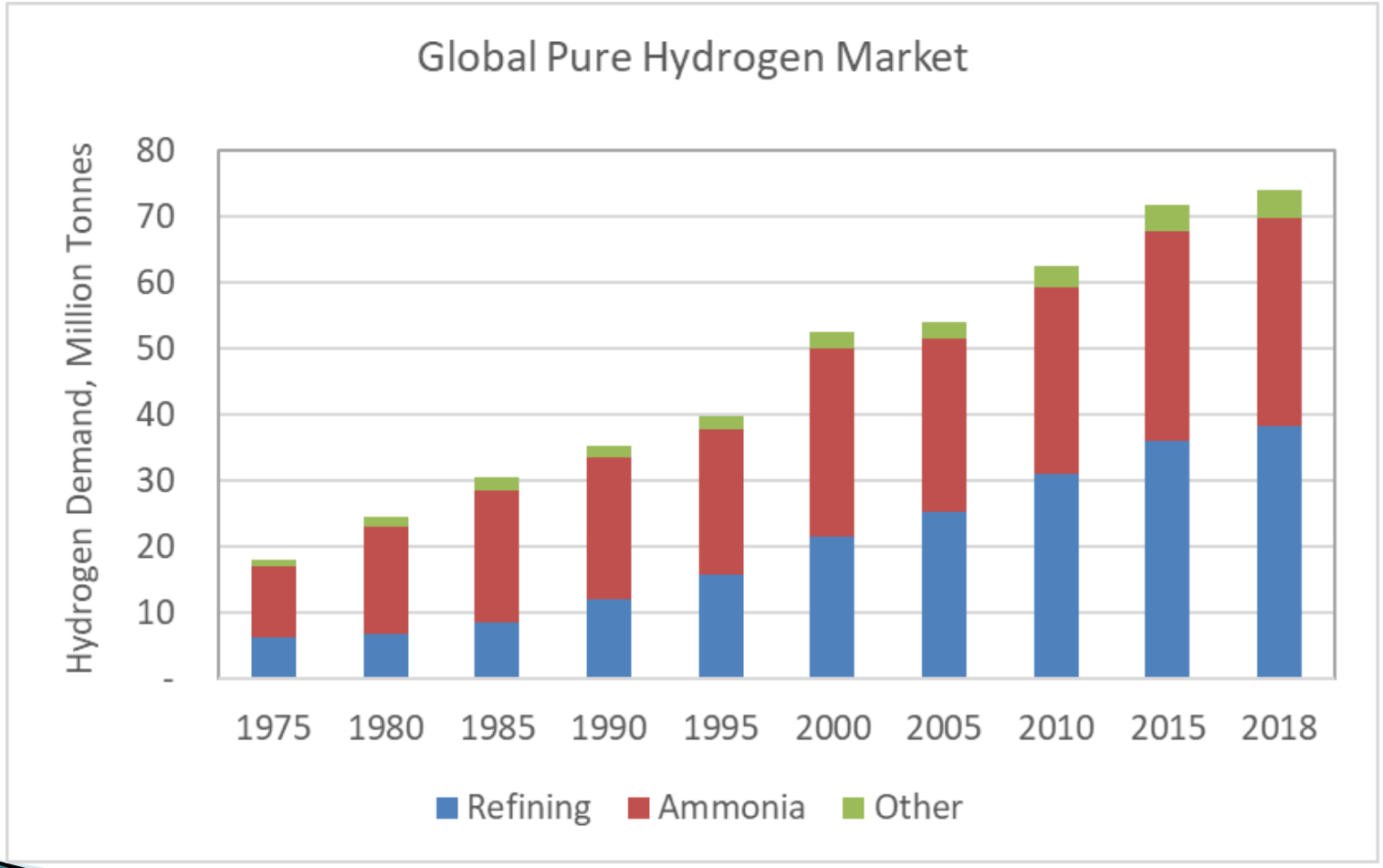
Source: IEA 2019.

CO_2 Emissions with Electrolysis



Sources: Blank and Molloy 2020; EIA 2020a; IEA 2019.

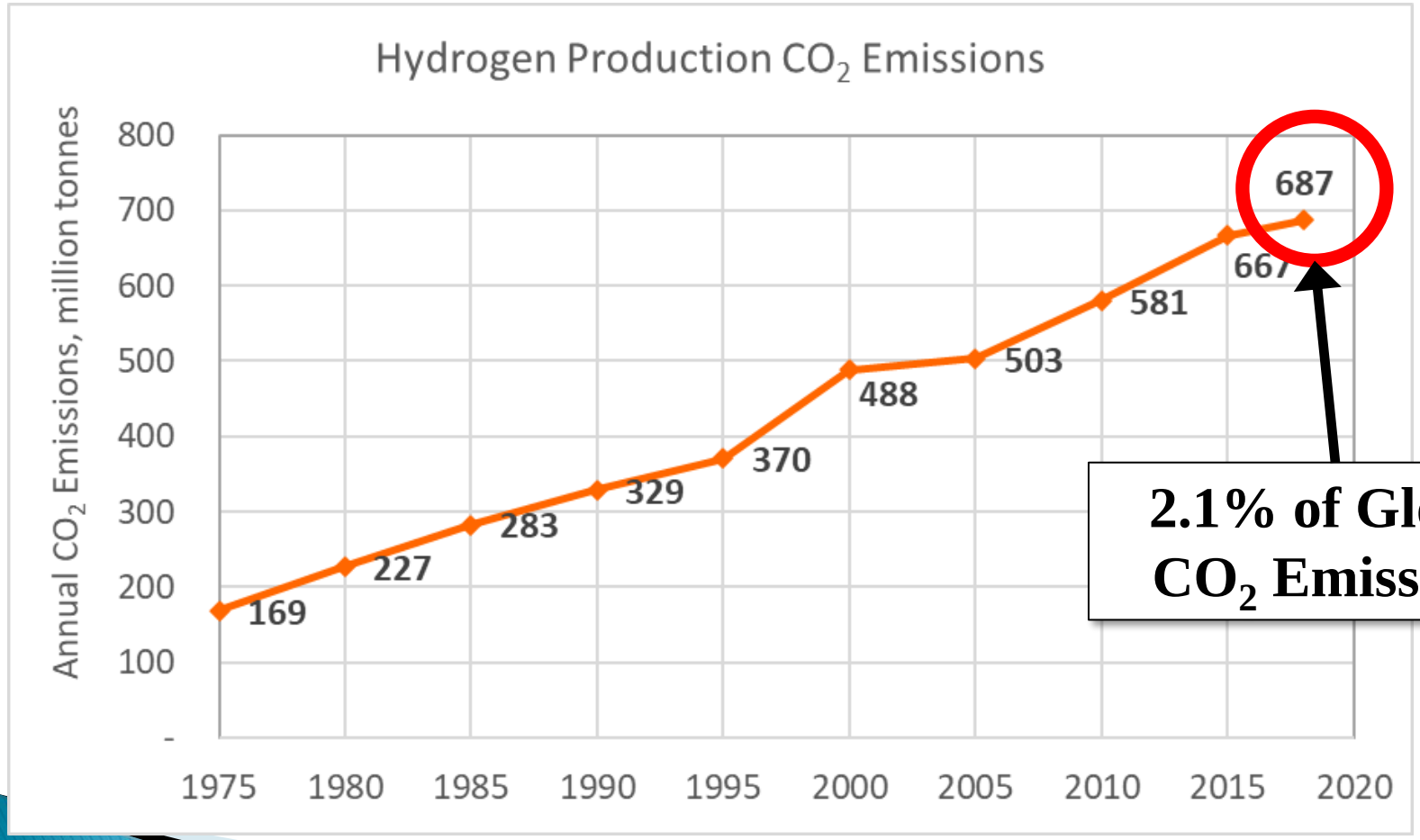
Global Pure Hydrogen Market – 80 million tonnes per year and growing



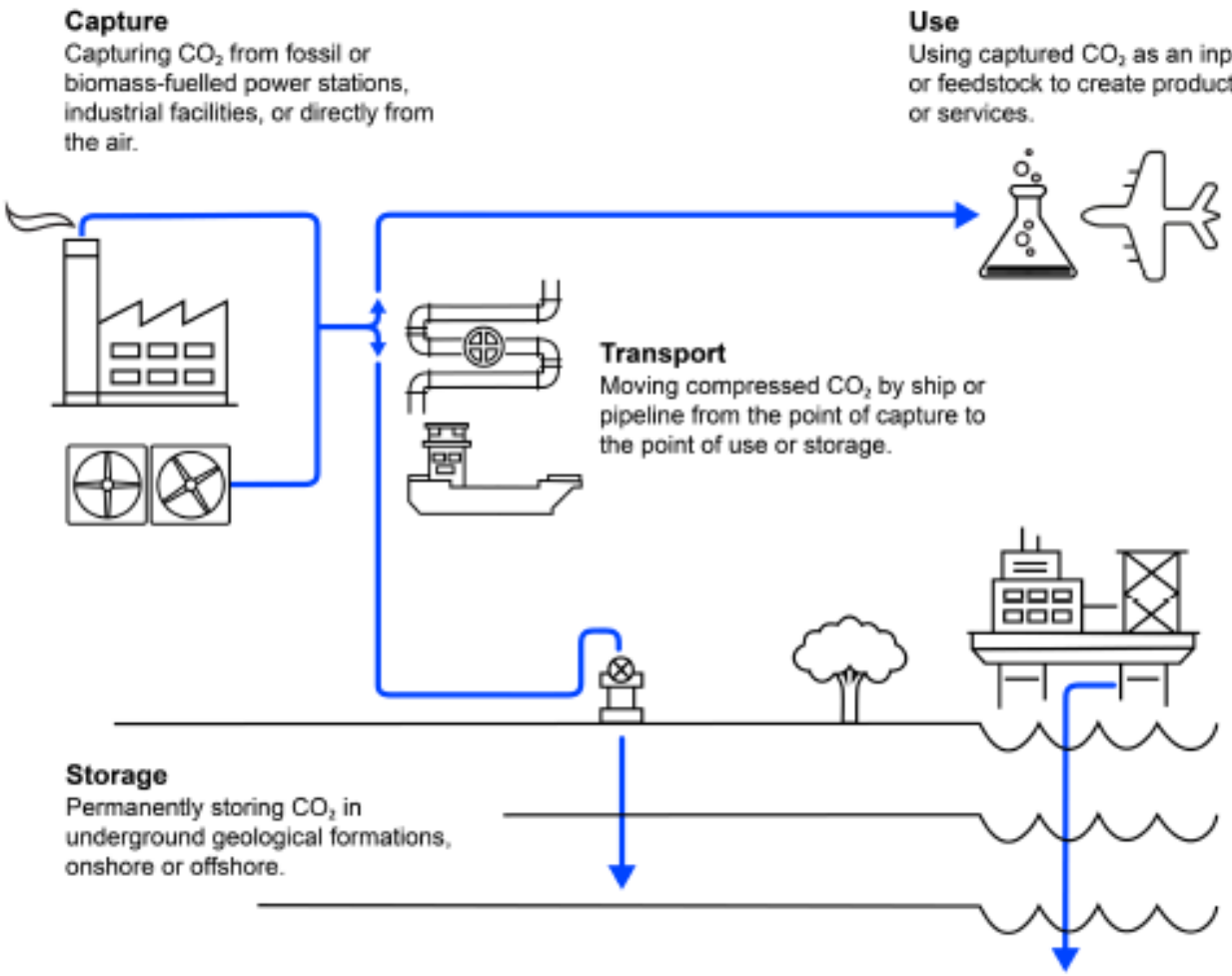
Steam methane reforming emissions' rates

SMR Carbon Emissions	kg CO2/kg H2
Combustion for reforming energy	1.78
Combustion for steam	1.20
Power for separation & compression	0.05
Natural gas reaction	6.26
Total	9.30

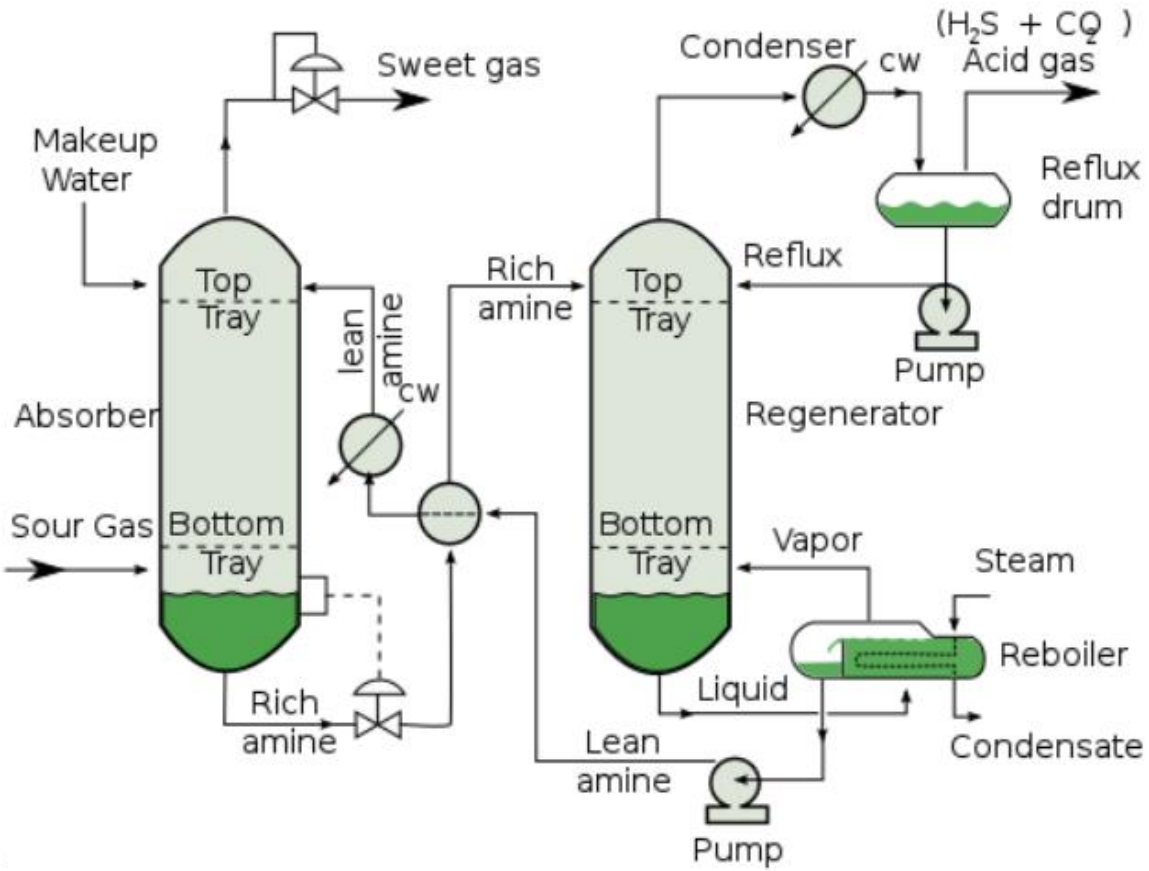
Global emissions' contribution of hydrogen production



Carbon Capture, Use and Sequestration



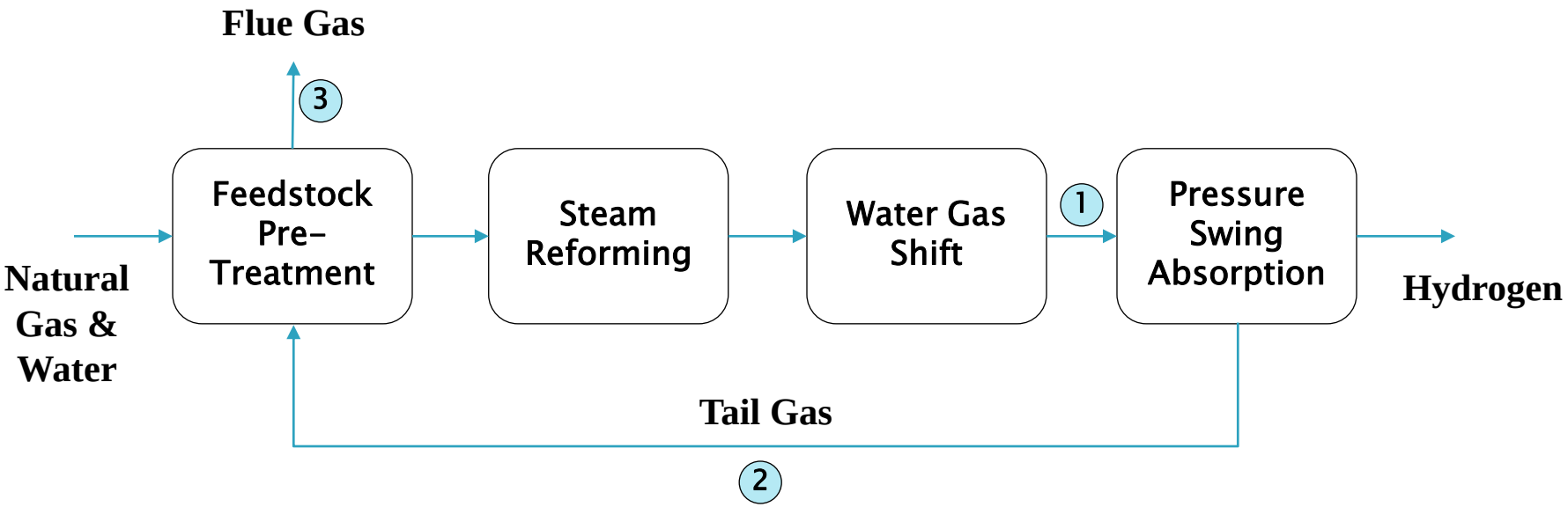
Illustrative Amine Treater Diagram



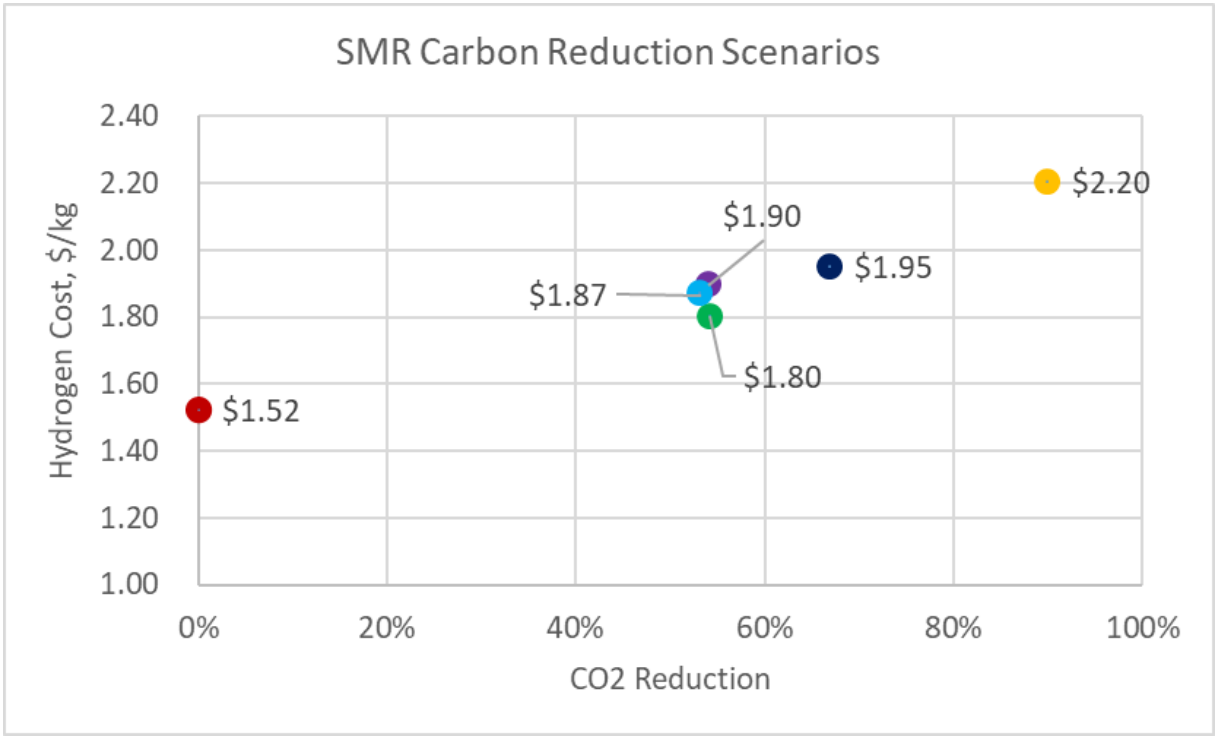
Typical amines used and their relative concentrations

- Monoethanolamine (MEA): About 20 % for removing H2S and CO2, and about 32 % for removing only CO2.
- Diethanolamine: About 20 to 25 % for removing H2S and CO2
- Methyldiethanolamine (MDEA): About 30 to 55 % for removing H2S and CO2
- Diglycolamine: About 50 % for removing H2S and CO2

Simplified Steam Methane Reforming Diagram

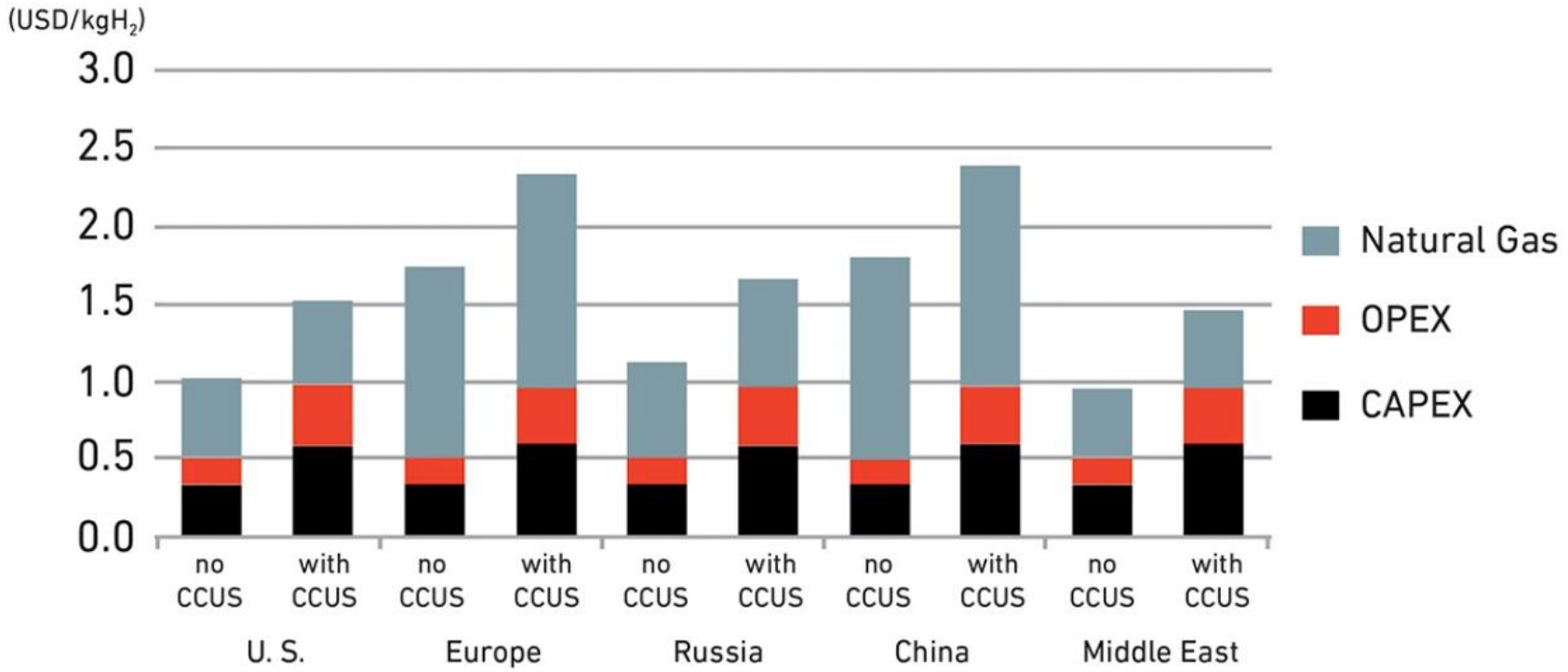


Economics of SMR with CCUS



Base Case	
Case 1A: Capture of CO2 from Shifted Syngas using MDEA	
Case 1B: Burners firing Rich H2 Fuel & CO2 Capture from Shifted Syngas w/MDEA	
Case 2A: Capture of CO2 from PSA Tail Gas Using MDEA	
Case 2B: Capture of CO2 from the PSA Tailgas Using Cryogenic & Membrane Separation	
Case 3: Capture of the CO2 from the Flue Gas Using MEA	

Additional economics data of SMR with CCUS by region



Carbon separation utilizing methane pyrolysis

- **Hallam, Nebraska - Monolith Materials**
  - Plant separates hydrogen and carbon through methane pyrolysis
  - Produces 14,000 metric tons of carbon black per year
  - Mitsubishi Heavy Industries invested an undisclosed amount in 2020
  - Plans a second much larger plant to produce anhydrous ammonia using the hydrogen
- **C-Zero**
  - Based in Santa Barbara - Developing carbon separation technology utilizing methane pyrolysis
  - Recently received $11.5 million investment from Mitsubishi Heavy Industries, Breakthrough Energy Ventures, AP Ventures, and Eni Next
  - The company has also won $3 million through two grants from the U.S. Department of Energy, and a $350,000 project with California utilities Pacific Gas & Electric and Southern California Gas
  - C-Zero, after experimenting with molten salts and metals, settled on a molten-nickel-based catalyst in a continuous flow process, he said.
  - C-Zero expects its process to yield hydrogen at a cost of about $1.50 per kilogram, about the same as gray hydrogen

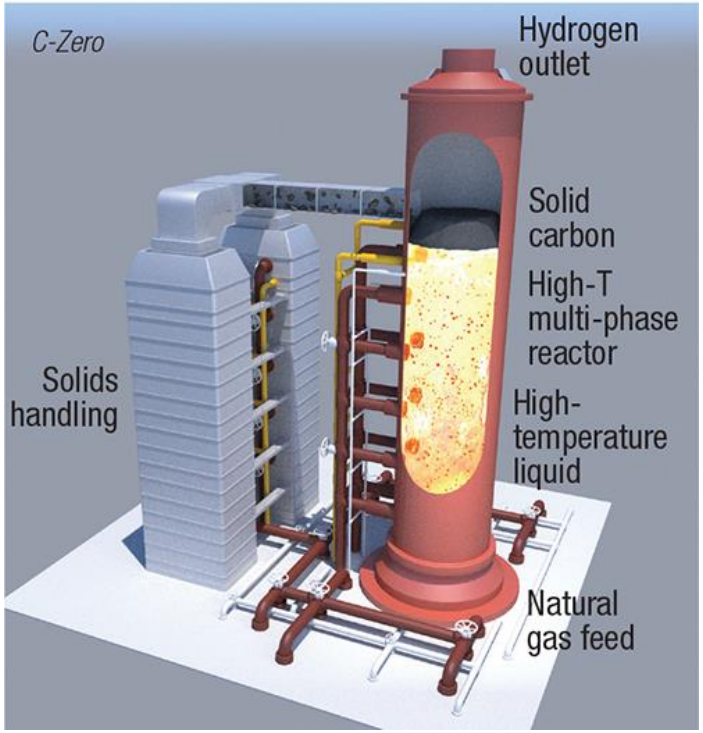
Carbon separation utilizing methane pyrolysis

- **BASF - Germany**
  - Chemicals giant BASF is building a turquoise hydrogen pilot plant in partnership with a consortium of German companies and research organizations
- **Hazer Group - Australia**
  - Australian company Hazer Group has won government backing to build a pilot plant testing its own pyrolysis process.
- **TNO - Netherlands**
  - TNO, in the Netherlands, has developed their EMBER methane pyrolysis process.

Carbon separation utilizing methane pyrolysis

Monolith Materials

C-Zero



Air Products Steam Methane Reformer

Facility Name	Air Products Steam Methane Reformer
Facility Category	Commercial CCS
Facility Status	Operational
Country	USA
Operational	2013
Facility Industry	Hydrogen Production

Air Products retrofitted each of its two steam methane reformers SMRs, located within an existing refinery at Port Arthur, Texas, to separate CO2 from the process gas stream. Carbon dioxide capture capacity is at around 1 Mtpa when both plants are fully operational. The captured CO2 is transported to oil fields in Texas for enhanced oil recovery. More than 6 million tonnes of CO2 has been captured since the facilities became operational in 2013.

Tomakomai CCS Demonstration Project

Facility Name	Tomakomai CCS Demonstration Project
Facility Category	Pilot and Demonstration CCS Facility
Facility Status	Operational
Country	Japan
Operational	2016
Facility Industry	Hydrogen Production

Endorsed by Japan's Ministry of Economy, Trade and Industry (METI), the Tomakomai CCS Demonstration Project captures CO2 from a hydrogen production unit at Idemitsu Kosan's Hokkaido Refinery at Tomakomai port, Hokkaido, Japan. Approximately 100,000 tonnes of CO2 per annum is to be injected into two near shore storage sites over the period FY2016-2018, with post-injection monitoring continuing for another two years following termination of injection.

Quest

Facility Name	Quest
Facility Category	Commercial CCS
Facility Status	Operational
Country	Canada
Operational	2015
Facility Industry	Hydrogen Production

Quest, located in Alberta, Canada, retrofitted CO2 capture facilities to three steam methane reformers SMRs at the existing Scotford Upgrader. Launched in November 2015, Quest has the capacity to capture approximately 1 Mtpa of CO2. The captured CO2 is transported via pipeline to the storage site for dedicated geological storage. In July 2020, Quest announced it had captured and stored over five million tonnes of CO2.

HyNet North West

Facility Name	HyNet North West
Facility Category	Commercial CCS
Facility Status	Early Development
Country	United Kingdom
Operational	Mid 2020
Facility Industry	Hydrogen Production

HyNet North West is an integrated low-carbon hydrogen production, distribution and carbon capture, utilization and storage (CCUS) project being developed by Cadent (lead) together with Progressive Energy. The CO2 is planed to be captured from the Hydrogen Production & Carbon Capture plant, and transported, together with captured CO2 from existing nearby industrial sites, to the decommissioning Hamilton and Lennox gas fields in Liverpool Bay owned and operated by ENI for dedicated geological storage.

Hydrogen Energy Supply Chain (HESC) project

Facility Name	Hydrogen Energy Supply Chain (HESC) project
Facility Category	Commercial CCS
Facility Status	In Construction
Country	Australia
Operational	2020 – 2021
Facility Industry	Hydrogen Production

The aim of HESC is to establish a full-chain commercial-scale low-carbon emission hydrogen supply to Japan. The project will be carried out in 2 phases: pilot phase and commercial phase.

Carbon Negative Energy Plant

Facility Name	Carbon Negative Energy Plant
Facility Category	Commercial CCS
Facility Status	Early Development
Country	Central Valley, USA
Operational	2025
Facility Industry	Power Generation and Hydrogen Production

Clean Energy Systems is developing its commercial Carbon Negative Energy plant in an existing biomass gasification plant in the Central Valley by 2025, capturing ~0.32 million tonnes per annum (0.35 million tons per annum) CO¬ via bio-energy with carbon capture and storage.

Northern Gas Network H21 North of England

Facility Name	Northern Gas Network H21 North of England
Facility Category	Commercial CCS
Facility Status	Early Development
Country	United Kingdom
Operational	2026
Facility Industry	Hydrogen Production

The H21 North of England project aims to decarbonize power, heat and transport across the North of England. It aims to convert the UK gas grid from natural gas (methane) to zero-carbon hydrogen. The project could start in 2026 - 2028. By 2035, the project would have the potential to become the largest CCUS project in the world.

Hydrogen to Humber Saltend

Facility Name	Hydrogen to Humber Saltend
Facility Category	Commercial CCS
Facility Status	Early Development
Country	United Kingdom
Operational	2026-2027
Facility Industry	Hydrogen Production
Hydrogen to Humber (H2H) Saltend is in development to produce blue hydrogen via a new build 600 MW autothermal reformer to decarbonize/fuel-switch Triton Power's gas-fired power plant. It will capture up to 1.4 million tonnes of CO2 when in operation.	