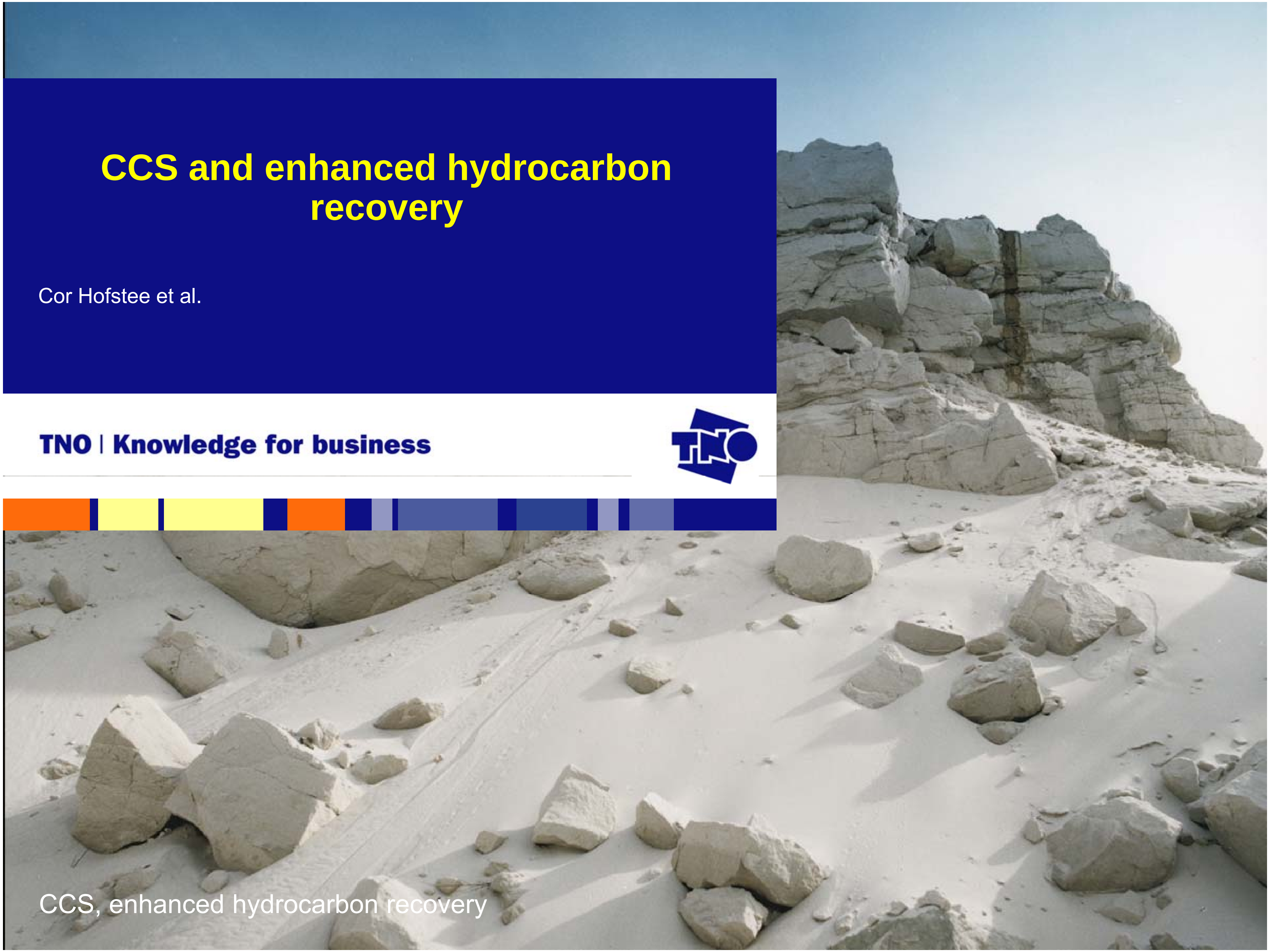


CCS and enhanced hydrocarbon recovery

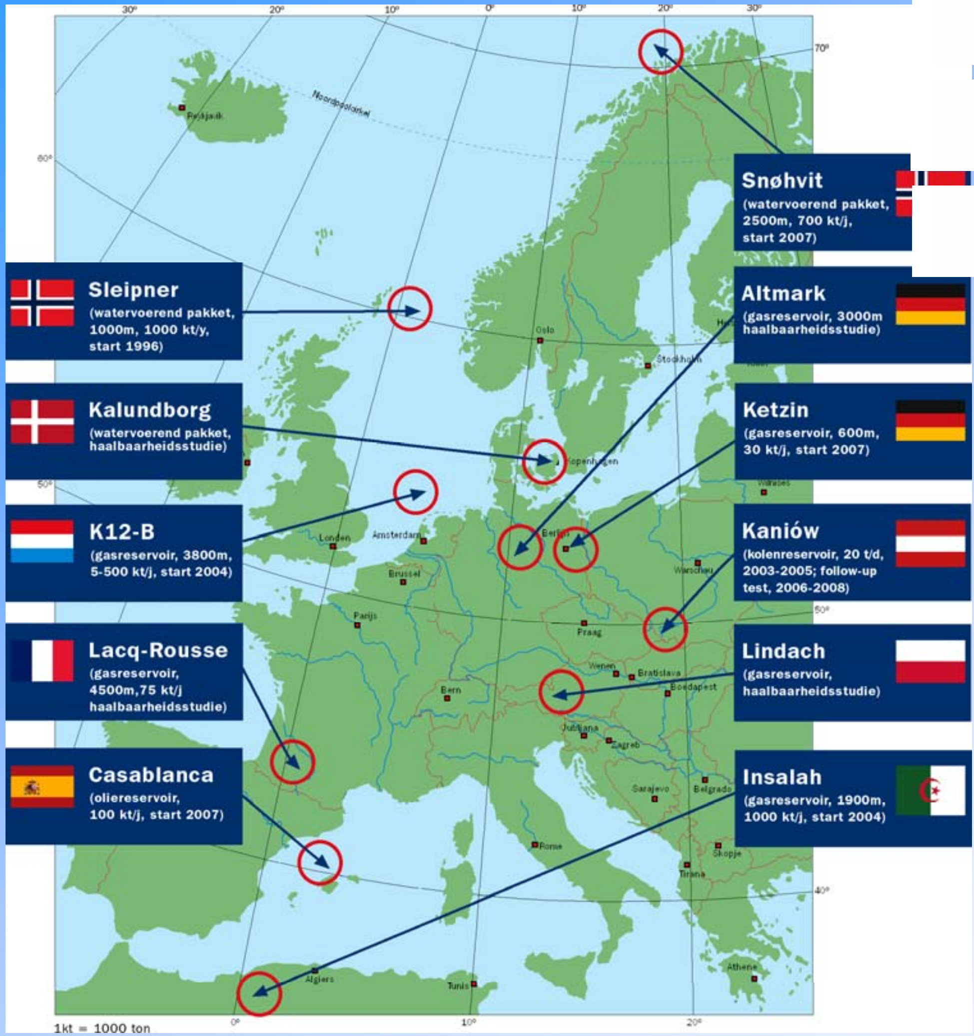
Cor Hofstee et al.

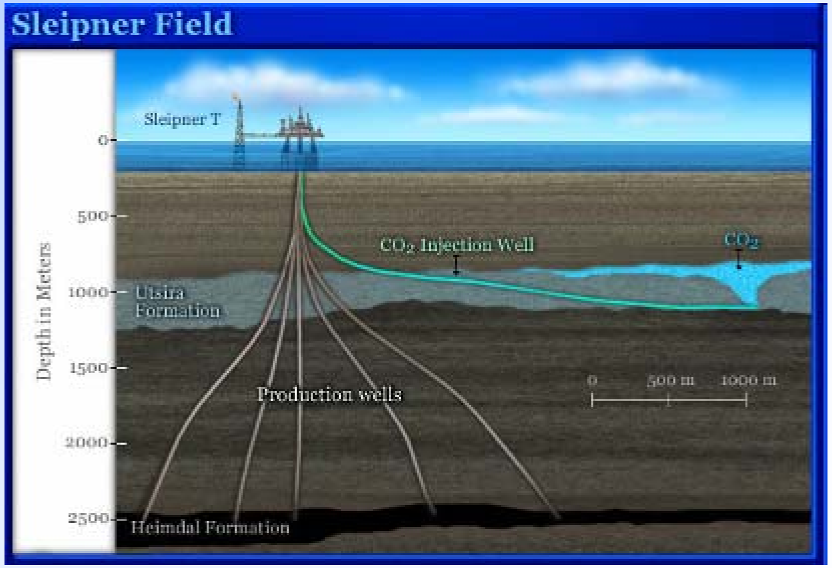
TNO | Knowledge for business

CO_2-Injection in Europe

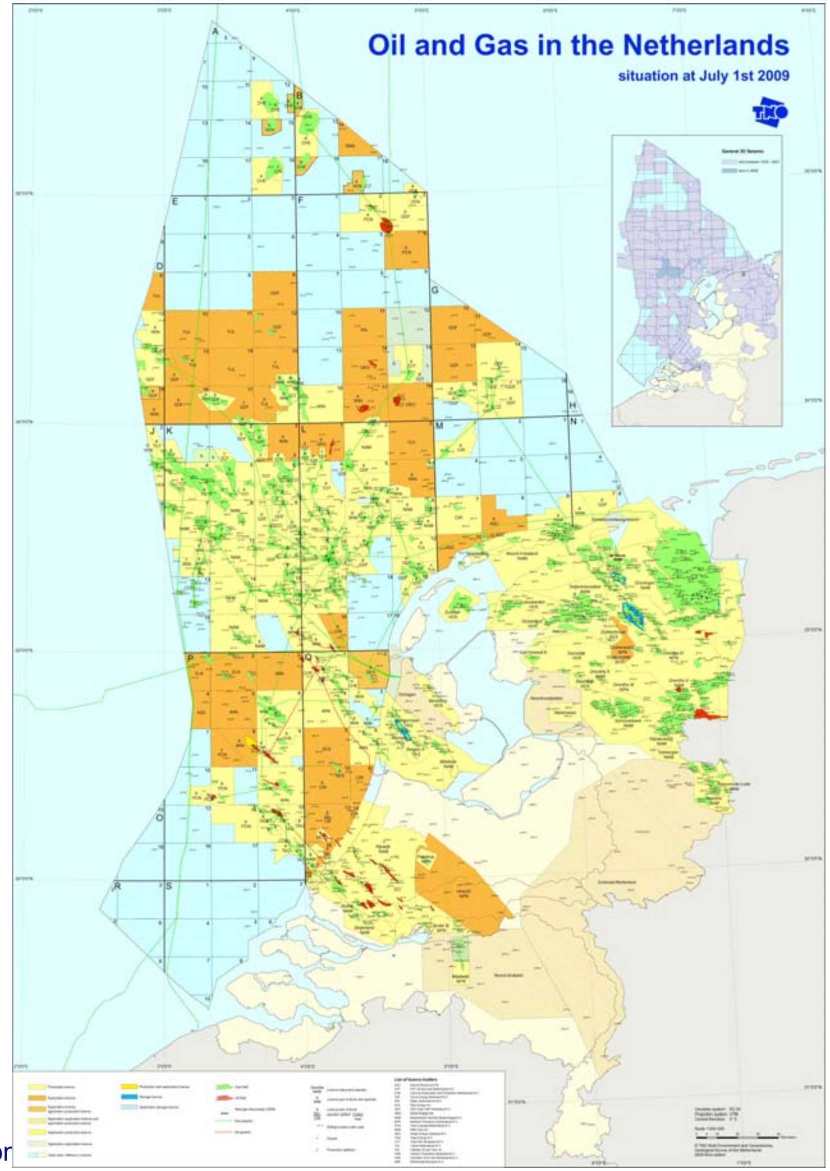
1996 – Norway, start Sleipner

2004 – Injection at K12-B (ORC)



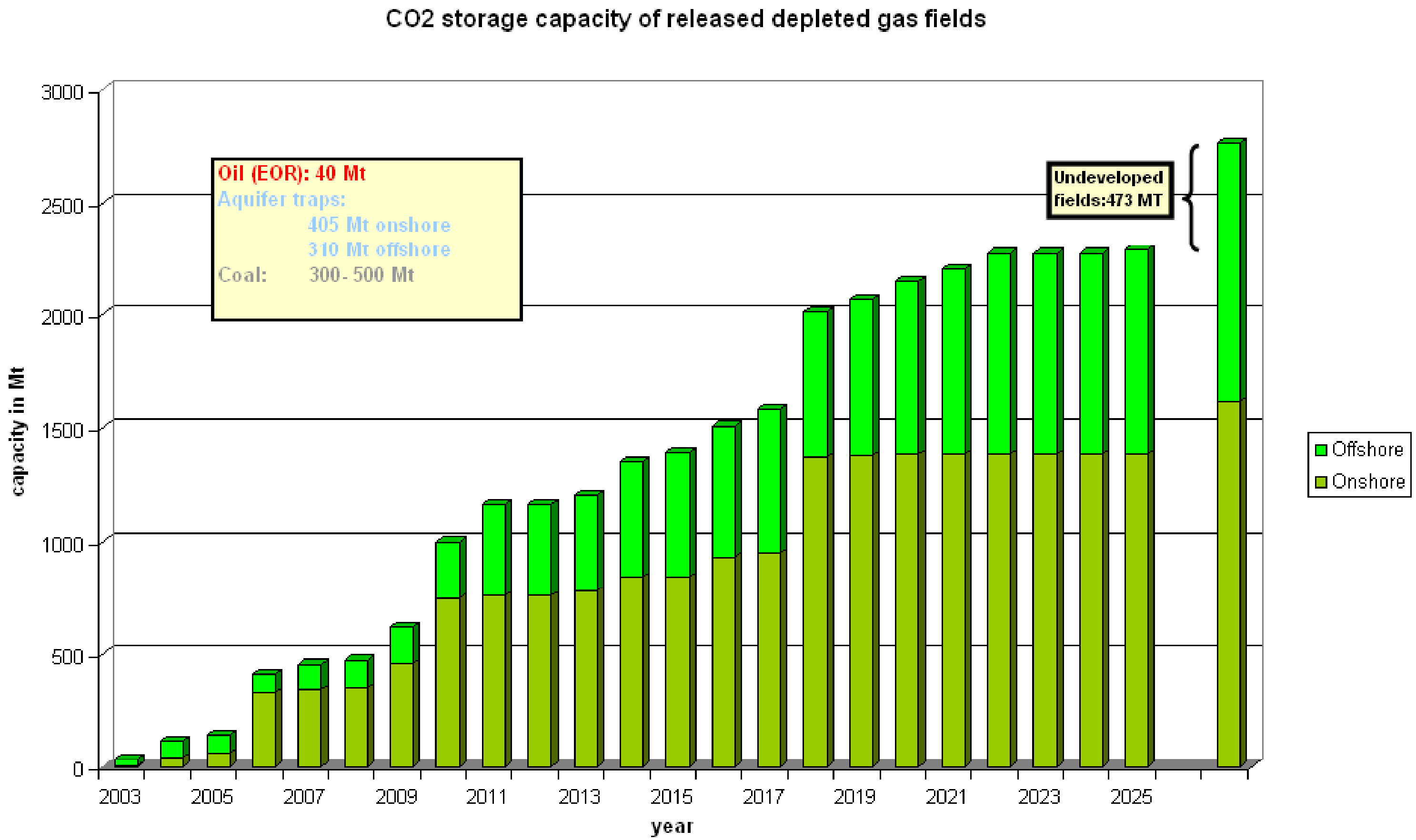


Storage opportunities



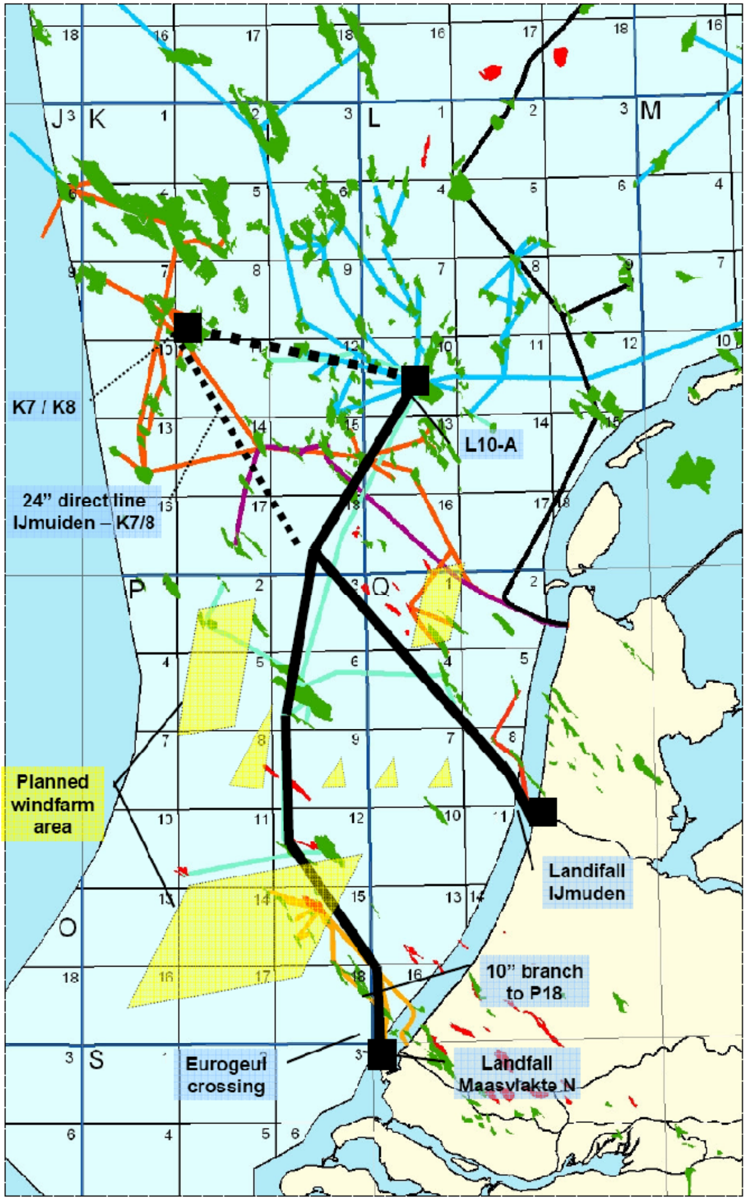
CCS, enhanced hydrocarbon

Theoretical Storage capacity



Off-shore fields

- Pipelines


K7 / K8
L10-A
24" direct line
IJmuiden – K7/8
Planned
windfarm
area
Landfall
IJmuiden
10" branch
to P18
Eurogeul
crossing
Landfall
Maasvlakte N

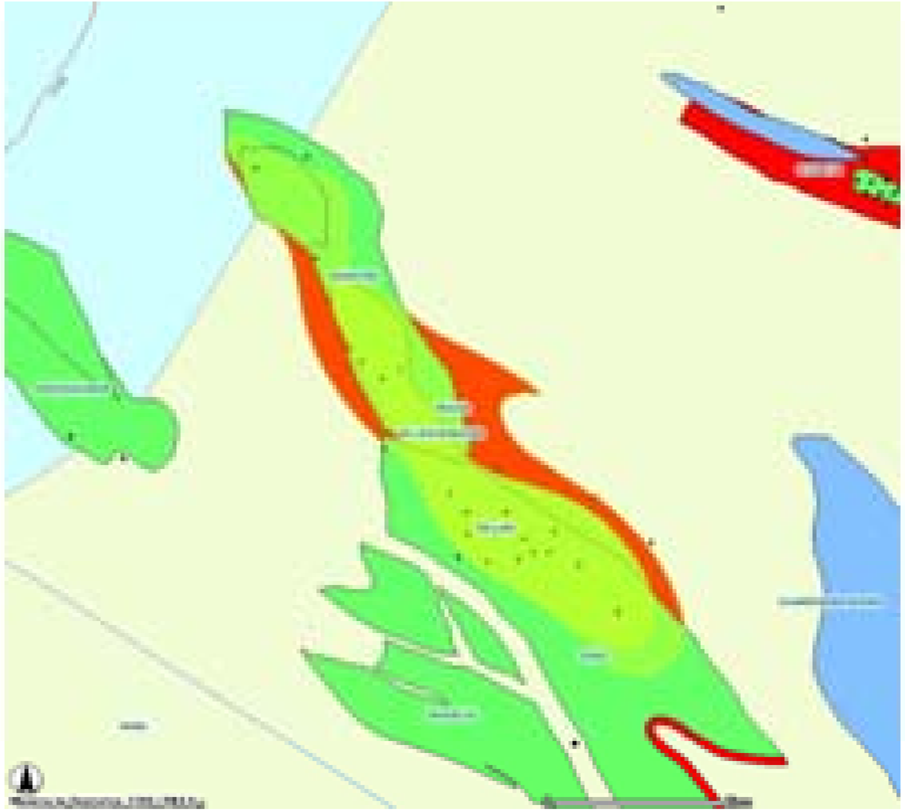
On-shore fields

Public perception

Competition of gas storage etc.

Risk assessment

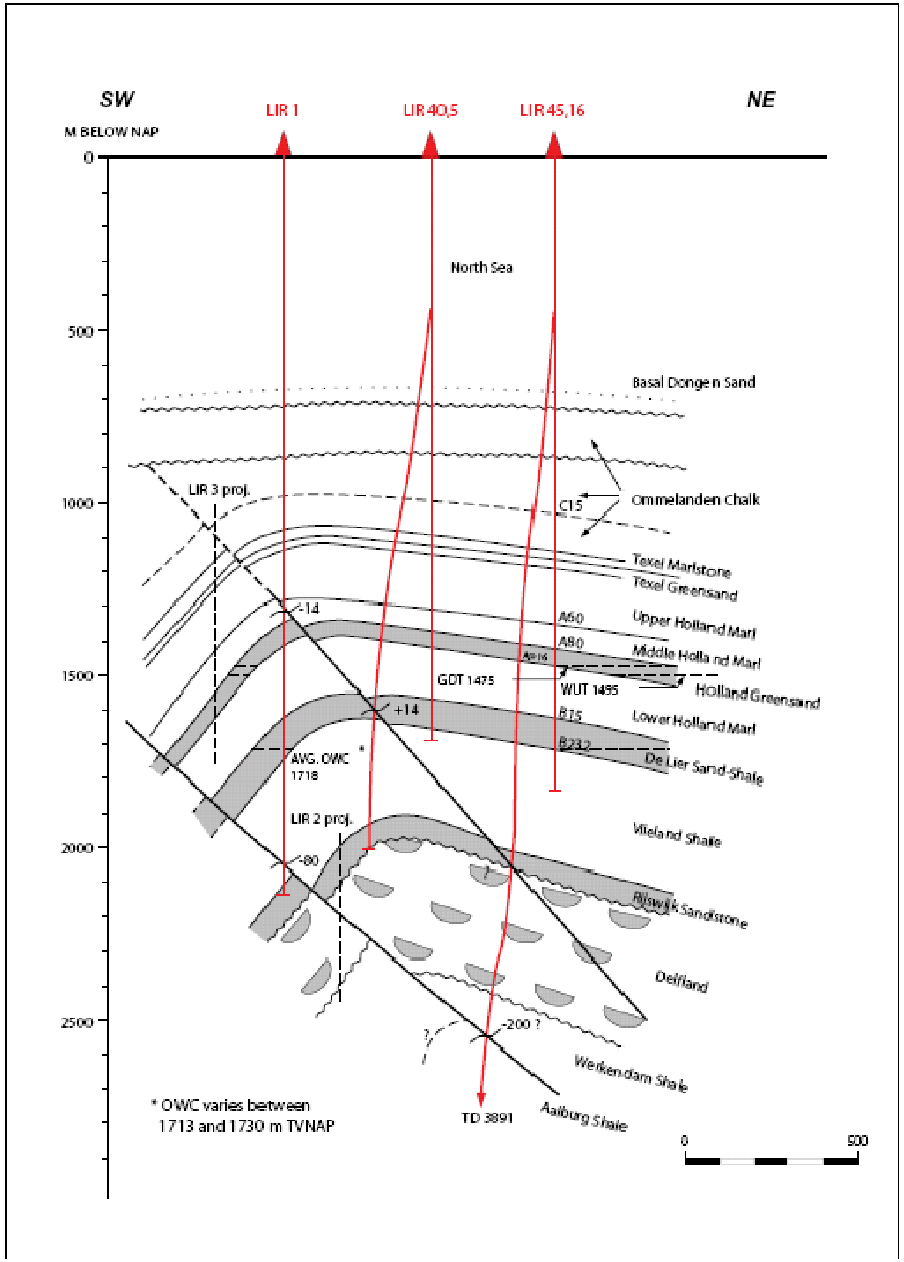
De Lier Field Background/History



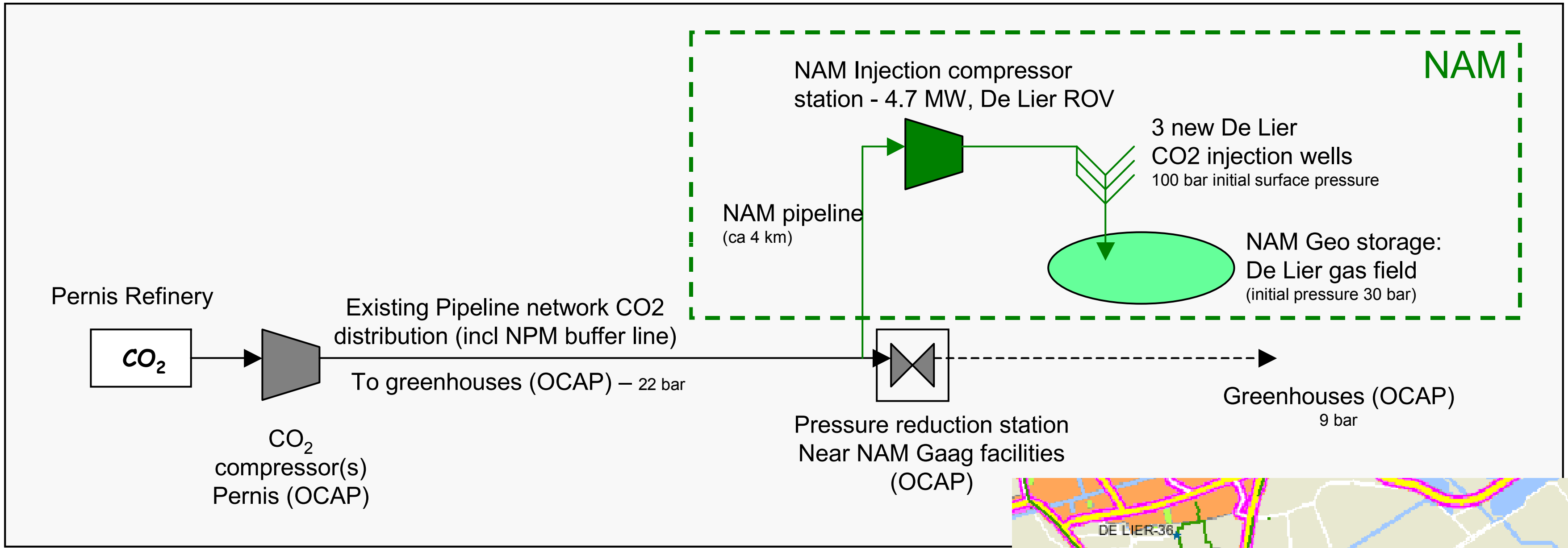
-Shallow (1400-1600 m) Gas field & Oilfield. 53 wells drilled
-Production started 1958
-100% NAM share (Rijswijk Concession)
-11 wells for gas production, 9 wells produced, peak 0.6 mln Nm3/d
-Production Ceased 1992

The wells

- Stacked reservoir
- Most wells completed in lower oil stack
- CO_2 injection in shallower depleted gas stack

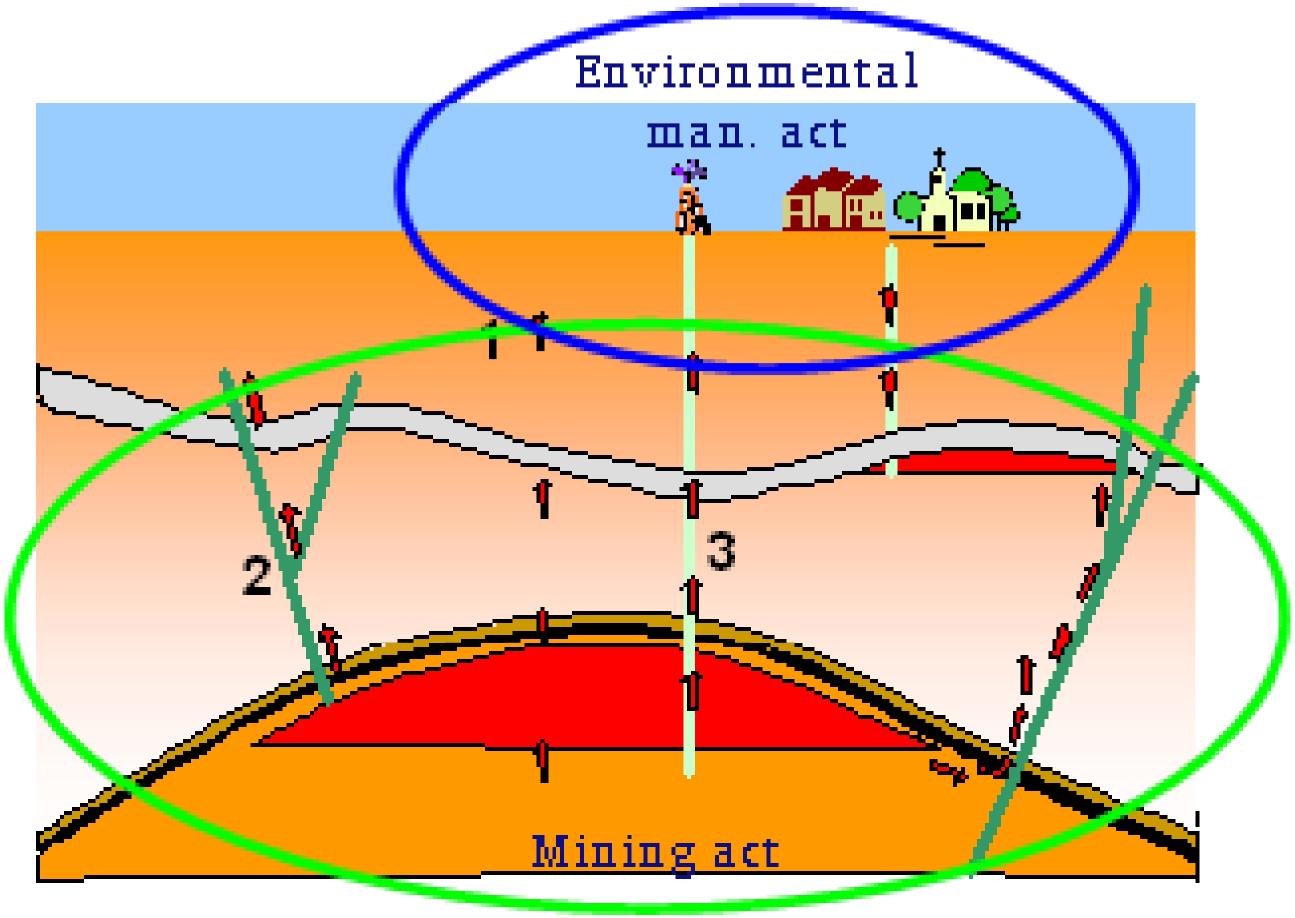


Notional Surface Scope

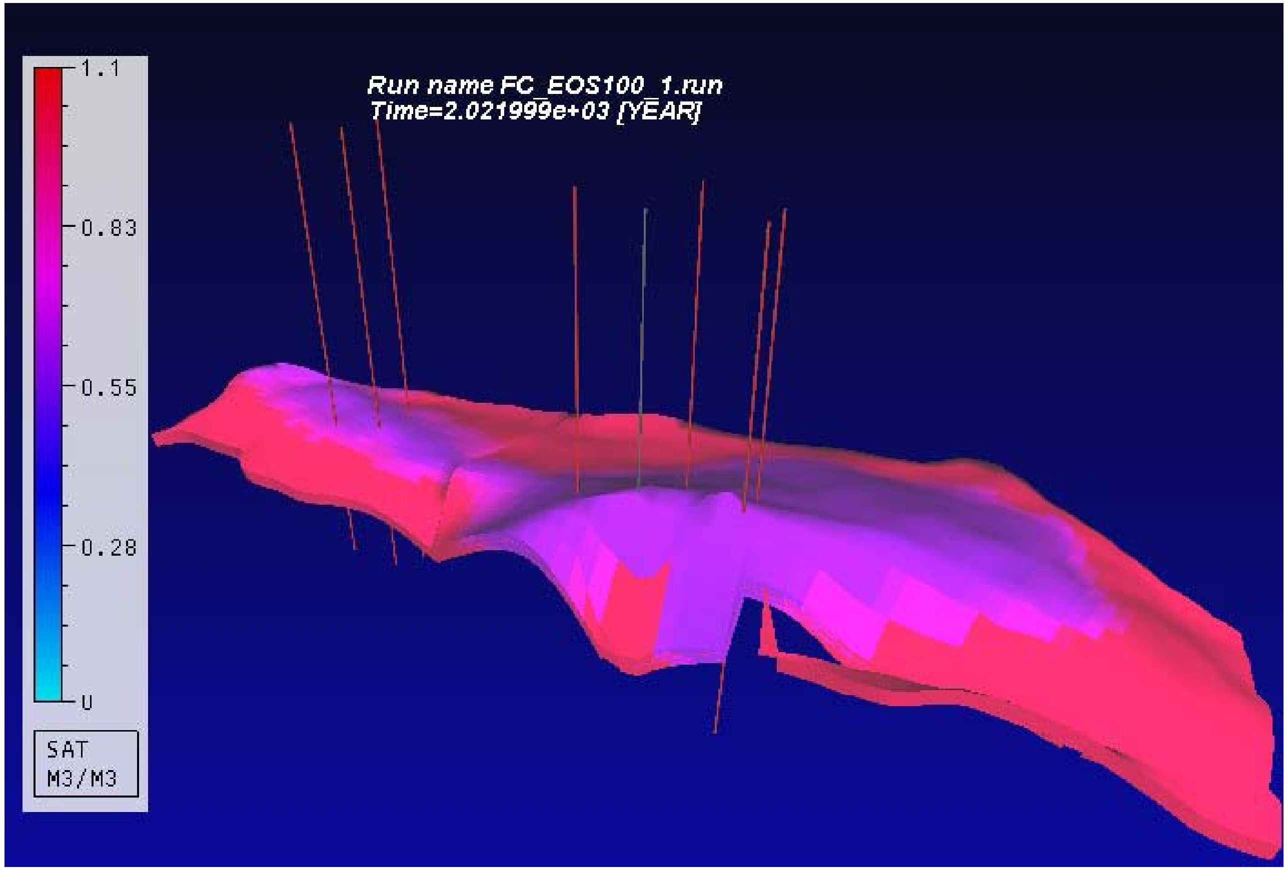


Hazard analysis

- Leaking Seal
- Leaking Fault
- Leaking Well



Compositional Reservoir simulation



PVT (CO_2)

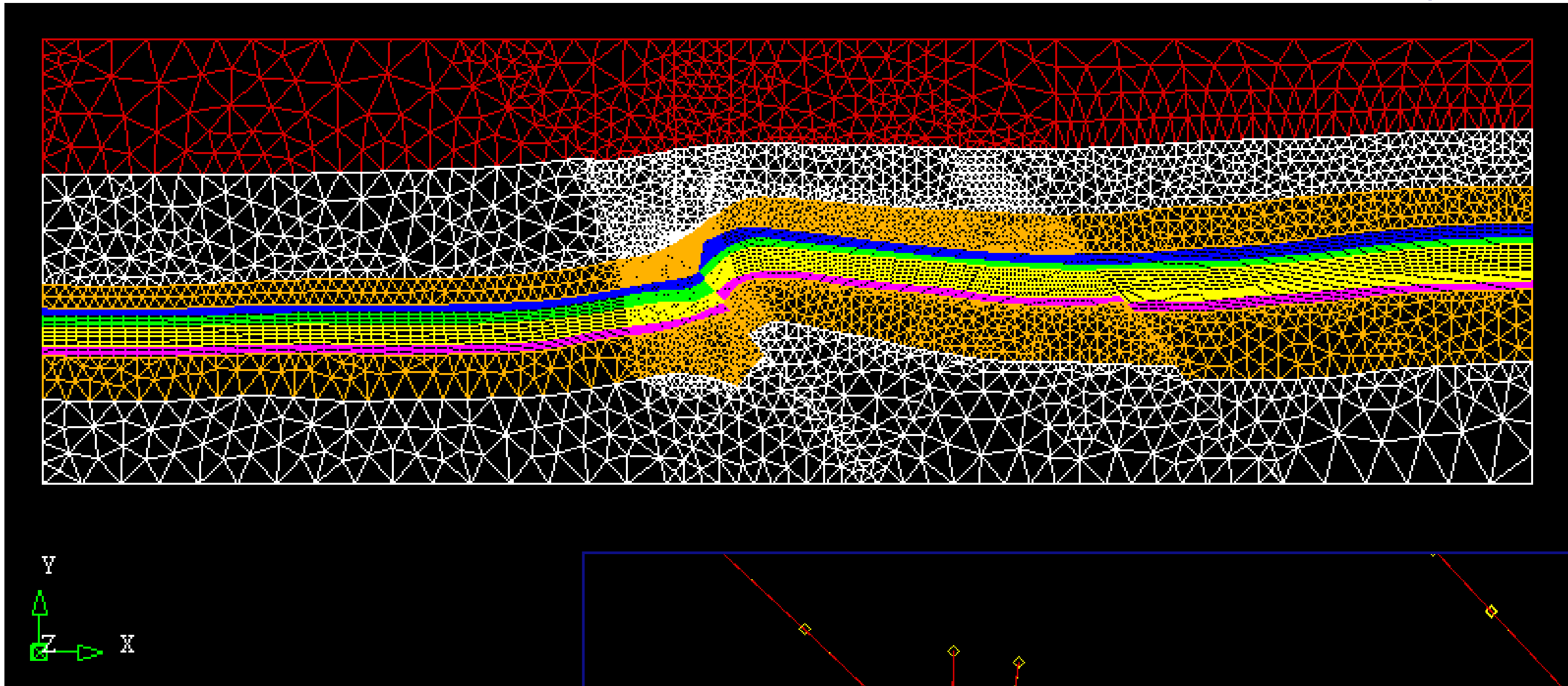
Transport and behavior (CO_2 and other gas Components)

Injection strategie

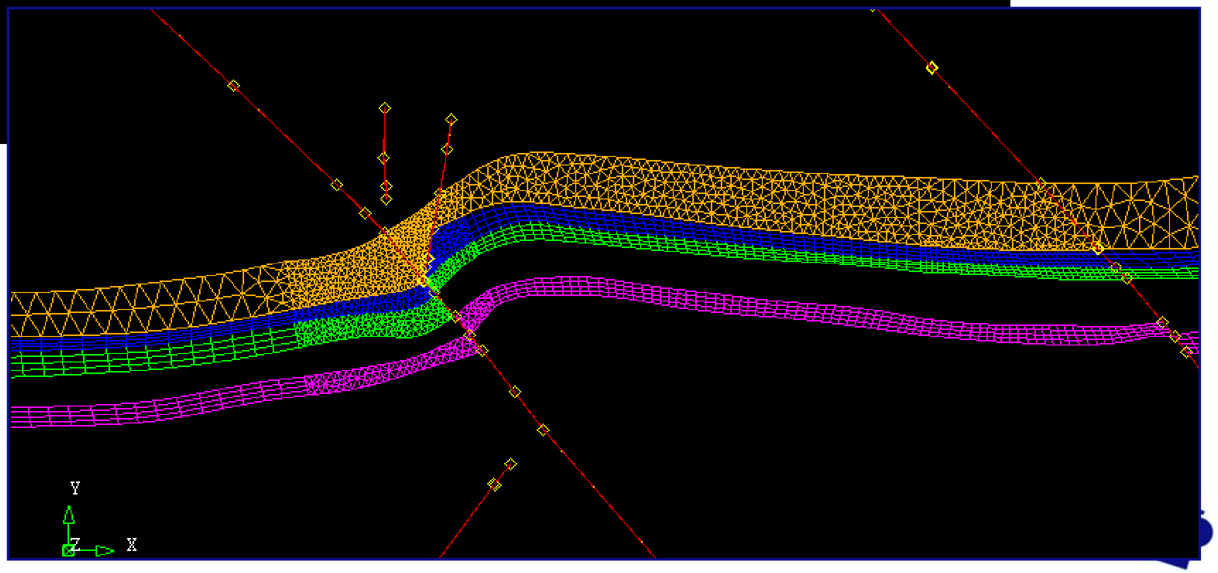
Input data

SEAL/FAULT integrity

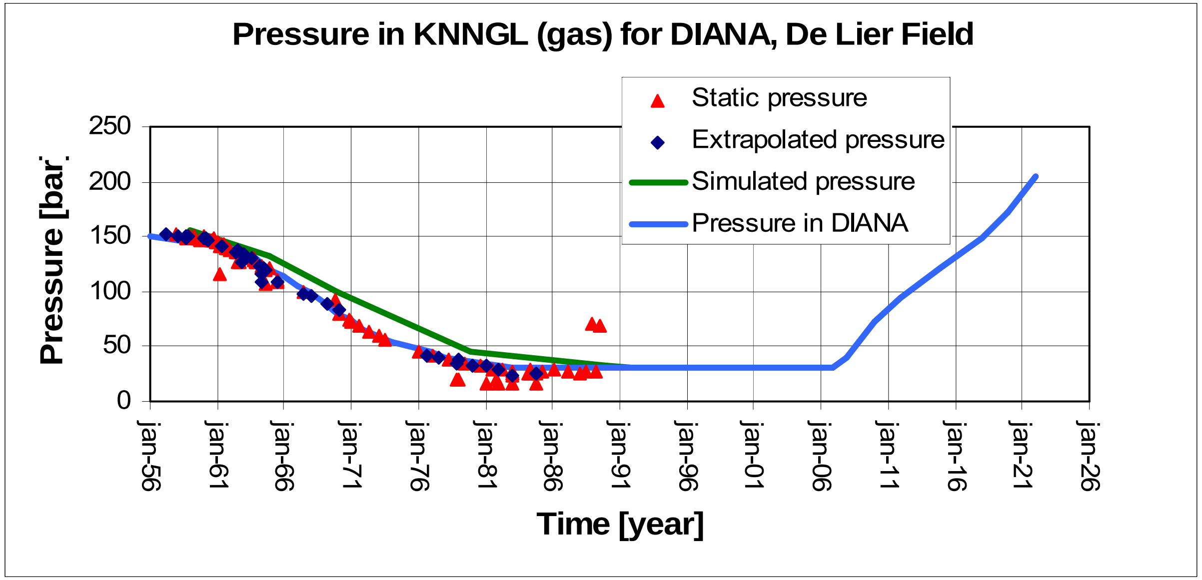
Model: A 2D FE DIANA model (10x3 km)

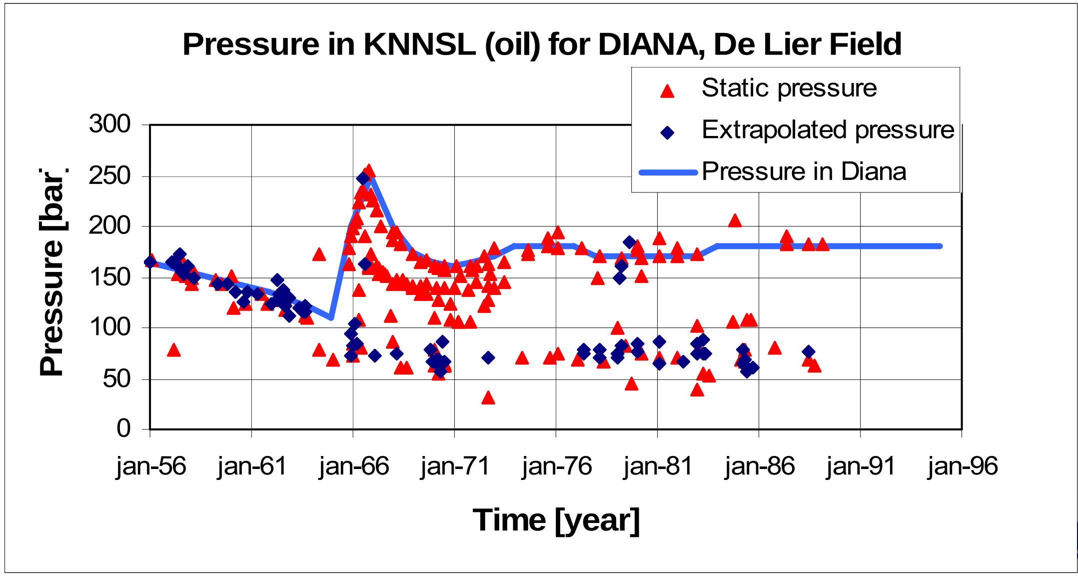


Fracture propagation: PWRI-Frac



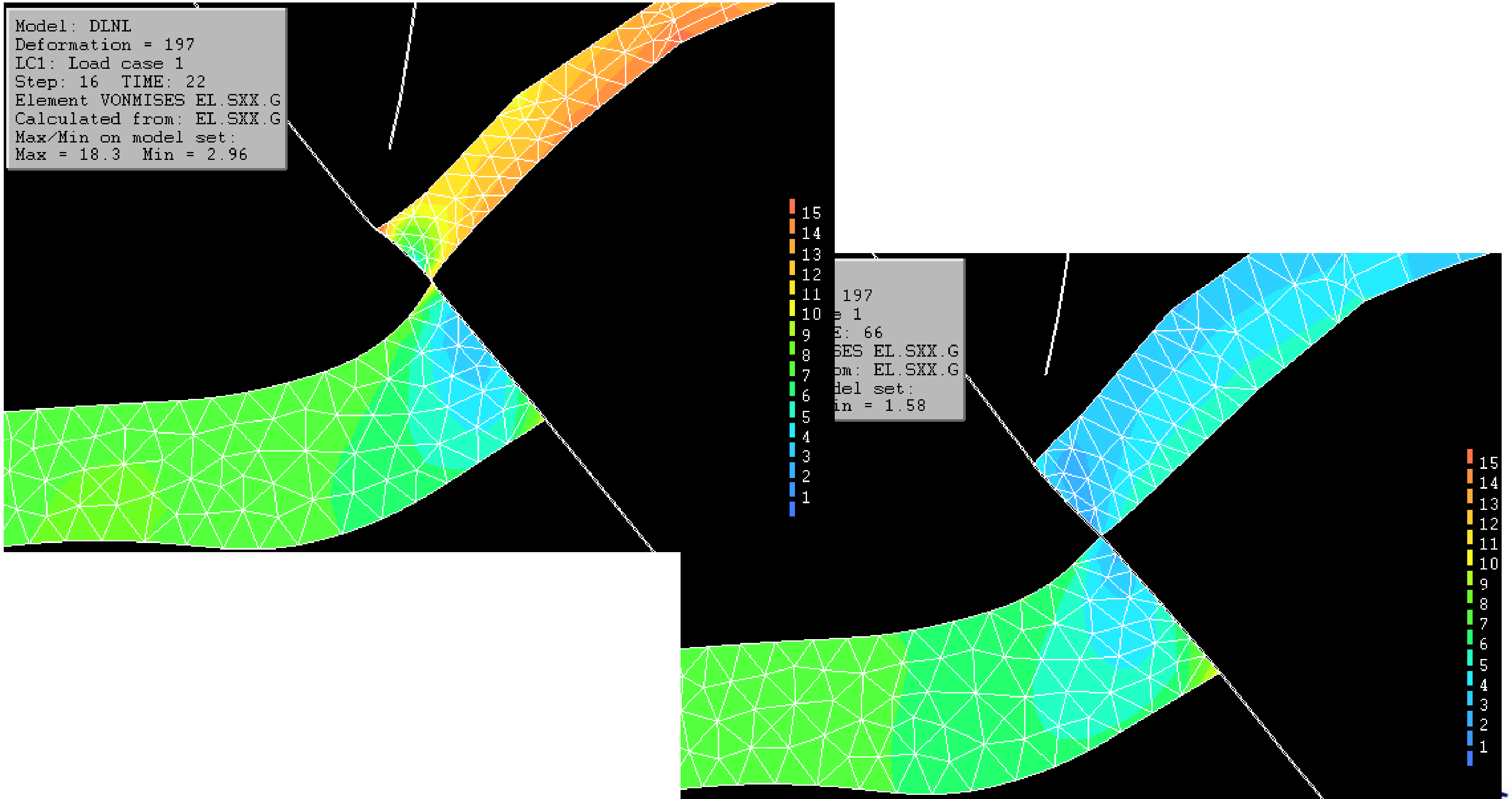
Model input: Pressures



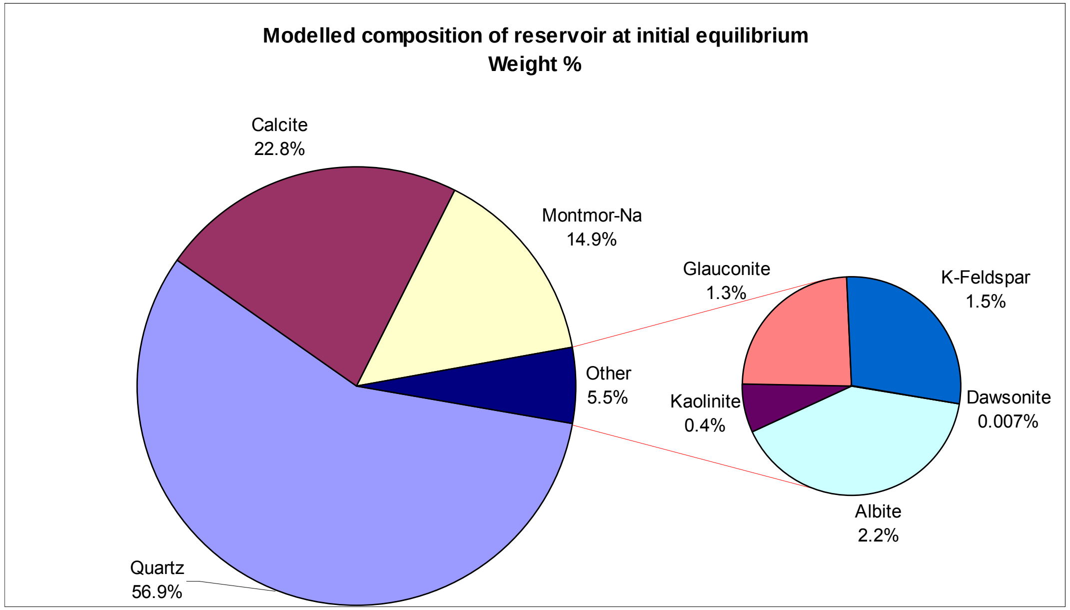


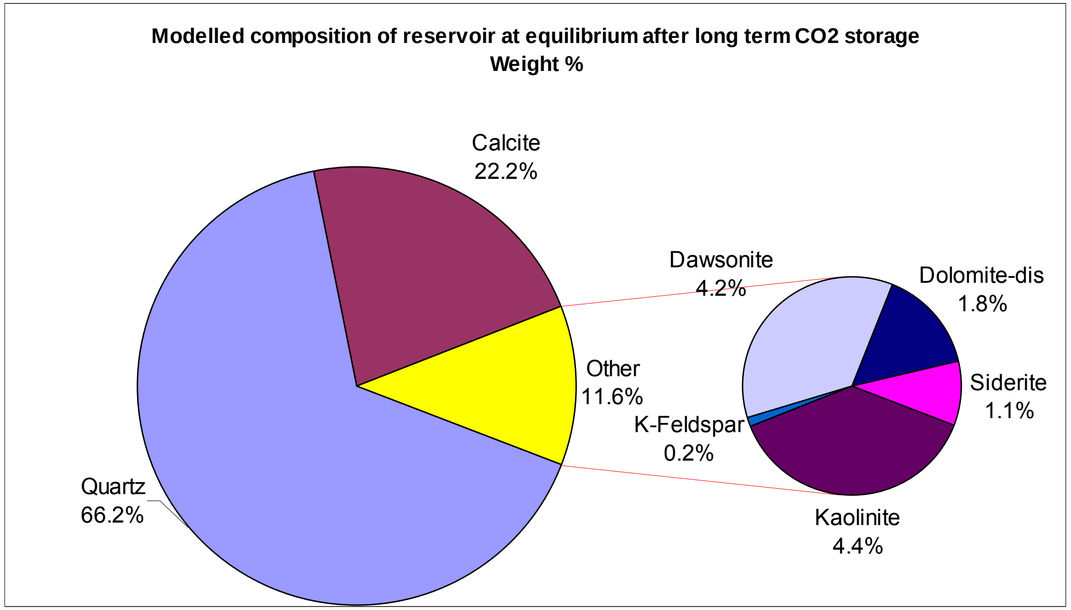
Results: stress change

The largest stress change at reservoir edges : depletion (left) and injection (right)



Long-term chemical effects in reservoir



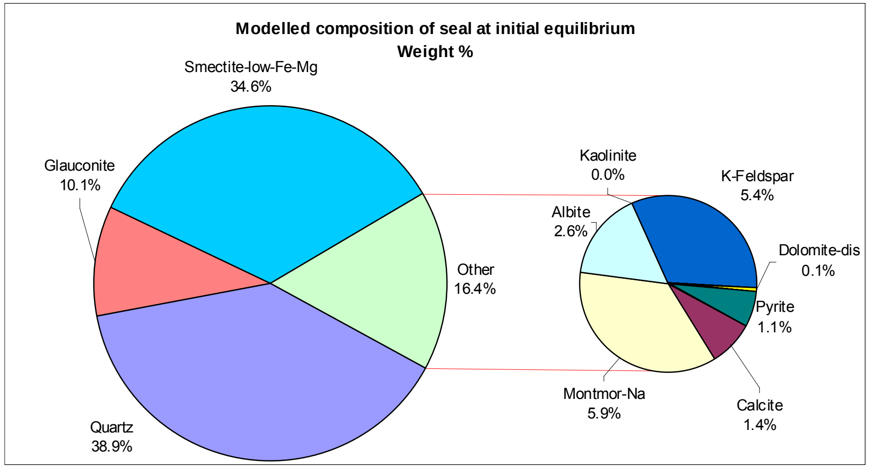


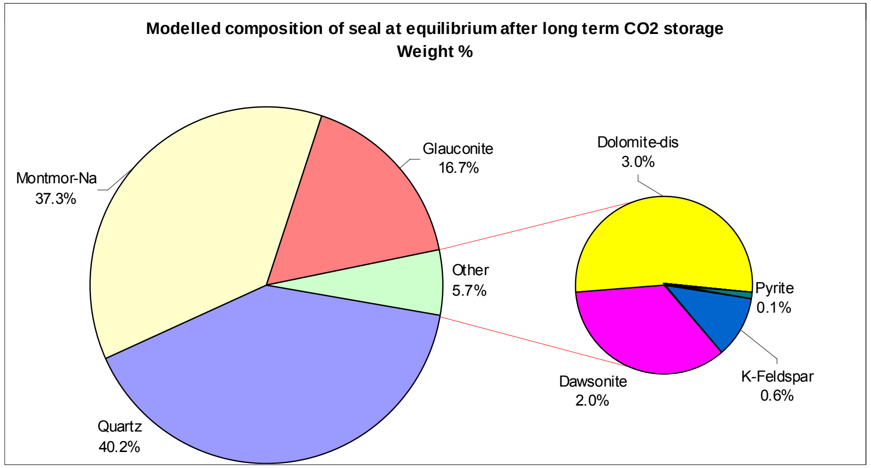
PHREEQC

High Quartz Content
Low chemical reactivity
Low buffering capacity

Increased porosity

Long-term chemical effects in seal

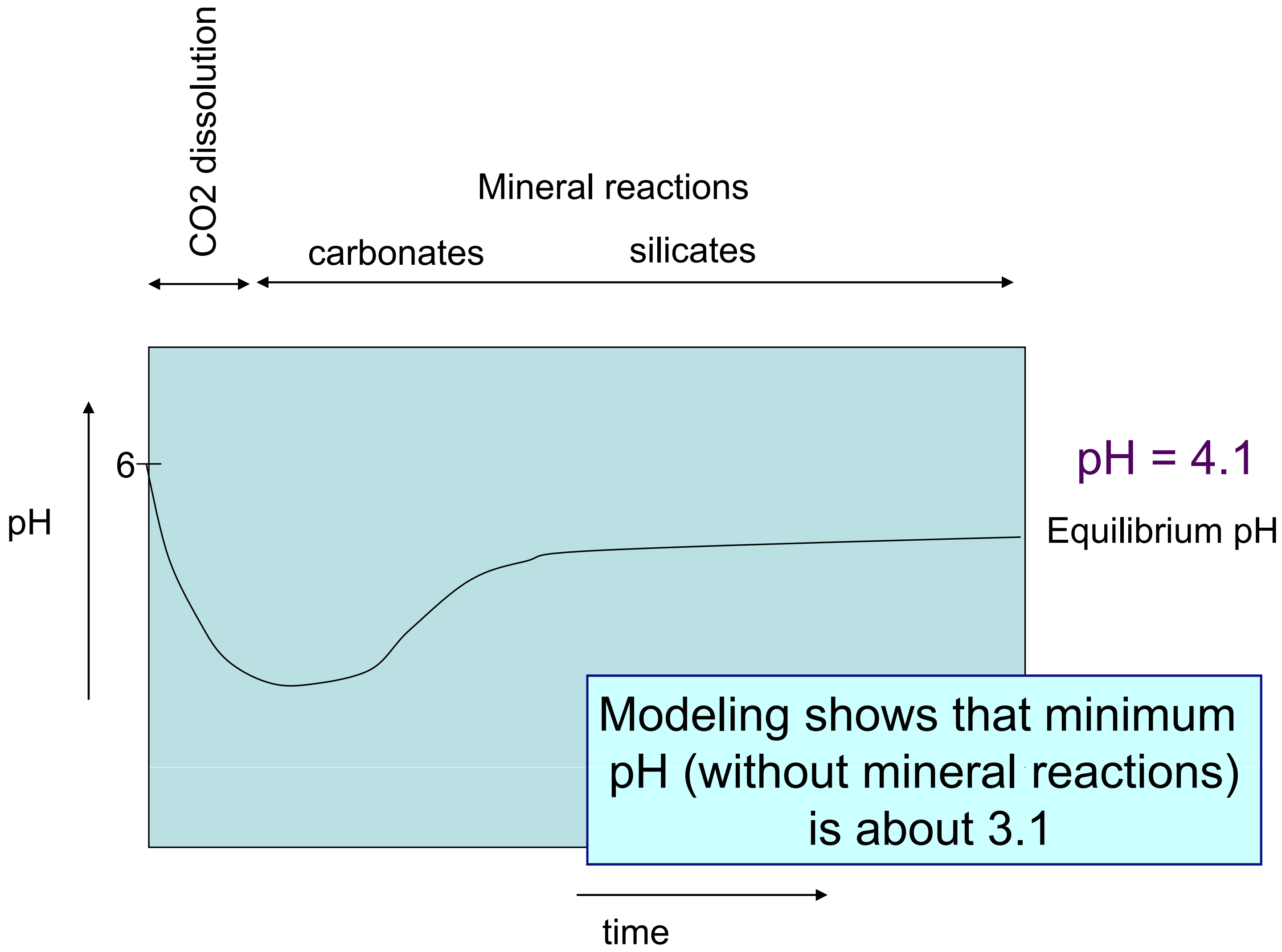




Significant re-arrangement minerals

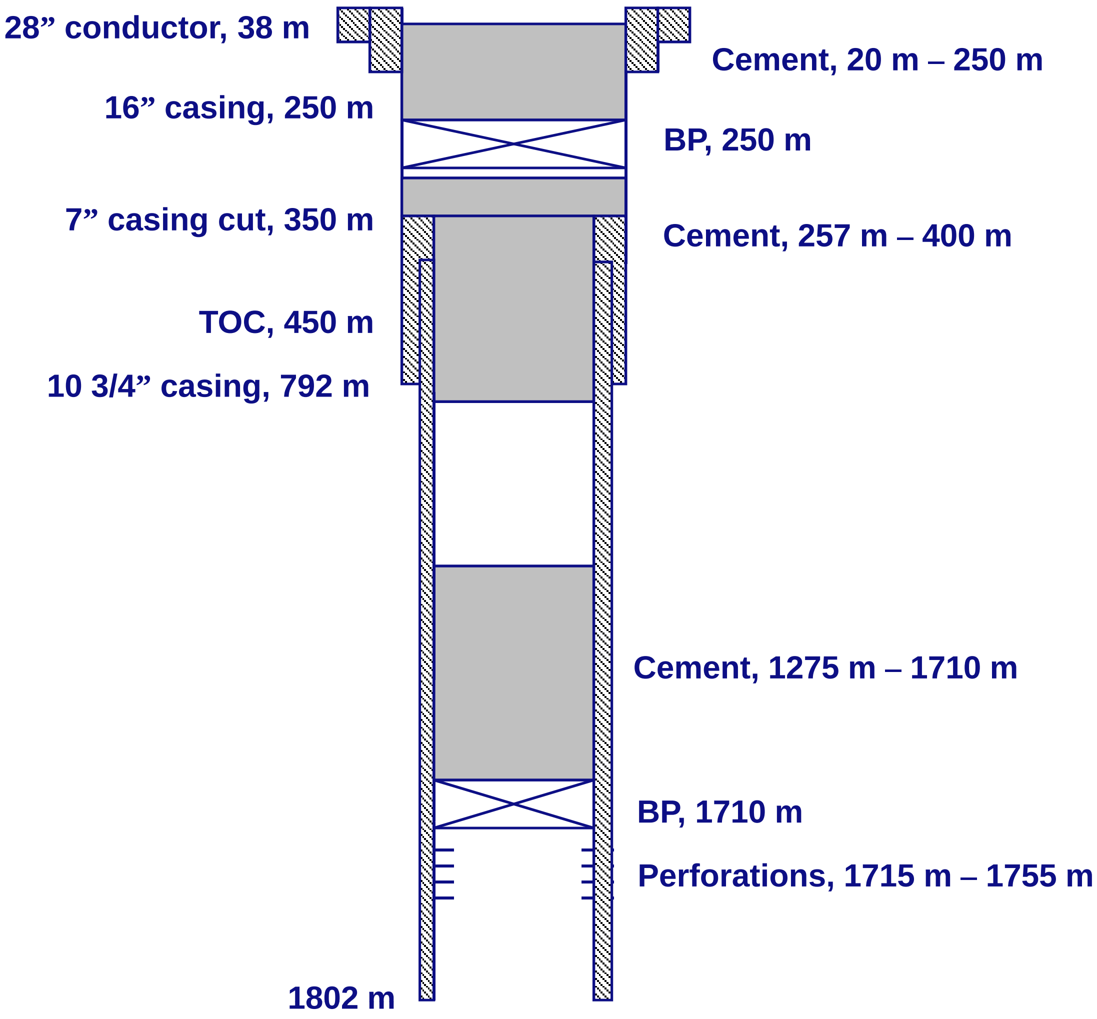
Decreased porosity

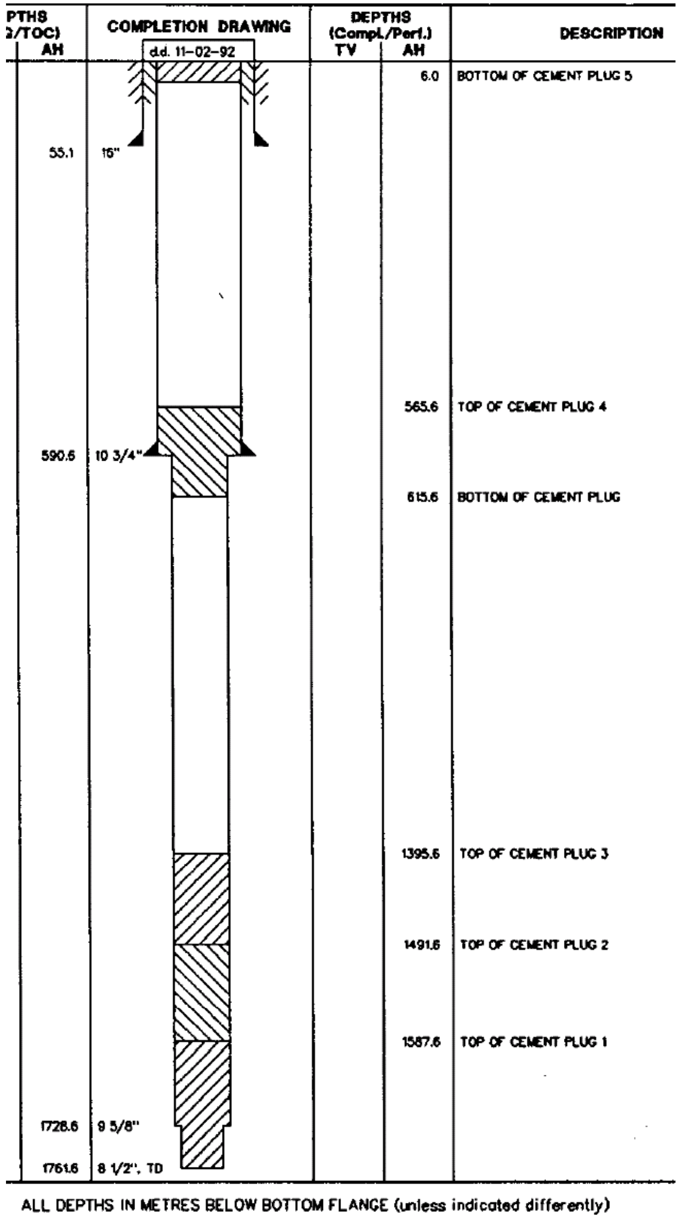
Short term chemical reactions



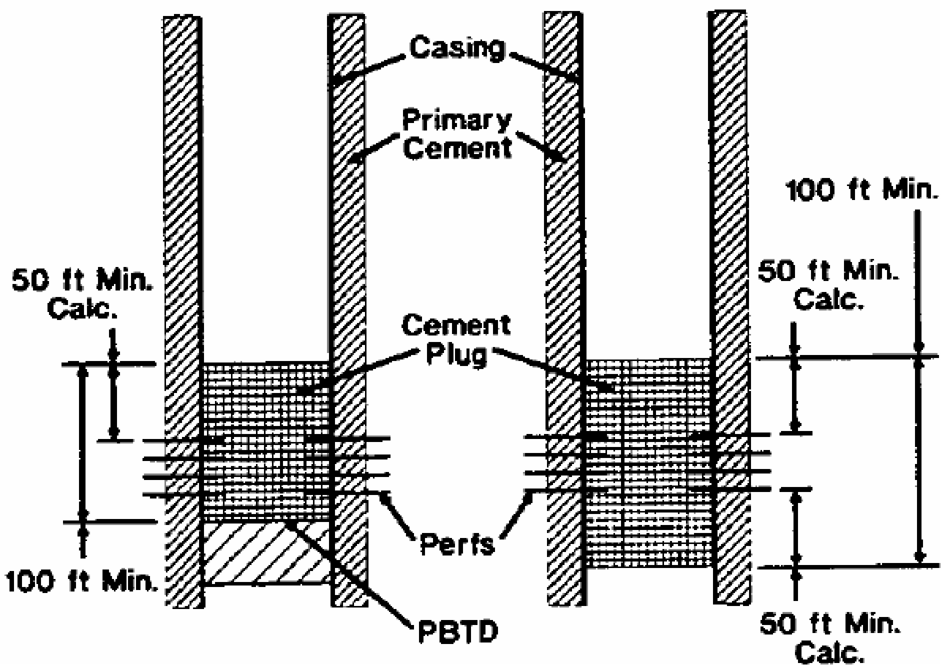
Modeling shows that minimum pH (without mineral reactions) is about 3.1

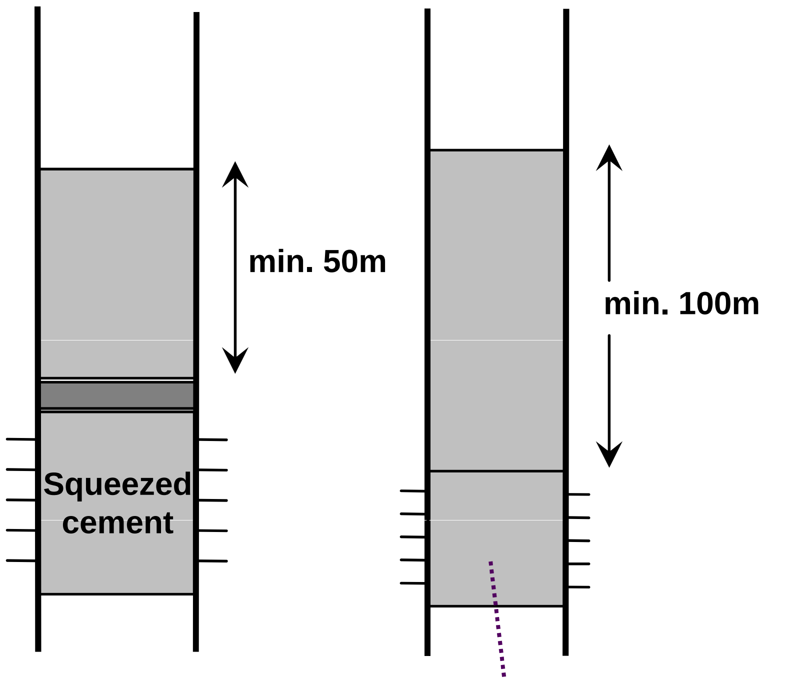
Examples of wells





Cement plug lengths according to Dutch Mining Law

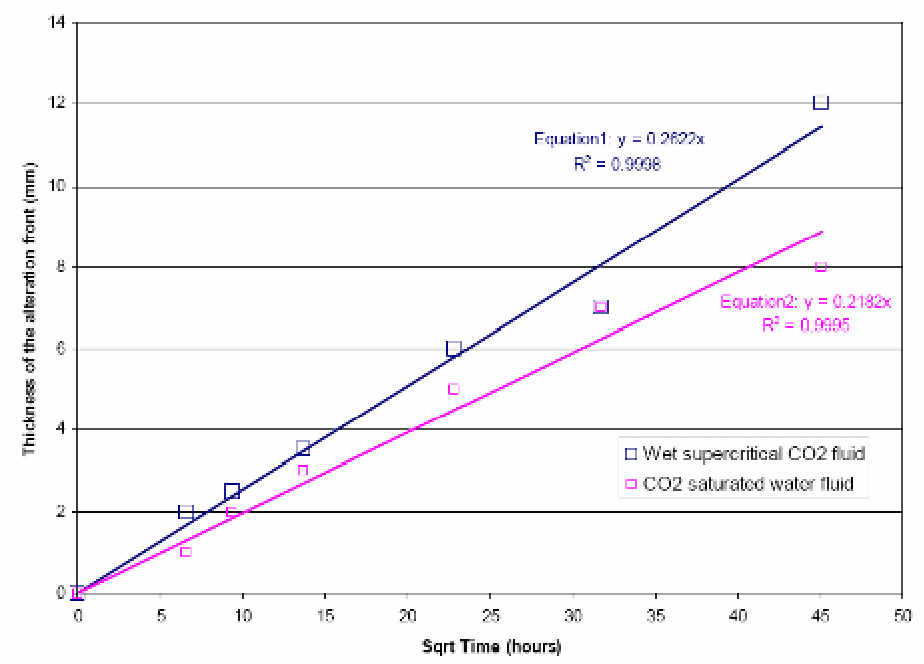


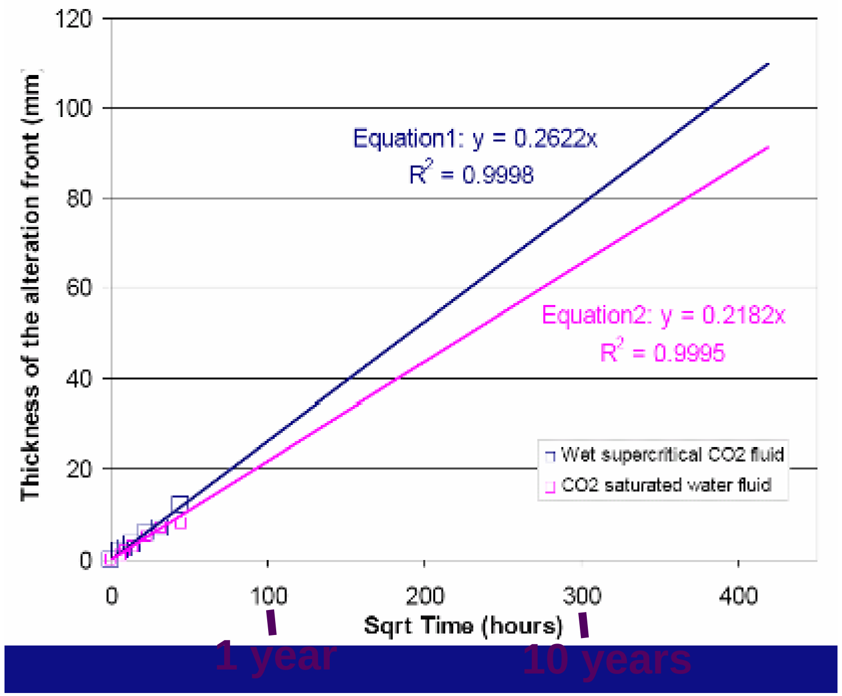


Bridge plug as close to top of perforations as possible

Cement at level of perforations is optional

Chemical degradation of Portland cement





Source: Barlet-Gouedard *et al.* 2006

Watersaturated supercritical CO_2 fluid: $d[mm] = 0.2622 \cdot \sqrt{t[h]}$

CO_2 saturated water fluid: $d[mm] = 0.2182 \cdot \sqrt{t[h]}$

Chemical degradation of Portland cement

Extrapolated from Barlet-Gouedard *et al.* (2006):

Plug length	Corrosion time (years)	
	Wet supercritical CO_2	CO_2-saturated water fluid
1 inch = 2.54 cm (primary cement sheath)	1.1	1.5
6 m (smallest plug length)	60,000	86,000
10 m	170,000	240,000
50 ft = 15.24 m	390,000	560,000
100 ft = 30.48 m	1,500,000	2,200,000
50 m	4,100,000	6,000,000
100 m	17,000,000	24,000,000

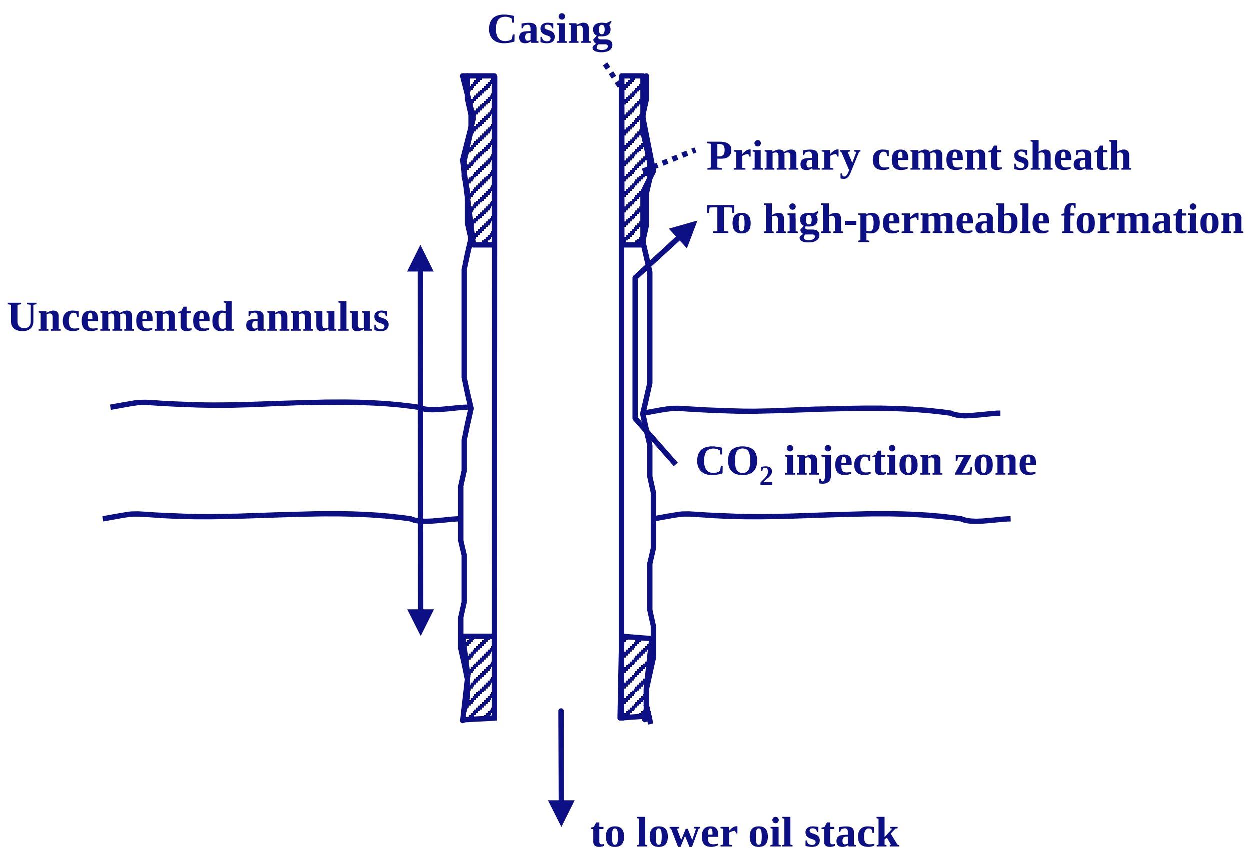
All plugs were pressure tested according to DML standards

Cement plug testing as prescribed by Dutch Mining Law

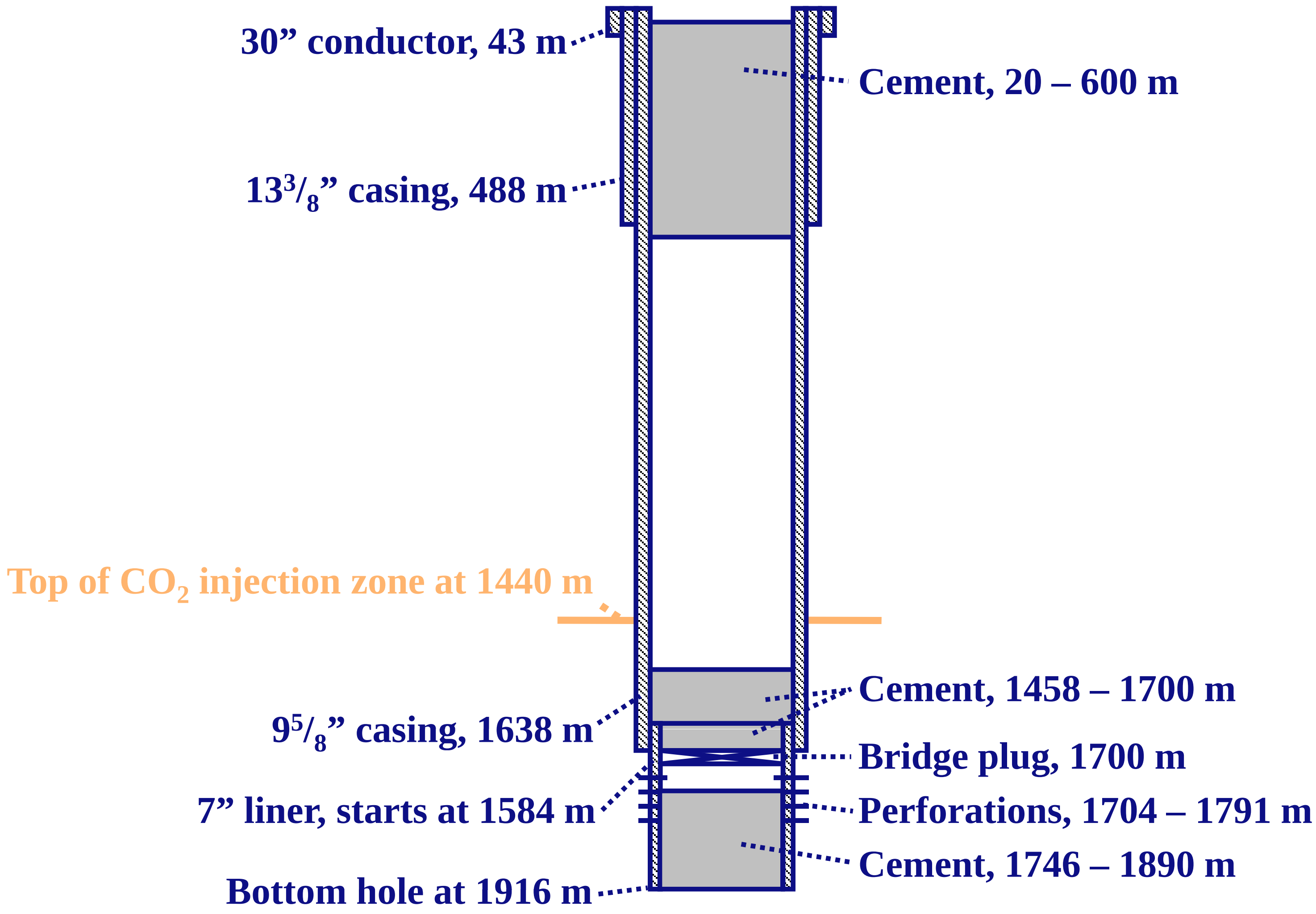
DML requires a cement plug to be tested
by passing at least one of the following tests successfully:

- Weight test of at least 100 kN
- Pressure test of at least 50 bars during 15 minutes
- Inflow testing the well and verification that no fluid or gas flows from the reservoir into the well

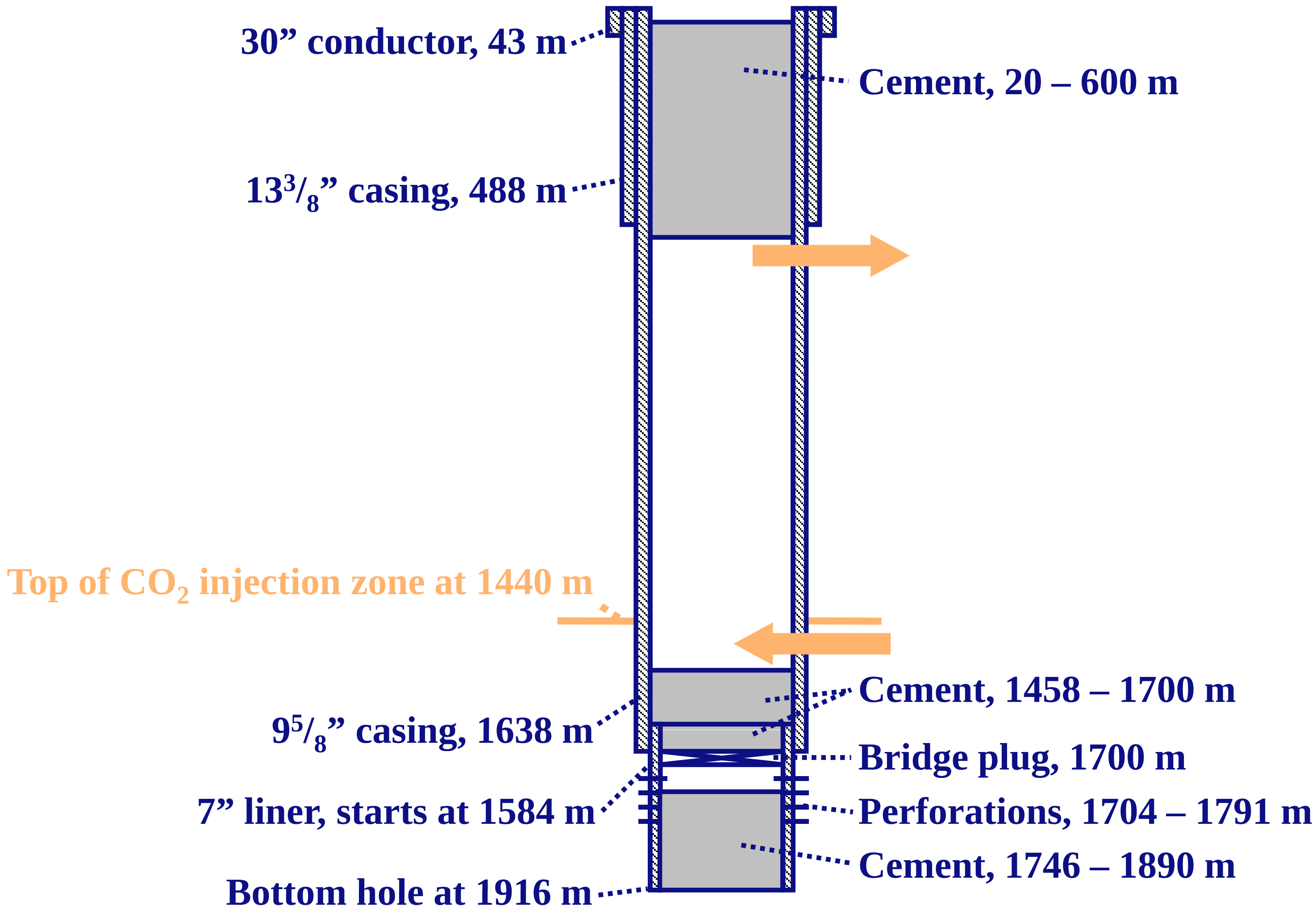
Two main concerns: the first



Two main concerns: the second



Questions: corrosion and leakage rates?



Resources used for rough corrosion rate estimation in radial well direction

Cement (1 inch)

- Barlet-Gouedard et al. (2006): > 1 year
- Duguid et al. (2006): < 700 years
- Duguid et al. (2004): ~ 60 – 110 years

Casing

- De Waard & Lotz (1993): < 20 mm / year
- Carvalho et al. (2005): ~ 0.3 – 0.9 mm / year
- Cui et al. (2004): < 30 – 2.5 mm / year
- George (2003): < 6.3 mm / year

Conclusion operator

- The operating company decided not to conduct the project and is looking now at other cases with control on abandonment

Comparison with oil field

- Lower ultimate recovery
- Seal only proven for high-viscosity fluids
- Many production/water injection wells

Enhanced hydrocarbon recovery

Drivers CO_2 enhanced hydrocarbon recovery

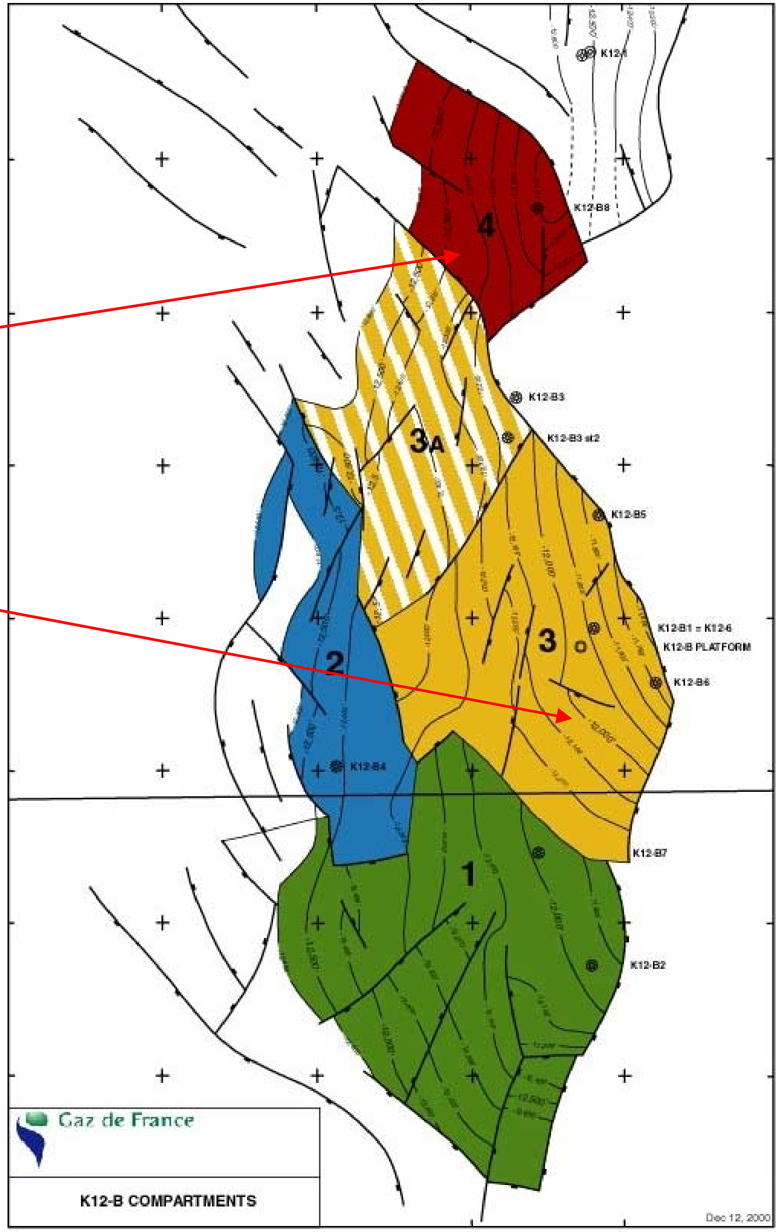
- Climate change
- Energy supply

A lot of interests of public, governments

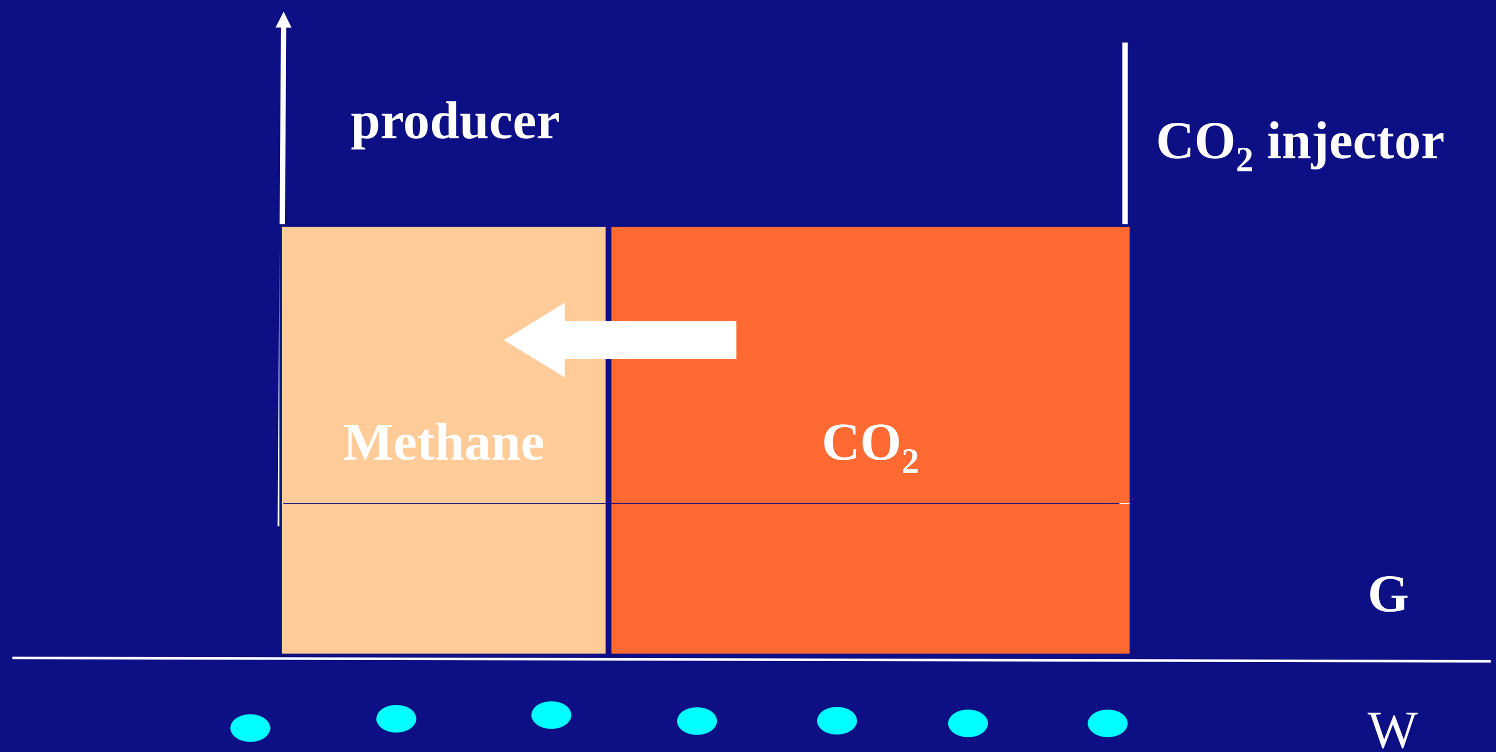
K12-B Compartments

- Single well compartment
- CO_2 injector and gas producers

CCS, enhanced hydrocarbon recovery



Enhanced gas recovery



Tracer Analysis

Determination Breakthrough

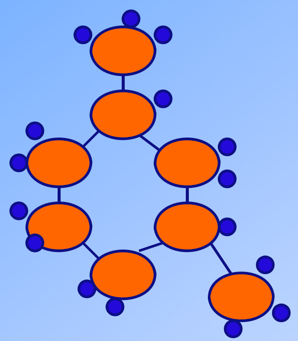
Investigation retardation process

Two tracers: 1,3-PDMCH & PMCP

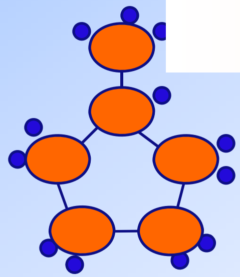
1 kg of each tracer were injected in well K12-B6

Date injection: 1 March2005

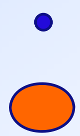
Sampling of produced gas at K12-B1 and -B5



1,3-PDMCH



PMCP



Tracer Analyse

Breakthrough well K12-B1 after 130 days

Breakthough well K12-B5 after 460 dagen

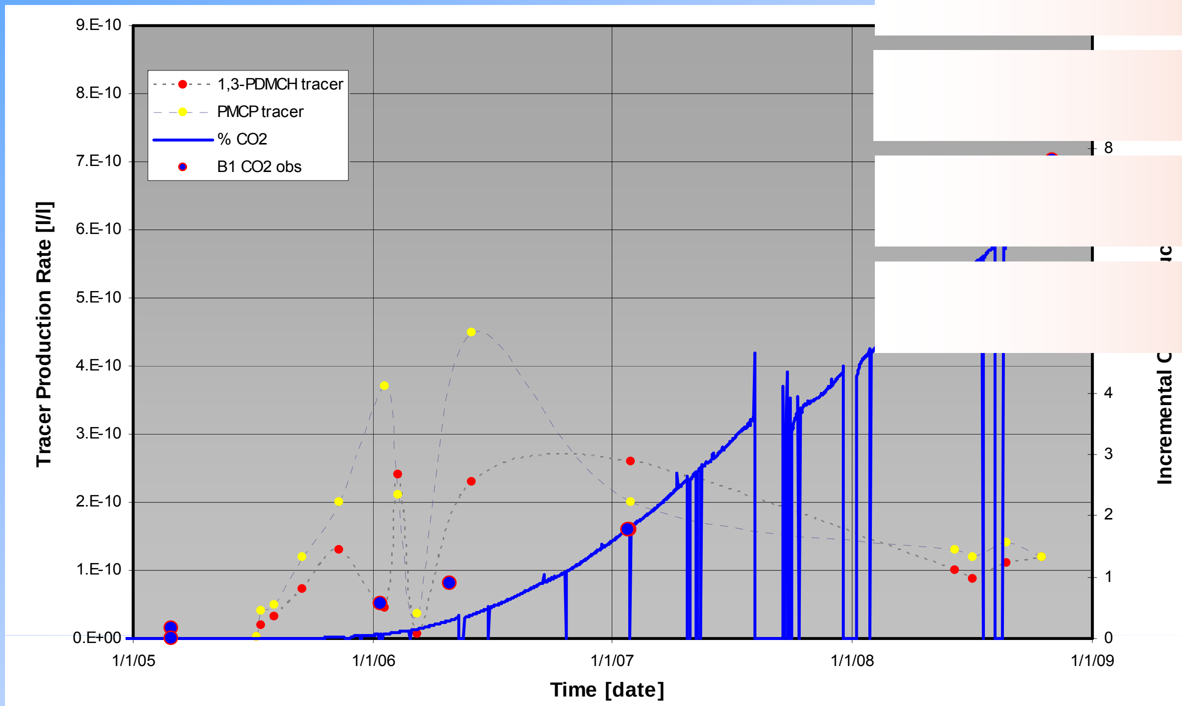
Solubility CO_2 >> CH_4 and tracers

Retardation of CO_2

Impact on EGR

Recovery: 54% per 1,3 PBMCH

33% van PMCP per september 2008



CO_2 Massabalans en EGR

Compartiment was voldoende accuraat gemodelleerd

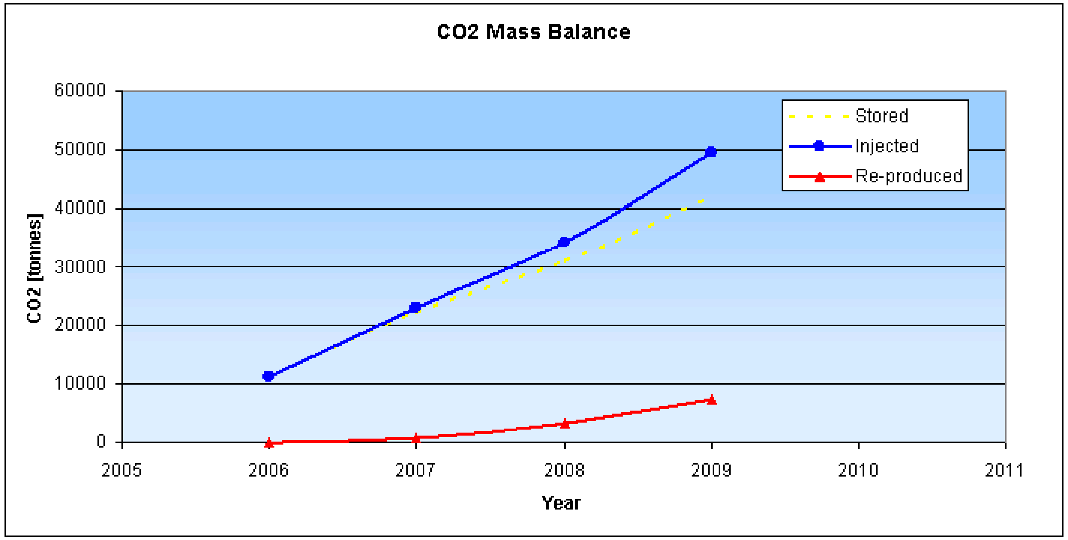
Original CO_2-concentration compartment 3: 13%

Current CO_2-concentration at well K12-B1: > 20%

Quantity of CO_2 injected (jan. ’09): 50 kT

Reporduced CO_2: 7.4 kT

CO_2 storage in compartment 3: 42 kT



EGR by pressure support

Additional gas produced from compartiment 3: so far 50 mln. Nm^3

Oil Recovery

Total production = sweeping efficiency * production per swept volume.

Example: a) the water flood sweeps 60 % of the field

b) the water replaces 65 % of the oil

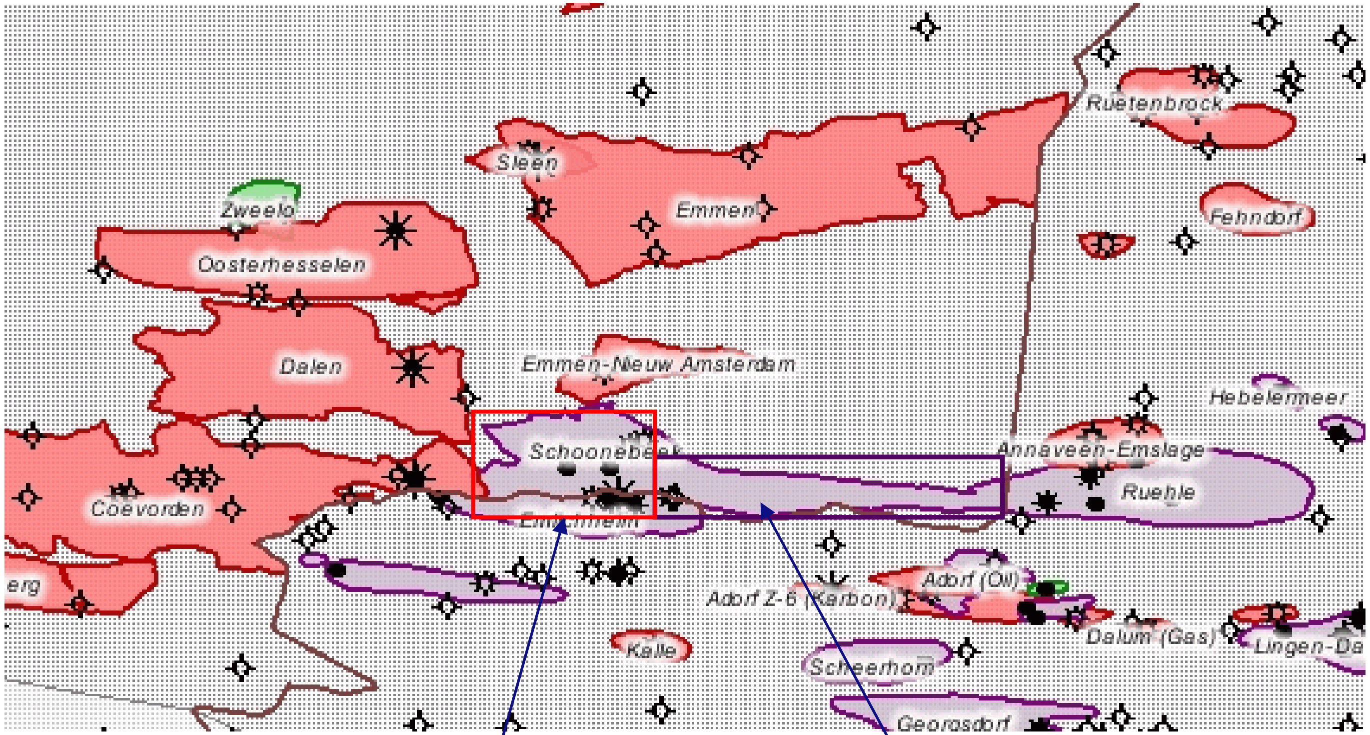
Then the ultimate recovery is 0.6 * 0.65 = 39 %

Introduction

STOIIP 10^9 BBL

Schoonebeek field NL

25 % produced



SAGD

Water drive
P>80 Bars

CO_2 enhanced oil recovery

Miscible/immiscible (roughly: light oil vs HVO)
90% of floods is miscible
Breakthrough generally between 0.5 and 2 yrs, independent of miscibility
Severe gravity override limits RF, independent of miscibility

Principles CO_2 enhanced oil recovery

Immiscible CO_2 flooding

Below minimum miscibility pressure (MMP)

Partitioning CO_2 in oil phase > swelling > lowering viscosity

Viscous oil

For pressures > 80 Bar (steam injection expensive)

CO_2 net use: 0.15-0.26 ton/BBL.

Miscible CO_2 flooding

Above the MMP, CO_2 extracts/puts lighter components of in the oil.

Mixtures miscible with original oil.

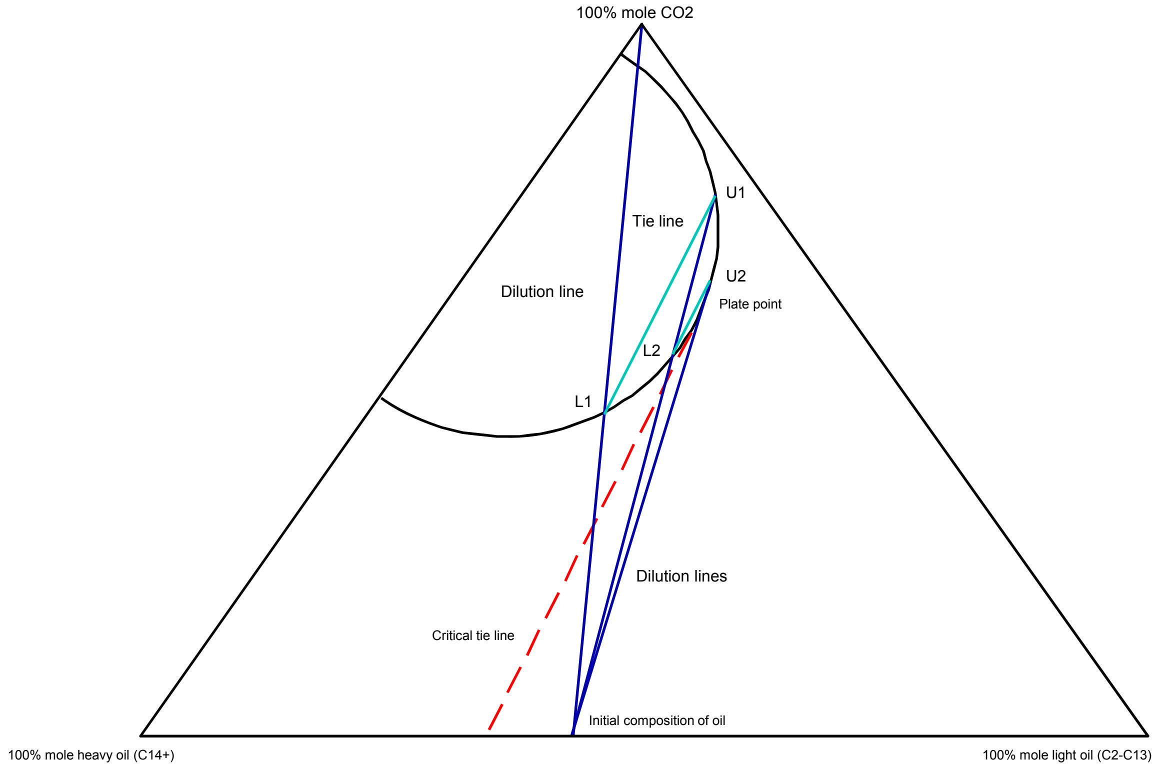
CO_2 net use 0.30-0.52 ton/BBL.

Miscible CO_2 flooding (a)

P>MMP

Vaporizing Gas Drive mechanism

stripping



Pseudo ternary phase diagram

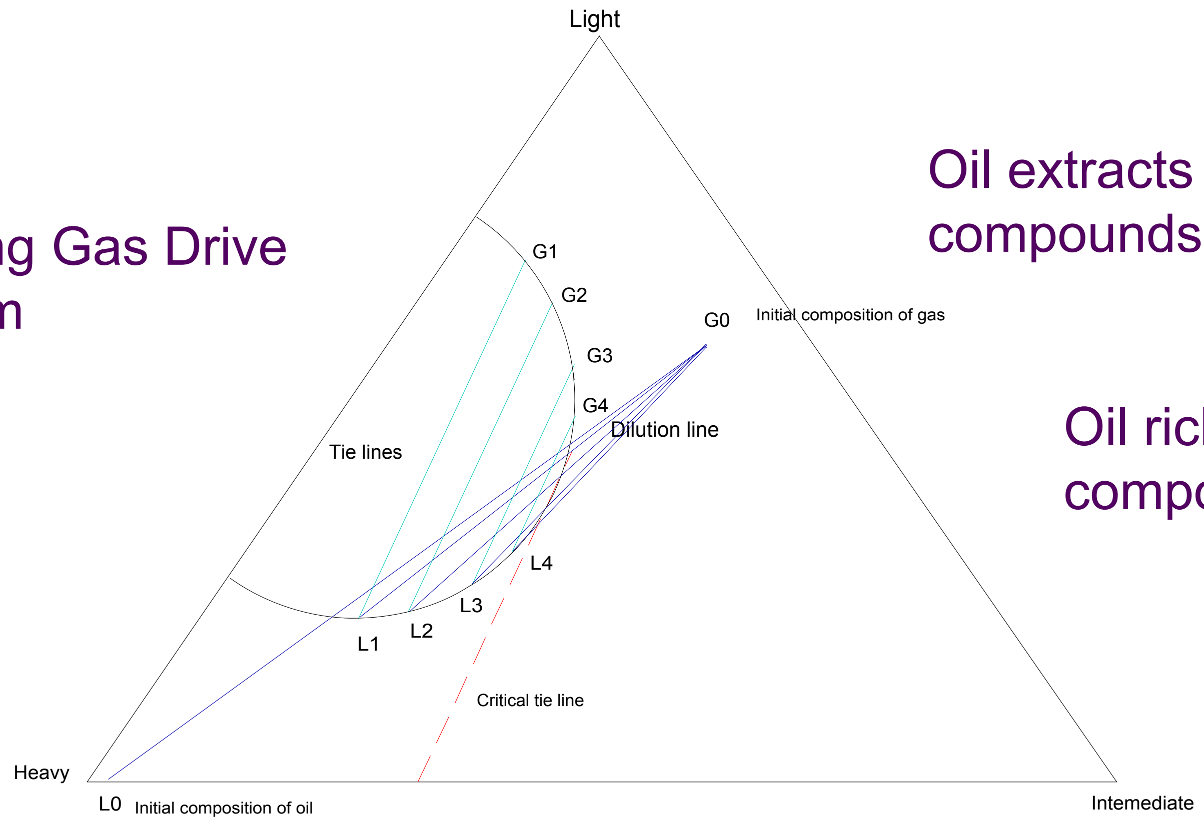
Miscible CO_2 flooding (b)

Mixture CO_2-intermediate compounds

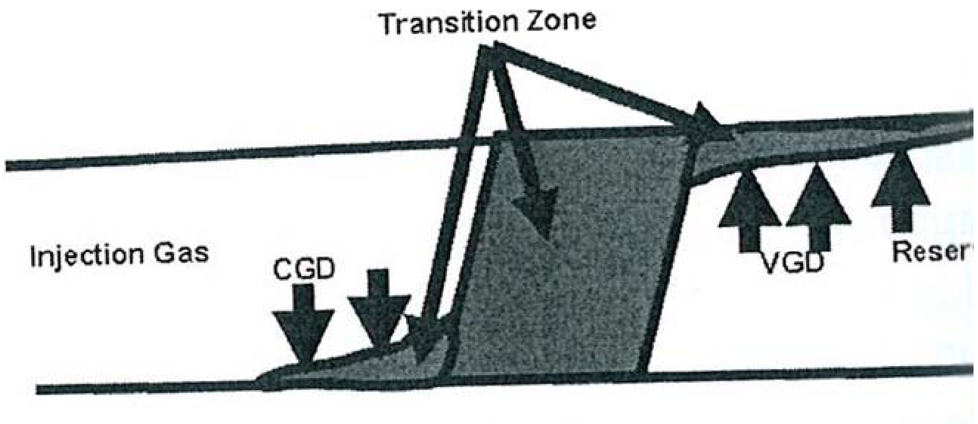
Condensing Gas Drive Mechanism

Oil extracts intermediate compounds

Oil rich in heavy components



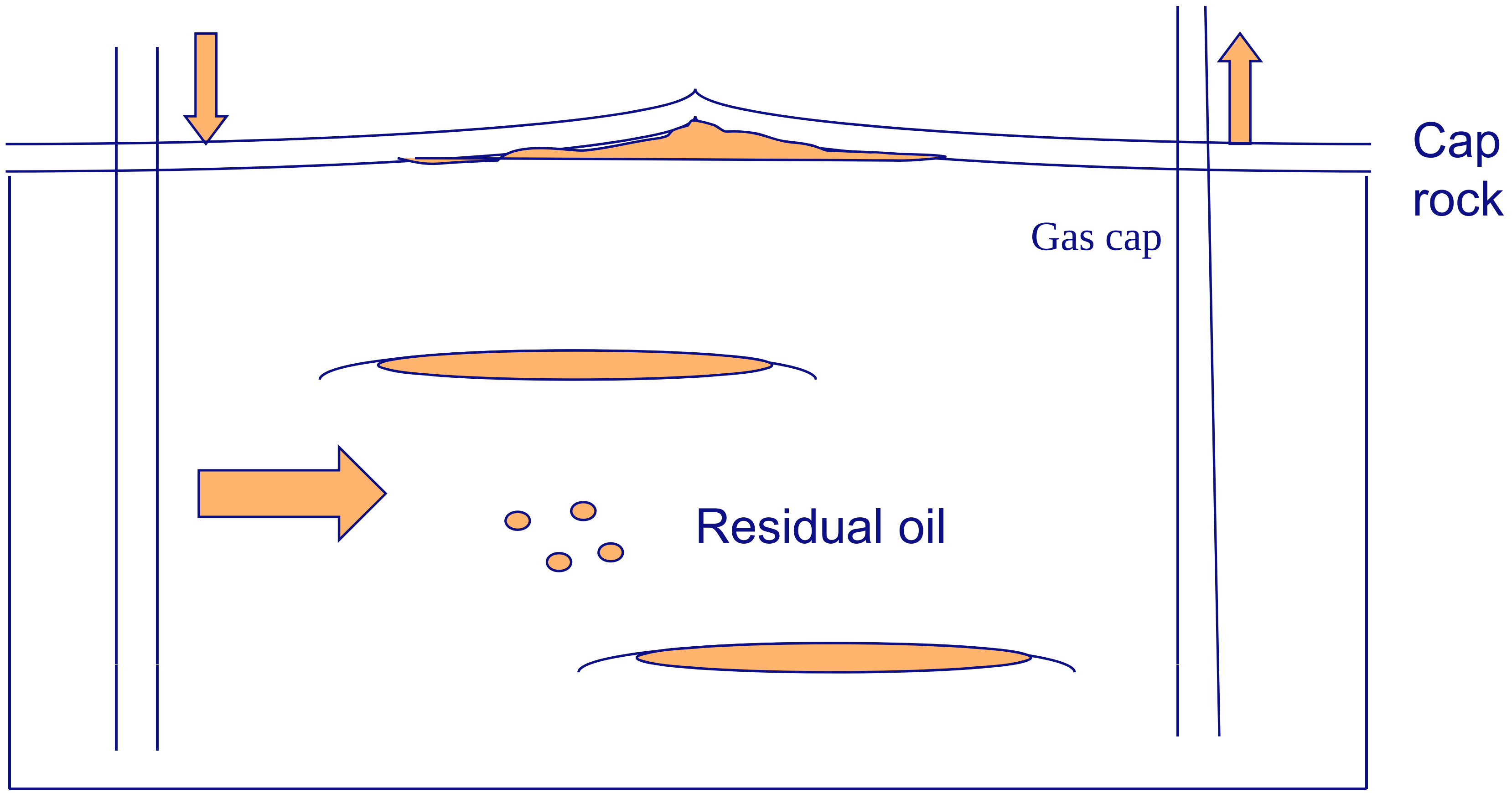
- Often combination vaporizing/condensing gas drive
- Injected fluid generally does not contain hydrocarbon fraction
- Miscibility is reached in zone proceeded by vaporizing gas drive followed by condensing gas drive.



Sweep efficiency

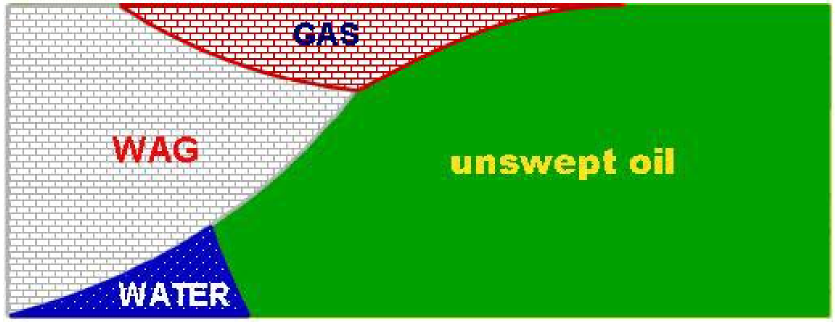
Gas migration very sensitive to heterogeneities

PVT



Fine reservoir model required

Injection strategy



- Continuous injection

- WACO water-alternating CO_2
  More stability for flood
  less use of expensive CO_2

3-fluid relperms
Hysteresis

A lot of circulation of $CO_{2,}$ separation and re-injection

Gross volume of $CO_2 \approx 2$* net volume (purchased CO_2)

EOR pre-requisites

A good EOR process implies:

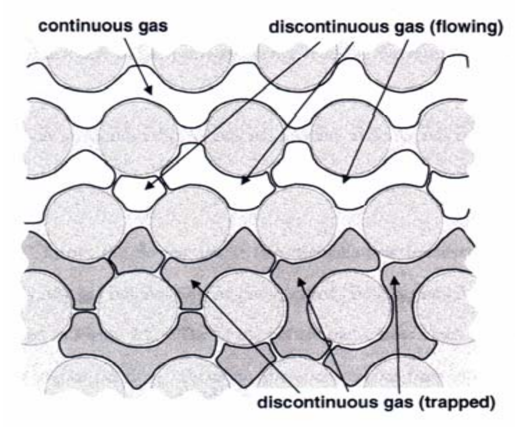
1) good contact of oil by drive fluid
2) viscous forces dominate over capillary forces

Good mobility control

$$M = \frac{\lambda_o}{\lambda_c} > 1$$

Perfect microscopic displacement

$$N_c = \frac{\mu u}{\sigma} >> 1$$



CO_2 EOR economics

- Extra oil
  - Miscible 10-15% STOIIP
  - Immiscible 5-7%
- CO_2 net consumption
  - Miscible 0.4 t/bbl
  - Immiscible 0.2 t/bbl
- CO_2 purchasing dominates UTC

CO_2 EOR economics, Texas

- West Texas: CO_2 cost indexed to oil price
  Crude @ 50$/bbl => CO_2 @ 33$/t
- Miscible net consumption 0.4 t/bbl
  CO_2 purchasing cost: 14 $/bbl
- Assume CAPEX+OPEX ≈ CO_2 costs, so CO_2 EOR miscible UTC: 28$/bbl
- Immiscible UTC estimated at 21 $/bbl @50 $/bbl; and 11 $/bbl @25 $/bbl

CO_2 EOR economics with increased viscosity

- Assume CO_2 has viscosity increase by factor 10 – 100
- Vertical sweep Schoonebeek improves by factor of +/- 2 (Shell CO_2 sequestration screening tool)

=> extra oil: 2*0.05= 10 %

- Schoonebeek: 50 .10^6 BBL

Complications

- Asphaltene disposition (wells and reservoir)
- Dissolution and subsequent disposition in carbonate reservoirs
- Salt precipitation/ clogging

West Texas : 175 000 bdl/day (was 250000 bbl/day)

90 % miscible, 10 % immiscible
500 mile pipeline

Weyburn: an additional 130 million barrels of oil
storage of 30 million tons of CO_2
204 mile pipeline

Elsewhere

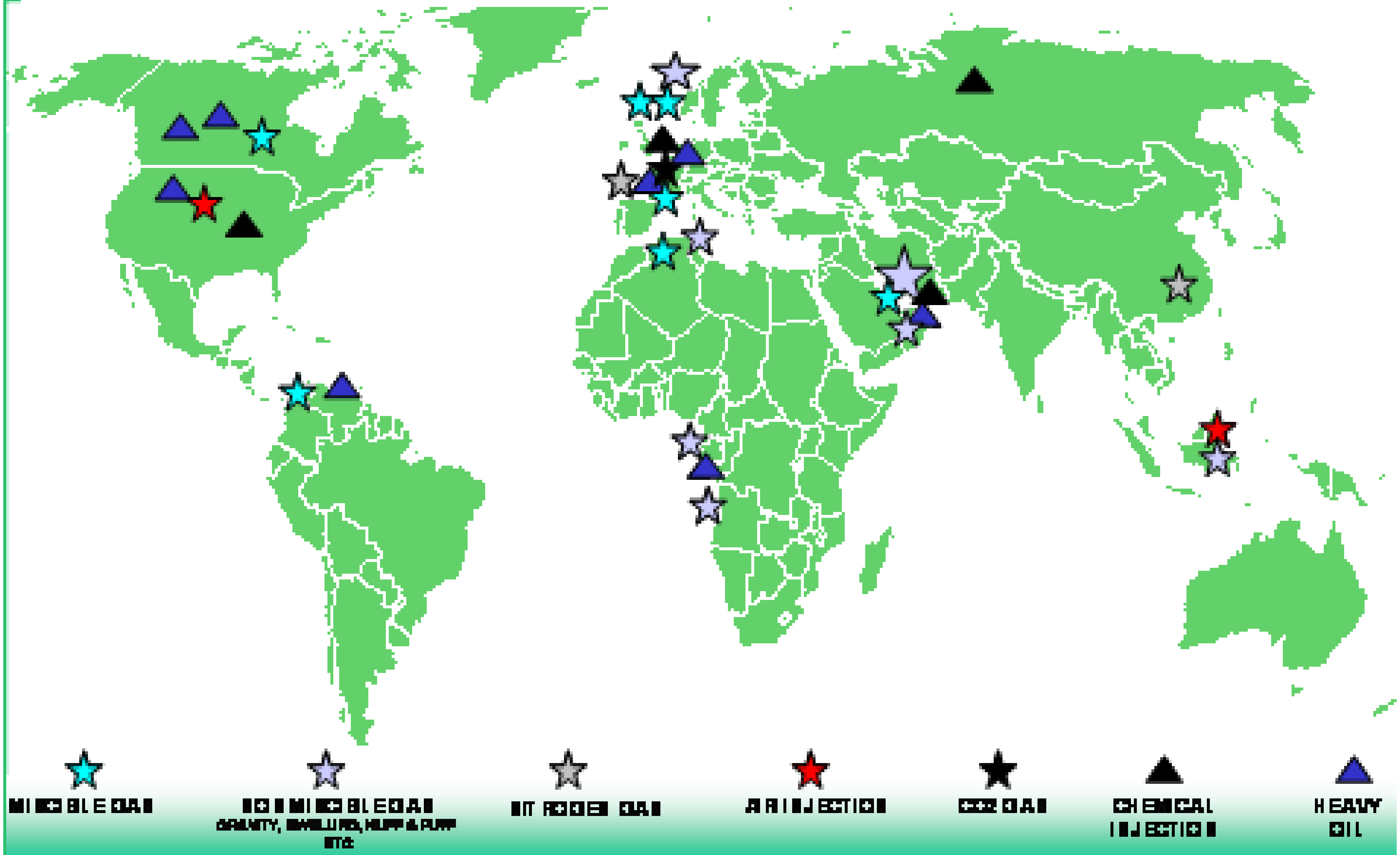
Hungary, 1969
domestic natural CO_2

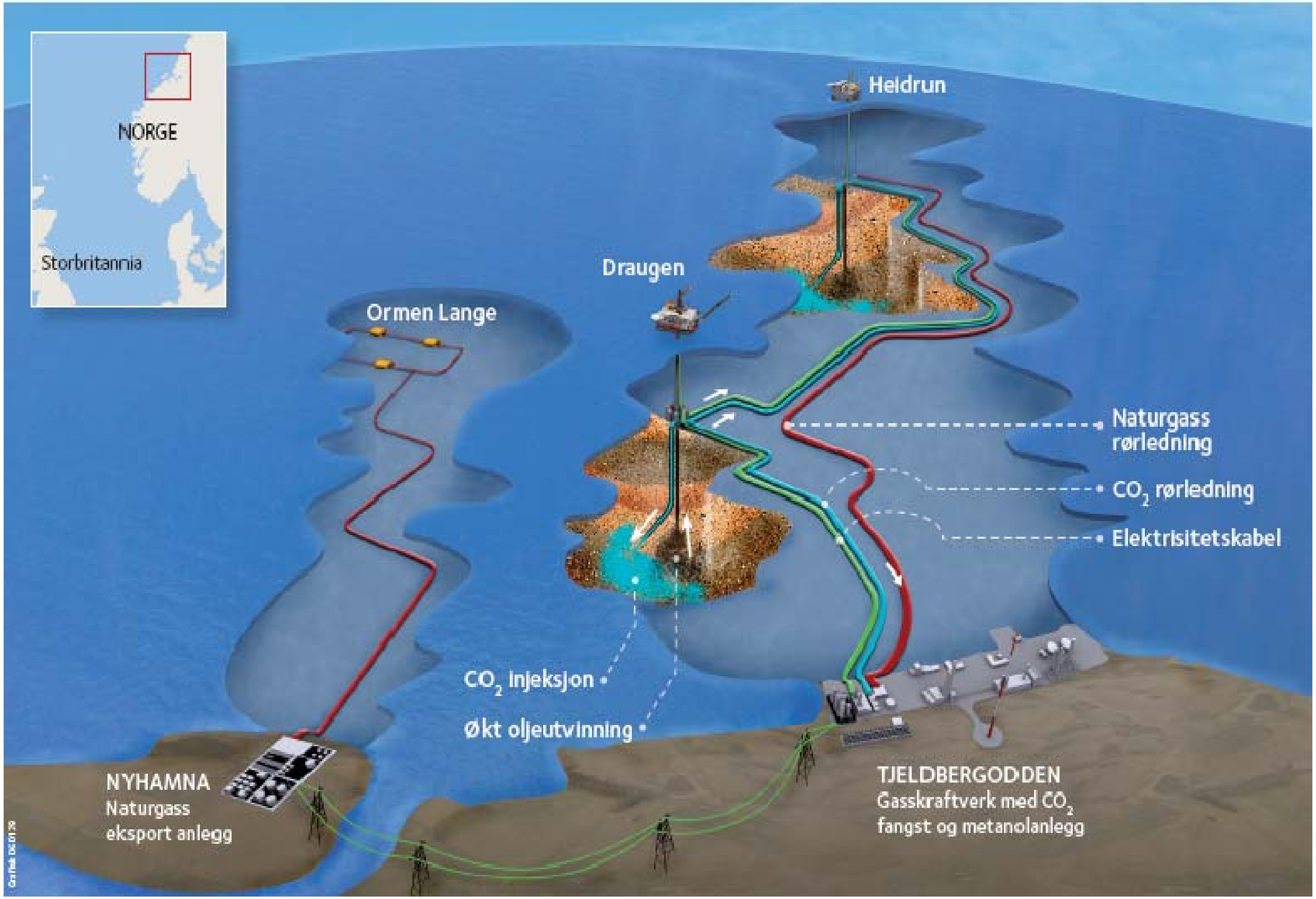
Bati Raman field, Turkey (Turkish Petroleum Corporation) SPE 106575

- Very viscous and heavy oil, fractured lime stone reservoir
- Pipeline to nearby CO_2 reservoir DODAN (about 2.8 Mton/Day)
- Immiscible CO_2 flooding, pilot application in 1980
- Expected increase production 10 %

- Surface installations were designed (at that time only one CO_2 pipe line in operation)
- Recycling costs (since 1988) similar to the natural source
- Huff and Puff applications
- Increased production due to increased pressure and effects CO_2
- From 25 BBL/Day (before injection) to 100 BBL/Day (1991)
- Current average 40 BLL/Day per well (5 % production increase)

World Wide Experience in EOR





CCS, enhanced hydrocarbon recovery

E&P multinationals

- Shell: currently not active
- Statoil: currently not active
- BP: just stopped Miller project
- Wintershall: currently not active.

Conclusions

- CO_2 enhanced oil production is technically feasible (Companies ready)
- Currently too expensive unless CO_2 is readily available
- Situation likely to change as emission restrictions increase