MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

Carbon Capture solutions for raw materials industry

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EVP NEXT Energy Systems

8th Greek Raw Materials Community Dialogue
09.11.2023 , Athens

Mitsubishi Heavy Industries, Ltd.

MITSUBISHI HEAVY INDUSTRIES

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- Introduction – decarbonisation drivers
- Recent updates: Carbon Capture Technology
- Application examples: Steel, Cement, Aluminium
- Future Trends in CCUS
- Conclusions

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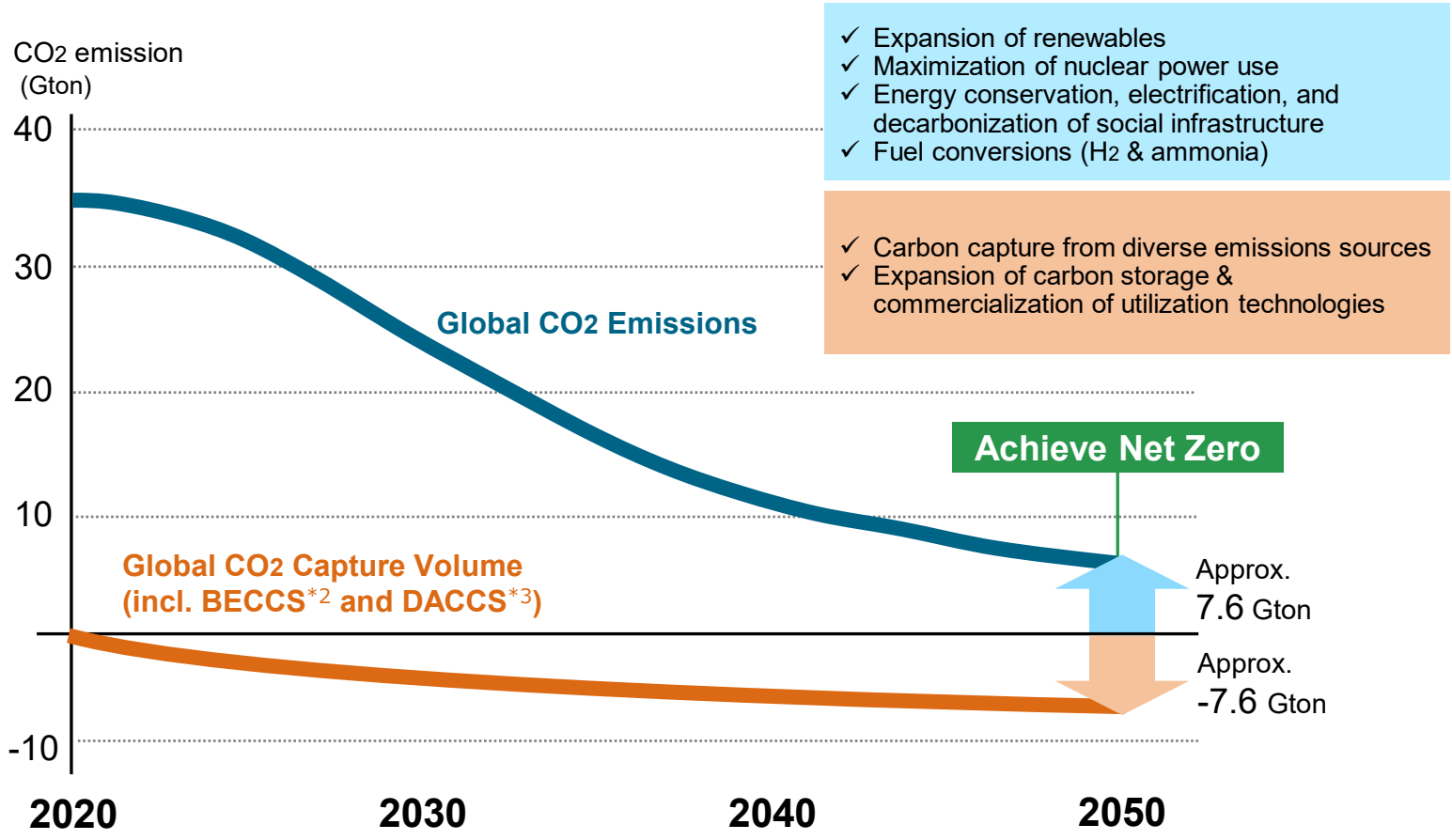
Realizing a carbon solutions ecosystem

- Carbon capture combined with reduction of CO_2 emissions is essential to achieve Carbon Neutrality
- Need increasing for compact carbon capture systems for industrial plants in addition to large scale capture systems for energy and chemical sectors
- Initiatives in capture, transport, storage, and utilization are gaining momentum

MHI Projections Based on Major Reports *1

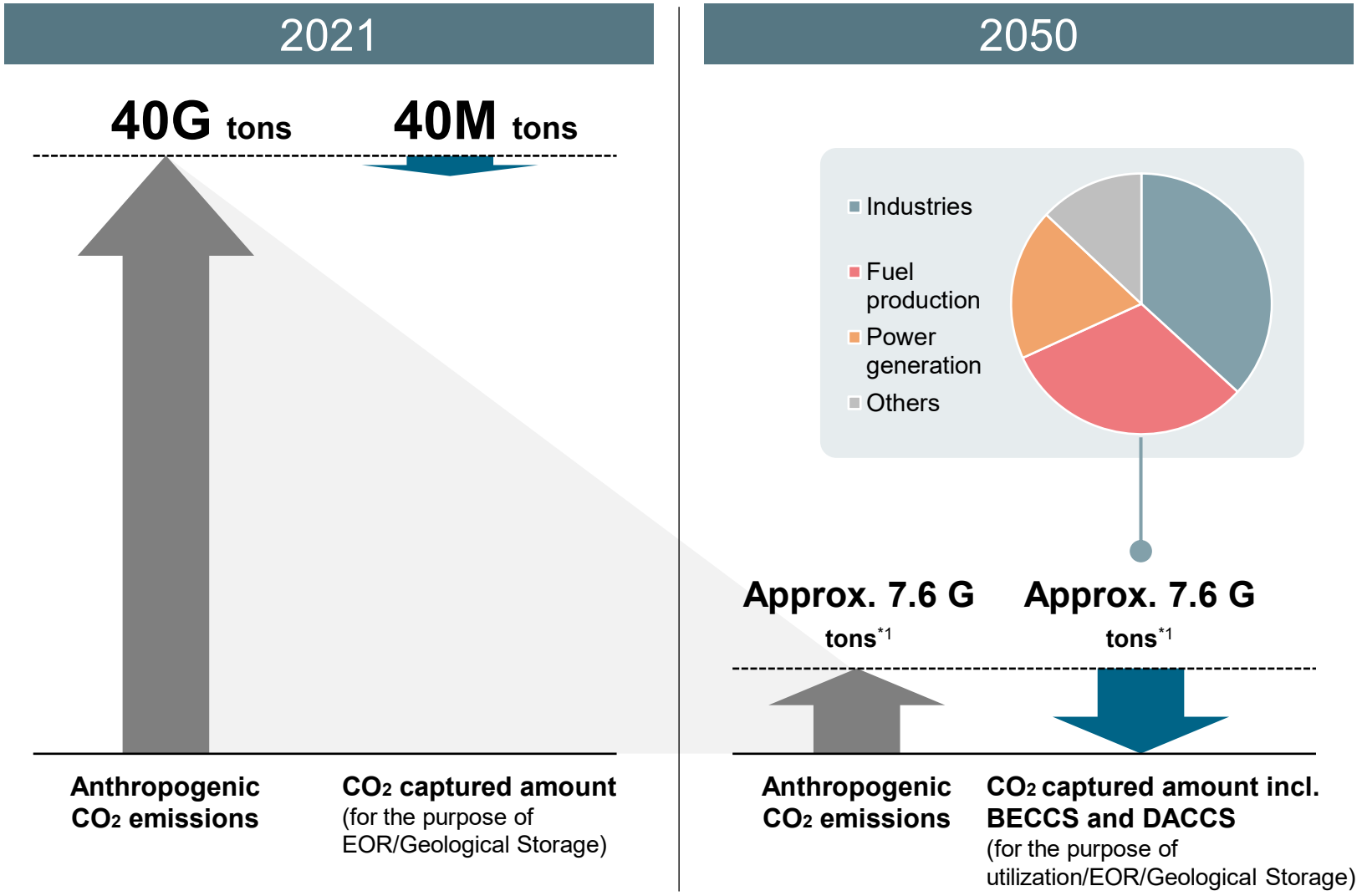


*1 : Includes IEA Net Zero by 2050 and McKinsey 1.5°C Scenario reports
*2 : Bio Energy with Carbon Capture and Storage
*3 : Direct Air Carbon Capture and Storage

Annual carbon capture amount to achieve carbon neutrality

- In order to achieve carbon neutrality in 2050, anthropogenic Carbon emissions must be reduced. However, even after such efforts, we expect around 7.6G tons of CO_2 emissions to remain.
- To capture this remaining CO_2, 100 to 300 times the current capacity is needed.
- In 2050, Carbon capture will operate in a wide range of sectors, including industries, fuel production (including blue fuel production), power generation, and others (aviation, transportation, etc.).

Deployment of CCUS is required in a wide range of sectors



*1 : Annual estimates based on our internal analysis of reports including McKinsey 1.5ºC scenario, IEA Net Zero by 2050, IEA SDS, and IPCC materials.

EU regulatory framework facilitating CCS and impact on industry

“Fit for 55” package:

- GHG emissions reduction by at least 55% by 2030
- Tightening EU ETS: reduction target to 62% (from 43%)
- Including maritime and aviation in EU ETS
  - Coverage of maritime shipping in EU ETS starting 2024 and full phase-out of free allowances in 2026
  - Phase-out of free allowances for aviation by 2027

→ Further ETS price increase:

→ Accelerating CCS in “hard to abate” sector

→ Accelerating zero carbon fuels (methanol, SAF) → CCU

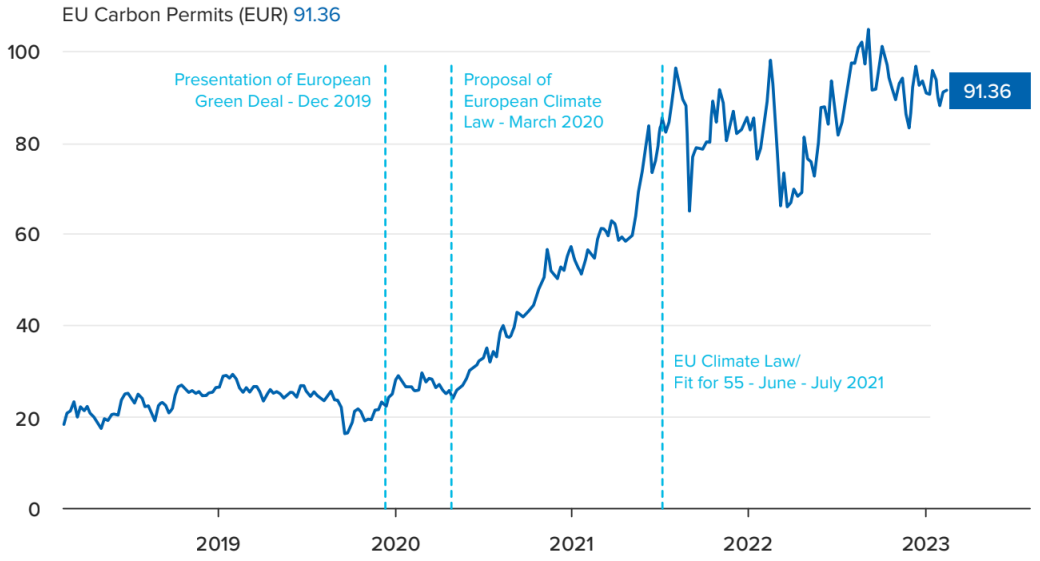


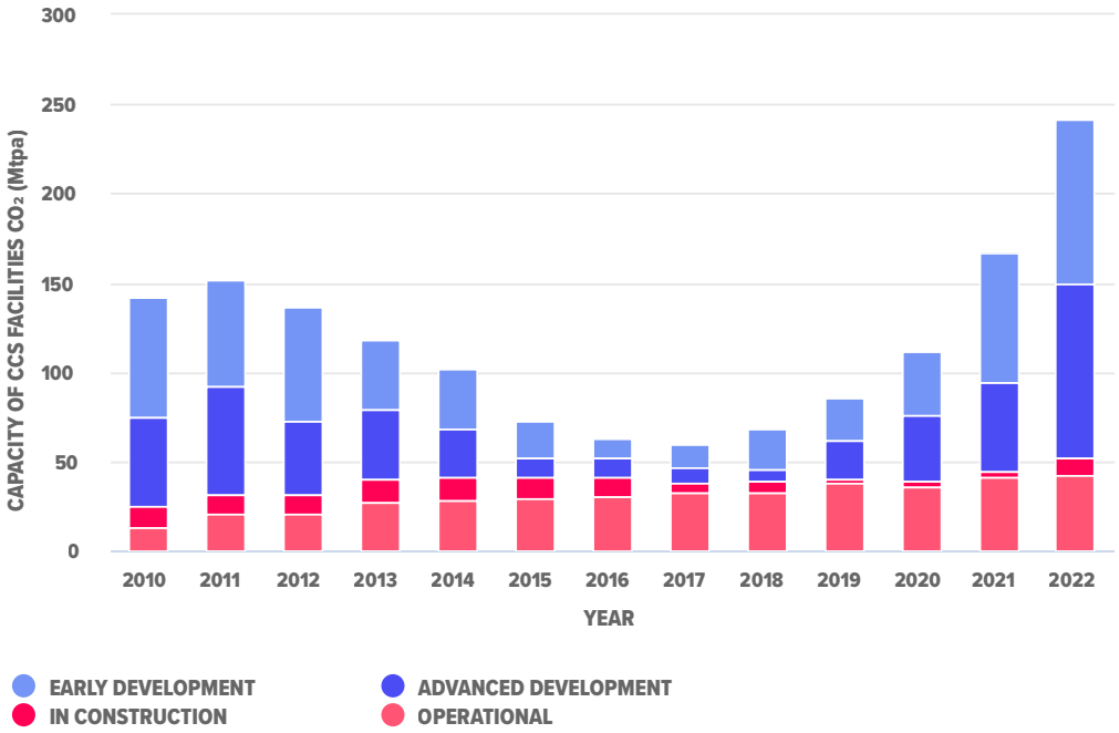
Figure 2: EU ETS price chart dated 15 August 2023. Source: Global CCS Institute

Carbon border adjustment mechanism (CBAM)

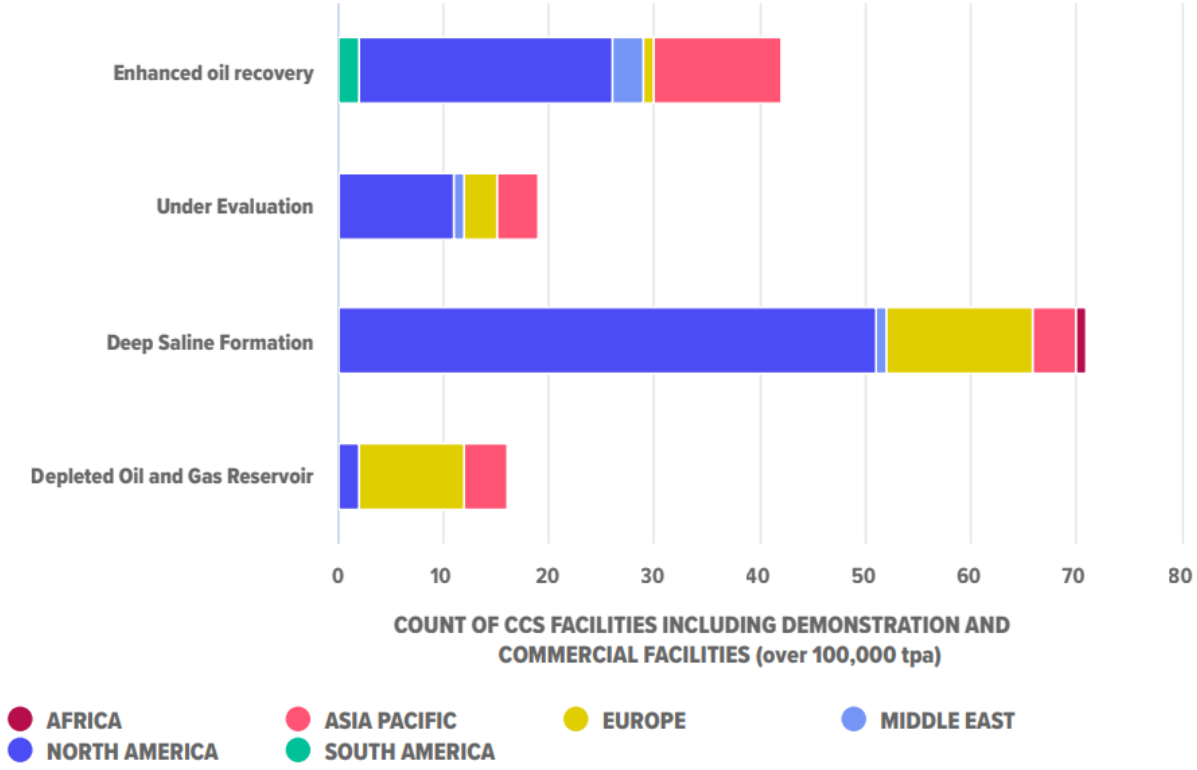
- Carbon duty on imports (carbon intensive goods) from countries without an equivalent carbon tax or price

→ protection and facilitation of decarbonisation for hard to abate

Evolution of CCS projects worldwide



Evolution capacity of global CCS projects (MTPA)

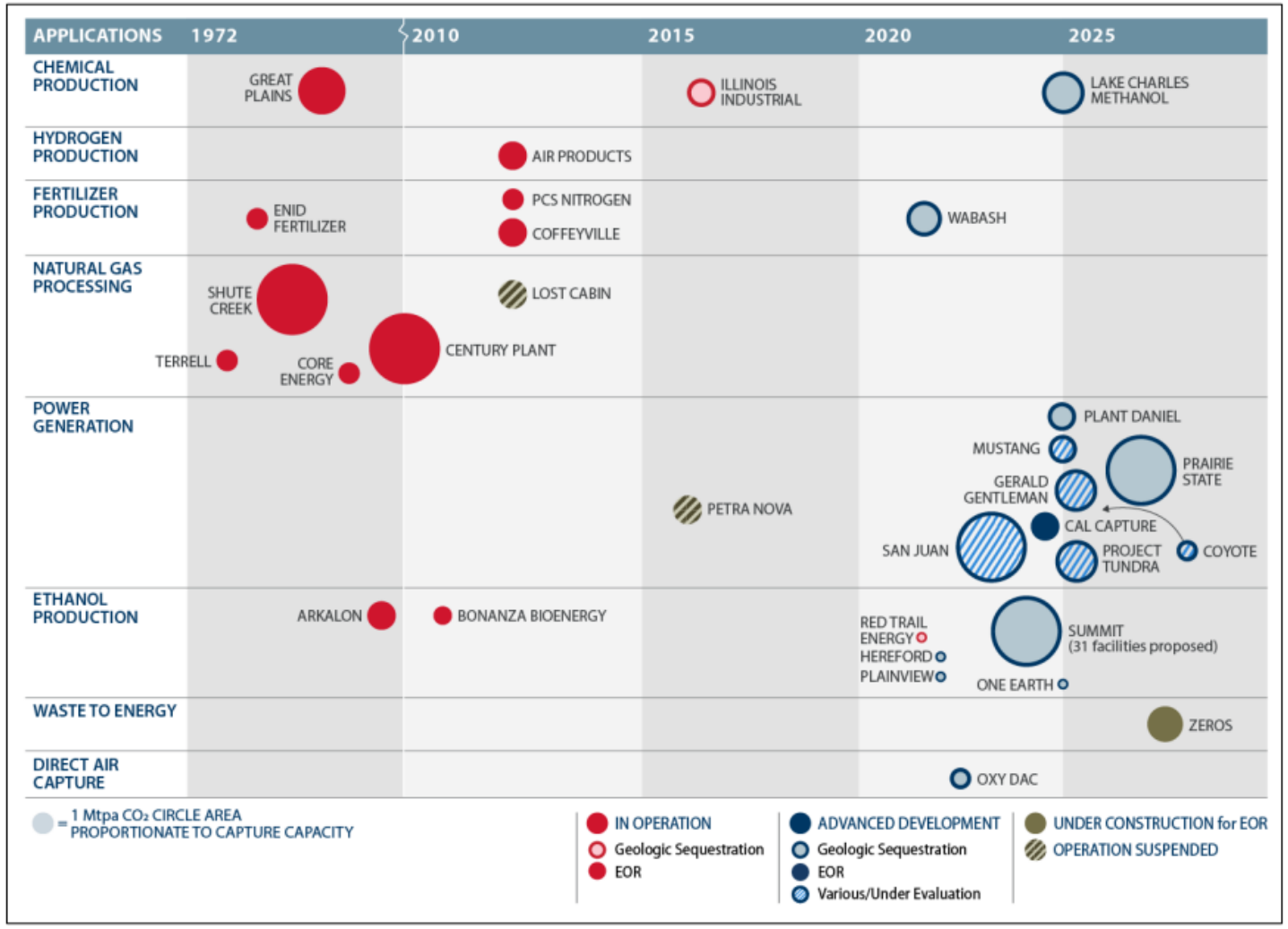


COUNT OF COMPLETED, CURRENT AND FUTURE CO2 STORAGE PROJECTS

DATA DERIVED FROM OVER 150 CCS FACILITIES, INCLUDING COMMERCIAL AND DEMONSTRATION PROJECTS (OVER 100,000 TPA CO2) ACROSS ALL STAGES OF DEVELOPMENT.

https://status22.globalccsinstitute.com/wp-content/uploads/2023/03/GCCSI_Global-Report-2022_PDF_FINAL-01-03-23.pdf

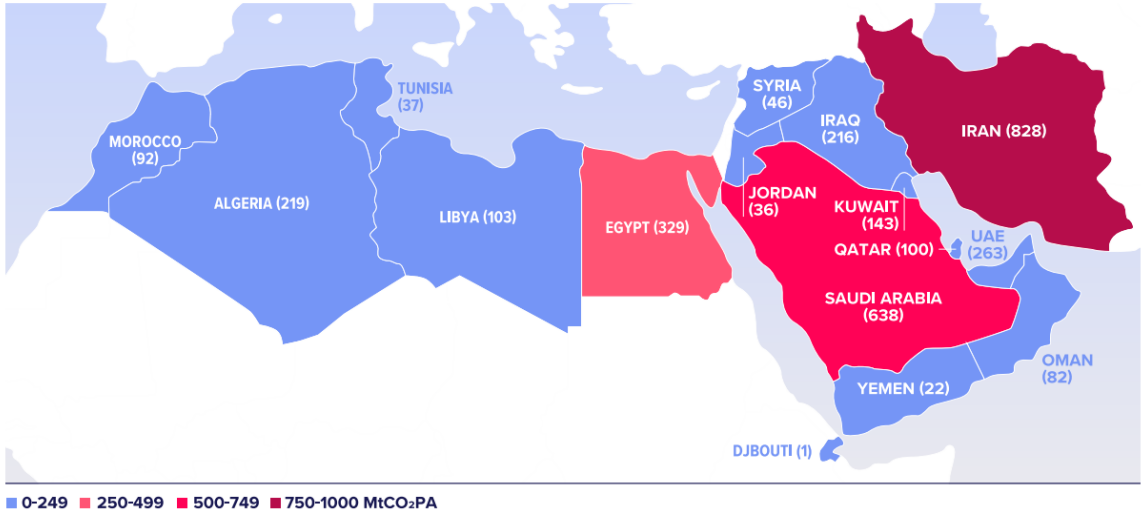
Evolution of CCS projects in US



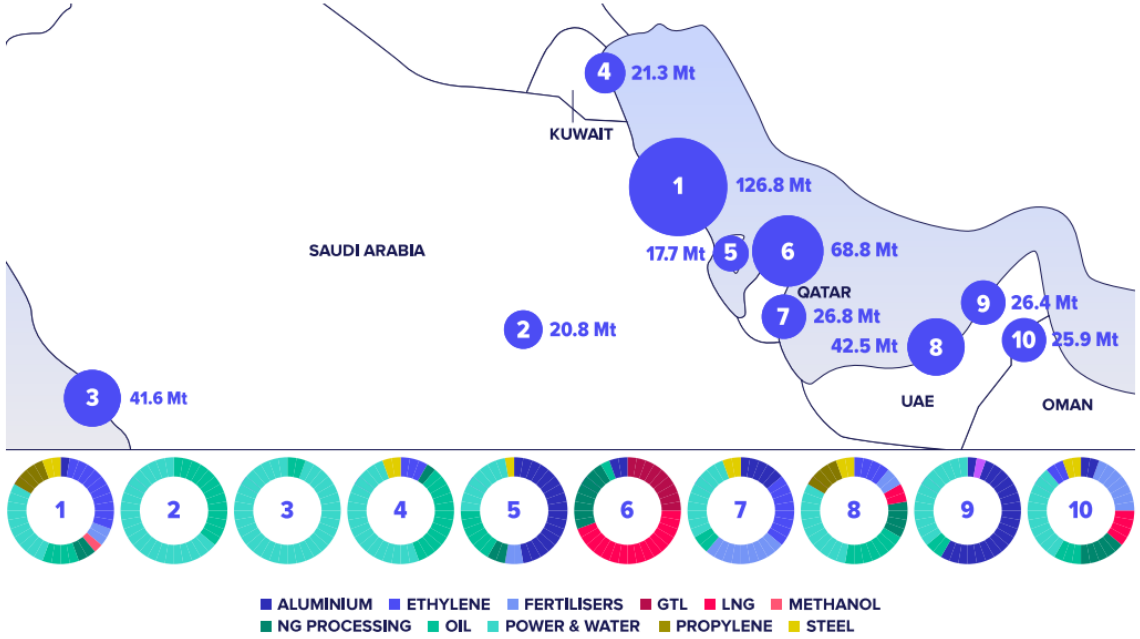
Operational, Planned, and Suspended Facilities in the United States Injecting CO2 for Geologic Sequestration and EOR

Source: Congretional Research Service 2022, adapted from Global CCS Institute, Global Status Report 2021

CCS Developments in MENA region



GREENHOUSE GAS EMISSIONS ACROSS THE MENA REGION



POTENTIAL HUBS ACROSS THE GCC COUNTRIES (SOURCE: ENERGY REVIEW MENA)

Overview of storage projects in Europe (under development)

Belgium
- Leilac
- Kairos@C and Antwerp@C
- Carbon Connect Delta (Port of Ghent)

Croatia
- iCORD
- CO2 EOR Project Croatia
- **Bio-Refinery Project**

Denmark
- Greensand
- Bifrost
- Stenlile (onshore)
- Aalborg (onshore

Germany
- H2morrow

Iceland
- Orca
- **Hellisheidi**

Netherland
- Porthos
- Magnum
- Athos
- Aramis
- Carbon Connect Delta

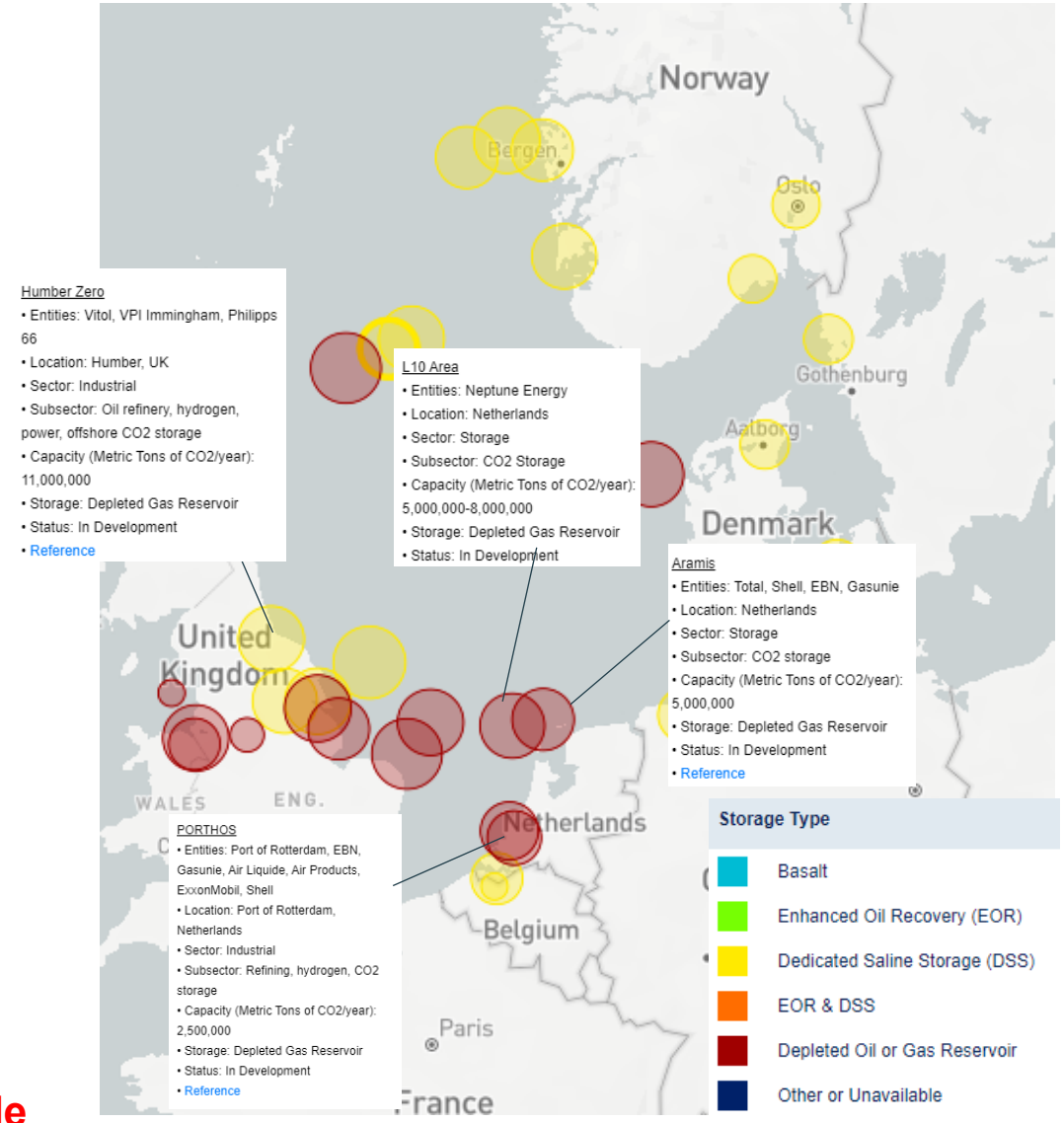
Norway
- **Sleipner CO_2 Storage**
- **Snøhvit CO_2 Storage**
- Longship

Ireland
- ERVIA

Sweden
- Preem CCS
- Stockholm Exergi Bio-CCS

Italy
- CCS Ravenna Hub

Greece
- Prinos



Europe has identified over 300 billion tonnes of geological carbon capture storage space available

Source: https://www.catf.us/ccsmapeurope/

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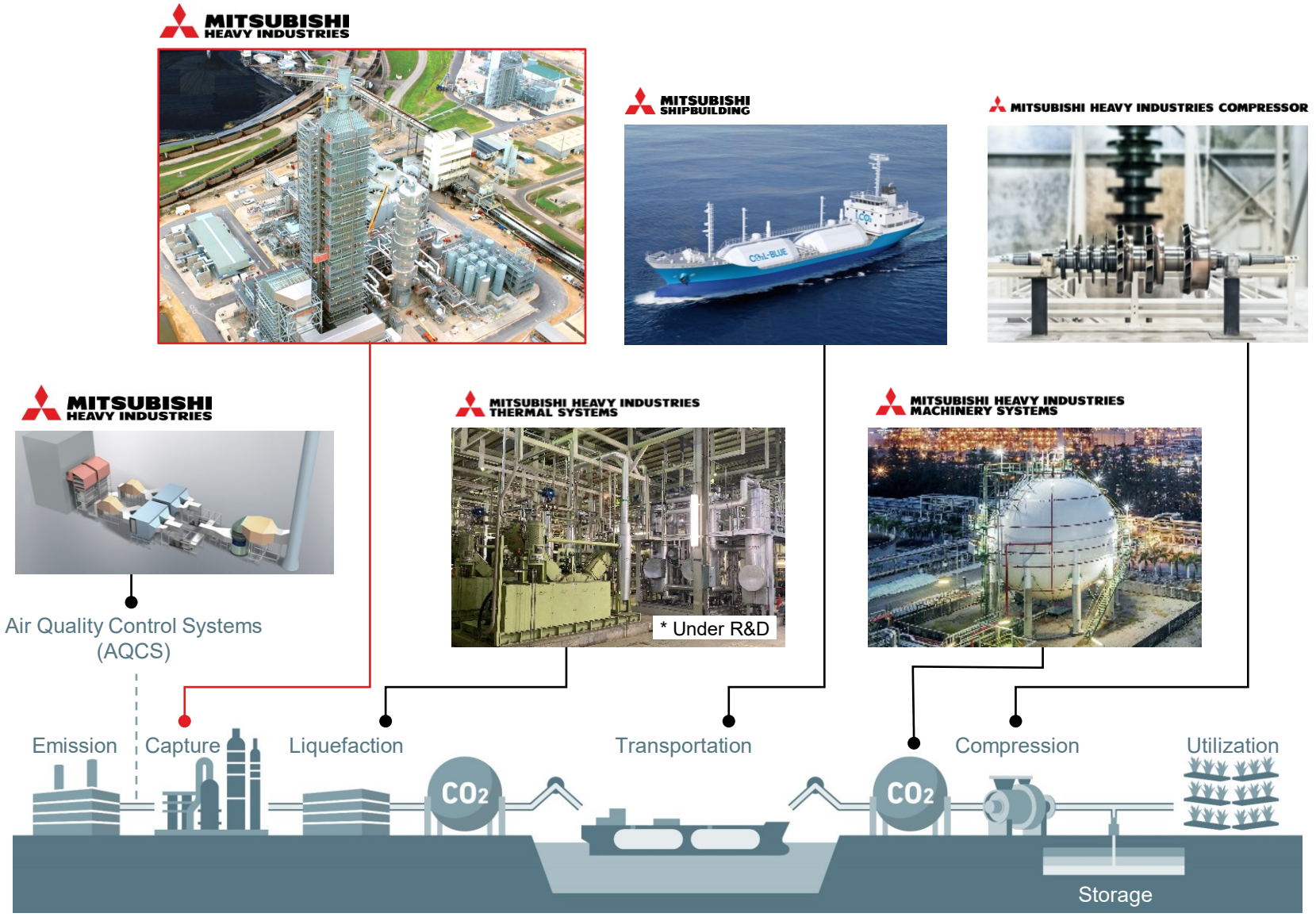
Core technologies of the CCUS Value Chain

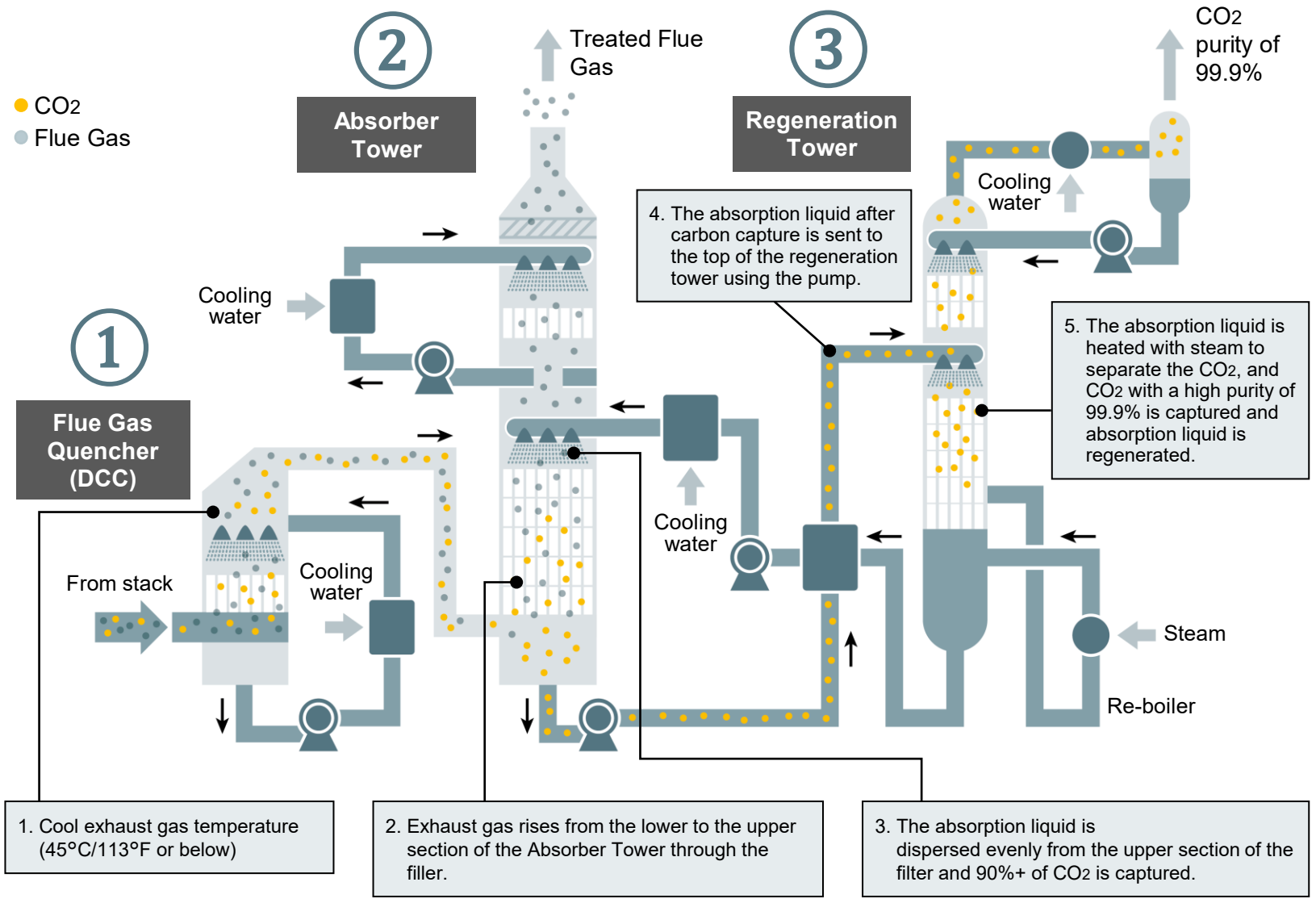
- MHI group has a core technologies essential for CCUS including carbon capture, transportation, storage, and compression. Carbon liquefaction is under in-house research & development (R&D) stage.
- **MHI group** has a solution for **carbon capture and capability to collaborate with CCUS technologies**



Post combustion CO_2 capture process of MHI

KM CDR Process™

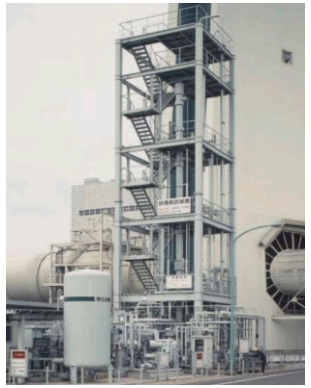
- KM CDR Process™ = ***Kansai Mitsubishi Carbon Dioxide Recovery Process***
- Amine-based technology
- Capable of capturing 95+% CO_2 from combustion gas (depending on source)
- Automatic load adjustment control (ALAC)
- Amine filtration and purification systems
- Tower design capability for even gas/liquid distribution



History of carbon capture technology development

Technology Centre Mongstad

In-house Pilot Plant in
Nagasaki R&D center



Pilot Plant in
Nanko Power Station

Pilot Plant in Plant Barry

Present

Verification of applicability to
Various carbon emission sources

2021

KS-1 and KS-21 were tested in
Technology Centre Mongstad (TCM)
Testing was on both cogen and cat cracker exhaust

2011~2014

Plant Barry 500 Mt/d
demonstration project

2008

Large absorber flow test at Mihara works

2006

10 Mt/d coal pilot test at Matsushima

2003

Developed proprietary energy
efficient process

2002

1 Mt/d coal in-house pilot test at
Hiroshima R&D Center
(present transferred to Nagasaki R&D Center)

1994

Developed KS-1™
and KM CDR Process™

1991

2 Mt/d pilot plant at
KEPCO's Nanko Power Station

1990

Began R&D with
Kansai Electric Power Co.

HISTORY OF CARBON CAPTURE TECHNOLOGY DEVELOPMENT

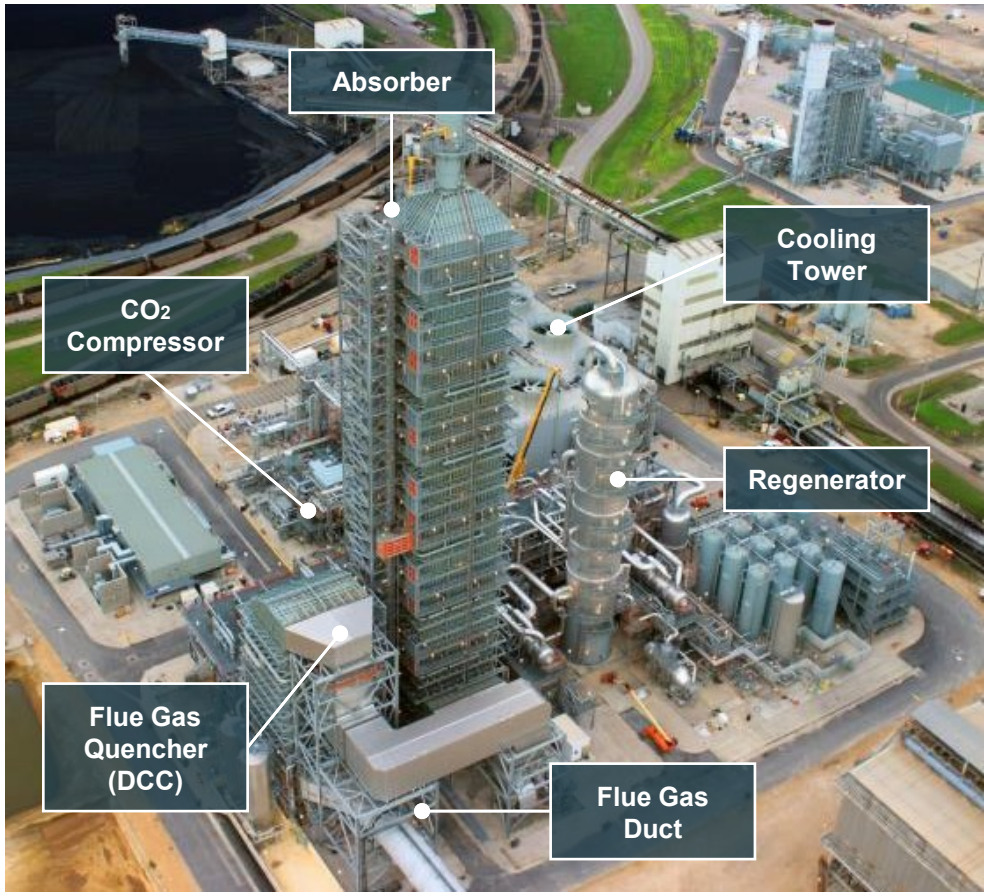
Petra Nova Project

The World's Largest Post-Combustion Carbon Capture Plant

EPC full turnkey project

- MHIENG has provided the world's largest carbon capture plant on coal-fired flue gas delivered in December 2016 for Petra Nova Project
- Supported by DOE (U.S. Department of Energy) grant program (CCPI* Round 3) and Japanese government finance (JBIC / NEXI)

Project Formation	• Consortium of MHIENG / Kiewit / The Industrial Company (TIC) • MHIENG: Engineering and Procurement for Carbon Capture Plant • Kiewit: Utility and balance of plant • TIC: Construction
Plant location	NRG WA Parish Power Plant (Thompsons, TX)
Project owner	Petra Nova - partnership between NRG Energy and JX Nippon Oil&Gas Since 2022, full ownership under JX Nippon Oil&Gas
Plant scale	240 MW_{eq}
CO_2 capacity	4,776 Mt/d (1.4 million tons per year)



Carbon Capture Plant

*Clean Coal Power Initiative
*U.S. Department of Energy "W.A. Parish Post-Combustion CO_2 Capture and Sequestration Project Final Environmental Impact Statement Volume I" (Feb, 2013), DOE/EIS-0473

Courtesy: NRG Energy and JX Nippon Oil & Gas

Advanced KM CDR Process™- Overview and Features

- MHI has developed upgraded process **Advanced KM CDR Process™** and upgraded solvent KS-21™.
- **KS-1™ / KS-21™ tested in Technology Centre Mongstad (TCM) carbon capture facility in Norway in 2021 with great success.**
  - ✓ Testing was on both CCGT and cat cracker exhaust
  - ✓ **95-98% carbon capture rate** was maintained for CCGT flue gas during the campaign.
  - ✓ Maximum **99.8%** was achieved for CCGT flue gas, then absorber outlet CO_2 % is lower than CO_2 content in air.
  - ✓ **KS-21™** showed reduced reclaiming duty and comparable or better energy performance than KS-1™
- **Advanced KM CDR Process™** is a process that enabled cost savings by using **KS-21™**.
- Ready for new commercial projects

Technology Centre Mongstad (TCM) ;
The world's largest and most flexible test centre for developing carbon capture technologies (an annual capacity for handling up to 100,000 tons of CO_2) and a leading competence centre for carbon capture.

Technology Centre Mongstad

Tanaka et al, "Advanced KM CDR Process™ using New Solvent",
14th International Conference on Greenhouse Gas Control Technologies

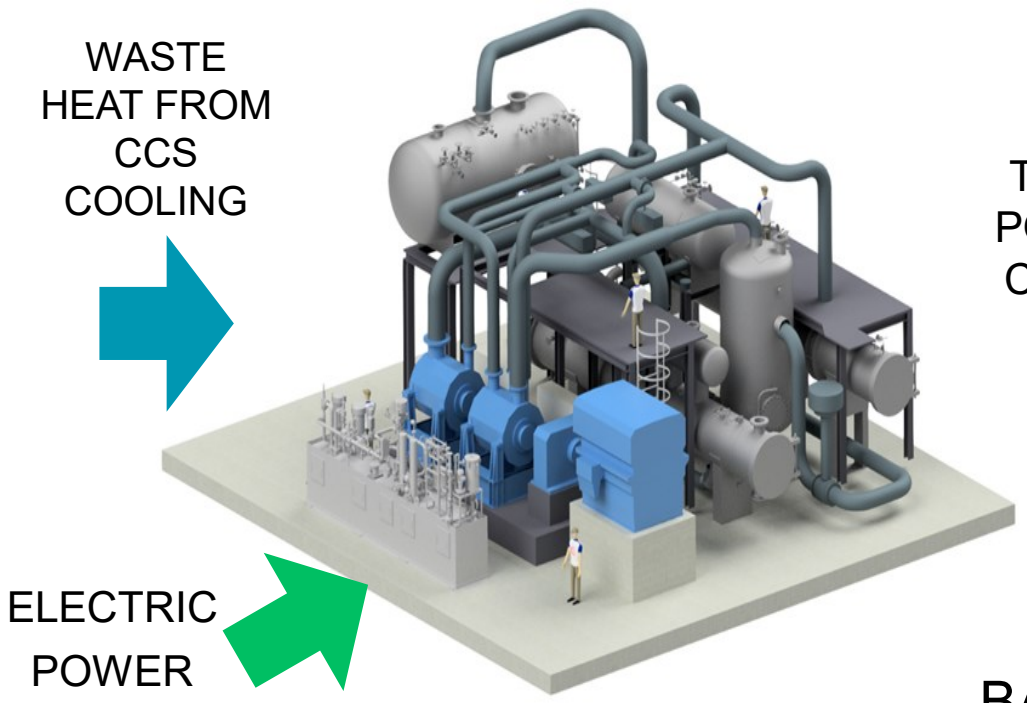
Photograph courtesy of Technology Centre Mongstad

Why heat pump integrated in CCS? Background & Motivation

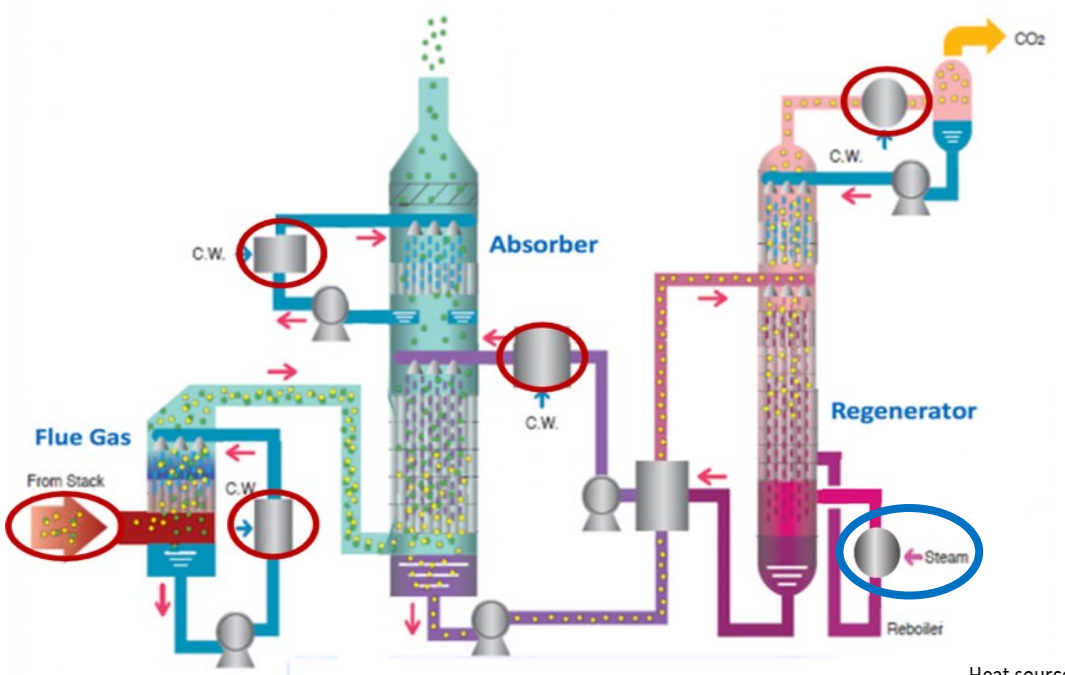
- ✓ Major voices of OPEX: Heating energy for regenerator & Cooling energy for process
- ✓ Heat pump system: OPEX improve by utilizing waste heat energy for regenerator
- ✓ Avoid additional CO2 emissions and water consumption

	Heat input to regenerator	Cooling duty
Duty (MW%)	40	100 (Base)
Temperature (deg.C)	110 to 120	40 to 70

Typical duty and temperature of heating and cooling in KM CDR Process™



THERMAL POWER TO CCS HEAT USER



BASE and A(i) and (ii)

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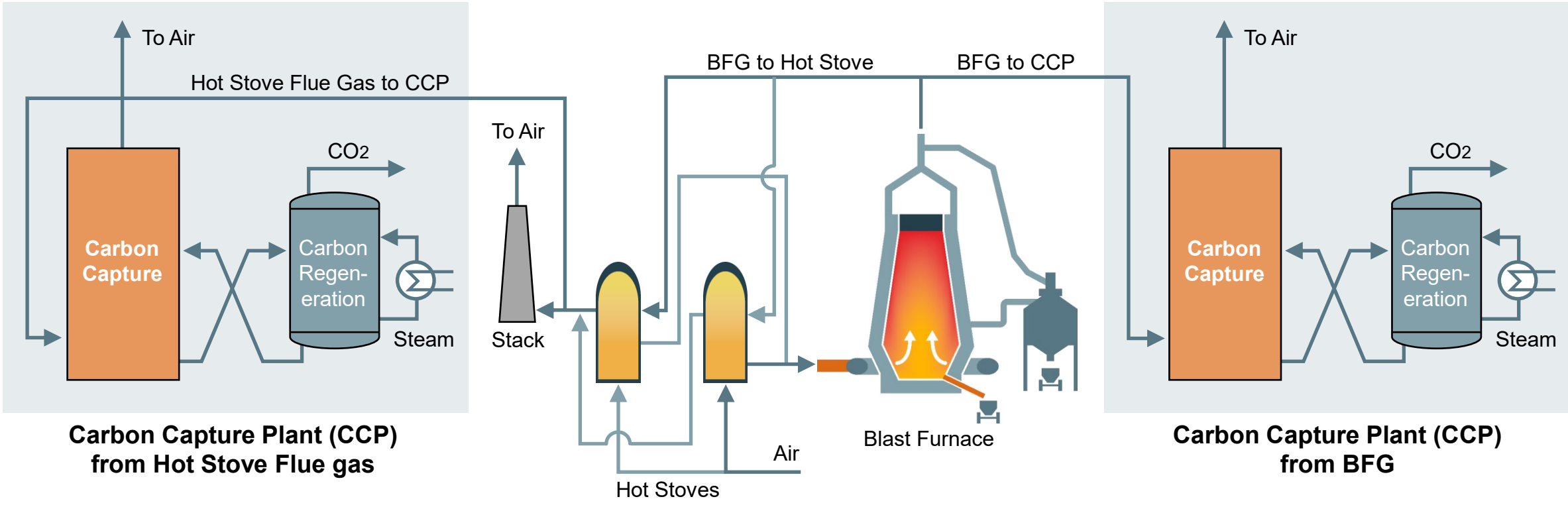
Application - Steel / Iron Making

Robustness against impurities specific to Steel Plant

- Blast Furnace Gas (BFG) or Hot Stove Flue Gas are treated
- Collected CO_2 is storaged

➢ Sample Configuration



Carbon Capture Plant (CCP) from Hot Stove Flue gas

Carbon Capture Plant (CCP) from BFG

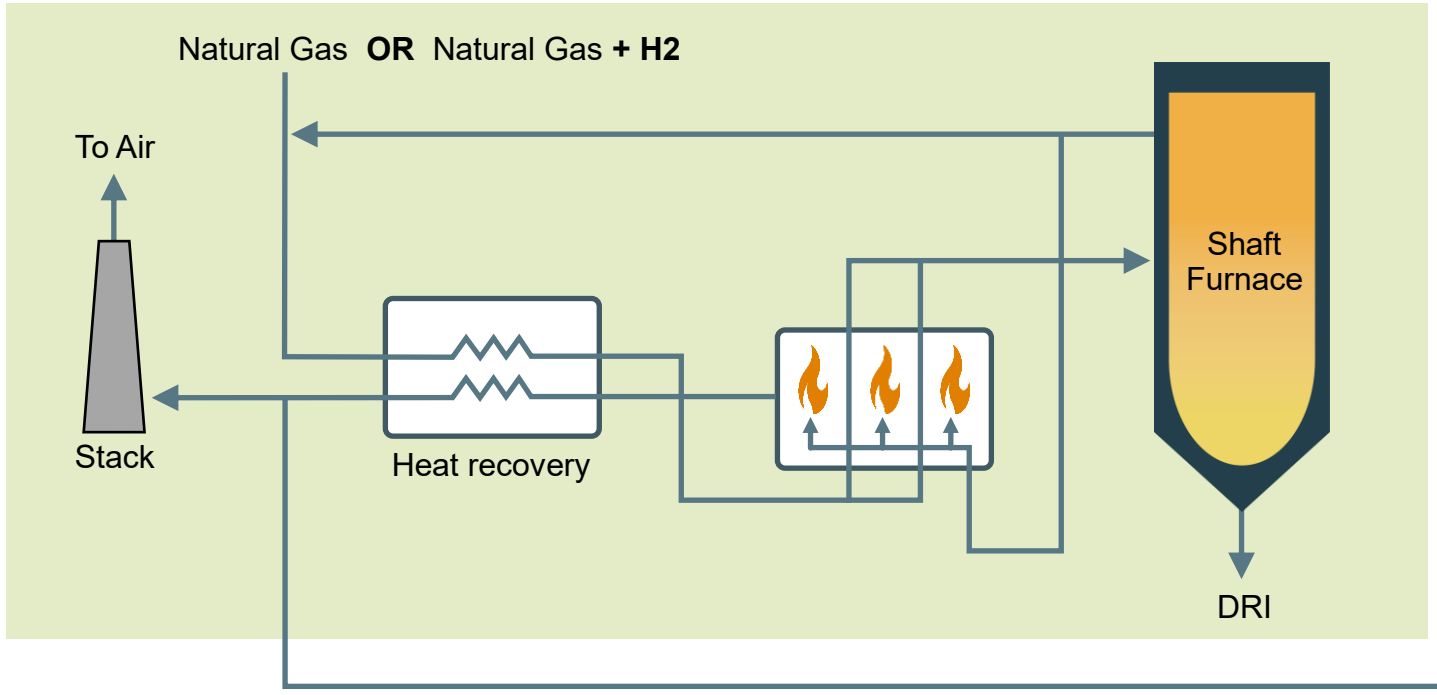
Carbon Capture Process in Steel/Iron Manufacturing

Application - Steel Plant (DRI)

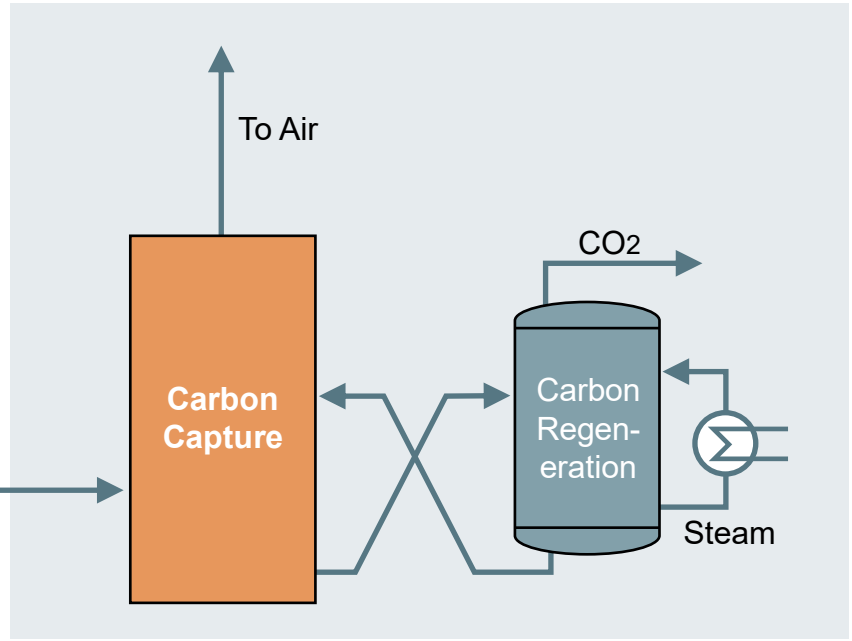
Robustness against impurities specific to Steel Plant

- CO_2 capture from flue gas of DRI plant ejector stack

➢ Sample Configuration



Direct Reduced Iron Manufacturing Process (MIDREX® Process*)



Carbon Capture Plant

* Licensed Technology of Midrex Technologies, Inc., a 100% subsidiary of Kobe Steel

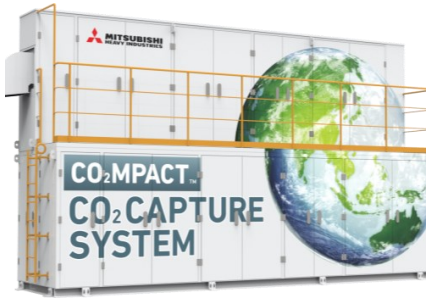
ArcelorMittal's Steel/Iron Making Plant

Verification of applicability for Steel/Iron Making

- ArcelorMittal, the world's leading global steel and mining company, BHP, Mitsubishi Development Pty Ltd, and MHI are collaborating on a multi-year trial of MHI's carbon capture technology with ArcelorMittal

Project Formation	◆ ArcelorMittal is facilitating the trial at its 5 million tons per year steel plant in Gent, Belgium, and at another location in North America ◆ MHI demonstrate its proprietary technology by small scale test unit and perform engineering study for full scale plant
Plant Location	ArcelorMittal's steel plant ✓ Gent, Belgium (Blast Furnace) ✓ North America (DRI plant)
CO_2 Source of Emissions	✓ Blast Furnace gas ✓ Hot Strip Mill Heater flue gas ✓ DRI reformer flue gas
CO_2 capacity	0.3 Mt/d

ArcelorMittal Steel/Iron Making Plant



CO_2MPACT_{TM} 0.3 Mt/d

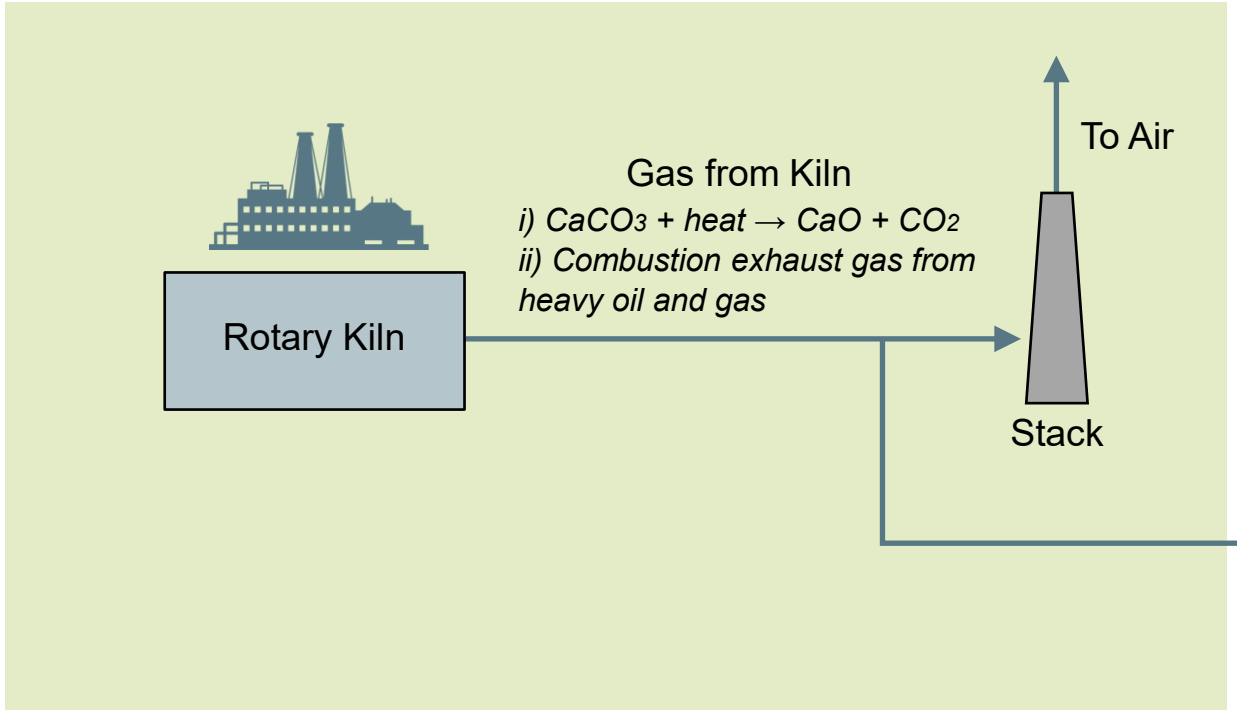
Courtesy: ArcelorMittal, S.A.

Application - Cement Manufacturing

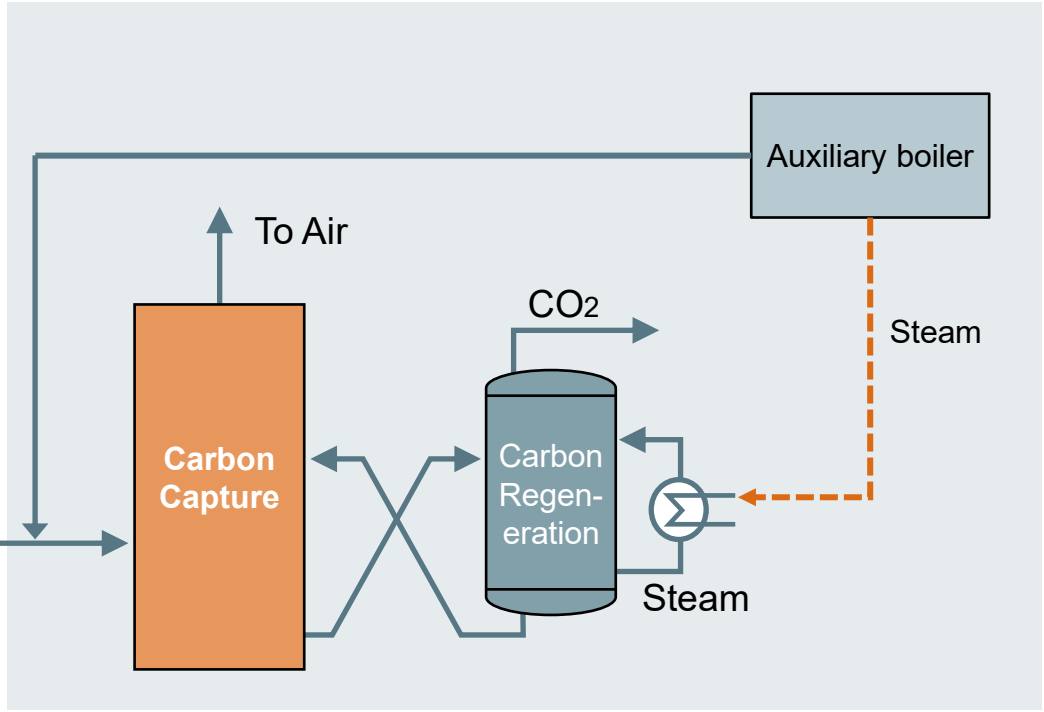
Optimization to Impurities Specific to Cement Plant

- Flue gas from Kiln (over 90% of CO_2 from Cement Plants) and steam generation
- Captured CO_2 to be put to sequestration

➢ Sample Configuration



Cement Manufacturing Process



Carbon Capture Plant

Lehigh Cement (Heidelberg Materials)

Feasibility study
The world's first study on carbon capture for cement manufacturing in the North America

Project Formation	• Advancing low carbon in cement industry CCS on cement plant in Edmonton, Alberta • Looking at a viability of capturing 90-95% CO_2 • Co-study with International CCS Knowledge Centre • Funded by Emissions Reduction Alberta* (local government) * invests innovative science and engineering that propels reducing GHG • Contributing to Canada Climate Plan
CO_2 Source of Emissions	Exhaust emissions from the flue gas Kiln (over 90～95% of CO_2 from Cement Plants) and Steam Generation
CO_2 capacity	Planning 0.6 Million Mt/y

Lehigh Cement Plant

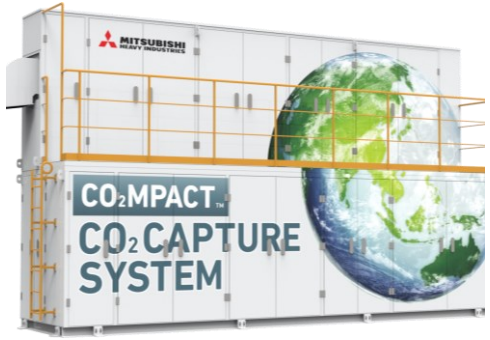
Courtesy: Lehigh Cement Company

Tokuyama's Cement

Verification of applicability for Cement Plant

Project Formation	• Tokuyama Corporation Cement plant operation management, test equipment installation, and Utility supply • MHI Manufacturing of CO_2MPACT$_{TM}$ 0.3 Mt/d and Leading of the verification • Both companies Analysis and evaluation of gas and applicability after recovery
CO_2 Source of Emissions	Exhaust emissions from the flue gas Kiln
CO_2 capacity	Planning 0.3 Mt/d

Tokuyama Cement Plant



CO_2MPACT$_{TM}$ 0.3 Mt/d

Courtesy: Tokuyama Corporation

Padeswood cement (Heidelberg Materials)

Verification of applicability for Cement Plant

Project Formation	• Pre-FEED for Padeswood , cement plant (UK), Heidelberg Materials
CO_2 Source of Emissions	Exhaust emissions from the flue gas kiln
CO_2 capacity	Planning 0.8 Million Mt/y

PRESS INFORMATION

MHIENG Awarded Pre-FEED Contract for Carbon Capture Plant at a Cement Production Facility in UK -- The Project Will Have the Ability to Capture and Store 800,000 Tonnes of CO_2 Per Year --

2022-12-15

- Pre-FEED for the UK's first CO_2 capture initiative in the cement industry
- Expanding applications of proprietary CO_2 capture technologies in hard-to-abate industries help in achieving carbon neutrality on a global scale

Padeswood cement plant (photo courtesy of Hanson UK)

Aluminium Bahrain (ALBA)

MoU on Decarbornisation of aluminum production

Project Formation	• MoU with Aluminium Bahrain
CO_2 Source of Emissions	Exhaust emissions from the aluminium smelter and CCGT
CO_2 capacity	Tbc

PRESS INFORMATION

MHI Group to Conduct Feasibility Study for Applying CO_2 Capture Technology at Aluminium Smelting Plant in Bahrain -- Project to Support the Kingdom's Sustainable Development and Enhance MHI's Presence in the Middle East --

2022-03-28

Mitsubishi Heavy Industries EMEA, Ltd.
Mitsubishi Heavy Industries Engineering, Ltd.

• MOU on development of CO_2 capture project concluded with Alba, a major aluminium producer in Bahrain.
• Will be the first application of CO_2 capture technologies in the aluminium industry when realized.

MOU signing ceremony

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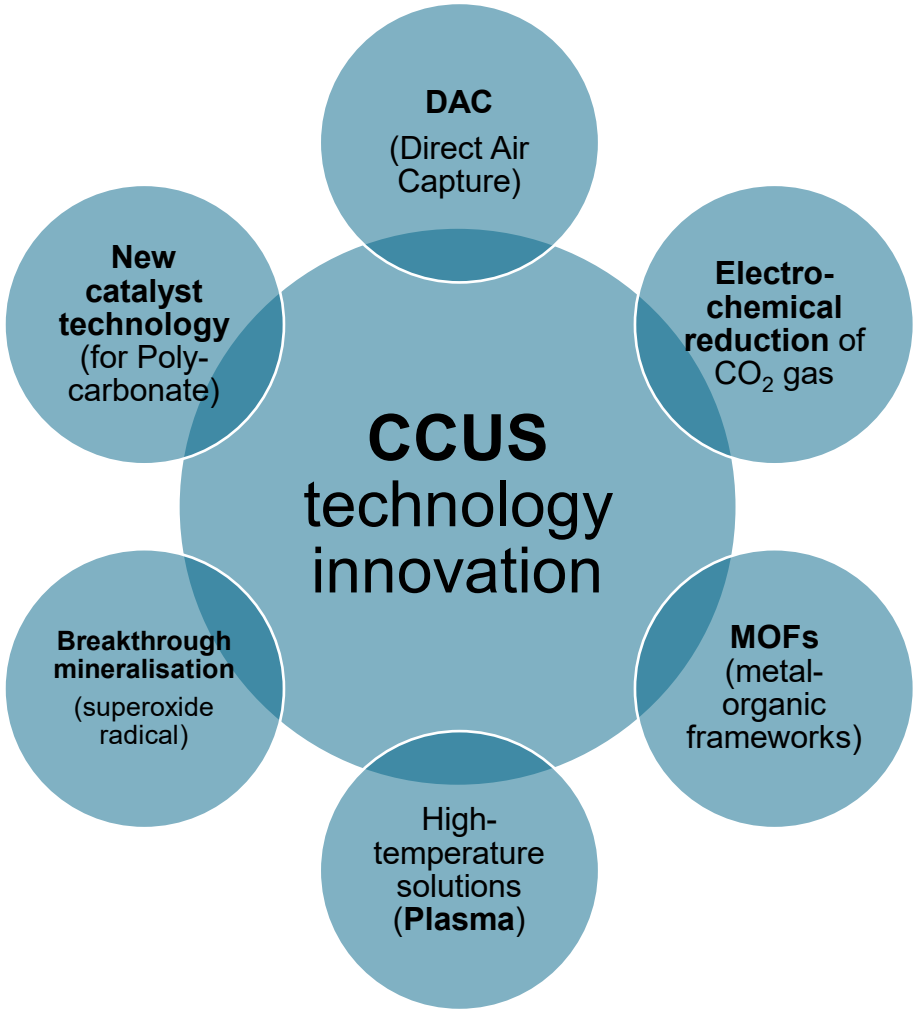
CCUS in Clean Energy Transitions

- Two-thirds of the cumulative emissions reductions from CCUS through to 2070 in the Sustainable Development Scenario relative to the Stated Policies Scenario come from technologies that are currently at the prototype or demonstration stage. Given the time lags involved, innovation needs to be stepped-up now to ensure key applications are commercially available in the coming decade.
- There is a disconnect between the level of maturity of individual CCUS technologies and the areas in which they are most needed. For example, the most advanced technology for CO2 capture in the cement industry is only at the demonstration stage, but a lack of alternative technology options means CCUS is needed to deliver 60% of the sector's emissions reductions in the Sustainable Development Scenario. Other CCUS applications that will require a major innovation push include chemicals and steel production, gas-fired power generation, BECCS and DAC.



https://www.iea.org/reports/ccus-in-clean-energy-transitions/ccus-technology-innovation

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Conclusion

- ✓ Post combustion CO_2 capture based on amines is most advanced technology available at large industrial scale
- ✓ MHI is a leading company in CO_2 capture industry with 30 years of experience and more than 15 industrial scale references based on its proprietary amine based technology (KM CDR^{TM})
- ✓ Further development of carbon capture technology ongoing: a) development of new generation of solvents and optimising plant design, b) electrification of overall process using heat pumps
- ✓ Applications and specific examples in hard to abate sector are already available

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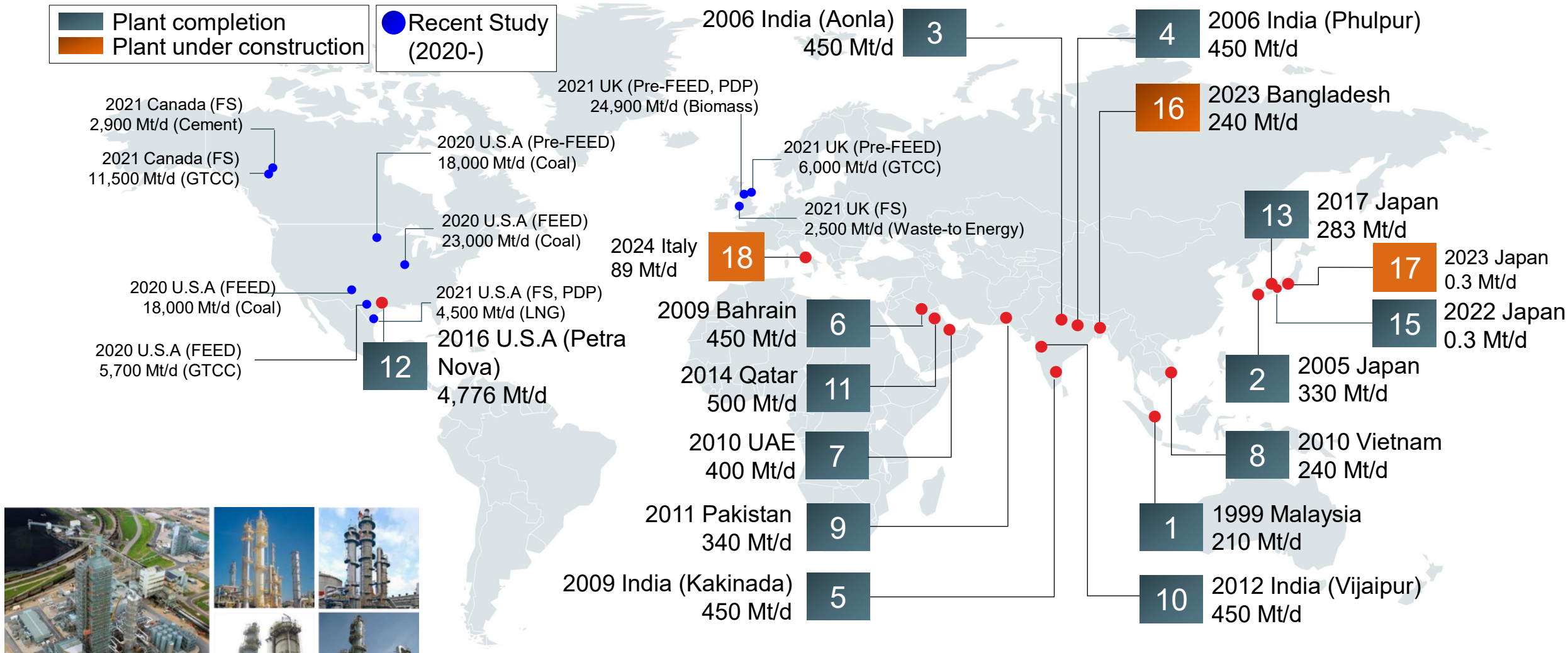
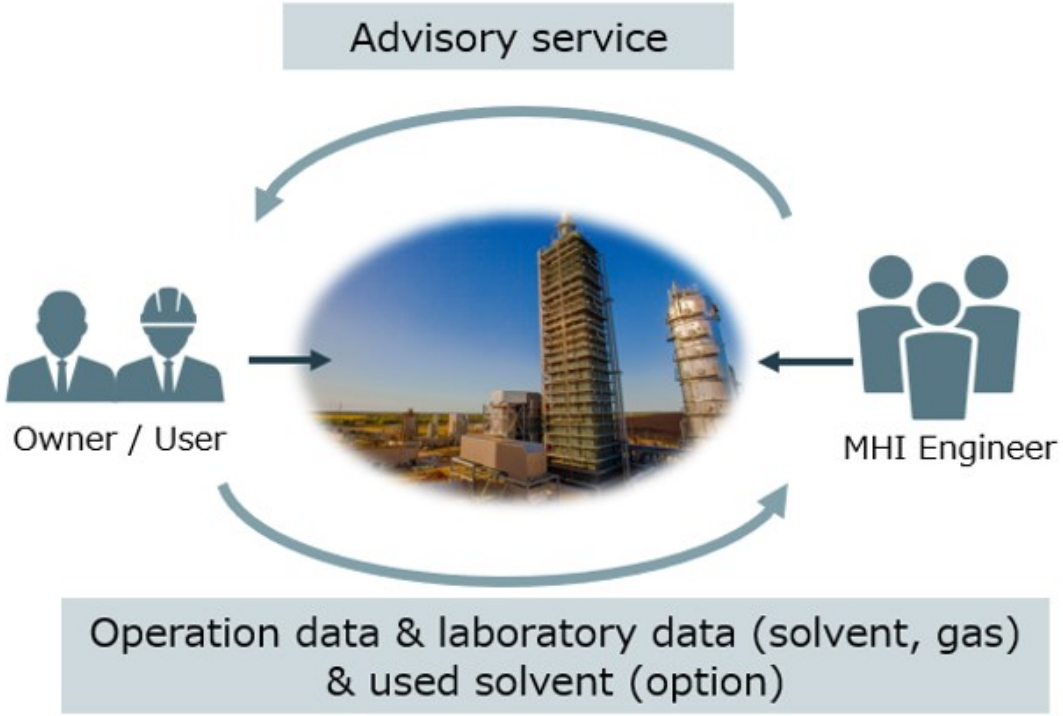
KM CDR Process™ - Worldwide Commercial Experience



Feedback from commercial units

VOC (Voice of Customers)

- ✓ Licensor Operation Advise
- ✓ Remote Monitoring



User Conference

- ✓ All users shared their own operation experiences with each user
- ✓ Incorporate lesson & Learned into KM CDR Process™

@Bahrain, 17-18 May 2023

Alliance overview

Overview:

The push to decarbonize the industrial and power-generation segments has never been stronger, and CCS technologies are among the most viable large-scale solutions on the market today. ExxonMobil is leading the effort to provide integrated CCS solutions, many of which involve the KM CDR Process liquid amine carbon capture technology from Mitsubishi Heavy Industries (MHI), which is one of the only CO_2 capture technologies commercially demonstrated at greater than 1 million metric tons per year. The ExxonMobil and MHI collaboration supports the development of scalable solutions and technology advances, while deploying the companies' complementary capabilities to effectively serve industrial and power-generation customers.

ExxonMobil | MITSUBISHI HEAVY INDUSTRIES

Source:
https://www.mhi.com/news/22113001.html
https://corporate.exxonmobil.com/news/news-releases/2022/1129_exxonmobil-and-mitsubishi-heavy-industries-form-carbon-capture-technology-alliance

Overview of storage projects (under development)

Figure 2: European CO_2 injection capacity

Annual injection capacity provided by currently proposed CO_2 storage projects in the European Economic Area, showing those which have received exploration licences.[7]

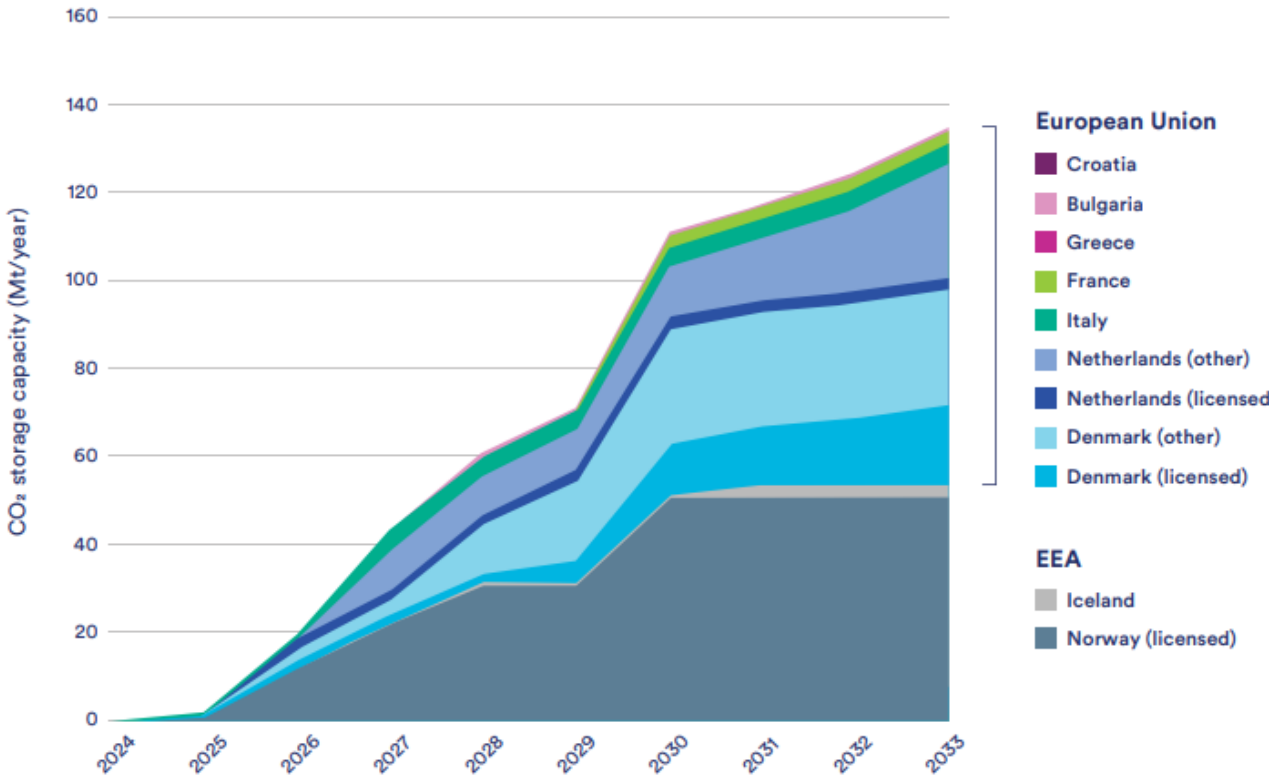


Figure 4: A map of planned CO_2 infrastructure projects in the 6th list of PCI candidates for cross-border CO_2 networks