Carbon Capture and Carbon Dioxide (CO₂) EOR & Storage – A “Game Changer” CCUS Technology (India)

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Outline

1. GHG Challenges and Importance of Fossil Fuels
2. Anthropogenic CO2 Capture, Utilization and Storage (CCUS)
3. CCUS Projects – Examples (Worldwide)
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

- Petroleum
- Natural gas
- Coal
- Renewables
- Nuclear

Year:
- 1950
- 1970
- 1990
- 2010
**Motivation – Global Fossil Fuel Emissions**

Annual Fossil CO₂ Emissions and 2019 Projections

Projected global emissions growth: +0.6% (-0.2% to +1.5%)

Projected Gt CO₂ in 2019

**All others 15.1**

<table>
<thead>
<tr>
<th>Country</th>
<th>Emissions (Gt CO₂)</th>
<th>Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>10.3</td>
<td>2.6% (+0.7% to +4.4%)</td>
</tr>
<tr>
<td>USA</td>
<td>5.3</td>
<td>-1.7% (-3.7% to +0.3%)</td>
</tr>
<tr>
<td>EU28</td>
<td>3.4</td>
<td>-1.7% (-3.4% to +0.1%)</td>
</tr>
<tr>
<td>India</td>
<td>2.7</td>
<td>1.8% (+0.7% to +3.7%)</td>
</tr>
</tbody>
</table>

From: Global Carbon Project, 2019
CO\textsubscript{2} in Energy Production, Transportation and Consumption

**CO\textsubscript{2} Emission Sources**

**Production**
- Combustion and rotating equipment, flaring, venting
- Gas associated with oil production

**Transportation**
- Pipelines
- Vessels
- Vehicles

**Refining and Petrochemical Production**
- Heaters
- Boilers

**End Use**
- Consumer - use of gasoline, diesel, and coal

**Sources**
- CO\textsubscript{2}
- Methane

**Emission**
- CO\textsubscript{2}
- Methane
- Primarily CO\textsubscript{2}
- CO\textsubscript{2}
CARBON DISPOSAL OPTIONS

- Direct Geological Storage
  - Injection of captured CO₂ into Deep Saline Aquifers
  - Injection into Depleted Oil or Gas Reservoirs

- CO₂ Utilization
  - Enhanced Oil Recovery (EOR)
  - Other possible industrial usage

- “Natural Sinks” Storage in Soils and Vegetation
### Anthropogenic CO₂ EOR Projects – Worldwide*

<table>
<thead>
<tr>
<th>Project</th>
<th>Operator</th>
<th>Location</th>
<th>CO₂ Source</th>
<th>Size (MM Ton/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uthmaniyah</td>
<td>Saudi Aramco</td>
<td>Saudi Arabia</td>
<td>Hawiyah NGL Plant</td>
<td>0.8 EOR</td>
</tr>
<tr>
<td>Abudhabi ESI - Phase 1</td>
<td>AlReyddah ADNOC, Mustang, etc</td>
<td>UAE</td>
<td>Steel Plant</td>
<td>0.8 EOR</td>
</tr>
<tr>
<td>Santos Basin</td>
<td>Petrobras</td>
<td>Brazil (Offshore)</td>
<td>NGL plant - FPSO</td>
<td>1.0 EOR</td>
</tr>
<tr>
<td>Sleipner</td>
<td>Statoil</td>
<td>North Sea (Offshore)</td>
<td>Gas Field (9% CO₂)</td>
<td>0.85 EOR</td>
</tr>
<tr>
<td>PetroNova</td>
<td>NRG &amp; Nippon (Japan)</td>
<td>Houston (TX)</td>
<td>Post combustion CO₂ – Power Plant</td>
<td>1.4 EOR</td>
</tr>
<tr>
<td>Gorgon</td>
<td>Chevron</td>
<td>Australia Barrow Island</td>
<td>Natural Gas processing</td>
<td>3.4 - 4</td>
</tr>
</tbody>
</table>

Various Projects in Japan and China in Early Phases

UH involved in a carbon capture project in India

*CO₂ injected is used for EOR instead of storage*

Source: Global CCS Institute
Gorgon Carbon Dioxide Injection Project

- The first project in Australia to significantly reduce emissions by the underground injection of CO₂
- Gorgon Project emissions are expected to be reduced by approximately 40%
- Injection will be between 3.4 and 4.0 million tonnes of reservoir CO₂ 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 CO₂ project to undergo detailed environmental impact assessment (including public review and comment)
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 CO2 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 required to reduce impact of rising pressure on CO2 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
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 CO₂ EOR in U.S.

- **1910’s-1970’s** - CO₂ Field Discoveries (Bravo Dome, McElmo Dome, Jackson Dome, Sheep Mountain)
- **1950’s-1960’s** – Development & Testing
- **1972** - First Notable CO₂ EOR Flood in Permian Basin (SACROC)
- **1973** - First Notable CO₂ EOR Flood in Gulf Coast (Little Creek)
- **1986** - First Notable CO₂ EOR Flood in Rockies (Rangely)
- **2000** - First Anthropogenic CO₂ EOR Flood (Weyburn/Canada)
- **2017** - First Commercial-Scale Anthropogenic CO₂ EOR Project (Petro Nova/Texas)
Case Study: First Commercial CO₂ EOR - SACROC

First Commercial CO₂ 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 CO₂ pipelines
- Oil Production showed quick response to CO₂ injection soon after peak water flood production response occurred
- CO₂ 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 CO₂ 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 CO₂ 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
CO₂ 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
- H₂S
- C₁ and N₂ impurities
- H₂O and O₂
- Surveillance and Monitoring
- WAG optimization
- SDP (Storage Development Plan)

**COMMERCIAL/SOCIAL**
- Capital intensive
  - Front end loaded
- CO₂ 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
CO₂ EOR is a Proven Process

Significant CO₂ 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 CO₂ 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 (ConocoPhillips)

**Canada**
- Dokota Gasification (Cenovus, Apache)

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- **Statistic of US CO₂ EOR Project in 2014 (²)**
- Total 136 ongoing CO₂ EOR projects
- 300,000 STB/D Production, ~3% of total U.S. production
- CO₂ 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 CO₂ capture process from power plant (1.4 MM T/yr)
- NRG and Japan’s Nippon Oil JV

Captured CO₂ is used for CO₂ EOR in West Ranch oil field
## CO₂ EOR Screening Criteria

### Screening Parameters | FIELDS
<table>
<thead>
<tr>
<th></th>
<th>Little Knife</th>
<th>SACROC</th>
<th>Goldsmith San Andres Unit</th>
<th>Lost Hills</th>
<th>Rangely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity</td>
<td>&gt; 25° API</td>
<td>41°</td>
<td>41°</td>
<td>37°</td>
<td>18° to 34°</td>
</tr>
<tr>
<td>Viscosity</td>
<td>&lt; 15 cp</td>
<td>0.2 cp</td>
<td>0.35 cp</td>
<td>0.7 cp</td>
<td>6 cp</td>
</tr>
<tr>
<td>Composition</td>
<td>Int. HC (C₅-C₂₀)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Reservoir</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual Oil Sₒₑ</td>
<td>&gt;30% PV</td>
<td>41 to 42% *</td>
<td>NA</td>
<td>42% **</td>
<td>13-39% **</td>
</tr>
<tr>
<td>Formation</td>
<td>SS/Carbonate</td>
<td>Dolomitic Limestone</td>
<td>Limestone</td>
<td>Dolomite</td>
<td>Diatomite</td>
</tr>
<tr>
<td>Net thickness</td>
<td>Rel. thin</td>
<td>15 - 31 ft</td>
<td>10 to 800 ft</td>
<td>80 -120 ft</td>
<td>600 ft</td>
</tr>
<tr>
<td>Avg. Perm</td>
<td>Not Critical</td>
<td>23 to 29 md</td>
<td>3.03 md</td>
<td>32 md</td>
<td>0.1 to 10 md</td>
</tr>
<tr>
<td>Depth</td>
<td>&gt; 2000 feet</td>
<td>9,700 - 9,900 ft</td>
<td>6,700 ft</td>
<td>4,200 ft</td>
<td>2,000 ft</td>
</tr>
<tr>
<td>Temperature</td>
<td>Not Critical</td>
<td>245°F</td>
<td>130°F</td>
<td>94°F</td>
<td>110-120°F</td>
</tr>
</tbody>
</table>

* data is Sₒₑ to waterflood – oil saturation at start of CO₂ flood was not published
** data is Sₒₑ to waterflood – assumed to be start of CO₂ flood

Publication: SPE-10696, SPE-17321, SPE-48945, SPE-62526, SPE-7060-PA
CO₂ & Gas EOR in Unconventional Resources (Texas GURI Grant Funding)

• Main Objectives
  – Improve reservoir characterization and modeling
  – Unlock the full potential of unconventional resources through CO₂ & Gas EOR

• Detailed Studies of CO₂ & 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 CO₂ EOR & CO₂ storage

• Technology transfer, knowledge share, field research experience – Permian Basin

Key Equipment
Dual Minimum Miscibility Pressure – Core Flooding Apparatus
HPHT Full Visibility PVT System
Capillary Pressure and Resistivity Index (PcRI system)
Cambridge HPHT Viscometer
Spinning Drop Tensiometer, Contact angle goniometer
X-ray CT Imaging capability (in progress)
(Lab Space 1200 sq ft)
CO₂ 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 CO₂ EOR Pilot Design
  - CO₂ EOR Scoping Study
  - CO₂ EOR Pilot Design

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

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

- **CO₂ Capture and Transportation by Truck and Rail**
  Suitable for smaller quantities of CO₂; Trucks are planned to be used, moving the CO₂ from where it is captured to a nearby EOR/storage location.
CO₂ EOR/Storage Oil India Ltd. Project

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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

- **CO₂ EOR:**
  - a proven technology
  - demonstrated significant success over five decades in conventional oilfields in US

- **Contribution of CO₂ EOR:**
  - 136 ongoing projects, with 340,000 BO/D (>3% of US total oil production)

- Anthropogenic CO₂ capture, storage and utilization for EOR is rapidly growing in the US and worldwide. Several projects planned in India with UH involvement.

- CO₂ 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?