MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

# KM CDR Process™
# Post-combustion $CO_2$ Capture Technology

## 26th Annual CO2 Conference

December 8, 2020



MITSUBISHI HEAVY INDUSTRIES AMERICA

# Presentation Outline

1. Introduction to MHI
2. MHI's KM CDR Process™ Carbon Capture Technology
3. Recent Highlights

# Introduction to MHI

# Mitsubishi Heavy Industries Group at a Glance

As a global leader in engineering and manufacturing, Mitsubishi Heavy Industries (MHI) Group delivers innovative and integrated solutions across a wide range of industries from commercial aviation and transportation to power plants and gas turbines, and from machinery and infrastructure to integrated defense and space systems.

## COMPANY HIGHLIGHTS

| | | |
|---|---|---|
| **$36.7BN**<br>Annual revenue | More than<br>**24,600**<br>Patents | **52%**<br>Sales outside Japan |
| **$1BN**<br>Profit | **82,728**<br>Employees worldwide | **400+**<br>Domestic & overseas companies |

(FY2019 Results @110JPY/$)

# Mitsubishi Heavy Industries Group Domains

## MHI GROUP DOMAINS

### POWER SYSTEMS

- Thermal Power Systems
- Nuclear Energy Systems
- Offshore Wind Power Systems
- Pumps
- Marine Machinery
- Compressors
- Aero Engines

**$16.1 B NET SALES**

### INDUSTRY & INFRASTRUCTURE

- Material Handling Equipment
- Engine & Energy
- Turbochargers
- Air-Conditioning & Refrigeration
- Machine Tool
- Automotive Thermal Systems
- Industry & Precision Instruments
- Machinery/Equipment
- Mechatronics Systems/ITS
- Metals Machinery
- Environmental Systems
- Chemical Plants
- Shipbuilding & Ocean Develop.
- Land Transportation Systems

**$17.2 B NET SALES**

### AIRCRAFT, DEFENSE & SPACE

- Commercial Aircraft
- Mitsubishi SpaceJet
- Defense Aircraft
- Missile Systems
- Space Systems
- Special Vehicles
- Naval Ships
- Maritime & Space Systems

**$6.5 B NET SALES**

# MHI Group Presence in North America

**MHI in North America**

- **9,000+** EMPLOYEES
- **100+** OFFICE & FACTORIES
- **4,154** PATENTS
- **$6.5BN** IN REVENUE
- Relationships with around **200** SUPPLIERS

**WASHINGTON**
**Moses Lake**
Moses Lake Flight Test Center for Mitsubishi Space Jet
**Seattle**
MHIA Office
**Renton**
Mitsubishi Aircraft Corporation America

**OREGON**
**Portland**
Diamond WTG Engineering Services

**COLORADO**
**Ft.Collins**
MD&A Control Systems

**CALIFORNIA**
**Silicon Valley**
MHIA Office
**Los Angeles**
MHPS
**Newport Beach**
MHIA Office
**Whittier**
Southern California Material Handling

**ALBERTA**
**Calgary**
Mitsubishi Hitachi Power Systems Canada

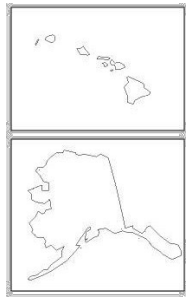
**ONTARIO**
**Mississauga**
MHI Aerospace Canada

**ILLINOIS**
**Chicago**
Mitsubishi Turbocharger and Engine America
**Marengo**
UniCarriers Americas

**MISSOURI**
**St.Louis**
MD&A Generator and Steam Path Engineering & repair

**ARIZONA**
**Tucson**
MHIA Office

**TEXAS**
**Fort Worth**
MHIA Office
**Houston**
Mitsubishi Heavy Industries America (MHIA) HQ
MHIA Engineered Systems Division
MHIA Oil & Gas Division
Mitsubishi Caterpillar Forklift America
Equipment Depot
MHI Compressor International



**Addison**
MHIA Aircraft Product Support Division
MHIA Office
**Plano**
Mitsubishi Aircraft Corporation America

**MICHIGAN**
**Harrison**
Federal Broach Holdings
**Grand Rapids**
Rapid Parts
**Wixom**
MHIA Machine Tool Division

**INDIANA**
**Franklin**
Mitsubishi Turbocharger and Engine America
MHI Climate Control

**OHIO**
**Leetonia**
MHIA Tire Machinery Division

**NEW JERSEY**
**BASKING RIDGE, NJ**
MHPS Technology Center

**MARYLAND**
**Hunt Valley**
MHIA Corrugating Machinery Division

**WASHINGTON, D.C.**
MHIA Office

**GEORGIA**
**Alpharetta**
Primetals Technologies USA
**Pooler**
Savannah Machinery Works for MHPS

**NORTH CAROLINA**
**Charlotte**
Mitsubishi Nuclear Energy Systems

**FLORIDA**
**Lake Mary**
Mitsubishi Hitachi Power Systems Americas (MHPS)
**Orlando**
Orlando Service Center for MHPS
**Miami**
Crystal Mover Services

**MASSACHUSETTS**
**Andover**
MHIA Office
**Cambridge**
MHIA Office
**Woburn**
MHIA Office
**Worcester**
Primetals Technologies USA

**CONNECTICUT**
**Hartford**
MHIA Office
**Glastonbury**
PW Power Systems

**NEW YORK**
**Latham**
Mechanical Dynamics & Analysis

As of July 2019

# MHIA Engineered Systems Division

**MHI America, Inc.'s Engineered Systems Division**, based in Houston, provides sales, administration, engineering, and project management support for MHI Engineering, Ltd.'s business in the US.

**ENGINEERING**
**A RELIABLE FUTURE**

Mitsubishi Heavy Industries Engineering offers reliable technologies gained from engineering synergies realized within the Mitsubishi Heavy Industries (MHI) Group.

We contribute to the development of society by supplying numerous EPC (Engineering, Procurement, Construction) projects covering large-scale infrastructure, such as chemical plants, environmental plants, and transportation systems, in many countries and regions around the world.

$CO_2$ Capture Plants

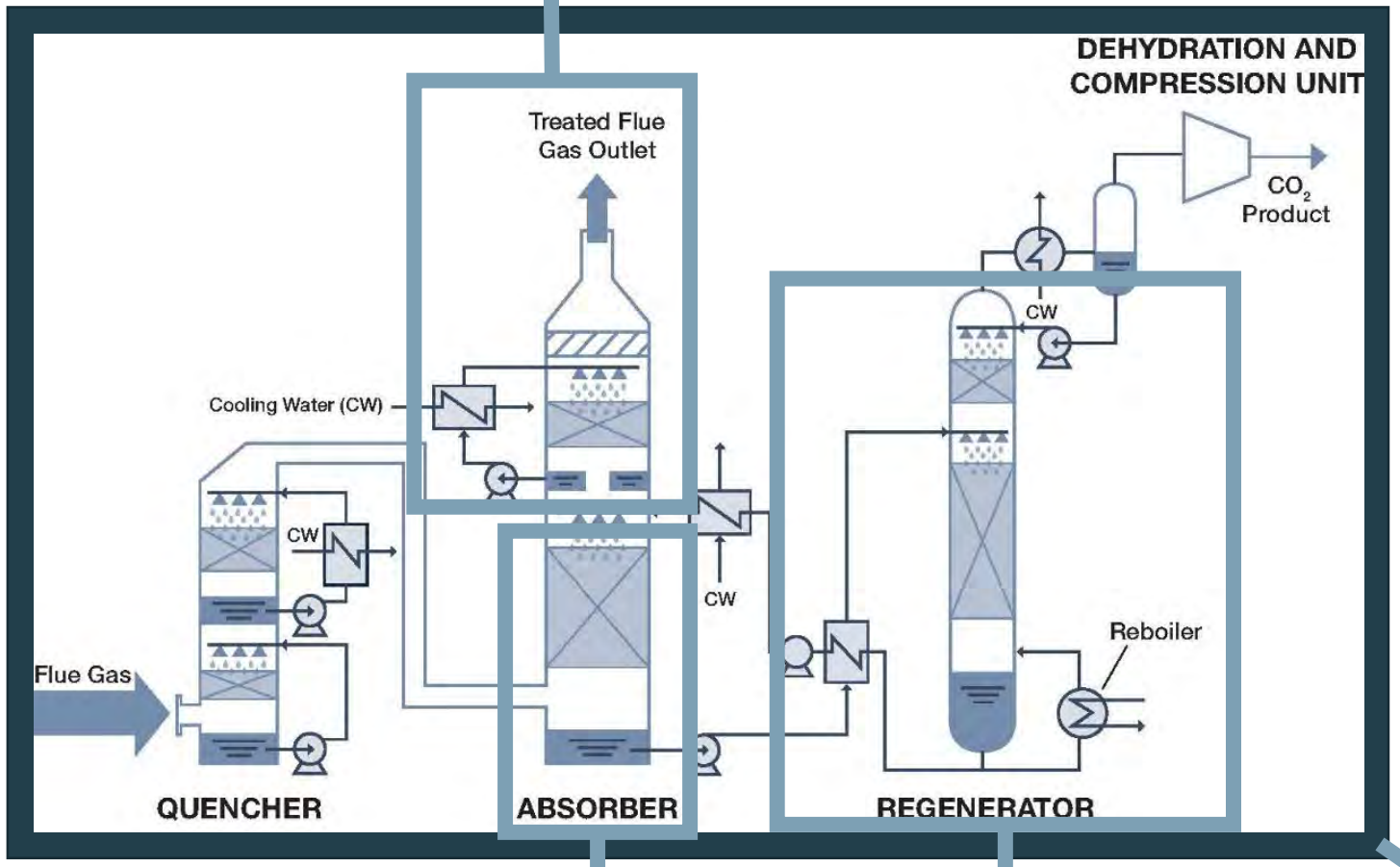
Chemical Plants

Transportation

# MHI’s KM CDR Process™ Carbon Capture Technology

# KM CDR Process™ Overview and Features

**Amine washing** system reduces VOC emissions and amine loss



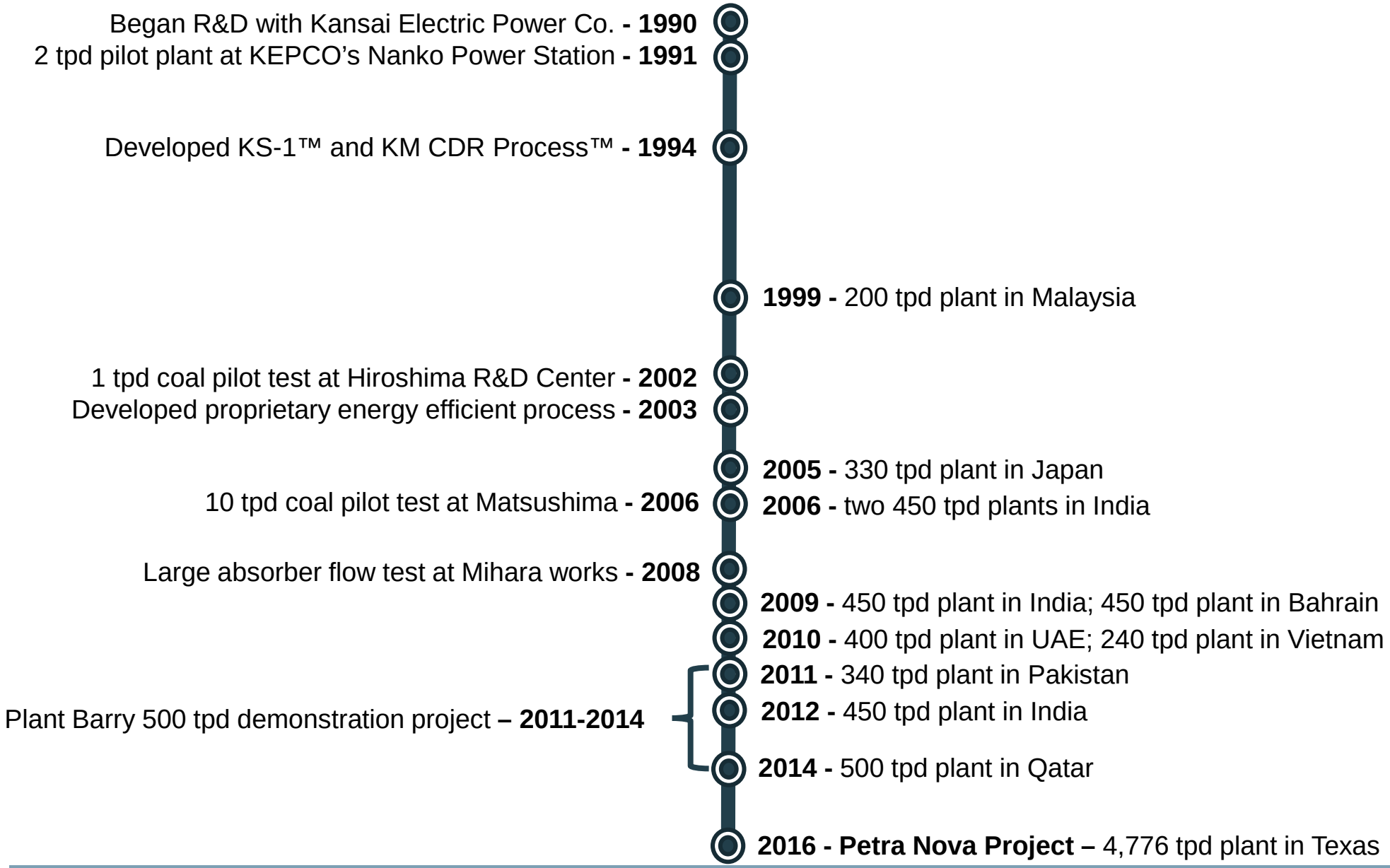

- **KM CDR Process™** = *Kansai Mitsubishi Carbon Dioxide Recovery Process*
- Amine-based technology
- Capable of capturing ~90+% $CO_2$ from combustion gas sources
- Proprietary features developed over 28 years of experience
- CO2 purity >99.9% (dry basis)

- Automatic load adjustment control
- Amine filtration and purification systems
- Proven tower design for even gas/liquid distribution

**KS-1™ solvent** with high $CO_2$ capacity, low degradation, and low regeneration energy

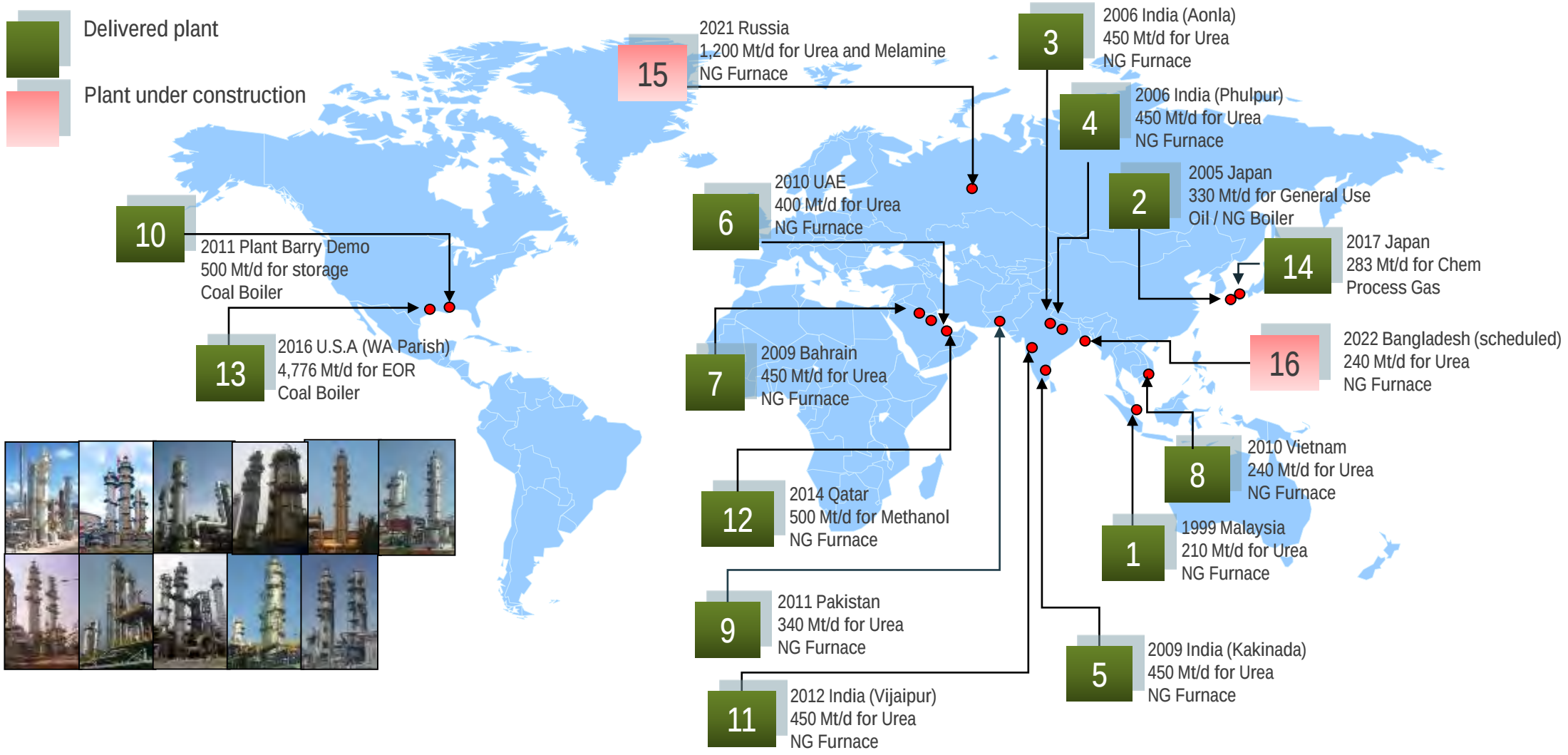
**Heat integration** system to reduce steam consumption

# KM CDR Process™ Technology Development Timeline



# MHI leads the world in large scale $CO_2$ capture plant deployment

## Chemical production has been the main driver for the deployment of the KM CDR Process™.



# MHI's KM CDR Process™ can be used on a variety of flue gases

**The KM CDR Process has been applied to a variety of gases, and the effects of various impurities on the amine and the system have been tested.**

## Tested gases include:

- Natural gas-fired boiler exhaust
- Oil-fired boiler exhaust
- Coal-fired boiler exhaust
- Gas turbine exhaust (simulated)

## Industrial applications:

- Power plants (NGCC, coal-fired, or biomass)
- Steam methane reformer furnace exhaust
- Cement plants
- Steel plants
- Catalytic crackers
- Natural gas processing

**Typical Flue Gas Conditions**

| | Unit | Coal fired Boiler | NG fired GT | NG fired Boiler |
|---|---|---|---|---|
| $CO_2$ | Vol.% | 10 - 14 | 3 - 4 | 8 - 9 |
| $O_2$ | Vol.% | 4 - 6 | 10 - 15 | 1 - 2 |
| SOx | ppm(dry) | 1 - 50 | <0.3 | <1 |
| PM (Dust) | $mg/Nm^3$ | 3 - 10 | NA | NA |

**Other possible constituents in the flue gas depending on the industrial application:**

- NOx
- CO
- $H_2S$
- Hydrocarbons
- Heavy metals
- Halides (HCl, HBr, HF)

# MHI delivered the world's largest post-combustion $CO_2$ capture plant


Fall 2016 View of the Site

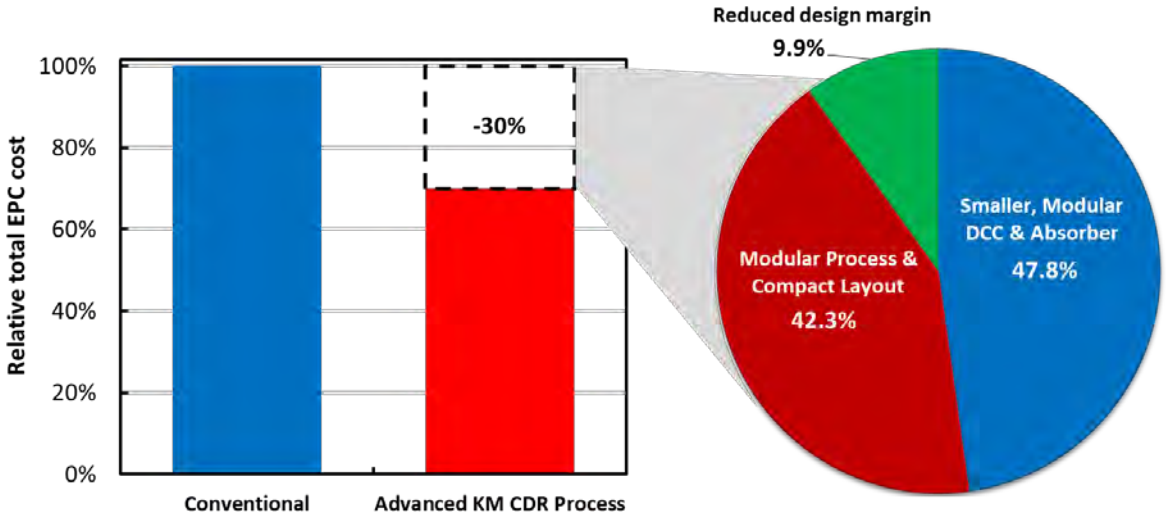
**The Petra Nova Project is MHI's first commercial power project. Performance test was completed in December 2016.**

- Plant is owned by NRG and JX Oil & Gas.
- Located at NRG's WA Parish Plant Unit 8 near Houston, TX.
- Captures 4,776 metric tons/day (240 MWeq, 90% capture) from a ~37% flue gas slip stream (1.4 million metric tons/year).
- MHI and TIC consortium provided full turnkey EPC delivery of the $CO_2$ capture plant.

**Operating $CO_2$ capture plants on coal fired flue gas has provided valuable insights that can be implemented into the next projects.**

- ***Re-evaluate equipment and tower design based on actual performance.***
- ***Modularize, and optimize plot plan.***
- ***Develop realistic gas impurity assumptions during design.***
  - Impurity concentrations greatly affect the design of mitigation processes.
- ***Increase design capture rate from 90% to 95% at same $/ton cost basis.***

# Advanced KM CDR Process™ – Capital cost optimization




| Cost Relative to conventional | Conventional | Advanced KM CDR Process |
|---|---|---|
| **Pumps** | 100 | 49 |
| **Heat exchangers** | 100 | 80 |
| **Tower internals** | 100 | 74 |
| **Filtration system** | 100 | 43 |
| **Tanks** | 100 | 74 |

| Spec Relative to conventional | Conventional | Advanced KM CDR Process |
|---|---|---|
| **Footprint (% in $m^2$)** | 100 | 75 |
| **Structural steel (% in tonnes)** | 100 | 76 |
| **Piping (% in tonnes)** | 100 | 79 |

✓ **Technology risks are significantly reduced after large-scale unit experience**

✓ **Improvement from new technology & lessons learned**

- Reduce height of DCC and Absorber which are the major cost centers (>30% of CAPEX)
- Reduce Regenerator diameter by 10% by selecting new packing
- Optimize equipment design

✓ **Optimized & minimized layout and modular design**

- Fabricated in shop as skids to reduce on-site fabrication, reducing construction labor hours by 60% and improving productivity, schedule & budget control
- Minimized footprint reduces material quantities resulting lower construction cost

# New Solvent – KS-21™

| Parameters Relative to KS-1™ | KS-1™ | KS-21™ |
|---|---|---|
| Volatility | 100 | 50-60 |
| Thermal degradation rate | 100 | 30-50 |
| Oxidation rate | 100 | 70 |
| Heat of absorption | 100 | 85 |

## ✓ Thermal stability

- Reduce thermal degradation and allow higher stripping T and P, reducing compression work

## ✓ Oxidative stability

- Potentially more tolerant to impurities
- Reduce amine oxidation and HSS formation rate

## ✓ Volatility

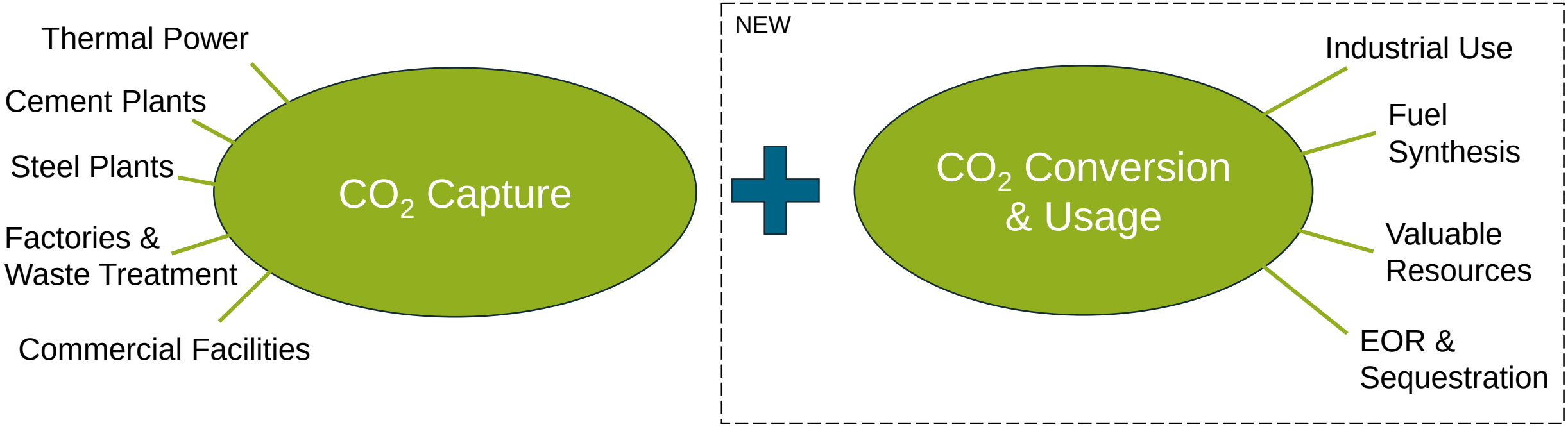
- Reduce amine loss from emission and cost of water wash system
- Steam consumption savings outweigh cost increases due to higher solvent circulation

***Ongoing FEED studies using the Advanced KM CDR Process™ and KS-21™ solvent.***

# Recent Highlights

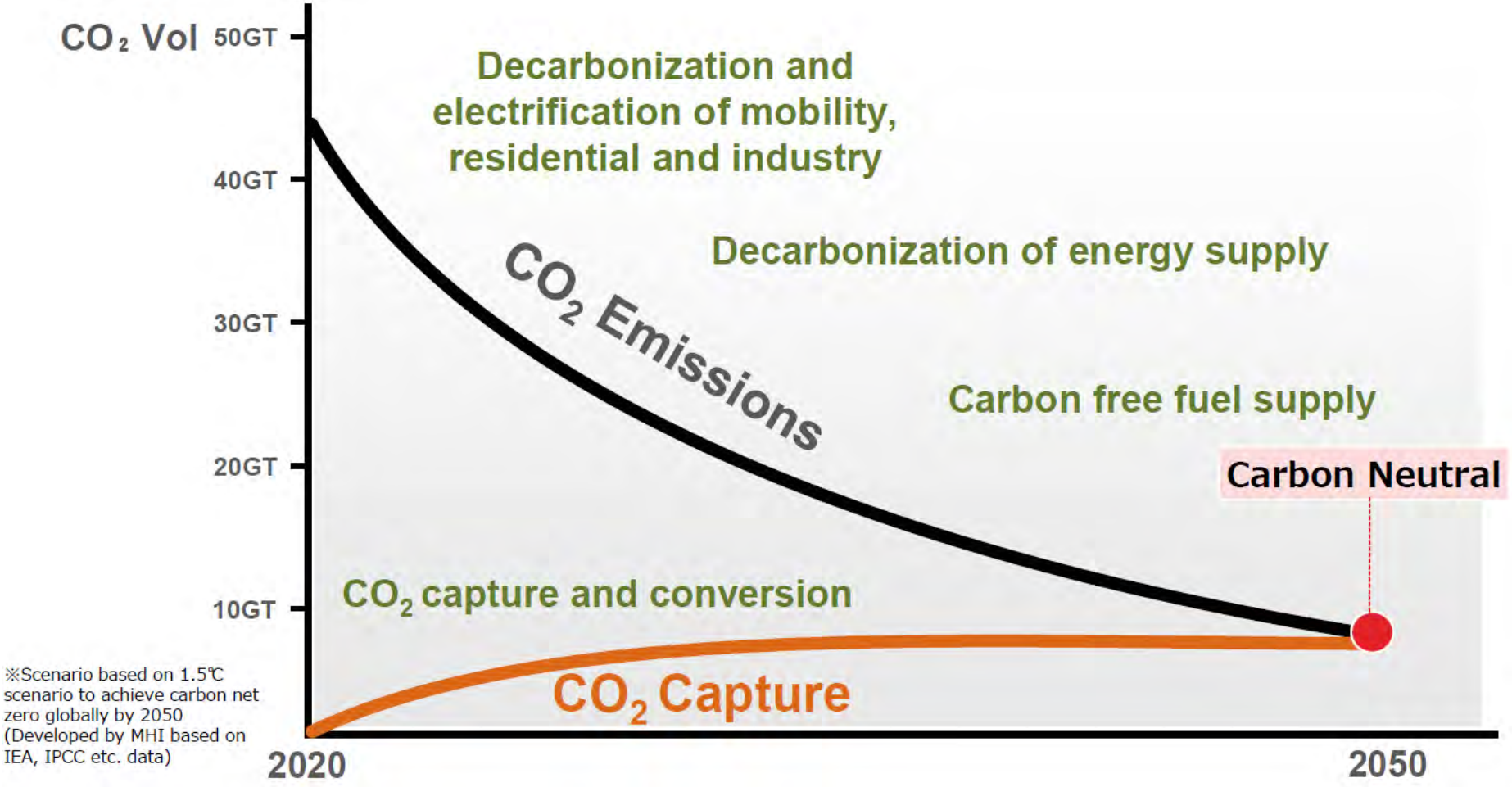
# MHI Decarbonization Strategy

- **Initial investments to begin in FY 2021**
- **MHI commitment: to bring about a carbon-neutral world by 2050**
- **Carbon capture and use will be a central focus**
- **MHI will expand its product lineup and invest in conversion & usage technologies**



# Path to Net-zero

MHI Group will use its technological strengths to lower and capture $CO_2$ emissions and achieve a carbon neutral 2050



## The KM CDR Process™ for BECCS – delivering negative emissions

- Drax Group and MHI Engineering to demonstrate carbon capture with a pilot project at Drax Power Station in North Yorkshire, England
- MHI's 12-month pilot will capture ~300 kg $CO_2$/day to confirm the suitability of our technology for use with biomass flue gases at Drax Power Station
- Two of MHI's proprietary solvents are planned for testing, KS-1™ and KS-21™
- Project will further the understanding of the potential for deploying BECCS at scale at Drax – taking them closer to achieving their world-leading ambition to be a carbon negative company by 2030

*"This is an exciting collaboration between Drax and Mitsubishi Heavy Industries which has the potential to further the development of technology which could help the UK achieve net zero greenhouse gas emissions by 2050 and contribute to the post-Covid economic recovery."*

*Nigel Adams MP, Minister of State at the Foreign and Commonwealth Office and the Department for International Development*

# Carbon Capture on the Ocean (CC-Ocean)

**World's first marine-based demonstration test of $CO_2$ capture.**

- Cooperation between Mitsubishi Shipbuilding Co., Ltd., Kawasaki Kisen Kaisha, Ltd., and Nippon Kaiji Kyokai
- Applying the existing land-based $CO_2$ capture system to a marine environment
- Manufacturing expected to begin in 2021
- Project expected to last for two years
- Aiming to validate $CO_2$ capture as an option for reducing the emissions from marine equipment and ships

# Final Quote

**“Today’s worldwide installed capacity of CCS is around 40 Mtpa. To achieve net-zero emissions, it must increase more than a hundredfold by 2050.”**

Global Status of CCS 2020 Report
Global CCS Institute

MOVE THE WORLD FORWARD

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