Field Examples of IOR

- **Ekofisk, Eldfisk**: Chalk reservoirs
- **Gullfaks**: Complex structurally
- **Tordis**: sub sea field development
- **CO₂ injection**

Ekofisk Field

- Chalk reservoir with fractures
- Oil originally in place: 1074 mill Sm³
- Production start 1971
- Recoverable reserves (current estimate)
  - Oil 524 mill Sm³ (3.2 bill barrel)
  - Gas 185 bill Sm³ (6.5 TCF)

![Ekofisk Structure Map](image)

**Ekofisk today**

Production:
- Oil - 360 000 bpd
- Gas - 350 mmcmd
- Water injection - 900 000 bpd

Well locations for 'Ekofisk growth project'

![Ekofisk Map](image)
Ekofisk Oil Production History

Water injection and production over 35 years

- Successful water injection
- Successful field development
- Advanced drilling and well technology

Water
- Close to 900,000 barrels of cleaned water is pumped into the Ekofisk area each day
- Same amount of water supply needed for Stavanger and Bergen together

Production
- Successful waterflood
- Extended field lifetime
- Drilling and completion technology
- Recovery of flank reserves

Water Injection At Ekofisk

Water Injection At Ekofisk

Pilots
- Injectivity
- Chalk integrity
- Efficiency

Phase 1
- Injection facilities
- 20 Injection Wells

Phase 2
- Capacity upgrade
- 15 Injection Wells
- 6 Producing Wells
- Extending Area

Phase 3
- Capacity Upgrade
- Rented facility
- Extending Vertically

Oil Recovery At Ekofisk

At Sanction

- 27%

Current Estimates

- 44%

Major contributions to the increase
- Successful waterflood
- Extended field lifetime
- Drilling and completion technology
- Recovery of flank reserves
Ekofisk Waterflood strategy

- Continue to optimize current waterflood
- Effectively sweep entire reservoir
- Continue infill drilling program to maximize recovery
- Balance production/injection to minimize seabed subsidence
- Plan for depressurization at late time (+2020)

Examples of NPD involvement in Ekofisk during production

- Gave limits for GOR in wells
- Promoted water injection (and gas injection)
- Facilitated research
- Required Extended Field Study
- Threatened to close down platforms due to subsidence and condition (based on HSE)
- Recommended special tax conditions for water injection project
- Recommended license extension for re-development

Improved recovery – new technology

- Optimization of improved oil recovery
- Improved mapping of remaining oil for improved well placement
- Cost effective drilling in order to reach flank areas

Ekofisk EOR screening

Further Reserves Growth
Ensure maximum economic waterflood sweep
Combine waterflooding with other IOR methods
Ekofisk EOR External Research Activities

COREC
• Water additives
• Depressurization
• Gas injection options
• CO₂ evaluations

EU Thermie
• Air injection

Joint Chalk Research
• Fundamental chalk research
• Forum for experience transfer

CO₂ Injection Evaluations

Issues:
- CO₂ Supply & Source
- Corrosion
- Chalk Interaction
- Recovery Mechanisms
- Sales Gas Cleaning
- Pilot Logistic Challenges

Resources:
- CO₂ Spectrum Technology Corec
- JCR
- Sintef

CO₂ Injection Evaluations

First critical step to improved estimates of CO₂ efficiency is to understand the reservoir response

• Will CO₂ contact oil?
• Will CO₂ weaken the rock?

EOR at Ekofisk

Estimated impact of waterflood

The Ekofisk Waterflood will most probably continue to perform well

The Ekofisk Field does still have a long producing life

Evaluations of alternative EOR techniques will be very challenging,

Studies will be progressed to refine understanding for later life (2015+) implementation.
Historic oil production from Eldfisk

Comparison of Ekofisk and Eldfisk
Field Performance

IOR on GULLFAKS
Comparison between prognosis as basis for oil production at Gullfaks field

Draining strategy

- Support from natural water drive
- Water Injection
- Reservoir pressure over boiling point

Resource potential at Gullfaks: availability

Original oil in place in one reservoir layer
Undrained resources in the same layer today
Draining strategy

Secondary methods
- Gas injection "up dip"
- WAG injection
- Horizontal wells
- Reservoir pressure under bubble point
- Commingled production from several zones

Why?
- Avoid reduced production when gas export is on peak
- Reduce storage cost and CO2 tax
- Produce structurally high oil
- Contact areas beyond reach for water injection
- Uniform draining, reduce sand production
- Drain "bypassed" oil
- Generate gas lift
- Accelerate production

Ambition – oil production 400 MSm³
Experiences with WAG:

- WAG/Gas injection done in 20 wells on the field.
- Total injected 9700 Mill. Sm³ gas
- 50-60% av injected gas is produced back.
- Estimated IOR from gas injection is 10 – 10.5 Mill. Sm³ oil
- Effect: ca. 1 Sm³ oil pr. 900 Sm³ gas
- Best well historically: A-11 WAG with 1 Sm³ oil pr. 700 Sm³ gas injected over 10 year (1500 Mill Sm³ gas total).

Used IOR methods at Gullfaks

- WAG
- Surfactant System
- Gel
- Horizontal wells
- Fractured wells (with and without proppant)
- 4D seismic
- CT drilling
- Multilateral wells
- Sand handling system

AMIOR

- Alternative project to reduce residual oil at Gullfaks.
- Add nitrate (doing already due to reduction of H₂S), phosphate and oxygen to the injection water.
- Reducing surface tension between oil and water and thereby mobilize oil.

BACTERIA + OIL + N + O₂
MOBILISED RESIDUAL OIL
ENHANCED SWEEP EFFICIENCY

Subsea Separation, Boosting and Injection concept at Tordis field

Subsea systems
- Existing Tordis subsea
- PLIM
- SSPS station
- W1 Well

HPU module
Power module
Gullfaks C modifications
Several fields are suited for CO₂ injection.

• Approximately 60% of total reservoir volume in existing oil fields are technically suited when it comes to mixing ability with CO₂ (small reservoirs and reservoirs with a large gas volume are considered not ideal for CO₂ injection).

• Uncertainty related to access and price of large volumes of CO₂ and large modifications on the installations.

• Time critical fields reduces the overall total EOR potential.
CO₂ injection and production require extensive modifications in an expensive offshore environment

- New installations may be needed to get all the equipment onboard.
- Modifications for our big fields have estimates between 3 to 6 billion NOK:
  - process upgrades
  - corrosion protection
  - additional wells
  - separation plant to meet sales gas and transportation specifications when justified.

CO₂ for EOR on the NCS - feasibility study

CONCLUSION:
CO₂ injection is technically feasible. There is a large technical potential for increased oil recovery, but it is NPD’s assessment that CO₂ injection based on available technologies and frame works is not a viable commercial alternative for the license owners on the Norwegian shelf. The initial costs are too high, 6-9 billion NOK for capture and transportation and 4-7 billion NOK in modifications etc. Other sectors need to carry their parts of the “burdens”.

A majority of the fields (80%) have increased the reserves since PDO