CO_2 EOR

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Recovery factor and EOR

$RF = \eta_A \times \eta_V \times \eta_\mu$

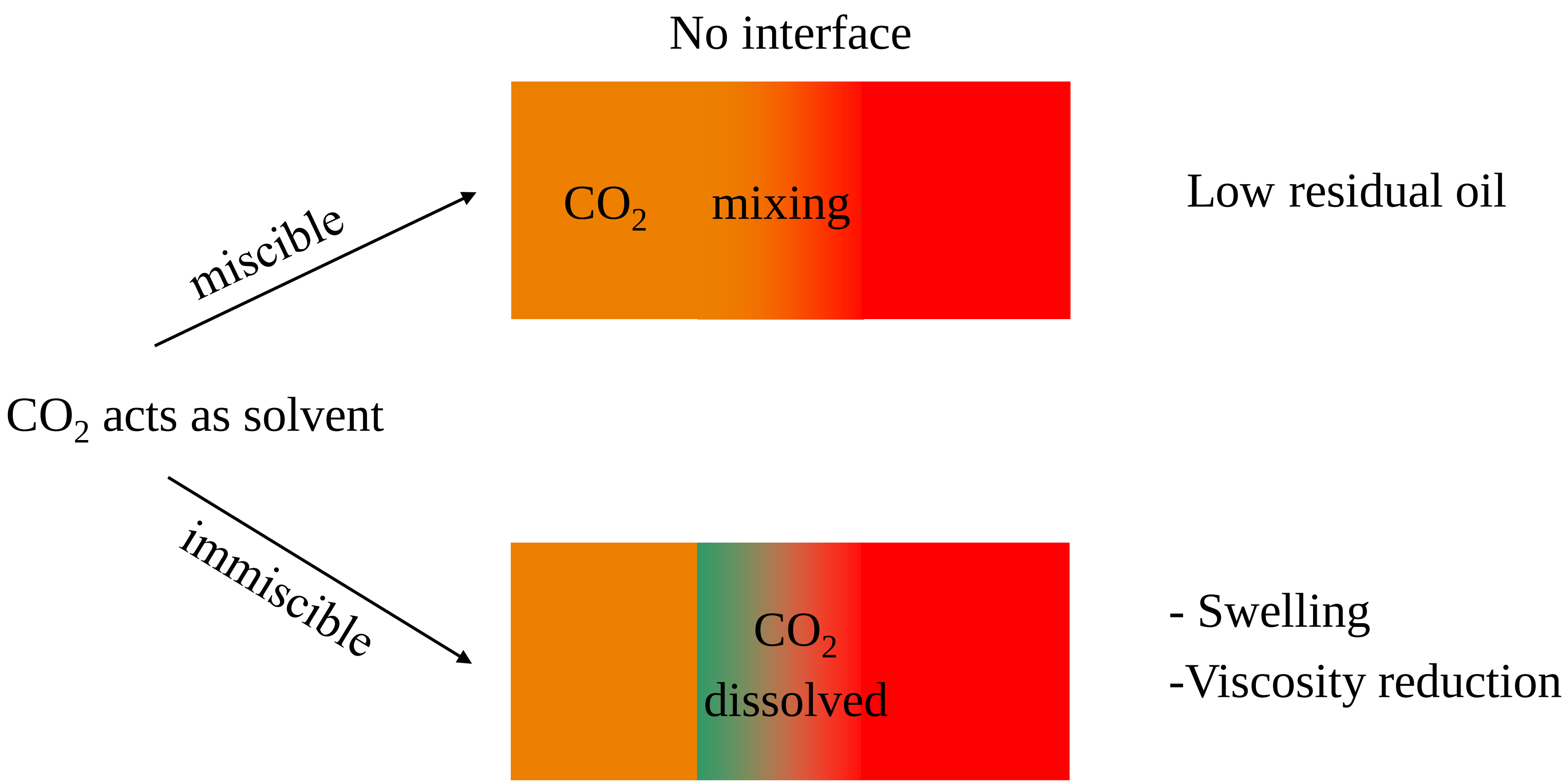
Typically:

- $\eta_A = 0.8$, dependent on mobility ratio, geology
- $\eta_V = 0.8$, dependent on geology, impact of gravity
- $\eta_\mu = 0.6$, dependent on process, wettability

EOR is about increasing η_μ

CO_2 EOR

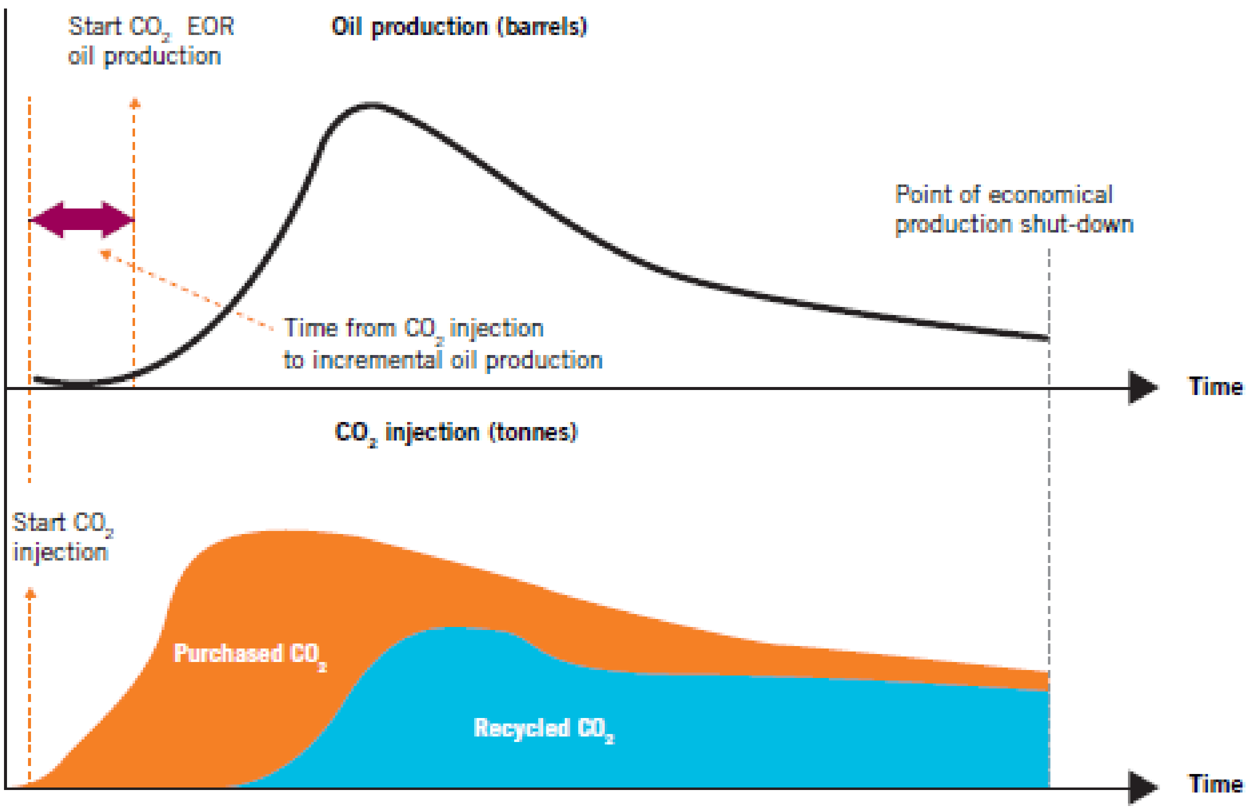
- CO_2 EOR is mature technology (>30yrs, currently 200 000 bbl/d globally)
- CO_2 breakthrough between 0.5 and 2 yrs
- Severe gravity override limits RF
- Mainly CO_2 from natural sources


No interface
CO2
mixing
Low residual oil
miscible
CO2 acts as solvent
immiscible
CO2
dissolved
- Swelling
-Viscosity reduction

Miscible vs Immiscible floods

- Extra oil 10-15% vs 5-7% for immiscible
- Consumption 0.4 tCO_2/bbl vs 0.2 tCO_2/bbl immiscible
- 90% is miscible
- Massive recirculation
- $WACO_2$ is standard approach
- Largest operations were around 15 000 bbl/d extra oil
- No primary drives, EOR only

FIGURE 67 The relationship between oil production, purchased CO_2, and recycled CO_2



Source: Jakobsen et al. (2005).

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

CO_2 EOR Economics TEXAS

- Dominated by purchasing costs of CO_2
- West Texas: CO_2 cost indexed to oil price

  assume crude @ 50 $/bbl -> CO_2 @ 33 $/t
- Assume for miscible net consumption: 0.4 t/bbl

  CO_2 purchasing cost 14 $/bbl
- Assume CAPEX+ OPEX ≈ CO_2 costs

  CO_2 EOR miscible UTC: 28 $/bbl
- UTC for immiscible estimated 21 $/bbl @ 50 $/bbl

Capital Intensive

- High UTC for CO_2:

- Smaller companies
- State oil companies

How CO_2 EOR started

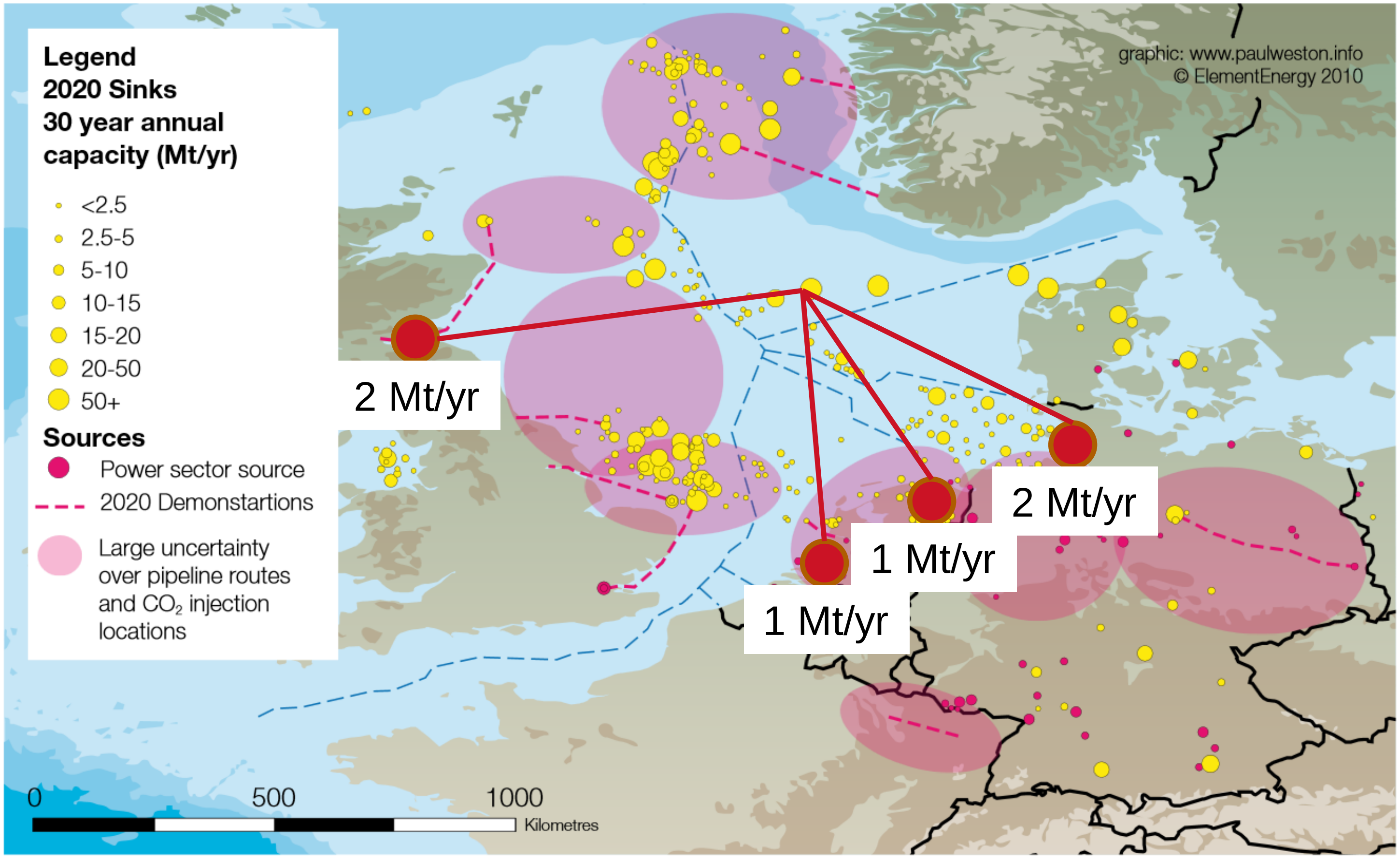
Texas – one pipeline from CO_2 reservoir to one oil field

Canada – one pipeline from Beulah (USA) to Weyburn (Canada)

Netherlands – P18-4, Q1, K12B …………

Coal-fired Power station
Boundary dam
Saskatchewan, Canada

Ship transport
Kick-start CO_2-EOR in North Sea?



Map: One North Sea, Element Energy, 2010

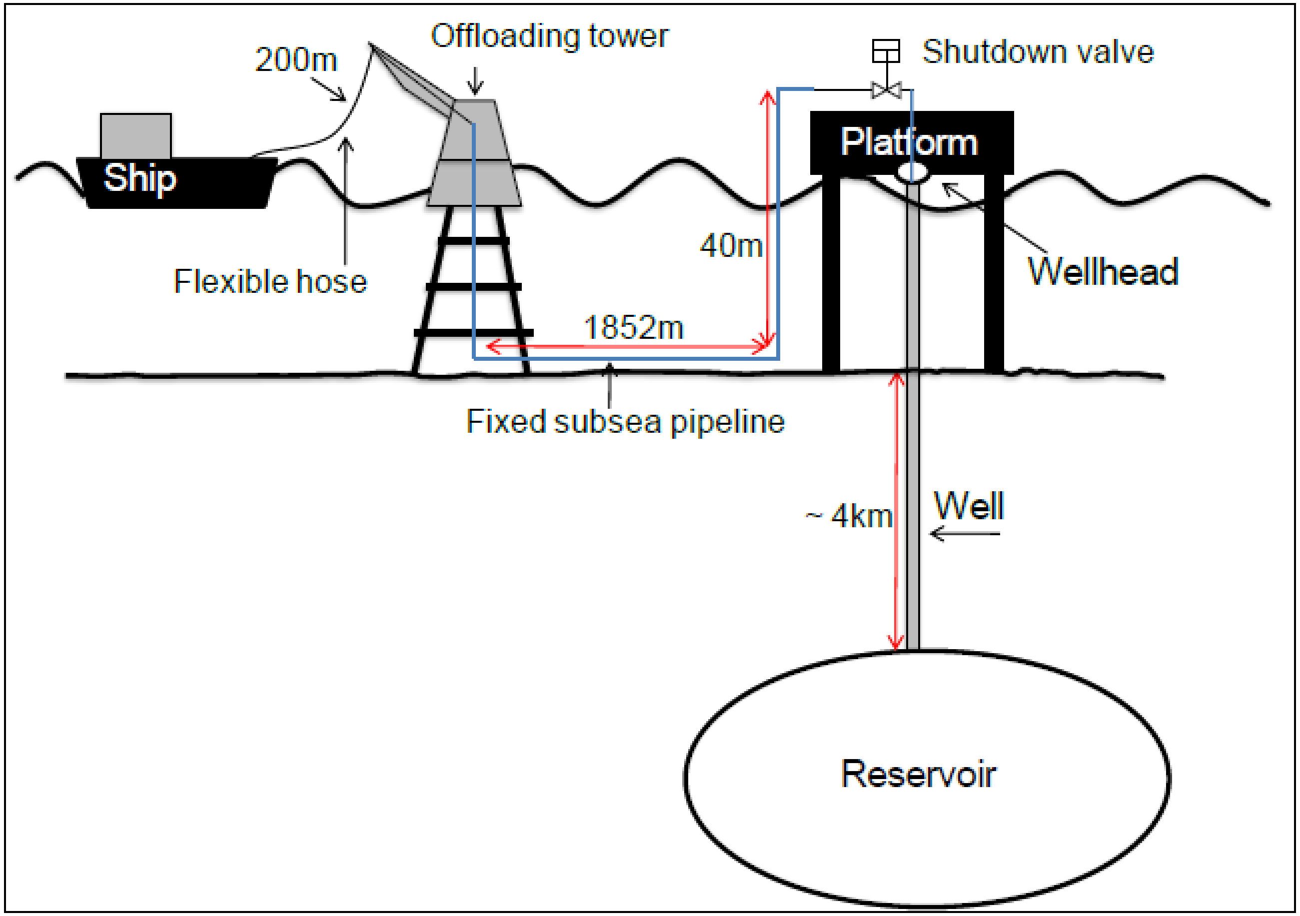
http://www.npd.no/Global/Engelsk/3%20-%20Publications/Reports/OneNorthSea/OneNortSea_Final.pdf

Volumes and routes – added by presenters to the OneNorthSea map

Proposal for a pilot project: shipping CO_2 to the K12-B reservoir and beyond

Courtesy Anthony Veder

Potential pilot project: shipping CO_2 to the K12-B reservoir



Source: http://cdn.globalccsinstitute.com/sites/default/files/publications/19011/co2-liquid-logistics-shipping-concept-llsc-overall-supply-chain-optimization.pdf

P, T conditions in ship – flowline – reservoir system

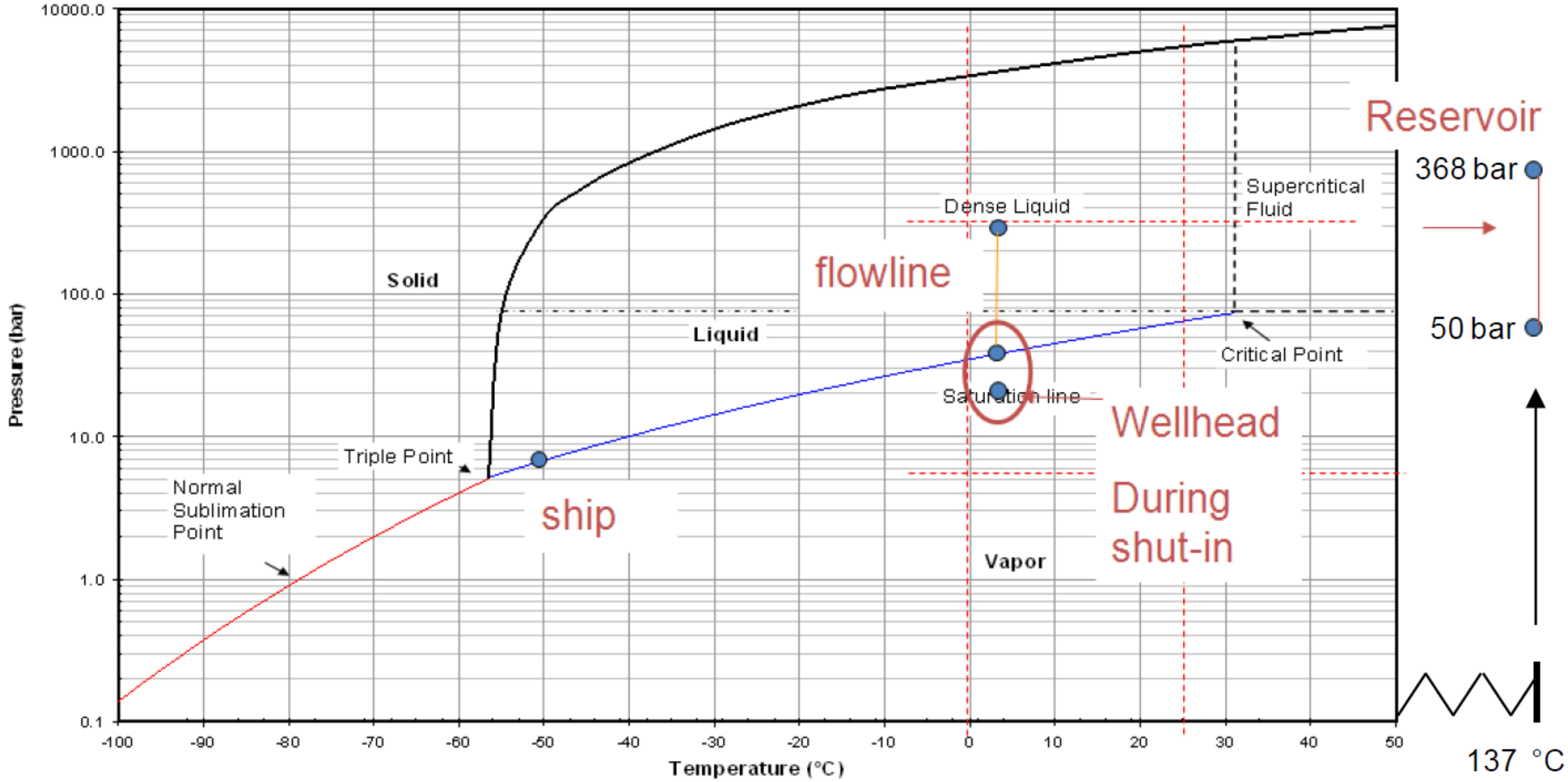
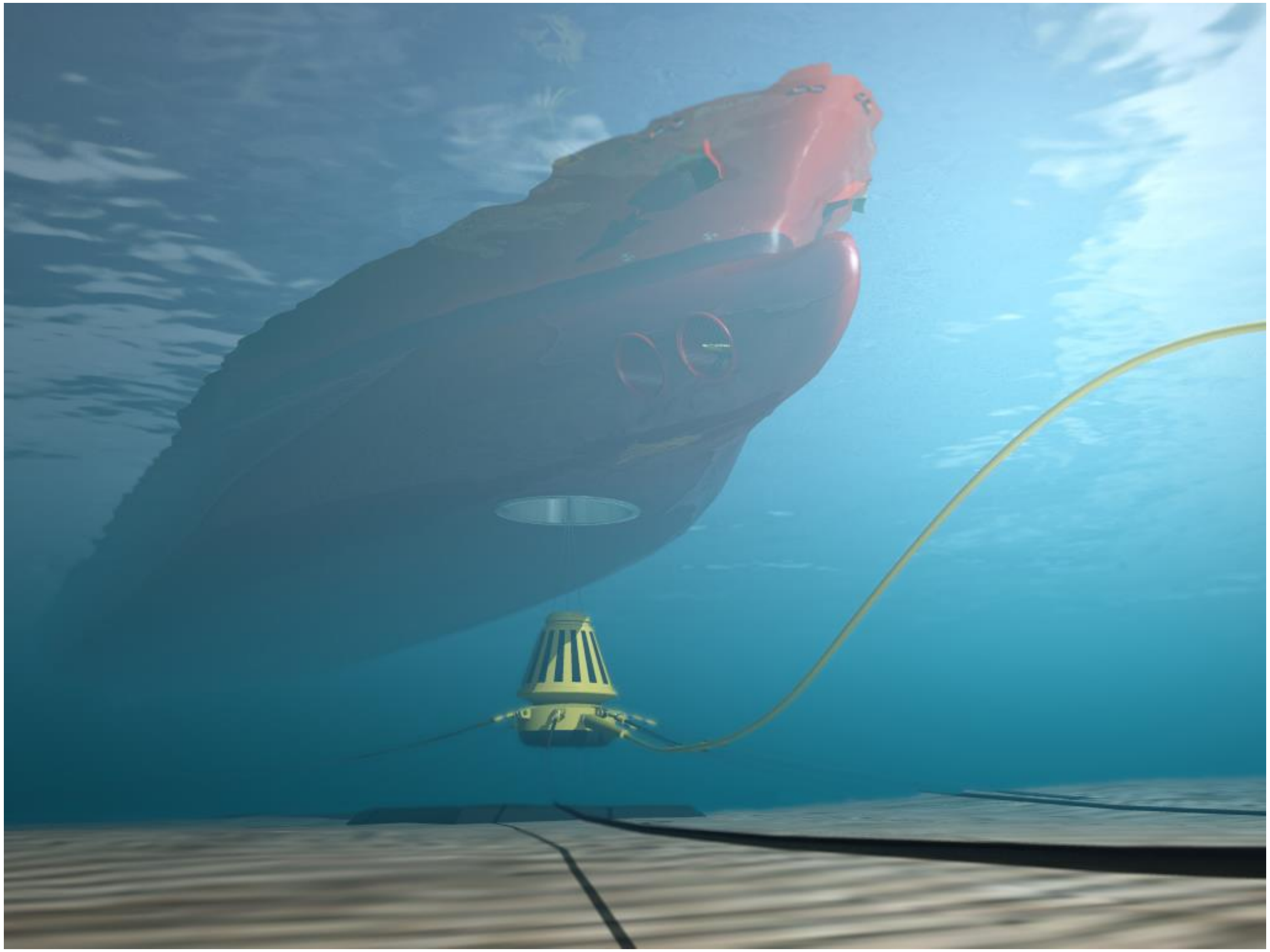


Photo of an offloading tower

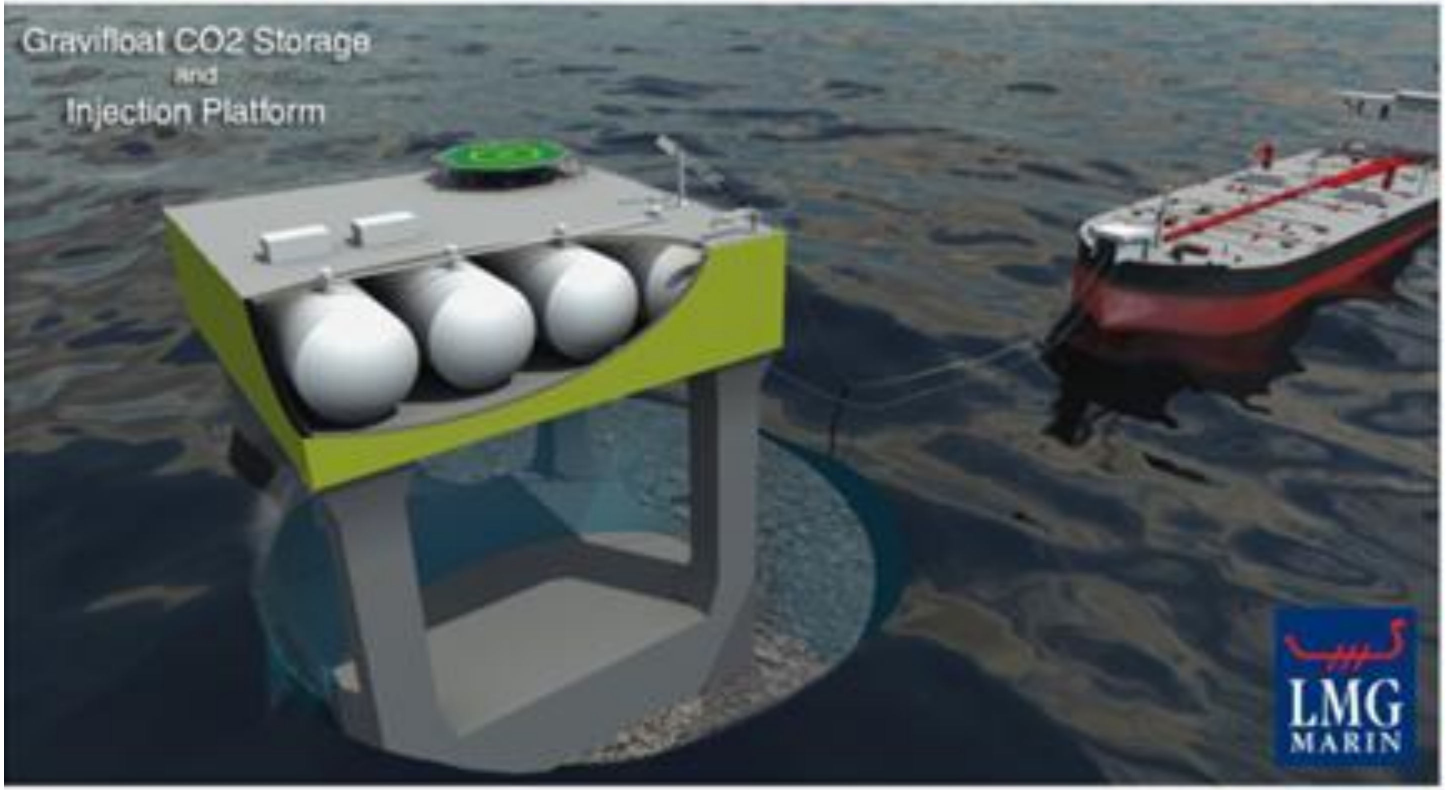
Courtesy SBM offshore

Artistic impression of a submerged turret loading (SRV2)



Courtesy APL

Artist's impression of a gravifloat CO_2 storage and injection platform



Water-alternating-Gas (WAG)

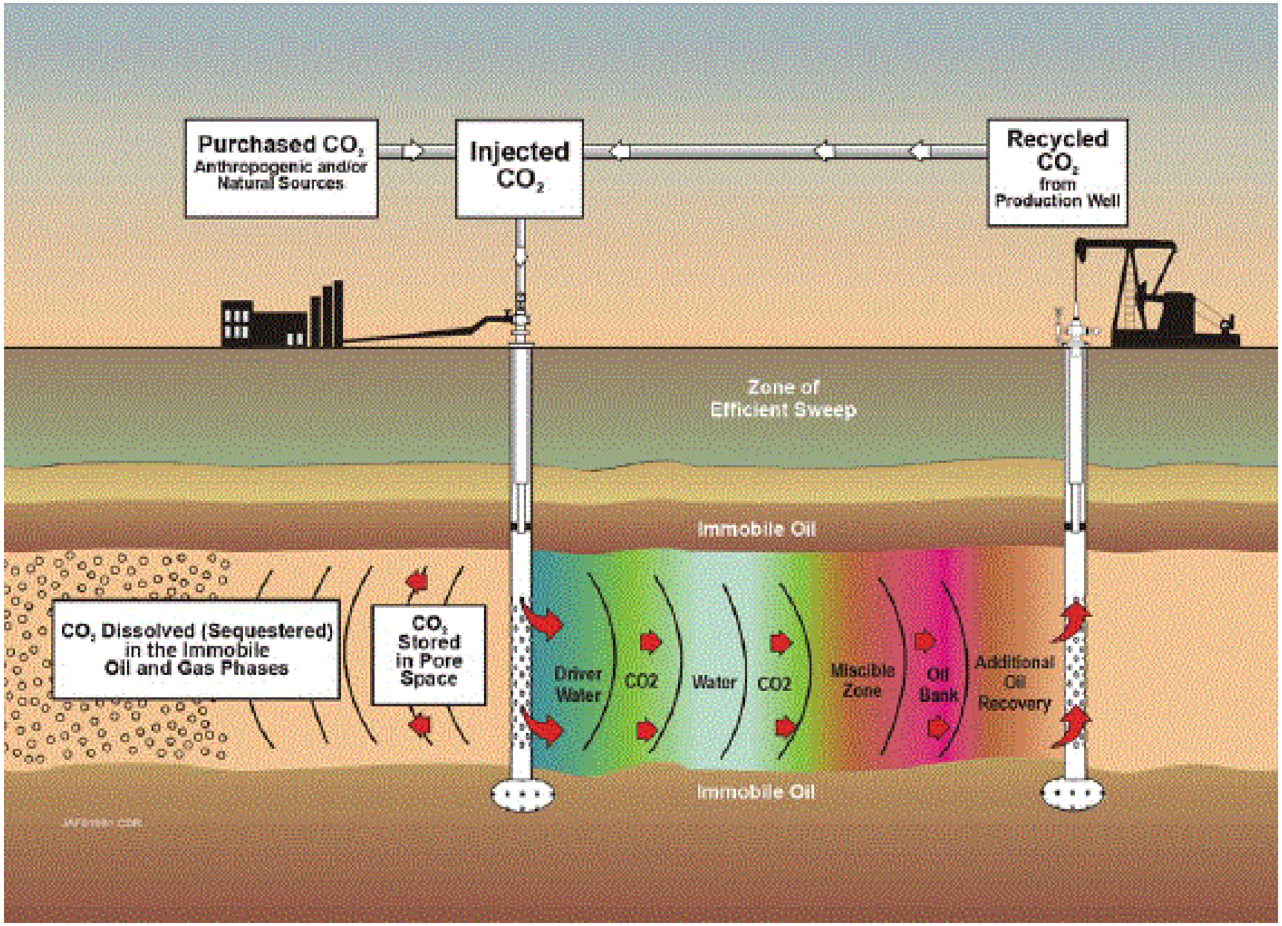
- Often executed by trial-and-error

- CO_2 EOR without storage objective
  - CO_2 commodity
  - Minimisation of costs of CO_2

- CO_2 EOR with storage objective
  - Maximisation of CO_2 storage (Carbon credits)

- predictions combined with optimisations are required

FIGURE 66 Schematic diagram of a water-alternating-gas (WAG) miscible CO_2 EOR operation



Source: ARI and Melzer Consulting (2010).

Applied Reservoir models

- Properties of oil as a function of CO_2 concentration
- Based on lab tests

- Simulator
- Black-oil simulator Eclipse 100
- (Schlumberger)

Initialisation Simulator

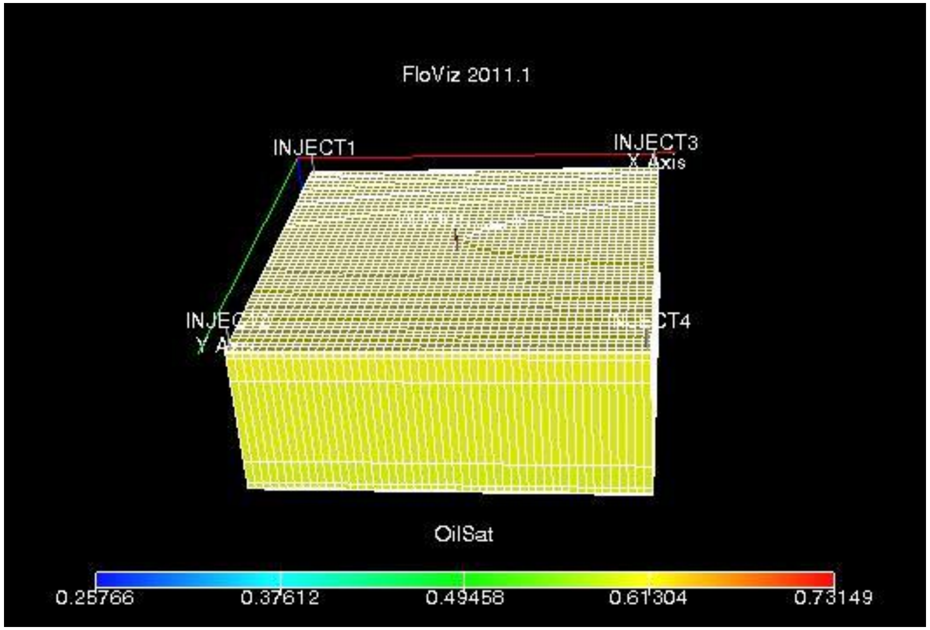
Immiscible CO_2 EOR

5 spot pilot

$P_{i} =$ 150 Bar

Δz

1 4 16 58 16 4 1



constraints

Inject. = 165 bar
Prod.=100 bar

250 m

Medium heavy oil

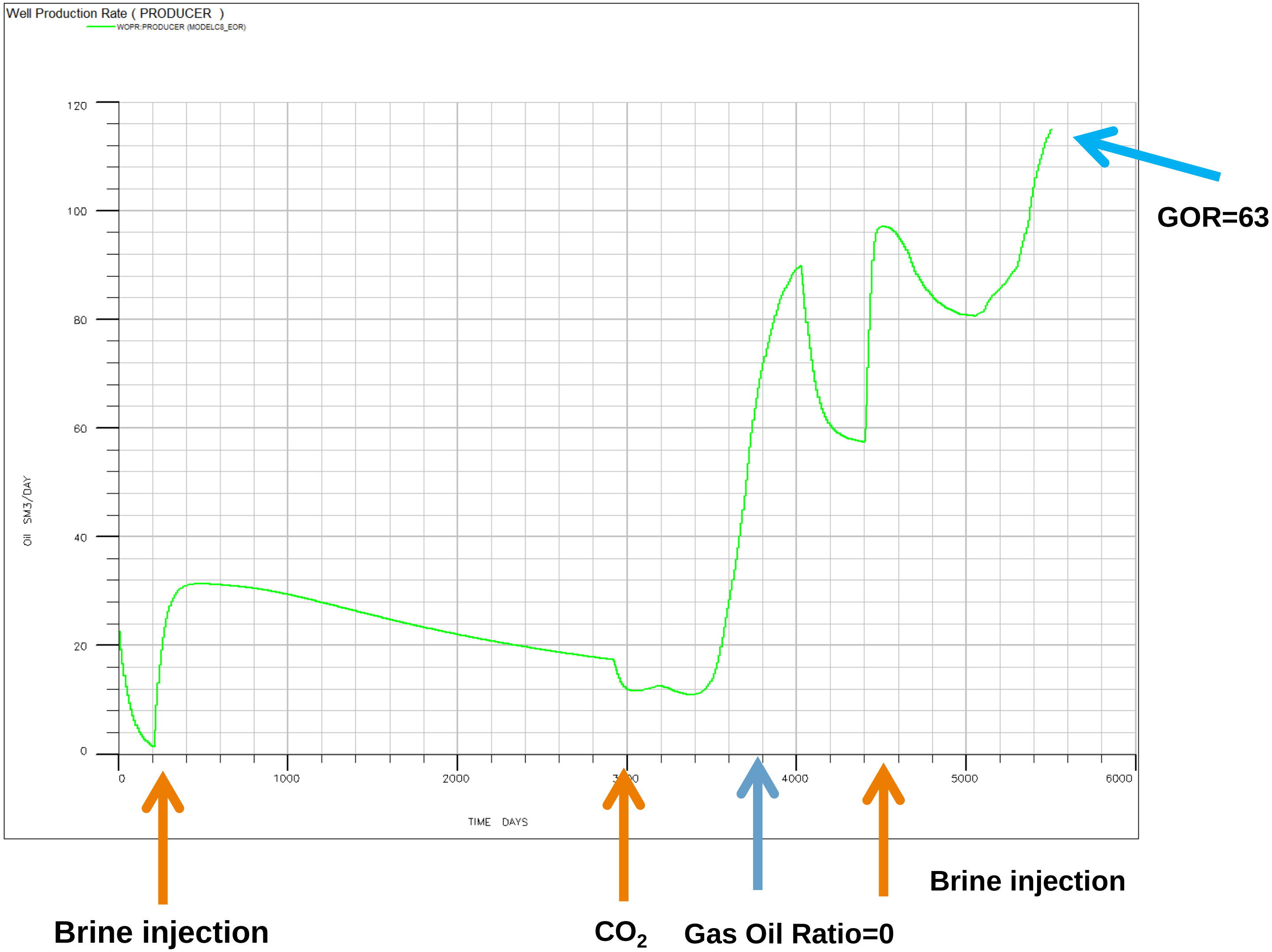
PERM = 200 mD

50*50*7 grids

kv/kh=0.1

Properties oil as function of CO_2 (SPE 107163)

Predicted oil production as function of time



Optimization of CO_2 WAG

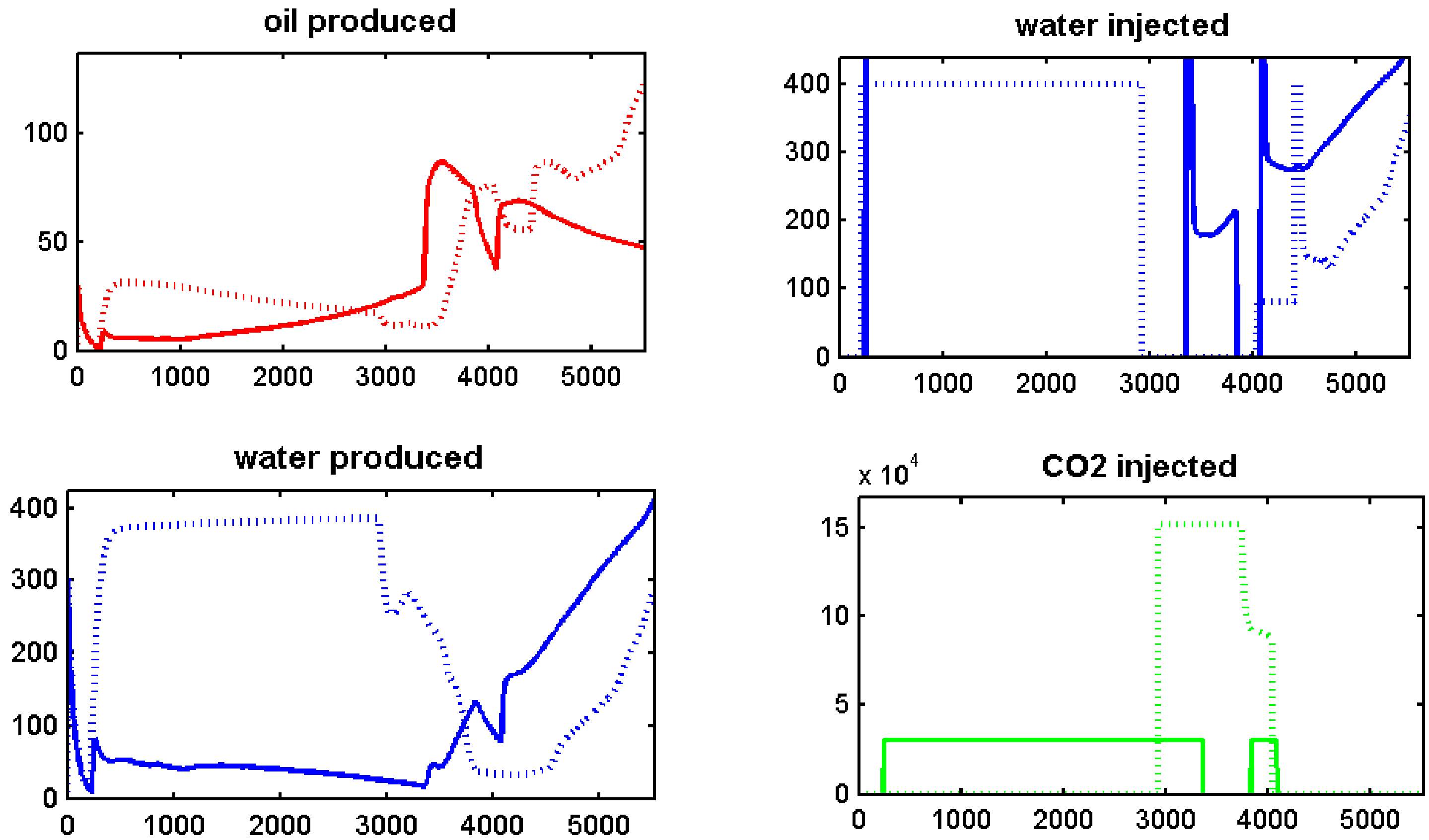
- In-house optimization tool
- Simple Net Present Value model based
  - on cost and benefits of water, CO_2 and benefits of produced oil
- reservoir model and controls as before
- Results are compared against original predictions

Optimisation assumptions *

- Benefits oil produced : 50 $/bbl
- Costs of water injection: 1 $/bbl,
- Costs of water produced: 0 $/bbl,
- Costs of CO_2 injected: 50$/ton
- no discounting
- 2 WAG cycles (CO_2-water)

- * example only

Optimisation Example



Dashed line: reference case, solid line: optimisation example

Conclusions

- Real flow of multiple phases quite different form ideal picture as shown
- Besides swelling and reduced viscosity, different sweeping areas between the injected water and CO_2 may also lead to higher overall sweeping efficiency and oil production

- Optimisation
  - Variable costs and benefits lead to different injection and production schemes

Prices

Marginal costs: water (injection (conditioning) and production):

CO_2 (recycling/transport/capture (ETS) correct

Rate and temperature

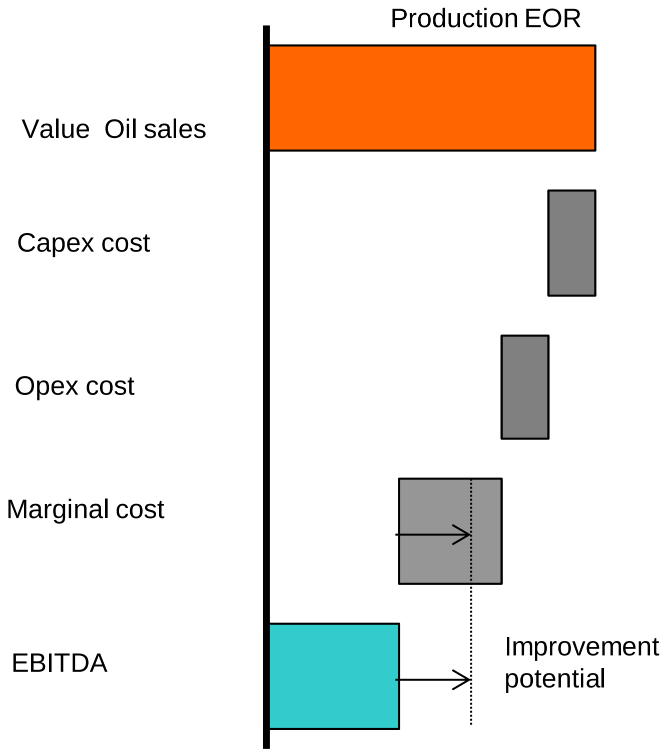
Energy consumption etc.

Revenues: price BBL oil (fluctuating).

Whole chain optimalization by combination of economical model and reservoir model

Example case study: EOR applied @ existing fields in NW Europe

Ref. Scenario NPV ….M€



Drivers	**Assumptions**
• Oil price sensitivity	• High available of CO2 at platform
• Investment cost: live time extension and CO2 infrastructure • No abandonments costs	• CO2 recycle at platform
• Continue operations extra maintenance • obsolete equipment	• No major changes at platform
• Optimization CO2 WAG • ETS prices CO2 • Cost of energy(utilities)	• ETS system • CO2 sources are available and CO2 infrastructure • CO2 transport cost in CO2 cost price

- **It is most likely that no financial support is required when infrastructure is sufficiently deployed**
- **ETS is a good instrument for commodity pricing of CO2, which differs from other areas in the World**
- **Potential NPV improvements, subject to technical conditions oil field**

- **Significant value improvement potential for existing fields in the North Sea**
- **Extension of the operational window and recovery factor**
- **Postpone abandonments cost**
- **CO2 WAG major instrument to improve production and revenues**

Source: Team analysis