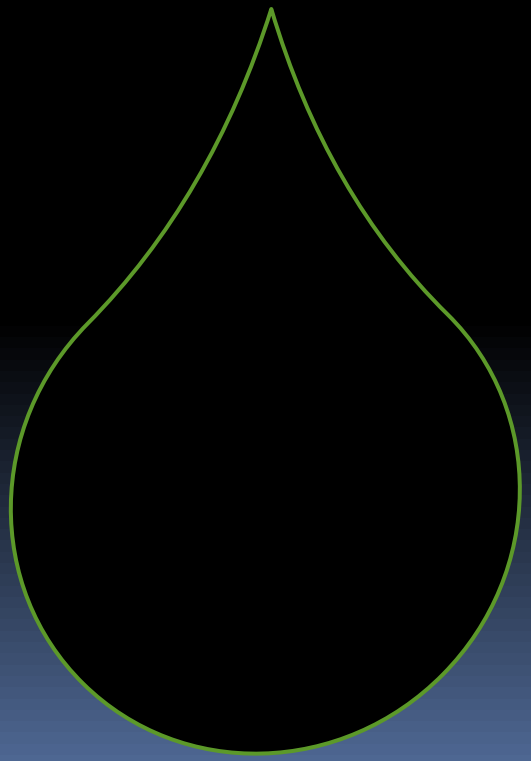
ENHANCED OIL RECOVERY

IS

The introduction of a fluid into a pressure-depleted oil reservoir to increase its pressure and ultimate oil recovery



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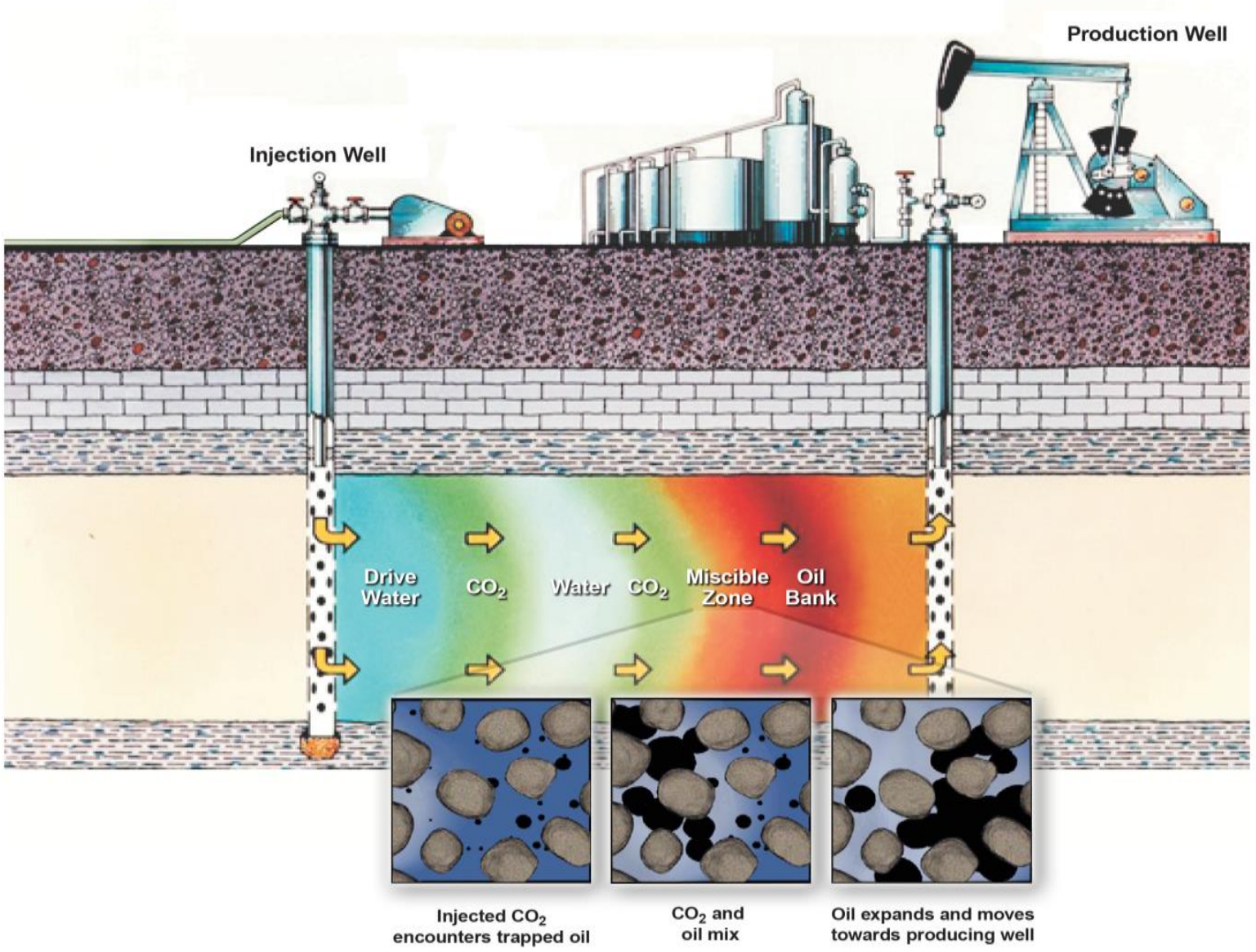
EXHAUST GAS INJECTION CO2 EOR



EXHAUST GAS INJECTION EOR

- Proven – production increases up to 50X current production.
- Mobile - generate gas at wellhead, no gas or CO2 pipeline cost.
- Green – dual fuel source, propane or methane.
- Volume – 1-Mmcfd modular units, trainable to any volume/flowrate
- Pressure – as required, from low pressure to >2,000-psi injection.
- Drive – N2 segregates; forms gas drive to push Oil/CO2 thru porespace
- CO2 – lowers oil viscosity; swells oil up to 50% for greater mobility.
- Thermal – gas up to 900*, alternative to Steam Flood, without water.
- Patented Process – Weatherford Intl, exclusive licensing partner.

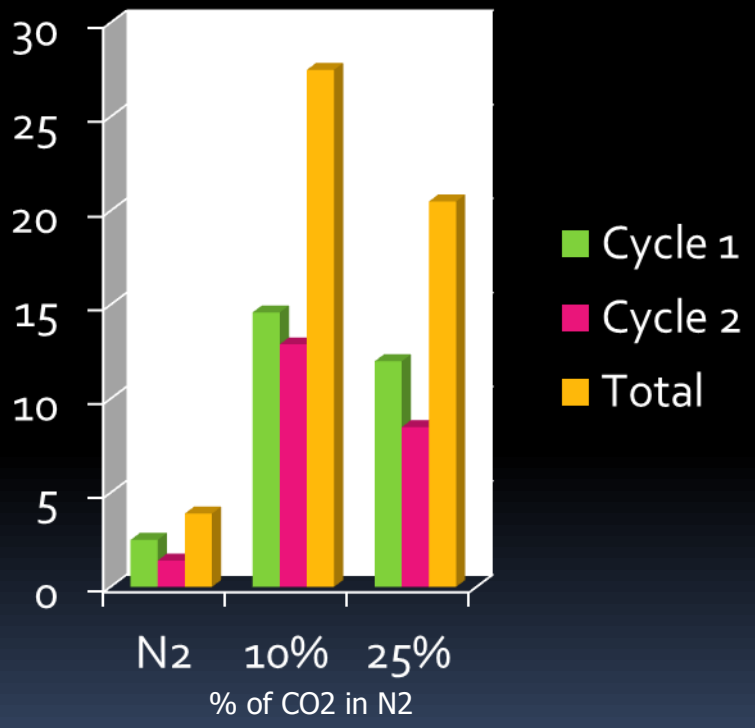
Exhaust Gas CO2 EOR

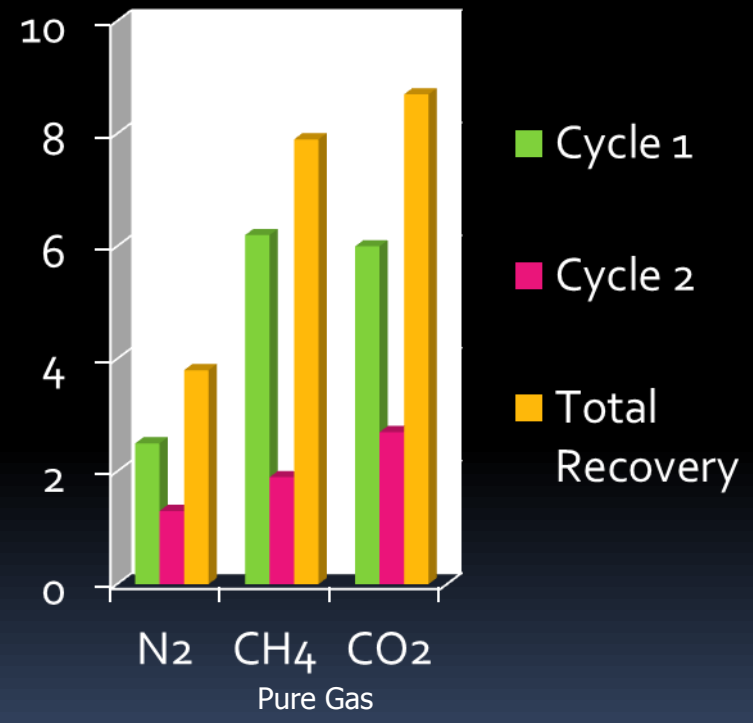
Exhaust Gas (CO_2 + N_2)

- Combustion gas from a standard internal combustion engine provides an ideal gas for enhanced oil recovery. Combustion gas is comprised of approximately 13% CO_2 and 87% Nitrogen.
- Researchers at Louisiana State University compared the exhaust gas to pure 100% CO_2 in simulated conditions and found that exhaust gas has significantly better performance than pure CO_2 in the recovery of crude oil.
- In a pure CO_2 flood, the CO_2 combines with the oil under miscible pressure, doubling the volume of the oil and reducing the viscosity. This allows the oil to flow more freely towards the producing well. The CO_2, however, does not provide drive. In a pure CO_2 flood, gas injection is followed by water (WAG, **W**ater **A**nd **G**as) , which provides pressure and drive to push the oil towards a producing well.
- In an exhaust gas flood the 13% CO_2 separates from the Nitrogen, and combines with the oil under pressure, providing the needed swelling and increase in oil flow. Meanwhile, the 87% Nitrogen gas rises to the top of the reservoir, providing a pressure source which is more effective than water at driving oil towards a producing well.

Gas Efficiencies

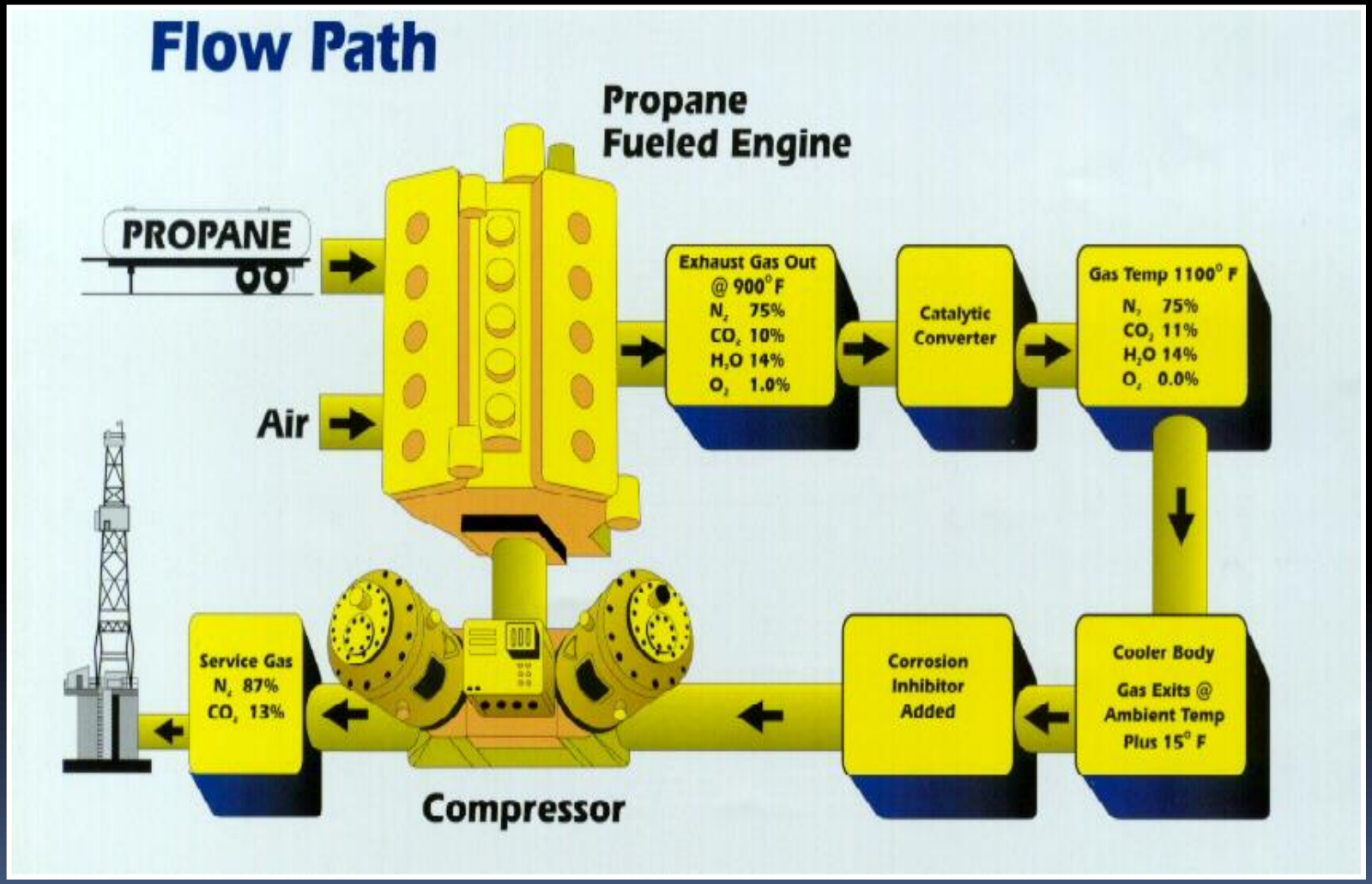
Exhaust Gas 2 times more efficient in oil recovery then pure CO2-only





SPE Paper # 36687
LSU, U of M Rolla

Exhaust Gas Systems – *Process Flow*



Fossil Bay Exhaust Gas Generators

- 82% N2, 15% CO2, < 2% CO, < 75ppm O2
- Minimal corrosion considerations
  compared to 100% CO2 used in CO2 flooding
- No combustion or explosive risks
  compared to 100% CO2 used in CO2 flooding
- Wide range of operational parameters
- Variable Injection rates and Pressures
- Fuel sources either methane or propane
- PORTABLE – no infrastructure needed
- COMPRESSION – part of the process.

Exhaust Gas Generator

Remote Operated Portable Unit

Exhaust Gas Applications

Enhanced Oil Recovery

- Pinnacle reefs, primary recovery 25%
- Most conventional reservoirs are candidates
- Unconventional Shales – new studies show 10% added EUR
- Incremental oil recovery after water-flood
- CHOPs – re-pressurization & heating
- Alternate EOR versus water-flood

Enhanced Gas Recovery – EGR

- Re-pressure depleted natural gas reservoirs
- Sweep gas for natural gas reservoirs (CBM)
- Gas over oil replacement (Surmont)

Thermal applications

- Gas temperature up to 900*
- low Gravity – Heavy Oil reservoirs
- Alternative to SAGD

GAS INJECTION EOR

Common Techniques

- CO_2 – most common gas used, competition for limited supplies; high infrastructure cost requires large reservoirs only - limited by sparse availability of CO_2 pipelines to provide services to EOR-worthy fields
- CH_4 (Methane) used mainly during primary production-pressure maintenance, costly to strip liquids, added supply cost of royalties owed for produced-gas used
- N_2 - miscible at high pressure of 4000-psi, and expensive to separately produce large N_2 volumes; best used in immiscible form as drive to push CO_2 and oil through reservoir pore space.

- **Best Gas Injection Technology**

- Exhaust Gas- N_2-CO_2 mixture (85%-15%)
  Unlimited supply
  Field Proven

CO2 Gas Flooding

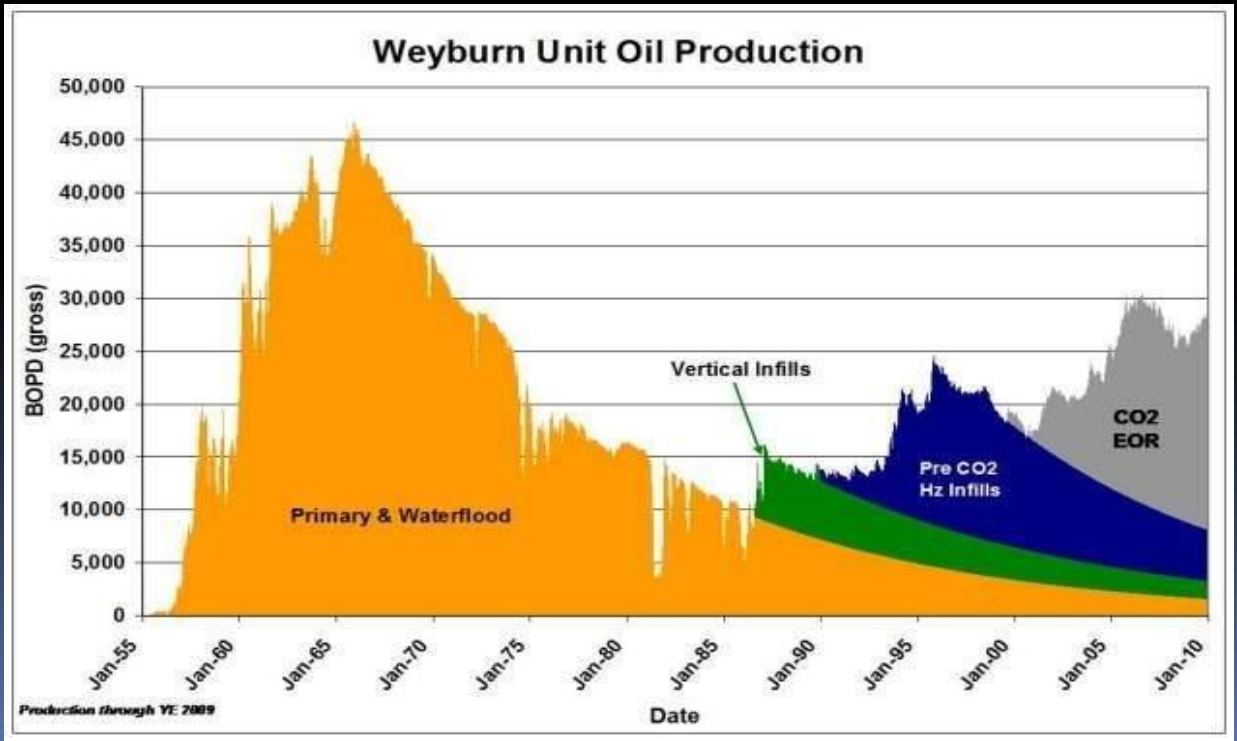
CO2 Supply Issues (current demand for EOR exceeds supply)

80+ Projects in Operation = 290,000 BOPD - Large Reservoirs only (>10 MMBO)

Recoveries Exceeding 50% OOIP – High Project Costs (>100's of millions of $$$)

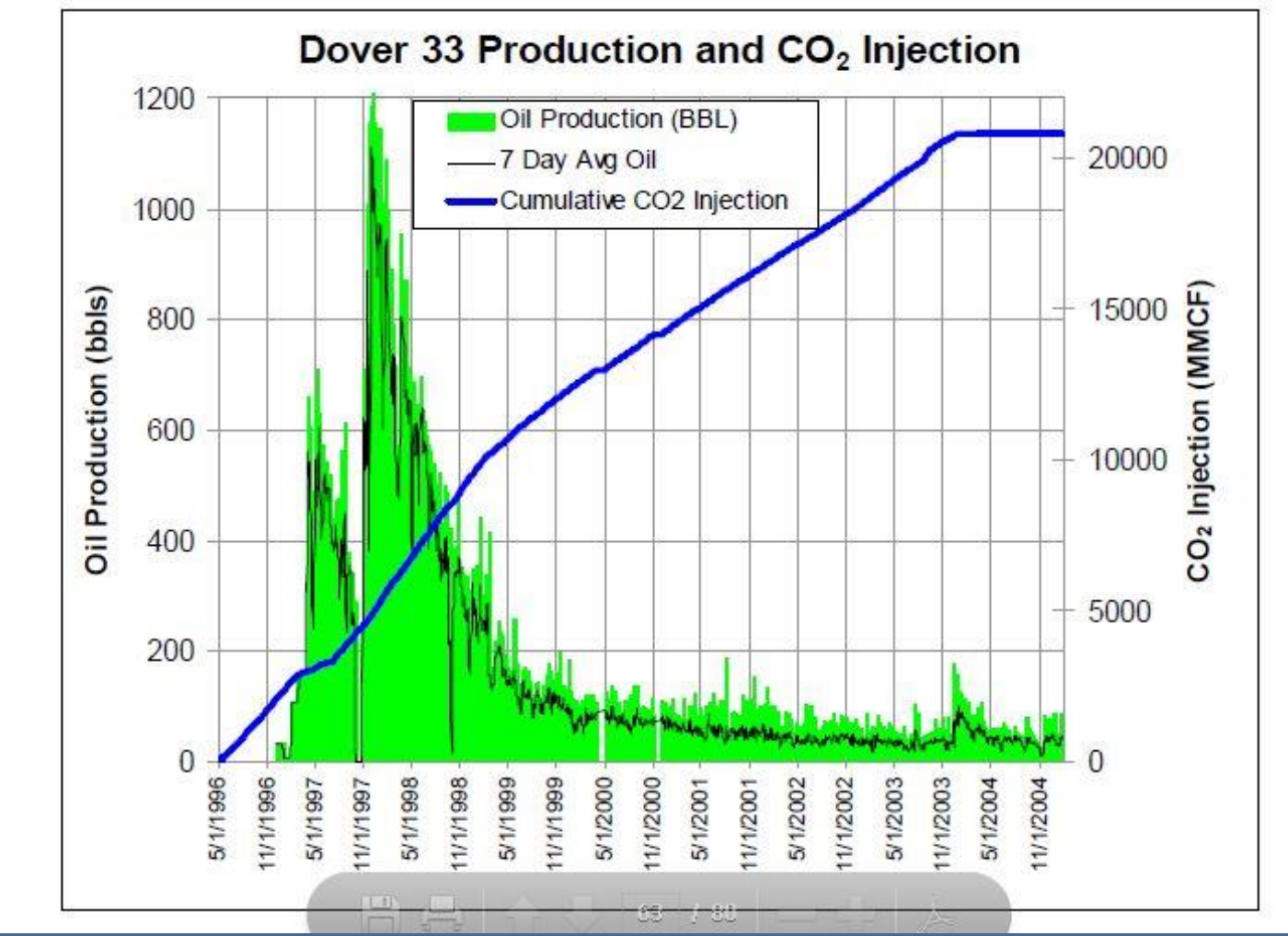
100% CO2 Only - No Drive Mechanism- Suffers Early gas breakthrough

Horizontal Flooding – fluid override lowers recovery



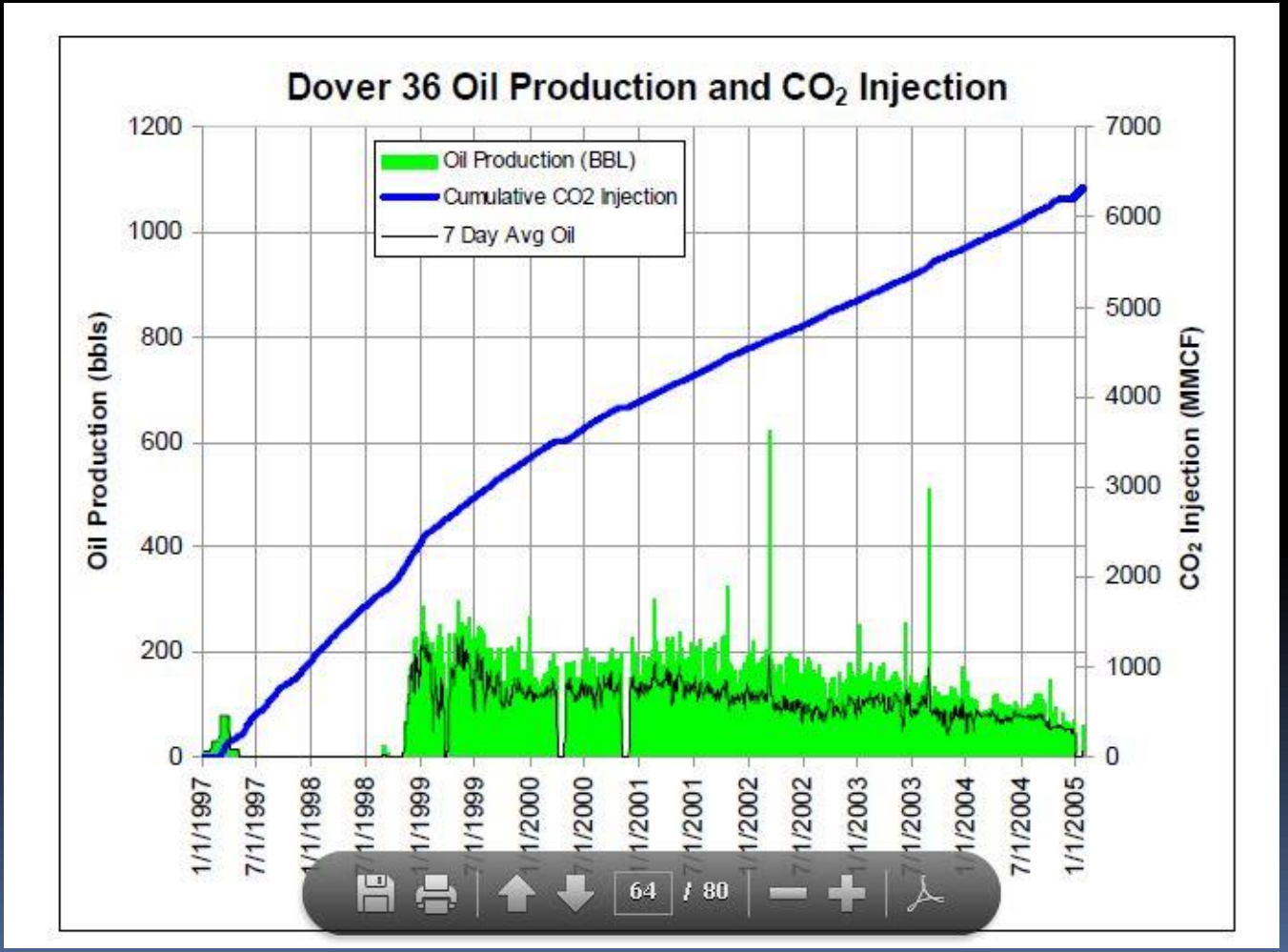
MICHIGAN CO2 FLOOD – N.REEF

Horizontal Producer - +500 BOPD Average first 2 years



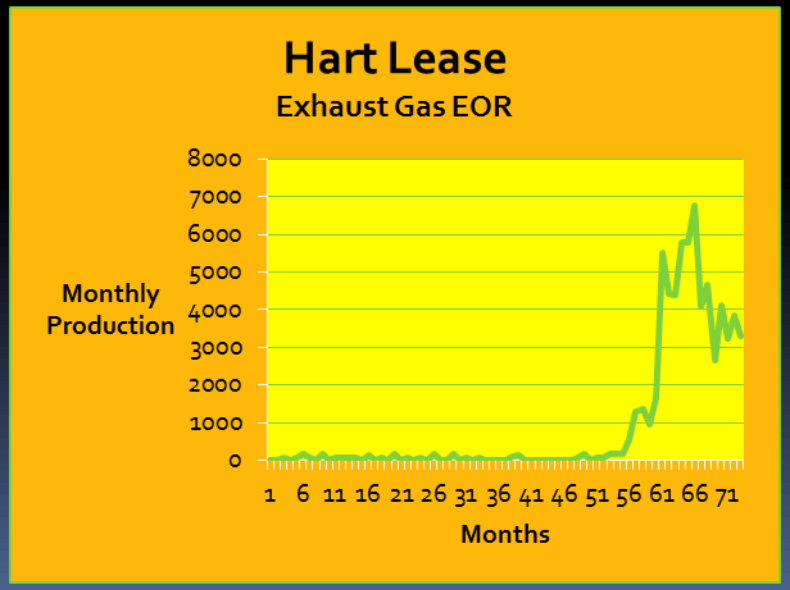
MICHIGAN CO2 FLOOD – N.REEF

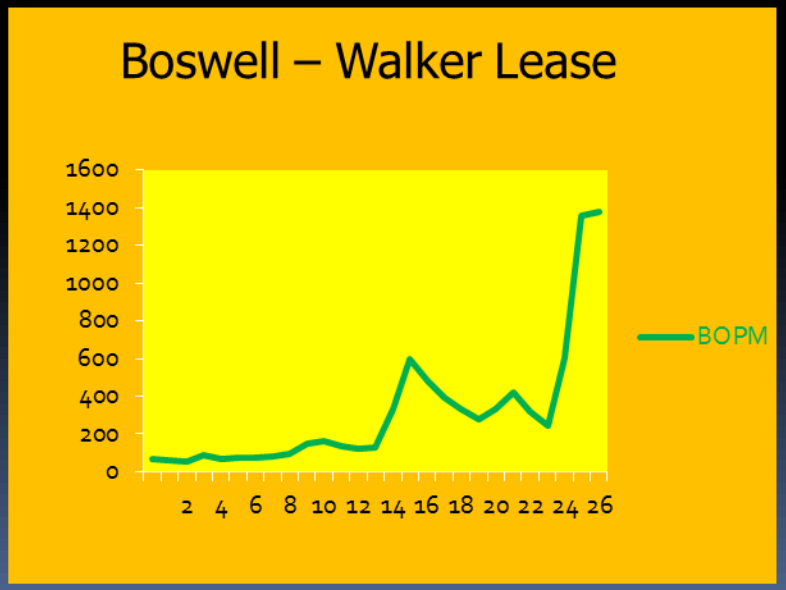
Vertical Producer – Averaged 190 bopd, first 4 years



Springhill Grove Exhaust Gas Projects

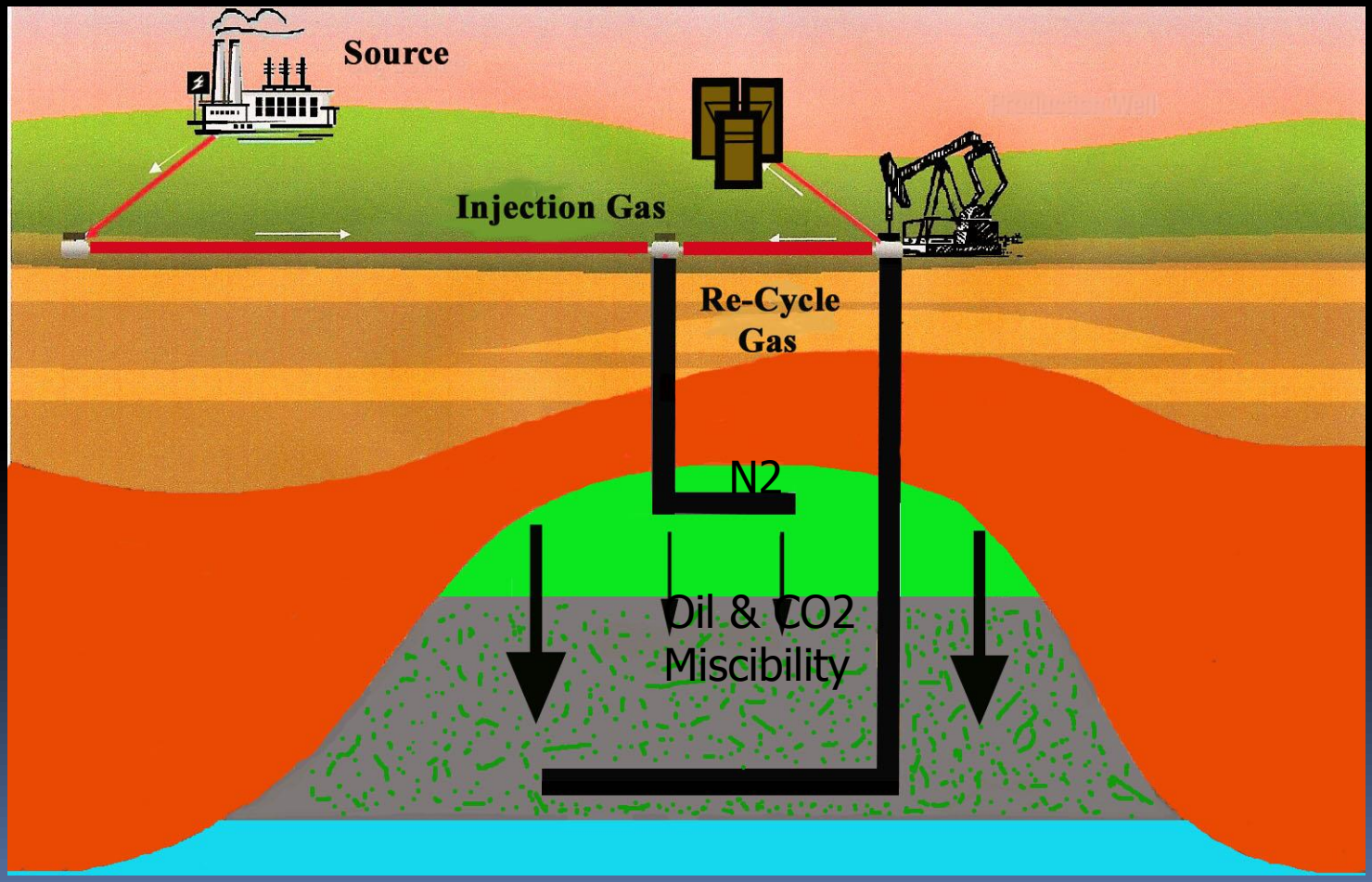
The Spring Grove field was discovered in 1958 and the two wells produced 1-2 bopd. In 1961, the operator bought an 80mcfd Exhaust Gas Processor, and production went up to 6bopd. In 1964, the field was bought, the new operators bought other EGP's for a total of 200mcfd and started injection. Within 4 months the Spring Grove field was producing at rates over 5000 bopm. The offsetting Boswell-Walker Leases saw production increases from 150bopm to 1300bopm by virtue of the exhaust being injected in the Hart Lease. In 1964, a full scale development was initiated on this lease.





Gas Cap Injection + Gravity Drainage

Injected Gas Mixture (CO_2+N_2) Fills Reservoir Gas Cap
N_2 Pushes CO_2 to Mix With Oil and Flow to Production Well



Gas Flooding EOR -- also known as *miscible* gas flooding -- is one of the leading enhanced oil recovery (EOR) technologies employed for recovering the stranded, trapped oil, left behind in pressure-depleted oil reservoirs after initial primary oil recovery has ended.

Gas flooding typically includes CO2, natural gas or N2 nitrogen as the gas that is injected.

Gas flooding is an "enhanced oil recovery" application for injecting miscible (and immiscible) gases into an oil reservoir to increase oil production by re-pressurizing the reservoir to push the oil to the production wells.

Miscible means that the injected-gas "mixes" with the oil, thereby reducing its viscosity and interfacial tension of the oil and rock. Miscible gas flooding also increases oil "swelling" and localized pressure or drive within the reservoir.

"Immiscible" flooding means that the injected-gas does not mix or go into solution, but instead provides the energy “push” (drive) by increased pressure. Immiscible flooding does not produce as much oil as miscible gas flooding, however there are certain applications and reservoirs wherein immiscible flooding is well-suited