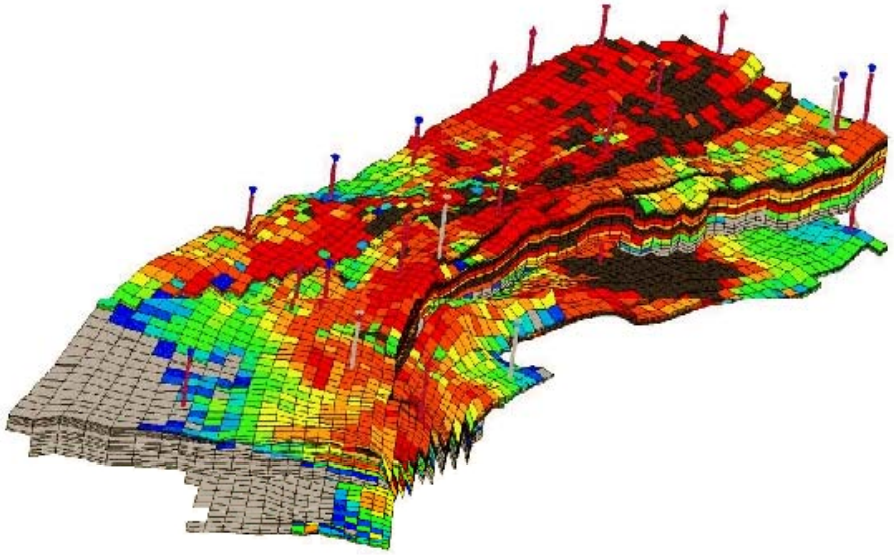

Improved Oil Recovery
- an overview

Eva Ljosland
Regional Director, INTSOK
December 8, 2009
Da Nang, Vietnam

The purpose of this presentation is to identify the relation between different measures and technologies in IOR

Definitions

Improved oil recovery - IOR
(Norwegian Petroleum Directorate)

The planning and execution of measures intended to increase or accelerate oil recovery from a hydrocarbon field in a profitable manner compared to current plans with corresponding forecasts

Improved Oil Recovery - IOR
(Society of Petroleum Engineers)

Any of various methods, chiefly reservoir drive mechanisms and enhanced recovery techniques, designed to improve the flow of hydrocarbons from the reservoir to the wellbore or to recover more oil after the primary and secondary methods (water and gas floods) are uneconomic.

Enhanced Oil Recovery (EOR)

Term normally used for the advanced chemical recovery processes, which can be part of an IOR project.

IOR in INTSOK

'Improved Oil Recovery' (IOR) is used for all measures which can increase or accelerate the oil recovery of a field.

There is emphasis on measures based on information gathered during production, and on measures based on advanced technology.

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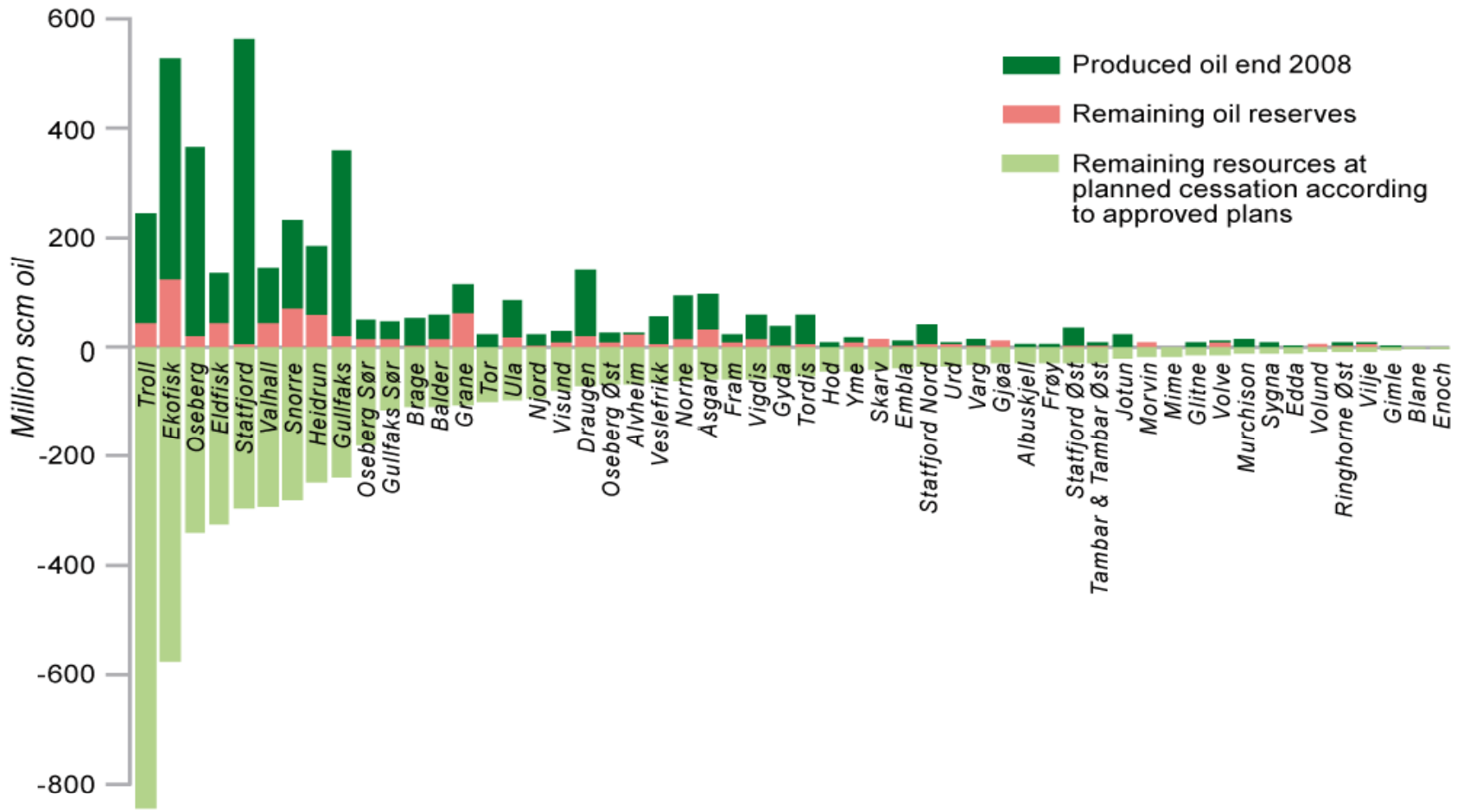
The unrealised potential



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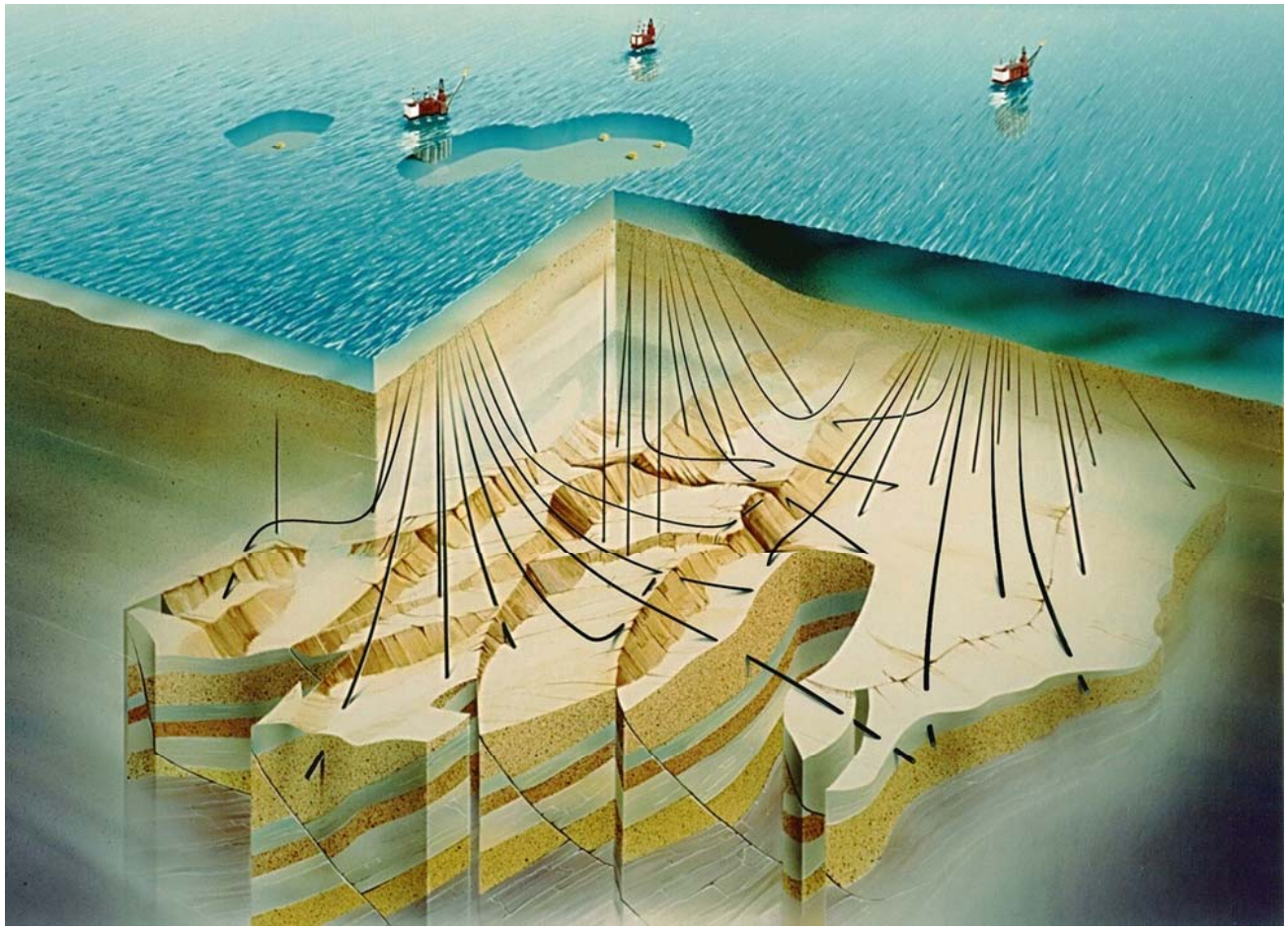
Reservoir Management - IOR - Success stories

Expected ultimate recovery factors

	1986	1996	2004	Current ambition
Statfjord	49 %	61 %	68 %	70 %
Gullfaks	46 %	49 %	60 %	68 %



- Reservoir modelling
- Water and gas injection
- Production start
- Advanced wells and cost efficient infill drilling
- Well intervention
- 4D seismic
- Produced water management
- Top side modifications

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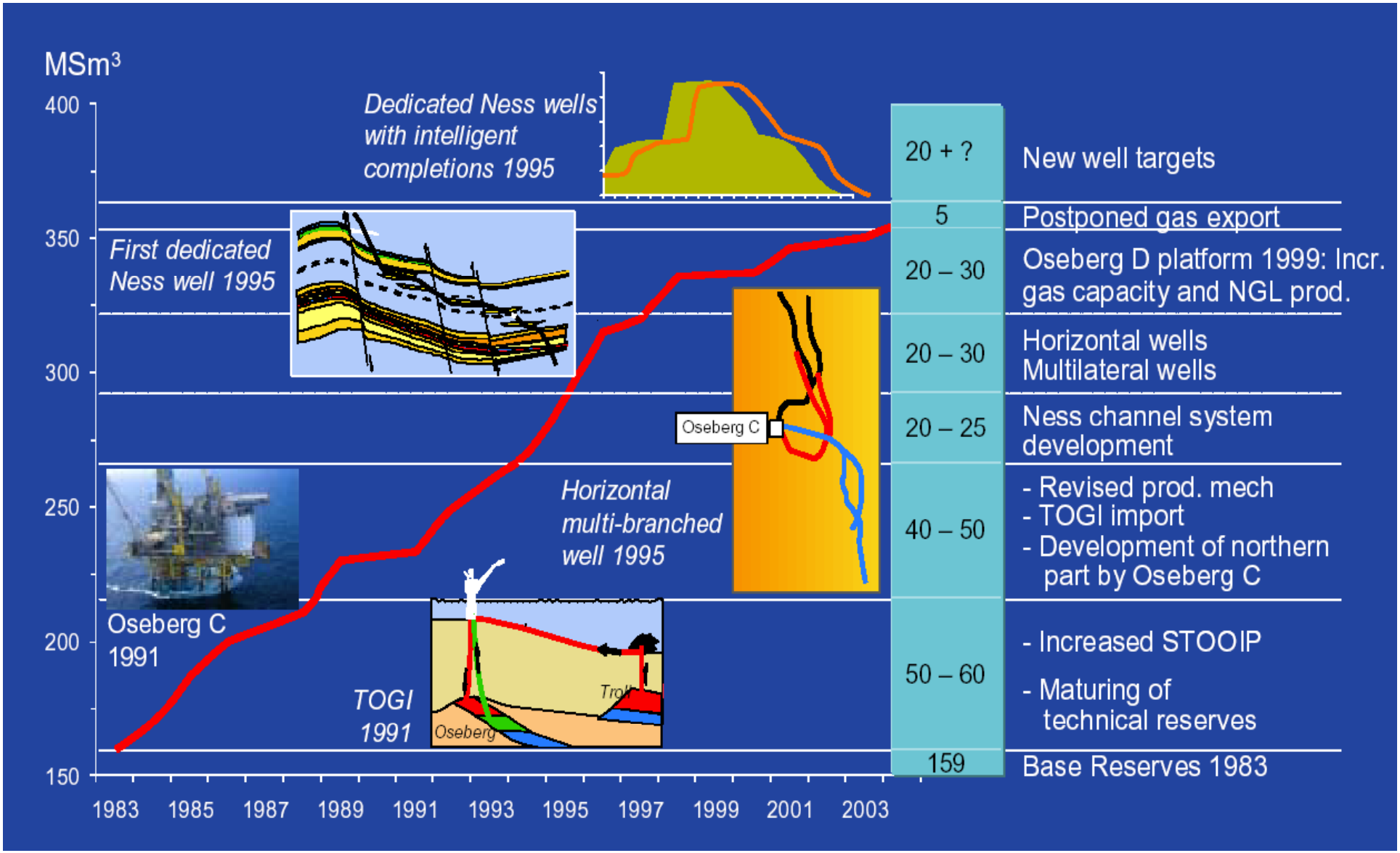
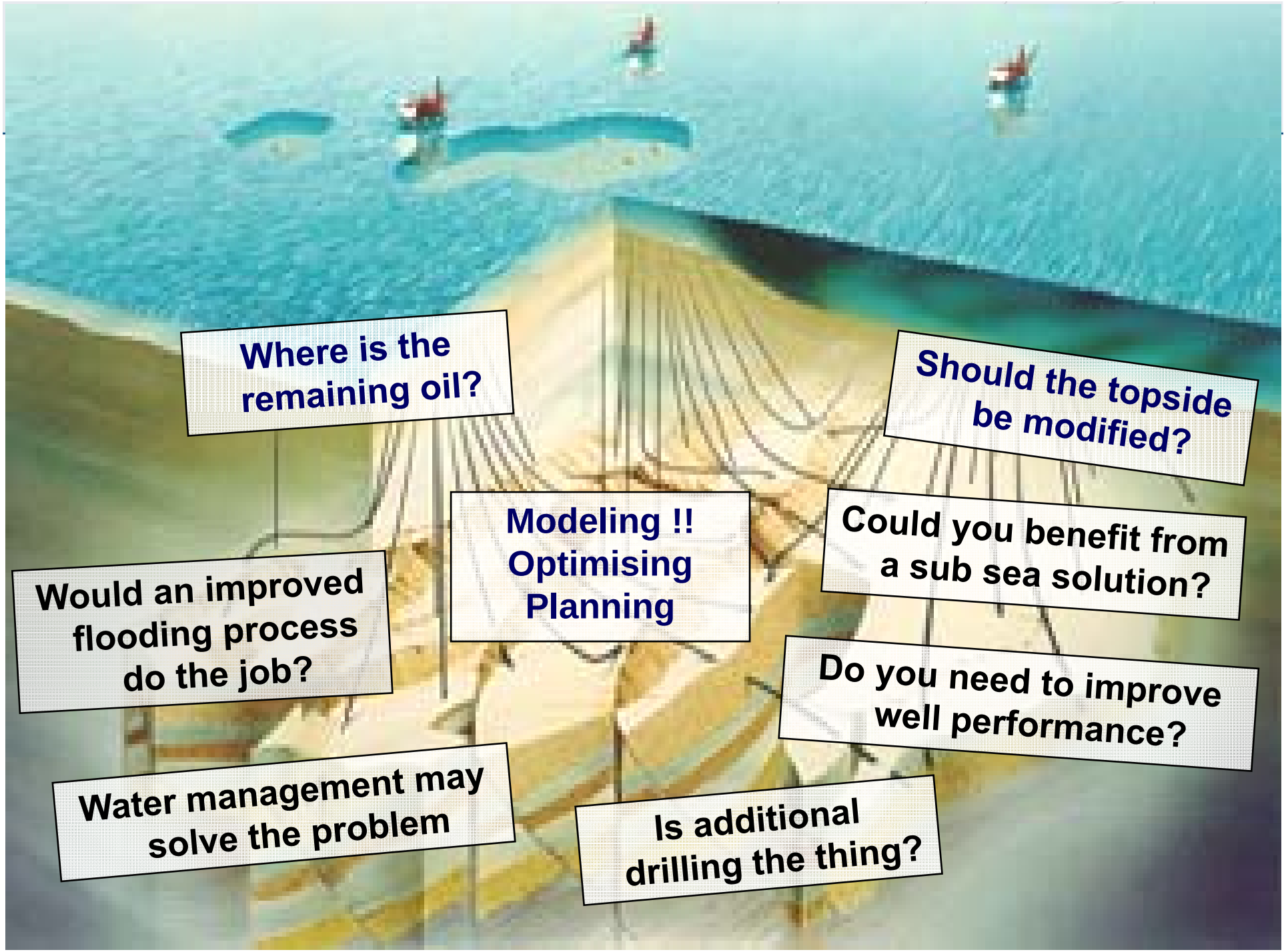
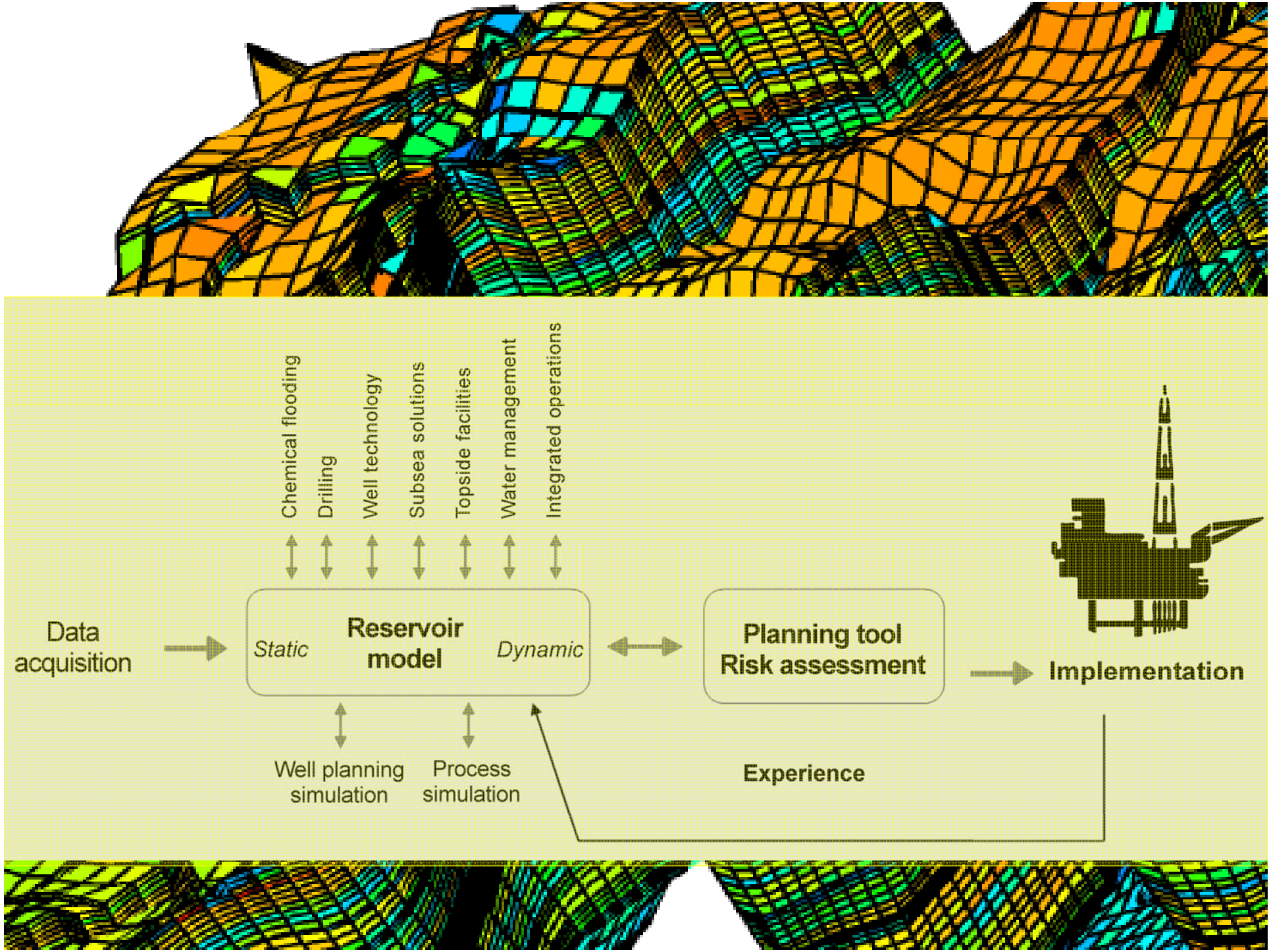
Oseberg - continuous increase of reserves




Where is the remaining oil?
Should the topside be modified?
Modeling !! Optimising Planning
Could you benefit from a sub sea solution?
Would an improved flooding process do the job?
Do you need to improve well performance?
Water management may solve the problem
Is additional drilling the thing?

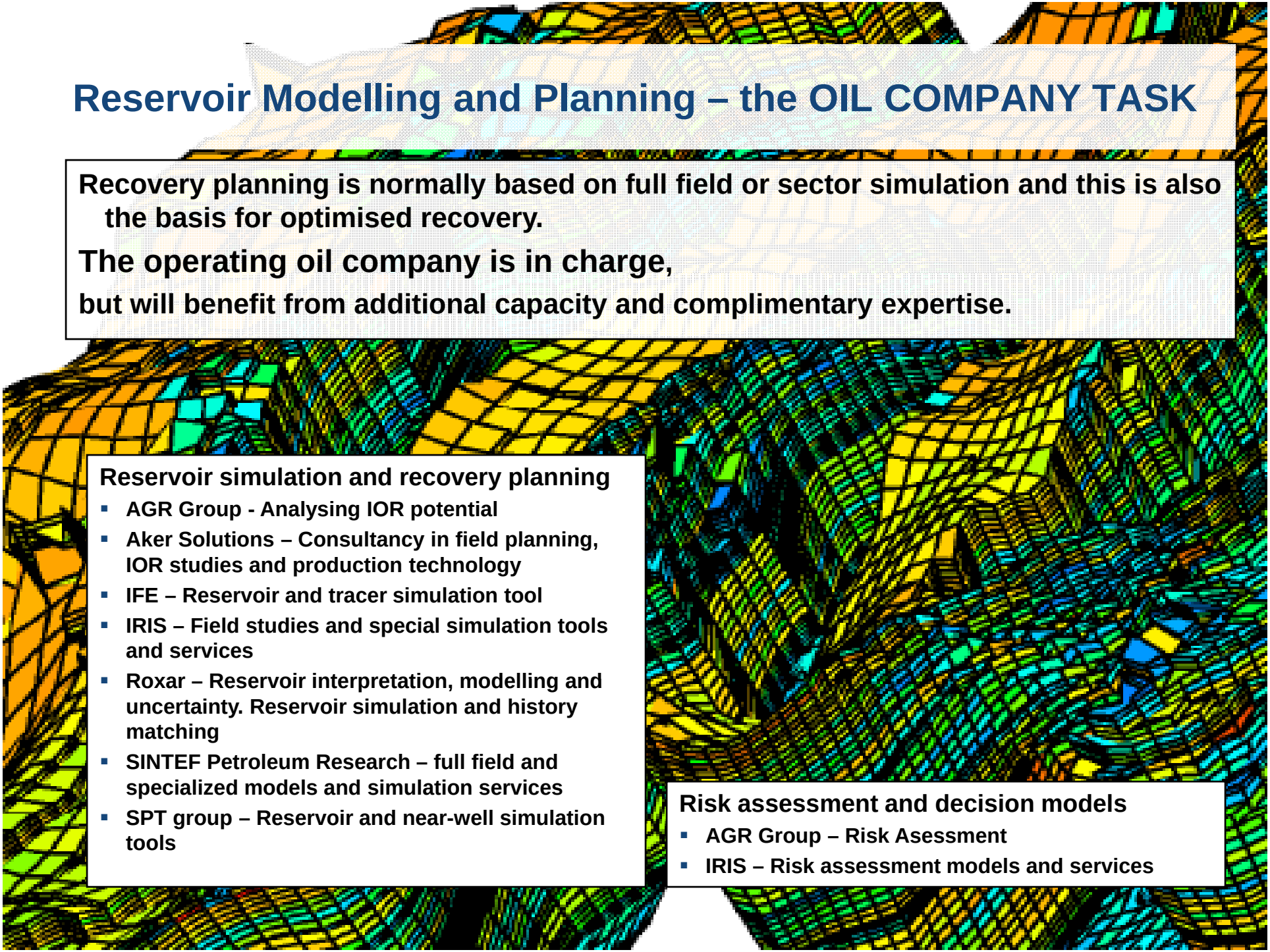

Chemical flooding
Drilling
Well technology
Subsea solutions
Topside facilities
Water management
Integrated operations
Data acquisition
Static
Reservoir model
Dynamic
Planning tool
Risk assessment
Implementation
Well planning simulation
Process simulation
Experience

Reservoir Modelling and Planning – the OIL COMPANY TASK

Recovery planning is normally based on full field or sector simulation and this is also the basis for optimised recovery.

The operating oil company is in charge,

but will benefit from additional capacity and complimentary expertise.



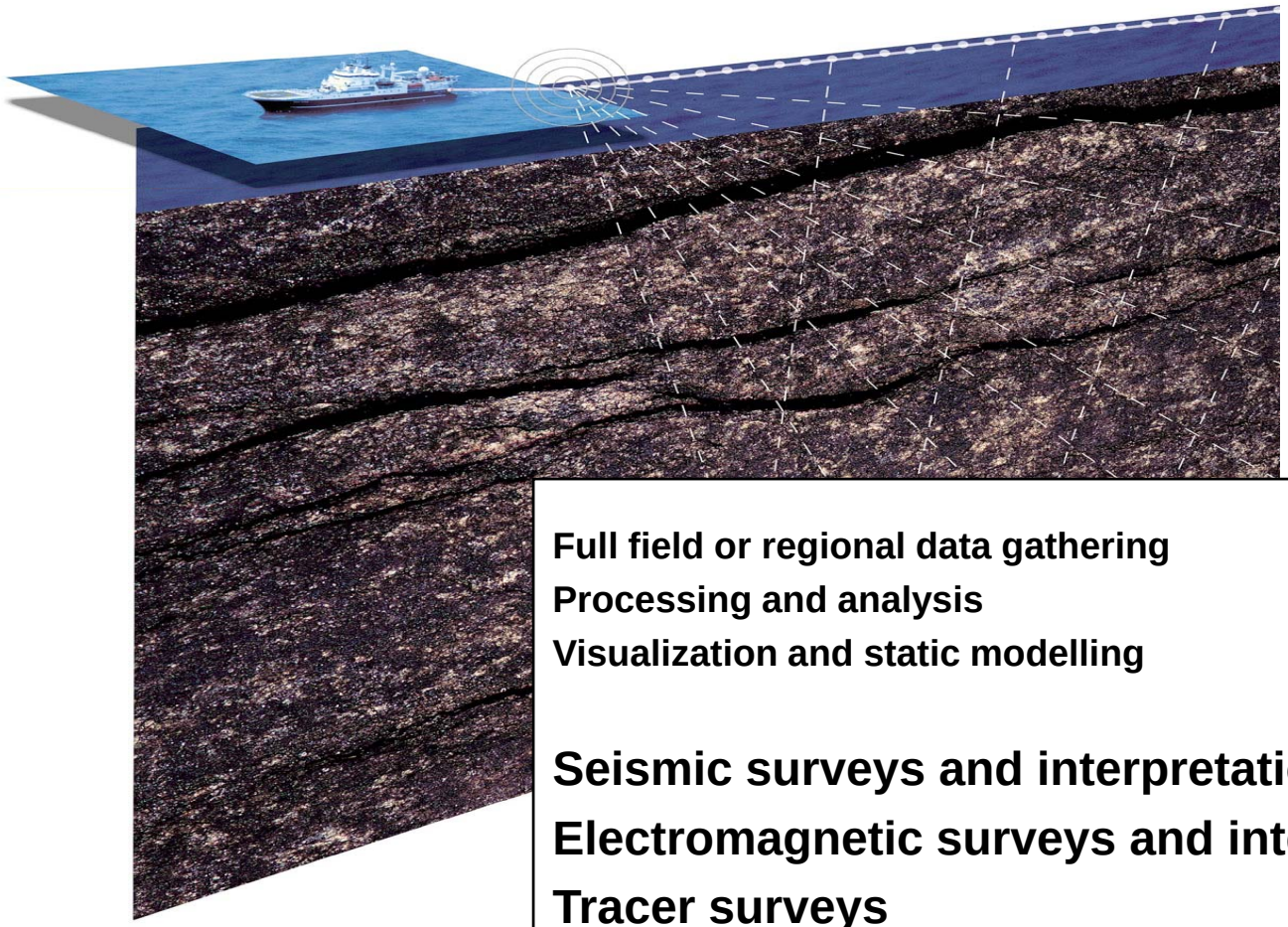
Reservoir simulation and recovery planning

- **AGR Group - Analysing IOR potential**
- **Aker Solutions – Consultancy in field planning, IOR studies and production technology**
- **IFE – Reservoir and tracer simulation tool**
- **IRIS – Field studies and special simulation tools and services**
- **Roxar – Reservoir interpretation, modelling and uncertainty. Reservoir simulation and history matching**
- **SINTEF Petroleum Research – full field and specialized models and simulation services**
- **SPT group – Reservoir and near-well simulation tools**

Risk assessment and decision models

- **AGR Group – Risk Asessment**
- **IRIS – Risk assessment models and services**

Data Acquisition and Processing – full field



Full field or regional data gathering
Processing and analysis
Visualization and static modelling

Seismic surveys and interpretation
Electromagnetic surveys and interpretation
Tracer surveys
Pressure surveys

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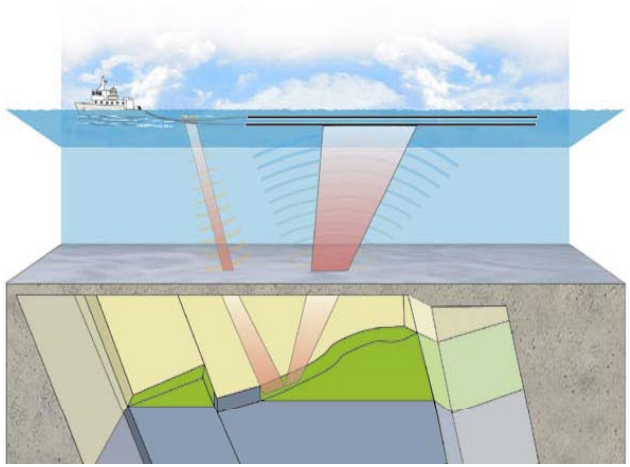
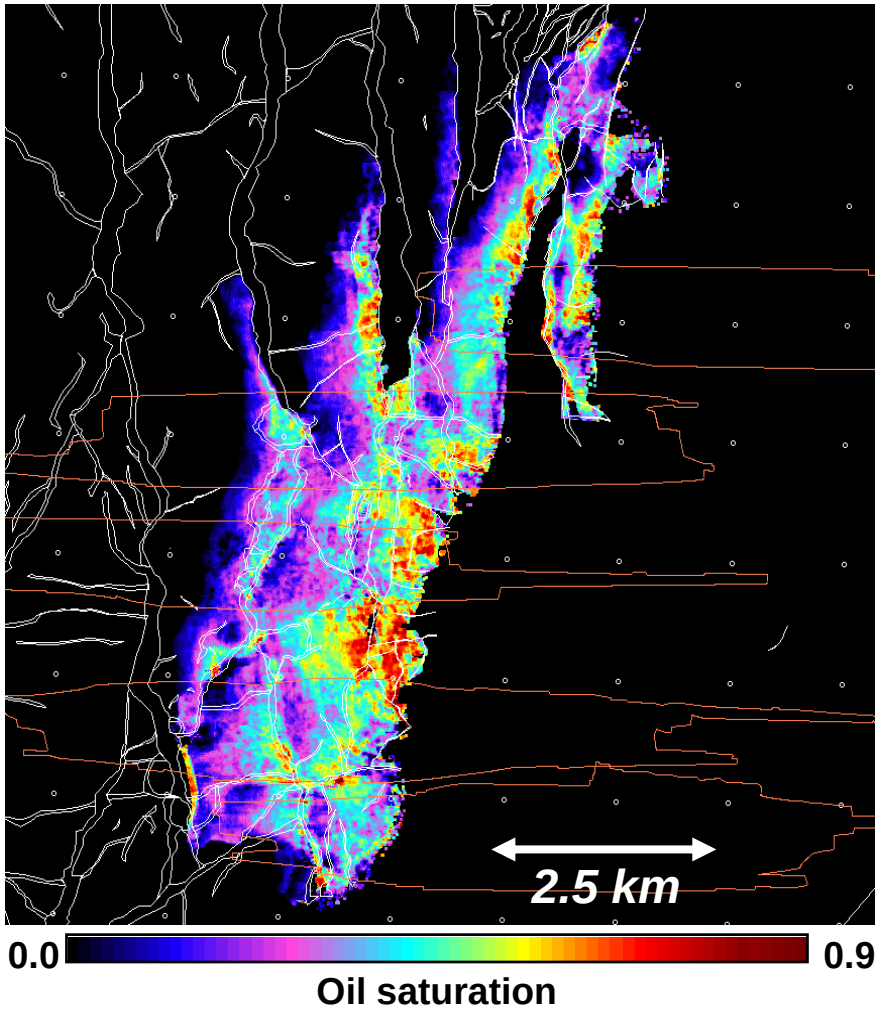
Highlights of 4D seismic in Statoil

- Pioneered in Statoil since the early 1990s.
- Both towed streamers and ocean-bottom surveys (OBS) have been used
- 4D feasibility study performed for all fields
- Ongoing 4D projects on most fields
- More than 40 wells drilled based on 4D seismic
- Pilot on permanent fibre optical OBS being installed





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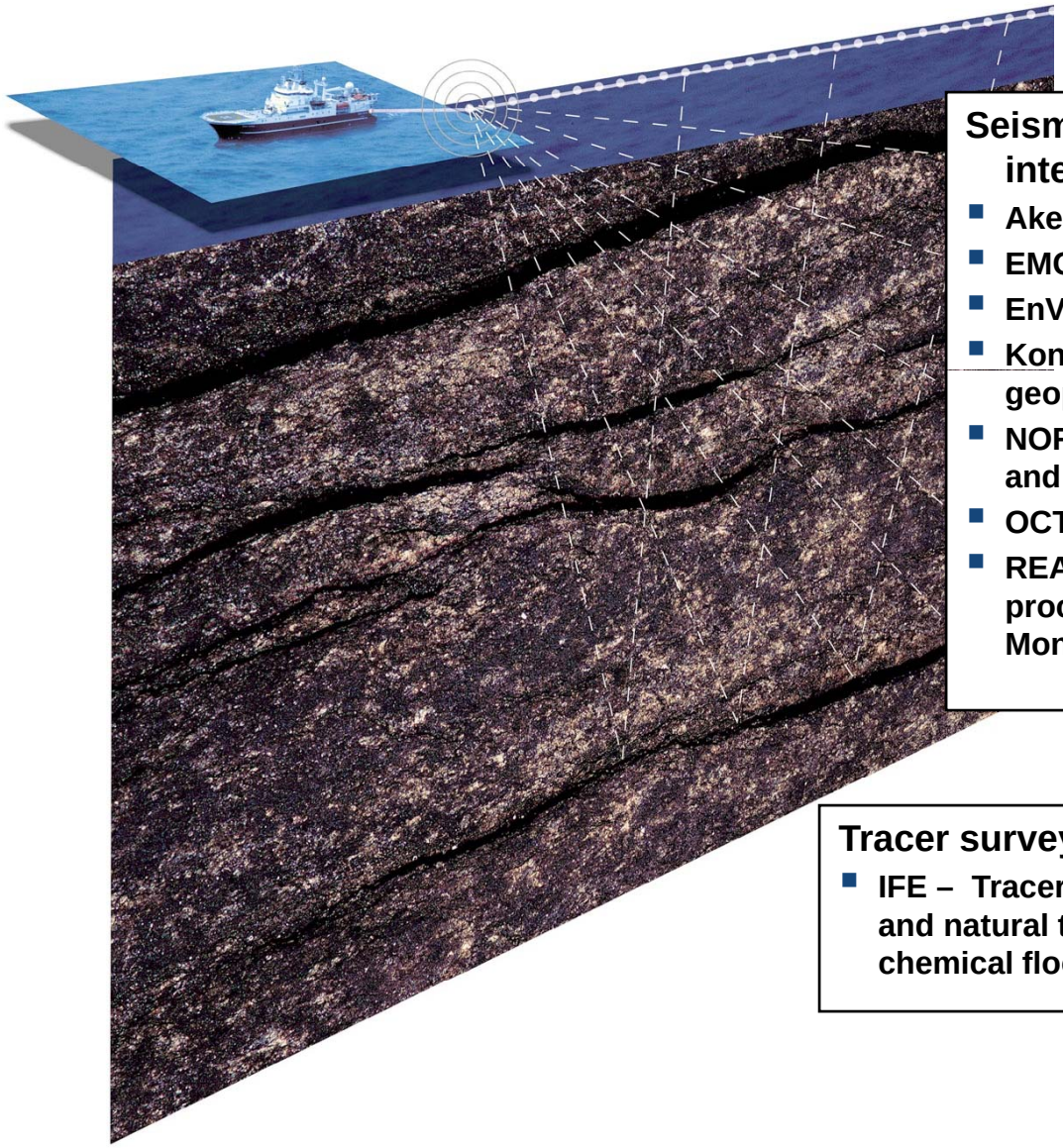
Data Acquisition and Processing – full field



Seismic and other full field surveys and interpretation

- Aker Solutions – seismic interpretation
- EMGS – Electromagnetic surveys
- EnVision –Visualization of pressure data (EnFind)
- Kongsberg - Visualization of reservoir and geophysical data
- NORSAR Innovation – 4D seismic modeling software and services
- OCTIO – Acquisition and processing seismic data
- READ – Down hole seismic acquisition and processing (VSP). Permanent Seismic Down hole Monitoring (PSM)

Tracer surveys

- IFE – Tracers mapping reservoir dynamics – ideal, partitioning and natural tracers, injection services and analysis. Monitoring chemical flooding.

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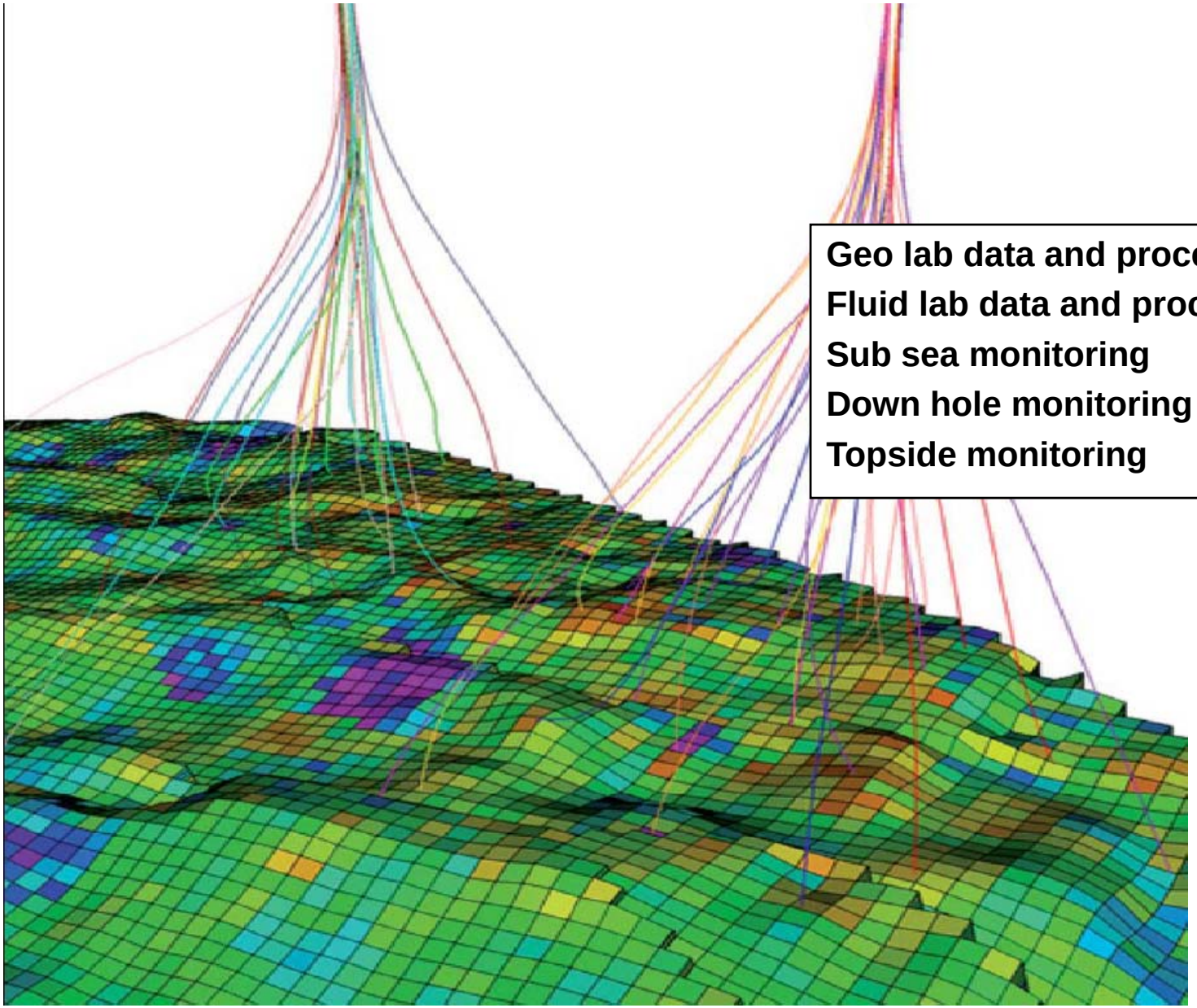
Data Acquisition and Processing – local measuments and lab



- Geo lab data and processing
- Fluid lab data and processing
- Sub sea monitoring
- Down hole monitoring
- Topside monitoring

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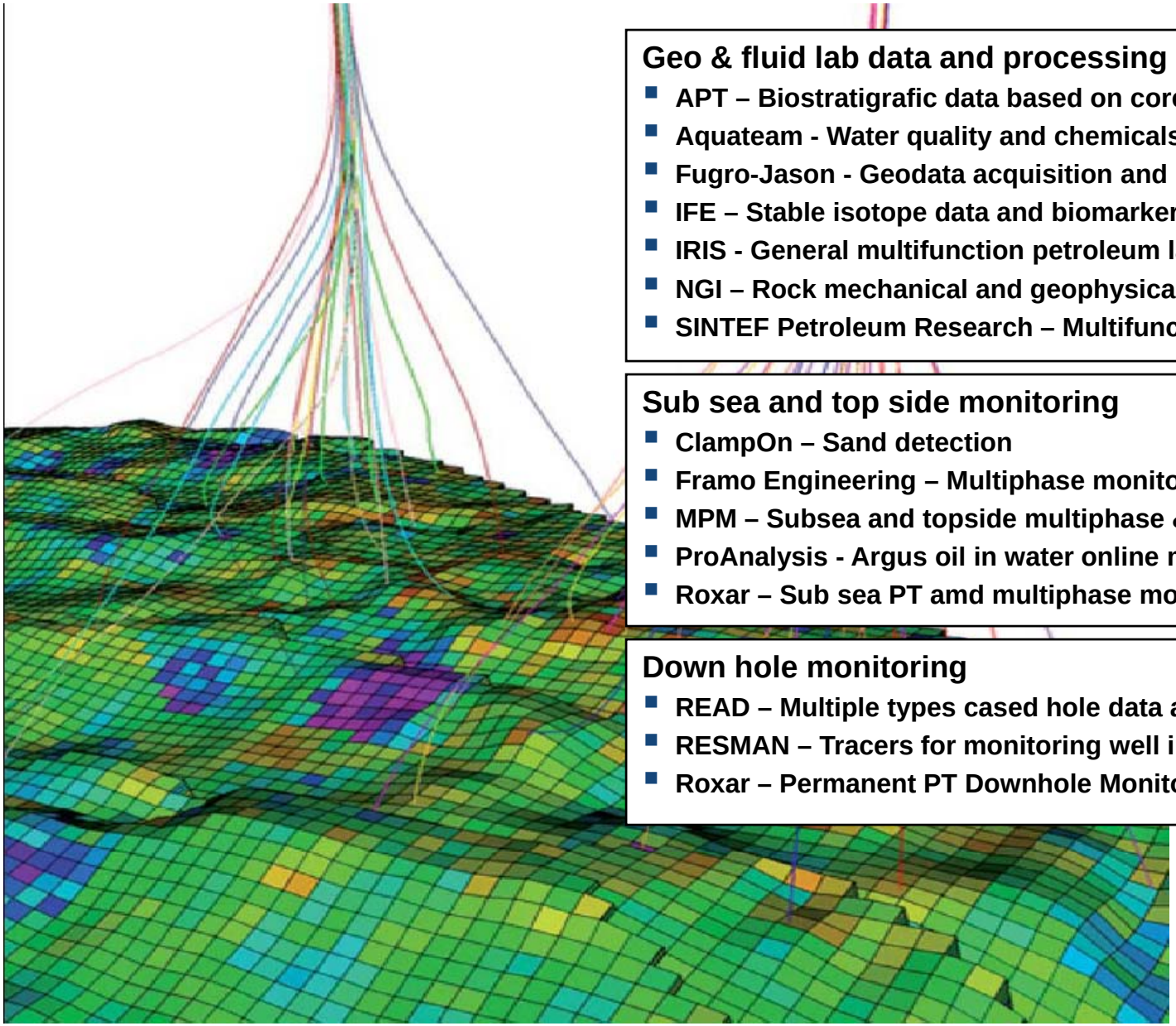
Data Acquisition and Processing – local measuments and lab



Geo & fluid lab data and processing

- APT – Biostratigrafic data based on core. Biosteering while drilling
- Aquateam - Water quality and chemicals. Lab- and pilot studies
- Fugro-Jason - Geodata acquisition and processing.
- IFE – Stable isotope data and biomarkers
- IRIS - General multifunction petroleum lab
- NGI – Rock mechanical and geophysical lab
- SINTEF Petroleum Research – Multifunction fluid lab

Sub sea and top side monitoring

- ClampOn – Sand detection
- Framo Engineering – Multiphase monitoring
- MPM – Subsea and topside multiphase & wetgas measurement
- ProAnalysis - Argus oil in water online monitors
- Roxar – Sub sea PT amd multiphase monitoring

Down hole monitoring

- READ – Multiple types cased hole data acquisition and processing
- RESMAN – Tracers for monitoring well inflow performance
- Roxar – Permanent PT Downhole Monitoring System (PDMS)

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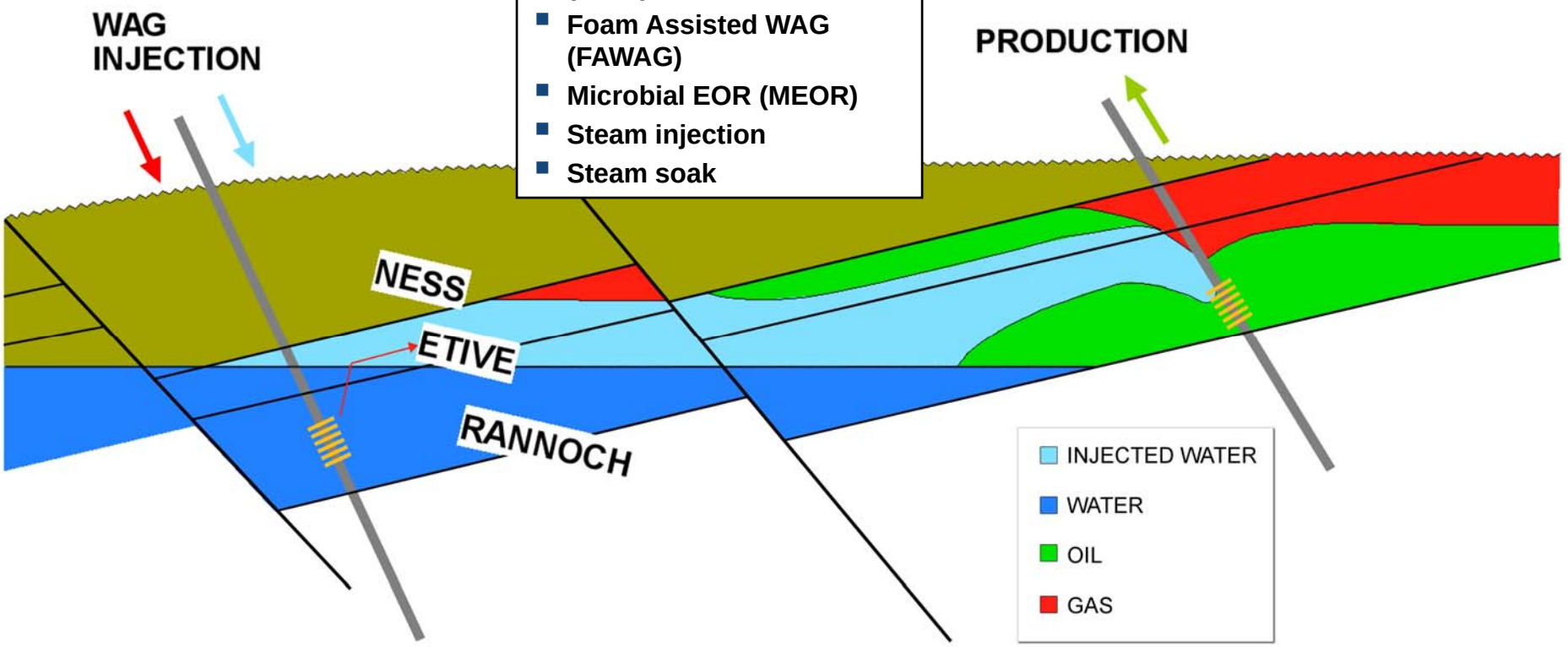
Chemical Flooding

Conventional methods

- Pressure depletion
- Water injection
- Injection of natural gas

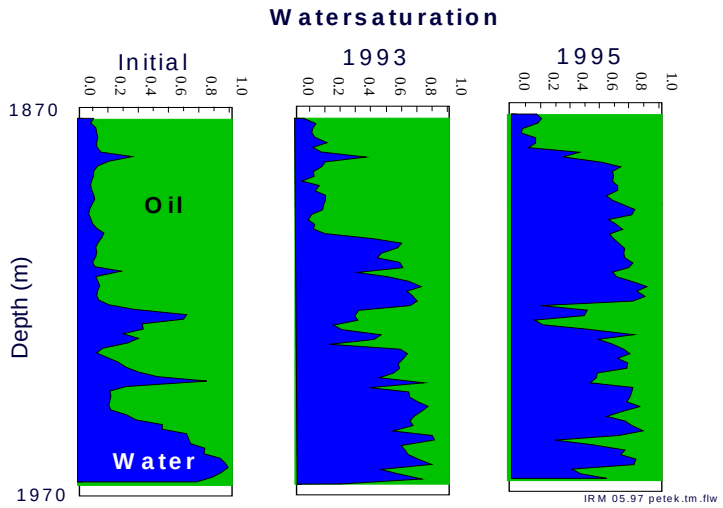
Advanced flooding

- Polymer flooding
- Surfactant flooding
- Gel treatment
- CO_2 injection
- N_2 injection
- Water Alternating Gas (WAG)
- Foam Assisted WAG (FAWAG)
- Microbial EOR (MEOR)
- Steam injection
- Steam soak



Water injection

- **Injection water for pressure maintenance**
- **Obtaining maximal volumetric sweep through monitoring, water shut-off and infill drilling**
- **Understanding remaining oil saturation after water flooding**
  - **Special core analysis (SCAL)**
  - **In situ observations**



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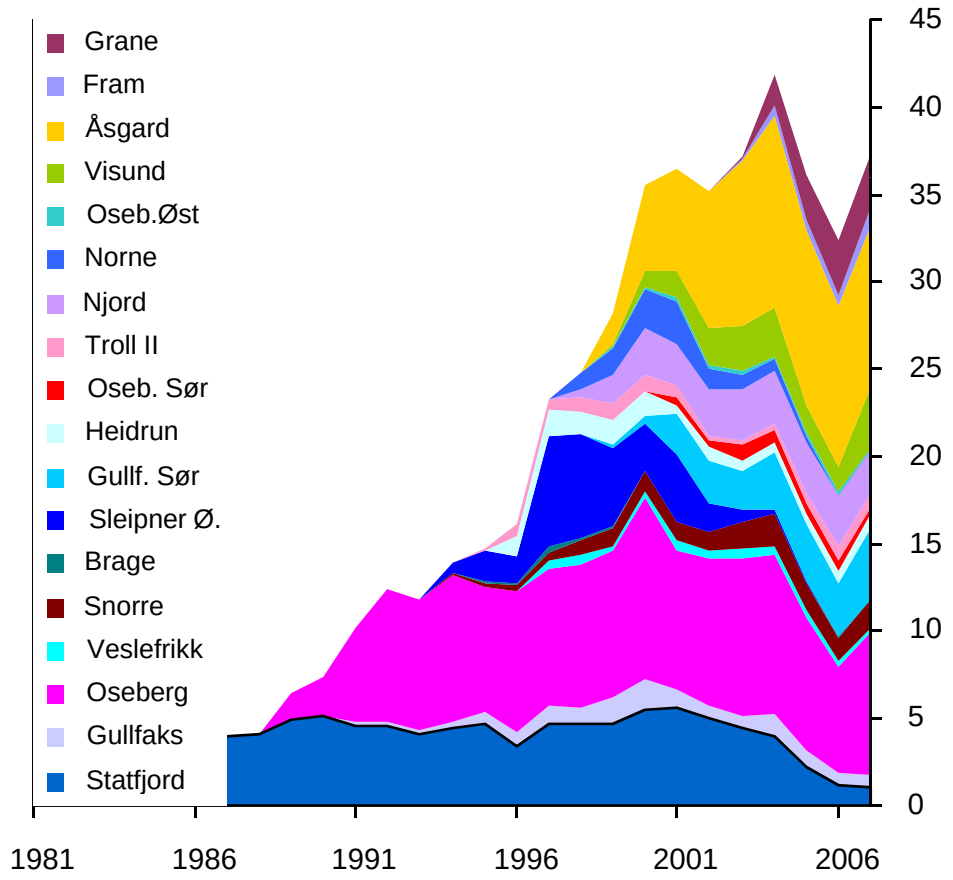
Gas injection

Yearly gas injection at Statoil NCS fields (bcm/year)



Gas injection projects in Statoil include:

- **Large-scale gas flooding (miscible and immiscible)**
- **Gas cycling in gas condensate reservoirs**
- **Gas cap reinjection**
- **Supplementary WAG injection**
- **Gas diversion by foam (FAWAG)**

CO2 injection

- **Extensively studied for IOR**
- **Currently only injected for storage in aquifers (CCS projects)**

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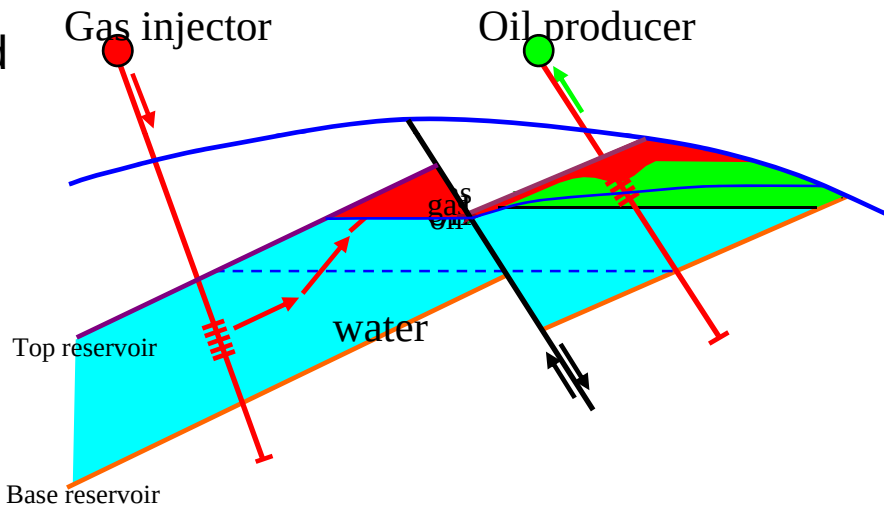
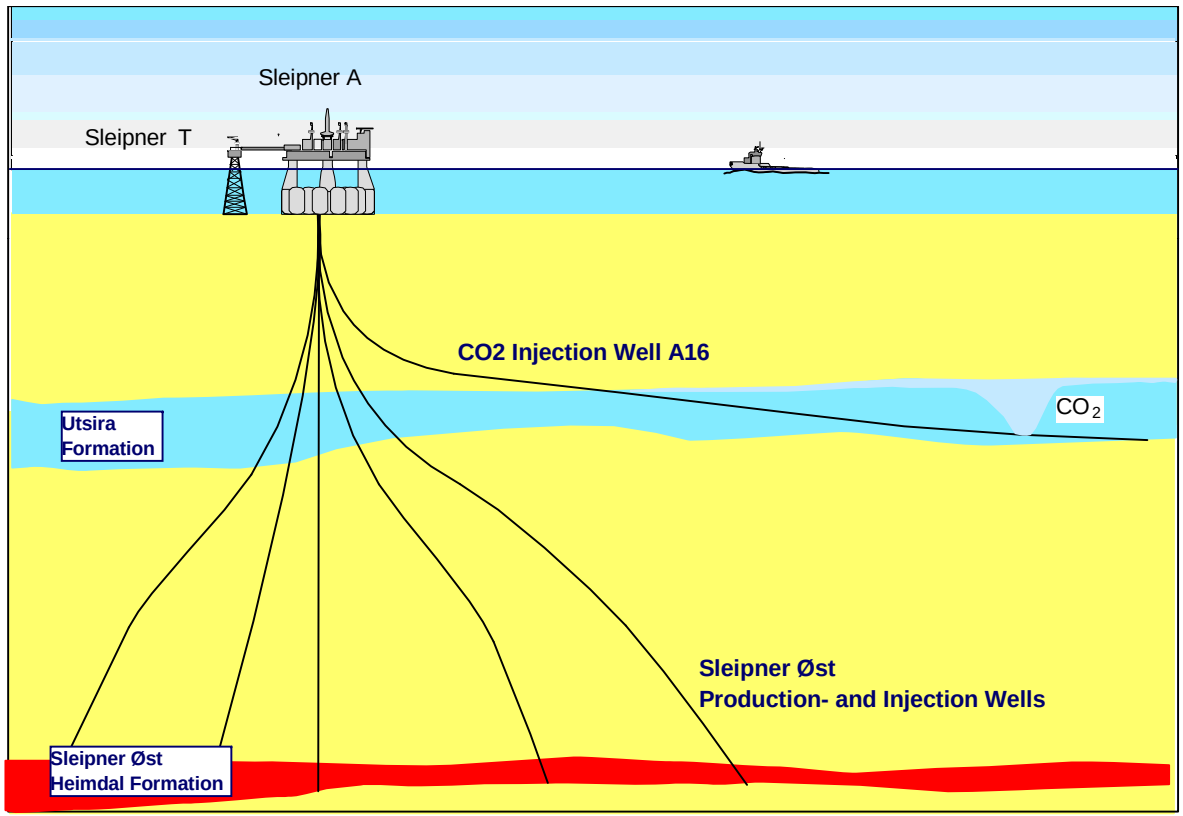
CO2 for EOR in North Sea

- Challenges in the North Sea
  - Large well spacing
  - Very costly offshore modifications
  - Extensive use of gas injection and water injection – low residual saturations
  - Contamination of sales gas
  - CO2 supply/CO2 sources
  - Competition with other methods



Sleipner CO2 injection - our starting point

- Objective to reduce the CO2 content from from 9% to 2.5% (sale spec.)
- The CO2 is captured by an amin plant
- CO2 storage in an aquifer
- Start up in Aug 1996
- Injection rate:
  ~ 1 mill ton CO2/yr
- Regularity: 98-99%



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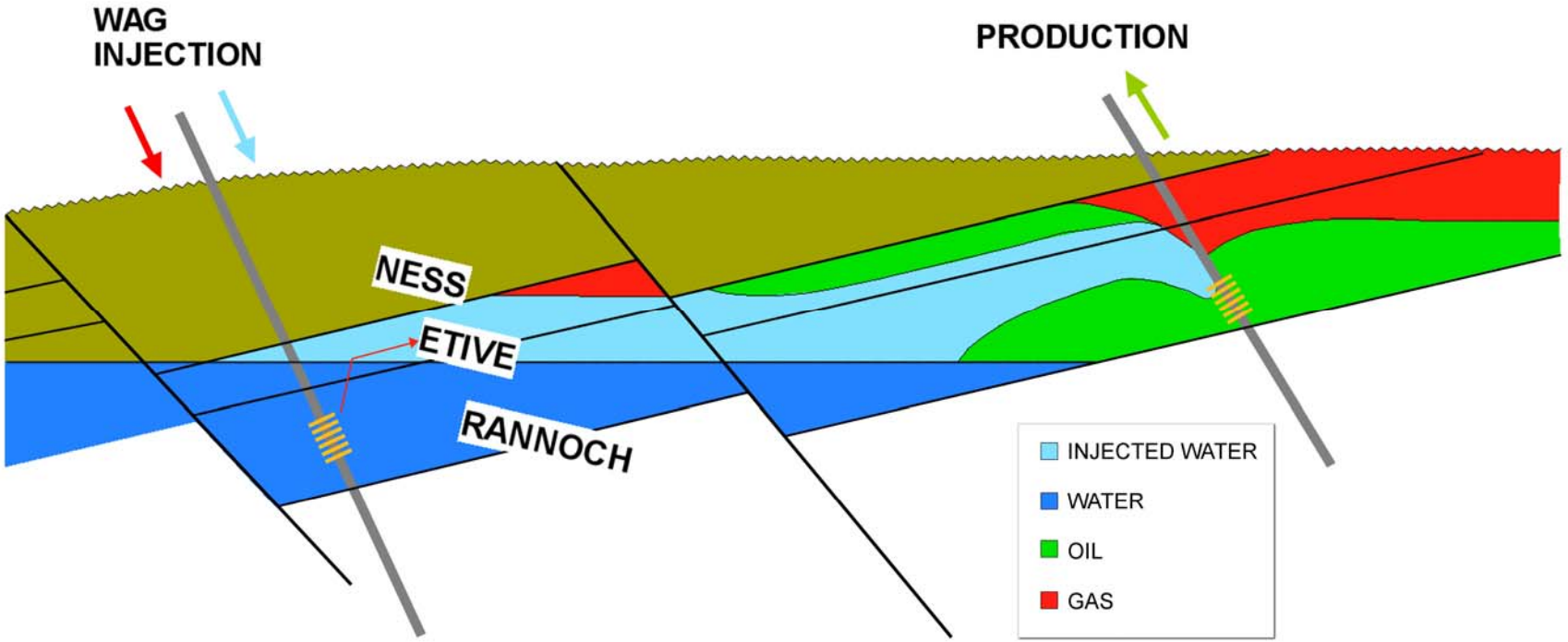
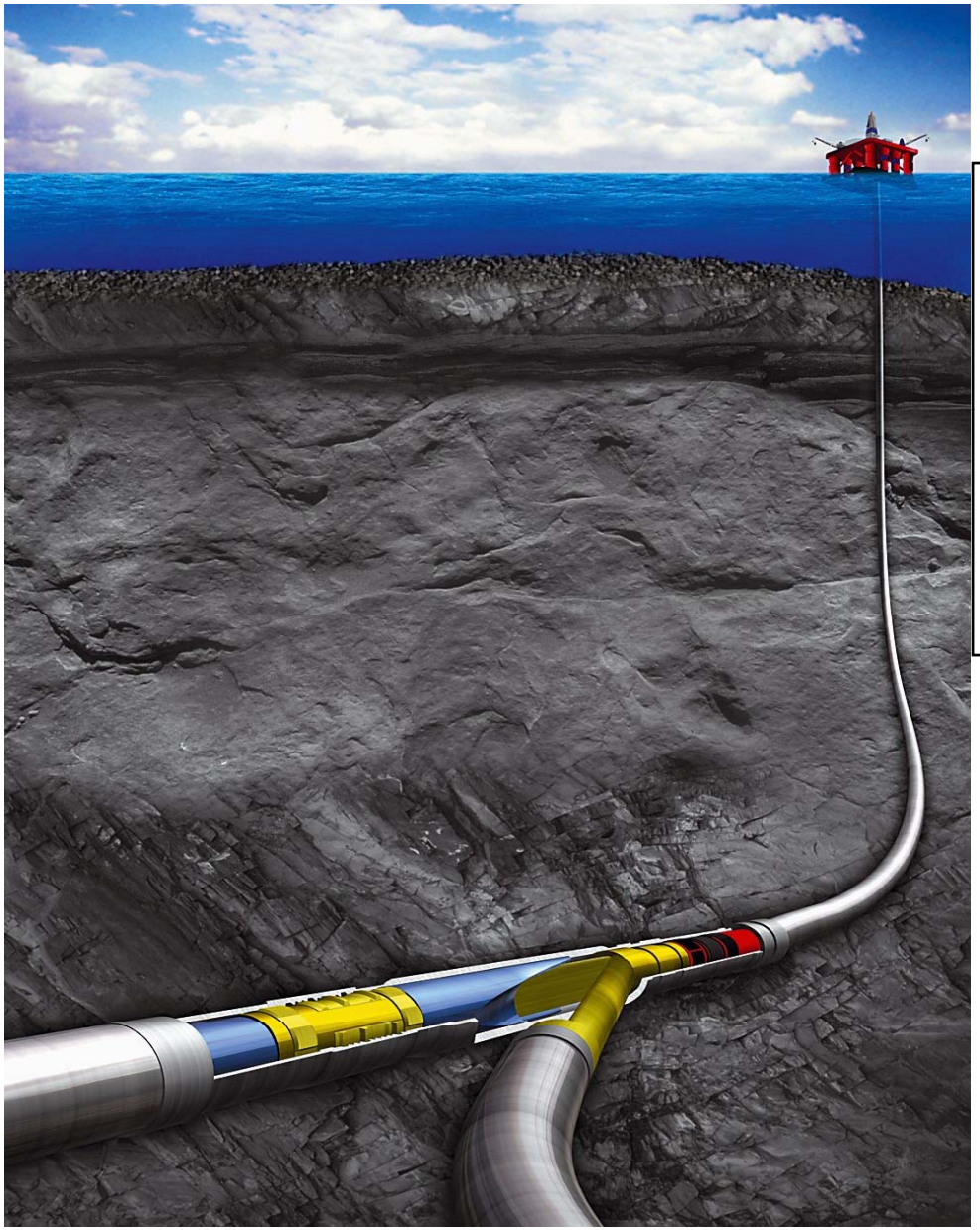
Chemical Flooding

R&D / assessment of chemical flooding

- AGR Group – Assess potential and decision basis for EOR projects
- Aquateam – Microbial EOR
- IFE - Broad petroleum research within recovery mechanisms and tracers for EOR operations
- IRIS – Broad petroleum research within reservoir technology, IOR & drilling
- NTNU - Broad Petroleum reseach
- SINTEF Petroleum Research – Broad Petroleum Research - WAG, FAWAG, polymers, surfactants, foam, CO2 sequestation, fluid flow in porous media



Drilling



Options for Improving recovery

- **Conventional infill wells**
- **Horizontal wells**
- **Multilateral wells**
- **TTRD (Through Tubing Rotary Drilling)**
- **Extended reach drilling**

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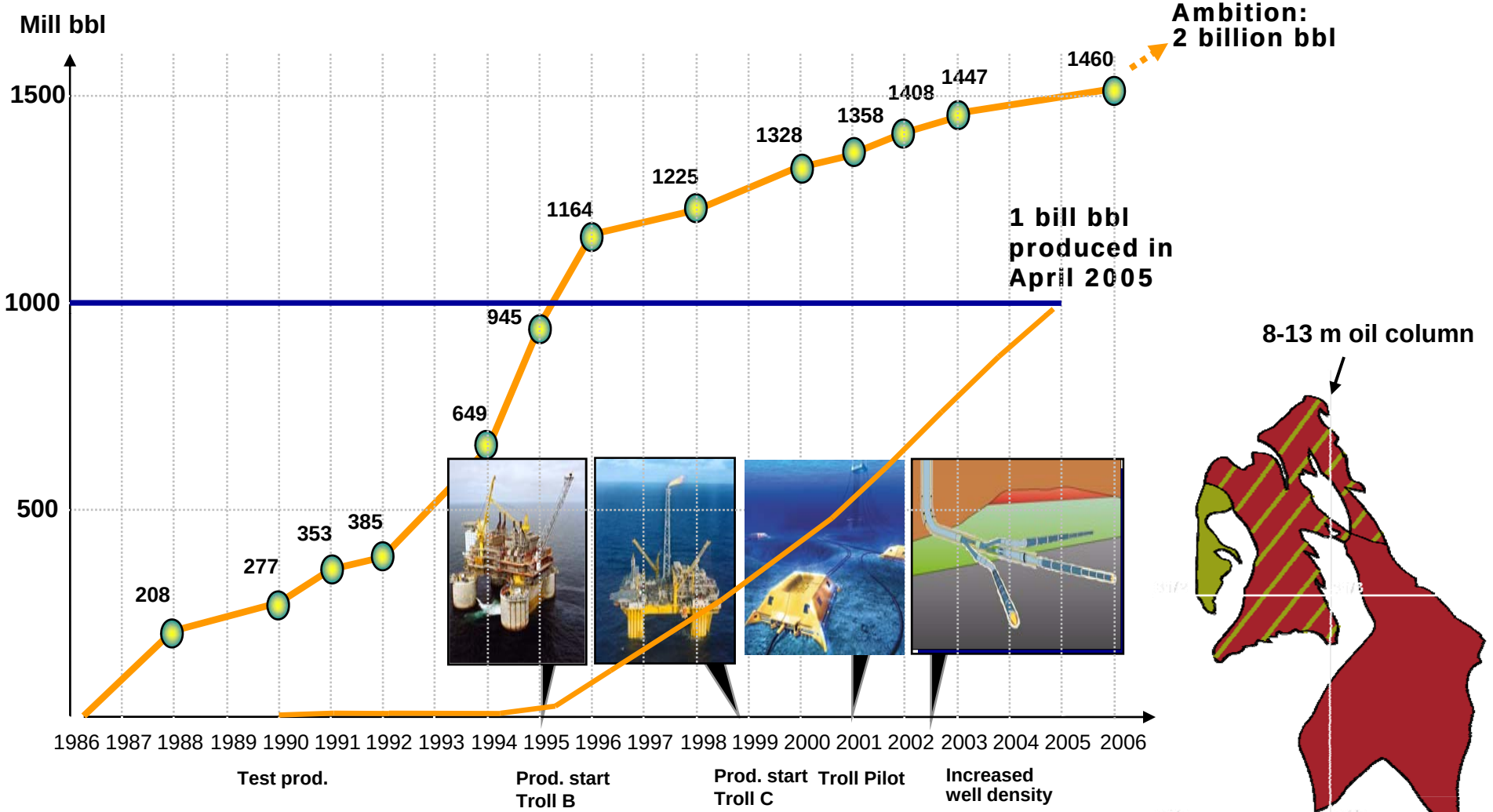
Troll Oil



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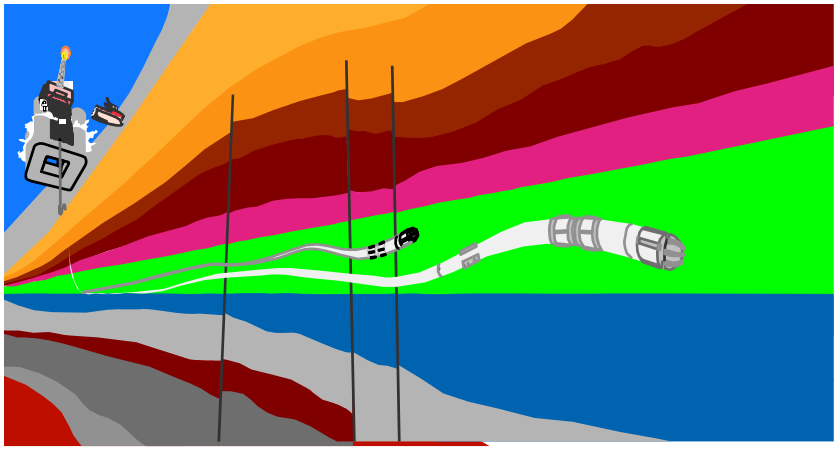
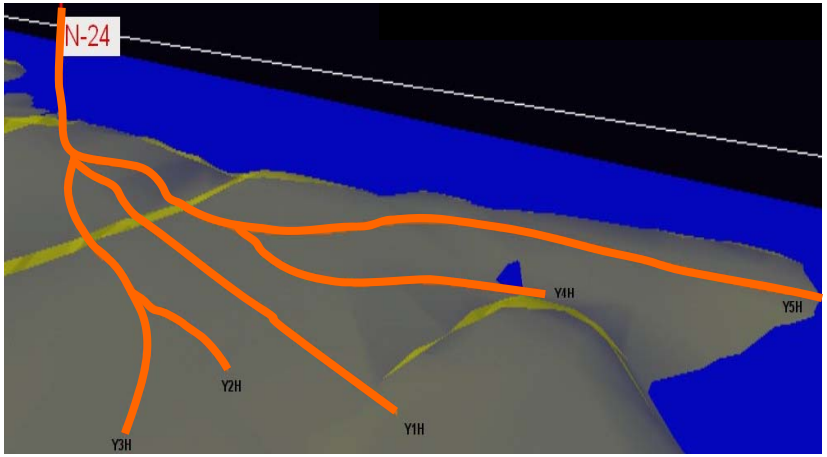
Troll oil wells

- Increasingly longer well paths
- Targeting a thinner oil column
- Presently 114 horizontal wells and 33 multilateral wells
- Inflow control devices (ICD) in many wells





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Drilling

Well design and planning

- add wellflow – Well planning consultancy
- AGR Group – Well planning, operations geosteering
- IRIS – research and verification of well design and down hole equipment
- SINTEF Petroleum Research – Support for well design, planning and real time analysis

Drilling technology and equipment

- AGR Group – Riserless Mud Recovery
- Geomec Engineering - Improved wellbore stability and mud loss management
- IRIS - Drilltronics
- PTC – Riser displacement cleaning tool
- Reelwell - Managed pressure drilling. Extended reach drilling

Alternative drilling and well intervention methods

- Aker Solutions – Coiled tubing. Light well intervention. Riserless well intervention
- FMCTechnologies – Riserless Well Intervention (RLWI)
- Odfjell Drilling – Snubbing
- TTS-Sense – Rack and Pinion technology

Rigs and drilling service

- AGR Group – Drilling management
- Odfjell Drilling – Rig and drilling services
- SeaDrill – Rig and drilling services

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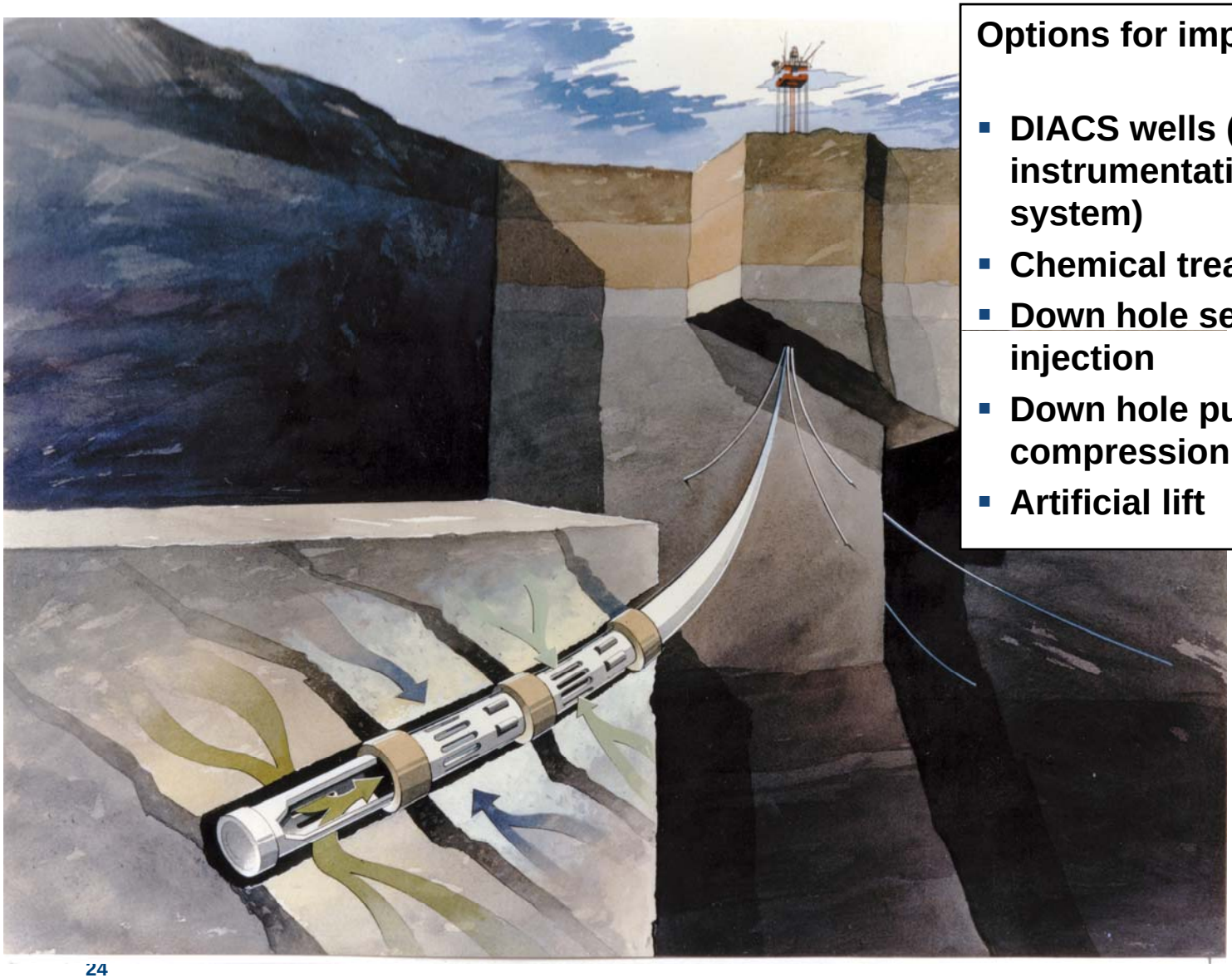
Well Technology



Options for improving recovery

- **DIACS wells (downhole instrumentation and control system)**
- **Chemical treatments**
- **Down hole separation and injection**
- **Down hole pumping and compression**
- **Artificial lift**

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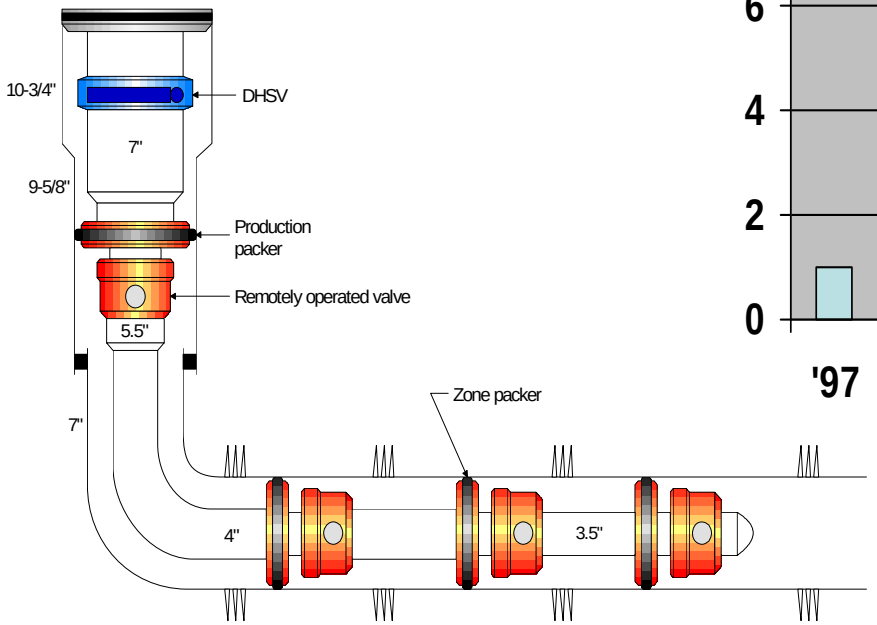
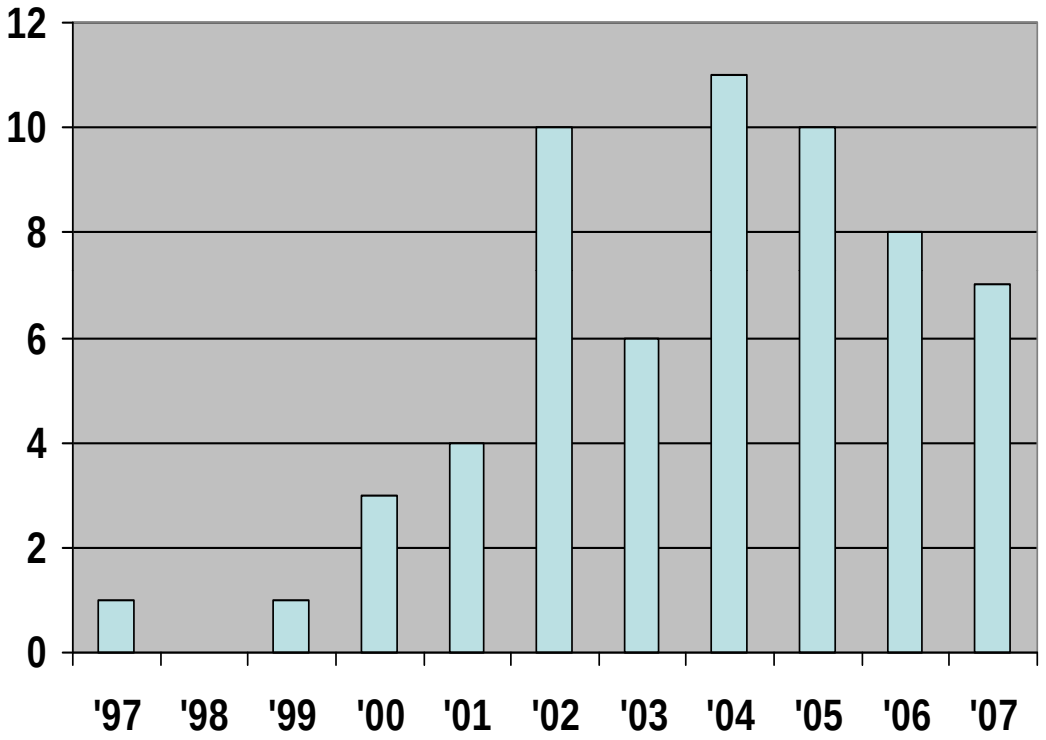
Using a diversity of wells

Increasing use of DIACS wells (downhole instrumentation and control system) both for injection and production



Installed DIACS wells in Statoil



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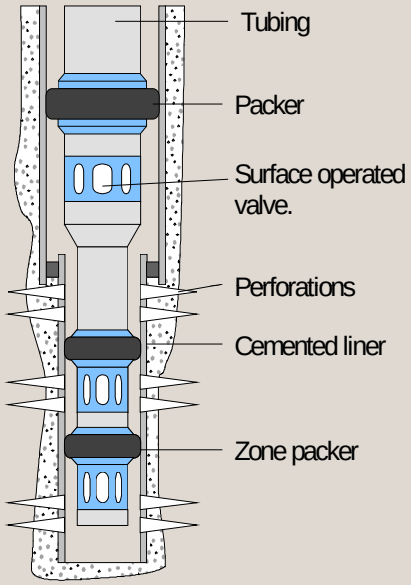
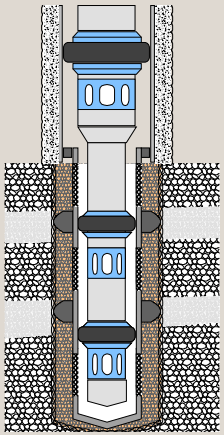
Use of DIACS

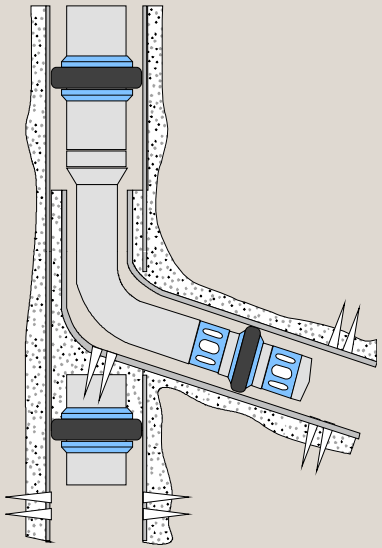
Standard



In combination with gravel pack



In MLT well



With ICD

- **Statoil - advanced well technology:**
  - 1997: First DIACS well (Snorre A)
  - 2003: First with open-hole sand screen and swell packs (Snorre B)
  - Open-hole gravel pack and chemical injection on zonal level (Urd)
  - First with optical flow meters on zonal level in a DIACS WAG injector (Veslefrikk)
  - Technology development on Troll - a success story difficult to match

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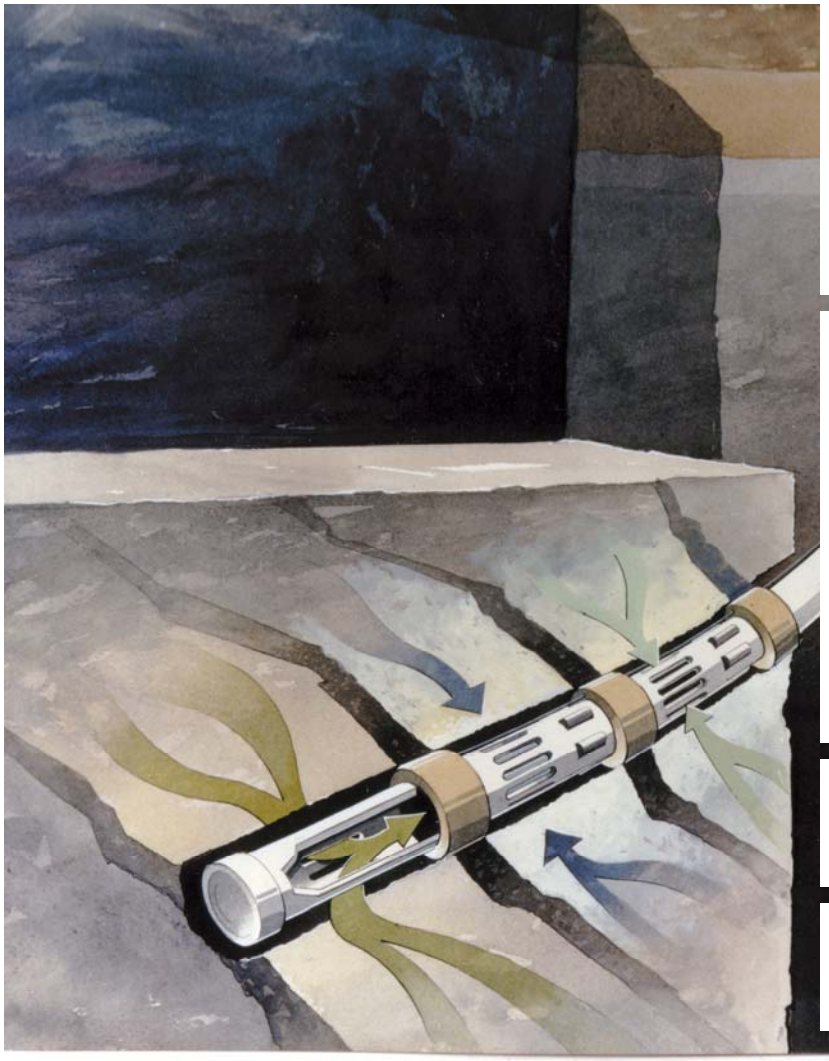
Well Technology



Well design and performance

- Geomec Engineering - Sand management, flooding optimisation
- IRIS – Research and verification of well design and down hole equipment
- Kongsberg – LedaFlow, dynamic multiphase simulations, flow assurance
- SINTEF Petroleum Research – Support on well design, planning and real time analysis, fracturing and filtercake topics
- SPT Group and IFE – Olga Rocx, well and near-well multiphase simulations

Well equipment

- AGR Group – Canseal, chemical zone isolation tool
- Aker Solutions - Wireline tractor and wireline logging services
- READ – Hydraulic expandable well systems, different kinds
- i-Tec – Equipment for smart wells
- Peak Well Solutions – Gas tight well barriers
- PTC – Equipment for Wellhead, Well intervention and completion
- SeaWell - Completion equipment and service
- TCO – Smart plugs

Artificial lift

- PTC – Gas lift equipment

Downhole separation

- READ – Flow splitter, cyclone based

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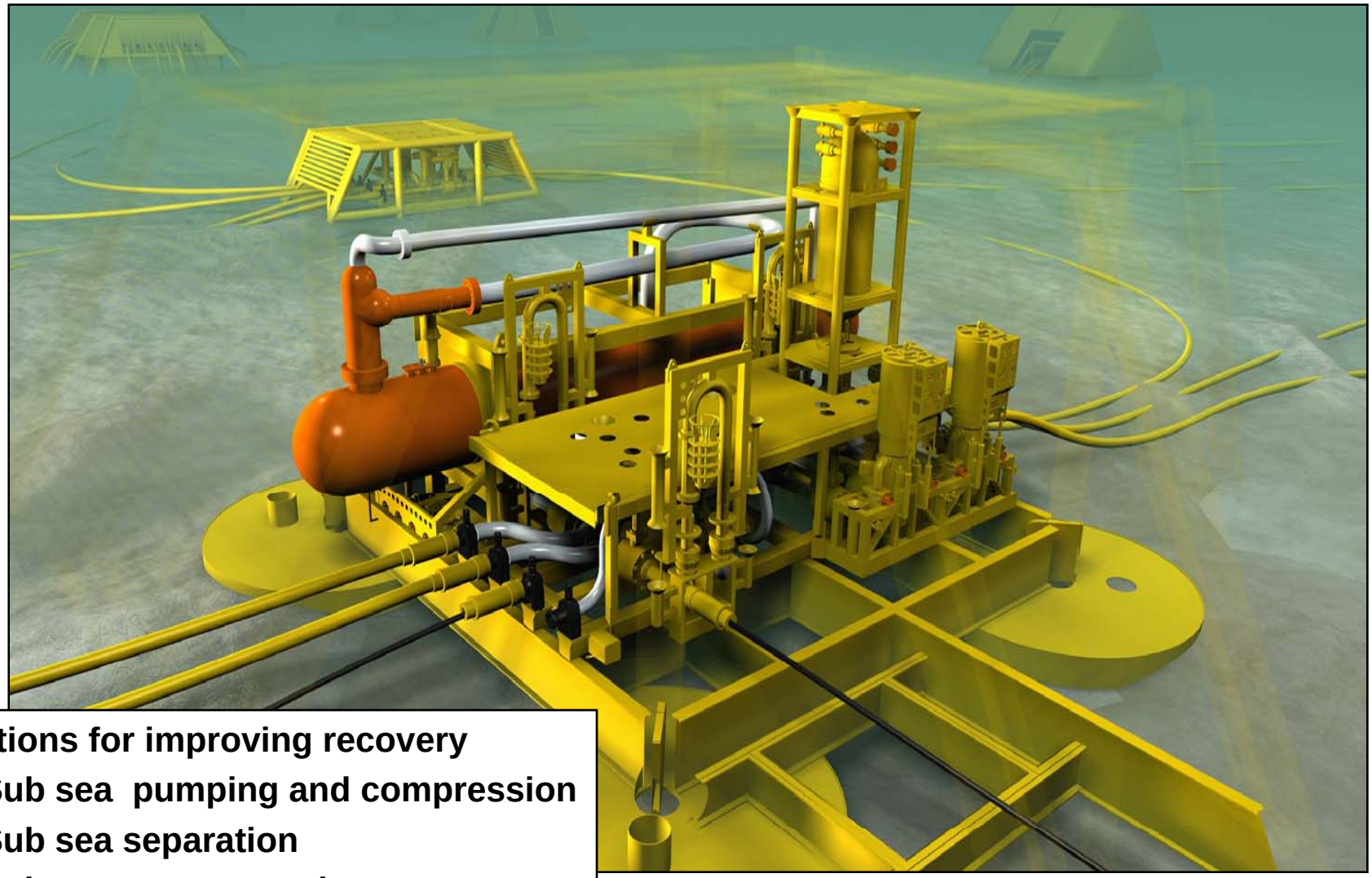
Sub Sea Solutions



Options for improving recovery

- **Sub sea pumping and compression**
- **Sub sea separation**
- **Sub sea power supply**

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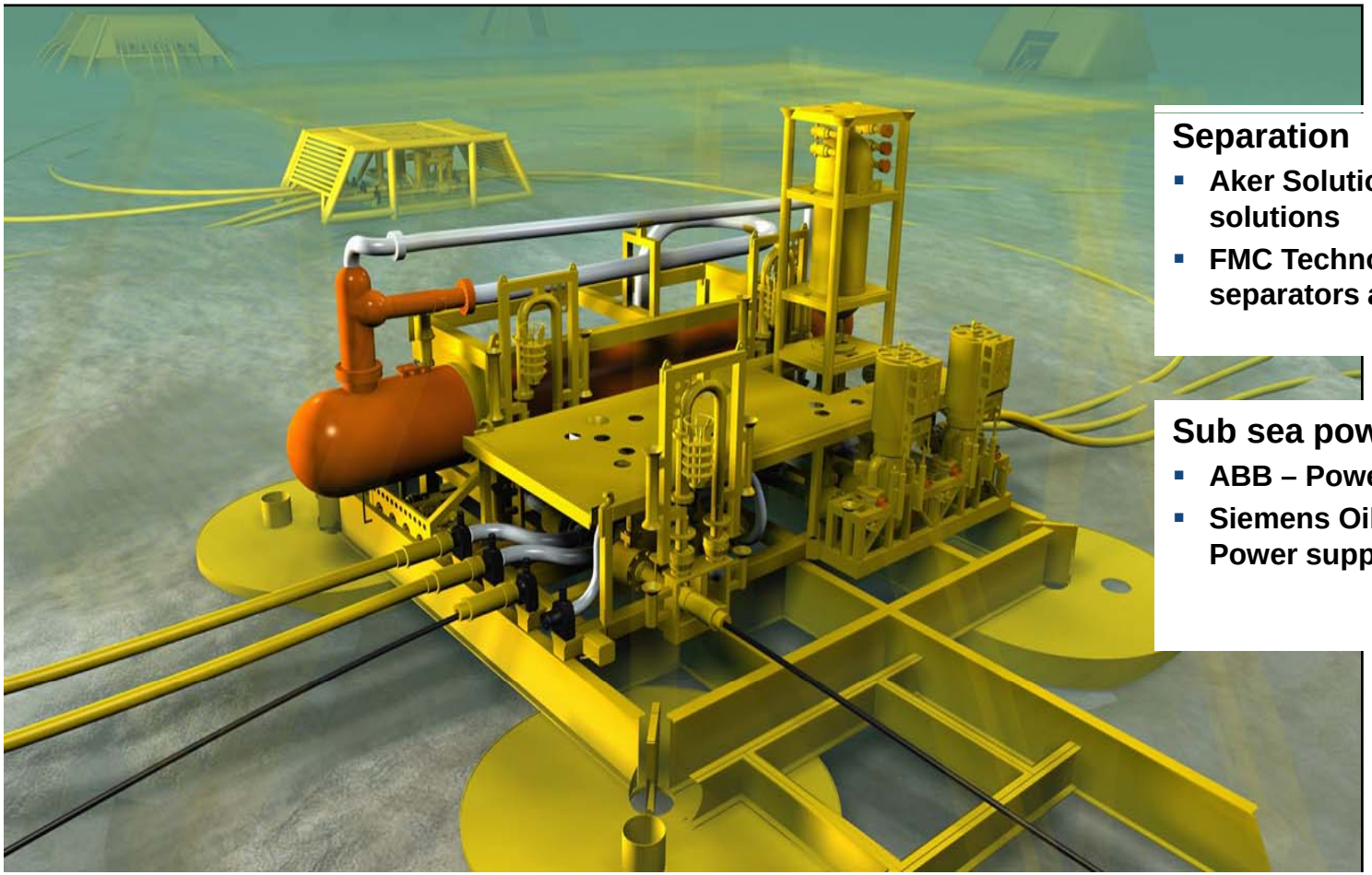
Sub Sea Solutions

Pumping and compression

- Aker Solutions – Multiphase pumping and compression solutions
- FMC Technologies – Multiphase pumping and compression solutions
- Framo Engineering – Water injection pumps, Multiphase Pumps and Wet Gas Compressor
- PG Pump Solutions – Multiphase pumps
- Siemens Oil and Gas Offshore – Wet gas compressor



Separation

- Aker Solutions – Processing solutions
- FMC Technologies– Subsea separators and solutions

Sub sea power supply

- ABB – Power supply
- Siemens Oil and Gas Offshore – Power supply

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Topside Modification

Topside modifications may be needed in an IOR project

- **– as a supplement to other measures or as Improved Recovery in itself**
  - **Simplification, and reducing down-time**
  - **Allowing low pressure production**
  - **Debottlenecking - Gas processing capacity - Separator capacity - Water injection capacity - Gas injection capacity - Produced water treatment etc**

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Topside Modification

In-line separation

- FMC – CDS inline separation cyclone based

Process simulation

- ABB – Prosess simulation and control systems
- AGR – Process simulation
- Aker Solutions – Process simulations
- FMC Technologies – process simulation
- IFE – Process simulation
- Kongsberg – Process simulation and control systems, lifecycle simulation, online and enterprise simulation
- Siemens Oil and Gas Offshore - Process simulation and control systems
- SINTEF Petroleum Research – Process simulation, flow assurance

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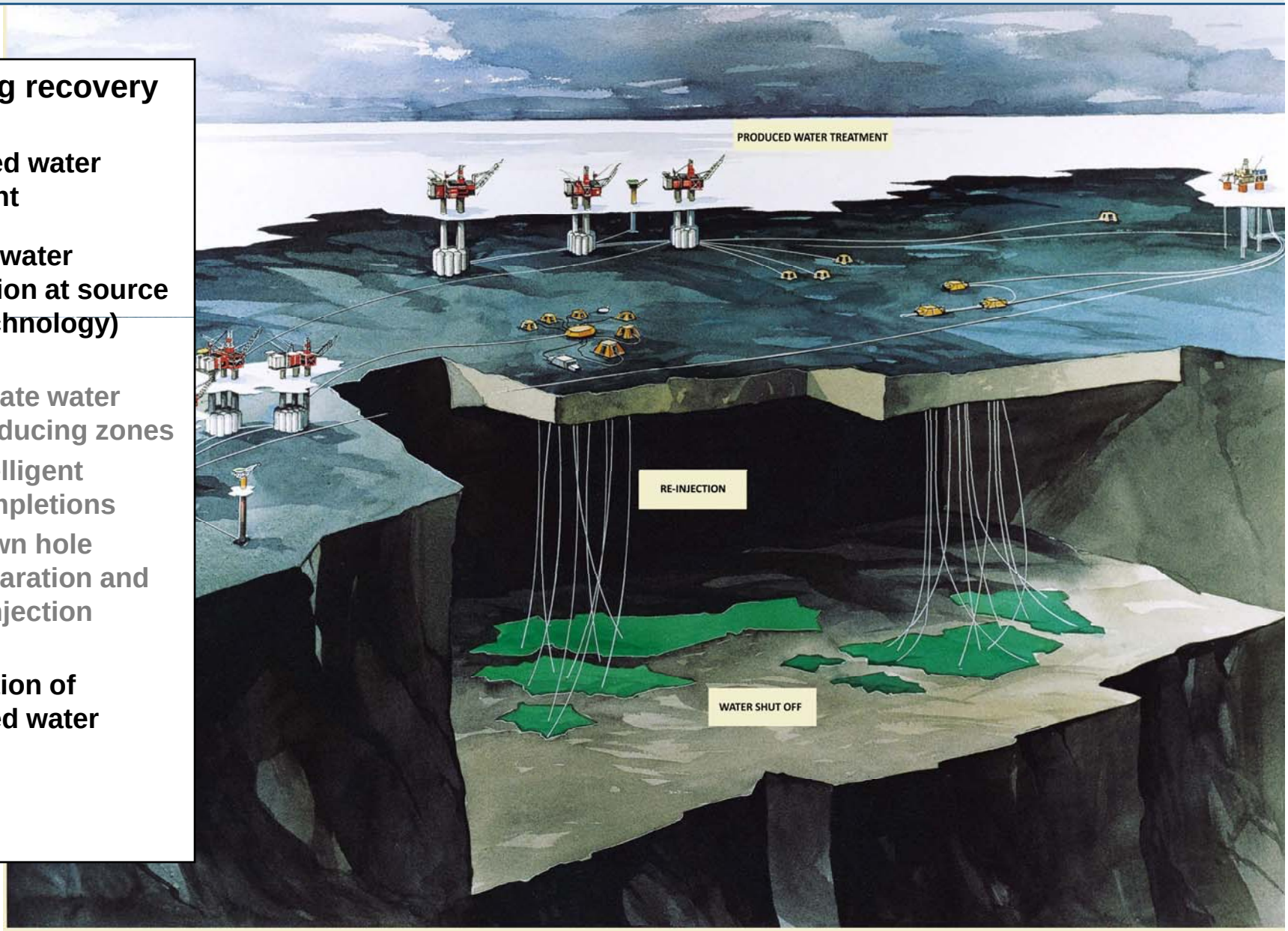
Water Management

Improving recovery

- **Produced water treatment**
- **Reduce water production at source (well technology)**
  - Isolate water producing zones
  - Intelligent completions
  - Down hole separation and reinjection
- **Reinjection of produced water**



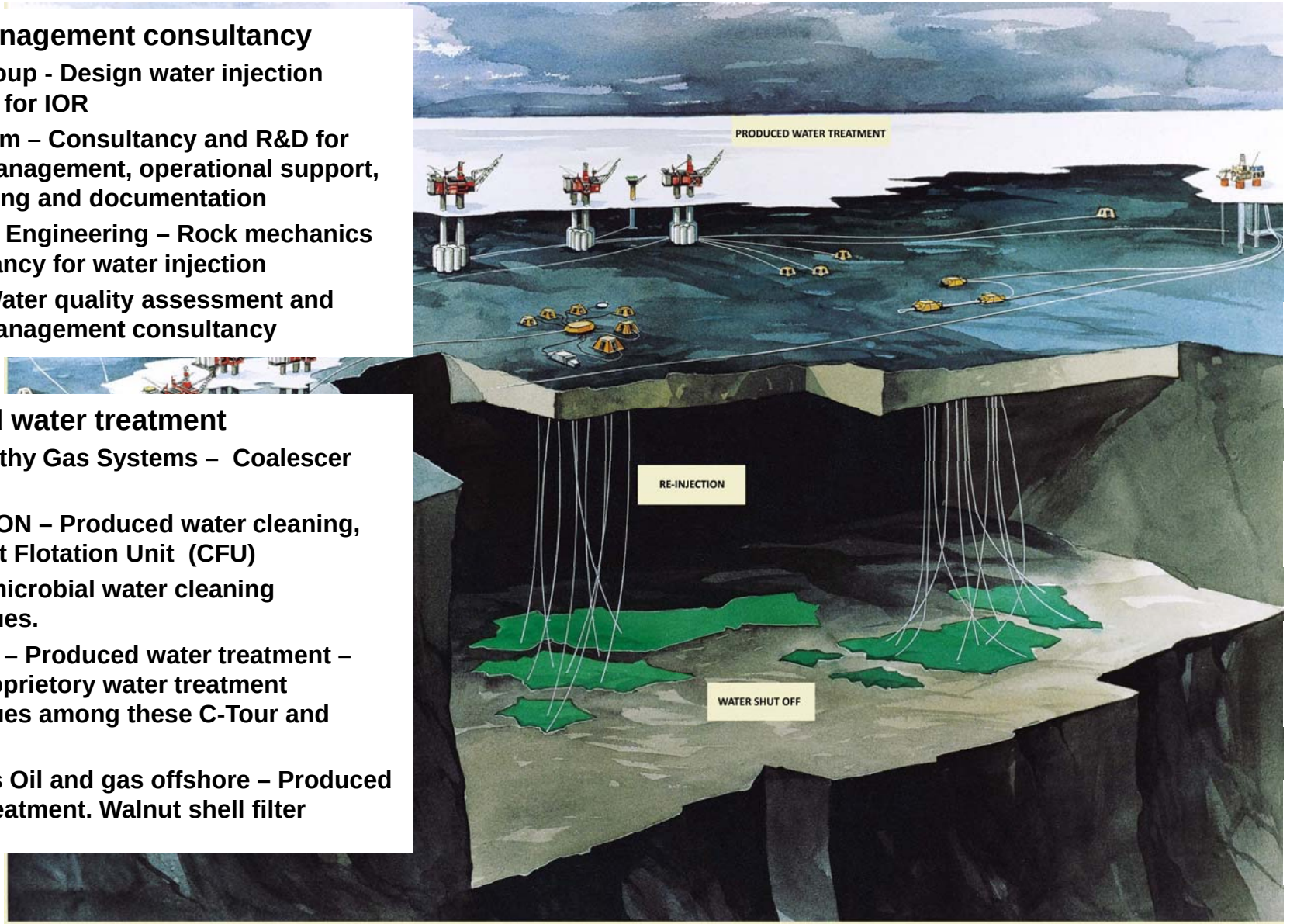
Water Management

Water management consultancy

- AGR Group - Design water injection projects for IOR
- Aquateam – Consultancy and R&D for water management, operational support, monitoring and documentation
- Geomec Engineering – Rock mechanics consultancy for water injection
- NIVA - Water quality assessment and water management consultancy

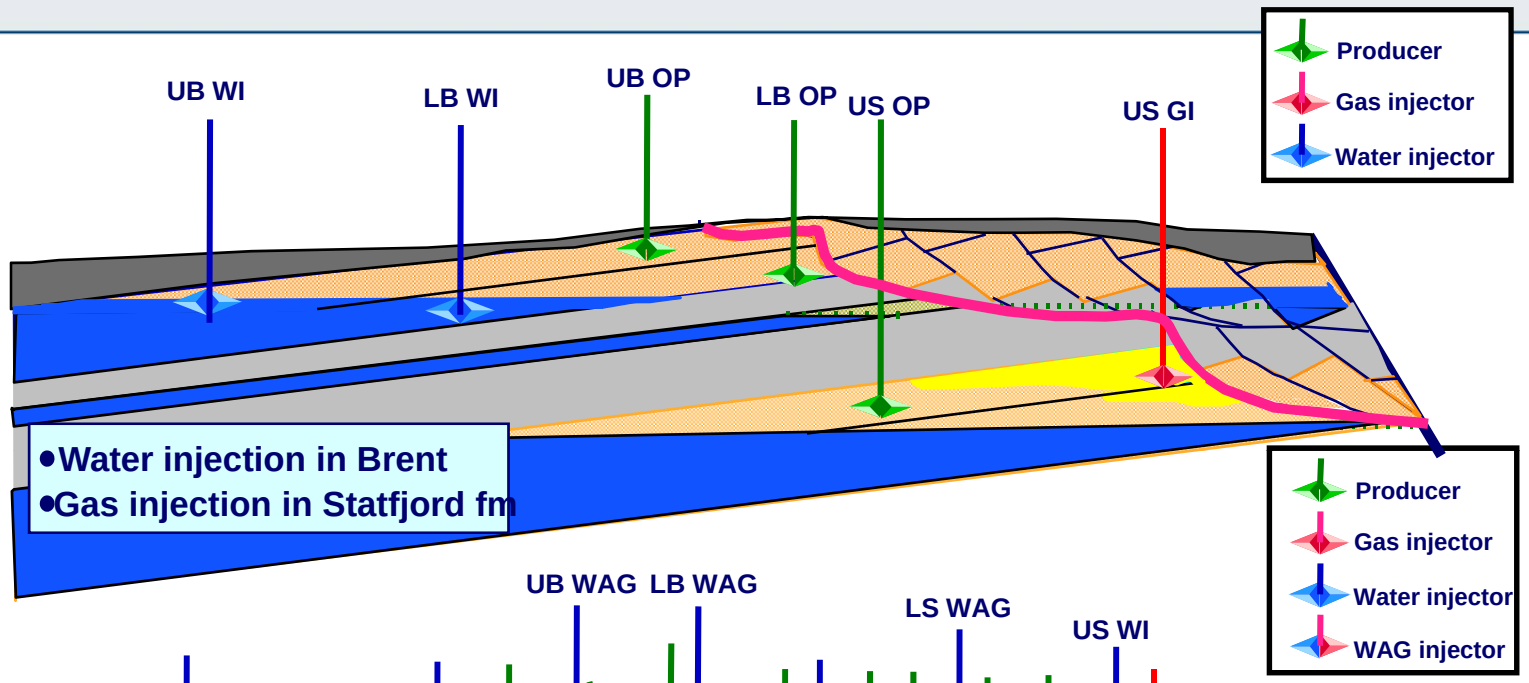
Produced water treatment

- Hamworthy Gas Systems – Coalescer (VIEC)
- M-I EPCON – Produced water cleaning, Compact Flotation Unit (CFU)
- NIVA – microbial water cleaning techniques.
- ProPure – Produced water treatment – Four proprietory water treatment techniques among these C-Tour and TORR.
- Siemens Oil and gas offshore – Produced water treatment. Walnut shell filter

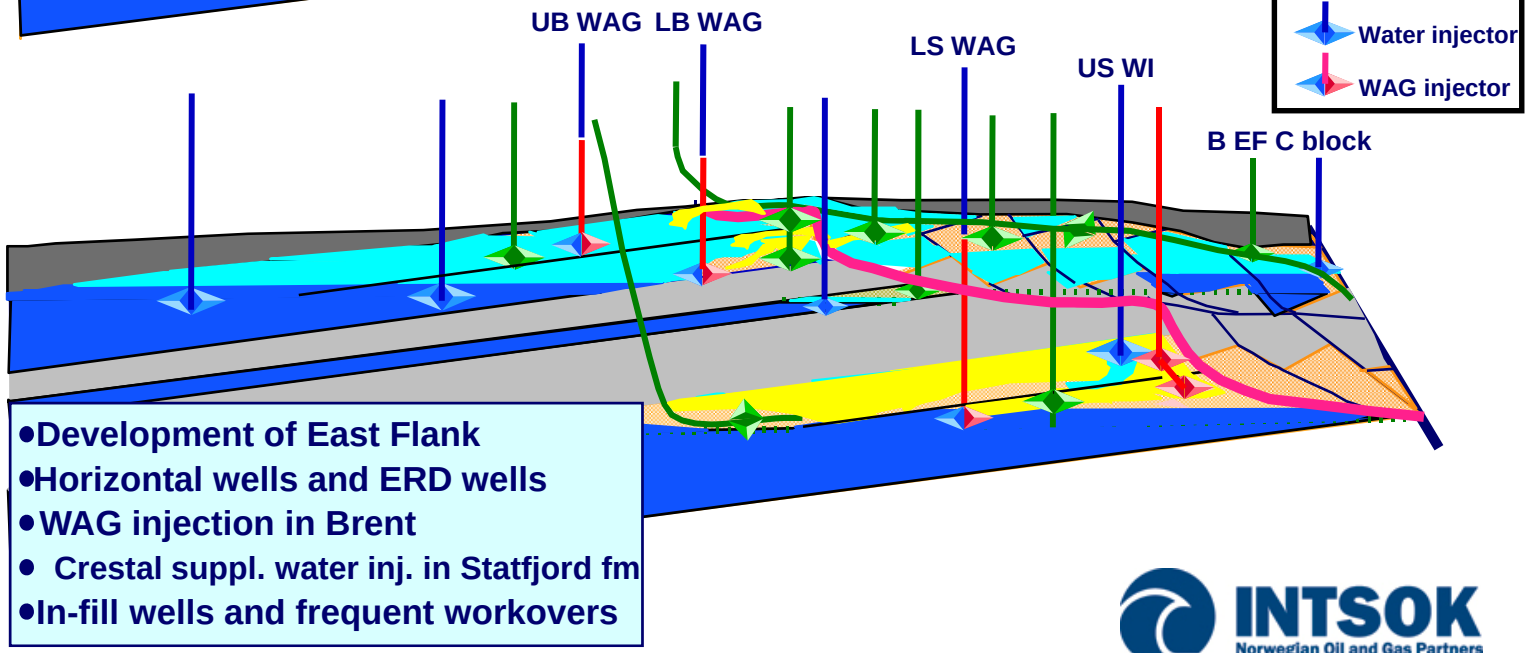


Statfjord drainage strategies

Early:



Later:



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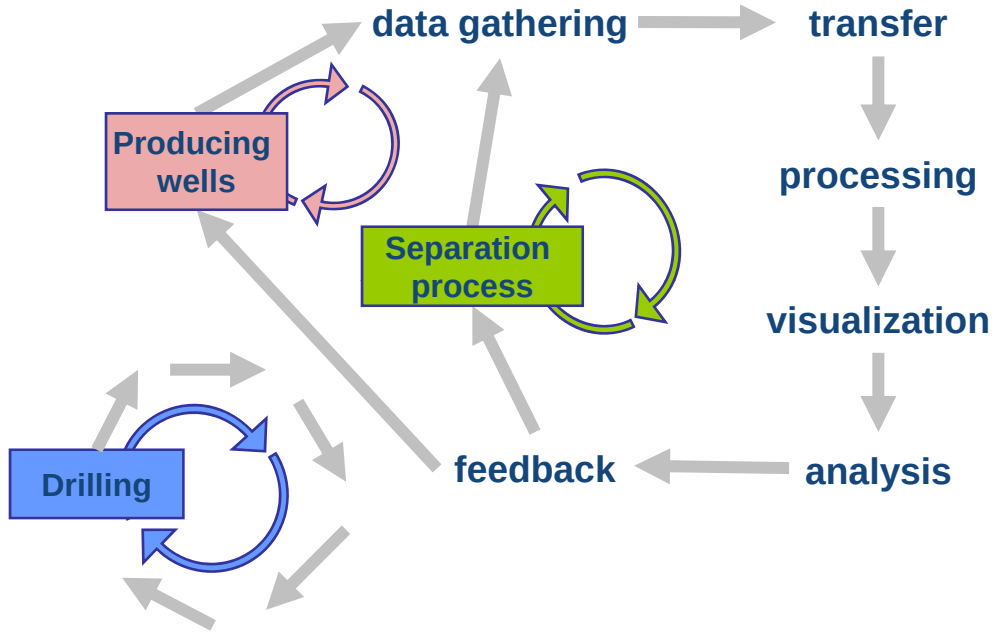
Integrated Operations

Integration of data from multiple sources in wells and production process or from drilling and reservoir model.

Real time analysis and action

Visualisation and control room solutions



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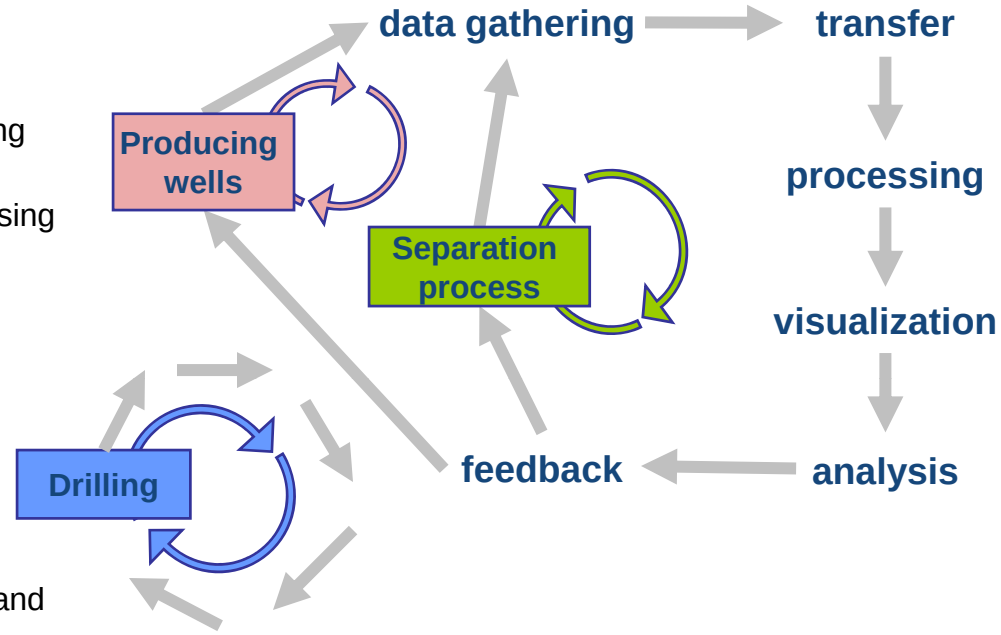
Integrated Operations

- ABB – Complete IO systems, data gathering, transfer, processing and control systems
- Abbon - Production monitoring
- AGR – Well planning and delivery process. Optimizing field operations
- Aker Solutions - Data gathering, transfer and processing
- Bjørge Naxys- Remote diagnostics software, communication systems
- EnVision – Visualisation of integrated data, mostly pressure.
- FMC Technologies – Flow management, production optimisation, software and control systems
- Framo Engineering – Integrated operation services for sub sea systems
- IFE – Integrated work processes analysis, software and consultancy. Tracer based process management
- IRIS – Integrated operation in drilling
- Kongsberg – Complete IO systems, data gathering, transfer, processing, visualization and control systems. Collaboration facilities and work process design
- Octio Geophysical – Real time decition systems
- Odfjell Drilling – Consultancy for drilling operations
- Roxar – Reservoir monitoring and data transfer.
- Siemens Oil and Gas Offshore - Complete IO systems, data gathering, transfer, processing and control systems
- SINTEF – Consultancy on IO for drilling



Research and Development

DNV – IO in the high North – Development of standards for data representation to facilitate communication in the IO chain.

NTNU – Center for Integrated Operations in the Petroleum industry. Partnership for development of IO technology.

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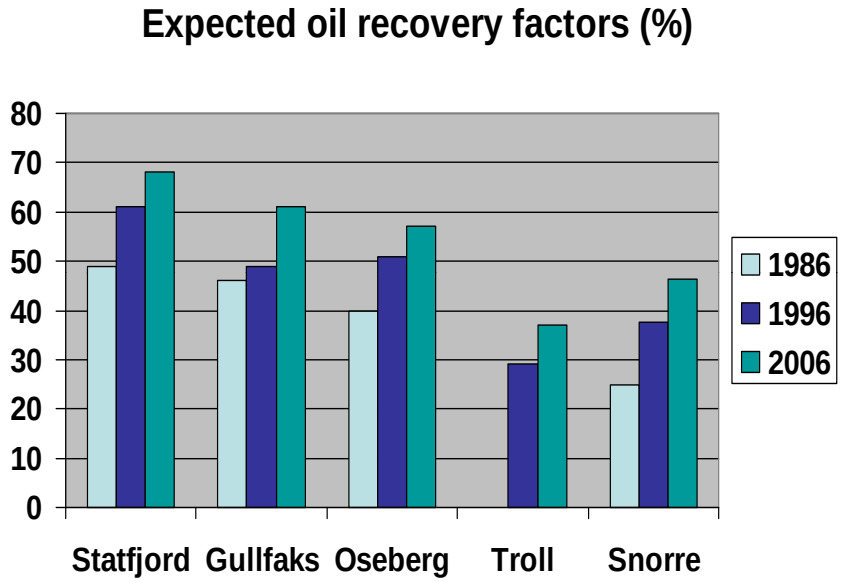
High recovery factors on Statoil-operated fields

- **Strong increase in expected ultimate RF during the last decades**
- **Strong ambitions for further increase**
- **Continued and persistent efforts is the key**



Expected ultimate recovery has grown by more than 4 bill bbl since 1990

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