Update on Mitsubishi's KM CDR Process™ and Experience

April 2018

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MITSUBISHI HEAVY INDUSTRIES ENGINEERING

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What is KM CDR Process™ ?

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History & Accomplishments of KM CDR Technology

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1990	Start R&D activities with Kansai Electric Power Company (KEPCO)
1991	Start a 2 ton per day pilot plant at KEPCO's Nanko Power station
1994	Development of proprietary hindered amine solvent "KS-1®" and "KM CDR Process®" with KEPCO
1999	First commercial plant in Malaysia (200 ton per day, to enhance urea synthesis from the CO_2 recovered from a reformer flue gas)
2002	Start a pilot test for coal-fired power plant at MHI's Hiroshima R&D center
2003	High energy efficiency - Development of proprietary energy efficient process "Improved KM CDR Process"
2008	First commercial plant in Middle east (400 ton per day) which "Improved KM CDR Process" applied
2011	World's first - Started 500 ton per day fully integrated CCS demonstration plant with Southern Company for a coal-fired power plant at Alabama Power's James M. Barry Electric Generating Plant
Dec-2016	World's Largest - a CO2 Capture & Compression plant of 4,776 ton per day for EOR developed by NRG Energy Inc. and JX Nippon Oil & Gas Exploration Corporation has been under an operation.

KM CDR Process™ – Features and Advantages

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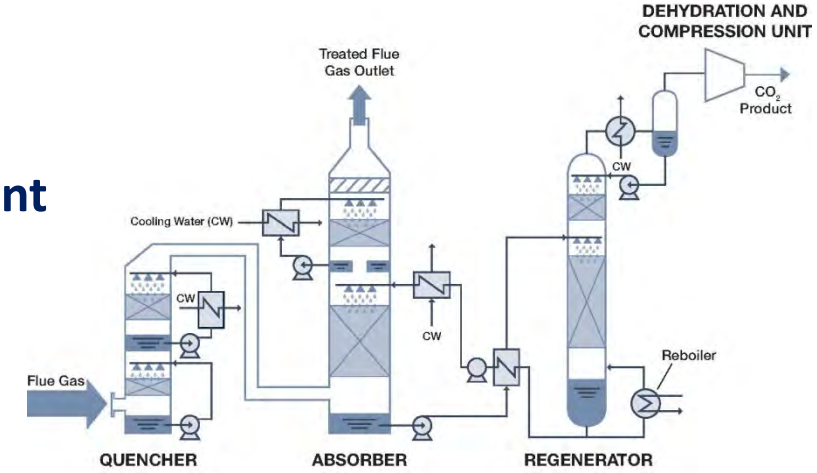
- ✓ **KM CDR Process™ – Kansai Mitsubishi Carbon Dioxide Removal**
  Jointly Developed by MHI Engineering & Kansai Electric Power Company (KEPCO)

- ✓ **World's most advanced R&D programs commenced in 1990 and ongoing**

- ✓ **Proprietary hindered amine solvent "KS-1™" with accompanying proprietary system**
  - KS-1™ solvent with low energy, low solvent degradation & Negligible corrosion
  - Proprietary heat Recovering (High energy efficiency system)
  - Deep Amine emission Reduction system
  - Automatic Load Adjustment (ALAC) System

- ✓ **Commercial proven & World's most energy efficient Flue gas CO_2 capture Technology**



- ✓ **Applicable for various flue gas sources such as Natural gas, Heavy oil, and Coal for variety of usages such as Urea, Methanol, General, and EOR.**

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Delivery Record of KM CDR Process™

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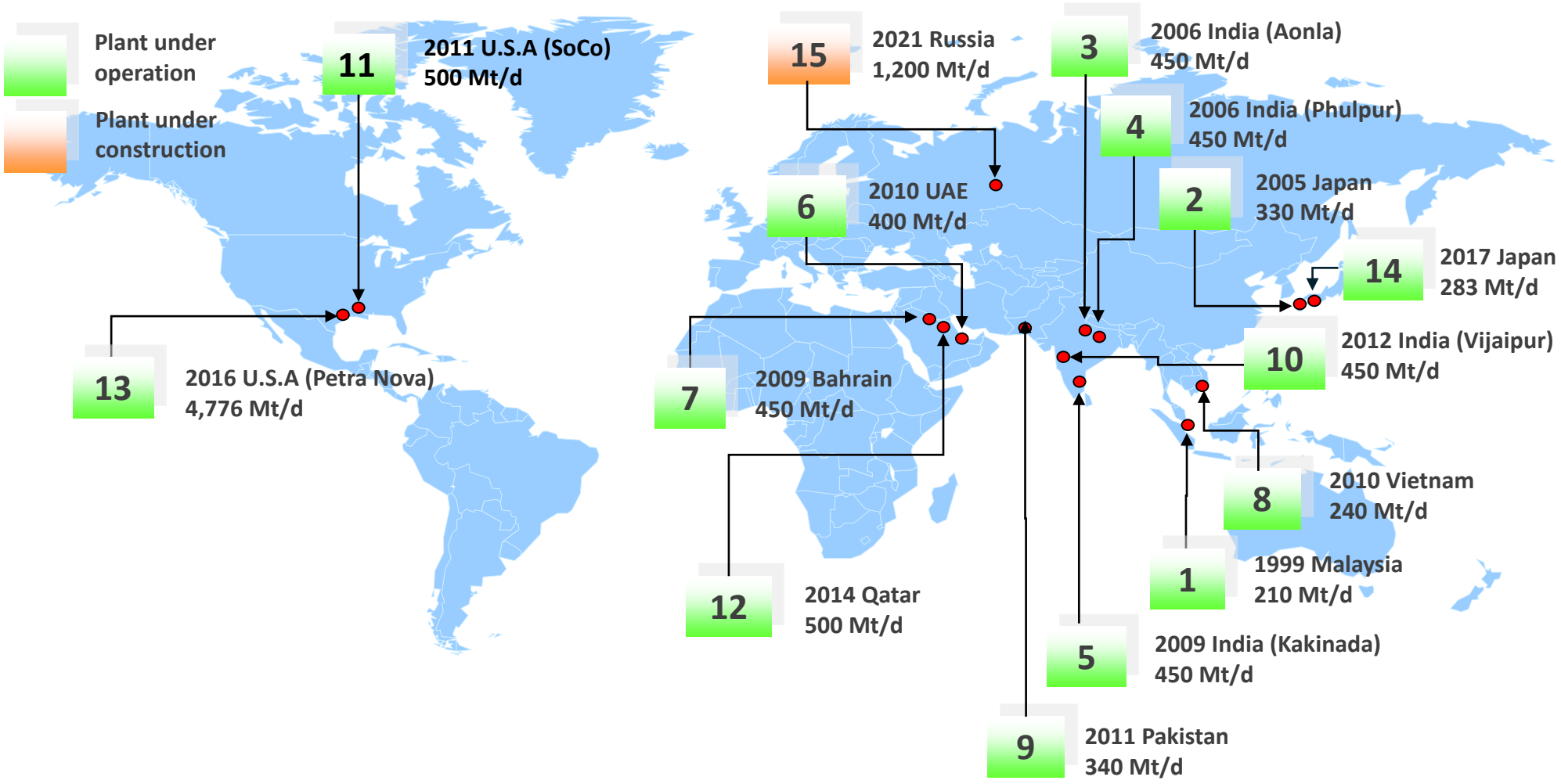
- **World's largest delivery of CO_2 capture plant for over 100 tpd capacity; 13 plants under commercial operation and 1 under construction**



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Commercial Plants of KM CDR Process™

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World's leading large scale post-combustion CO_2 capture technology licensor

13 plants in operation and 1 under construction, from a variety of natural gas, heavy oil, and coal flue gas sources.

1999
210 t/d Malaysia

2005
330 t/d Japan

2006
450 t/d India

2006
450 t/d India

2009
450 t/d India

2009
450 t/d Bahrain

2010
400 t/d UAE

2010
240 t/d Vietnam

2011
340 t/d Pakistan

2012
450 t/d India

2014
500 t/d Qatar

2016
4,776 t/d U.S.A.

2017
283 t/d Japan

2021
1200 t/d Russia

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Commercial Plants of KM CDR Process™

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- ✓ Commercialized since 1999
- ✓ Various flue gas sources: Natural gas, heavy oil, and coal
- ✓ CCUS has been the main driver of MHI's 14 commercial projects.

Year of Delivery	Country	Flue Gas Source	CO_2 Capacity (TPD)	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
2017	Japan	Gas Fired Furnace	283	General Use
2021	Russia	NG Fired Furnace	1,200	Urea & melamine Production

2nd KM CDR Users Conference

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

R&D Activities of KM CDR Process™

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World's most advanced and comprehensive industrial R&D programs commenced in 1990 and ongoing

1991–
Nanko Pilot Plant using natural gas-fired flue gas from Kansai Electric Power Plant (2 TPD)

Engineering HQ (Yokohama)

2002–
1 TPD Pilot Plant on Coal Exhaust/Simulated gas (MHI R&D Center)

2006 – 2008
J-Power Matsushima Pilot Plant using coal-fired flue gas (10 TPD)

2008 –
Large-scale rectangular CO_2 absorber test (MHI Mihara)

Approach from R&D to Full-scale Commercial Plant

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Commercial Plants

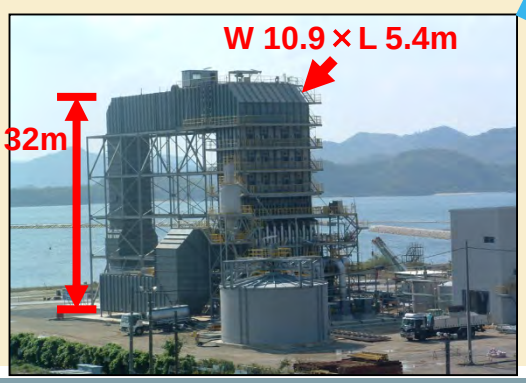
Lesson Learned

2016
Petra Nova

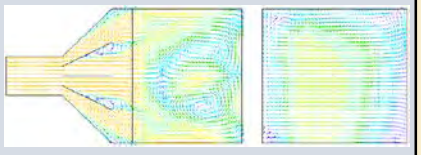
R&D Activities

1990
Pilot 2TPD

2008
Absorber 1 by 1 Scale Test (400 MWeq)



Simulators (CFD)



2011
Barry

2018 -
Reduction of CO_2 capturing cost (CAPEX&OPEX) through Technical Improvement

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CO_2 Application

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CO_2 Application

- ✓ **CCUS**
  - **Urea**
  - **Methanol**
  - **General use (Beverage, Dry ice, Welding, etc)**
  - **EOR (Enhanced Oil Recovery)**
  - **Soda Ash**
  - **GTL**

- ✓ **CCS**

Enhance Urea production

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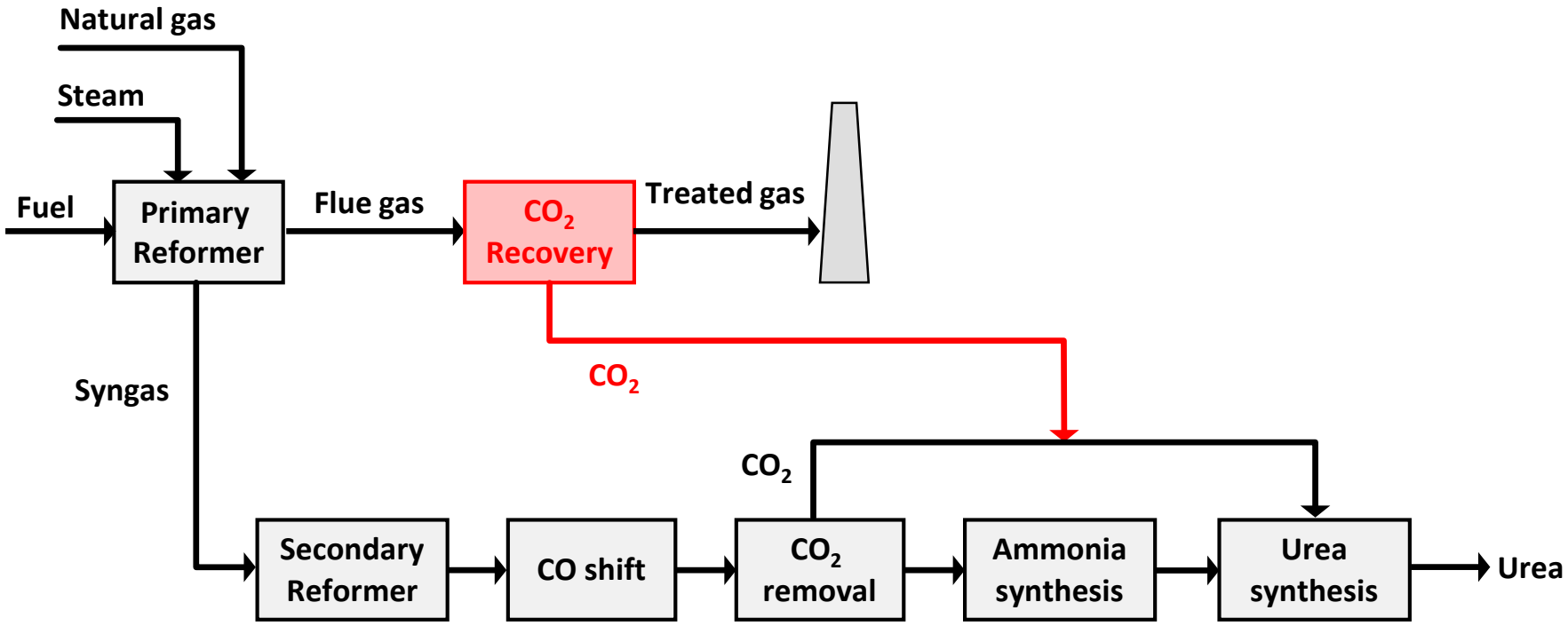
- ✓ **In natural gas based ammonia and urea plants, CO_2 is recovered from the reformer burner flue gas and used for urea synthesis**



Enhancing Methanol production

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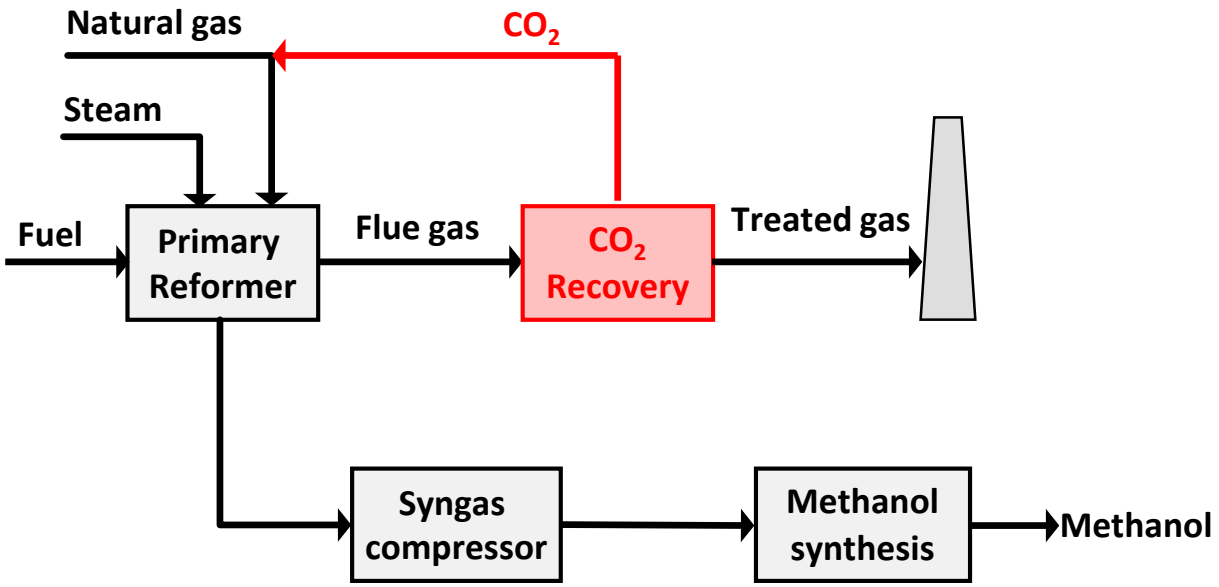
✓ **Methanol production is enhanced by adding external CO_2 that is captured from the reformer burner flue gas**



✓ **Optimize CO & H_2 ratio for Methanol synthesis**

Reformer : $CH_4+H_2O \Leftrightarrow CO+3H_2$

MeOH synthesis: $CO+2H_2 \Leftrightarrow CH_3OH$

Enhancing oil recovery (EOR)

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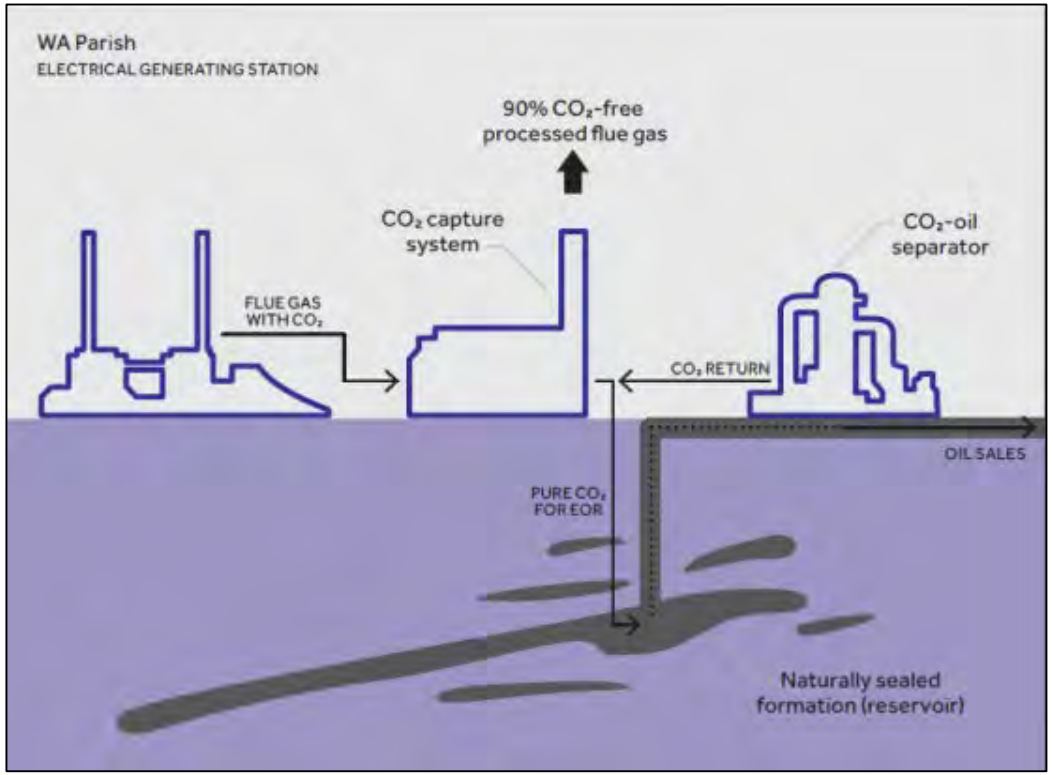
✓ Enhanced Oil Recovery is main driver for major North American CCUS projects



CO_2 supply chain

1) Fossil-fuel 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

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

Demonstration: CO_2 capture from coal-fired flue gas

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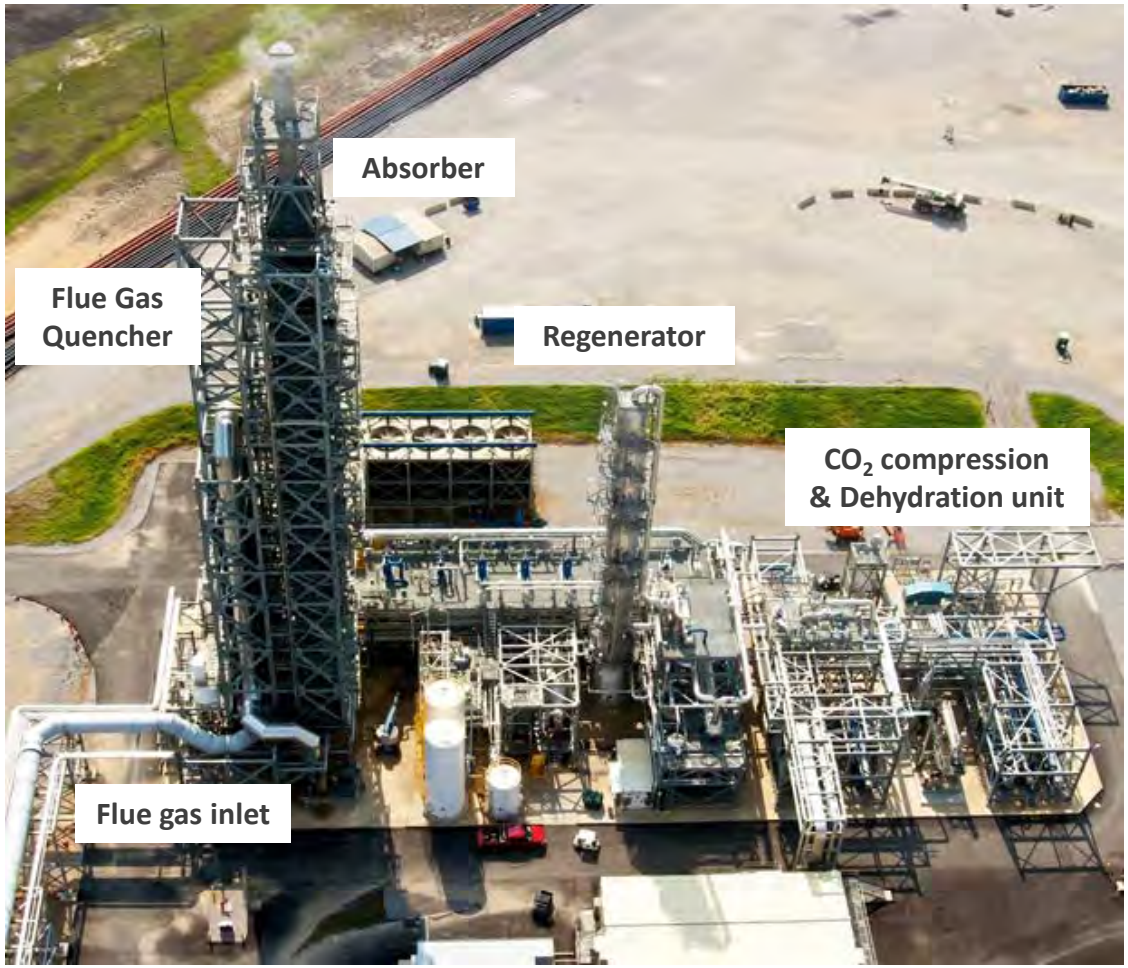
- ✓ **Part of a start-to-finish CCS project**
- ✓ **Executed by Southern Company Services (SCS) and MHI Engineering collaboratively**



Plant location	Alabama, US
Plant owner	Southern Company subsidiary Alabama Power
CO_2 Capacity	500TPD (25 MW_{eq})
CO_2 conc.	10.1 mol%-wet
CO_2 removal	90%
CO_2 use	Geological storage

Operating data as of 8/31/2014	
Operating time	12,400 hrs
Captured CO_2	230,100 tonne
Injected CO_2	115,500 tonne

Fully integrated CO_2 capture, transportation, and storage

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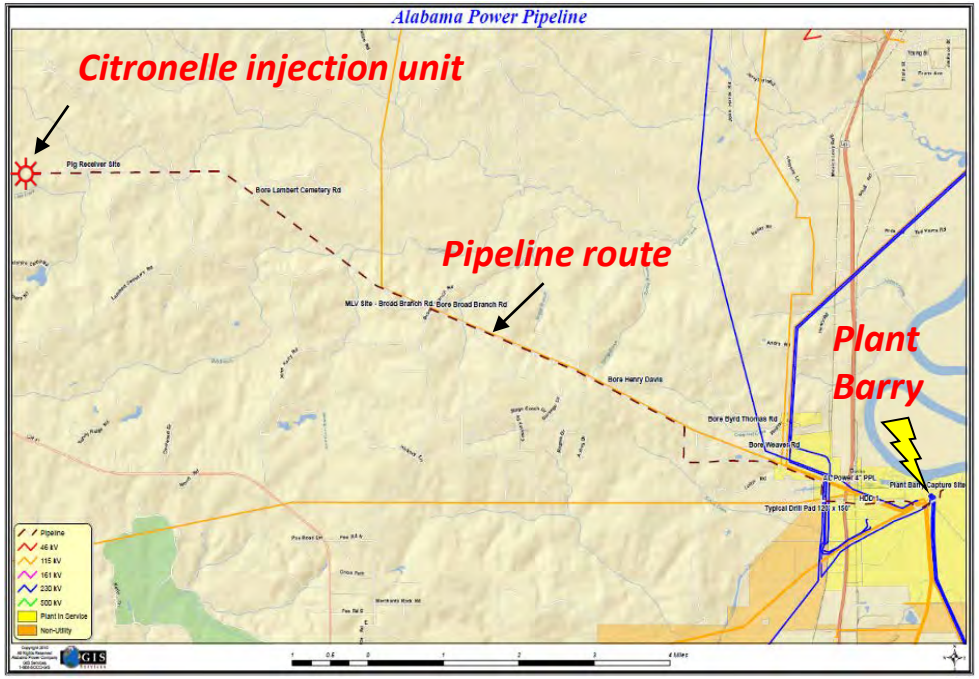
- ✓ Southeast Regional Carbon Sequestration Partnership (SECARB) Phase 3 "Anthropogenic Test" injecting man-made CO_2 from Plant Barry
- ✓ 12 miles CO_2 pipeline to the injection unit
- ✓ CO_2 injection into ~3km deep saline formation
- ✓ Monitoring of CO_2 storage during injection and 3 years post-injection



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Petra Nova Project

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Petra Nova Project: Overview

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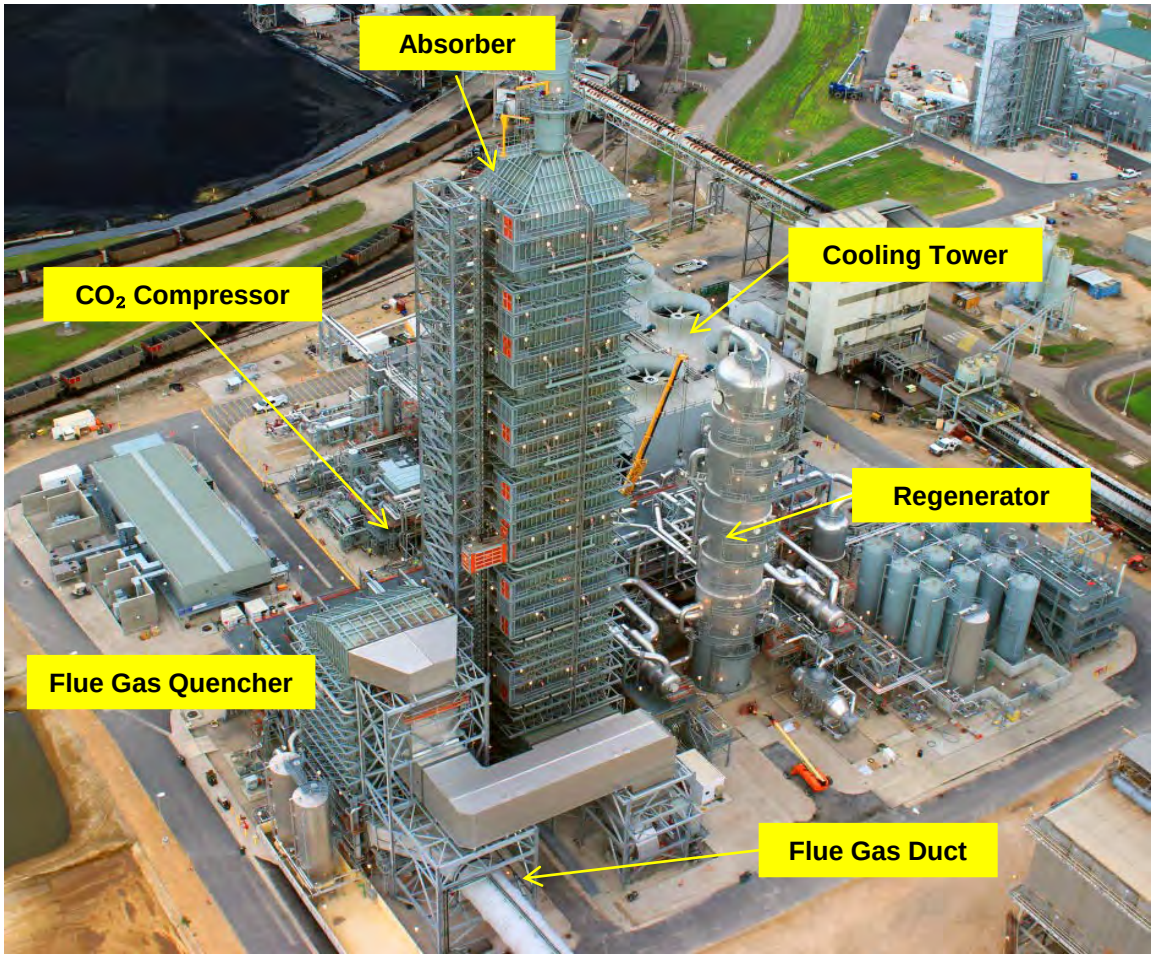
- ✓ **The world's largest CO_2 capture plant on coal-fired flue gas has been under commercial operation since December 2016.**
- ✓ **Supported by DOE grant program (CCPI Round 3) and Japanese government finance (JBIC / NEXI)**

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

Petra Nova Project: CO_2 for EOR

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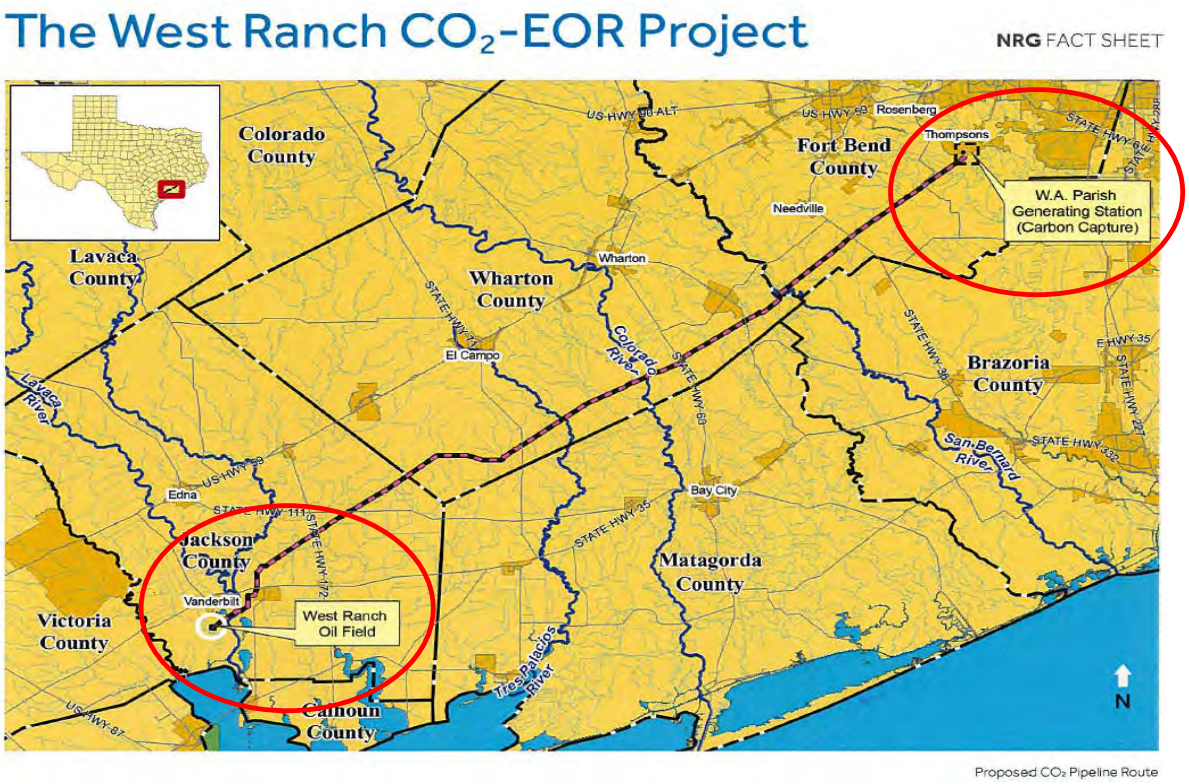
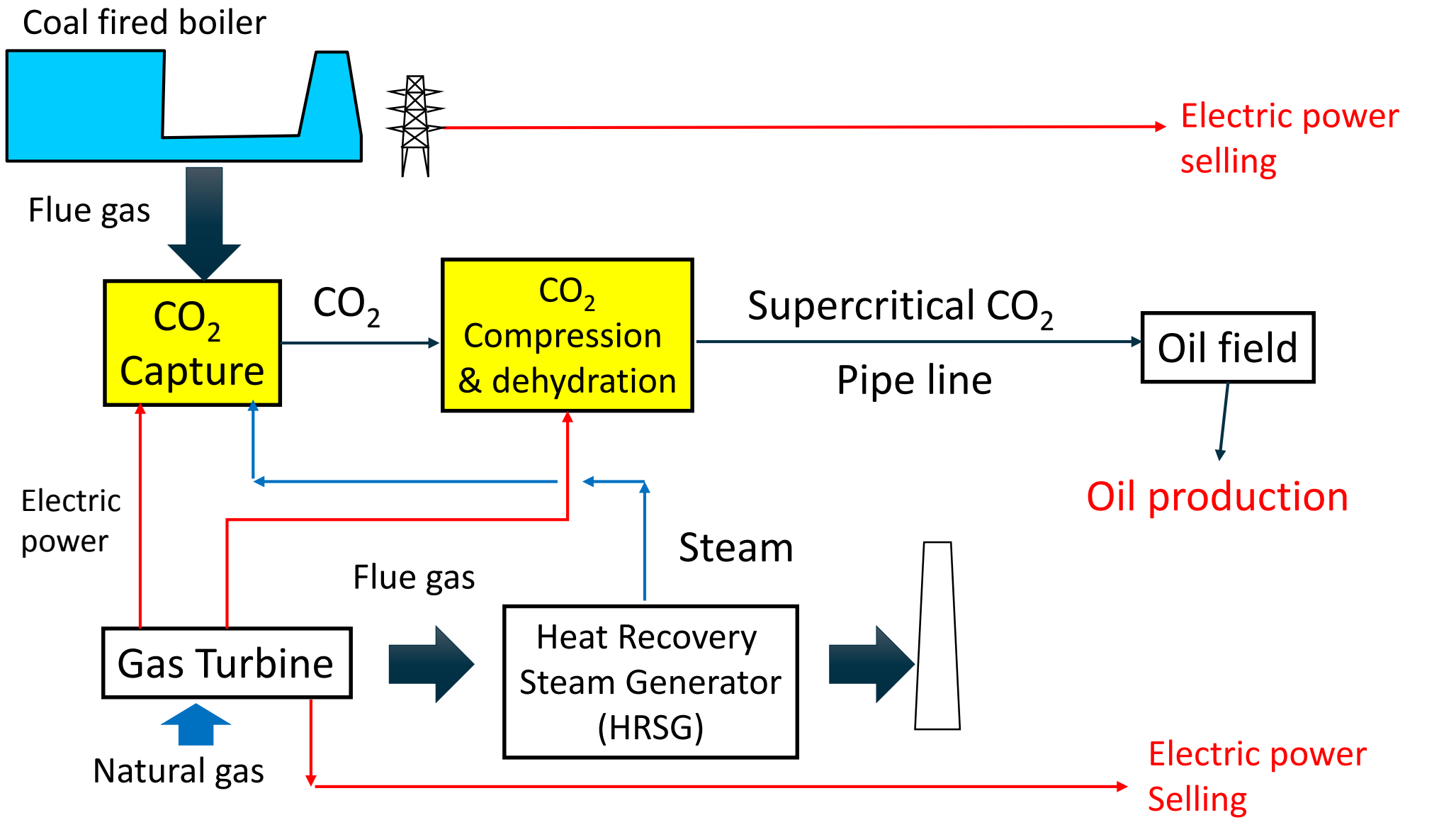
✓ CO_2 Captured for Enhanced Oil Recovery (EOR)

- Compressed CO_2 is delivered via an 81 mile CO_2 pipeline to the West Ranch oil field.
- Up to 1.4 million tonnes of CO_2 is annually injected into the West Ranch formation.



WA Parish CO_2 EOR Overall System



Petra Nova Project: Media responses

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"NRG Energy, JX Nippon complete world's largest post-combustion carbon capture facility on-budget and on-schedule"- selected Plant of the Year by Power Magazine

Financial Times

World's biggest carbon capture project on schedule

Petra Nova covers its costs by using the gas it captures for oil production

Coal-fired plant in Utah. It is hoped carbon capture technology can be used at coal-fired plants © Getty

Ed Crooks in New York

JANUARY 11, 2017

14

The world's largest project capturing carbon dioxide emissions from power generation has come into service in the US on time and on budget, pointing the way towards a potentially viable future for the technology as a way to curb greenhouse gas emissions.

Energy Wire

Business Wire

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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--

Thirteen-foot diameter ductwork takes flue gas from the coal plant to the carbon caption 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)

JX

January 10, 2017 01:00 AM Eastern Standard Time

HOUSTON & TOKYO--(BUSINESS WIRE)--NRG Energy, Inc. (NYSE:NRG) and JX Nippon Oil & Gas Exploration Corporation (JX Nippon) have completed construction, on-budget and on-schedule, of Petra Nova, the world's largest post-combustion carbon capture system.

#PetraNova, world's largest post combustion carbon capture system, is online and capturing CO2 from a coal plant.

Tweet this

"Completion of the Petra Nova project is an important milestone in our quest to help ensure reliable, affordable and increasingly cleaner energy from fossil fuels," said Mauricio Gutierrez, President and CEO of NRG Energy. "This project represents another major step in NRG's effort to reduce our carbon emissions and create a more sustainable energy future, and we are proud that this accomplishment was achieved on-budget and on-schedule in a competitive energy environment. I want to thank our partners at JX Nippon, Hilcorp and the U.S. Department of Energy as well as the State of Texas, our contractors and lenders for their commitment to the successful completion of this landmark project."

Power Magazine

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

08/01/2017 | POWER

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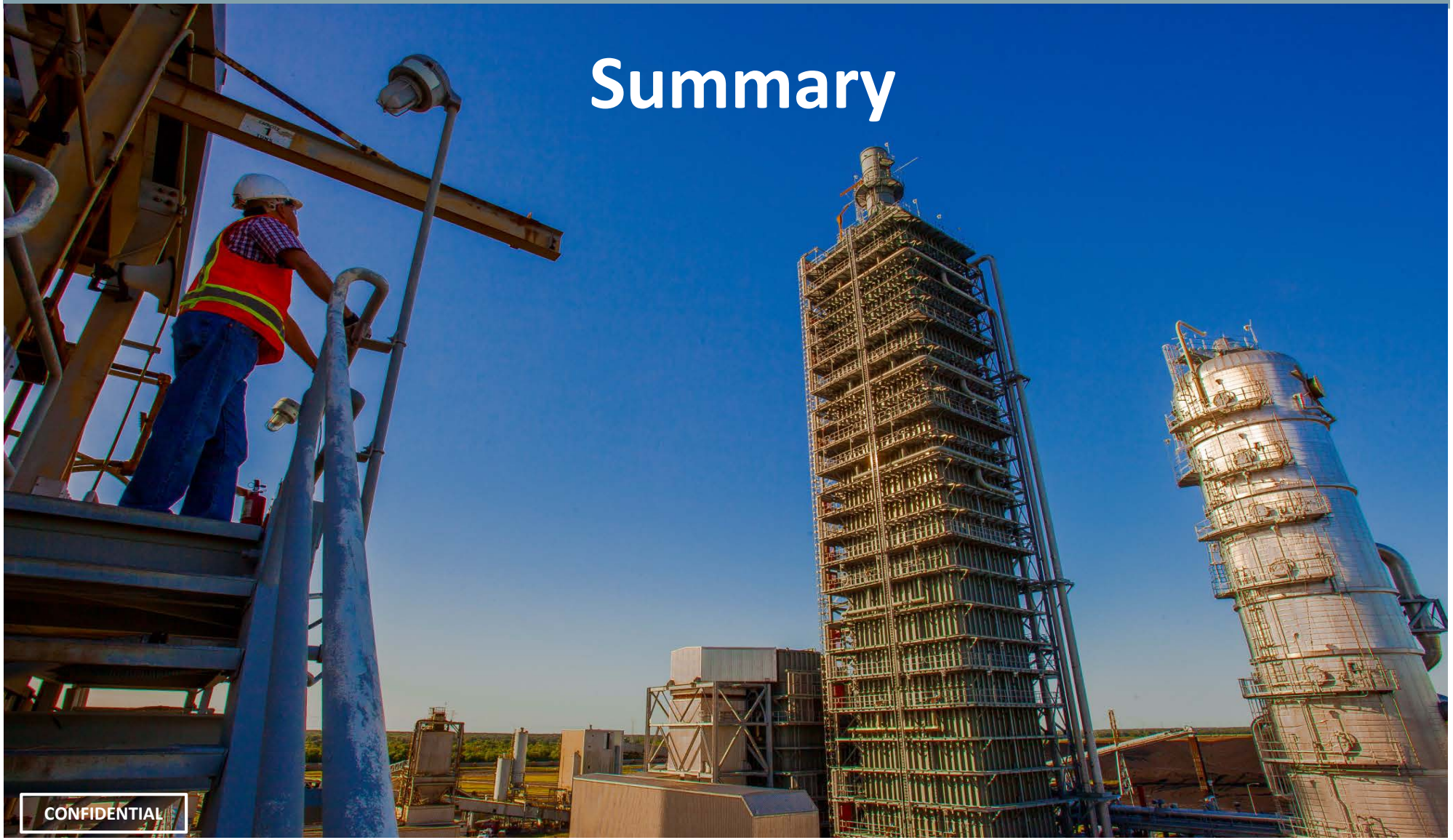
Courtesy: Kiewit

Winning POWER's highest honor, the U.S.'s first and world's largest commercial post-combustion carbon capture system at a power plant is distinctively both a globally significant environmental breakthrough and a trailblazing revenue-generating facility. Putting this $1 billion project online on time and on budget—despite a chaotic policy climate and other challenges that sank similar projects—was a top priority for its investor-owned owners and project partners.

Summary



Summary of KM CDR Process™

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1. World's largest delivery of CO2 Capture Plant for over 100 tpd capacity; 13 plants under commercial operation and 1 under construction

2. Commercially applied since 1999 to a variety flue gas sources of Natural gas, heavy oil, and coal for variety of CCUS; such as Urea, Methanol, EOR and other General usage.

3. World's largest operating post combustion CO2 capture plant (4,776 tpd) since 2016

4. The 'Complete Solution' – Proprietary hindered amine solvent "KS-1™" with accompanying proprietary equipment

5. World's most energy efficient Post Combustion Process – Reducing CAPEX & OPEX

6. World's most advanced and comprehensive industrial R&D programs commenced in 1990 and ongoing

7. Applicable to large commercial power, biomass plants or other large combustion plants

Next Way Forward
&
Suggestion

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Ongoing Effort by MHI Engineering;

- ✓ *Reduction of CO_2 capturing cost (CAPEX&OPEX) through Technical Improvement*
  - *- Increasing efficiency*
  - *- Preventing solvent degradation*

DOE/NETL CO_2 Cost Goal
2020 2nd Generation:
$40/ton
2025 Transformational:
Less than $40/ton

Suggestions to expand CCS and reduce carbon footprint;

- ✓ *Encourage the construction of CO_2 Capture Plant and associated facility through various incentives or subsidy system, in order to decrease the CO_2 capturing cost through scale up economics and learning curve.*
- ✓ *Prepare CO_2 pipeline and sequestration as social infrastructure, in order to decrease the uncertainty after capturing CO_2.*
- ✓ *Provide matching opportunities among various stakeholders.*

Thank you

Further Question
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