

KM CDR Process™ Post-combustion CO₂ Capture Technology

2019 CO₂ & ROZ Conference
Carbon Management Workshop
Midland, Texas

December 9, 2019

Agenda

1. Introduction to MHI
2. MHI's KM CDR Process™ overview and experience
3. Advanced KM CDR Process™
4. What's next?

Introduction to MHI

MHI GROUP DOMAINS



POWER SYSTEMS

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

\$12.9 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

\$15.6 B NET SALES



AIRCRAFT, DEFENSE & SPACE

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

\$6.3 B NET SALES

COMPANY HIGHLIGHTS

\$36.7BN
Annual revenue

More than
25,600
Patents

54%
Sales outside Japan

\$1.7BN
Operating income

80,744
Employees worldwide

235
Domestic & overseas companies

MHI IN NORTH AMERICA

 **9,300+**
EMPLOYEES

 **100+**
OFFICE & FACTORIES

 **3,927**
PATENTS

\$6.0BN
IN REVENUE

Relationships with around
200
SUPPLIERS

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.



CO₂ Capture Plants

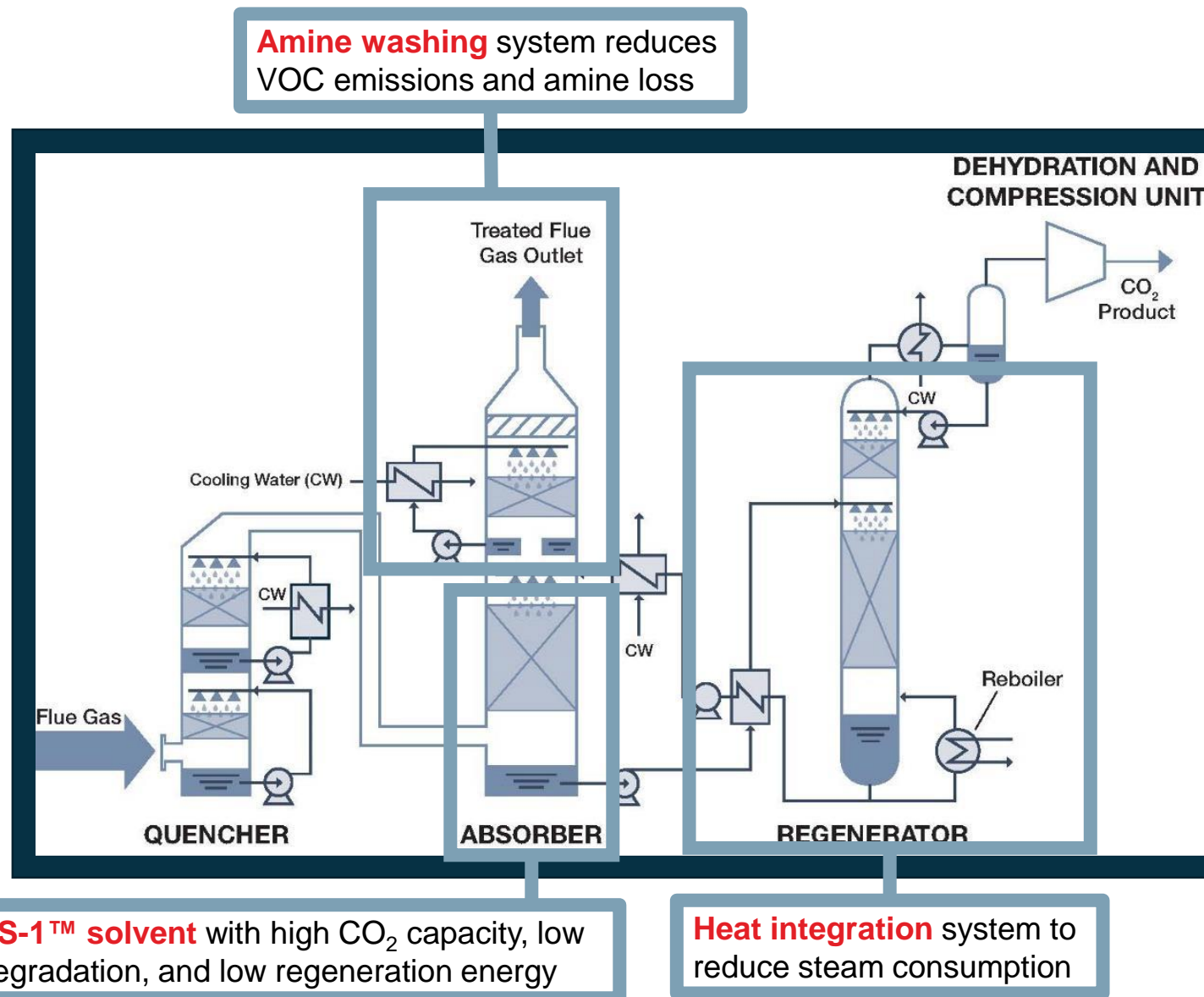


Chemical Plants



Transportation

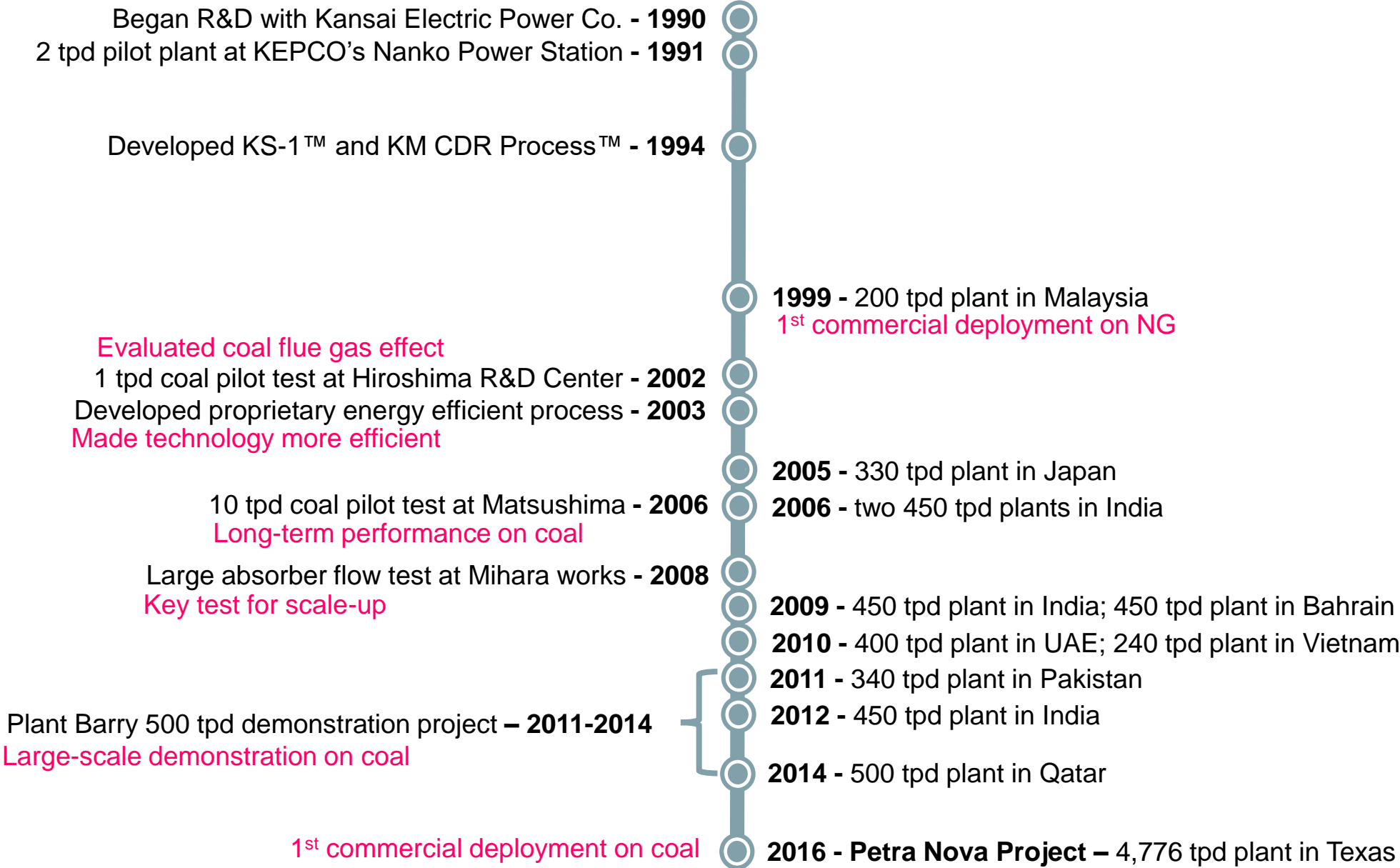
MHI's KM CDR Process™ overview and experience



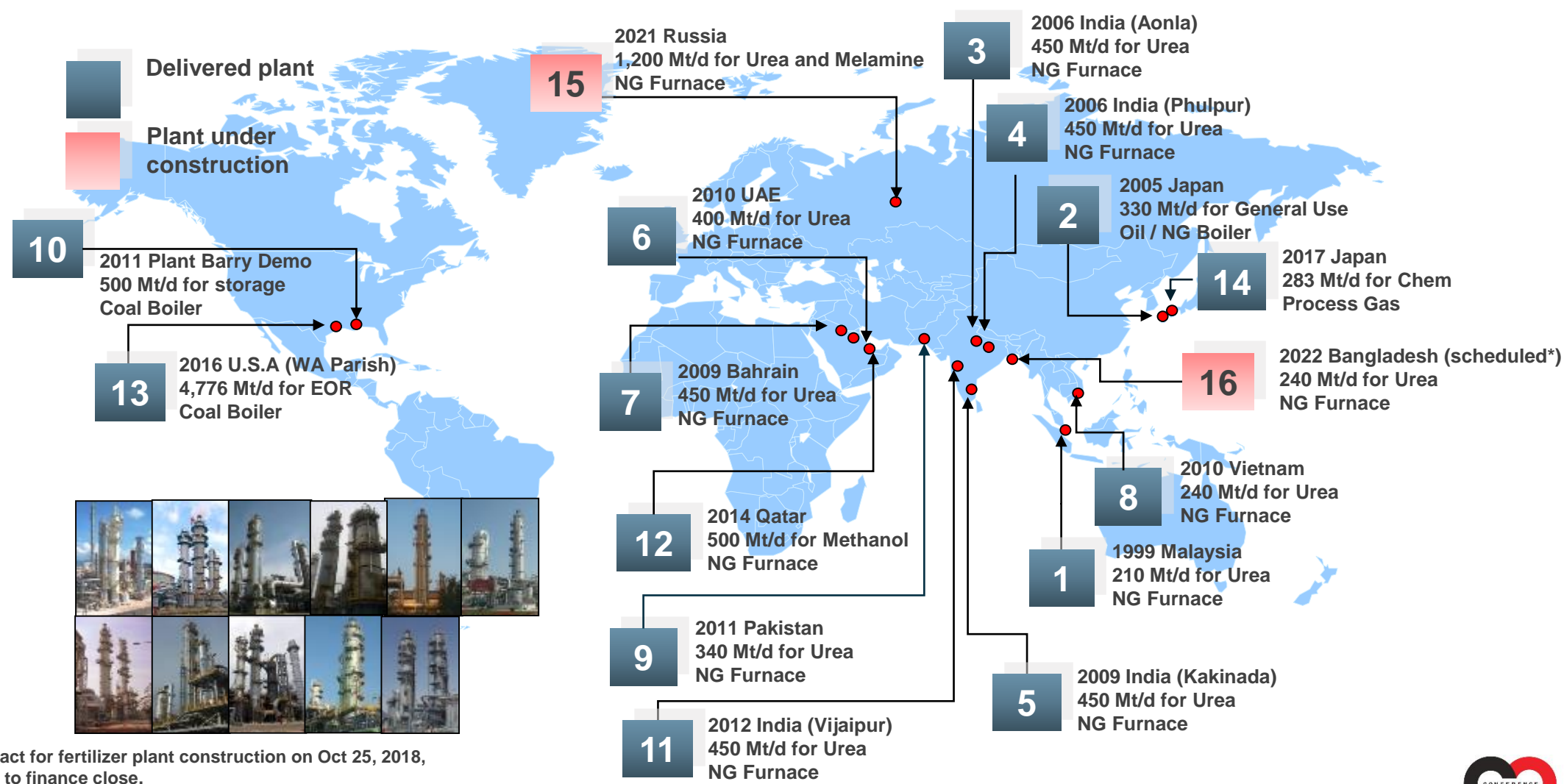
- **KM CDR Process™** = *Kansai Mitsubishi Carbon Dioxide Recovery Process*
- Capable of capturing ~90+% CO₂ from combustion gas sources
- CO₂ purity >99.9% (dry basis)
- Amine-based technology
- Proprietary features developed over 29 years of experience

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

KM CDR Process™ Technology Development Timeline



MHI is the world leader in large scale CO₂ capture plant deployments.



*Signed a contract for fertilizer plant construction on Oct 25, 2018, but still subject to finance close.

BusinessWire
A Berkshire Hathaway Company

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NRG Energy, JX Nippon Complete World's Largest Post-Combustion Carbon Capture Facility On-Budget and On-Schedule

--Part of NRG Energy's overall fossil fuel decarbonization strategy--

<http://www.businesswire.com/news/home/20170109006496/en/>



Sixteen-foot diameter ductwork takes flue gas from the coal plant to the carbon capture facility where the CO₂ is removed from the flue gas by the amine solution in the tall absorption tower and then separated from the amine as 99.9% pure CO₂ in the smaller regenerator tower to the right before being compressed and delivered to the oil field. (Photo: Business Wire)

Power Magazine “Plant of the Year” August 2017

Capturing Carbon and Seizing Innovation: Petra Nova Is POWER's Plant of the Year

08/01/2017 | POWER

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<http://www.powermag.com/capturing-carbon-and-seizing-innovation-petra-nova-is-powers-plant-of-the-year/>



**Petra Nova Project
“On-Budget and
On-Schedule”**



Fall 2016 View of the Site

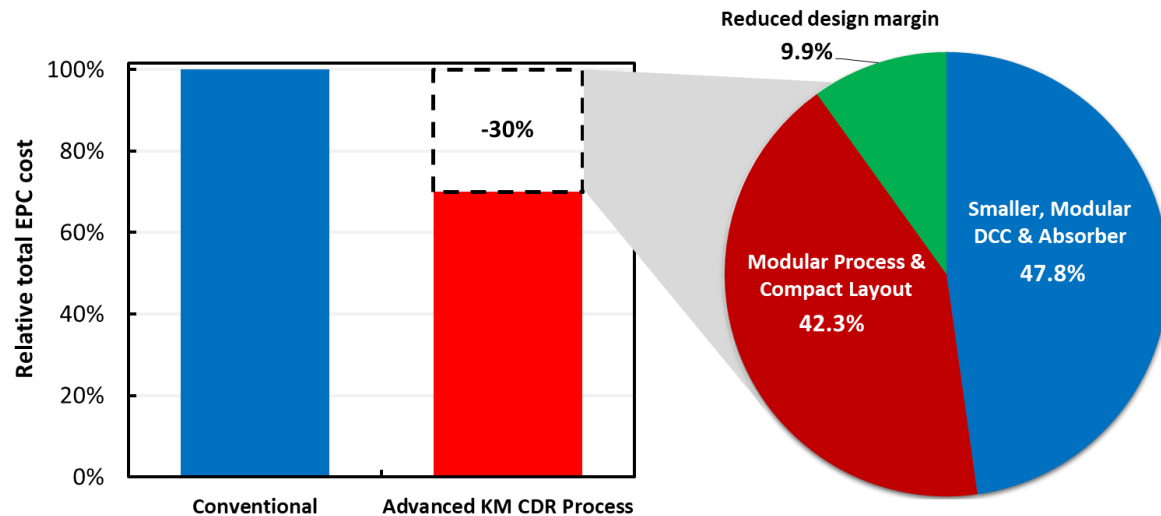
The Petra Nova Project is MHI's first commercial power project. Performance test was completed in December 2016.

- 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 CO₂ capture plant.

Advanced KM CDR Process™

Operating CO₂ 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.***



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

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

FEED studies initiated in 2019 using the Advanced KM CDR Process™ and KS-21™ solvent.

What's next?

FOA 2058: Front-End Engineering Design (FEED) Studies for Carbon Capture Systems on Coal and Natural Gas Power Plants

*Full-Scale FEED Study for Retrofitting the Prairie State Generating Station with an 816 MWe Capture Plant Using Mitsubishi Heavy Industries of America Post-Combustion CO₂ Capture Technology – **The Board of Trustees of the University of Illinois** (Champaign, IL) will complete a FEED study for the installation of a carbon capture system at the Prairie State Generating Company's (PSGC) Energy Campus in Marissa, Illinois. The project will be based upon the Advanced KM CDR Process™ carbon dioxide (CO₂) capture technology from Mitsubishi Heavy Industries. The project team that successfully completed the Petra Nova capture plant in Thompsons, Texas has been reassembled to benefit from lessons learned. The Advanced KM CDR Process is an amine-based capture system that uses the KS-21 solvent. If successful, the project would provide valuable insight into lowering the cost of carbon capture systems.*

Host site:	Prairie State Energy Campus
Owner:	Prairie State Generating Company
Location:	Marissa, Illinois
Load:	816 MWe
Technology:	Advanced KM CDR Process™ with KS-21™
Team:	<ul style="list-style-type: none">- University of Illinois- Mitsubishi Heavy Industries- Kiewit- Sargent & Lundy



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
SO _x	ppm(dry)	1 - 50	<0.3	<1
PM (Dust)	mg/Nm ³	3 - 10	NA	NA

Possible constituents in the flue gas depending on the industrial application:

- NO_x
- CO
- H₂S
- Hydrocarbons
- Heavy metals
- Halides (HCl, HBr, HF)

Thank you!

Come visit our booth!

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