Carbon Capture and Carbon Dioxide (CO_2) EOR & Storage – A "Game Changer" CCUS Technology (India)

Dec. 10, 2020

Dr. Ganesh Thakur*

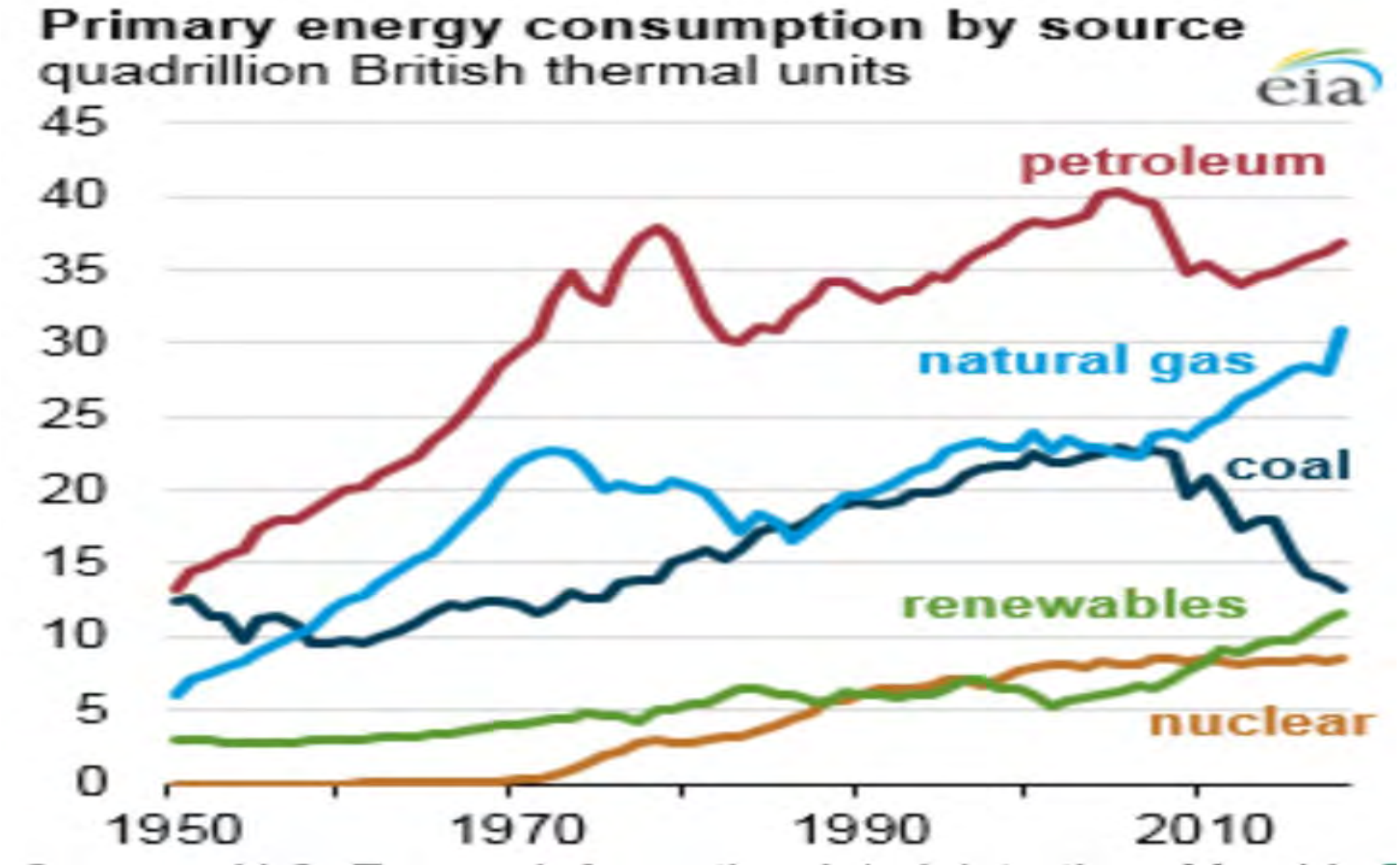
Member - National Academy of Engineering (USA)

Distinguished Professor, University of Houston & Director – EIP

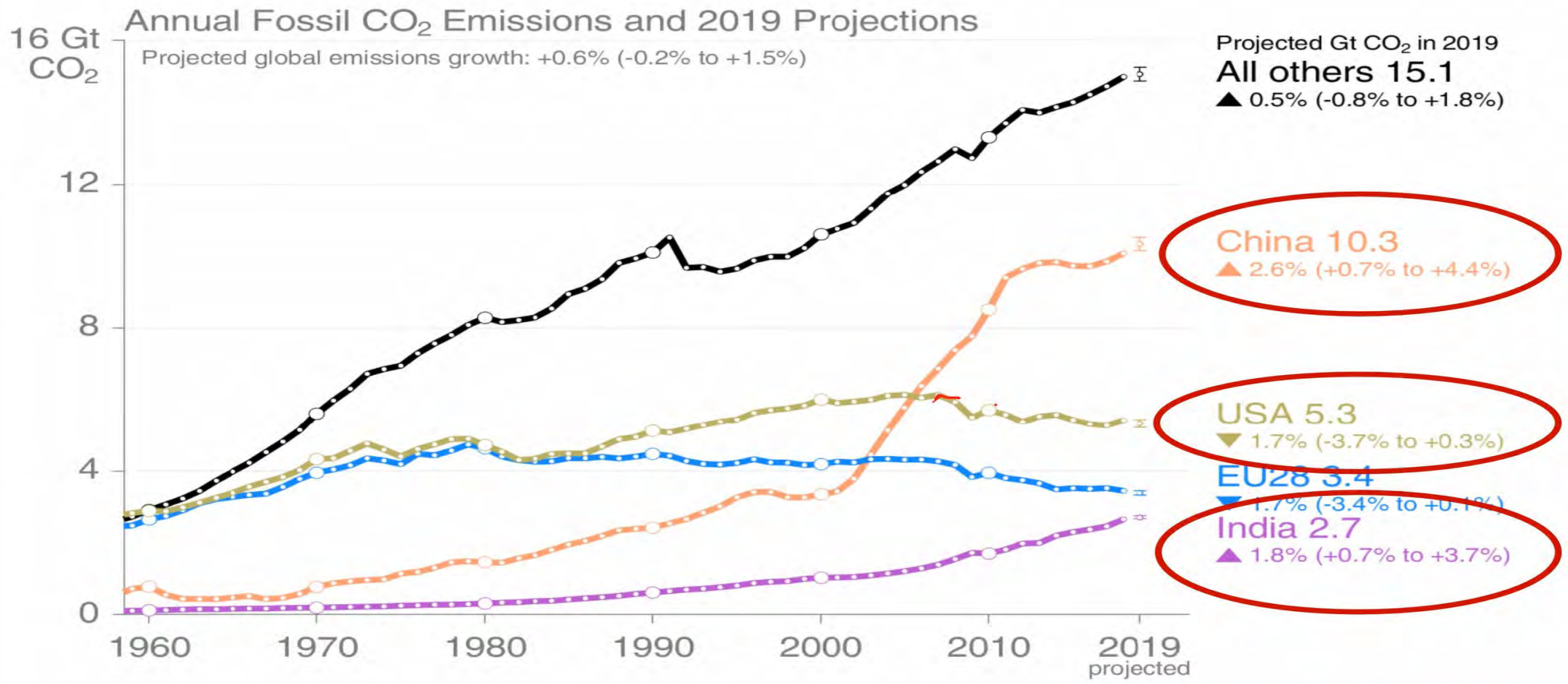
*** President – SPE Foundation, Former SPE Intl. President, Board Member – TAMEST, Former VP – Chevron**

Outline

1. GHG Challenges and Importance of Fossil Fuels
2. Anthropogenic CO2 Capture, Utilization and Storage (CCUS)
3. CCUS Projects – Examples (Worlwide)
4. CO2 EOR Historical Perspectives – US Examples
5. CCUS Research in India – Oil India Ltd. Project (UH and OIL Collaboration)
6. Path Forward & Summary


Primary energy consumption by source
quadrillion British thermal units
eia
45
40
35
30
25
20
15
10
5
0
1950
1970
1990
2010
petroleum
natural gas
coal
renewables
nuclear

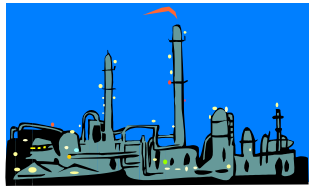
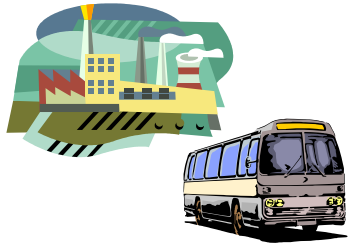
Motivation – Global Fossil Fuel Emissions



From: Global Carbon Project, 2019

CO_2 in Energy Production, Transportation and Consumption

CO_2 Emission Sources

	Production	Transportation	Refining and Petrochemical Production	End Use
				
Sources	■ Combustion and rotating equipment, flaring, venting ■ Gas associated with oil production	■ Pipelines ■ Vessels ■ Vehicles	■ Heaters ■ Boilers	■ Consumer - use of gasoline, diesel, and coal
Emission	■ CO_2 ■ Methane	■ CO_2 ■ Methane	■ Primarily CO_2	■ CO_2

Carbon Disposal Options

- Direct Geological Storage
  - Injection of captured CO_2 into Deep Saline Aquifers
  - Injection into Depleted Oil or Gas Reservoirs
- CO_2 Utilization
  - Enhanced Oil Recovery (EOR)
  - Other possible industrial usage
- "Natural Sinks" Storage in Soils and Vegetation

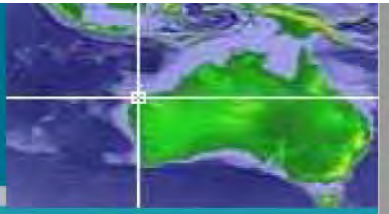
Anthropogenic CO_2 EOR Projects – Worldwide*

Project	Operator	Location	CO_2 Source	Size (MM Ton/yr)
Uthmaniyah	Saudi Aramco	Saudi Arabia	Hawiyah NGL Plant	0.8 EOR
Abudhabi ESI - Phase 1	AlReyddah ADNOC, Mustang, etc)	UAE	Steel Plant	0.8 EOR
Santos Basin	Petrobras	Brazil (Offshore)	NGL plant - FPSO	1.0 EOR
Sleipner	Statoil	North Sea (Offshore)	Gas Field (9% CO2)	0.85 EOR
PetroNova	NRG & Nippon (Japan)	Houston (TX)	Post combustion CO2 – Power Plant	1.4 EOR
Gorgon	Chevron	Australia Barrow Island	Natural Gas processing	3.4 - 4
Various Projects in Japan and China in Early Phases				
UH involved in a carbon capture project in India				

EOR → CO2 injected is used for EOR instead of storage
Source: Global CCS Institute

Australian Government
Department of Resources, Energy and Tourism
Geoscience Australia

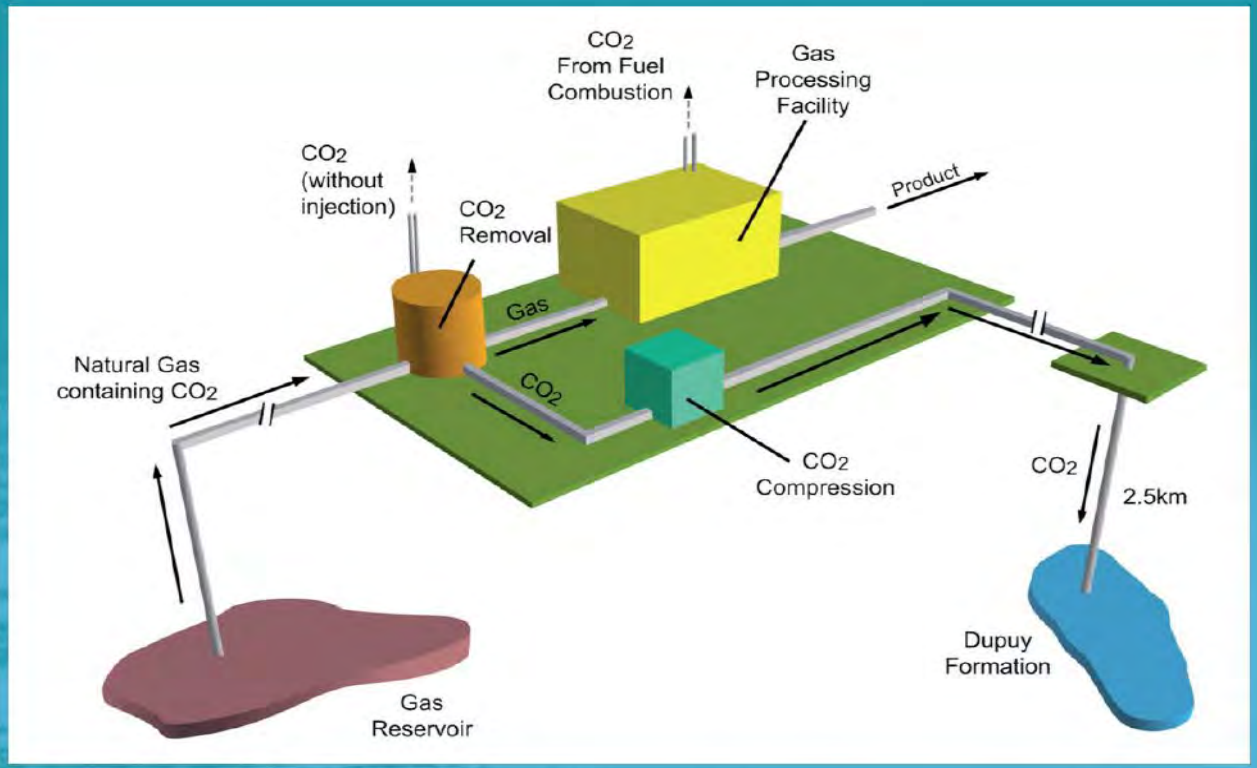
Gorgon Carbon Dioxide Injection Project



- The first project in Australia to significantly reduce emissions by the underground injection of CO_2
- Gorgon Project emissions are expected to be reduced by approximately 40%
- Injection will be between 3.4 and 4.0 million tonnes of reservoir CO_2 per year or more than 100 million tonnes over the life of the project
- Site appraisal cost $150 to $200 million
- Project capital cost will be around $2 billion
- Number of possible world firsts including –

✓ First greenhouse gas storage legislation – Barrow Island Act 2003 (WA)

✓ First CO_2 project to undergo detailed environmental impact assessment (including public review and comment)



Australian Government
Department of Resources, Energy and Tourism
Geoscience Australia

Carbon Dioxide Injection Project

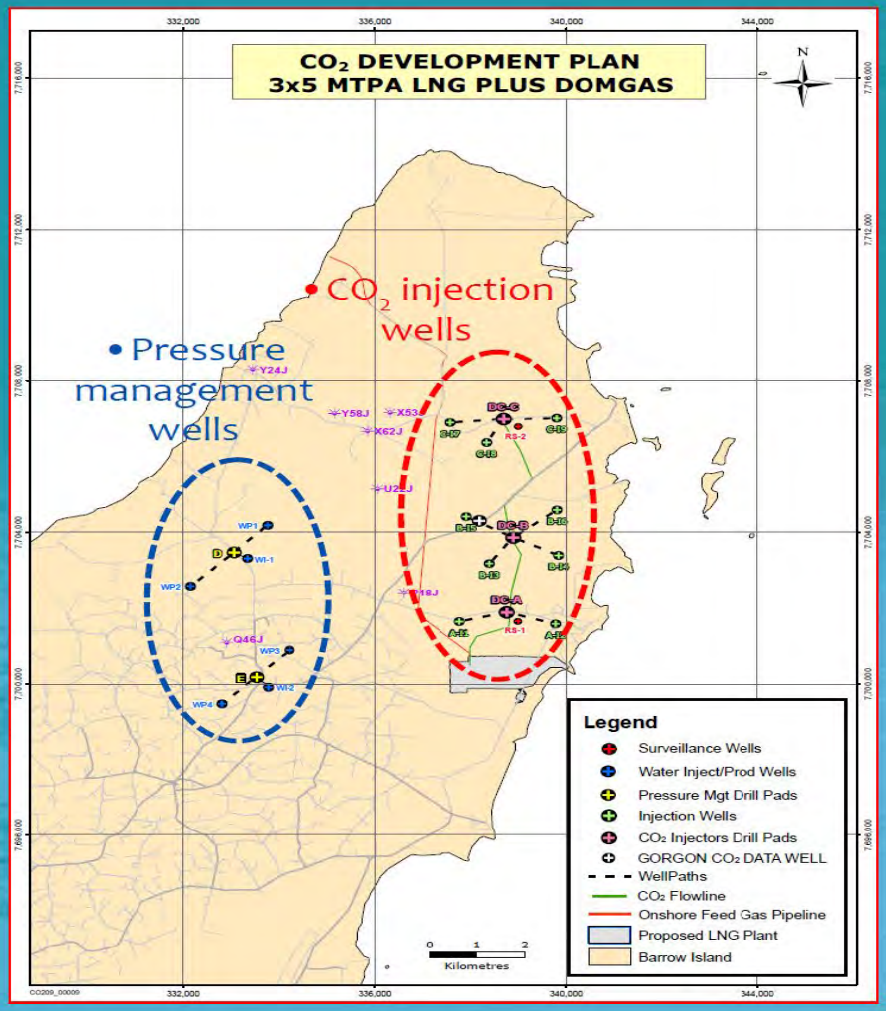
Approved Development Plan

- Project sited on north-east of island
- 4 stage compression at gas processing facility
- Buried CO2 pipeline extends north 7 km
- 9 CO_2 injection wells (from 3 drill centres)
- Pressure management (2 drill centres)
  - 4 water production wells
  - 2 water injection wells

Fit for purpose monitoring program

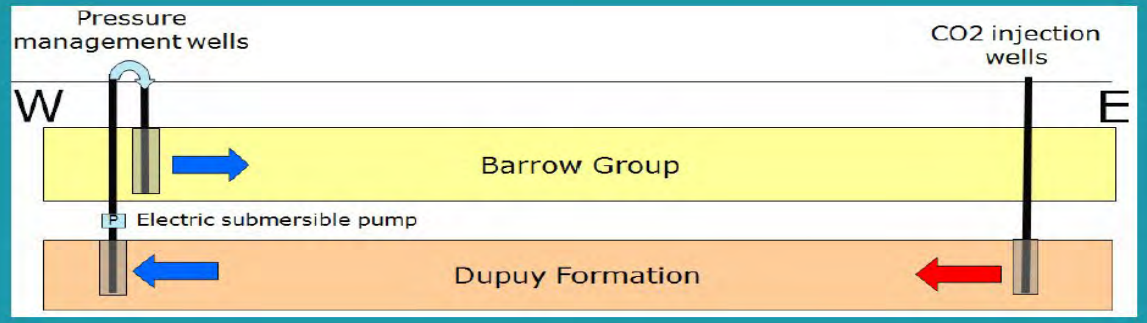
- 3D baseline seismic survey and repeat 2D and 3D seismic surveys to map lateral extent and broad vertical distribution of CO2
- 2 reservoir observation wells
- Soil gas flux sampling over the 3D seismic source grid and at potential near-surface seepage points

- **Program for ensuring existing well penetrations in the plume area do not provide seepage pathways**
- **Joint Venture commitment to make data from the ongoing monitoring program available to the public**



CCS in CDM Workshop – Abu Dhabi, 7-8 September 2011

Pressure Management

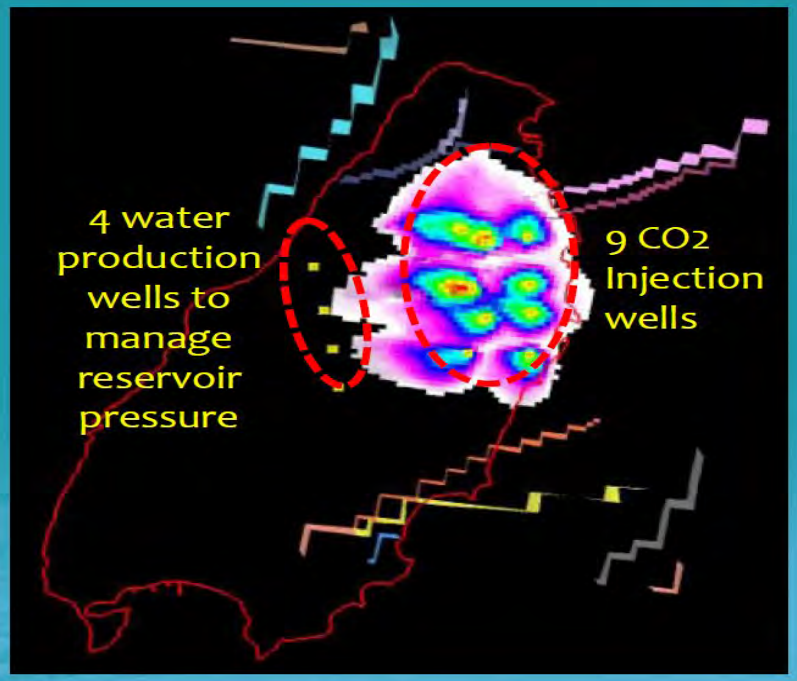


Pressure management required to reduce impact of rising pressure on CO_2 injection performance:

- Maintain injection rates
- Avoid reaching bottom hole pressure limit
- Optimise storage capacity

Monitoring

- Wellhead pressure and flow rate
- Continuous down-hole pressure gauges



- Plume movement is influenced by water off-take, reservoir and structure.
- Growth in plume area is most rapid at start of injection

AGBAMI FIELD MISCIBLE GAS INJECTION PROJECT

The Agbami FPSO was built by South Korea's Daewoo Shipbuilding & Marine Engineering.

- No flares policy, associated crestal NG injection, peripheral WI
- $5 billion project
- Discovered in 1998
- Start of production 2008
- $1.2 billion FPSO – 250,000 BOPD, 415 MMCFPD, 450,000 BWIPD

- Pi = 7000 psi
- BPP = 2800 psi
- MMP = 3500 psi
- Dip angle = 10 to 30 deg.
- Water depth = 4800 ft

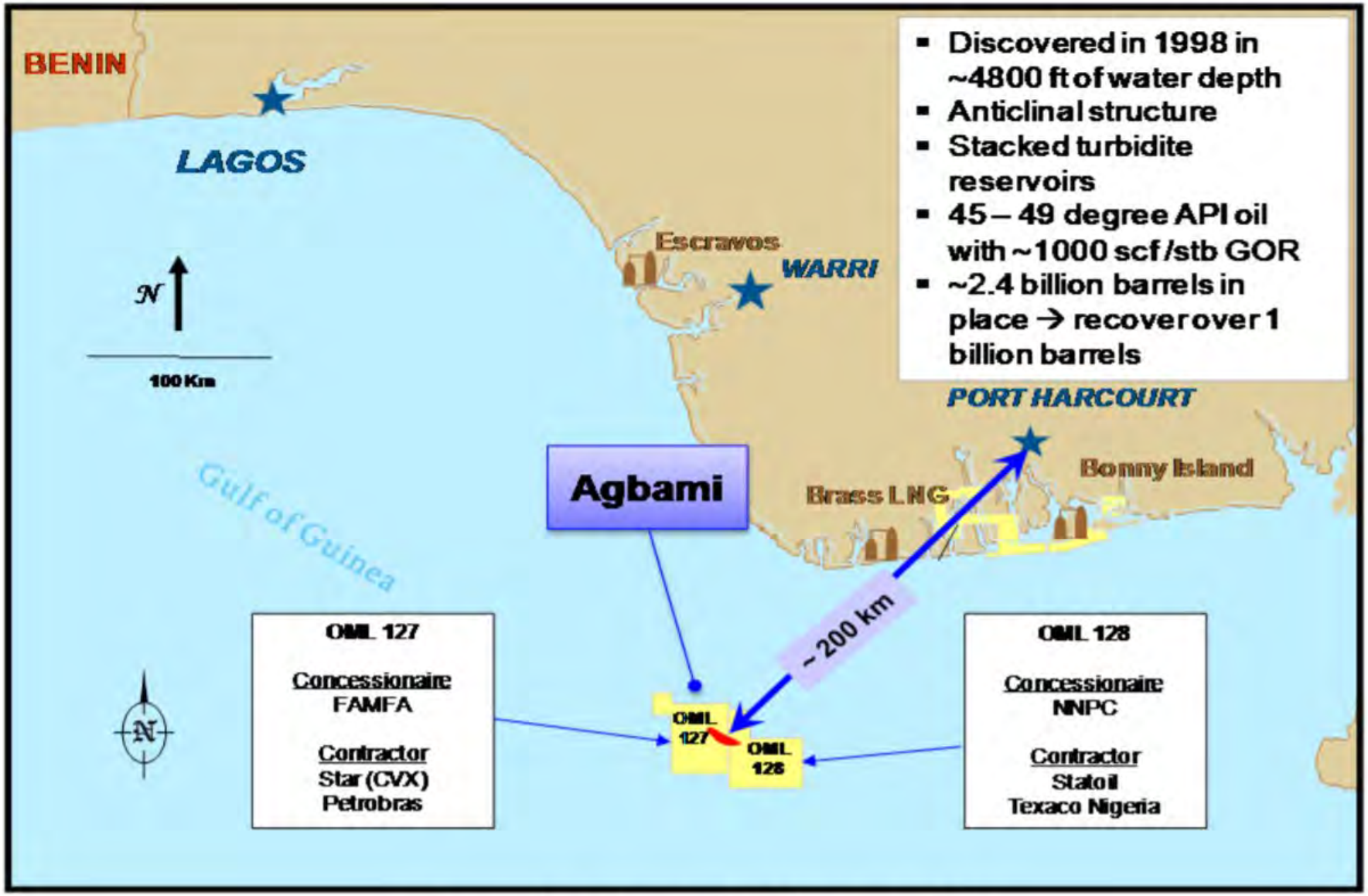
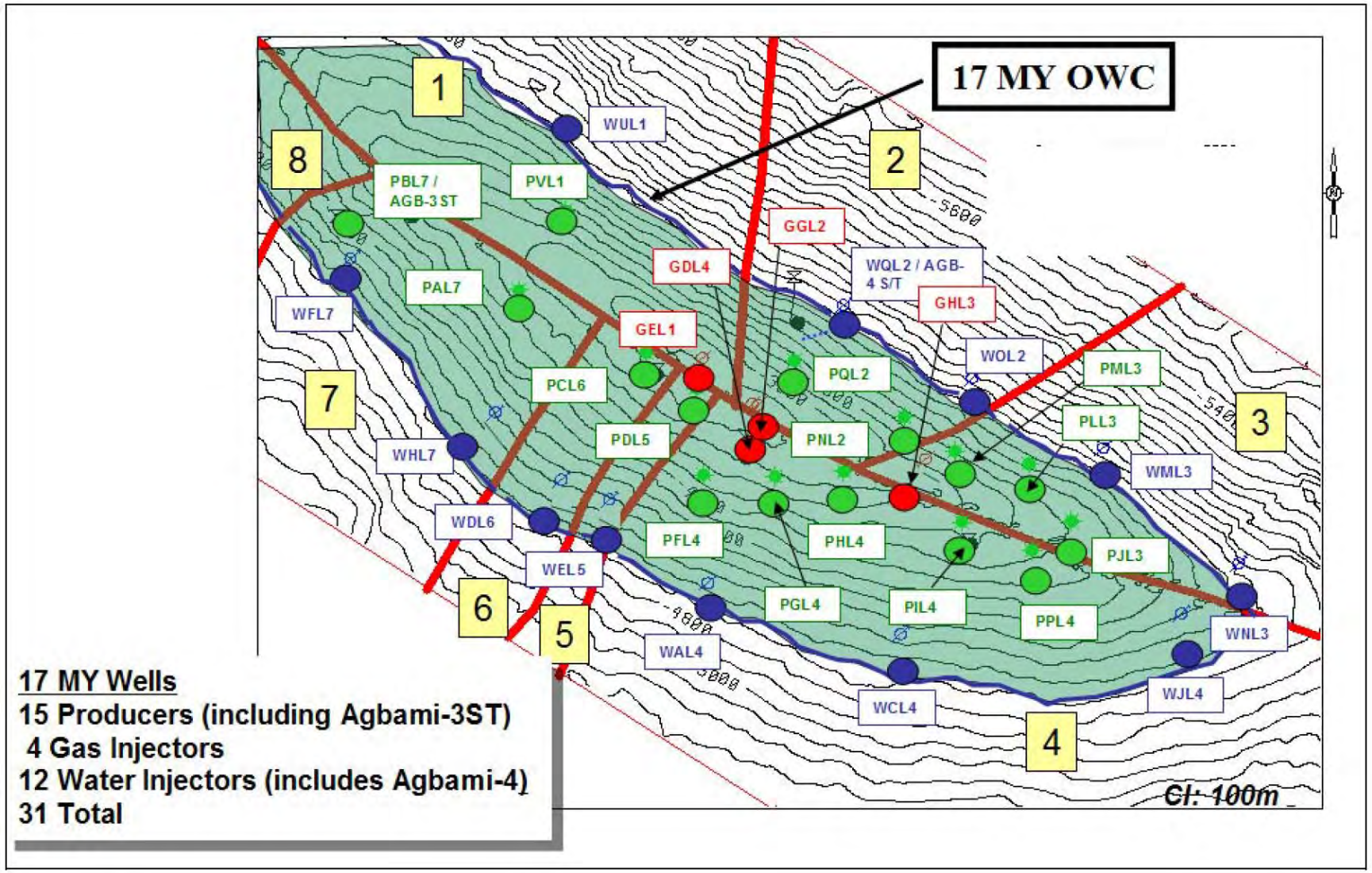


Figure 1: Agbami Field Location Map

Initial Development of Agbami Field, Nigeria (Miscible Gas Injection)



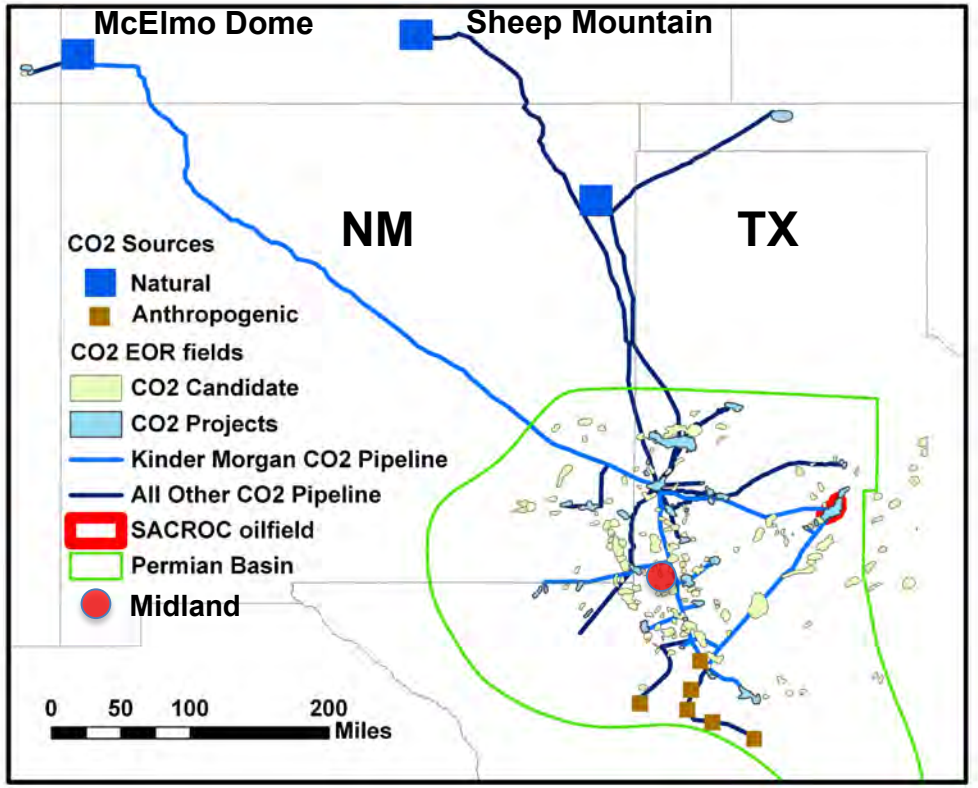
Brief History of CO_2 EOR in U.S.

- **1910's-1970's -** CO_2 Field Discoveries (Bravo Dome, McElmo Dome, Jackson Dome, Sheep Mountain)
- **1950's-1960's** – Development & Testing
- **1972-** First Notable CO_2 EOR Flood in Permian Basin (SACROC)
- **1973-** First Notable CO_2 EOR Flood in Gulf Coast (Little Creek)
- **1986-** First Notable CO_2 EOR Flood in Rockies (Rangely)
- **2000-** First Anthropogenic CO_2 EOR Flood (Weyburn/Canada)
- **2017-** First Commercial-Scale Anthropogenic CO_2 EOR Project (Petro Nova/Texas)

Case Study: First Commercial CO_2 EOR - SACROC

First Commercial CO_2 EOR was SACROC Unit (Scurry Area Canyon Reef Operators Committee) in the Permian Basin in 1972

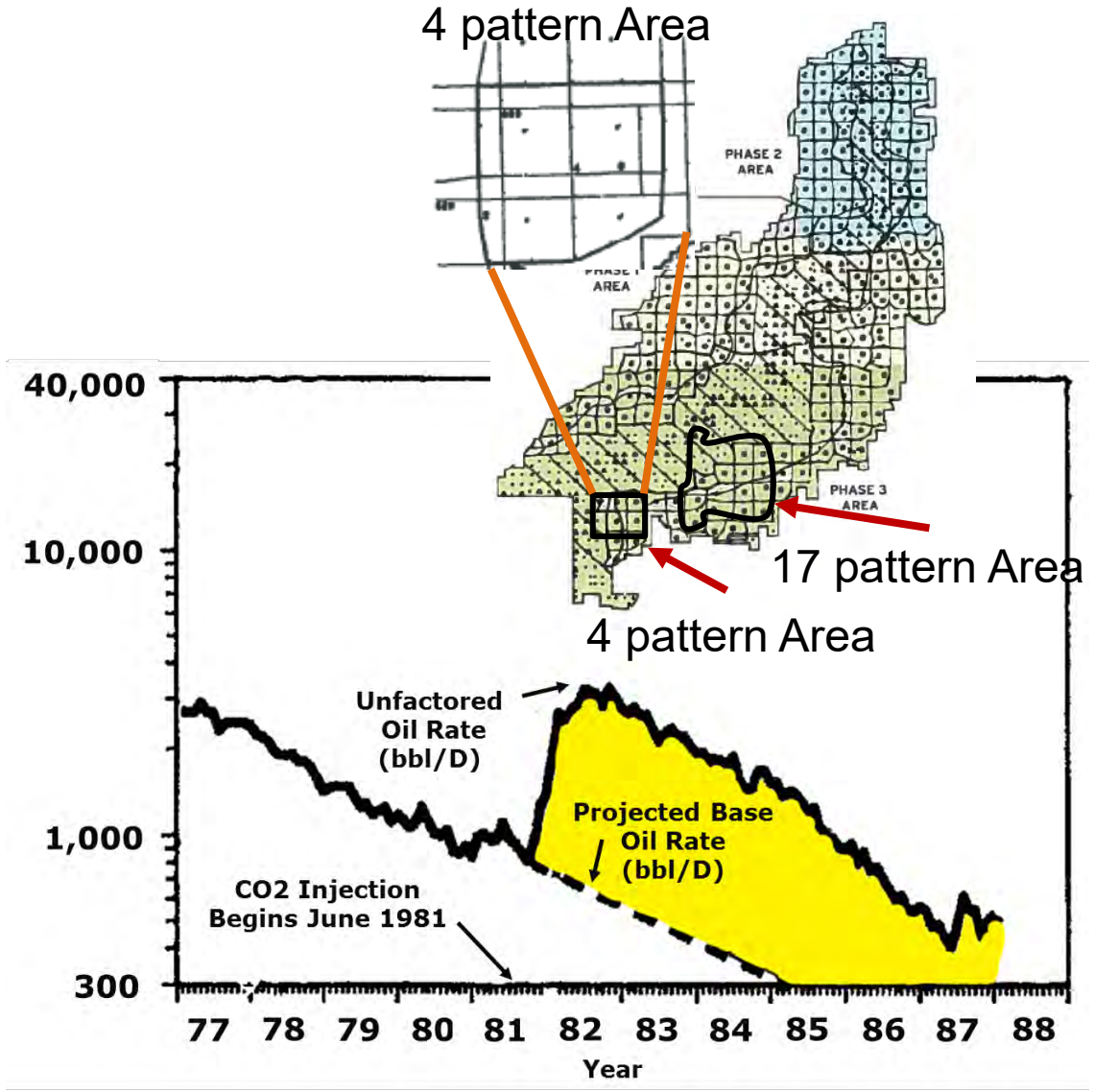
- The SACROC Unit covers 50,000 acres and was formed to optimize secondary and tertiary recovery of oil in the Canyon Reef
- Approximately 3900 miles of CO_2 pipelines
- Oil Production showed quick response to CO_2 injection soon after peak water flood production response occurred
- CO_2 EOR may add about 10% of OOIP



Kinder Morgan's presentation at the 19th Annual CO2 Flood Conference, 2013

Performance of the 4 Pattern Area – SACROC*

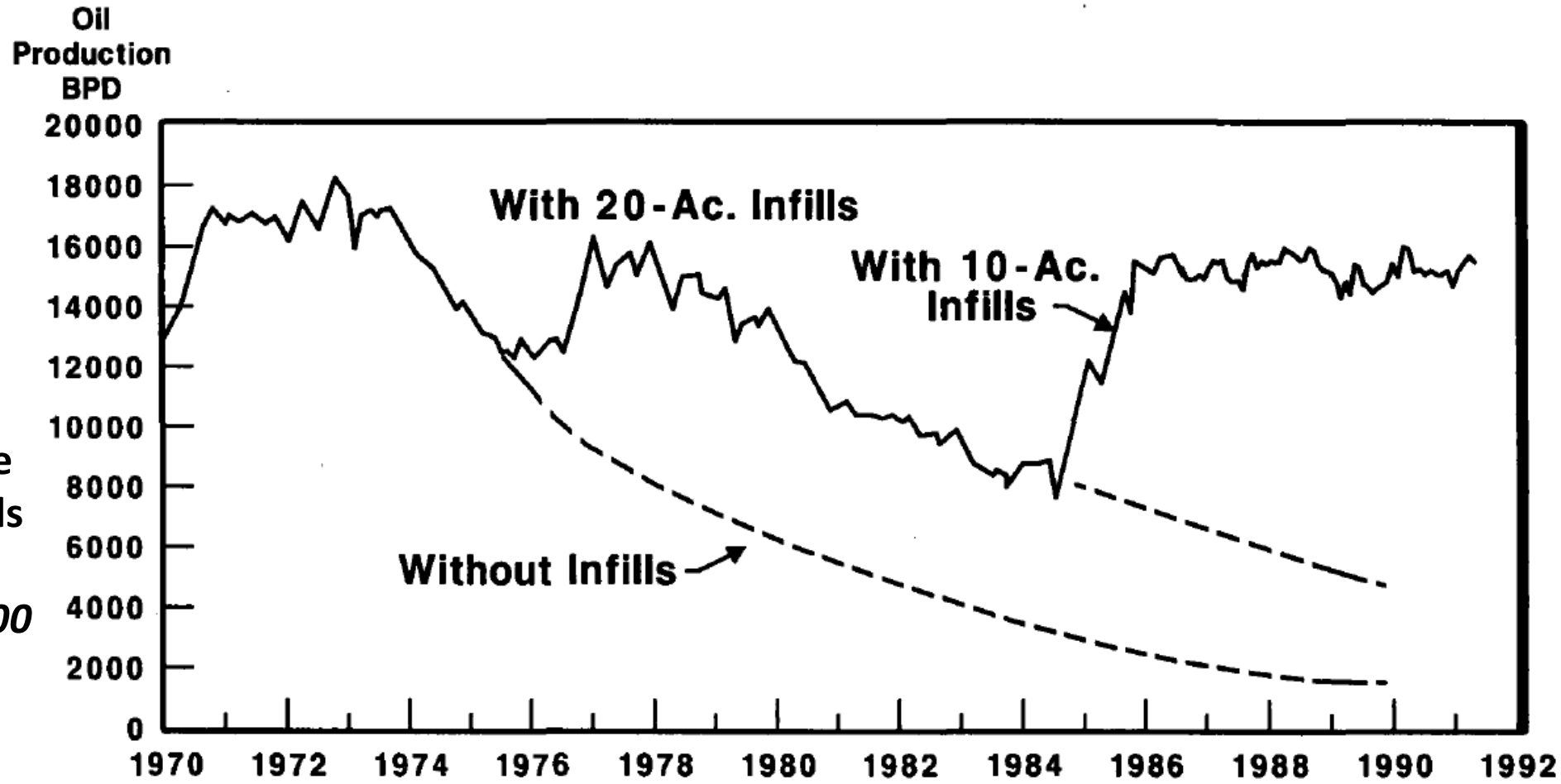
- Pilot conducted in south part of Unit ahead of the CO_2 injection expansion into the south of the Unit
- Pilot made up of four ~160-acre inverted 9-spot patterns
- 2000 BOPD+ of definitive oil response
- EOR accounted for ~10% additional RF after 30% HCPV CO_2 injection



Means San Andres Unit (Oil Production 1970-90)

Rigorous S&M Followed:

- Pressure falloff tests
- Step-rate tests
- Profile controls
- Artificial lift optimization
- Inj. well rate and pressure
- CO2 b.t. in individual wells
- WAG injectivity
- *Operating pressure = 2,000*
- *BHIPmax = 2,700 – 2,800*
- *MMP = 1,850 – 2,300 psi*



CO_2 EOR/Storage Challenges

TECHNICAL

- Sweep efficiency
  - Conformance
  - Gravity override
  - Mobility contrast
  - Reservoir heterogeneity
- Well spacing, injectivity
- Leakage - Faults/fractures/wells
- Retention and recycling

OPERATIONAL

- Corrosion
- H_2S
- C_1 and N_2 impurities
- H_2O and O_2
- Surveillance and Monitoring
- WAG optimization
- SDP (Storage Development Plan)

COMMERCIAL/SOCIAL

- Capital intensive
  - Front end loaded
- CO_2 prices
- Oil prices
- Tax incentives
- Helping decarbonize

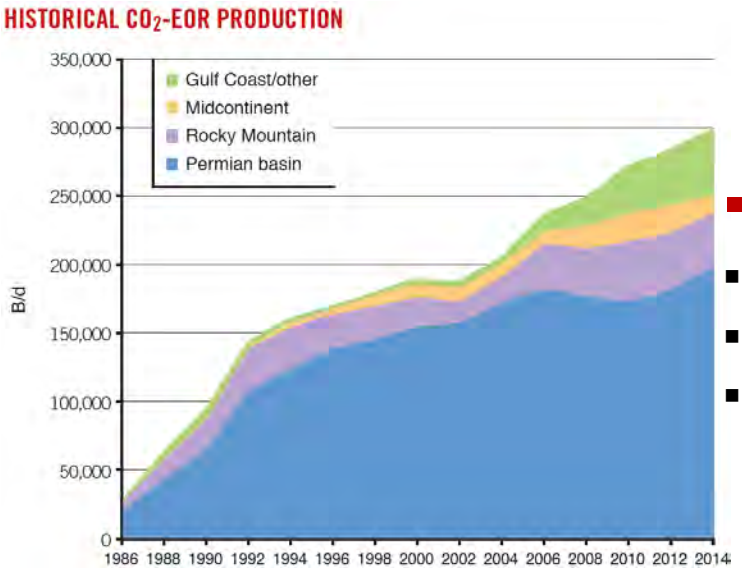
Current Technology Status

- Injecting more pore volumes of CO_2 in the reservoir
  - Increasing from 1 to 1.5 HCPV CO_2 injected
- Higher injection rates
- Improving sweep
  - Using foam with CO_2 for mobility control
  - Nanoparticles
- Targeting Residual and Transition Oil Zones (ROZ/TOZ)
- Injection of CO_2 in the tight reservoir (Shale)
- Implementing more anthropogenic CO_2 capture and storage projects, including aquifers - CCUS

CO_2 EOR is a Proven Process

Significant CO_2 EOR Operators by Region (1)	
Gulf Coast Region	
▪ Denbury Resources	
Permian Basin Region	
▪ Occidental	▪ Kinder Morgan
Rocky Mountain Region	
▪ Denbury Resources ▪ Devon	▪ FDL ▪ Chevron
Canada	
▪ Cenovus	▪ Apache

Significant CO_2 Supply by Region (1)
Gulf Coast Region
▪ Jackson Dome, MS (Denbury Resources) ▪ Port Arthur, TX (Denbury Resources) ▪ Geismar, LA(Denbury Resources)
Permian Basin Region
▪ Bravo Dome, NM (Kinder Morgan, Occidental) ▪ McElmo Dome, CO (ExxonMobil, Kinder Morgan) ▪ Sheep Mountain (ExxonMobil, Occidental)
Rocky Mountain Region
▪ LaBarge, WY (ExxonMobil, Denbury Resources) ▪ Lost Cabin, WY (ConocoPhilips)
Canada
▪ Dokota Gasification (Cenovus, Apache)

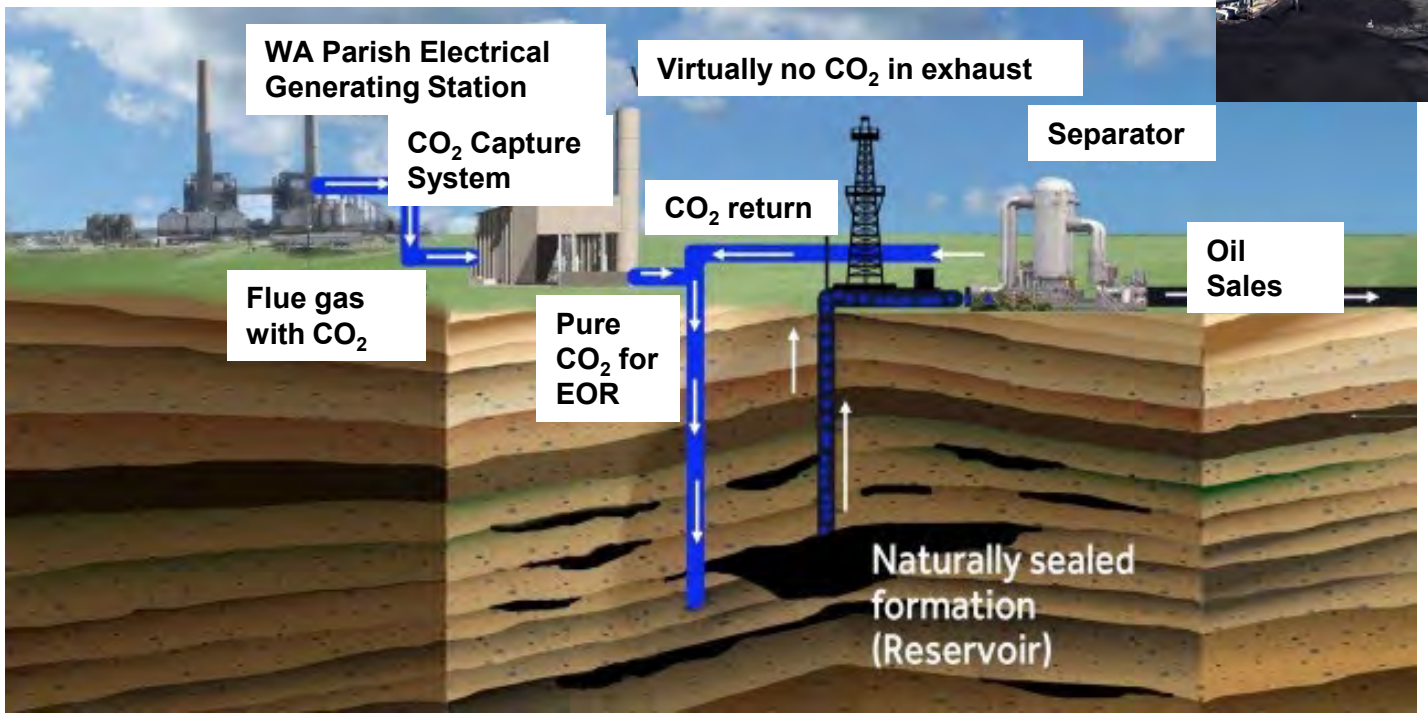


- **Statistic of US CO_2 EOR Project in 2014 (2)**
- Total **136** ongoing CO_2 EOR projects
- 300,000 STB/D Production, **~3%** of total U.S. production
- CO_2 injection rate: **3.5 BCF/D**, 83% from natural sources

(1) Based on Denbury Resources 2016 Nov. Corporate Presentation
(2) Oil & Gas Journal 2014

US DOE Completed Largest Carbon Capture System Project in Texas in 2017

- Petra Nova CCS Station near Houston
- Largest post combustion using flue gas CO_2 capture process from power plant (1.4 MM T/yr)
- NRG and Japan's Nippon Oil JV



Captured CO_2 is used for CO_2 EOR in West Ranch oil field

CO_2 EOR Screening Criteria

Screening Parameters		FIELDS				
		Little Knife	SACROC	Goldsmith San Andres Unit	Lost Hills	Rangely
Crude Oil						
Gravity	> 25° API	41°	41°	37°	18° to 34°	35°
Viscosity	< 15 cp	0.2 cp	0.35 cp	0.7 cp	6 cp	1.7 cp
Composition	Inter. HC (C_5-C_{20})	NA	NA	NA	NA	
Reservoir						
Residual Oil S_{or}	>30% PV	41 to 42% *	NA	42% **	13-39% **	
Formation	SS/Carbonate	Dolomitic Limestone	Limestone	Dolomite	Diatomite	Sandstone
Net thickness	Rel. thin	15 - 31 ft	10 to 800 ft	80 -120 ft	600 ft	900 ft
Avg. Perm	Not Critical	23 to 29 md	3.03 md	32 md	0.1 to 10 md	10 md
Depth	> 2000 feet	9,700 - 9,900 ft	6,700 ft	4,200 ft	2,000 ft	6,000 ft
Temperature	Not Critical	245°F	130°F	94°F	110-120°F	160°F
	Publication:	SPE-10696	SPE-17321	SPE-48945	SPE-62526	SPE-7060-PA

** data is S_{or} to waterflood – oil saturation at start of CO_2 flood was not published*
*** data is S_{or} to waterflood – assumed to be start of CO_2 flood*

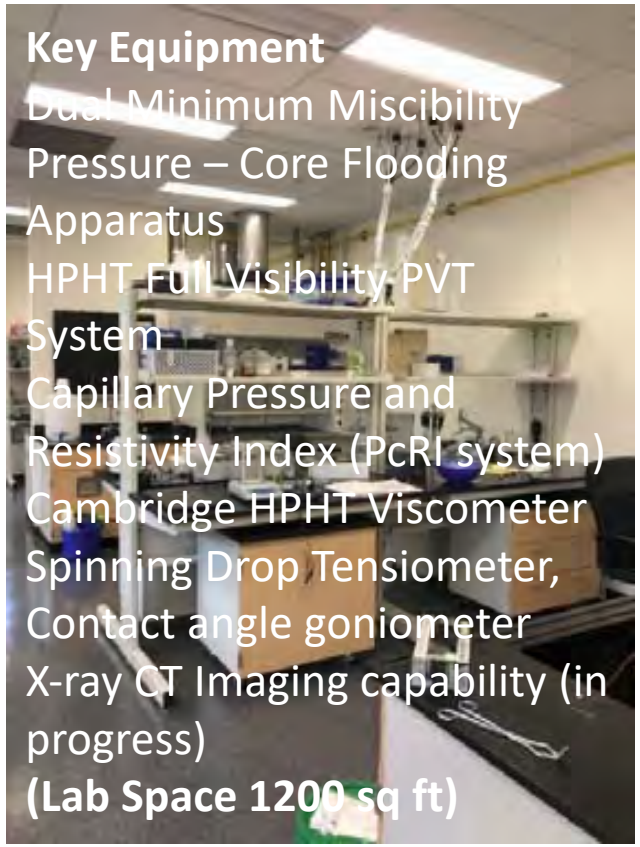
CO_2 & Gas EOR in Unconventional Resources (Texas GURI Grant Funding)

- **Main Objectives**
  - **Improve reservoir characterization and modeling**
  - **Unlock the full potential of unconventional resources through CO_2 & Gas EOR**
- **Detailed Studies of CO_2 & Gas EOR in Unconventional Oil Reservoirs (developing capabilities)**
  - **Laboratory and simulation studies**
  - **Reservoir characterization**
  - **Conformance control and sweep efficiency**
  - **Optimum pattern of wells and placement of fractures**
  - **Integrated reservoir-well-facilities studies**
  - **Effective reservoir management in CO_2 EOR & CO_2 storage**
- **Technology transfer, knowledge share, field research experience – Permian Basin**

CT Scanner

PVT system

Core flood
+MMP dual system



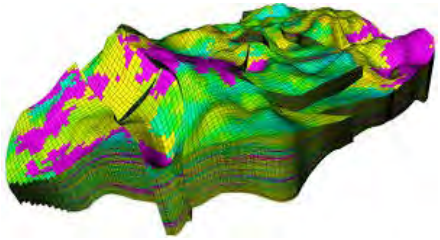
CO_2 EOR/Storage Oil India Ltd. Project

- **2016 Dec – 2017 May: Phase-1 Reservoir Screening Study**
  UH Advanced Reservoir Screening identified NHK079D as a candidate for CO2 EOR feasibility study; 50 other reservoirs screened

- **2017 Sep – 2018 Oct Phase-2 CO_2 EOR Pilot Design**

  ❑ CO_2 EOR Scoping Study ❑ CO_2 EOR Pilot Design

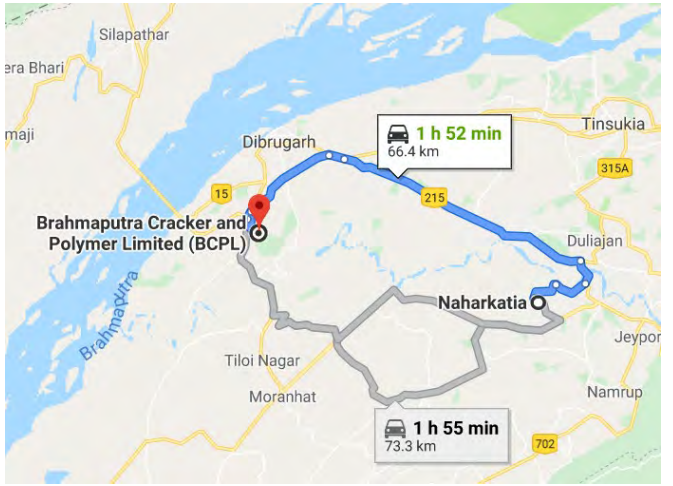
Laboratory Study	Simulation Study	Pilot Design
Slimtube MMP Test Swelling Test Coreflood Test	Geological Model History Match CO2 EOR Simulation	CO2 Source Study Facilities/Completion Economic Analysis



- **2019-2022 Phase-3 CO2 EOR Pilot Implementation**

- **CO_2 Capture and Transportation by Truck and Rail**

Suitable for smaller quantities of CO_2; Trucks are planned to be used, moving the CO_2 from where it is captured to a nearby EOR/storage location.



CO_2 EOR/Storage Oil India Ltd. Project

- **CO_2 Capture and Transportation by Truck and Rail**

Suitable for smaller quantities of CO_2; Trucks are planned to be used, moving the CO_2 from where it is captured to a nearby EOR/storage location.

Summary

1. Demand for energy significantly increasing in India, and they face the challenges of GHG emissions.

2. India imports > 80% of its oil consumption, so it is important to increase its production. Renewables are important, but fossil fuels still the primary energy source for several years.

3. India's carbon dioxide (CO_2) emission is one of the highest in the world.

4. Anthropogenic CO2 Capture, Utilization and Storage (CCUS) – a "game changer" technology.

5. Many successful CO2 EOR projects exist world-wide. LL and BP can be borrowed.

6. CCUS Research in India – Oil India Ltd. Project; and more will be implemented.

CO_2 EOR in Unconventional (UC) Resources

- Next frontier in CO_2 EOR
  - Most promising technology based on laboratory to pilot scale studies
  - Successful demonstration of field trials of miscible gas/CO_2 EOR by EOG resources
  - Oil majors and independents are actively studying CO_2 and gas EOR
    - Hydraulic fracture placement and well spacing
    - Surveillance and monitoring

Summary

- CO_2 EOR:
  - a proven technology
  - demonstrated significant success over five decades in conventional oilfields in US
- Contribution of CO_2 EOR:
  - 136 ongoing projects, with 340,000 BO/D (>3% of US total oil production)
- Anthropogenic CO_2 capture, storage and utilization for EOR is rapidly growing in the US and worldwide. Several projects planned in India with UH involvement.
- CO_2 EOR is the next frontier of UC resources and has the potential to double the recovery factor
- University of Houston:
  - is actively involved in transferring CC technologies for EOR to various operators & building capability for UC EOR

Thank you!

…. Any Questions?