Reserve Growth & Higher Recovery Using Nitrogen Gas Injection

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Benefits from Nitrogen Gas Injection

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- Proven hydrocarbon recovery method
- Cost effective
- A nitrogen plant can be located anywhere

Nitrogen:

- Can replace hydrocarbon recycle gas
- Is Inert
- Is non-corrosive
- Is dry
- Is oxygen free

Nitrogen -
A Proven Recovery Method

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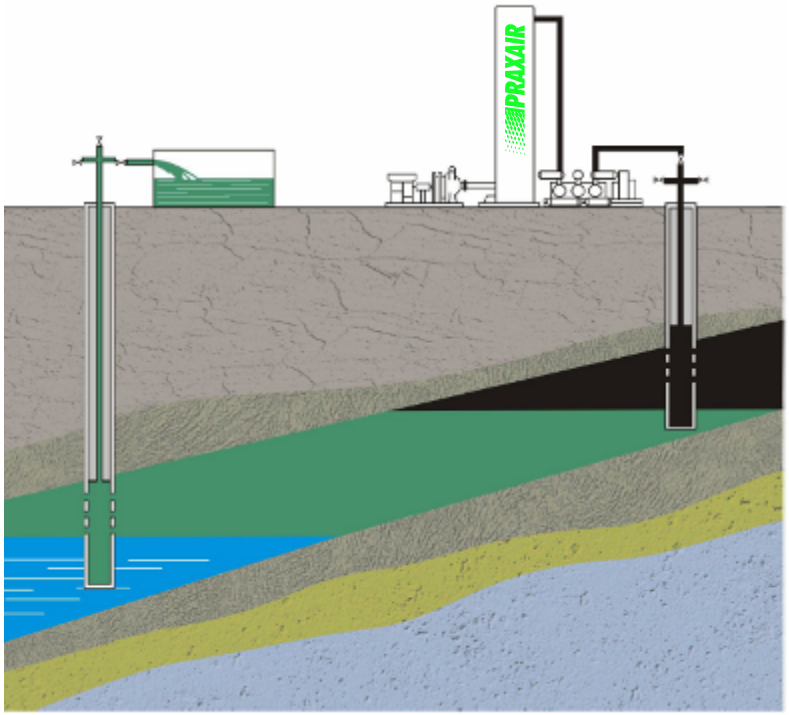
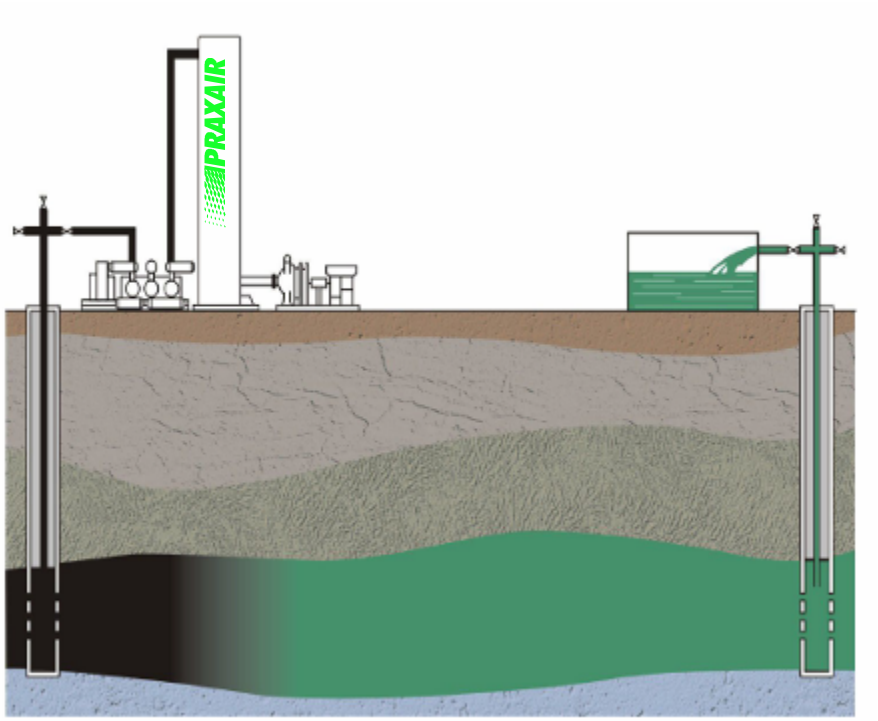


Gravity Drainage



Miscible Displacement

Nitrogen - A Proven Recovery Method

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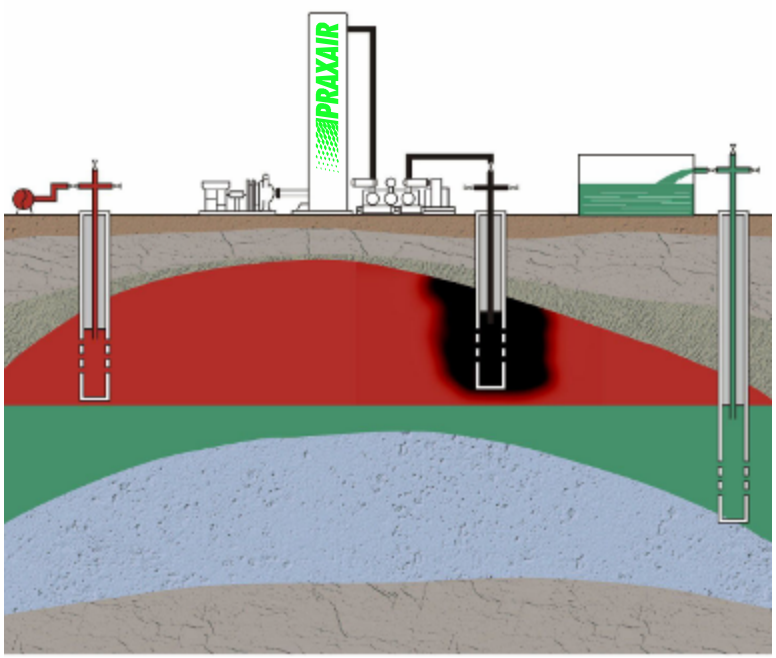
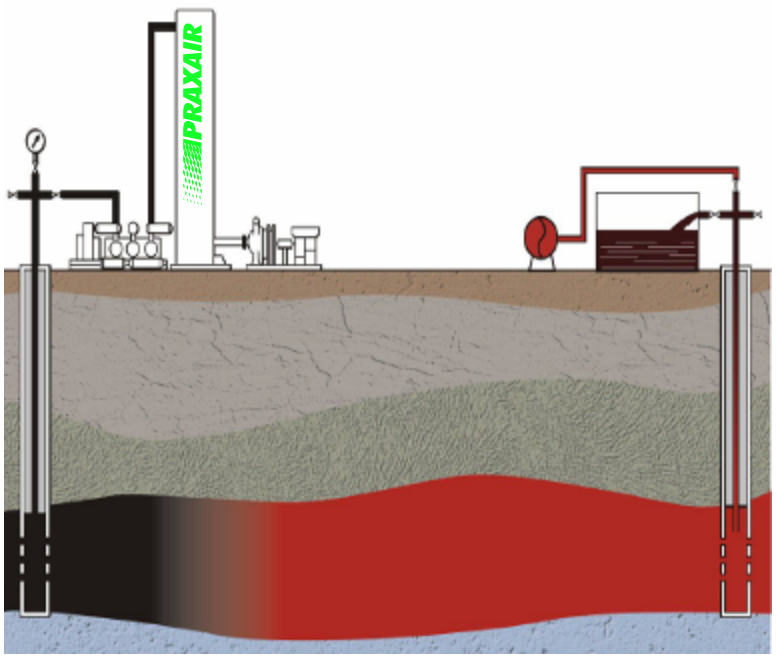


Gas Cap Displacement



Pressure Maintenance – Gas Condensate

Praxair At A Glance

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- A Fortune 500 company with 2007 sales of $ 9.4 billion
- One of the largest industrial gases companies worldwide and the largest in North and South America
- Operations in more than 40 countries
- 27,000 employees
- One million customers worldwide

Sales by Markets Served

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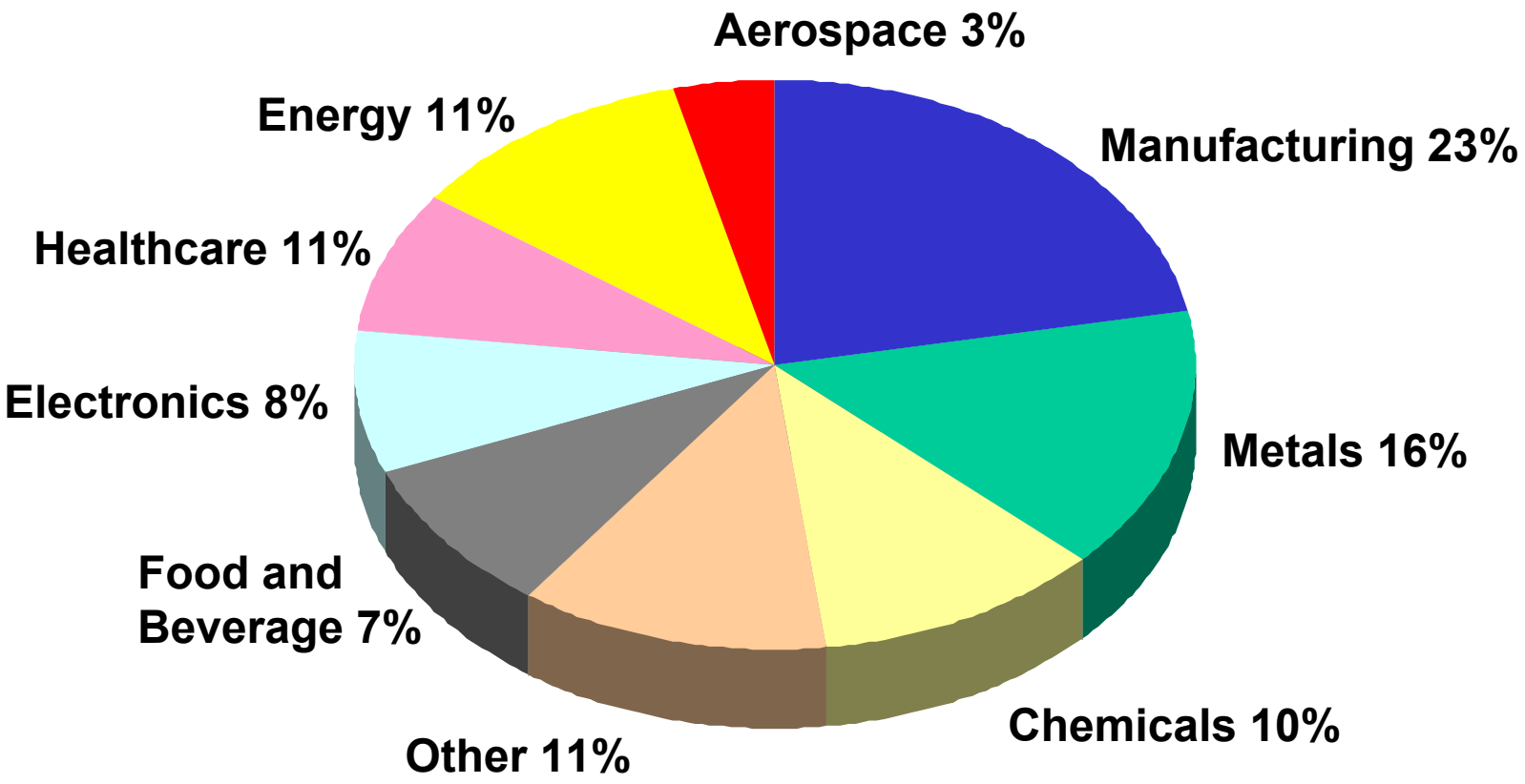

Praxair At A Glance

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On-Site/Pipeline Supply

- Nitrogen, oxygen, hydrogen
- 15 + year supply contracts
- Designed & operated for reliability

Liquid Supply

- Nitrogen, oxygen, argon, CO_2, helium, H_2
- Specialized cryogenic distribution equipment

Packaged Gases

- Welding, medical, specialty gases
- Cylinders for the retail market

Core Technologies

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- Cryogenic air separation
- Non-cryogenic air separation
- Hydrogen production
- Carbon dioxide capture and purification
- Atmosphere control
- Gas dissolution
- Gas-liquid separations
- Oxidation technology (combustion)
- Refrigeration

Praxair Industrial Gases Reach World-Wide

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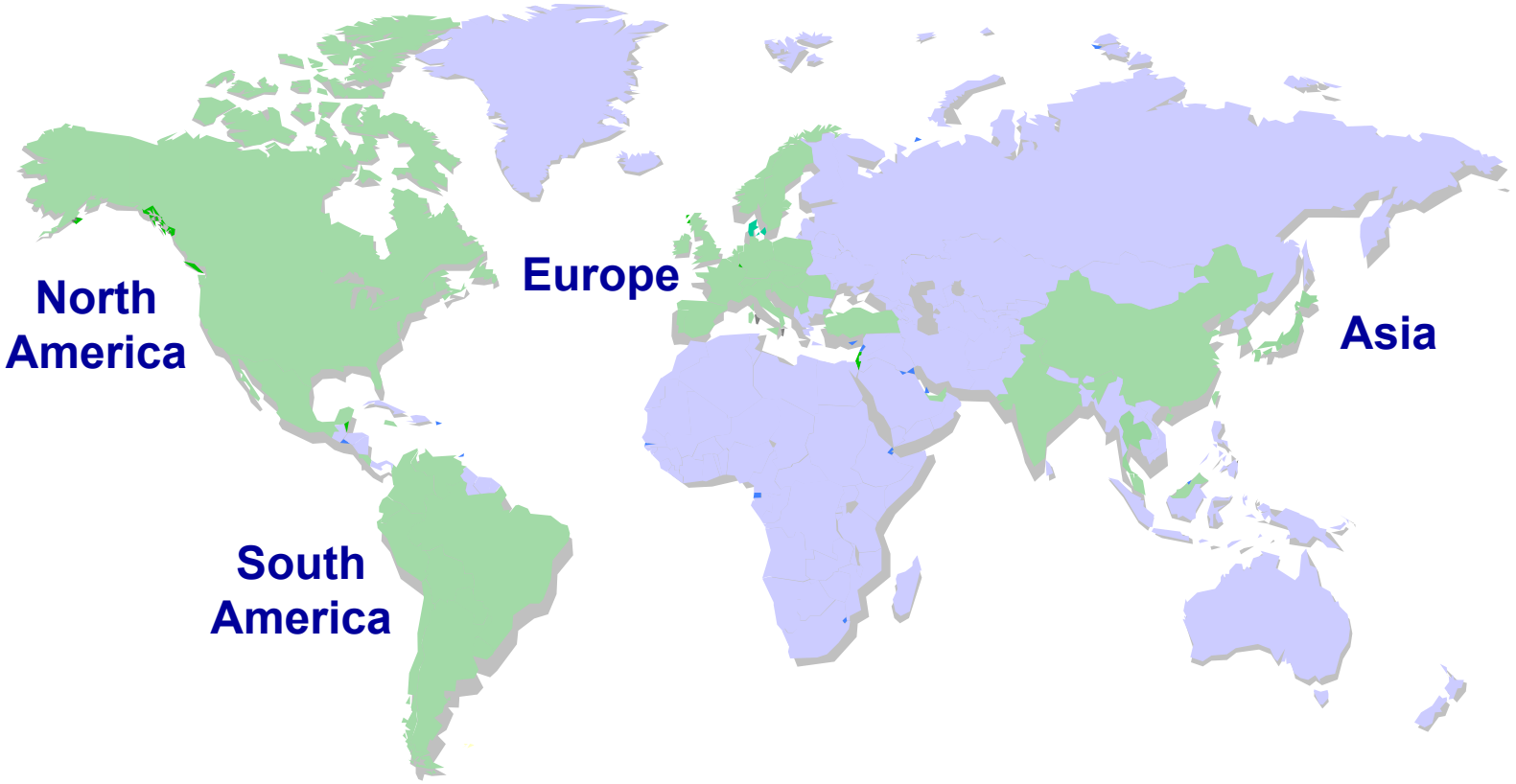

Exploration & Production

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- **Enhanced Oil Recovery**
  - Over 30 years experience with Gas Displacement Recovery (GDR)
    - Nitrogen
    - Carbon Dioxide
    - Methane
  - More than 25 projects
- **Well Stimulation Services**
- **CO_2 EOR Services**
- **CO_2 Capture & Purification**

Elk Hills 30 MMcfd / 1000 psig

Binger 15 MMcfd / 5000 psig / NRU

Hawkins 65 MMcfd / 2000 psig

Praxair's Portfolio of GDR Projects

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- **Miscible Displacement**
  - Block 31, TX, USA
  - Painter Field, WY, USA
  - East Binger Unit, OK, USA
  - Fannie Church, AL, USA
  - Vealmoor Field, TX USA
  - Headlee North, TX USA
  - Powell Field, Douglas, WY, USA
  - Sand Dunes Muddy WY, USA
- **Gravity Drainage**
  - Hawkins Field, TX, USA
- **Pressure Maintenance**
  - Samaria, Mexico
  - Anschutz Ranch East, WY, USA
  - Elk Hills CA, USA
  - Yates Field, TX, USA
  - Tatums, OK, USA
  - Colorado, USA
  - (2) Kansas, USA
- **ECBM**
  - Trinidad, CO, USA
  - Farmington, NM, USA

Samaria 190 MMcfd / 3000 psig

Anschutz 50 MMcfd / 6000 psig

Many Types of Projects

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- **Full field floods**
  - Cryogenic nitrogen plant
- **Single reservoir compartment**
  - Small cryogenic nitrogen plant
  - Non-cryogenic membrane plant
- **Pilot projects**
  - Small cryogenic plant
  - Membrane plant
  - Liquid transport vessels
- **Offshore gas lift applications**
  - Membrane plant for platform
  - Liquid transport vessels for platform/ship
- **Huff 'n' Puff applications**
  - Pumping equipment
  - Liquid transport vessels

Painter 50 MMcfd / 5000 psig

Elk Hills 30 MMcfd / 1000 psig

Offshore unit 2.5 MMcfd

Praxair EOR Services

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- Identification of potential fields for GDR
- Assist & facilitate with project development efforts
  - Reservoir engineering services
  - Selection of gas injectant
  - Recovery process simulation
  - Optimization of gas supply system
- Partner on GDR pilot projects
- Provide gas injectant requirements for full scale operations

Recoveries – Sample N_2 GDR Projects

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Field	EOR Application	Recovery (fraction OHIP)
Hawkins	Gravity drainage	0.20 *Carlson -ExxonMobil
Chunchula	Pressure maintenance	0.31
Block 31	Miscible displacement	0.6 (total) no secondary
Szeged Moravaros	Pressure maintenance	0.12
Jay/(LEC)	Miscible displacement	0.13
Lake Barre	Pressure maintenance	0.19
Fordoche Wilcox 8 & 12	Miscible displacement	0.195
Fordoche Wilcox 5	Pressure maintenance	0.19 – 0.46
Field B*	Immiscible displacement	0.36 * From Clancy
Anschutz Ranch East	Pressure maintenance	0.45-.53

GDR's Place in the Market

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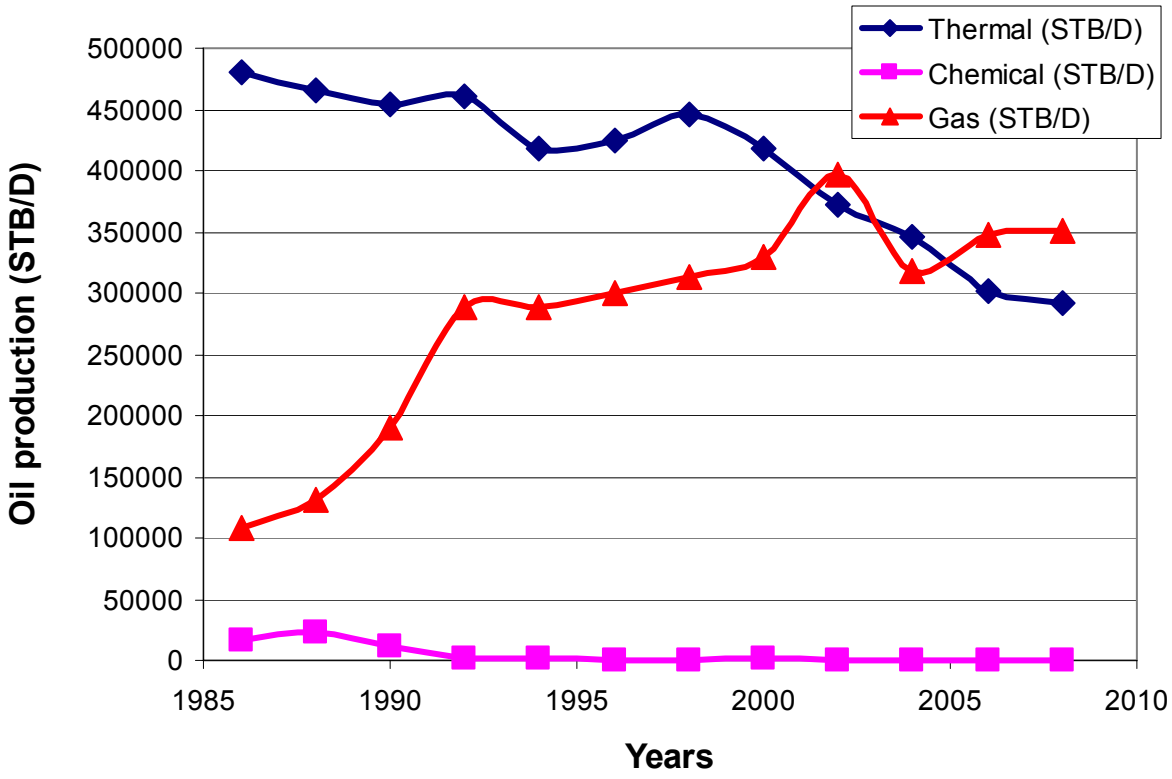
- **# 1 EOR method to add light oil reserves.**
- **"in the US chemical and thermal EOR projects have been in constant decline since the mid 1980s"***

Historical US EOR Production



*(Dr. Leonid Surguchev et al. World Petroleum Congress 2006)

Reserve Growth – From Two Sources

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- Increased sweep efficiency of moveable oil (contacting more oil)
  - Infill drilling
  - Fracing
  - Horizontal wells
  - Waterflood realignment
  - Gas displacement recovery (GDR)
- Increased displacement efficiency from residual oil (displacing more oil out of each pore)
  - Steam flooding
  - Chemical flooding
  - Gas displacement recovery (GDR)

N_2 Reserve Growth Applications

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- Pressure maintenance
  - Condensate and retrograde condensate reservoirs
- Miscible displacement
- Gravity drainage
- Immiscible displacement
  - Oil
  - Gas cap gas
- Driving agent for slug/buffer

Gas Condensate Pressure Maintenance

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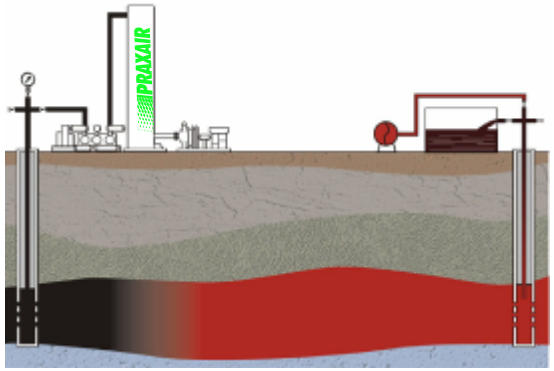
- Pressure depletion effects cause;
  - Reduction in gas permeability and well productivity
  - Aquifer encroachment
  - Lower ultimate hydrocarbon recovery by 10 to 40 %
- Screening criteria:
  1) Dew point pressure near the original reservoir pressure, under saturated by 150 to 300 psi,
  2) High condensate yield typically > 175 bbl/MMSCF produced,
  3) High liquid dropout rate with liquid condensation from 20 to 40 % of the hydrocarbon pore space.



N_2 Miscibility Displacement

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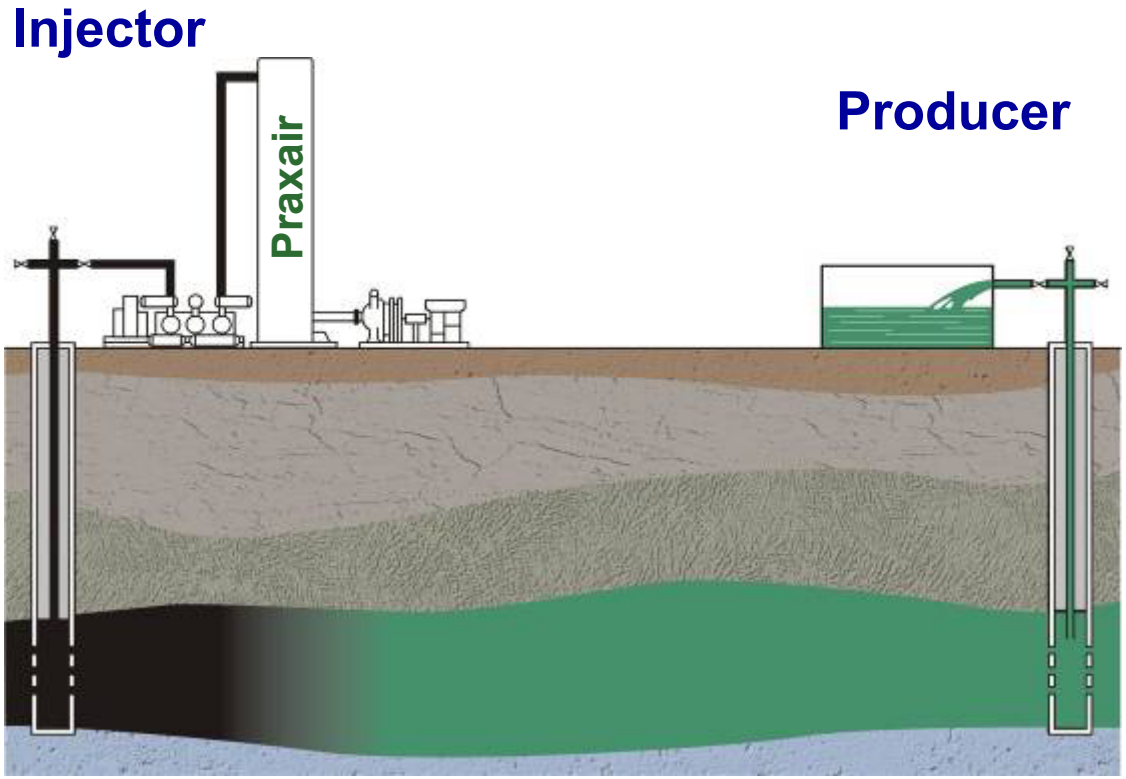
- There are three types of miscibility including;
  - First-contact miscibility
  - Multi-contact miscibility
  - Vaporizing mass-transfer miscibility
- Results in high displacement efficiency at the pore level



Gravity Drainage

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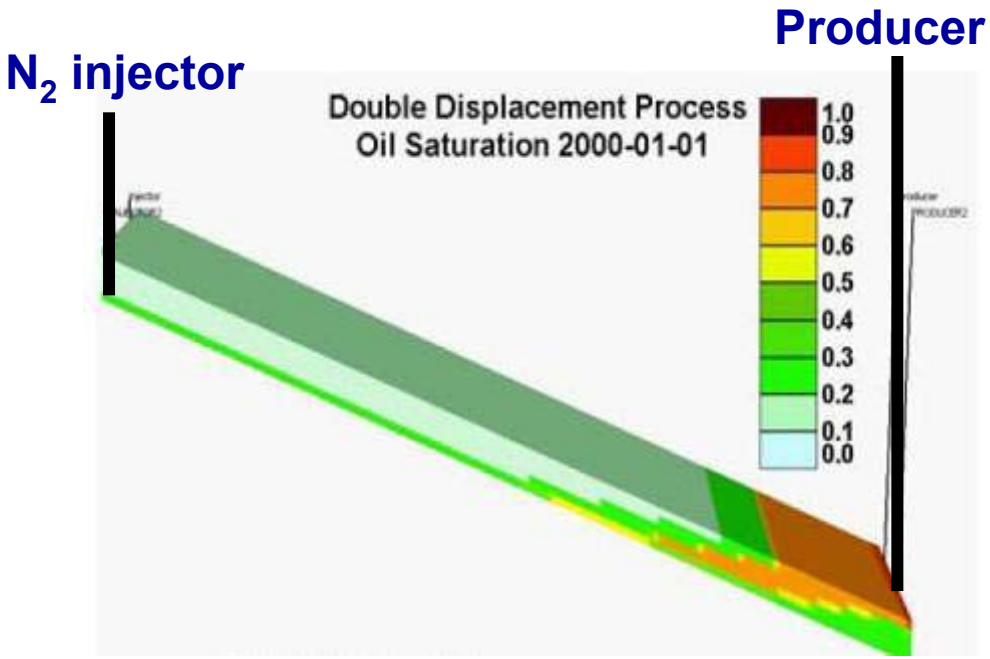
- The most common Gravity drainage processes are:
  - Gas assisted gravity drainage (no water present)
  - Double displacement process (water present)

- Double Displacement Process (DDP). The process of gas displacement of a water invaded oil column has been termed.
- The double displacement process consists of injecting gas up-dip and producing oil down-dip



Gravity Drainage
Double Displacement Process (DDP)

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- **Up dip gas injection into a dipping reservoir is one of the most efficient recovery methods.**
  - **Recovery efficiencies of 85 % to 95 %**
- **Increases sweep efficiency**
- **Increases displacement efficiency**
  - **Oil film flow is an important recovery mechanism**
    - **Film flow connects the isolated blobs of residual oil in the presence of gas**
  - **Strong water wet**
  - **Positive spreading coefficient**

Modified from Ren et al., 2000)

Gravity Drainage – General Design

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- Obtain piston like displacement (no gas fingering)
  - Horizontal gas-oil contact
  - Have gravity dominate the gas flow
- Optimize the time between gas injection and oil production.
  - As fast as possible without gas fingering
- The greater the dip angle the higher the injection & production rates w/o gas fingering
  - The greater the dip the more effective the gravity drainage

Hawkins Field
Double Displacement Process

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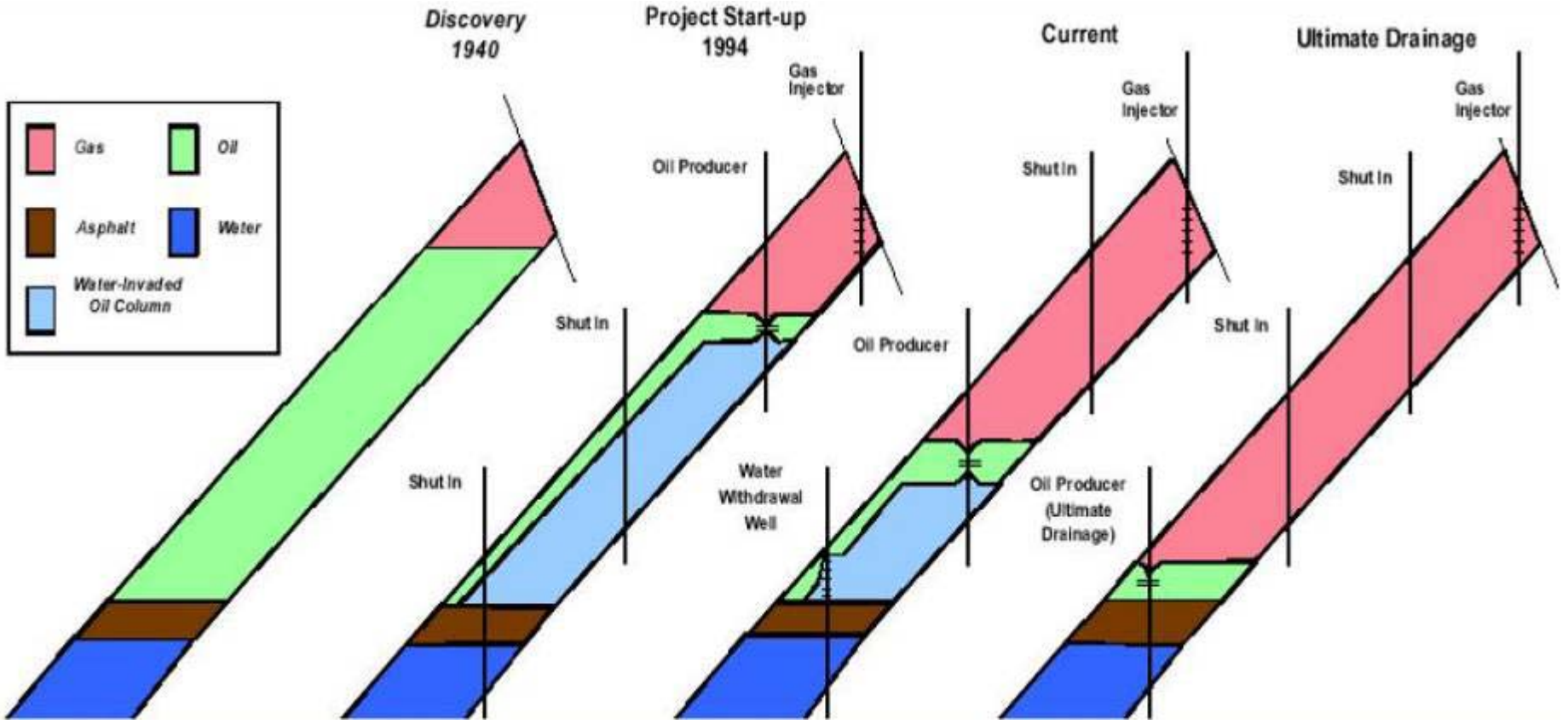
Double Displacement Process Schematic



Lawrence et al., 2003

N_2 as Driving Agent for slug/buffer (chase gas)

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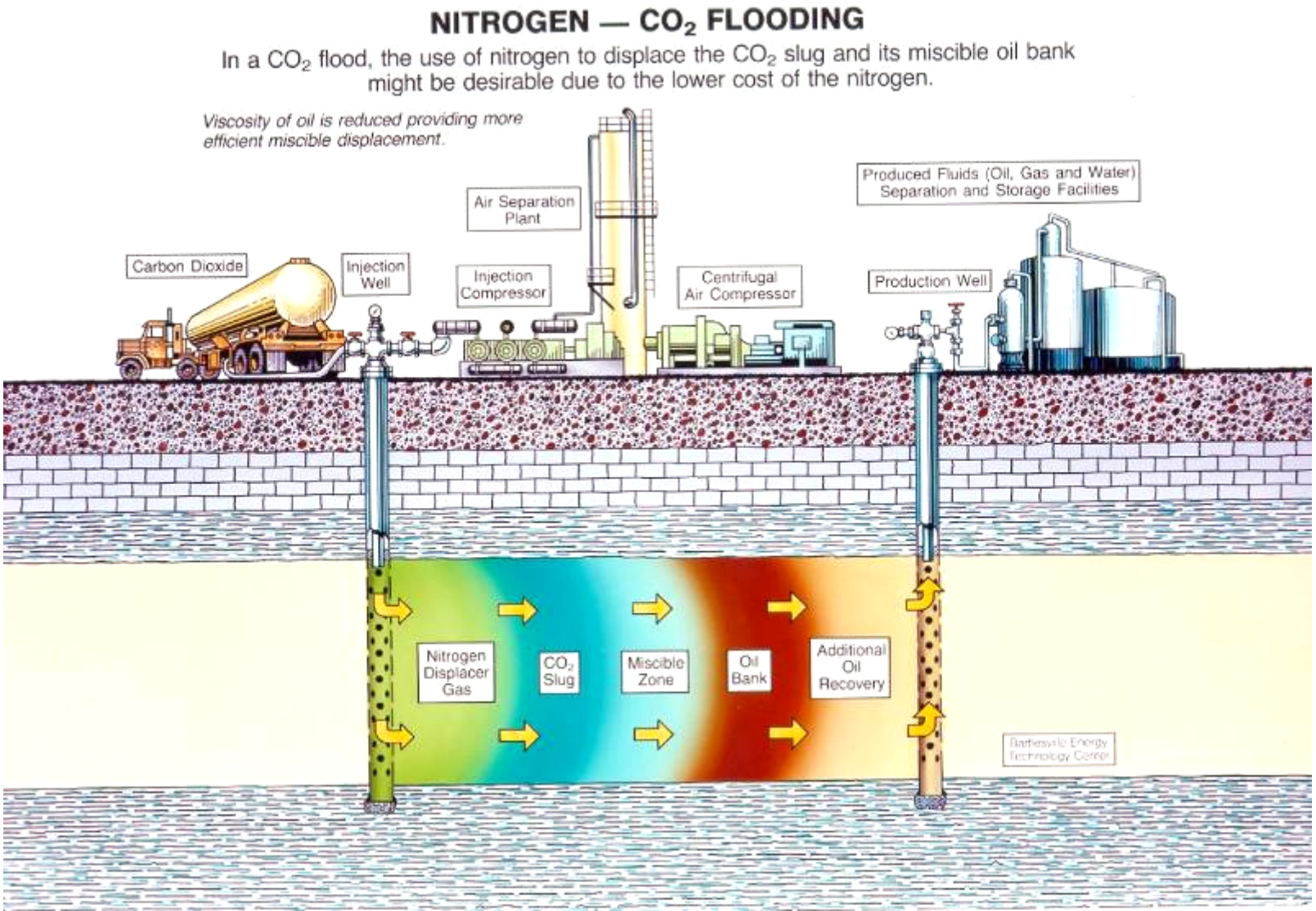

Tiffany Unit N_2 ECBM Pilot

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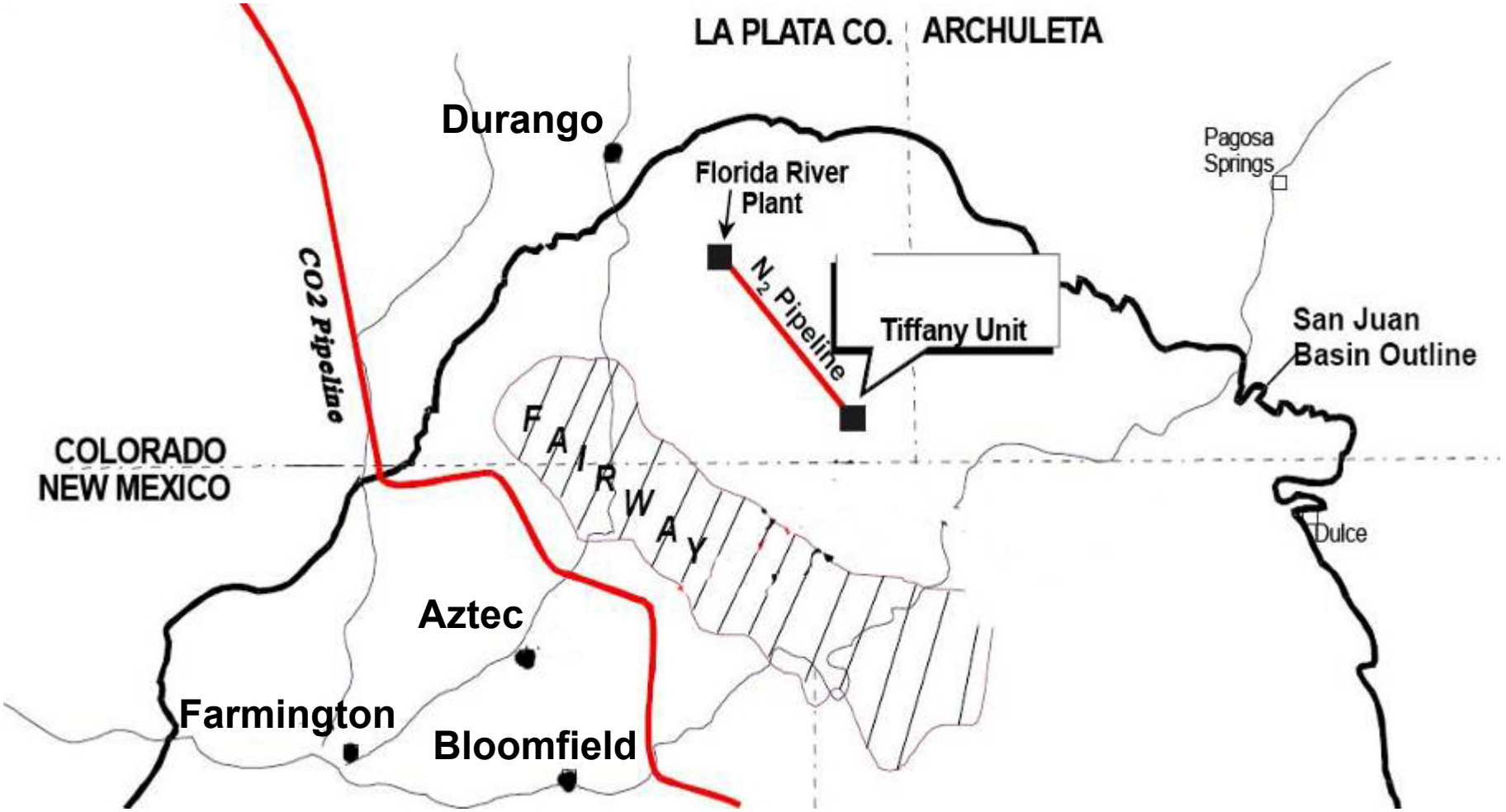

Reeves and Oudinot, 2005

Conclusions

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- Future reserve additions in large mature fields will primarily come from Gas Displacement Recovery.
- Reserve additions will occur through:
  - Pressure maintenance
  - Miscible displacement
  - Immiscible displacement
  - Driving agent for slug/buffer
  - Gravity drainage
- GDR typically increases both sweep and displacement efficiency in oil and gas reservoirs.
- Reserve growth targets can range from 10 to 45 % of OOIP/OGIP