Presentation about MHI CO2 capture technology

September 2017

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Petra Nova Project Overview

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

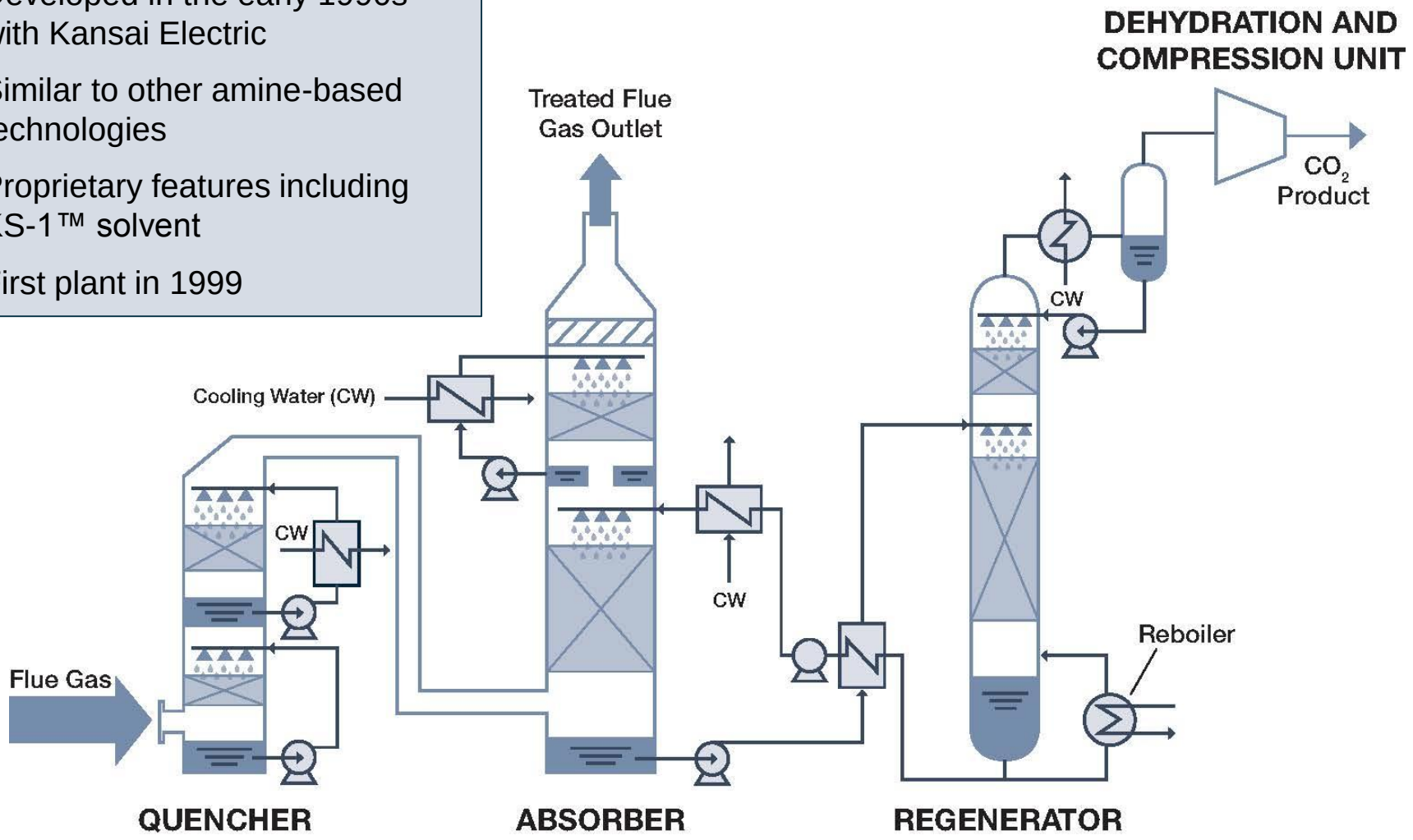
August 2017 – Power Magazine “Plant of the Year”

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

MHI's Carbon Capture Technologies

KM CDR – Kansai Mitsubishi Carbon Dioxide Removal – Process®

- Developed in the early 1990s with Kansai Electric
- Similar to other amine-based technologies
- Proprietary features including KS-1™ solvent
- First plant in 1999



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.)

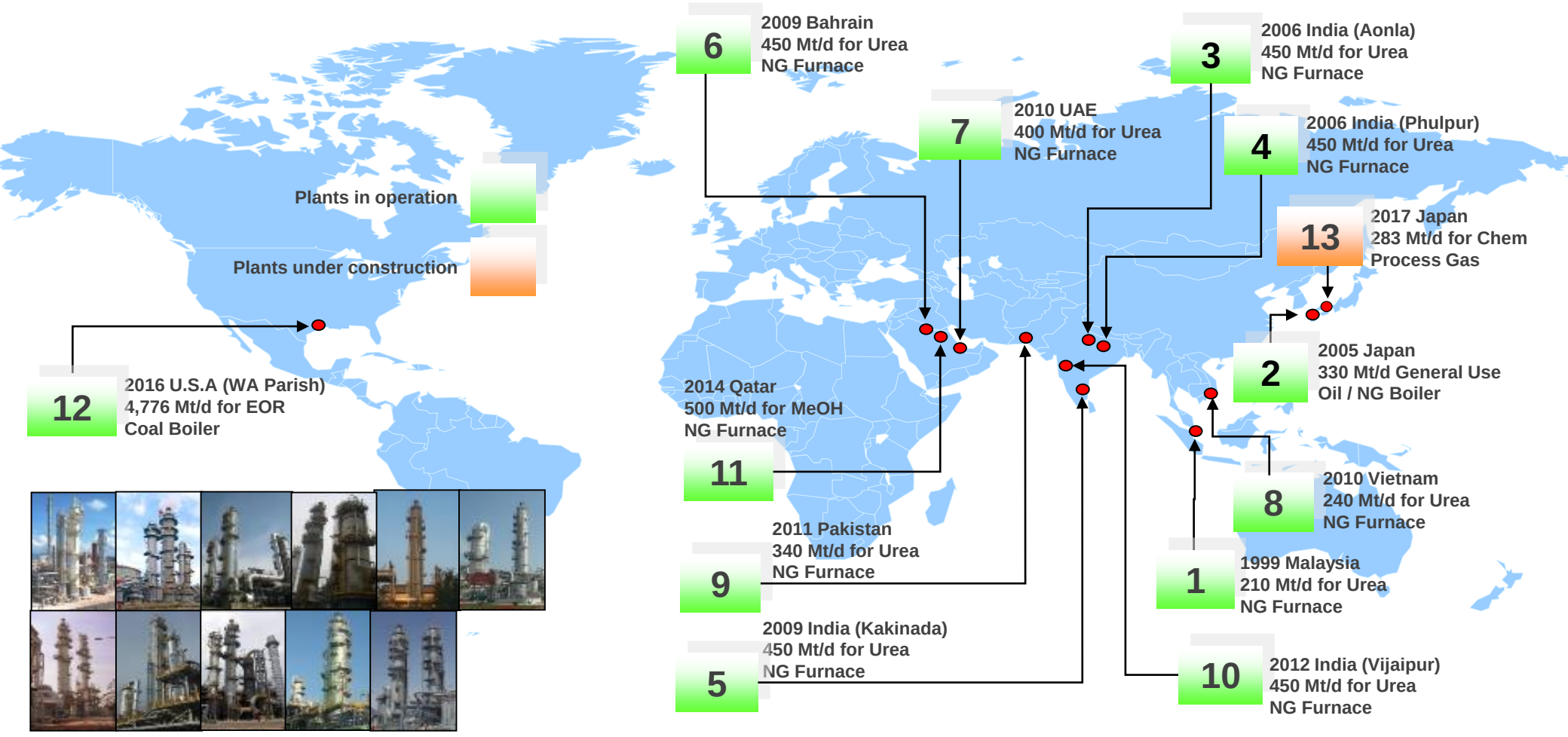
Engineering HQ (Yokohama)

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

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

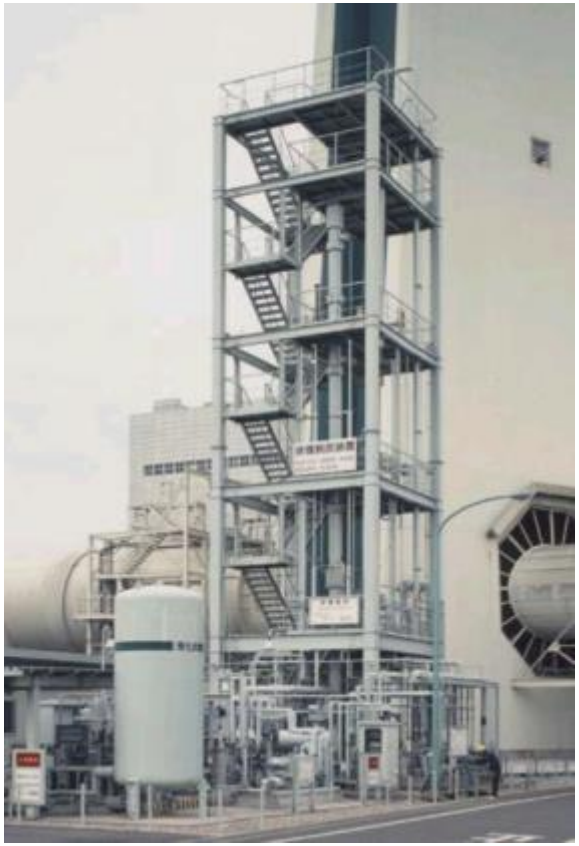
From 2006 –
10 TPD Matsushima Pilot Plant on Coal Exhaust (J-Power)

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



Solvent Development

MHI tested various chemicals to develop the KS-1™ solvent for the KM CDR Process®.



- MHI evaluated over 200 solvents and tested 20 solvents at its first CO_2 capture pilot plant at KEPCO's Nanko Power Plant in 1991.
- KS-1™ has exceptionally low corrosivity, high stability, and high CO_2 absorption capacity.
- MHI still uses the Nanko pilot plant to develop new solvents, new process schemes, and new equipment.

Impurities Testing for Coal-fired Flue Gas

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

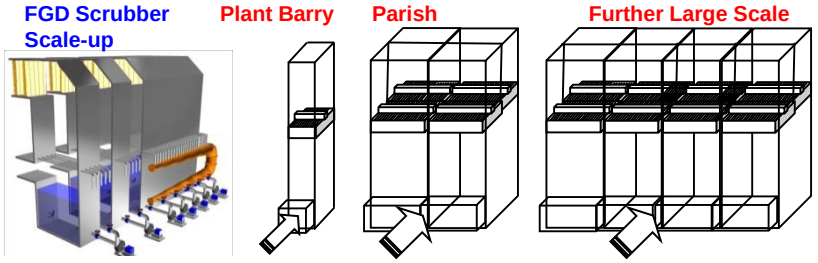
Hiroshima
R&D Facility
(1 mtpd)

Matsushima
Pilot Plant
(10 mtpd)

- 2002 – began testing on coal-fired flue gas at Hiroshima R&D Facility.
- 2006 – completed several test programs on a slip stream from a commercial coal fired power plant in Matsushima, Japan.
  - Performed long term operation to verify the impact of coal-fired flue gas impurities on the KM CDR Process®.

Scale-up Testing

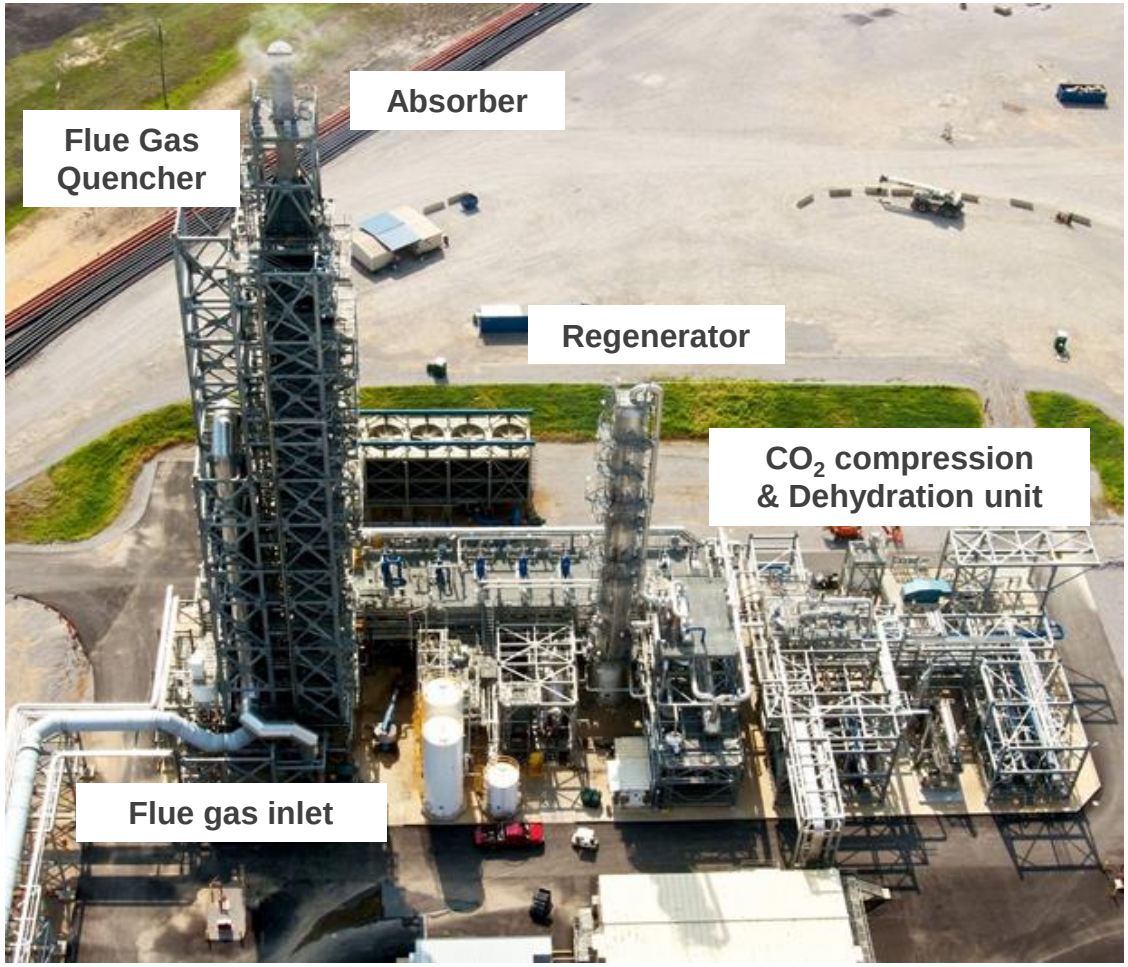
MHI had extensive experience and resources to ensure successful scale-up of its KM CDR Process®.



- High performance packing is very sensitive to liquid distribution.
- 2008 – tested malfunctions of liquid distributors at Mihara Works.
- Absorber measures ~35 ft x ~15 ft.
- The test program was invaluable to the final design and to guarantee performance for large scale projects.
- Scaling technique is similar to that used on more than 200 commercial FGD systems.

MHI's CO_2 Capture Technology & Experience

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

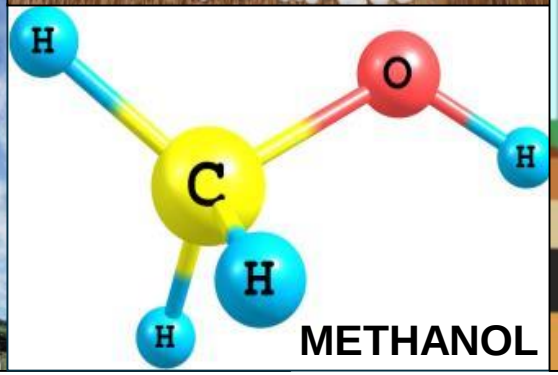


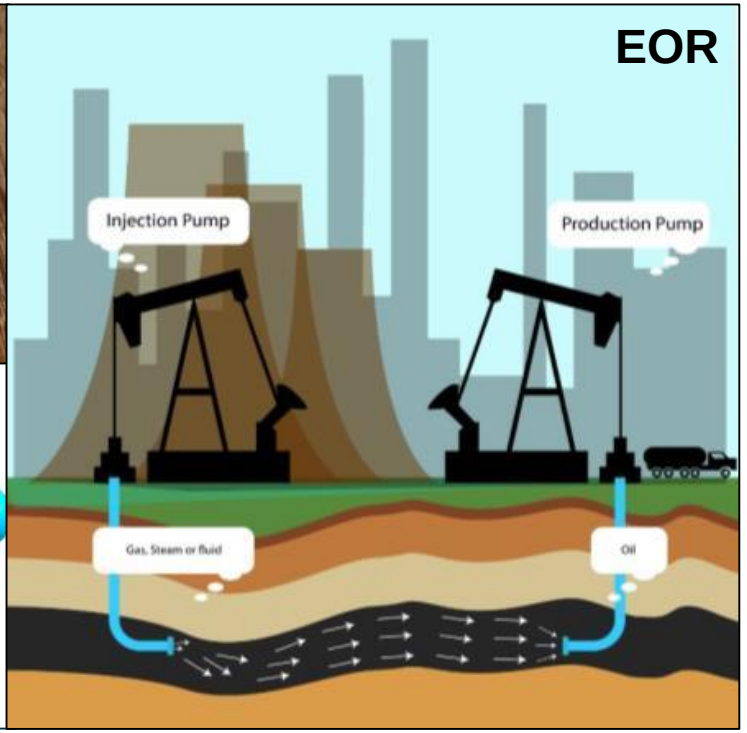
Plant location	Mobile County (Alabama, U.S.A.)
Plant owner	Southern Company subsidiary Alabama Power
Plant scale	25 megawatts (MW_{eq})
Flue gas amount	116,800 Nm^3/h
CO_2 conc.	10.1 mol%-wet
CO_2 capture capacity	500 metric ton/day (150,000 ton/year)
CO_2 removal	90%

Operating data as of 8/31/14:	
Operating time	12,400 hrs
Captured CO_2	230,100 metric ton
Injected CO_2	115,500 metric ton

* Additional technology demonstrations are on-going (HES, ACC).

Applications of CO_2 Capture Facilities





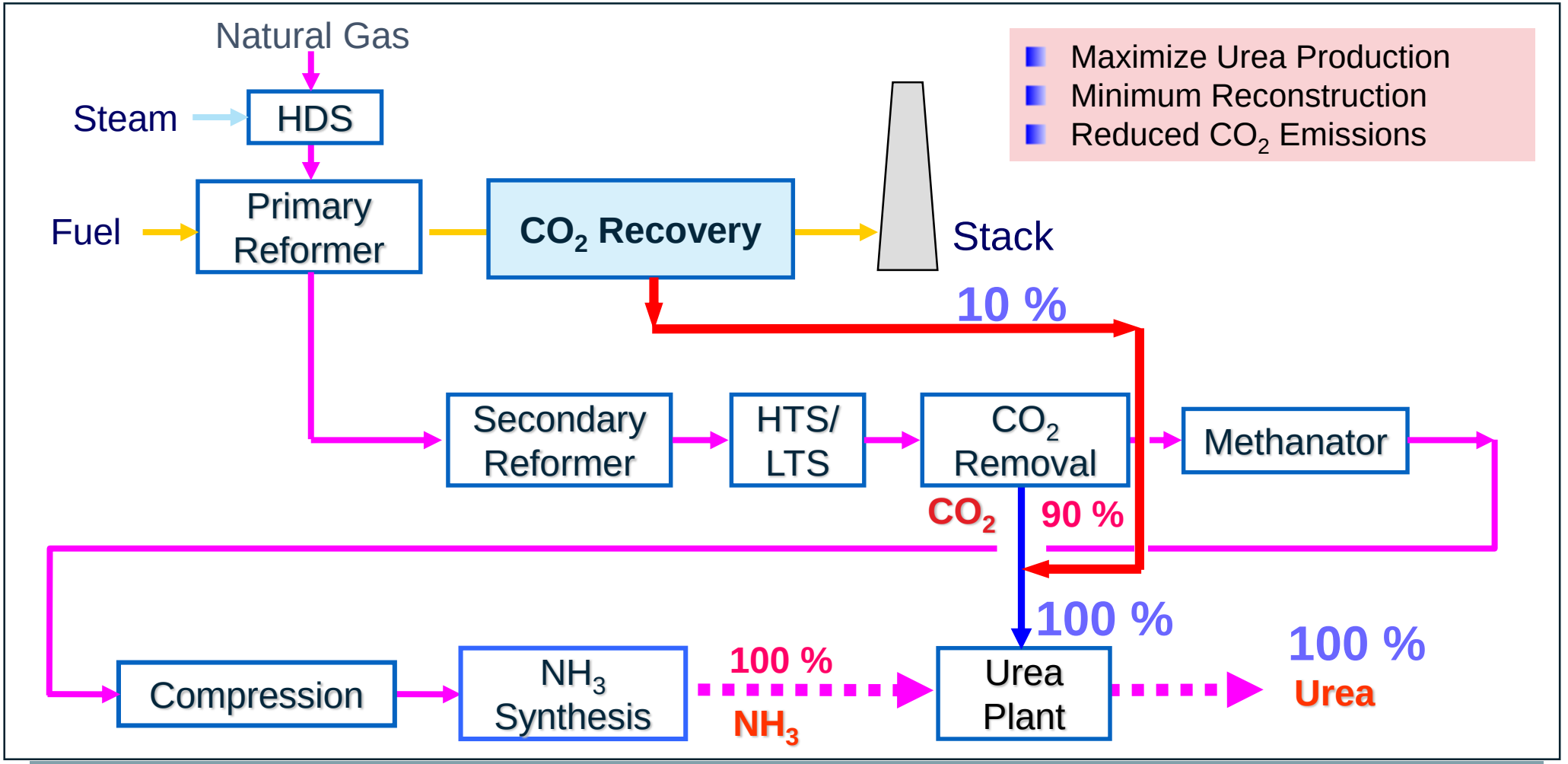
Applications of CO_2 Capture Facilities

Chemical production has been the main driver of MHI's 12 commercial projects.

Year of Delivery	Country	Flue Gas Source	CO_2 Capacity (mtpd)	Application
1999	Malaysia	NG Fired Furnace	210	**Urea Production**
2005	Japan	NG and Heavy Oil Boiler	330	General Use
2006	India	NG Fired Furnace	450	**Urea Production**
2006	India	NG Fired Furnace	450	**Urea Production**
2009	India	NG Fired Furnace	450	**Urea Production**
2009	Bahrain	NG Fired Furnace	450	**Urea Production**
2010	UAE	NG Fired Furnace	400	**Urea Production**
2010	Vietnam	NG Fired Furnace	240	**Urea Production**
2011	Pakistan	NG Fired Furnace	340	**Urea Production**
2012	India	NG Fired Furnace	450	**Urea Production**
2014	Qatar	NG Fired Furnace	500	**Methanol Production**
2016	USA	Coal-Fired Boiler	4,776	Enhanced Oil Recovery

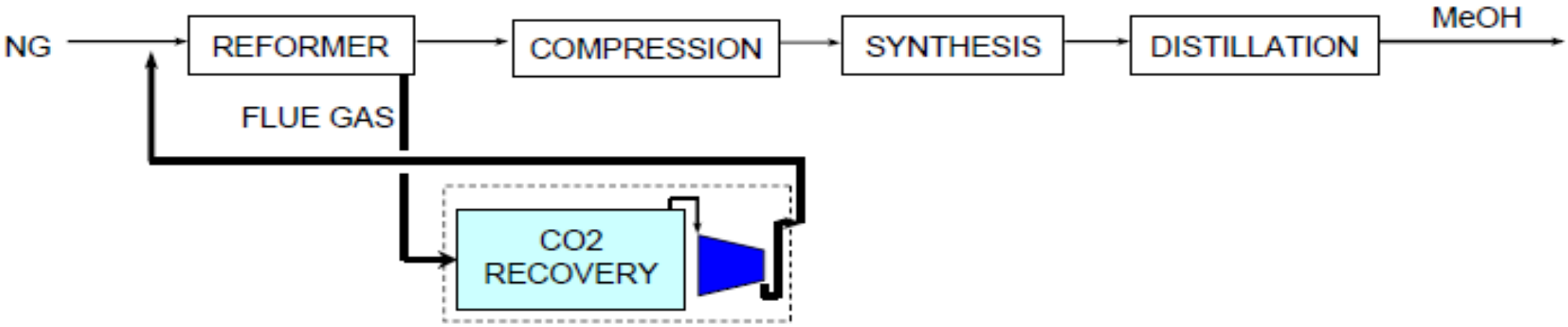
Increase of Urea Production

To install the flue gas CO_2 recovery unit can realize to maximize urea synthesis by balancing ammonia and CO_2

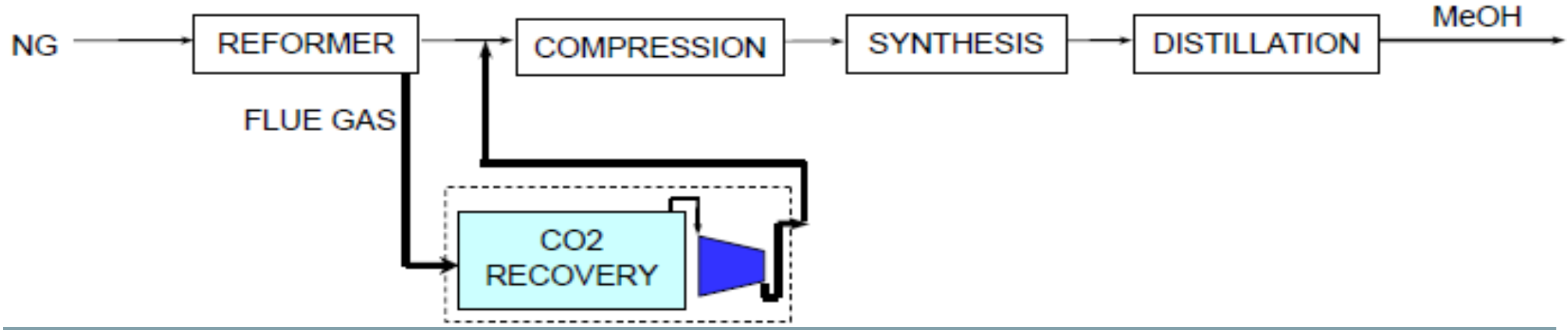


Increase of Methanol Production

Case-1: CO2 Recovery - CO2 Injection at Reformer Inlet

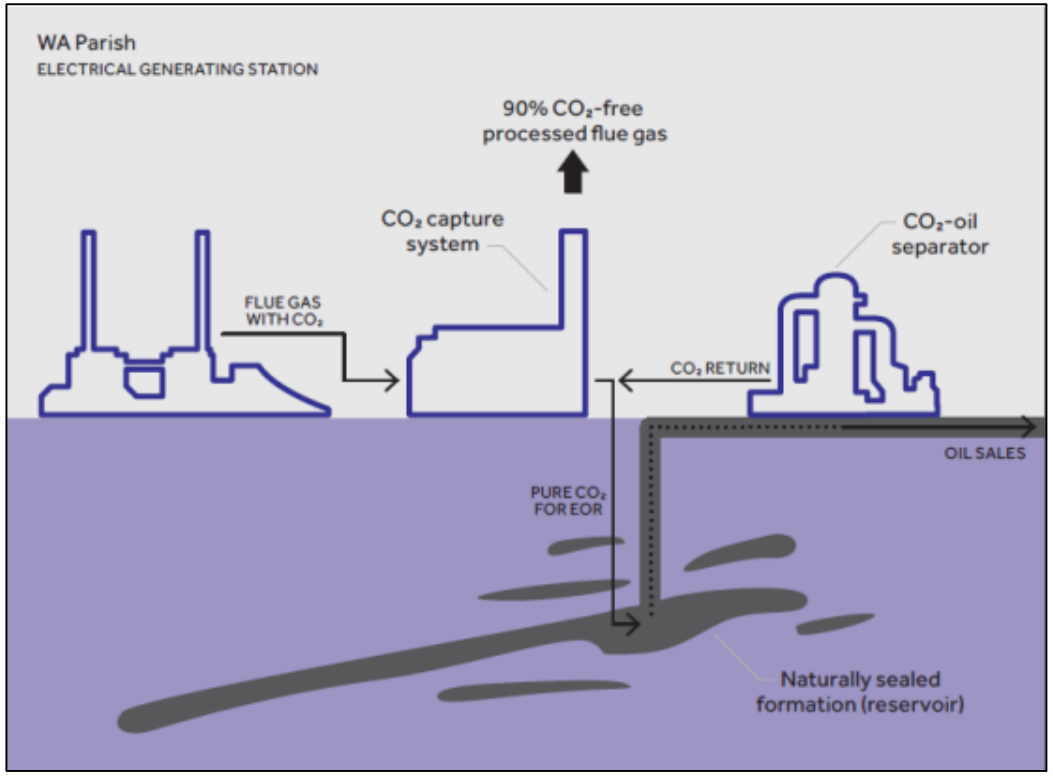


Case-2: CO2 Recovery – CO2 Injection at Reformer Outlet before Compression



CO_2-EOR Supply Chain

Enhanced Oil Recovery drives major North American CCUS projects.



CO_2 supply chain

1) Thermal Power Plant
   CO_2 is created from combustion
2) Capture System
   CO_2 is separated and compressed
3) Pipeline
   CO_2 is transported to oil field
4) Oil Field
   CO_2 is injected and recycled for oil production

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

MOVE THE WORLD FORWARD

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Commercial Plant for CO_2-EOR

Petra Nova Project Overview

The world's largest CO_2 capture plant on coal-fired flue gas began commercial operation on December 2016.

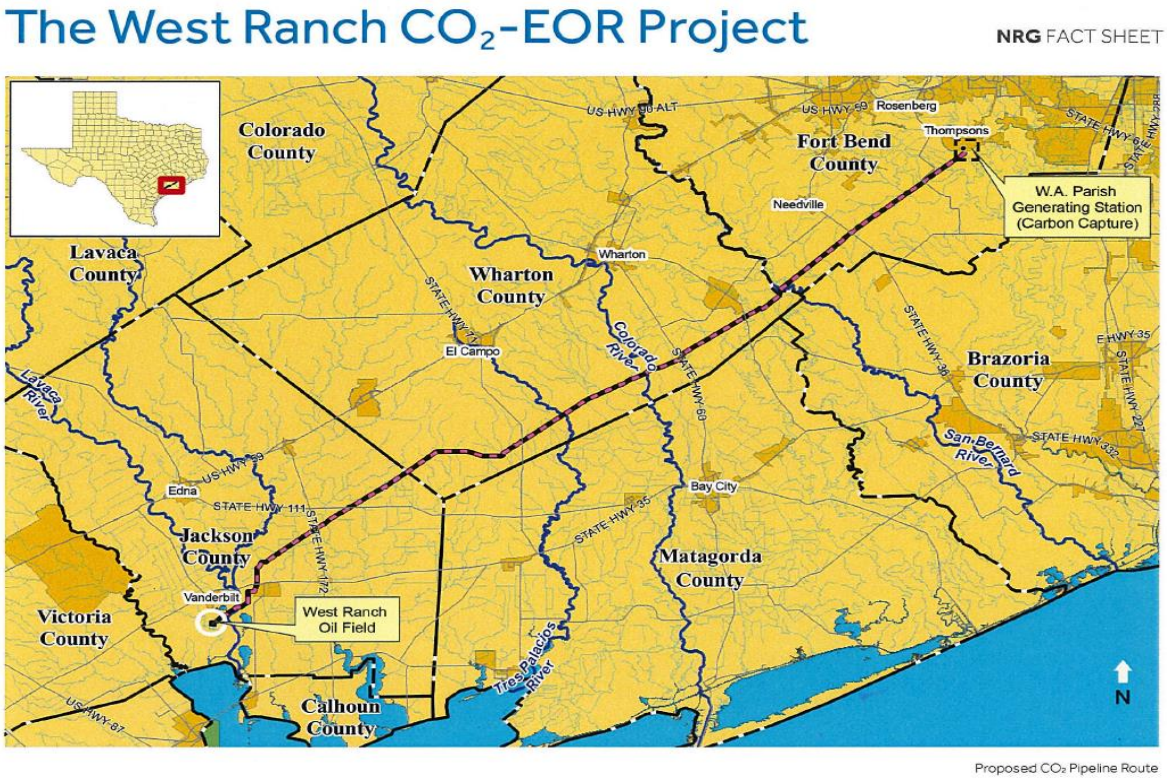
Plant location	NRG WA Parish Power Plant in Thompsons, TX
Project owner	Petra Nova – partnership between NRG Energy and JX Nippon Oil & Gas
Plant scale	240 megawatts (MW_{eq})
CO_2 conc.	11.5 mol%-wet
CO_2 capacity	4,776 metric ton/day (1.4 mil ton/year)
CO_2 removal	90%

CO_2 Used for CO_2-EOR	
Pipeline	12 in diameter, ~81 miles
Injection Site	West Ranch Oil Field

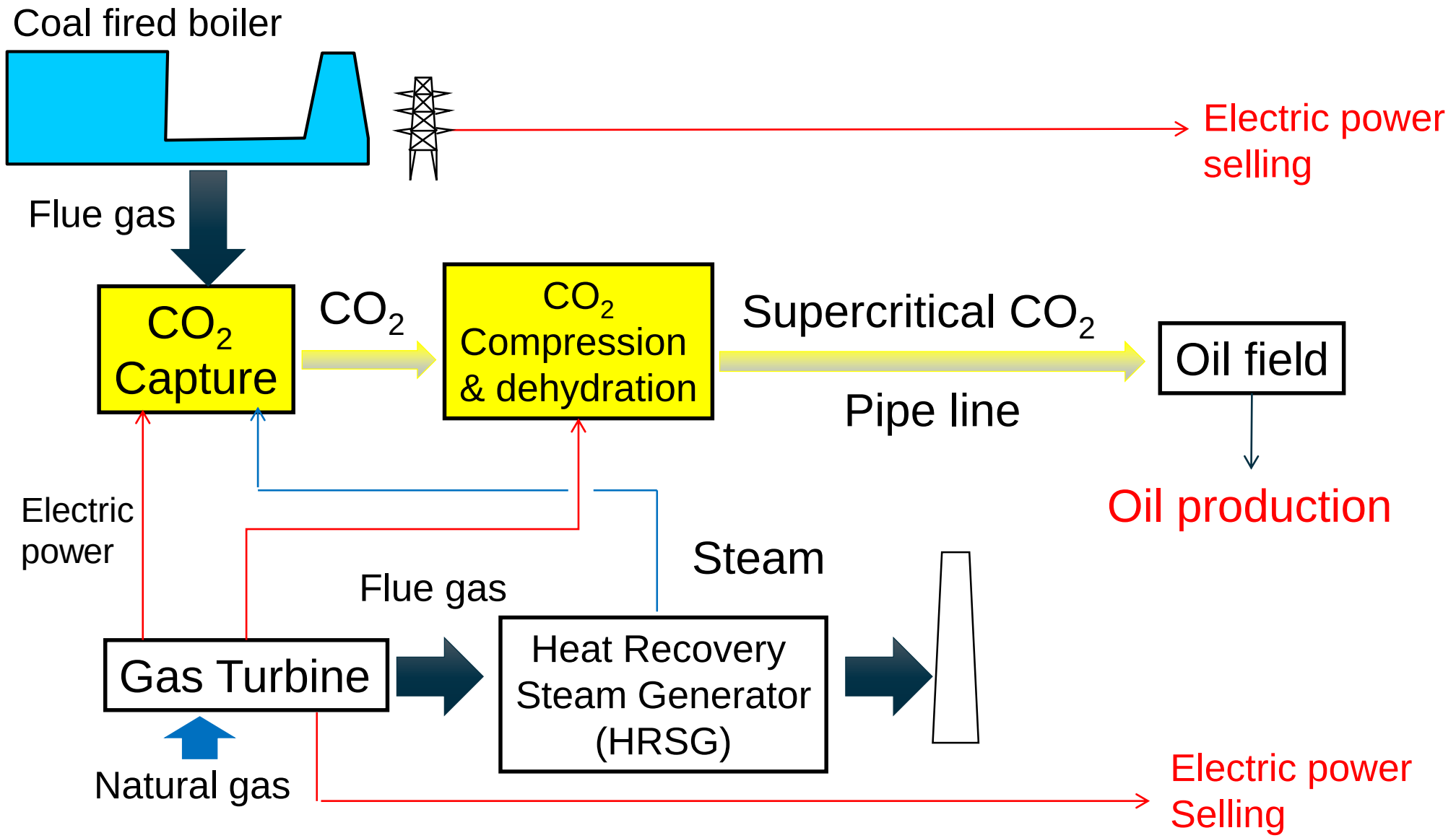
U.S. Department of Energy "W.A. Parish Post-Combustion CO2 Capture and Sequestration Project Final Environmental Impact Statement Volume I" (Feb, 2013), DOE/EIS-0473

CO_2 Captured for Enhanced Oil Recovery (EOR)

- Compressed CO_2 is delivered by an 81 mile CO_2 pipeline to the West Ranch oil field.
- Up to 1.4 million metric tons of CO_2 will be annually injected into the West Ranch formation.
- Oil production could be enhanced from **300 barrels/day to up to 15,000 barrels/day.**



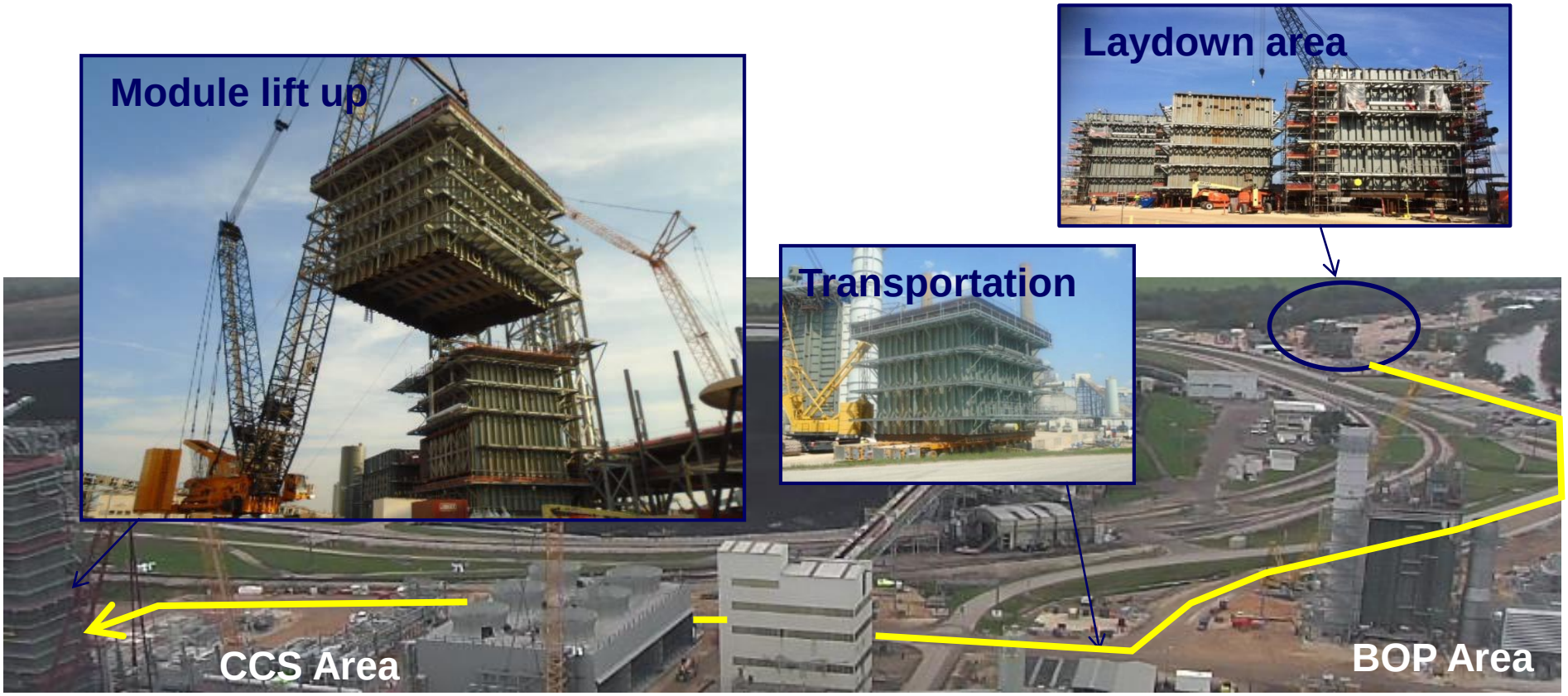
WA Parish CO_2 EOR Overall System



Quencher and Absorber Construction

Rectangular steel towers and modular construction

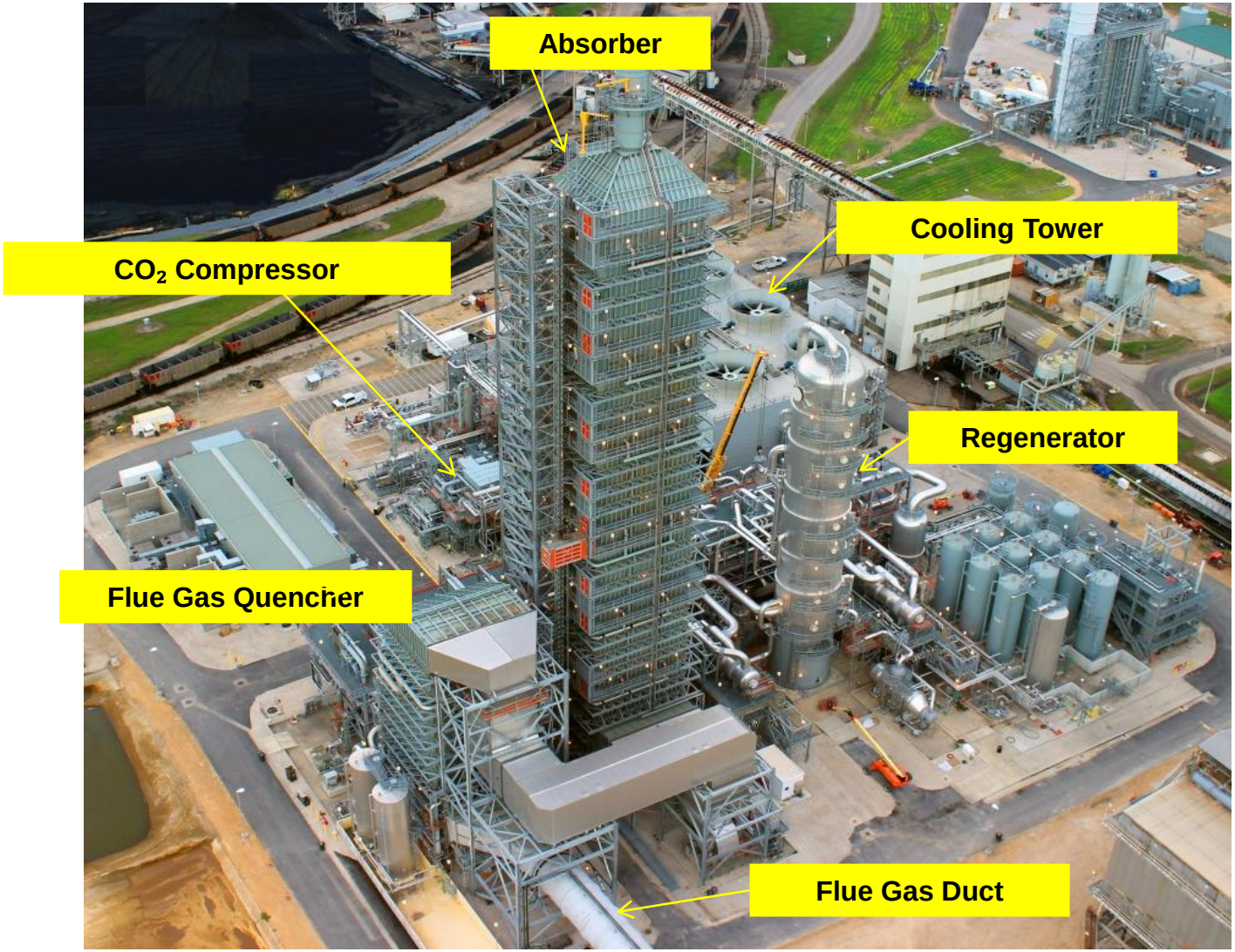
→ Speedy and flexible Construction method



Absorber Module Lifting

Petra Nova Project Overview

Petra Nova Site Photo



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Continuing Developments

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.

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

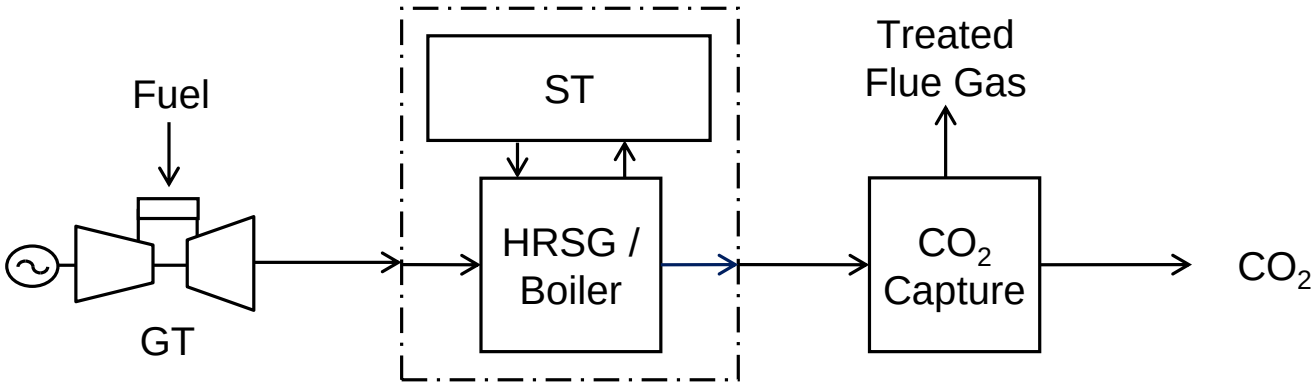
Typical Flue Gas Conditions

	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

- MHI operated 1 mtpd pilot plant for 3,000 hrs on simulated NGCC flue gas.
- KS-1™ 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

Summary

MHI's Carbon Capture Technology

- 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.

Commercial Plant for CO_2-EOR

- 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.

Continuing Developments

- 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.**