Presentation outline

— EOR Market Overview
— Gases for EOR
— What happens if there is no CO2?
— Gases other than CO2
— Summary
The good ol’ days...
The Linde Group in **North America**

- **Sales (2010)**: >$3 billion
- **Employees**: >5,000
- **Locations**: >400
- **Customers**: >100,000

**Cantarell, Mexico**
- Industry leading National Operations Center, New Jersey
- Linde Gas HQ: Murray Hill, NJ
- US Linde Engineering facilities:
  - Blue Bell, PA (Selas Fluid Processing)
  - Holly Springs, GA (Hydrochem)
  - Tulsa, OK (Linde Process Plants)

<table>
<thead>
<tr>
<th>Deliveries</th>
<th>Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>40,000 / month</strong></td>
<td><strong>80 million</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Fleet Size</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Drivers</td>
<td>1,200 drivers</td>
</tr>
<tr>
<td>Tractors</td>
<td>800 tractors</td>
</tr>
<tr>
<td>Trailers</td>
<td>1,200 trailers</td>
</tr>
<tr>
<td>Railcars</td>
<td>650 railcars</td>
</tr>
</tbody>
</table>
Linde is already heavily engaged in the oil and gas industry.

<table>
<thead>
<tr>
<th>Upstream</th>
<th>Midstream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas Production</strong></td>
<td><strong>Gas Processing</strong></td>
<td><strong>Refinery</strong></td>
</tr>
<tr>
<td>- Conditioning</td>
<td>- Conditioning</td>
<td>- Hydrogen</td>
</tr>
<tr>
<td>- Separation</td>
<td>- LNG</td>
<td>- Other gases</td>
</tr>
<tr>
<td><strong>Fracturing</strong></td>
<td>- NGL</td>
<td>- Fuel gas processing</td>
</tr>
<tr>
<td>- N$_2$ and CO$_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EOR/EGR</strong></td>
<td>- N$_2$ and CO$_2$</td>
<td></td>
</tr>
<tr>
<td>- NRU</td>
<td>- Combustion</td>
<td></td>
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<tr>
<td></td>
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</tbody>
</table>
EOR’s share in total oil production expected to increase dramatically

Why is Enhanced Oil Recovery (EOR) attractive now?

- Primary oil production from existing oil fields depleting
- World’s energy demand increasing
- Oil prices higher compared to historic norms
- Cost for new explorations typically increasing steeply (e.g. offshore, deep fields etc)

EOR contribution to total oil production capacity expected to increase from the current 3% to 20% in 2030 resulting in additional production capacity of 20 billion bbl/day.

Methods for Enhanced Oil and Gas Recovery

Oil field development Life Cycle
- Exploration
- Appraisal
- Development
- Primary Recovery
- Secondary Recovery/IOR (Improved Oil Recovery)
- Enhanced Oil Recovery - EOR

Intervention methods for improved/enhanced oil recovery

Source: Shell Oil publication

- N₂ injection can use existing Waterflood/natural gas infrastructure

- N₂ and CO₂ for EOR/EGR usually offer better economics than other techniques
- Replacement of natural gas with N₂ can allow increased gas production where needed
- N₂ is produced by air separation and can be applied in any location
- Carbon capture and storage is expected to create CO₂ sources for EOR/EGR in the future

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## General Selection Criteria for different EOR technologies

<table>
<thead>
<tr>
<th>EOR Method</th>
<th>Reservoir Characteristics</th>
<th>Oil Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Injection</td>
<td>Nitrogen (&amp; Flue Gas)</td>
<td>&gt; 6.000</td>
</tr>
<tr>
<td></td>
<td>Hydrocarbon</td>
<td>&gt; 4.000</td>
</tr>
<tr>
<td></td>
<td>Carbon Dioxide</td>
<td>&gt; 2.500</td>
</tr>
<tr>
<td></td>
<td>Immiscible Gases</td>
<td>&gt; 1.800</td>
</tr>
<tr>
<td>Thermal-Mechanical</td>
<td>Combustion</td>
<td>&lt; 11.500</td>
</tr>
<tr>
<td></td>
<td>Steam</td>
<td>&lt; 4.500</td>
</tr>
<tr>
<td>Chemical Injection</td>
<td>Polymers</td>
<td>&lt; 9000</td>
</tr>
<tr>
<td></td>
<td>Surfactants</td>
<td>&lt; 9000</td>
</tr>
<tr>
<td></td>
<td>Alkali</td>
<td>&lt; 9000</td>
</tr>
</tbody>
</table>

- N.C.: not critical; underlined: mean or average

- Criteria are Rule of Thumb only!
- Applicability and Economics of must be individually been determined for every specific oilfield

Source: EOR Screening Criteria Revisited, J. Taber et al., SPE Reservoir Engineering Aug. 1997, pages 189-205
Injection Gases for Enhanced Oil Recovery

Various classes of gases are used for gas injection

• Natural gas (dry, sweet, majority is methane)
• Associated gas (wet, sour, produced gas)
• Carbon dioxide (CO$_2$)
• Nitrogen (N$_2$)
• Flue gas exhaust (power plant, gas turbines engines or heater)

Mixtures of gases might be applicable - even in combination with other EOR methods

- Strong impact on oil production economics expected
- Technical and economical evaluation required case by case
## Miscible Drives

- Hydrocarbon gases- rich gas drive
- CO2 usually (depth related)
- High pressure air injection (HPAI)
- Nitrogen and flue gas in certain cases

## Immiscible Drives

- Flue gas
- Nitrogen usually (depth and oil type related).
- CO2 above a certain depth

### Successful miscible drives

- Permian Basin CO2 generally CO2
- Prudhoe Bay, Alaska HC
- Jay Field, Florida N2

### Successful immiscible drives

- Hawkins Field, Texas N2
- East Painter, Wyoming N2
- Cantarell, Mexico (offshore) N2
Why use other gases for EOR??

— Other gases ARE SUCCESSFUL in EOR
— Lack of CO2. Most areas in US are short of naturally occurring CO2
— CO2 may be available but is very expensive compared to naturally occurring CO2 in Permian Basin
— Other gases may be miscible in the right set of circumstances
— Stranded gas opportunity. Prudhoe Bay
— Timing is right. Look at total field economics. Look at present value calculations of using another gas now or waiting 5-10 years for potential CO2.
— Some are less corrosive than CO2
What’s wrong with waiting for “cheap” CO2?

Oil price risk

EOR development cost increase

Time value of money- what do project economics look like waiting for 5 years? 10 years?
## Advantages of different EOR gases

<table>
<thead>
<tr>
<th>NITROGEN</th>
<th>NATURAL GAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Can be miscible at depth</td>
<td>- Good recoveries, up to 70% of OOIP</td>
</tr>
<tr>
<td>- Cheaper than anthropogenic CO2</td>
<td>- Good use for stranded gas</td>
</tr>
<tr>
<td>- Non Corrosive</td>
<td>- Little in gas processing costs except for liquid stripping</td>
</tr>
<tr>
<td>- Secure source of supply with ASU</td>
<td></td>
</tr>
<tr>
<td>- Lower development cost</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HIGH PRESSURE AIR</th>
<th>CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>— Can be used in carbonates or sands</td>
<td>— Good recoveries</td>
</tr>
<tr>
<td>— CO2 generation in the reservoir</td>
<td>— Miscible at shallower depths</td>
</tr>
<tr>
<td>— No need for securing gas supply.</td>
<td>— Economics are better with natural supplies</td>
</tr>
</tbody>
</table>
Map of Williston Basin select HPAI projects

- Medicine Pole Hills
- Buffalo
- Capa
Medicine Pole Hills Production Performance

Fig. 4—MPHU production performance (1979–93).

From Kumar, SPE 27792
Linde’s experience with ISC CMD EOR

Legacy Energy’s ISC EOR Field in California
CMD EOR Well Arrangement

Vertical O2 (and/or CO2) Injection, Horizontal Oil Production

3D Illustration of CMD EOR*

Arrangement of wells in Pleito Creek Field, CA*

Simplified 2D sketch of CMD EOR*

* Source: Legacy Energy
Nitrogen Injection - 5 Applications

Immiscible displacement - generally less than 9,000’

Miscible displacement - deep reservoirs, light oil fractions

Gravity drainage enhancement - increases sweep and displacement efficiency.

Pressure maintenance - Retrograde condensate reservoirs, Habshan

Drive fluid for miscible gas slug
## Comparison of N\textsubscript{2} and CO\textsubscript{2} for EOR & EGR

### Nitrogen
- Produced from air using cryogenic air separation in large quantities
- Inert and needs no expensive metallurgy
- Miscible at higher pressures; applicable to deeper fields and lighter oil fractions
- Not easily dissolved in formation water
- Low fixed cost due to short pipeline to injection
- Lower operating costs if stranded or onsite associated gas available for power
- Can use existing WF/NG injection infrastructure

### Carbon Dioxide
- Obtained from large scale power plants or chemical plant off-gases. Also natural
- Corrosive and needs special metallurgy
- Preferred miscible agent for heavier oil fractions and where higher solubility helps
- GHG gas; potential for emissions credit
- Total costs strongly dependent on pipeline distance to injection
- Separation costs can be significant if not available in high concentration
- Significant costs for modifying injection infrastructure
Cantarell in 1996 - A Maturing Oil Field?

**Status in year 1996**
- 5 bn bbl produced after 17 years of production (~14% of OOIP)
- Reservoir pressure declined by 60%
- Productivity of some wells decreased by 75%
- Impeding water: OWC had risen by ~500 m
- Significant need for gas lift

**Technical Solution: Pressure Maintenance**
- High permeability, > 900 m thick reservoir section, 19-22° API, secondary gas cap
  -> Efficient gravity-drainage recovery mechanism
Cantarell, Mexico: A world scale N₂ supply for enhanced oil and gas recovery application

Linde has built and is the majority owner/operator of the air separation plants (ASU) providing N₂ for oil recovery

- 55,000 tpd of N₂ delivered at 125 bars to the well-head, supplied by 5 ASU trains
- Integrated power generation with gas turbines using associated gas recovered
- Pipeline (on-shore and offshore) to well head, 70 km off-shore
- Production increased by 60% within 12 month of the N₂ injection start up in 2000
### Qualitative Assessment of Pressure Maintenance Options for the Cantarell field

**Sources**

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Carbon Dioxide</th>
<th>Flue Gas</th>
</tr>
</thead>
</table>
| • Produced from Air by cryogenic air separation  
  - Technology proven since a century  
  - On-stream availability 95-99% incl. scheduled maintenance | • Natural source - not available  
• Carbon Capture from Flue gas or chemical plant off-gases | • Combustion Process |

**Properties & Impact**

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Carbon Dioxide</th>
<th>Flue Gas</th>
</tr>
</thead>
</table>
| + Inert, non corrosive  
  - no need for special metallurgy and corrosion inhibitors  
  - use existing NG injection infrastructure  
  - optional use in WAG scheme: single distribution/injection system for both nitrogen and water | - Corrosive  
  - requires additional CAPEX for corrosion resistant infrastructure or corrosion inhibitors, especially on production end  
  - Risk of formation plugging by asphaltenes precipitation  
  - Early CO2 breakthrough assumed  
  - CO2 removal from produced gas/oil costly | - Corrosive  
  - NOx/SOx  
  - DeSOx & DeNOx required  
  - High O2 content to be removed  
  • CO2 removal from produced gas/oil costly |
| + < 10ppm O2  
  - anaerobic condition  
  - no need for biocides |  
  
  
|  
  
  

➔ **N2 is Most Attractive Technical Solution!**

Dr. Guzmann – EOR Conference Abu Dhabi – March 27th 2012
Build Own Operate (BOO) Model

- Incl. 4 major elements: Nitrogen production, supply of power, associated supply and delivery pipelines, site preparation and infrastructure requirements
- Cost structure: fixed cost based on available production capacity; indexed operation and maintenance cost, variable cost: penalty/bonus based on fuel consumption, 15 years contract

Relative Costs of Gases

- 1.2 bscfpd delivered to offshore platform with **1520 psi** (105 bar) at **190°F**

<table>
<thead>
<tr>
<th>Injection Gas</th>
<th>Nitrogen</th>
<th>Carbon Dioxide</th>
<th>Natural Gas</th>
<th>Associated Gas</th>
<th>Flue Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight [g/mol]</td>
<td>28.01</td>
<td>44.01</td>
<td>16.46</td>
<td>23.43</td>
<td>30.93</td>
</tr>
<tr>
<td>Compression Factor [Z]</td>
<td>1.0184</td>
<td>0.6888</td>
<td>0.9151</td>
<td>0.7029</td>
<td>0.9959</td>
</tr>
<tr>
<td>Density [lb/cu.ft.]</td>
<td>6.00</td>
<td>13.93</td>
<td>3.92</td>
<td>6.45</td>
<td>6.77</td>
</tr>
<tr>
<td>Volume [MMscfd]</td>
<td>1,200</td>
<td>1,774</td>
<td>1,336</td>
<td>1,543</td>
<td>1,227</td>
</tr>
<tr>
<td>Viscosity [cps]</td>
<td>0.0229</td>
<td>0.0243</td>
<td>0.0154</td>
<td>0.0173</td>
<td>0.0231</td>
</tr>
<tr>
<td>Estimated Compression Required [hp]</td>
<td>500,500</td>
<td>665,500</td>
<td>528,000</td>
<td>578,600</td>
<td>510,400</td>
</tr>
<tr>
<td>Mass Flow [million lb/day]</td>
<td><strong>88.57</strong></td>
<td><strong>205.73</strong></td>
<td><strong>57.95</strong></td>
<td><strong>95.26</strong></td>
<td><strong>100.00</strong></td>
</tr>
<tr>
<td>Unit Price* [$/MSCF]</td>
<td><strong>0.23 - 0.56</strong></td>
<td><strong>1.00 - 1.25</strong></td>
<td><strong>2.10 - 2.20</strong></td>
<td><strong>1.25 - 1.50</strong></td>
<td><strong>0.55 - 0.82</strong></td>
</tr>
</tbody>
</table>

⇒ **N2 is Most Attractive both Technical and Economical Solution!**

*Estimated Unit Prices based on energy cost of US $ 1.50/MMBTU

Sources: CNC, OGJ, Mar. 12, 2001; SPE 35319

Dr. Guzmán – EOR Conference Abu Dhabi – March 27th 2012
Mirfa, approx. 50 km from Habshan, has been selected as the N₂ plant site due to availability of power and cooling water.

Today existing at site are a power plant and a desalination plant.

ADNOC is operating condensate fields at Habshan, Abu Dhabi.

Natural gas from the field is currently compressed and re-injected to keep the field pressure.

Due to alternative uses for the natural gas from 2010 onwards, ADNOC decided to replace Natural Gas by Nitrogen.

Notes: Elixier is a Joint Venture of ADNOC and Linde started in 2007, for the production and long-term supply of industrial gases in Abu Dhabi.
SUMMARY

— Other gases have proven to be successful in a wide range of EOR projects around the world.

— In Rocky Mountain region N2, CO2, and HPAI have proven successful

— Operational costs using N2 are lower than for CO2 or HPAI

— For N2 there are 5 different scenarios for EOR projects

— In the absence of CO2, different gases may be attractive for EOR.

— May be possible to inject N2 to pressure up reservoir and switch to CO2 when/if available.
Thank you for your attention.
Hydrocarbon Miscible Floods

— Very successful EOR technique.
— In North America a significant portion of HMF’s have been done in Canada.
— Very good technique in stranded gas areas. Prudhoe Bay
— In steeply dipping reservoirs gravity effects can substantially increase the estimated ultimate recovery.
Clean Energy is a mega trend that is changing the world

Energy demand growth

- Non-OECD Growth 2010-30: +65%
- OECD Growth 2010-30: 0%

Total 2010: ~500 quad. BTU
Total 2030: ~650-700 quad. BTU

Dominance of fossil fuels

- Renewables 2.4%
- Nuclear 1.9%
- Coal 1.9%
- Natural Gas 1.7%
- Liquids 1.1%

Oil, gas and coal will still cover >80% of global energy demand in 2030

Regulation and public funding

- EU ETS (2005)
- EU Climate package (2008)
- EEPR (2009)
- NER300 (2009)
- DOE Recovery Act (2009)
- Copenhagen (2009)
- Cancun (2010)

Energy trilemma

- Security of supply
- Triage of Energy
- Economics
N₂ and CO₂ for Enhanced Oil and Gas Recovery: Methods

- **Replacement**
  - N₂ replacement method
  - N₂ pressure maintenance (improved gravity drainage)

- **Gas Cap Production**
  - N₂ displacement of gas cap hydrocarbon gases
  - Retrograde condensate (C5+) recovery (gas cycling)

- **Displacement**
  - Miscible gas displacement (CO₂ or N₂)

Examples:
- Yates Field, Texas (DOE)
- Cantarell, Mexico (Linde)
- Ryckman Creek Field, Wyoming
  - Gandhar field proposal
- Elixier, Abu Dhabi
  - Katy Gas Field, Texas
  - Holland, Norway, UK studies
- Weyburn, Canada (CO₂)
In-situ combustion

Zero Emission Power

COS Ready CO₂

Air → ASU

Oxy-Fuel PowerGen
CO₂ Purification & Recirculation

Oil-Gas Separation

Oil

Underground

*Insitu* combustion and CO₂ EOR

Linde offering

- Integrated above ground gas producing / processing facilities from pilot to commercial
- Safe oxygen handling
- Related IP
- Has access to world renowned experts
Lost Soldier, Wertz Geology (Merit Energy)

Geological Information

- Lost Soldier and Wertz are both faulted anticlines.
- Located in Wyoming's Great Divide Basin.
Linde reference Beulah, North Dakota: CO2 pipelined from Beulah to Weyburn, Canada for CO2 EOR

- CO2 capture at Beulah, North Dakota as part of SNG production from lignite
- Start-Up in 1984
- Linde ASU
- Dry ash fixed bed gasifiers
- Rectisol wash used for gas treatment
- CO2 exported for EOR to Weyburn Canada for over 5 years
  - 18.3 million bbl incremental oil
  - 8.7 million tons CO2 injected
  - Host of IEA project for safe and reliable geological CO2 storage
- Use of CO2 for miscible displacement

Beulah lignite to SNG facility incorporating Linde ASU

13/09/2012 Fußzeile