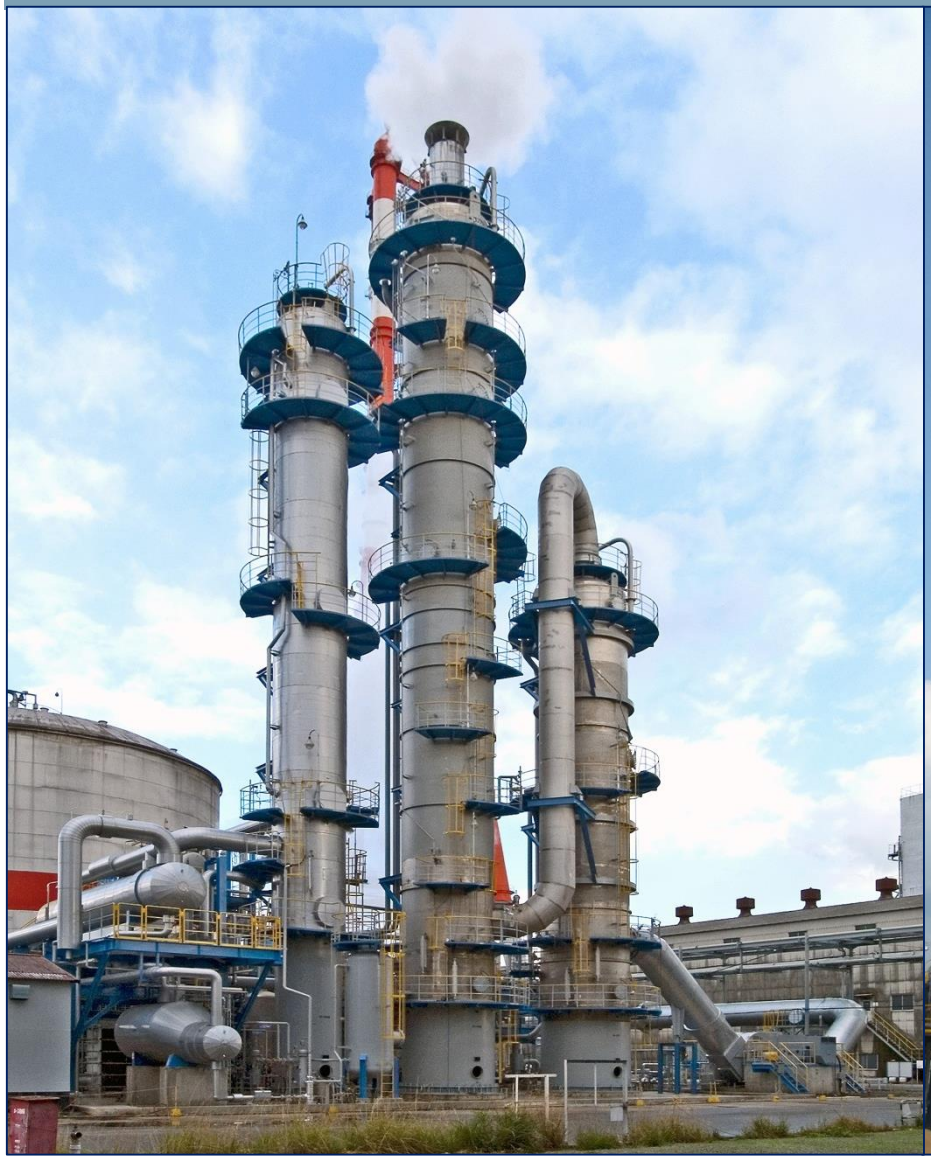
MHI's Carbon Capture Technology

2017 CO_2 & ROZ Conference
Carbon Management Workshop
Midland, Texas

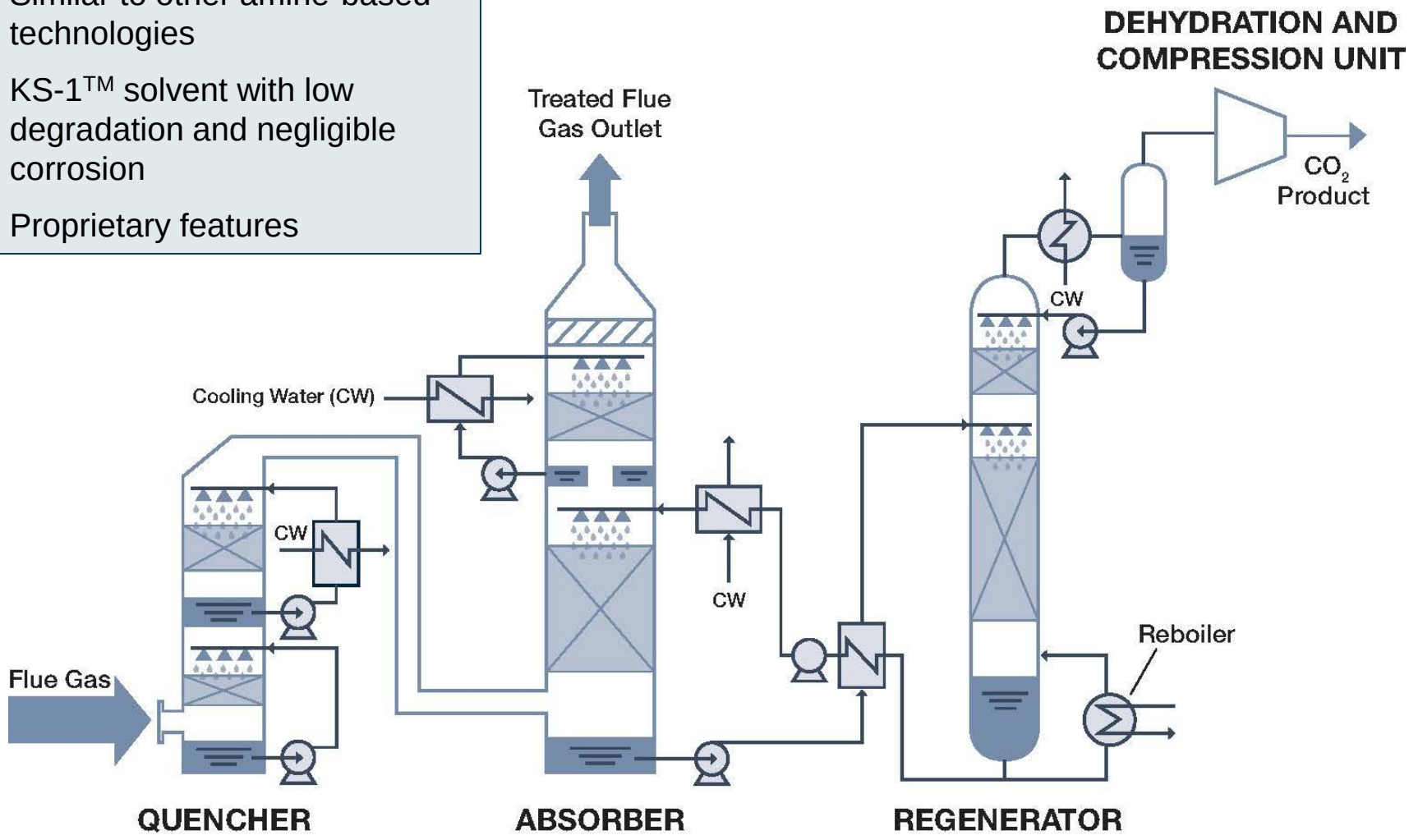
December 4

Background



KM CDR – Kansai Mitsubishi Carbon Dioxide Removal – Process®

- Similar to other amine-based technologies
- KS-1™ solvent with low degradation and negligible corrosion
- Proprietary features



KM CDR Process is a registered trademark of Mitsubishi Heavy Industries, Ltd., in Japan, the United States of America, European Union (CTM), Norway, Australia, and China.

KM CDR Process® Development History

From 1991 –
2 TPD Nanko Pilot Plant on Natural Gas Exhaust (Kansai Electric Power Co.)

Engineering HQ (Yokohama)

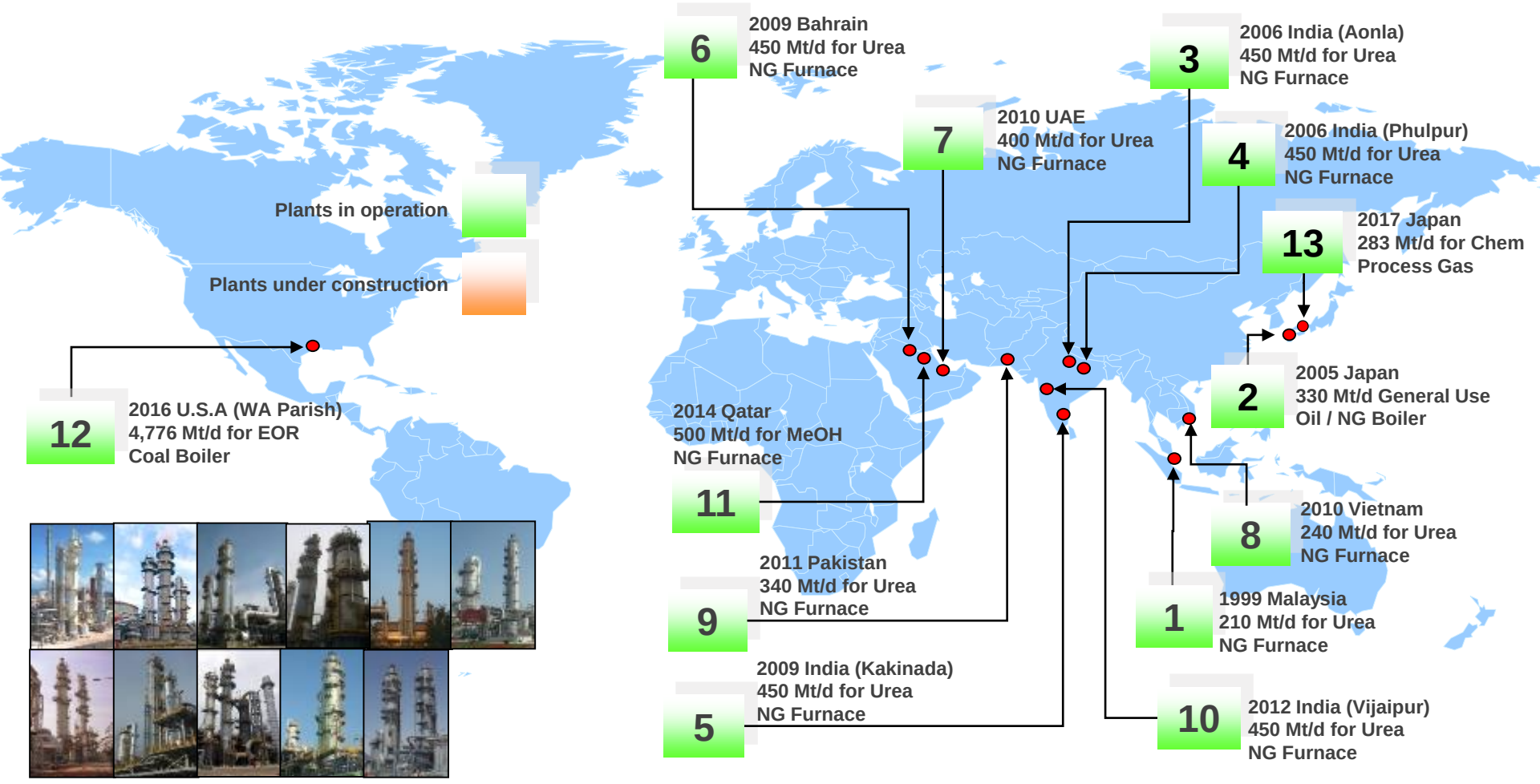
From 2002 -
1 TPD Hiroshima Pilot Plant on Coal Exhaust (MHI R&D Center)

From 2008 -
400MWeq Absorber Flow Tests (MHI Mihara)

From 2006 –
10 TPD Matsushima Pilot Plant on Coal Exhaust (J-Power)

KM CDR Process® Commercial Experience

MHI is the world's leading large scale post-combustion CO_2 capture technology licensor.



Testing and Scale-up for Coal-fired Flue Gas

2002 – Hiroshima R&D Facility (1 tpd)

2006 – Matsushima Pilot Plant (10 tpd)

MHI performed extensive testing to understand the impact of **flue gas impurities** and develop countermeasure technologies.

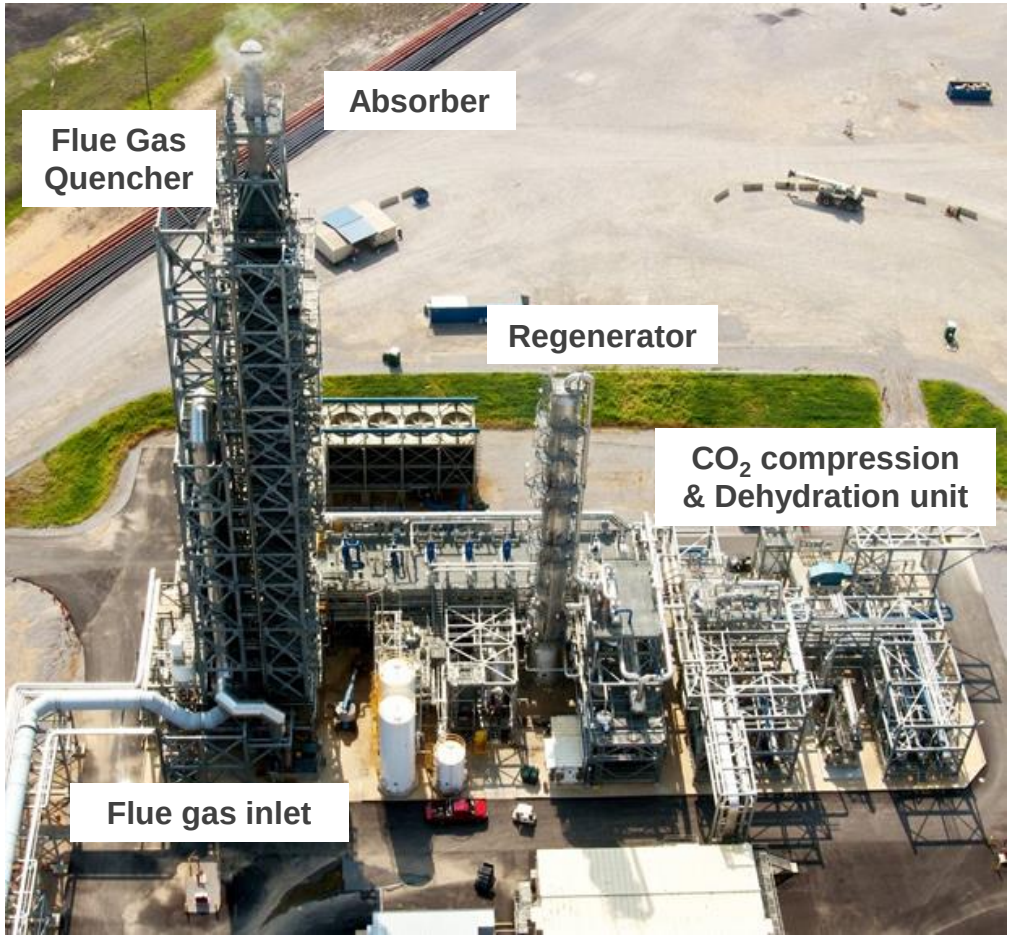
MHI performed liquid distribution tests for rectangular towers which **simplify scale-up and modularization efforts**.

(Scaling technique is similar to that used on more than 200 commercial FGD systems.)

2008 – Mihara Works (~35 ft x ~15 ft)

25MW$_{eq}$ CCS Demonstration Project at Plant Barry

Plant Barry CO_2 Demo Plant – helped prove commercial viability of carbon capture on coal fired flue gas



- Funding for capture facility from Southern Company, MHI, and others.
- Designed to capture 500 metric tons per day of CO_2 at 90% capture efficiency.
- From 2011-14: over 12,000 hours, over 250,000 tons captured, over 125,000 tons injected as part of SECARB sequestration demonstration.
- Tested multiple technology improvements.

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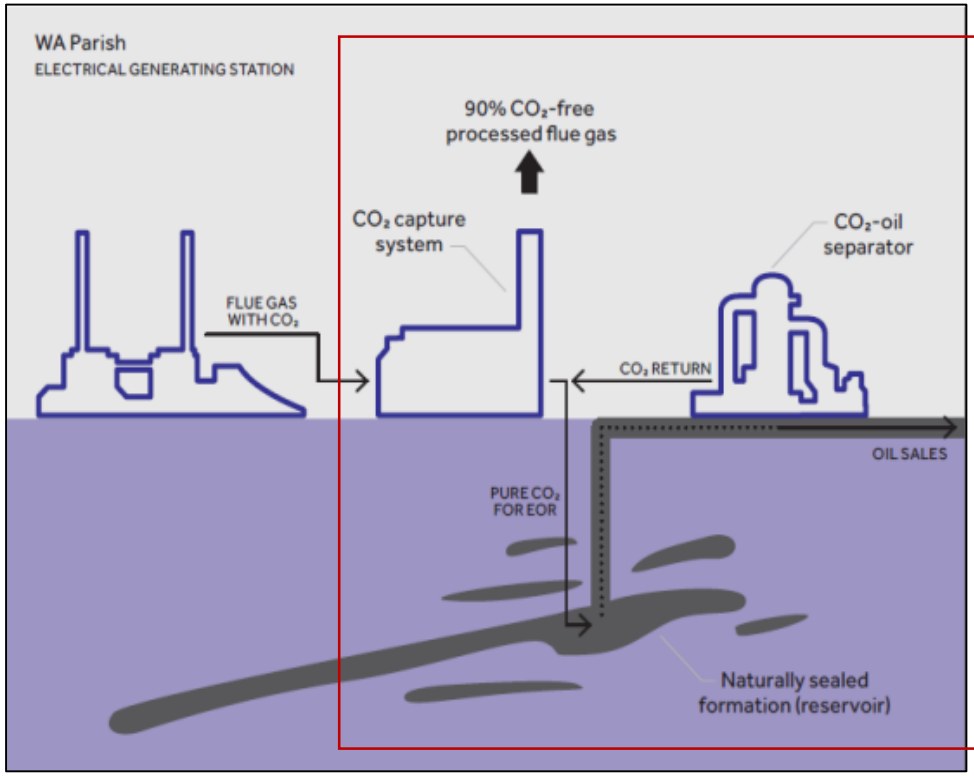
Petra Nova Project

Complete Petra Nova Project Overview

Oil revenues from CO_2 enhanced oil recovery can recover costs for the entire project without significant impact to the existing power plant.



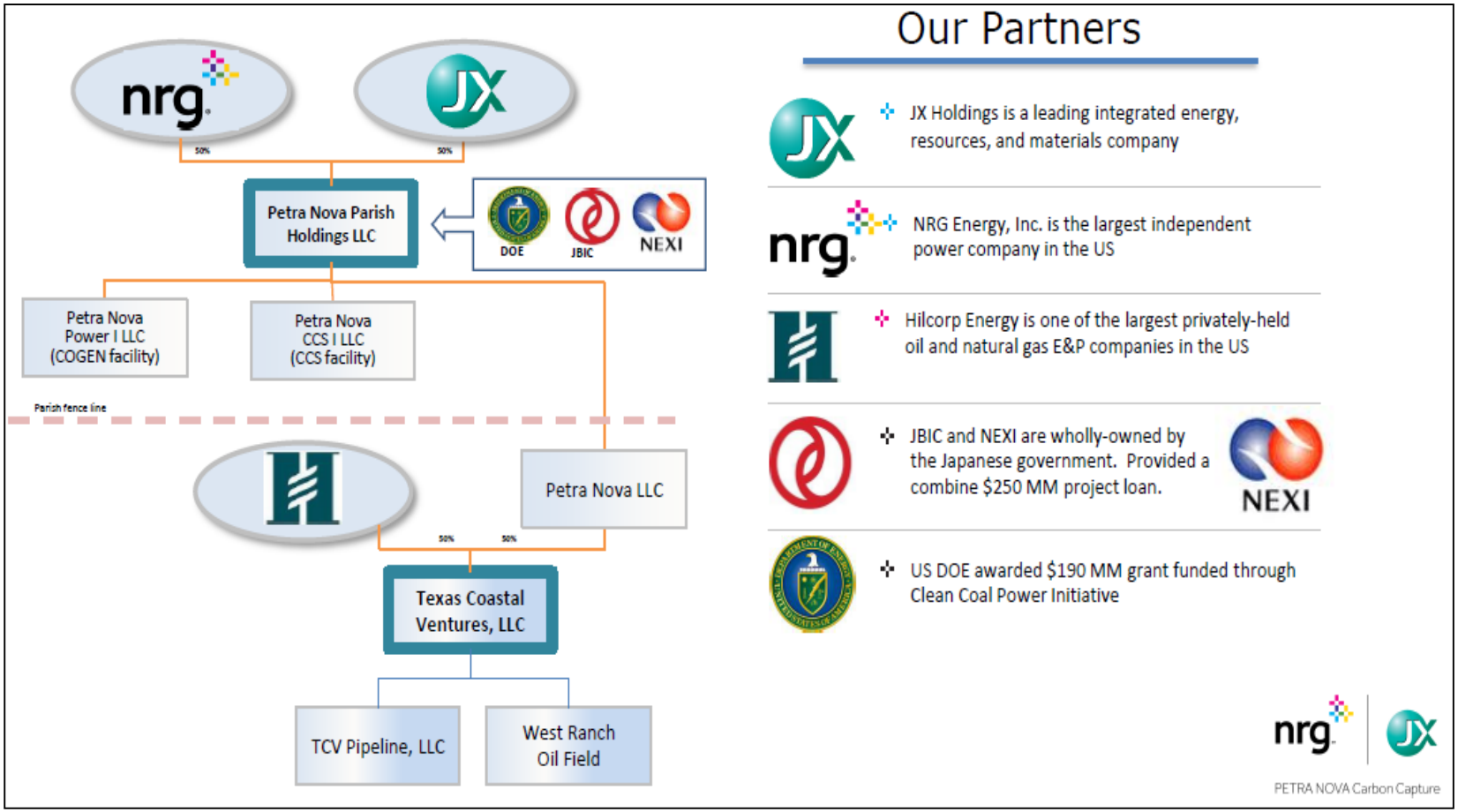
Four Key Components:

- **CO_2 Capture System** *(MHI technology)*
- **Cogeneration Plant**
- **CO_2 Transport / Pipeline**
- **Oil Field & Processing Facilities**

NRG Fact Sheet: Carbon capture and enhanced oil recovery: http://www.nrg.com/documents/business/generation/581409-factsheet-petra-nova-carbon-capture-final.pdf

Petra Nova Commercial Structure

NRG Energy and JX Oil and Gas formed the Joint Venture, Petra Nova Parish Holdings. They own the CCS facility and 50% of the CO_2 pipeline and oil field.



Reference: Petra Nova Parish Holdings

Petra Nova Carbon Capture Facility Project Overview

"NRG Energy, JX Nippon complete world's largest post-combustion carbon capture facility on-budget and on-schedule[1]"

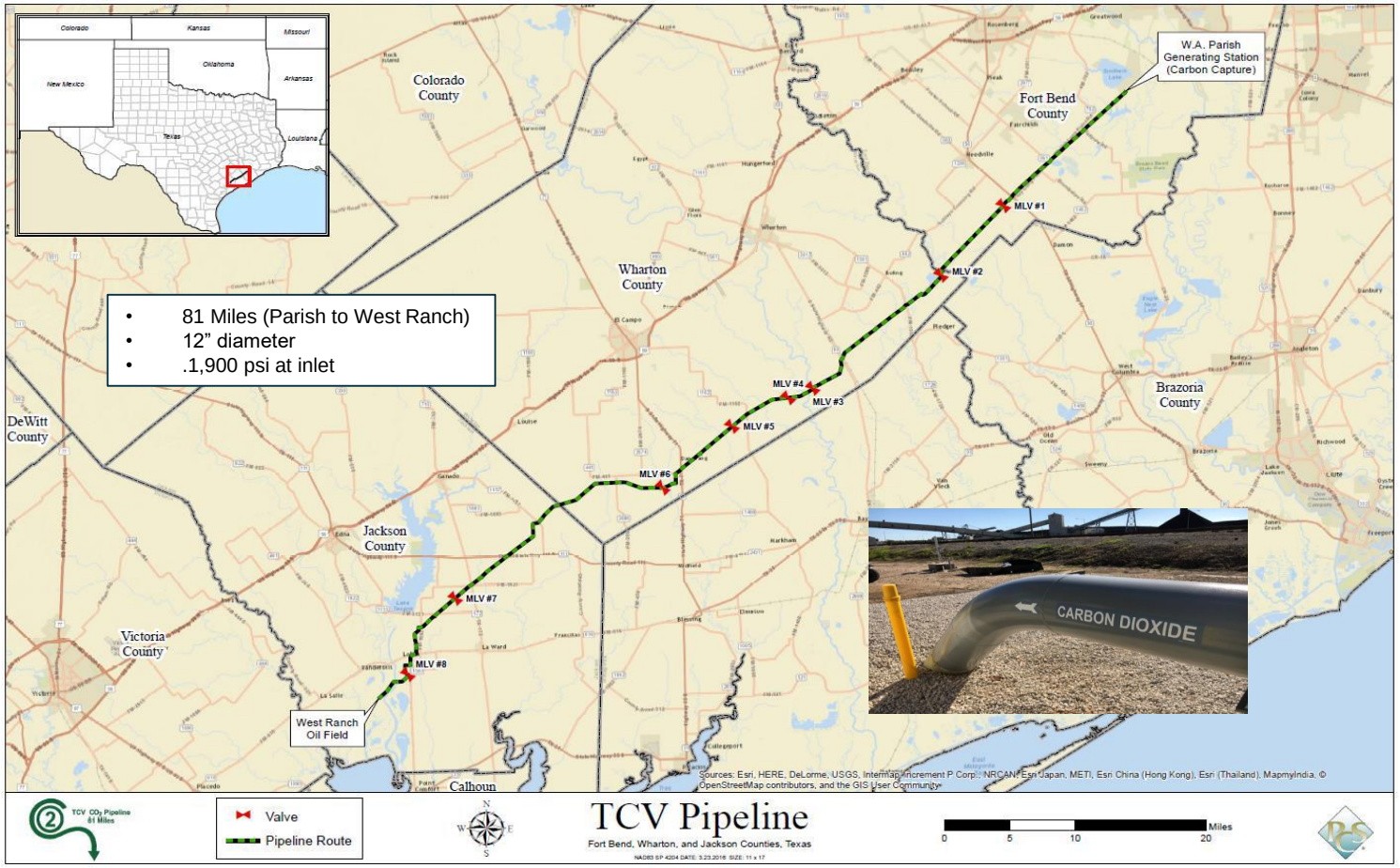
- Takes a partial "slip" stream from host unit - NRG's Parish Plant Unit 8
- Captures 5,200 tons of CO_2/day
- Achieved COD on Dec 29, 2016
- 2017 – Power Magazine "***Plant of the Year***"
- October 2017 – 1M tons of CO_2 captured

[1]NRG press release: http://investors.nrg.com/phoenix.zhtml?c=121544&p=irol-newsArticle&ID=2236424

Petra Nova Project CCS Facility Layout

Petra Nova Pipeline

Captured CO_2 is compressed by Mitsubishi's compressor and transported 81 miles by pipeline to the West Ranch Oil field for EOR.



Reference: Petra Nova Parish Holdings

Petra Nova Oilfield Facilities – EOR Operation

CO_2 captured from Parish Unit 8 is expected to boost oil production from 300 bbls/day to up to 15,000 bbls/day.

West Ranch Field Central Facilities

- 200 new wells to be drilled (over 100 now complete)
- 2 central processing facilities to separate oil-CO_2-water
- All produced CO_2 and water is reinjected into the formation

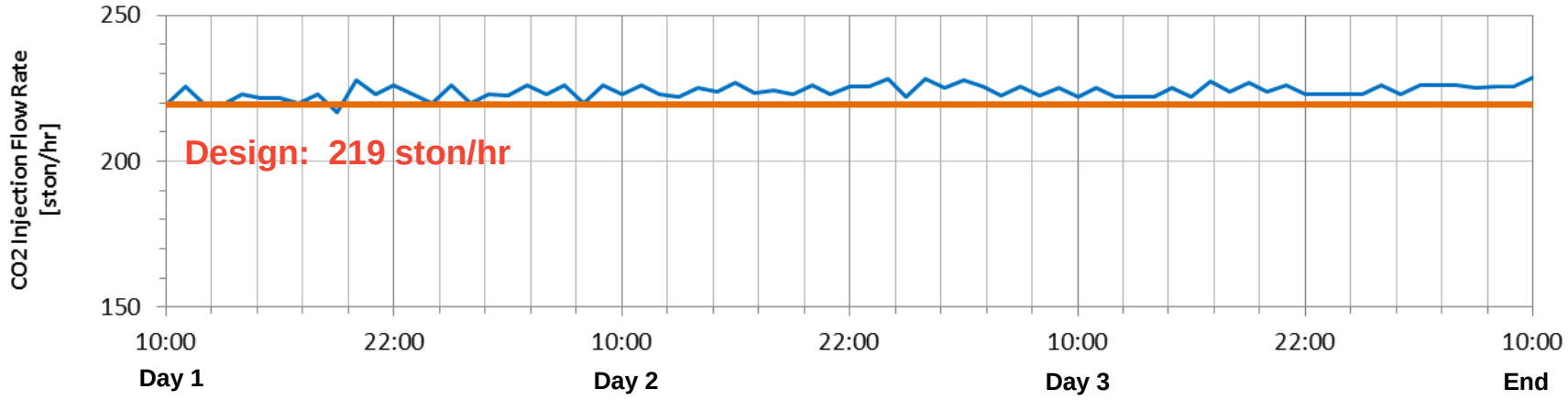
nrg | JX

PETRA NOVA Carbon Capture

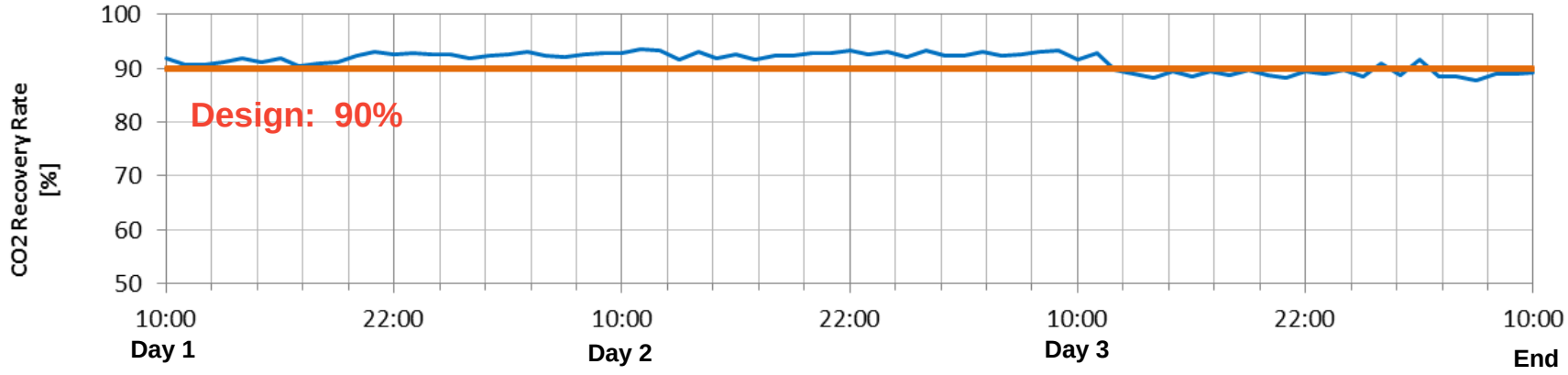
Reference: Petra Nova Parish Holdings

MHI's proprietary control system (ALAC) successfully maintained stable operation.

CO_2 Production Flow Rate Trend (72hrs)

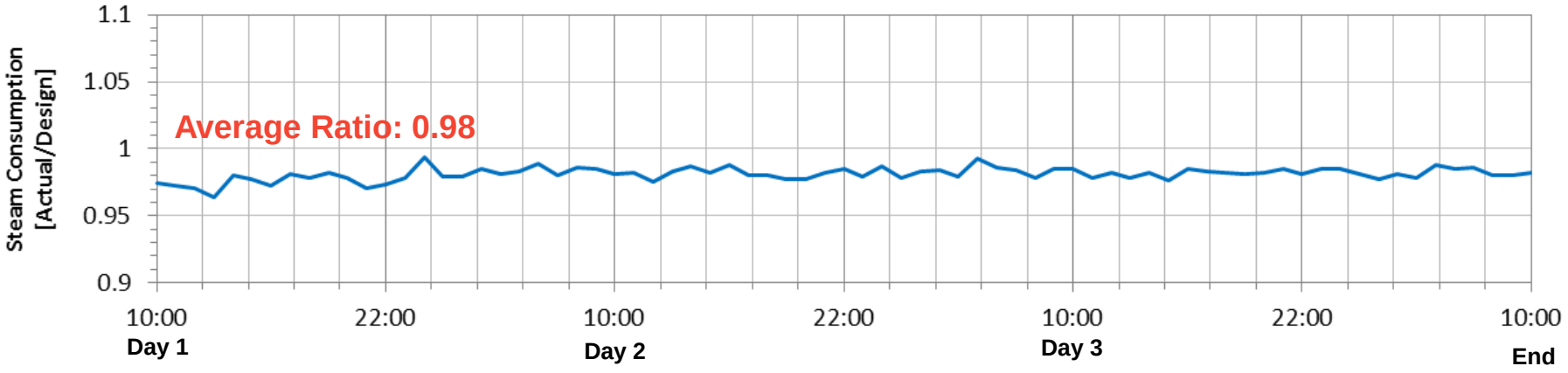


CO_2 Recovery Rate Trend (72hrs)

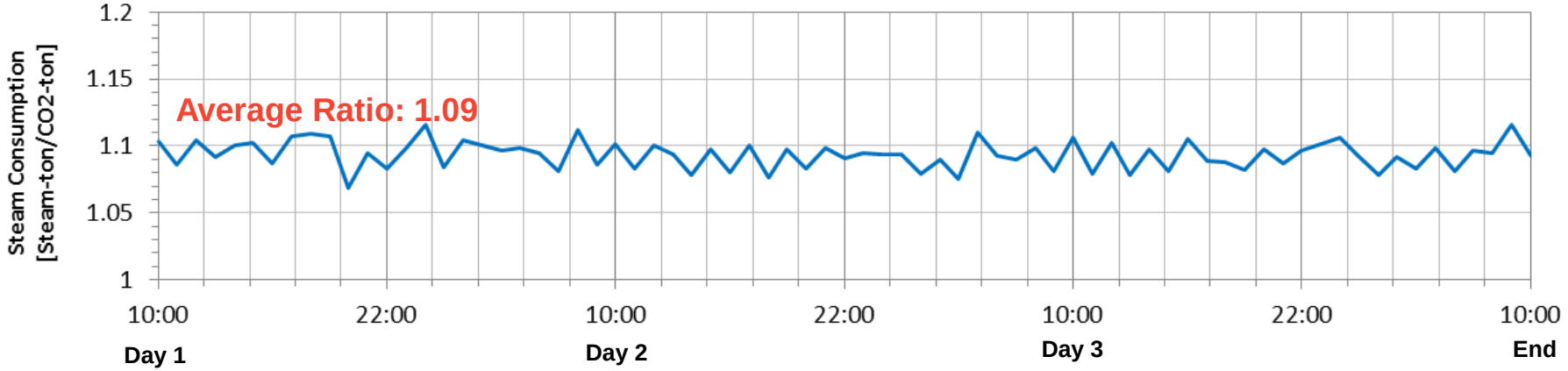


Steam consumption exceeded expectations and has been consistently below design.

Steam Consumption Trend (Actual / Design) (72hrs)



Steam Consumption Trend (steam-ton/CO_2-ton) (72hrs)

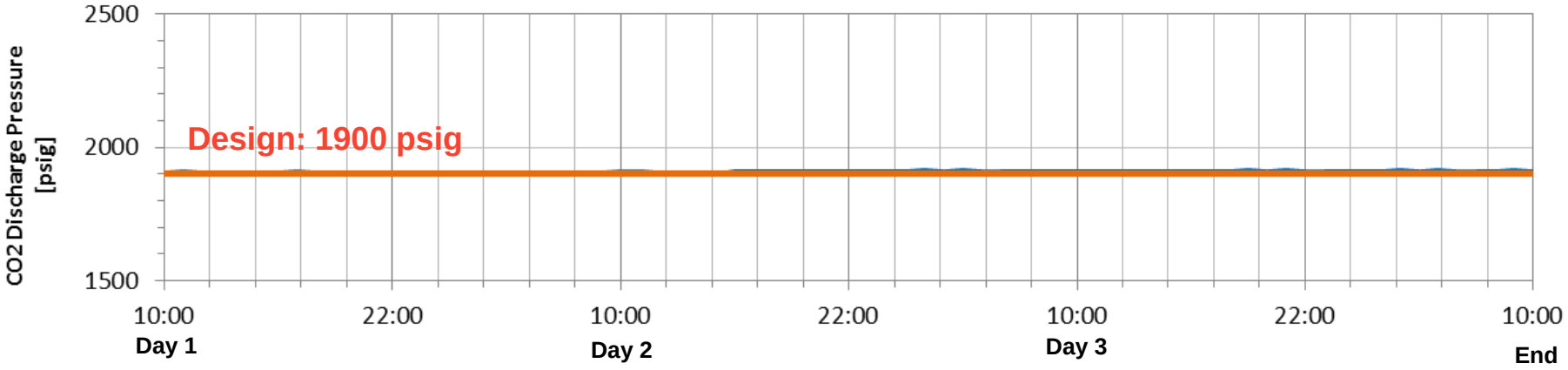


Petra Nova Project – Operation

World's largest integrally geared CO_2 compressor delivered by Mitsubishi Compressor.

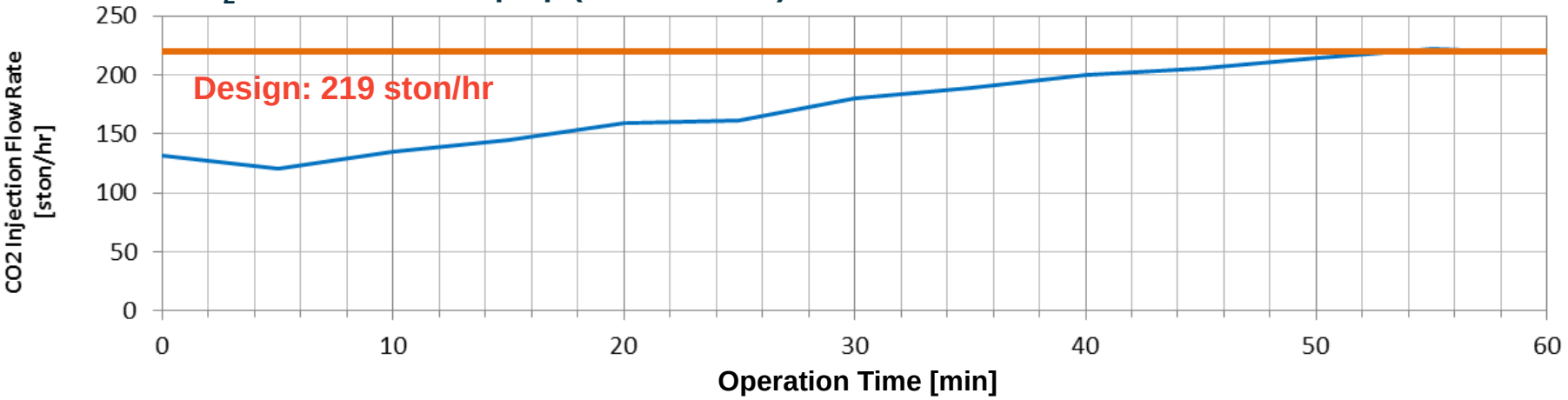
- **8 stages**
- **28,700 hp**

CO_2 Production Pressure Trend (72hrs)

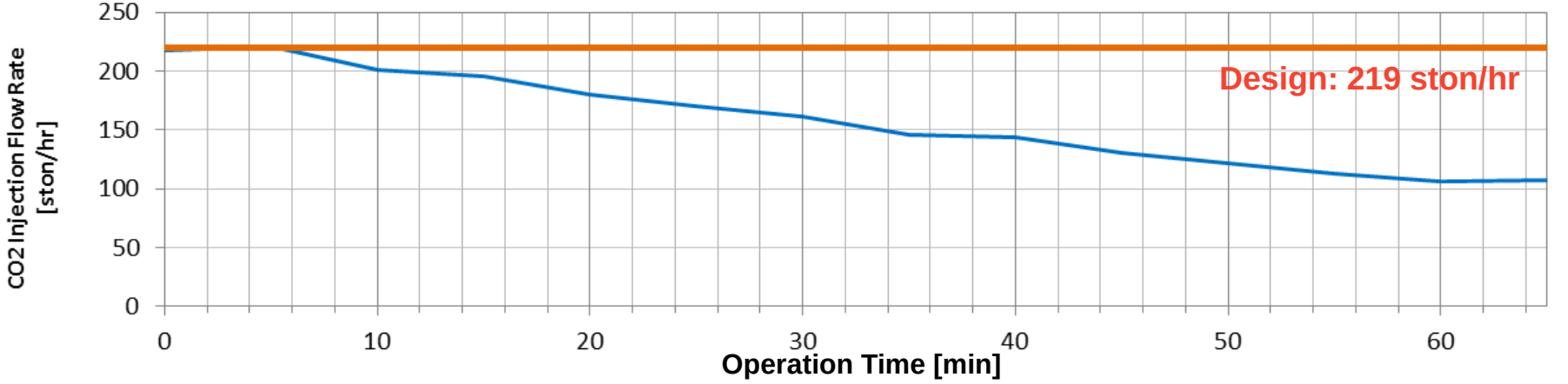


MHI's proprietary control system (ALAC) smoothly ramps CO_2 production from 50% to 100% in less than 1 hour.

Automatic CO_2 Production Ramp up (50% -> 100%)



Automatic CO_2 Production Ramp down (100% -> 50%)



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New Solvent Testing

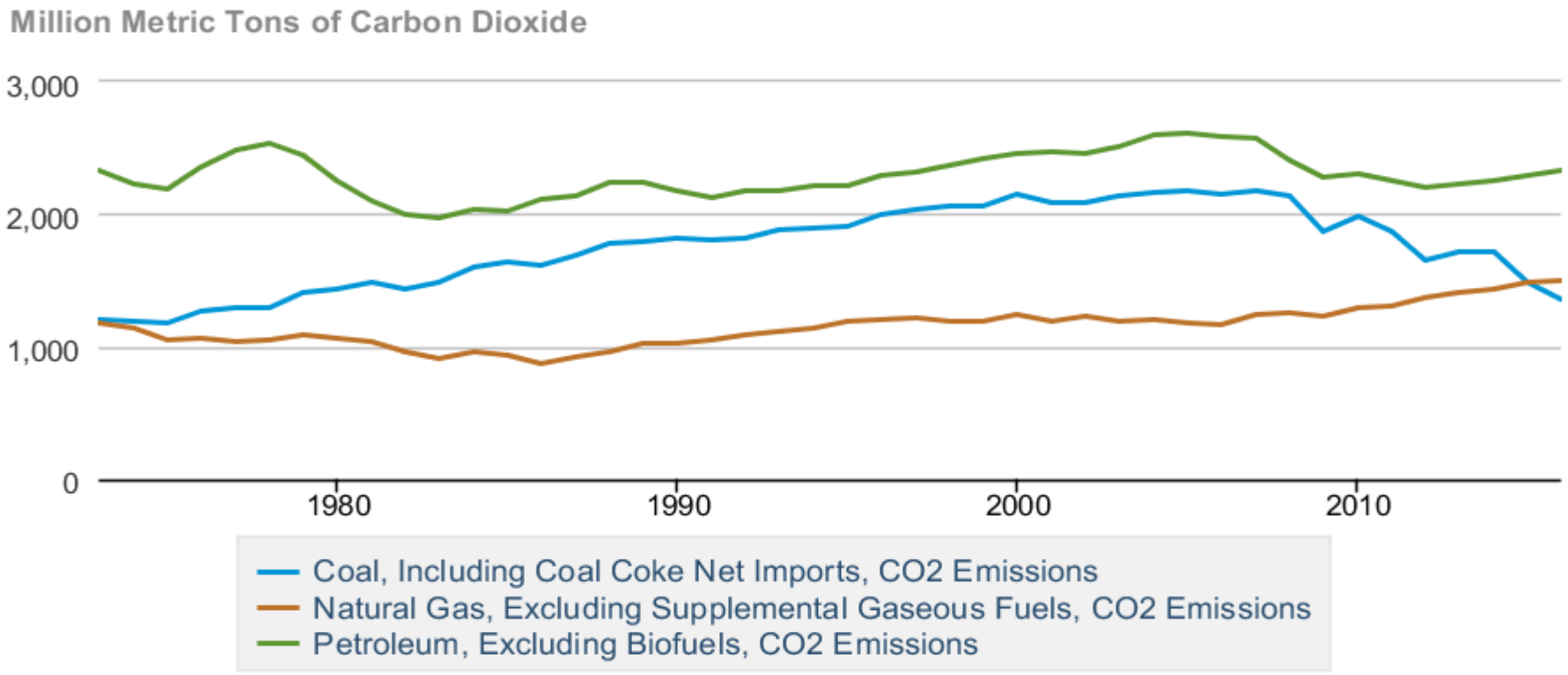
MHI has been investigating new solvents to further reduce the cost of CO_2 capture.

New Solvent Testing – Lab Results

	KS-1™	New Solvent
Steam Consumption	1	0.92
Solvent Degradation	1	0.53
Solvent Emission	1	0.40

- MHI conducted solvent screening in the laboratory and the Nanko pilot plant.
- New solvent has achieved lower steam consumption, solvent degradation, and solvent emissions than KS-1™.
- New solvent may require a higher solvent circulation flow rate which increases electricity consumption.
- Benefits appear to outweigh the higher flow rate.

Table 12.1 Carbon Dioxide Emissions From Energy Consumption by Source



eia Source: U.S. Energy Information Administration

NGCC CO_2 Capture Application

MHI's KM CDR Process® can be successfully applied to NGCC power plants.

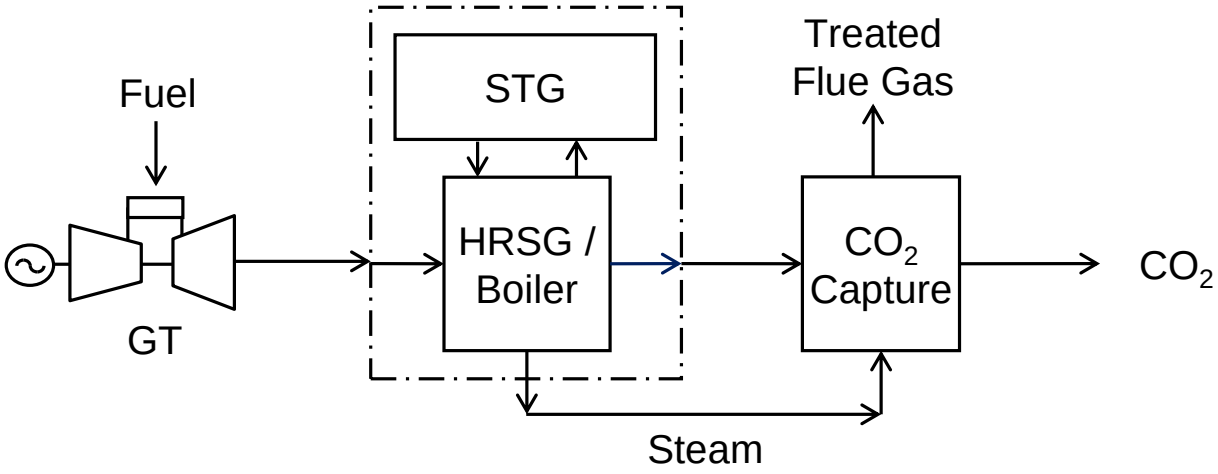
Typical Flue Gas Conditions

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

- KS-1™ has proved resistant to O_2 degradation despite higher concentration.
- MHI can provide large absorbers to account for lower CO_2 concentration.
- KM CDR Process® requires fewer treatment systems as a result of the minimal SOx and dust in flue gas.

NGCC CO_2 Capture Application

MHI has the capability to investigate advanced NGCC-CO_2 capture configurations to consider existing and new assets.



Fully optimized integration between NGCC and CO_2 capture can:

- Take advantage of high efficiency gas turbines
- Reduce parasitic load of CO_2 capture
- Reduce capital cost of CO_2 capture

MHI's Past, Present, and Future

Past

- Tested — MHI proved viability at multiple R&D facilities.
- Delivered — MHI delivered **eleven (11) operating commercial CO_2 capture plants** prior to the Petra Nova Project.
- Scaled-up — MHI successfully scaled-up and demonstrated long-term operation at Alabama Power's Plant Barry.

Present

- Petra Nova — **December 2016** – the world's largest post-combustion CO_2 capture project on coal-fired flue gas (4,776 mtpd) – completes performance testing.

Future

- New Solvents — MHI is developing new solvents to reduce utility consumption and emissions.
- NGCC — MHI is ready to optimize CO_2 capture for **NGCC applications.**

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