Shell Exploration & Production

Lecture for KIVI NIRIA OG

Making EOR work

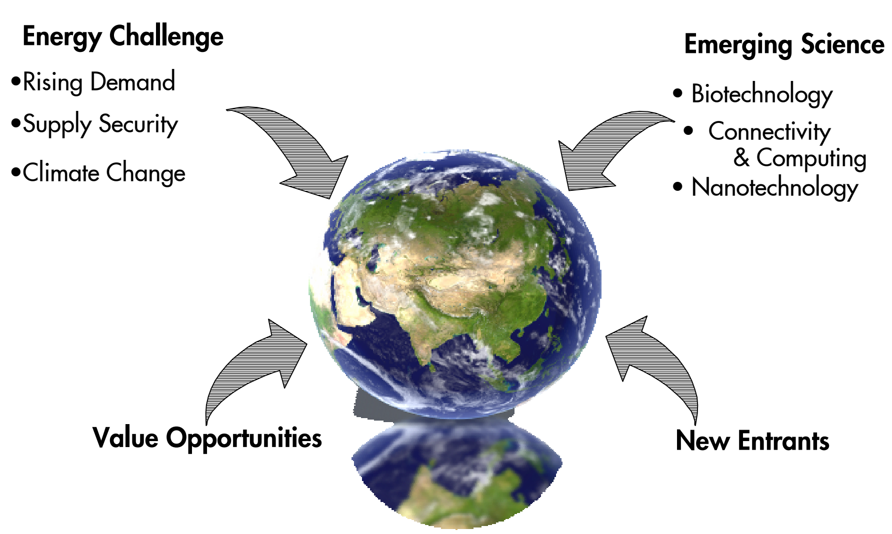
Willem Schulte
Chief Scientist Reservoir Engineering

Shell International Exploration and Production BV

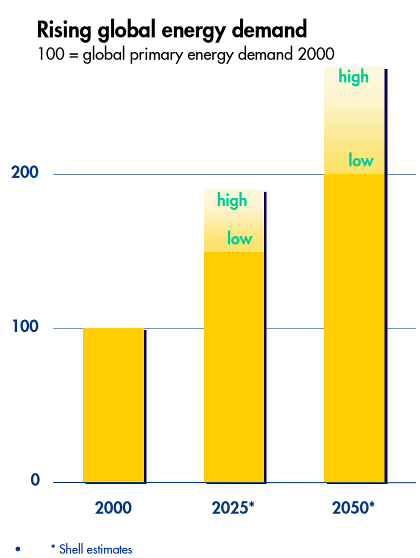
Agenda

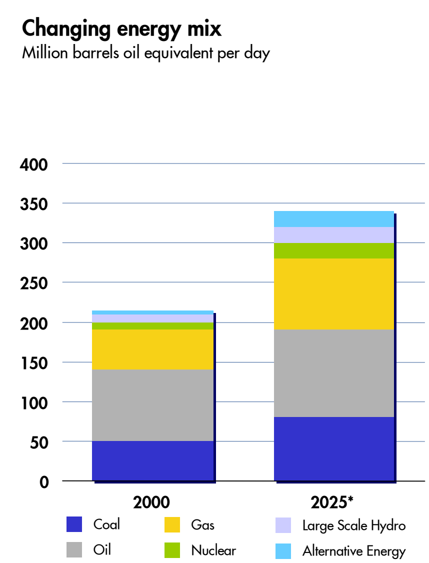
- The Energy Challenge
- EOR technologies, trends and challenges
  - Chemical
  - Gas
  - Thermal

INFLUENCING TODAY'S ENERGY WORLD



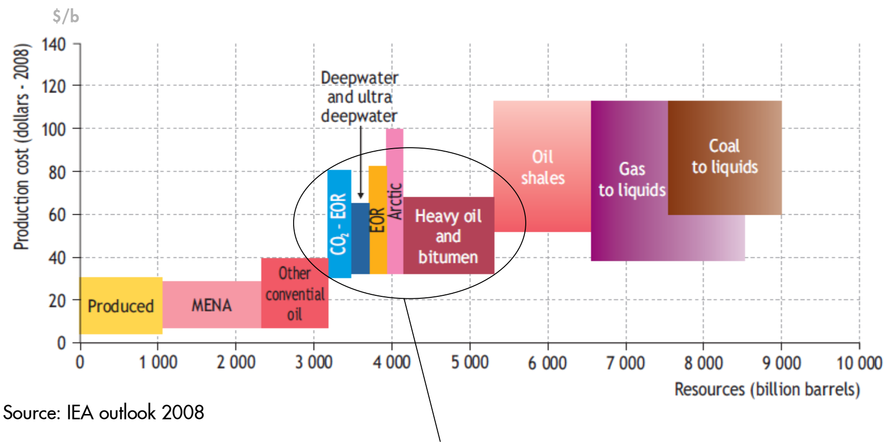
THE ENERGY CHALLENGE





Hydrocarbon Supply

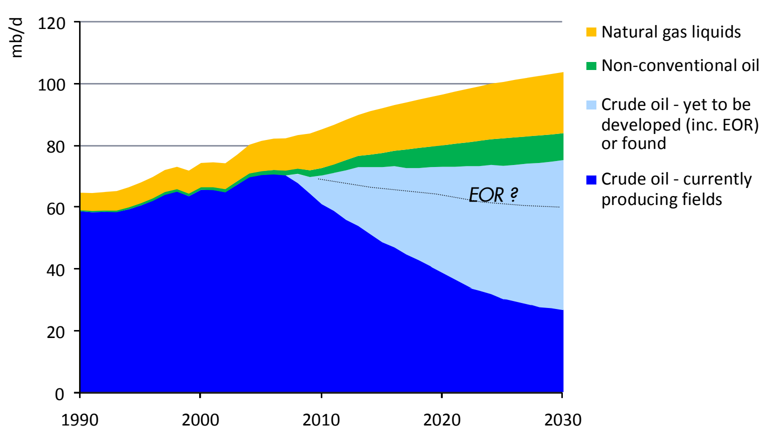
Long-term oil-supply cost curve



Source: IEA outlook 2008

it costs more to produce and will be CO2 intensive

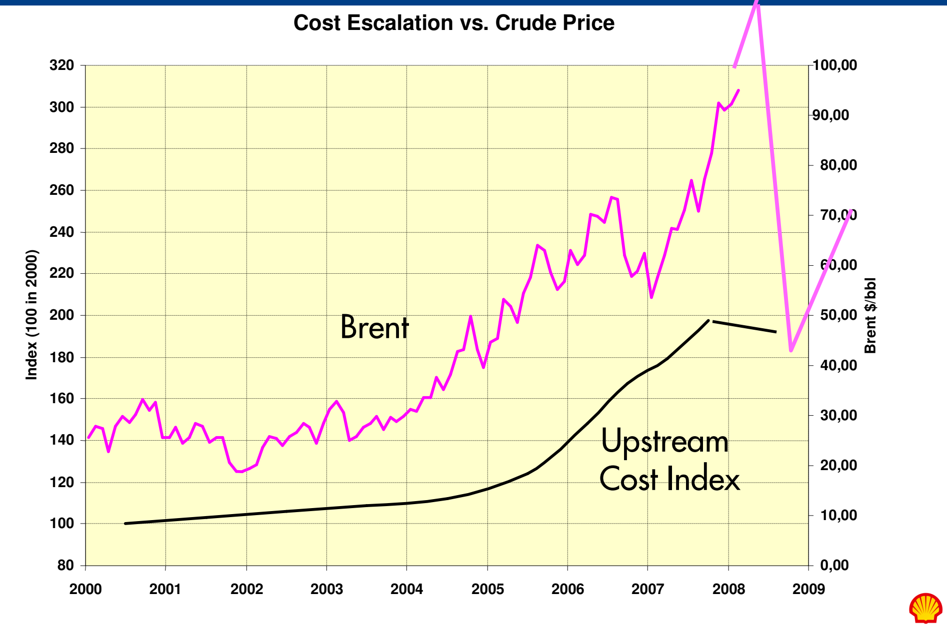
World oil production - IEA Reference Scenario



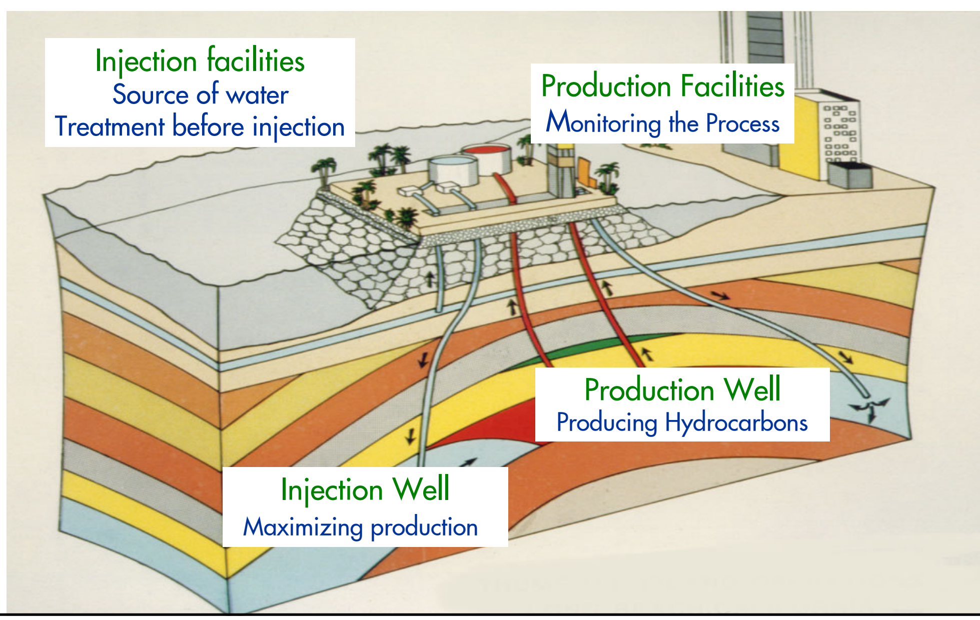
Source IEA 2008

Even if oil demand was to remain flat to 2030, 45 mb/d of gross capacity – roughly four times the capacity of Saudi Arabia – would be needed just to offset decline from existing oilfields

Prices Volatile - Cost Pressure



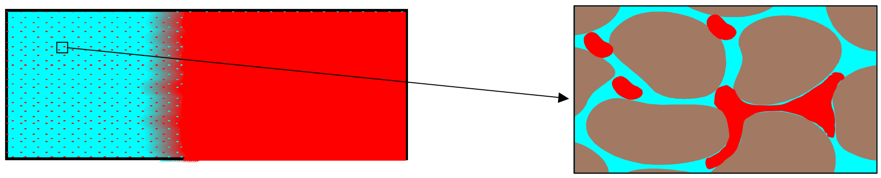
Water Injection as most common development strategy



The key issues to be resolved to maximise recovery

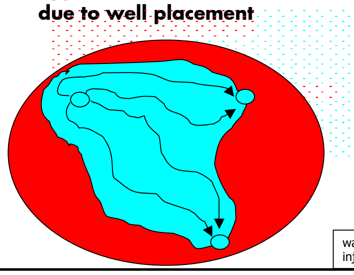
Residual oil saturation

Often around 20-30% of oil left trapped

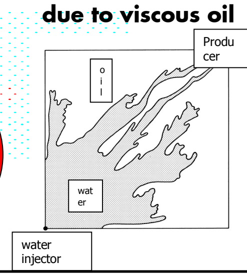


Sweep efficiency

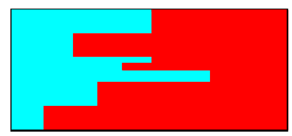
Bypassed zones due to well placement



Fingering due to viscous oil

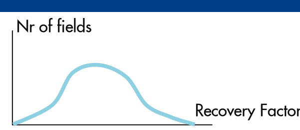


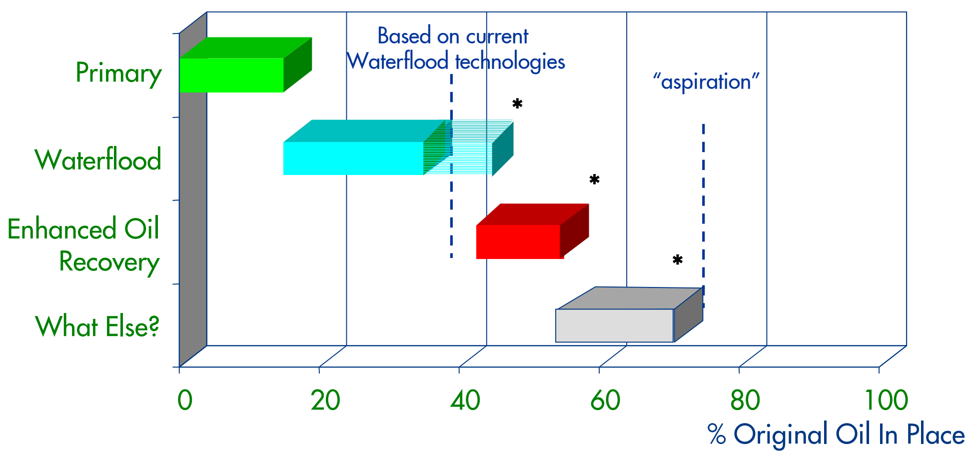
Thief zones by heterogeneity



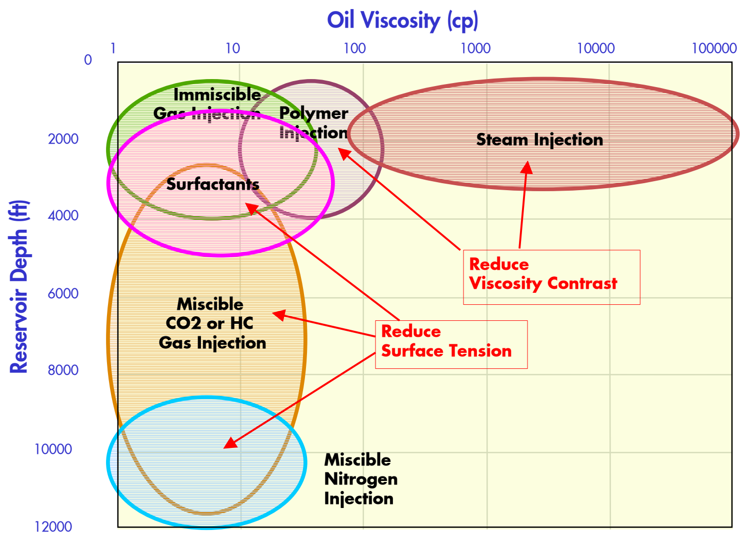
Maximizing Recovery – Average Recovery Factors

Average RF's: Some fields at 65%
Some fields at 10%



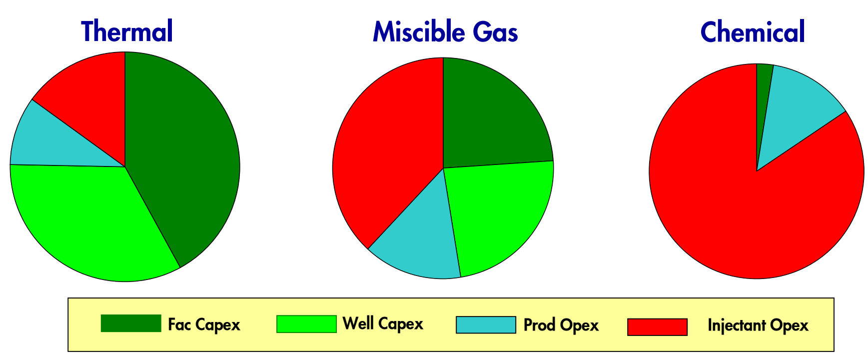


EOR Processes



Selection of best technique needs detailed reservoir modeling and analysis

EOR Value Drivers



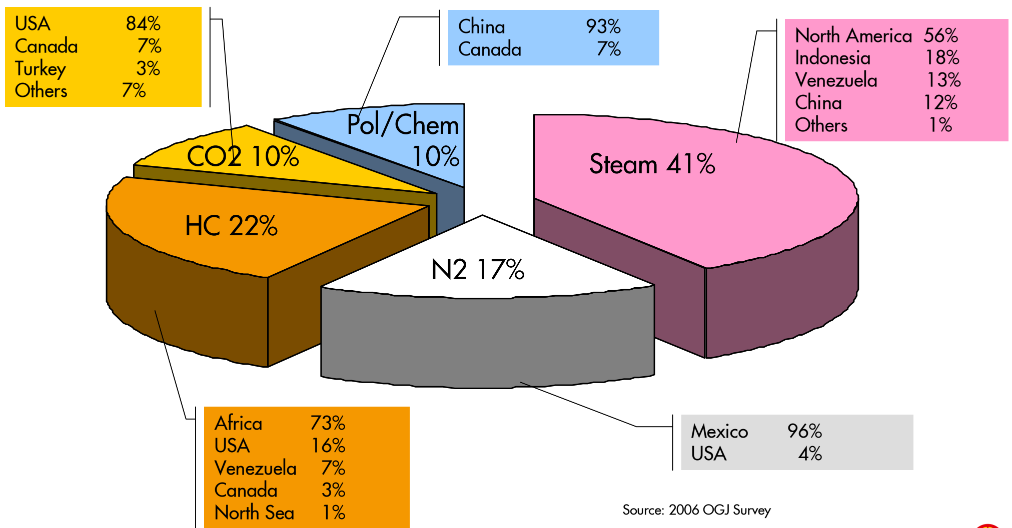
- Heat Placement
- Steam Generation Cost & Carbon Footprint
- Thermal Well Cost
- Surveillance & Data Management

- Gas Capture/Separation & Integrated Value Chain
- Infrastructure Usability
- Conformance & Sweep
- Subsurface-Surface Integration, Surveillance

- Chemical Formulation & Utilization Per Barrel
- Supply Cost & Logistics
- Waterflood Performance
- Operational Excellence (Inj QC & Prod Handling)

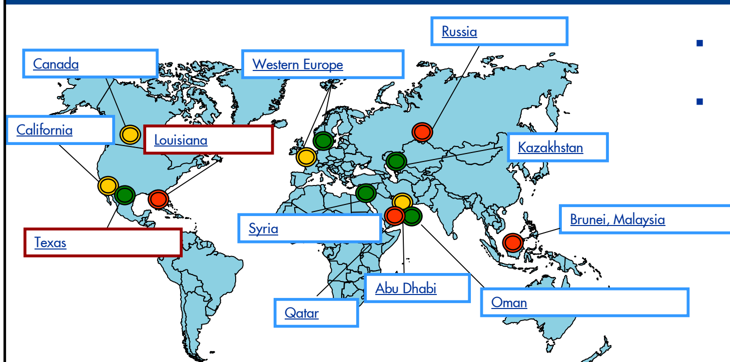
* Indicative UTCs - Actual project UTCs and breakdown splits will vary

EOR current Production
3 mln bbls/day worldwide



Source: 2006 OGJ Survey

Shell Enhanced Oil Recovery projects



- 11 EOR projects in construction/operation
- 20 EOR field projects/studies underway

Thermal projects
Chemical projects
Gas projects

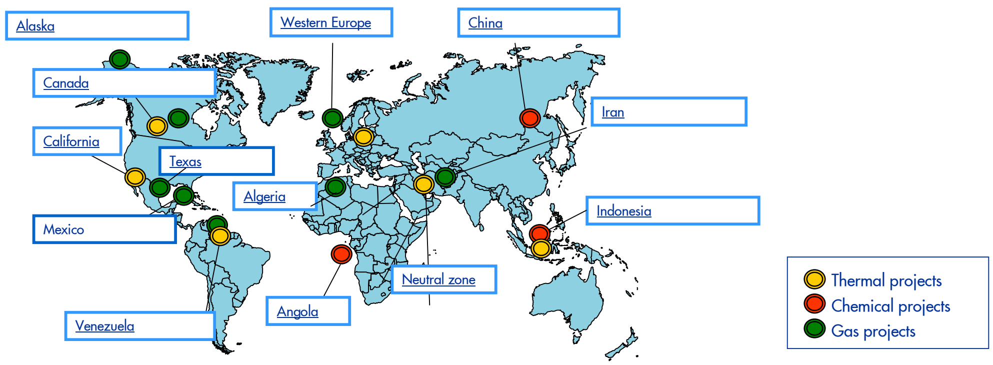
Steam injection, Oman

Chemical EOR, USA

Thermal EOR, Canada

Many Oil Companies are active in EOR

Some important projects to mention from outside Shell:



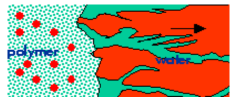
Trends

- Gas EOR
  - We can now transport gas through LNG and GtL
  - Too valuable to inject and use as drive fluid
  - Other gases still interesting: CO_2, H_2S
  - Key aspects are interaction gas/oil, impact geology & costs
- Thermal EOR
  - Often the only solution to heavy oil volumes, e.g. Canada, Venezuela, California
  - High CO_2 footprint: CCS becomes integrated part of project
  - High cost oil
- Chemical EOR
  - Less capital intensive, less CO_2 footprint
  - Add on to current water floods
  - Issues on stability and disposal

Chemical EOR

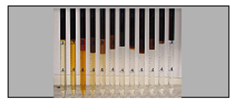
Low Salinity options

Polymer flooding



Surfactant flooding

Alkaline flooding



Enhanced Alkaline Flooding

Foam enhancements

History pre-2000

USA Multiple ASP tests (since 1960)

Discovery of the Enhanced Alkaline Flooding process (now know as ASP)

Pilots, pioneered by Shell Oil in 1980's

Polymer Flood Research (1980's)

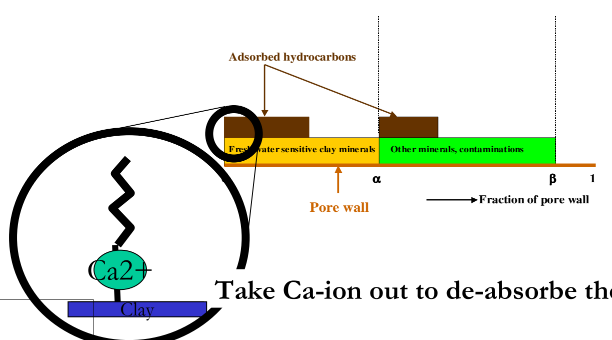
Successful Pilot tests in Oman

Current Chemical EOR Activities in Shell

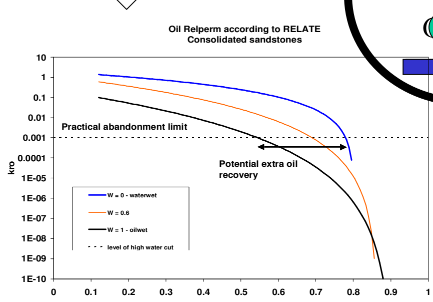
- **Oman**
  - Polymer flooding in the Marmul Field
  - Other polymer projects being evaluated
  - Multiple ASP flooding single well pilots in planning phase
- **Rest of the world**
  - Designer Water single well test and projects in sandstone
  - Series of ASP pilot tests in design phase
  - Other polymer projects being evaluated
- **Shell Chemical**
  - Delivery of chemicals to many areas

Low Salinity Flooding

Wettability correlates to water and oil relative permeability



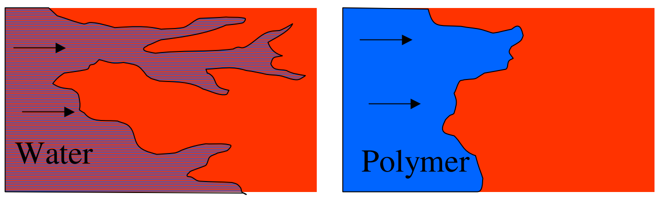
Take Ca-ion out to de-absorbe the oil



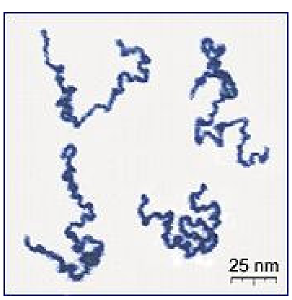
- How about carbonates?
- Impact of these mechanisms on other EOR techniques

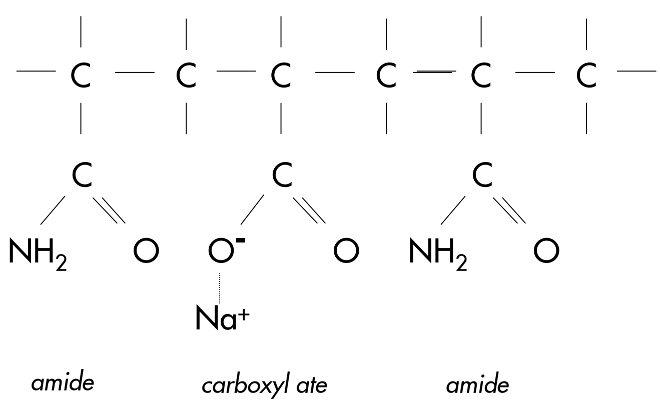
Polymer flooding

- Benefits:
  - Improved microscopic displacement due to displacement instability
  - Improved robustness for heterogeneous reservoirs
- Offshore: low demand on weight, space and logistics



Partially Hydrolyzed Polyacrylamide

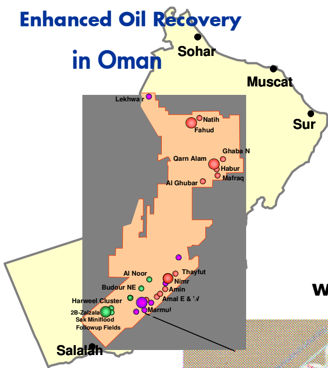




Salinity sensitive, viscosity of solution depends on shear

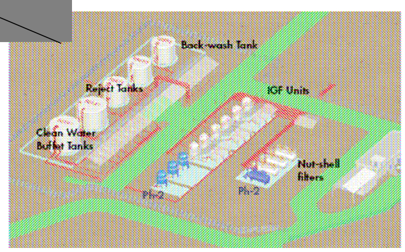
Polymer flood (starts early 2010)

Enhanced Oil Recovery in Oman

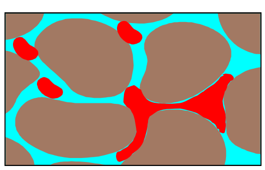


polymer mixing: 15 cP polymer solution to 27 patterns

water treatment



Recover Residual Oil with surfactants

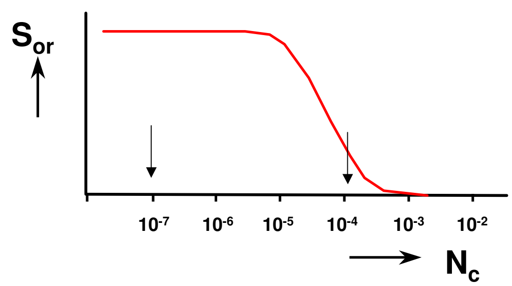


Ratio viscous to capillary forces:

$$N_c = \frac{K}{\sigma}|\nabla P| \approx \frac{\mu \cdot v}{\sigma}$$

Typical waterflood for light oil

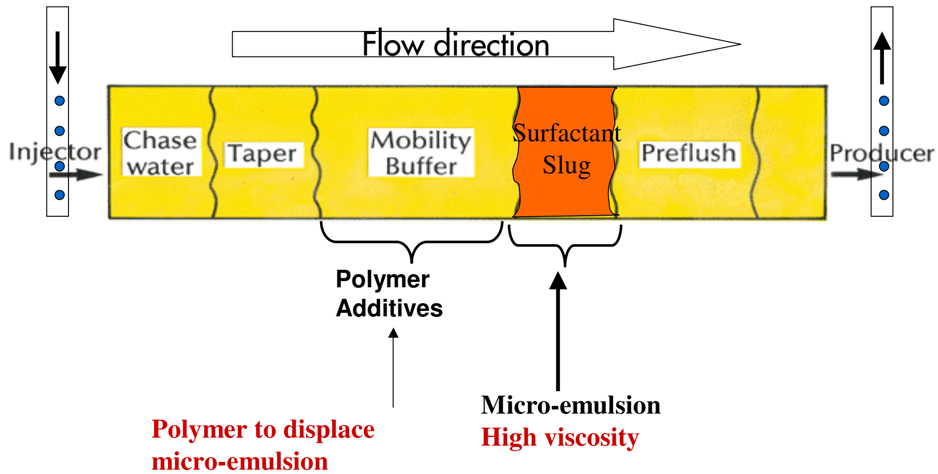
v = 1. ft/day μ = 0.001Pa.s σ = 0.03 N/m	→ $N_c = 10^{-7}$



To improve
you need > 3 orders increase in Nc

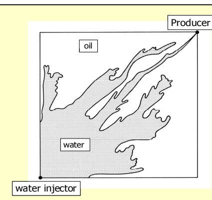
Reduce interfacial tension
(by adding surfactants)

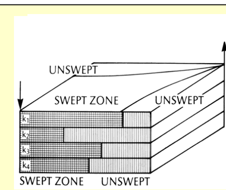
Typical Surfactant Flood…



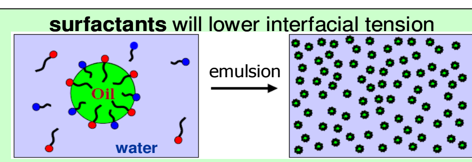
ASP
Alkaline-Surfactant-Polymer

Polymer:
- increase viscosity
- improve mobility control and sweep.

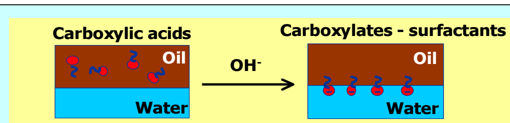




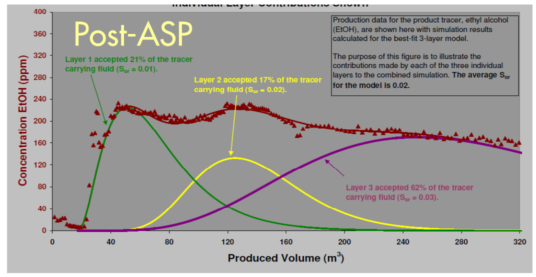
Surfactant
- mobilize residual oil.



Alkaline:
- high pH of 11
- natural surfactants (soaps)



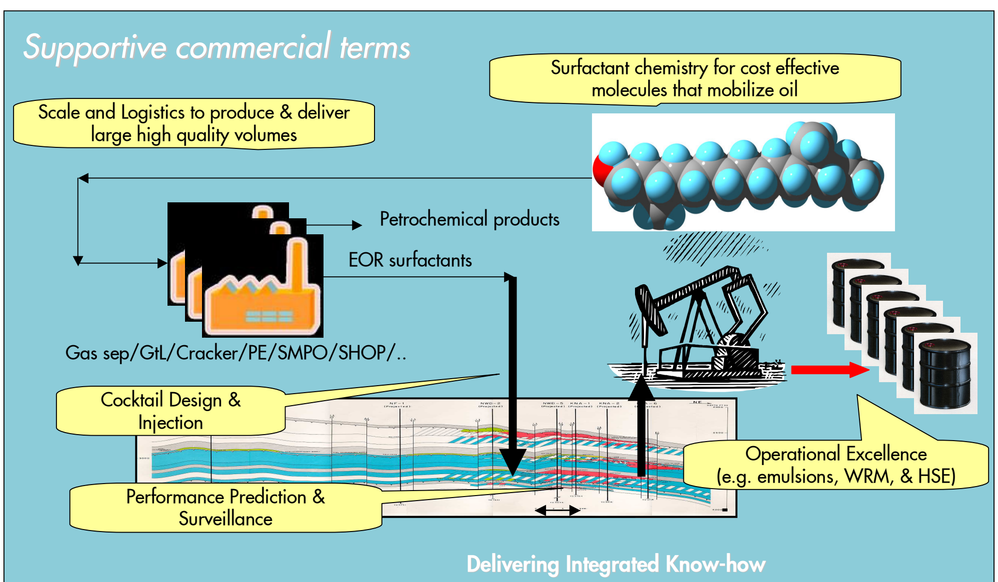
ASP Single Well tests: Positive Results



Conclusion: Significant reduction in residual oil saturation (Sor) with ASP

- Sor after WF ranges 20 – 30%
- Sor after ASP 0 - 2%
- Displacement of 90+% remaining oil confirming core flood results
- 2010 progression to pattern trials

ASP Critical Success Factors



Challenges for Chemical EOR

- Proper injectivity
- Stability of polymer over lifetime of project
- Discharge of produced fluids, Opportunities for re-injection
- Large volumes and costly logistics

R&D

- Extent to higher temperatures and salinities
- Shear behaviour: shear thicking versus shear thinning → new materials e.g. associative molecules??
- Bio-degradability
- Improved surfactant selection process using less chemicals
- Reduce IFT without creating emulsions

Gas EOR

Complexity

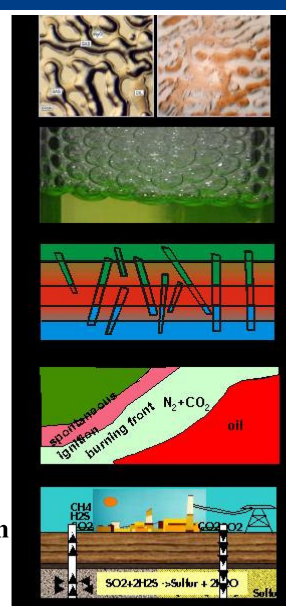
Miscible gas drive, CO_2, WAG

Foam diversion

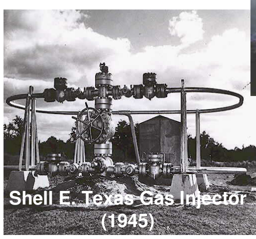
(thermal) GOGD

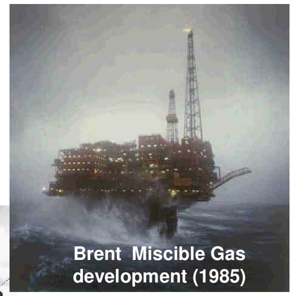
Air injection

Alternative gas injection



Gas Flooding, History pre-2000


Shell E. Texas Gas Injector (1945)

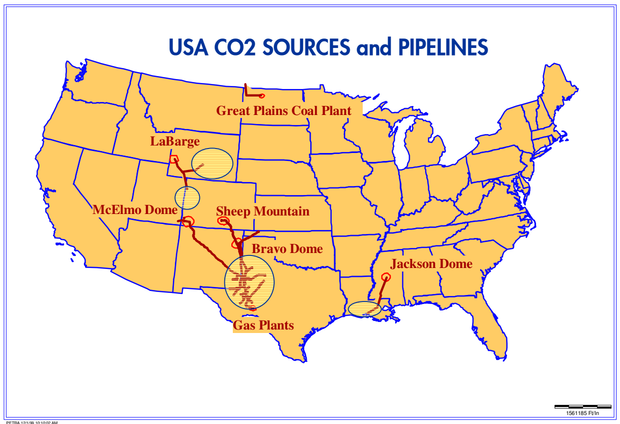

Brent Miscible Gas development (1985)


Shell Denver Unit (1995)

Current Gas EOR activities

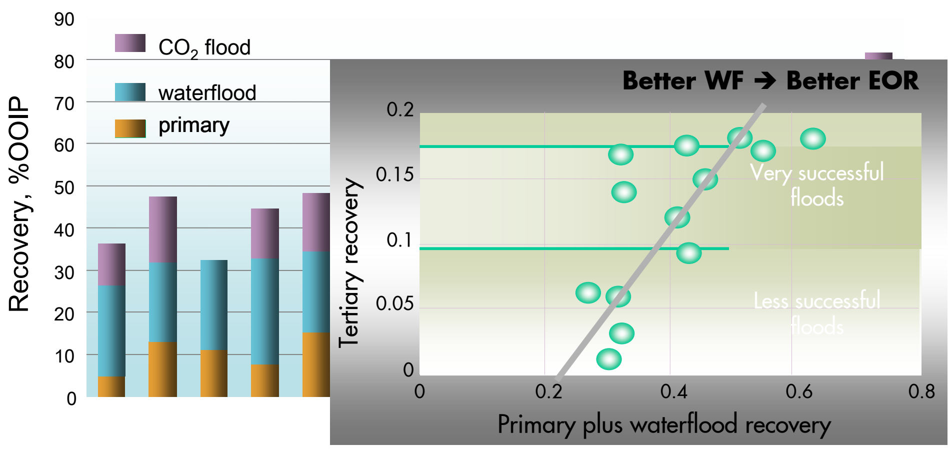
- **Miscible gas drives**
  - Kashagan EP450 [Kazakhstan]
  - Harweel [Oman]
- **GOGD**
  - Fahud & Natih
  - Thermally Enhanced GOGD
- **Flue gas or Air injection**
  - Pilot design
- **Studies for CO2 sequestration**
  - In USA, UAE, North Sea, Big thermal projects

CO2 Miscible Gas Injection
Taking a Game We Know into the Future



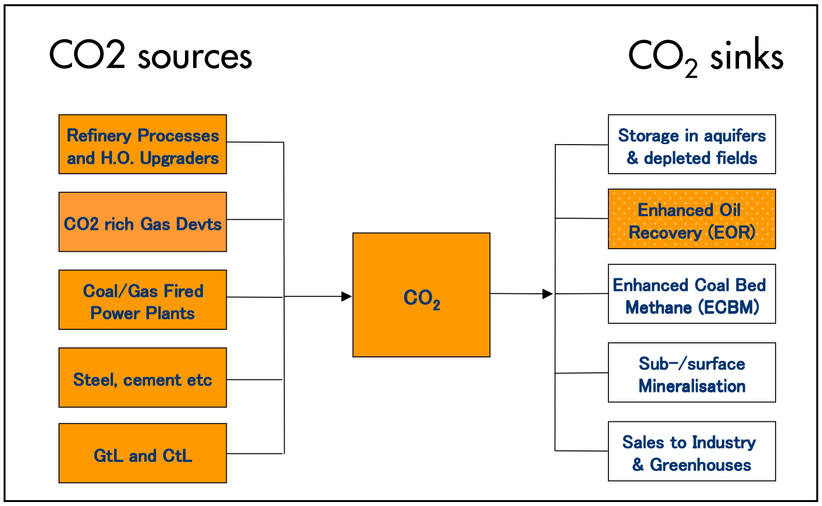
- Proven Technology
  - 30+ years experience
- Difference for the Future:
  - Anthropogenic CO2
  - Carbon Capture and Storage alternatives
- Next Wave Integration
  - Source-Sink frameworks
  - Cost reductions
  - Recovery improvements

West Texas CO_2 flood Recovery factors

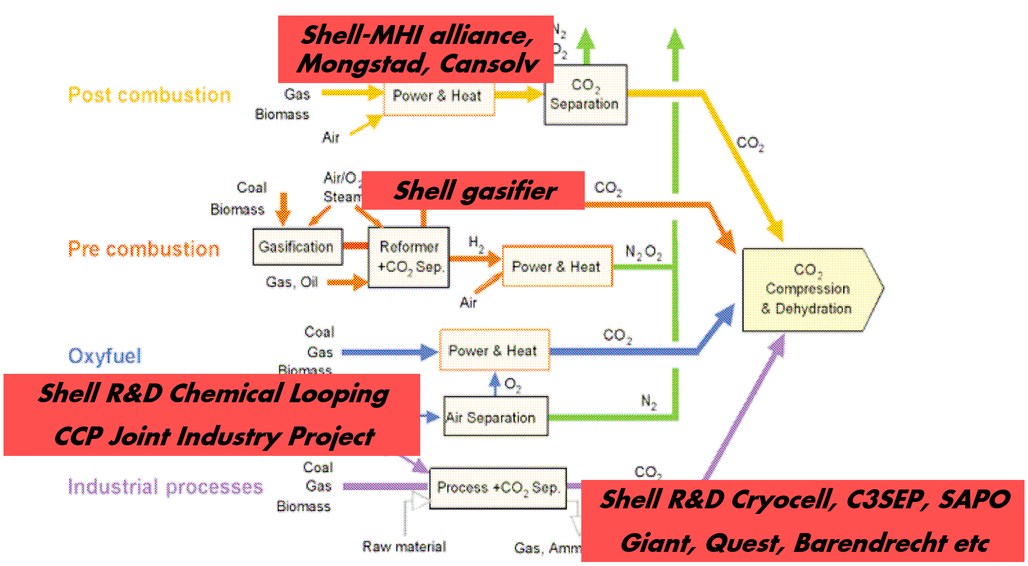


- High RF is achievable
- Requires good secondary development

CO2 EOR: Matching sources with sinks

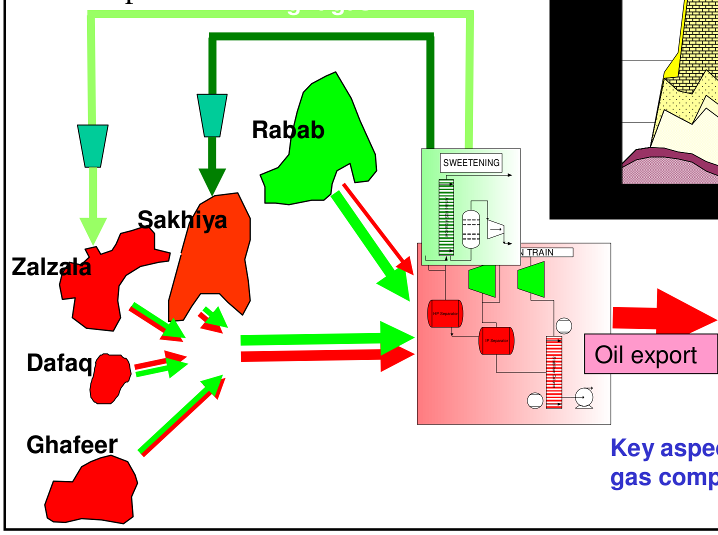


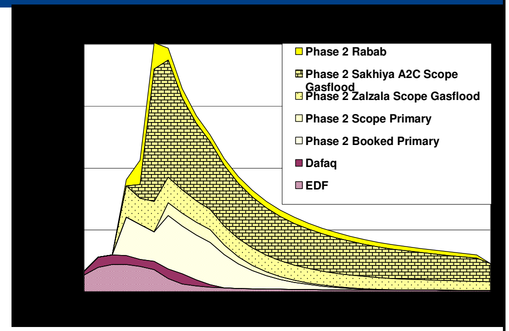
Link to power generation options



Harweel Gas Injection Project

South Oman
Deep carbonates in salt

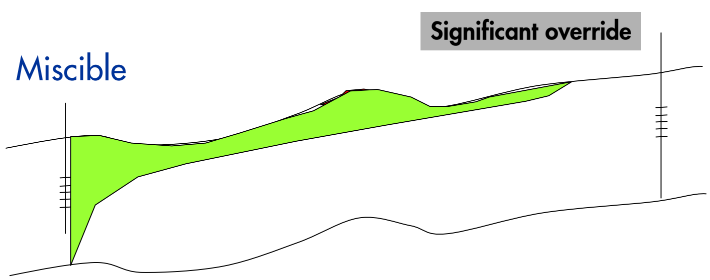




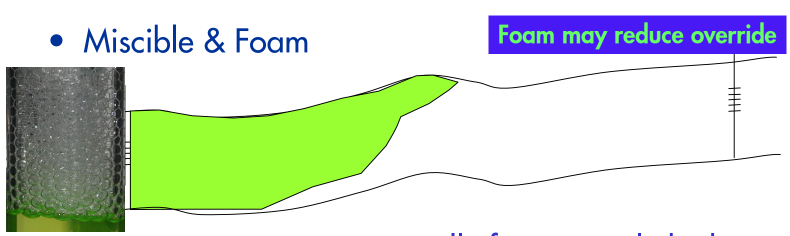
Key aspect is to adjust injected gas composition per target field

Using foam to improve sweep and lower Sor

- Miscible



- Miscible & Foam



Especially for CO2 – linked to CSS