EOR and CO_2 disposal – economic and capacity potential in the North Sea

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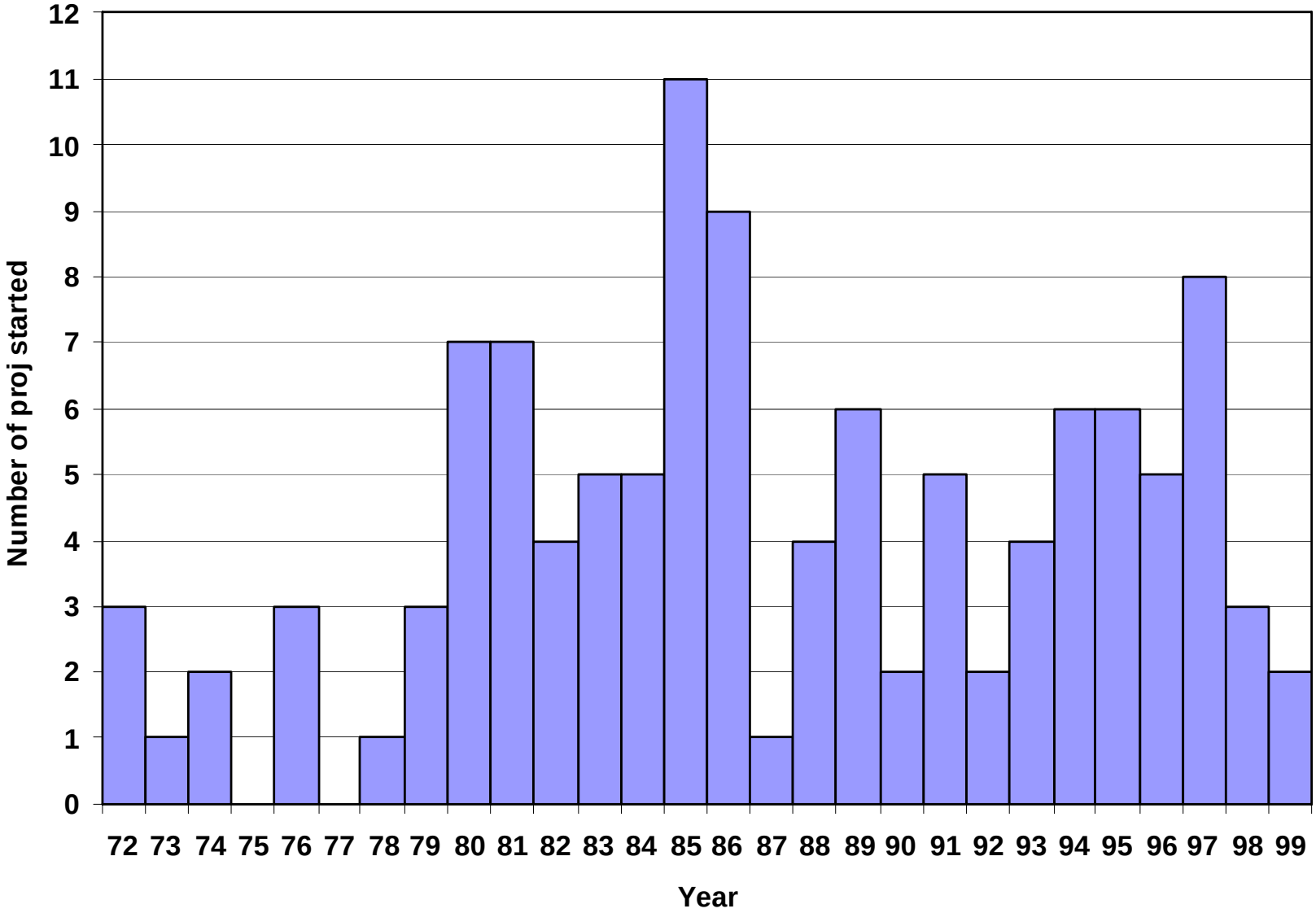
- Field experience from tertiary CO_2 injection projects
- Predictions of CO_2 EOR and storage in the North Sea (N and UK)
  - technical economical model
  - input parameters
  - scenarios
  - main results
- Conclusions

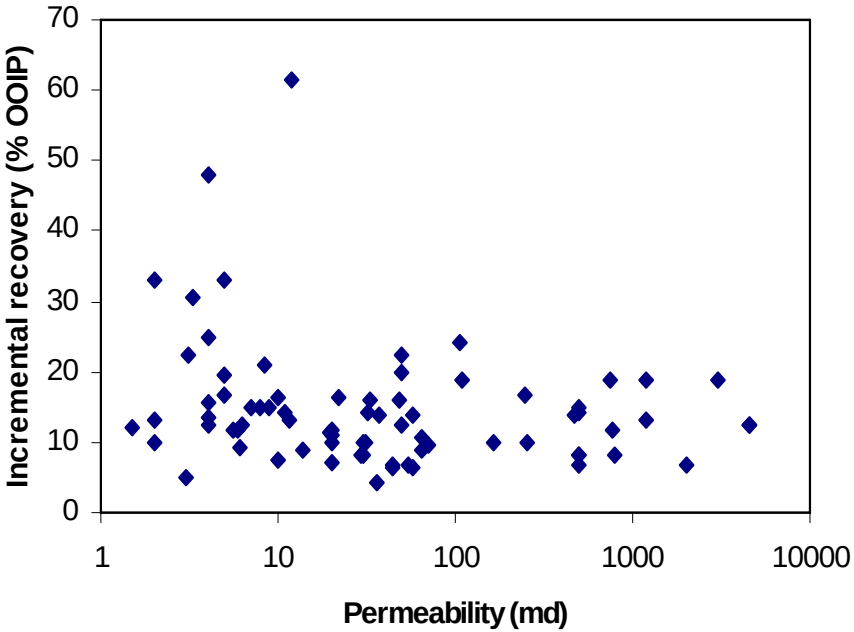
Field experience from tertiary CO_2 injection

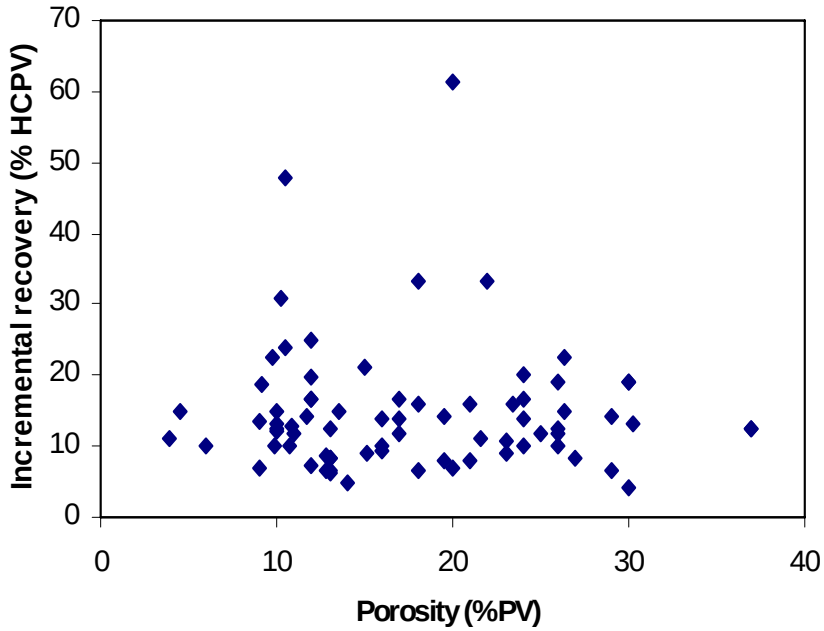
Results extracted from SINTEF's data base with 120 CO_2 EOR projects (pilots and full field flooding) mostly located in the Permian Basin

Start-up of CO_2 injection projects

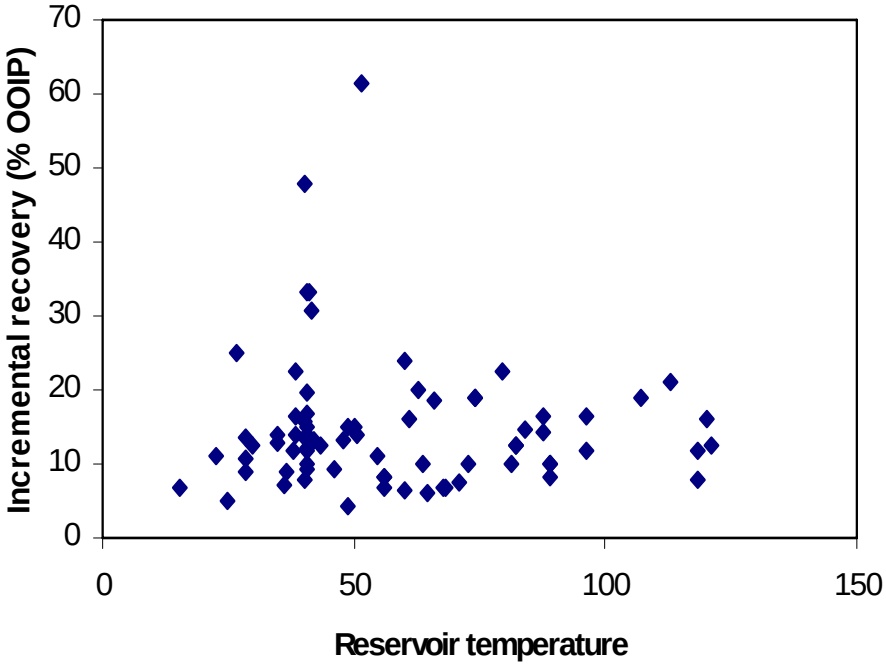


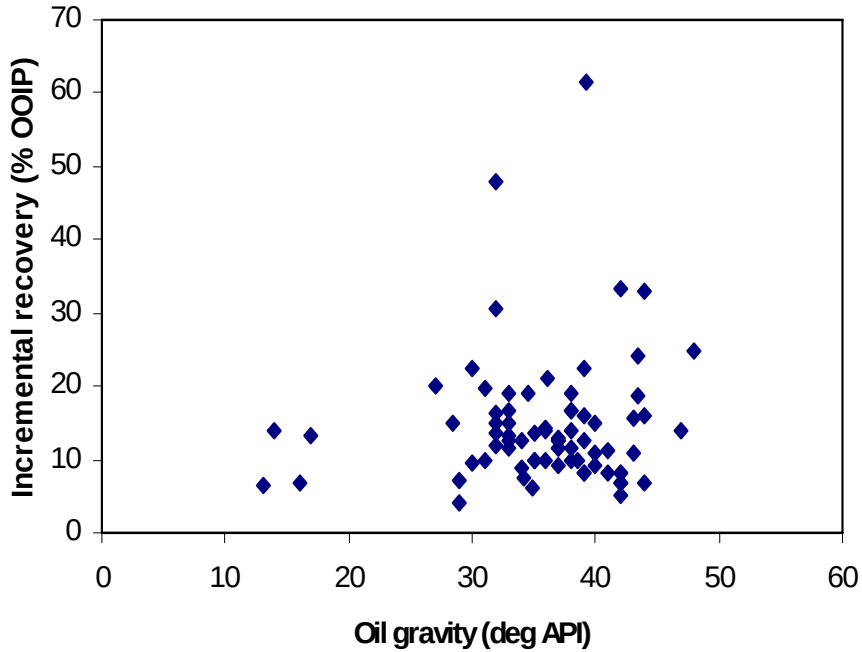
Incremental oil recovery vs. permeability and porosity



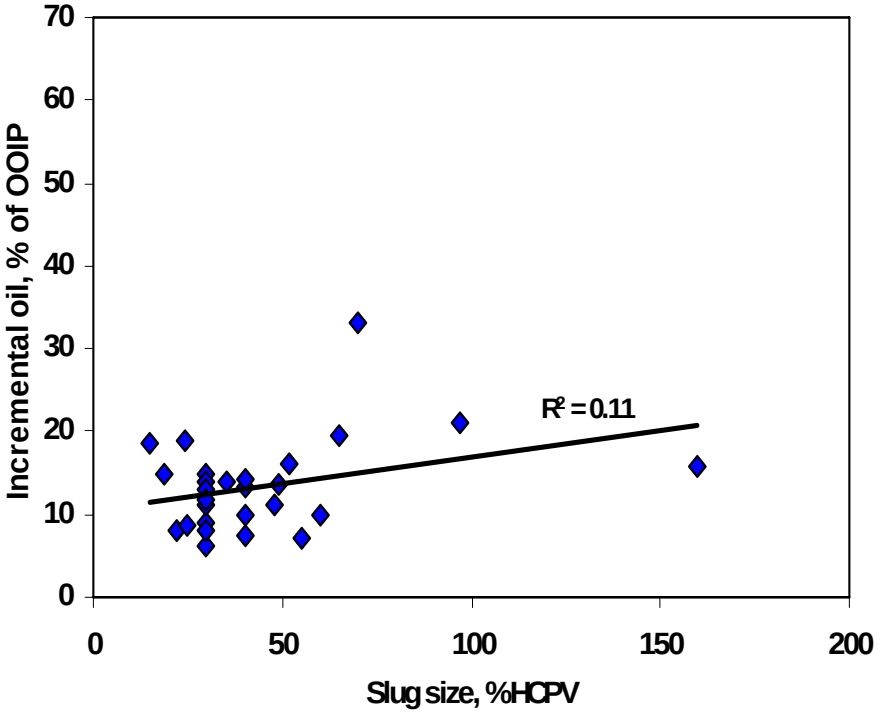


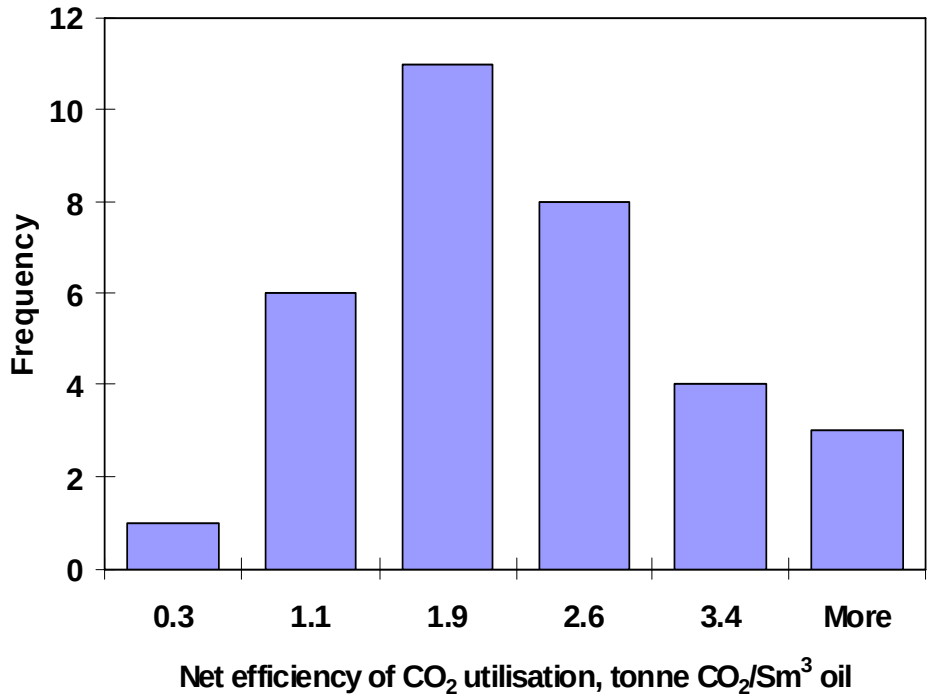
Incremental oil recovery vs. temperature and oil gravity





Incremental oil recovery vs. slug size





Summary of literature study

Average quantity	Sandstone reservoirs	Carbonate reservoirs
Incremental oil (% OOIP)	12.3	17.3
Gross CO_2 util.(tonne/Sm^3)	3.1	4.0
Net CO_2 utilisation (tonne/Sm^3)	1.9	2.0
Temperature (°C)	67	51
Reservoir depth (m)	1844	1705
Pressure (bar)	194	173
Porosity (% PV)	23	12
Permeability (md)	570	22
Oil density (°API)	35.2	34.6
CO_2 density	641	730

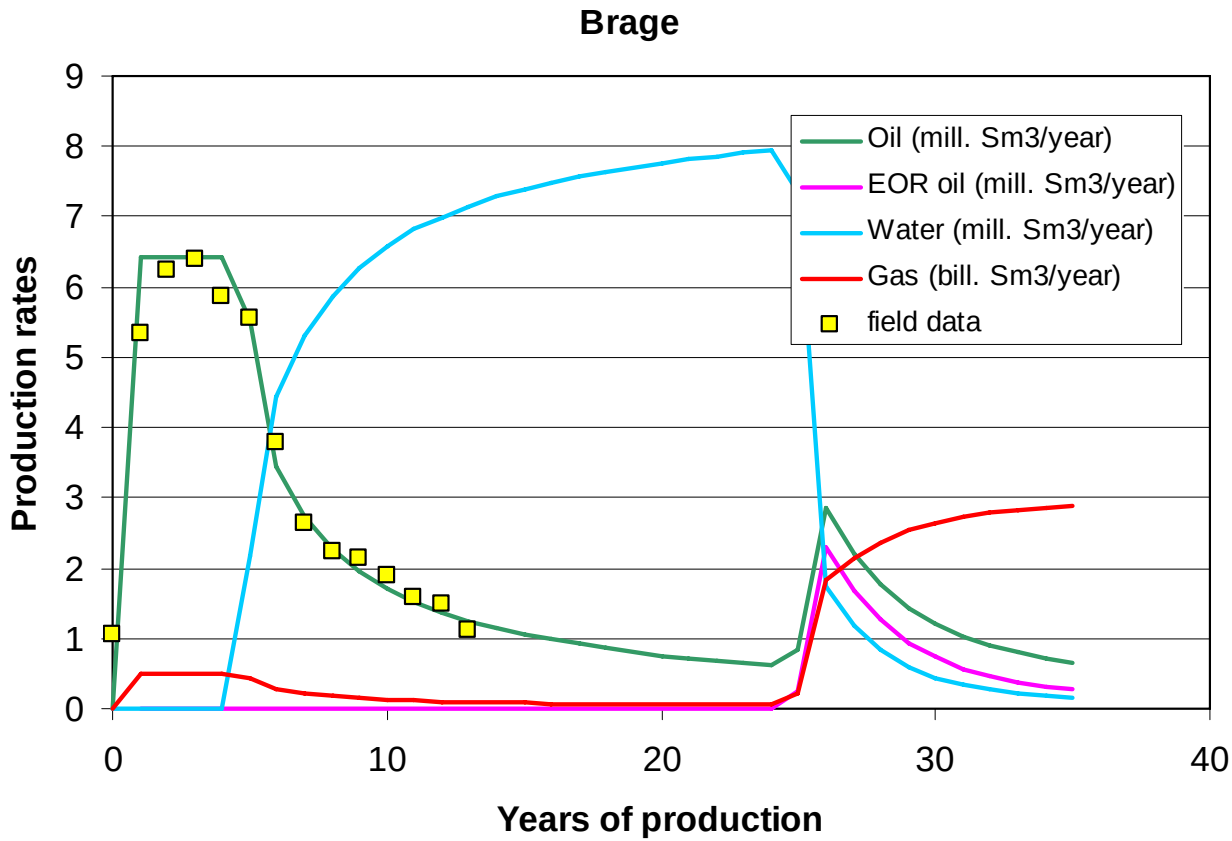
Predictions of CO_2 EOR in the North Sea

- technical economical model
  - pipeline transport model
  - EOR model
  - economic model
- scenarios
- 19 Norwegian and 30 UK oil fields in the database
  - will be expanded with Danish fields

Features of the EOR model

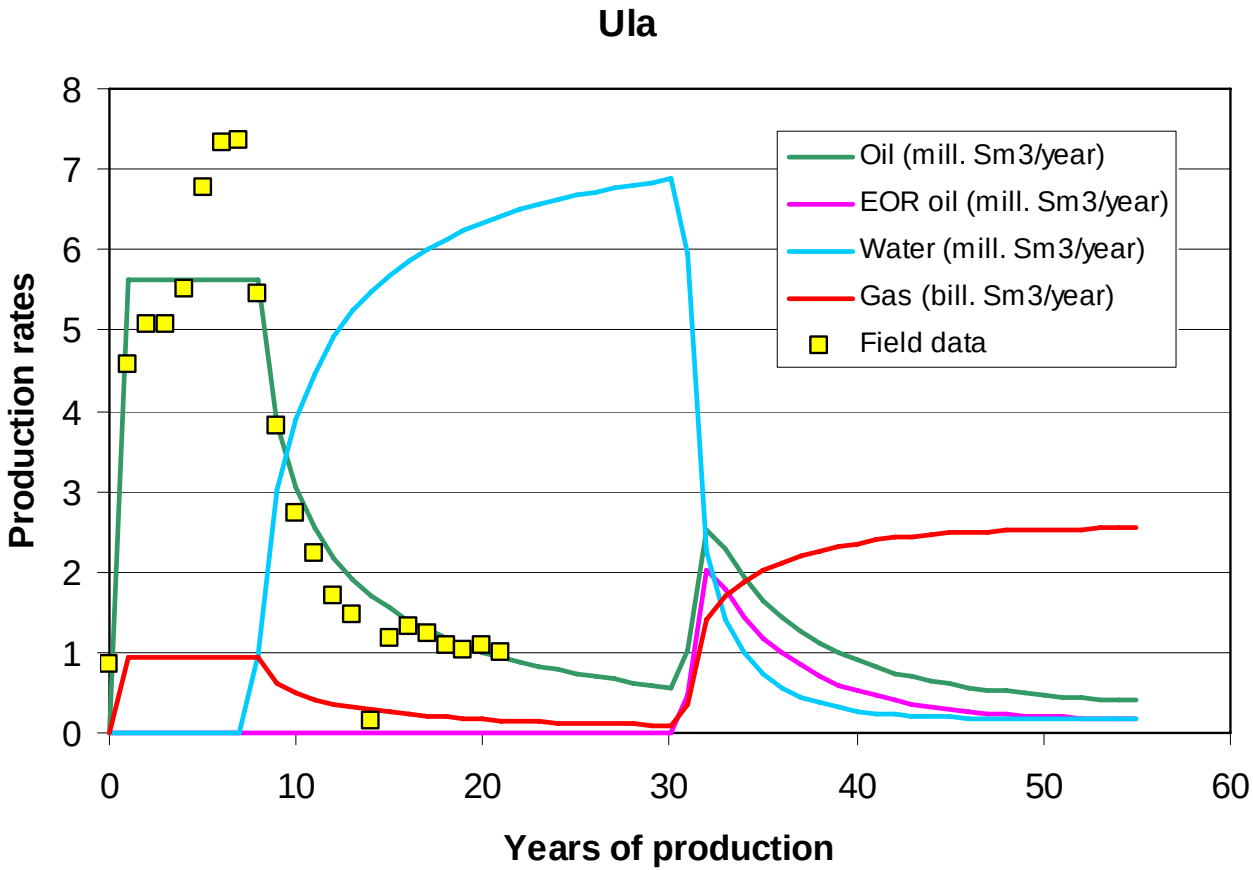
- A simple model to predict the incremental oil production due to CO_2-injection after water flooding depending on the state of the reservoir
- Based on a large number of reservoir simulations with varying process- and geological parameters
- Developed for continuous CO_2 injection only
- Assumes that water and CO_2 are injected at the same and constant flow rates
- CO_2 displaces oil miscible
- Requires a few reservoir specific input parameters
- Calculates functions for oil, incremental oil, water and gas production during CO_2 injection for each field

Example of production profiles calculated by the EOR module



The predicted oil recovery profile is matched to historic values by use of the two geological fit parameters (heterogeneity exponent, vertical permeability multiplicator)

Example of production profiles calculated by the EOR module



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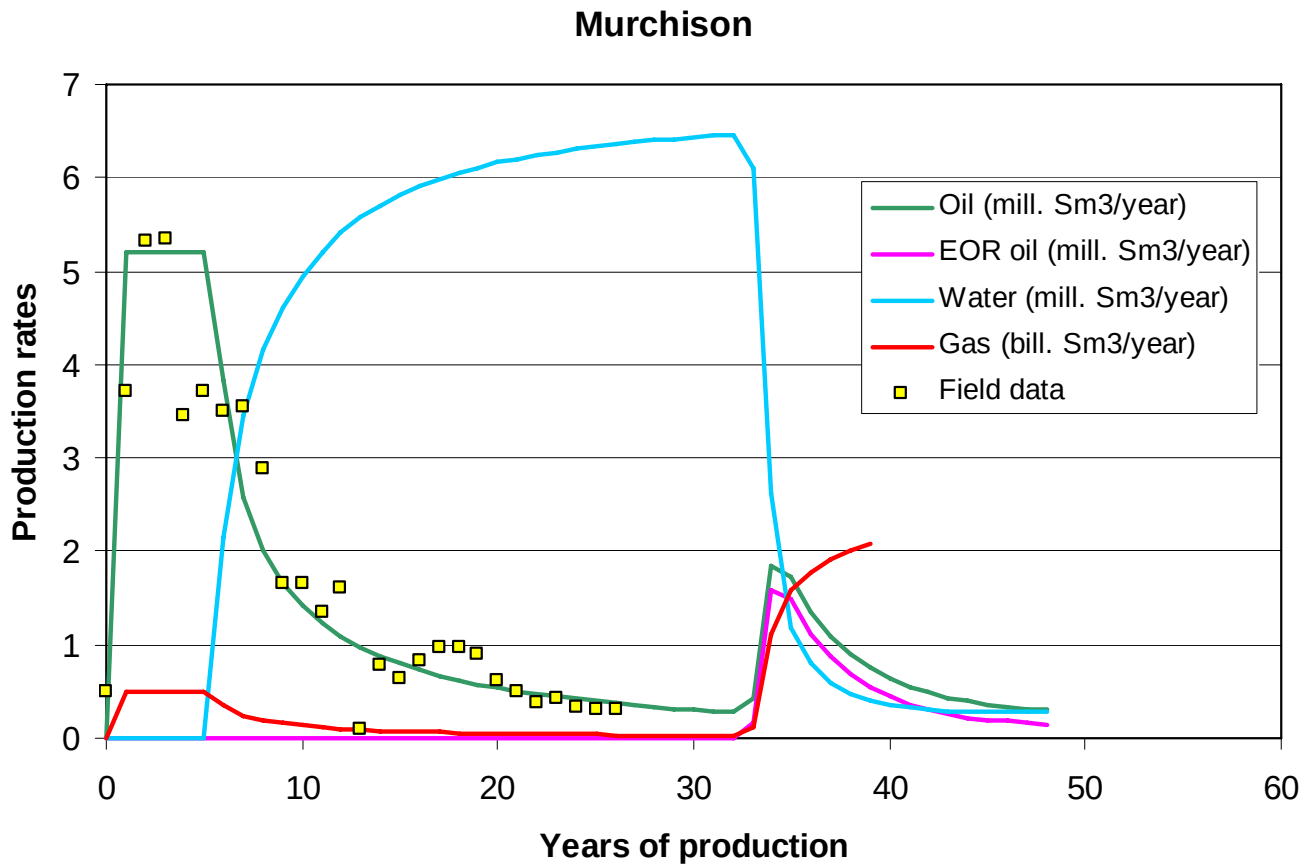

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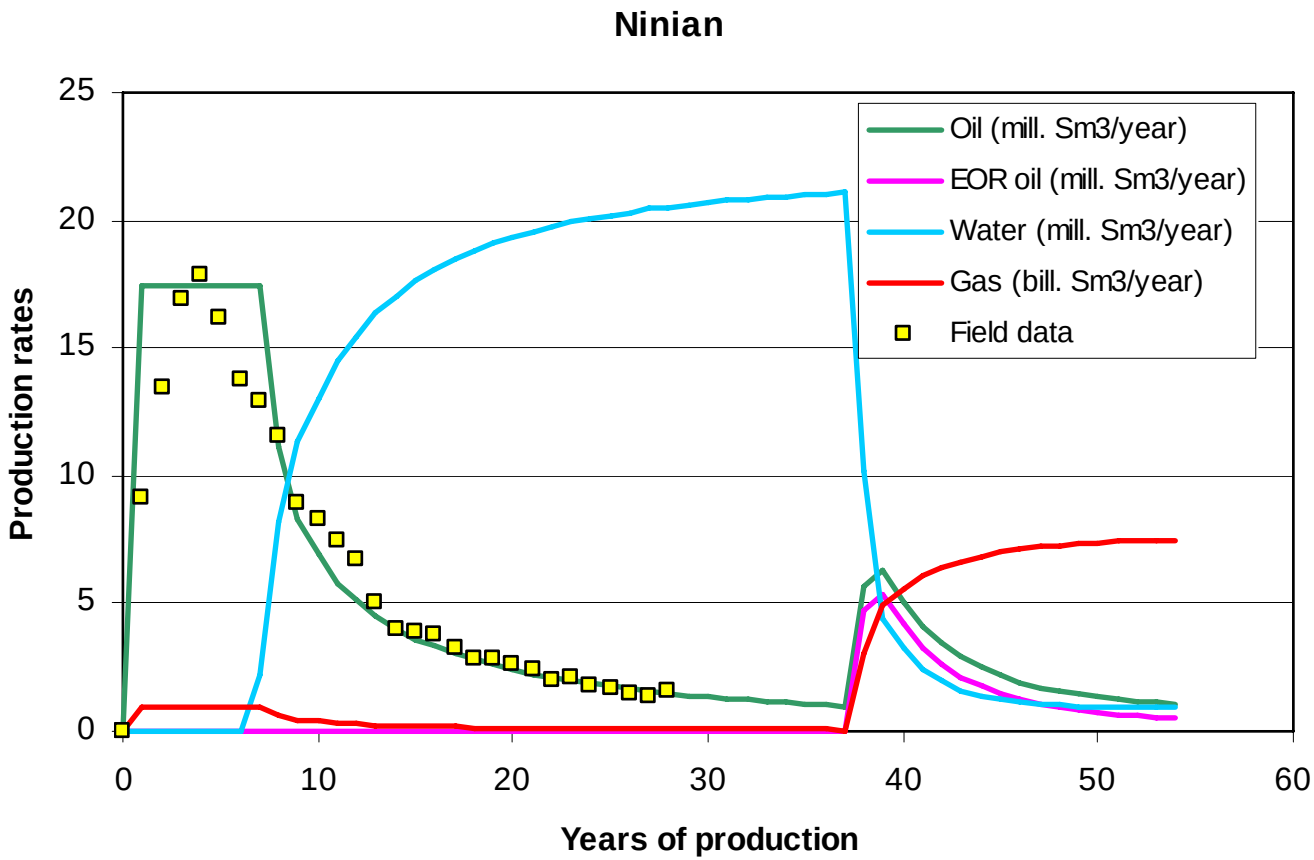

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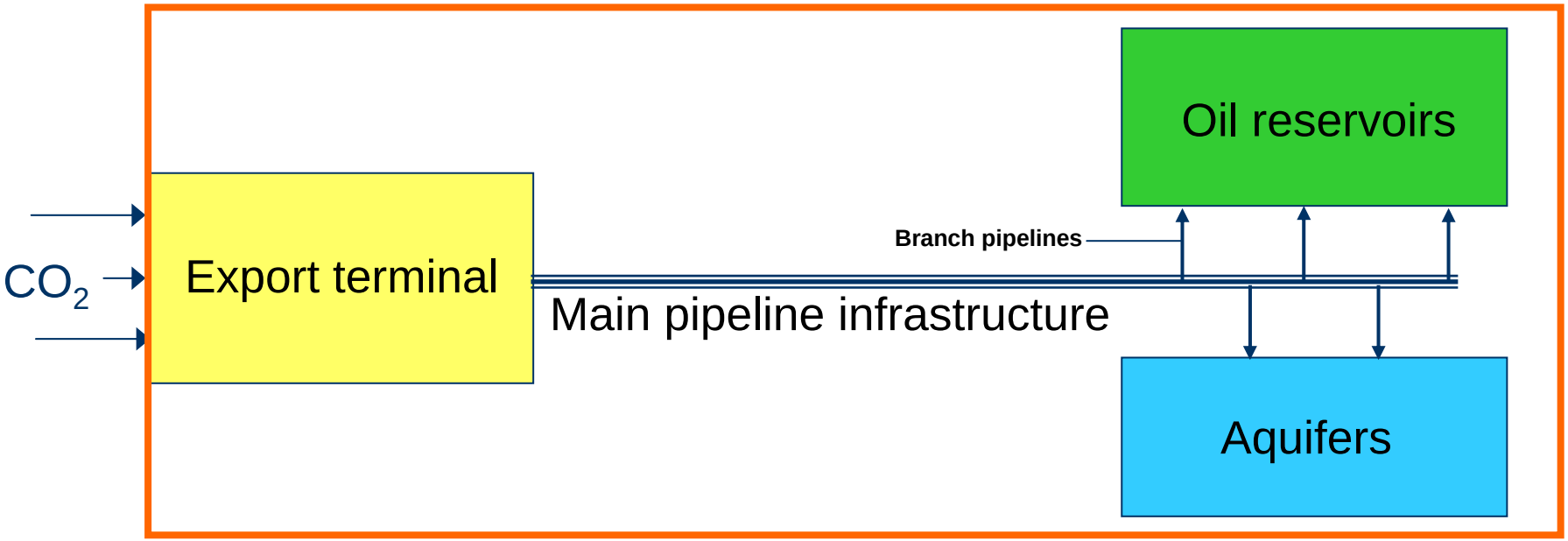
The technical- economical model



CO_2 from industrial point sources is collected, compressed and fed into main pipeline.

CO_2 is transported through the main pipeline and distributed to oil reservoirs and aquifers

CO_2 is transported to the deposition sites through branch lines. The oil producers buy CO_2 according their needs. Excess CO_2 is deposited in aquifers

The technical- economical model

- The model can be used to construct specific deposition scenarios for fields in the North Sea
- A constant amount of CO_2 is deposited during the lifetime of a scenario, excess CO_2 is injected into unspecified aquifers
- Break through CO_2 is re-injected into the reservoirs
- The model calculates incremental oil recovery and stored CO_2 in the oil reservoirs and aquifers
- Each EOR project in the scenario runs as long as the net cash flow is positive
  - incomes: EOR oil (the incremental oil only)
  - costs: CO_2, investments, operating costs
- In the figures presented here calculates a value for CO_2 that gives a zero NPV for all the EOR projects and aquifer deposition at the specified rate of return

Parameters used for economic modelling

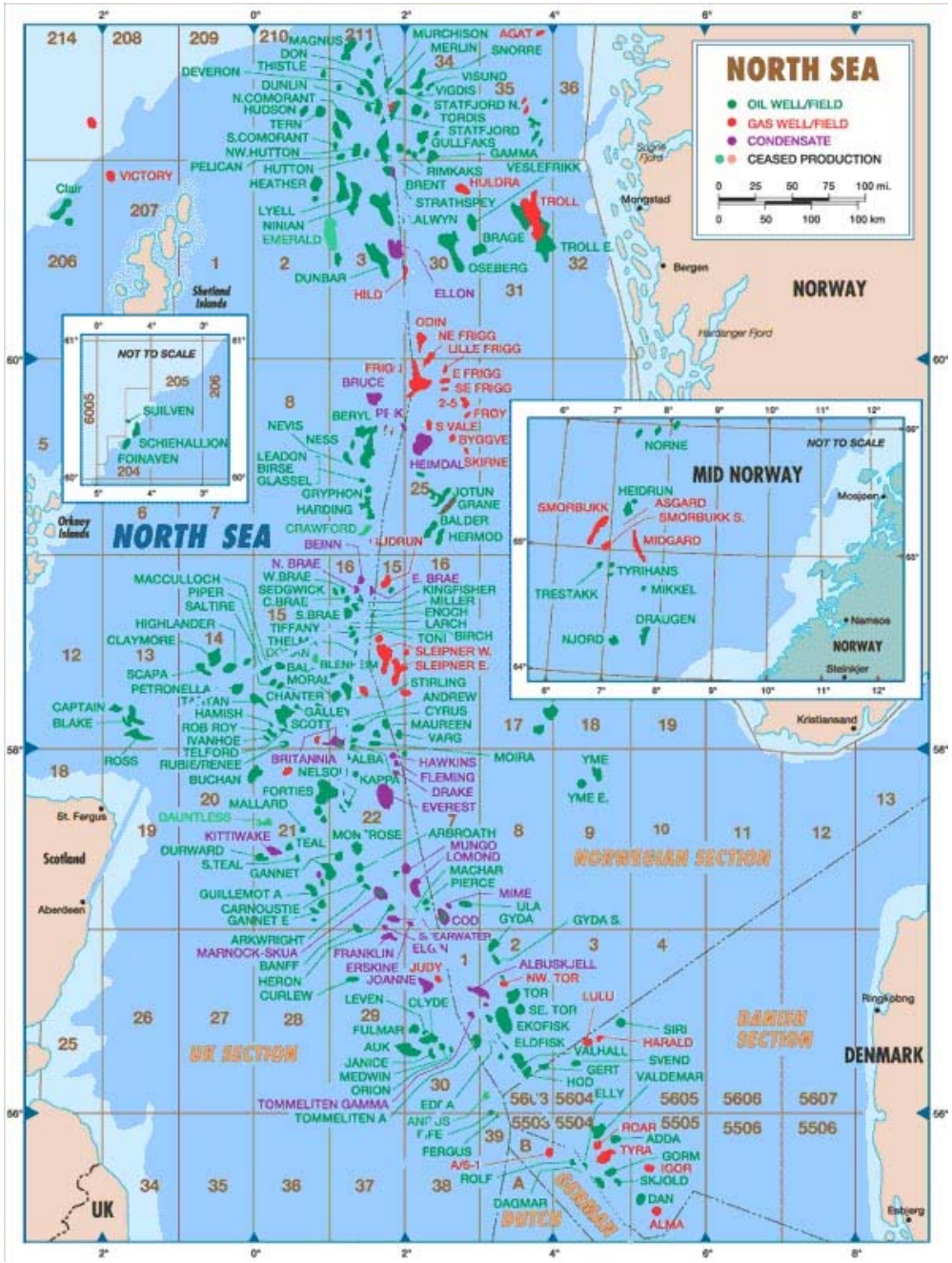
Variable economic parameters	value	unit
Well cost	30	mill. USD/well
Modification of oil production system	510	USD/(bbl/day)
Engineering costs	25	% equipment costs
Contingency costs	25	% equipment costs
Offshore factor	3	
Running and maintenance	5	% of equipment costs
Energy compressor	0.07	USD/kWh
Discount rate	7	%
Net present value	0	USD
Oil price	variable	USD/bbl
CO_2 transport cost	3.8	USD/tonne
Aquifer deposition costs	4.0	USD/tonne

A CO_2 deposition scenario

- Includes 19 Norwegian and 30 UK North Sea oil fields and unspecified aquifers
- Total injection rate is 178 million tonnes CO_2/year
- Project lifetime is 40 (or 30) years
- The scenario is not optimised

Results:

- Deposition profiles
- EOR production profiles
- Key economic figures
- Values for CO_2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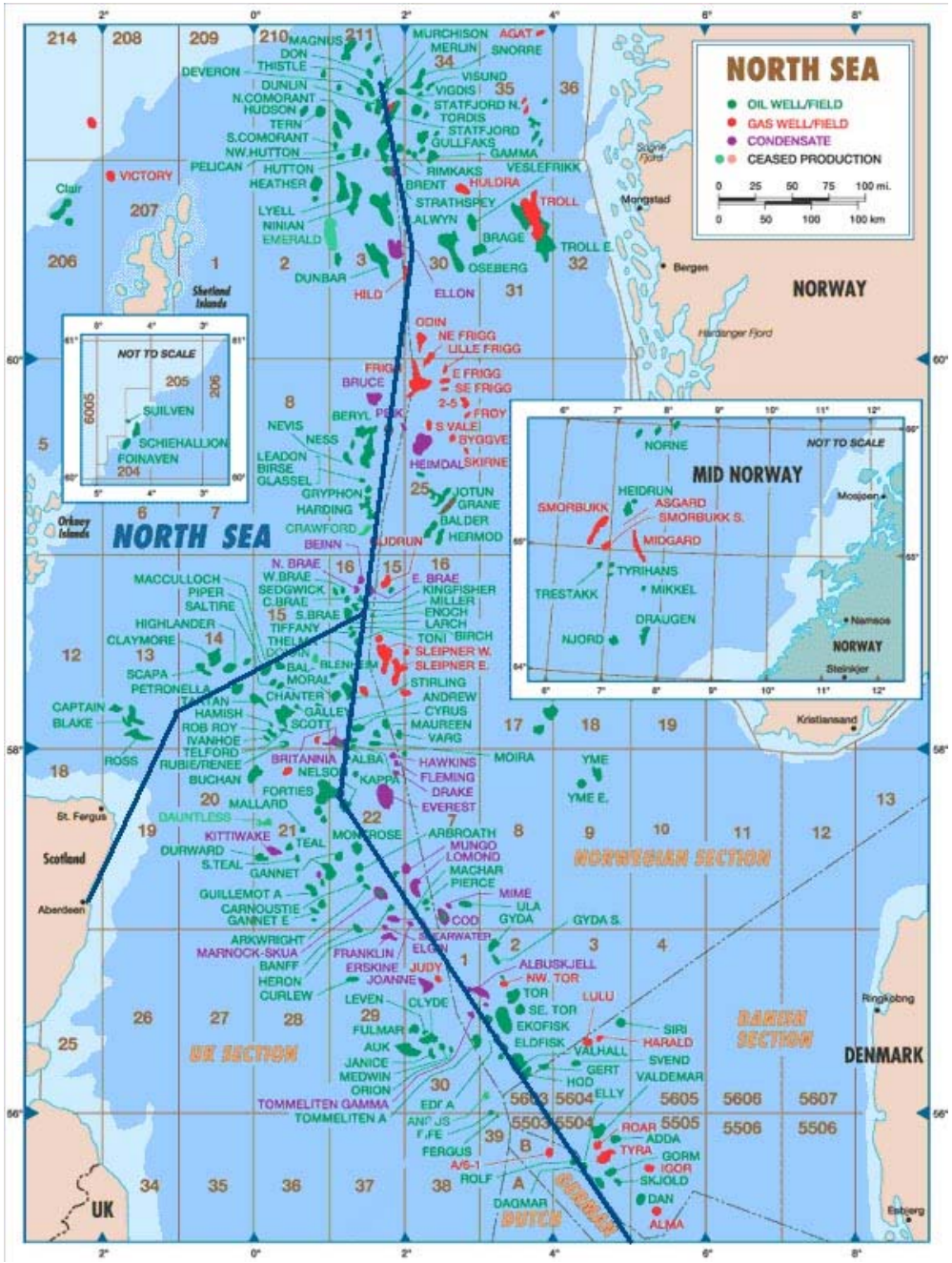
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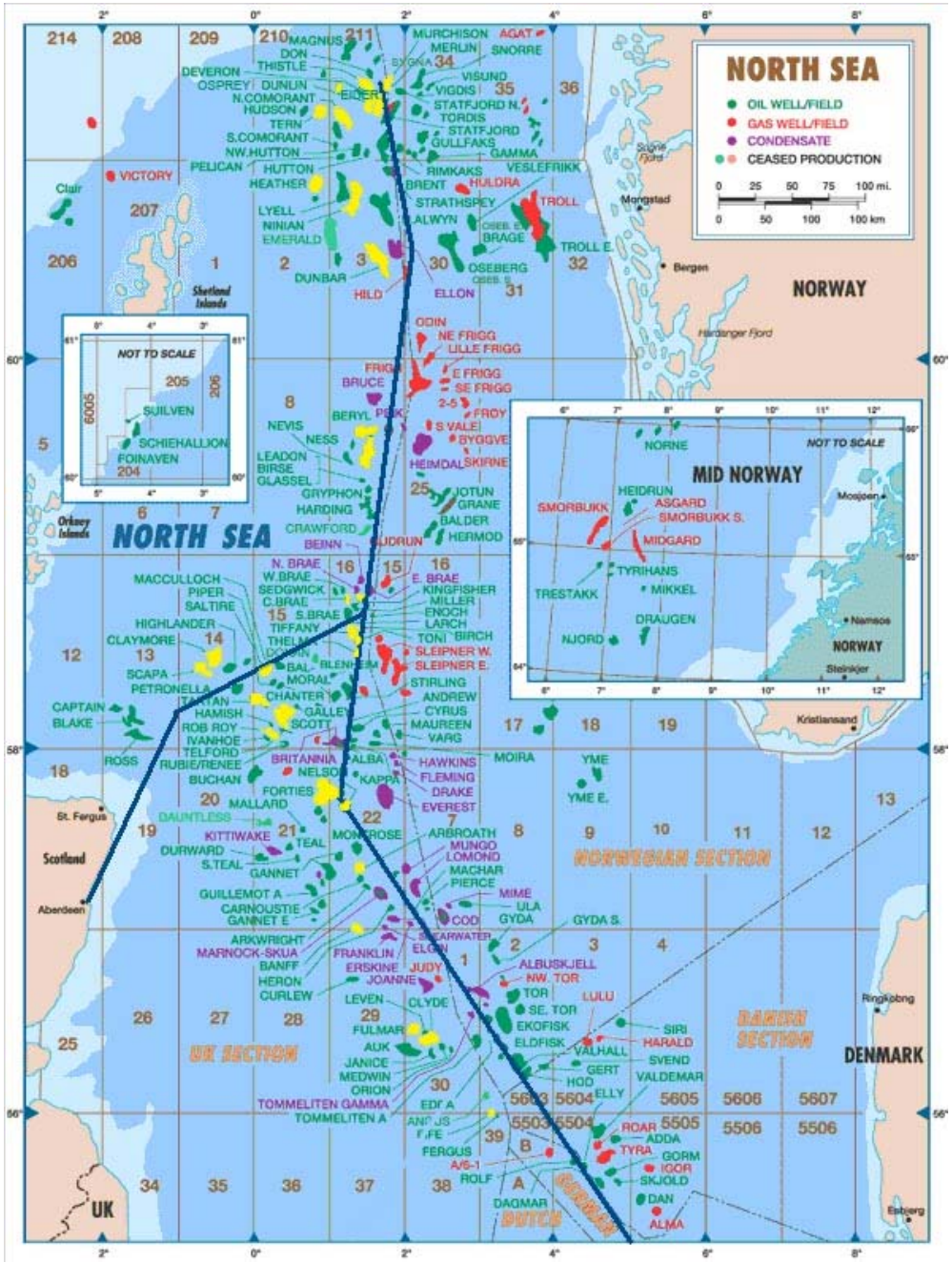
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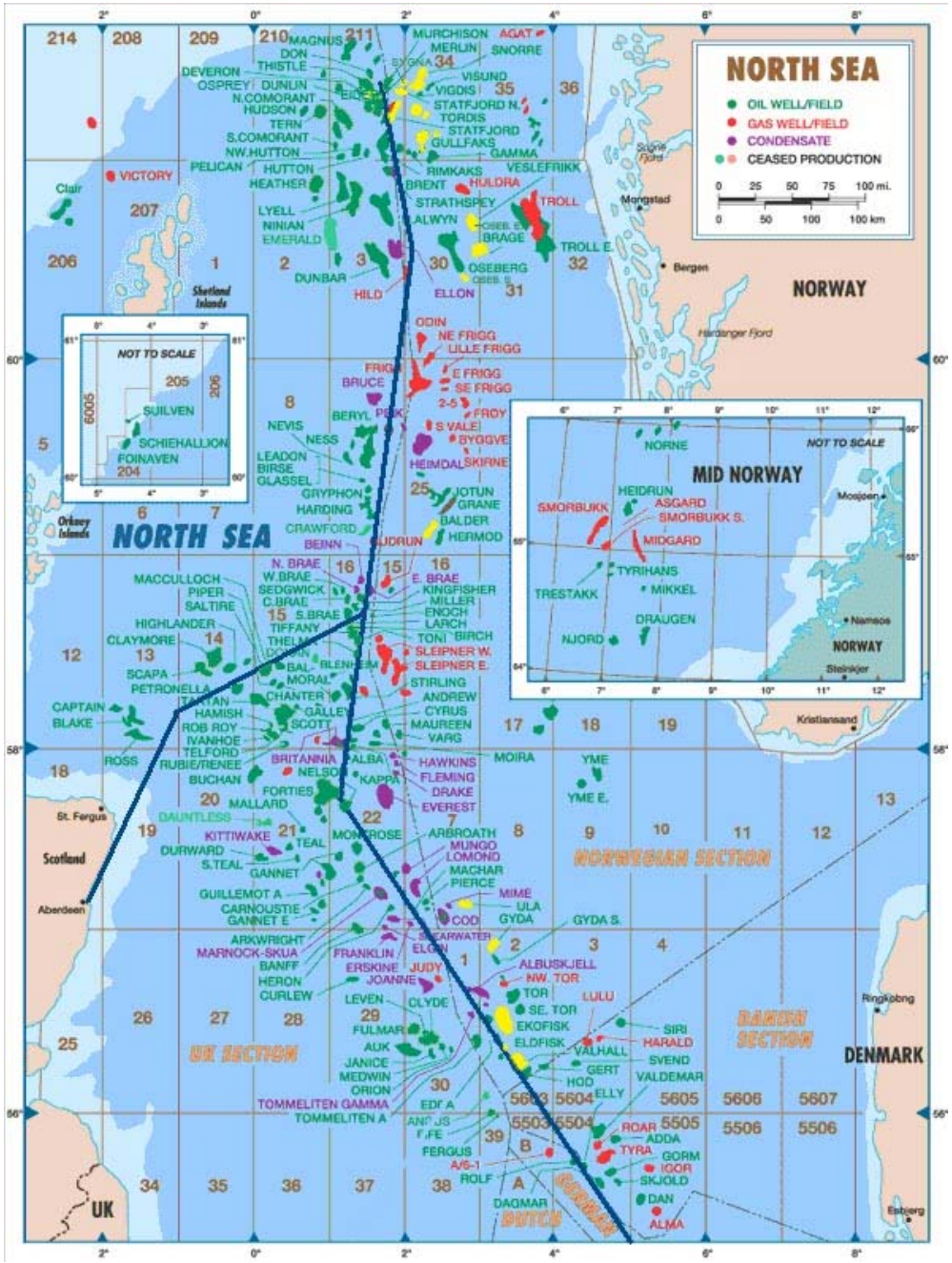
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ELDFISK
LULU
SIRI
HARALD
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VALDEMAR
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ADDA
TYRA
GORM
IGOR
SKJOLD
DAN
ALMA
NORNE
HEIDRUN
ASGARD
SMORBUKK
SMORBUKK S.
MIDGARD
TYRIHANS
TRESTAKK
MIKKEL
DRAUGEN
NJORD
Mosjoen
Namsos
Steinkjer
Sognefjord
Hardanger Fjord
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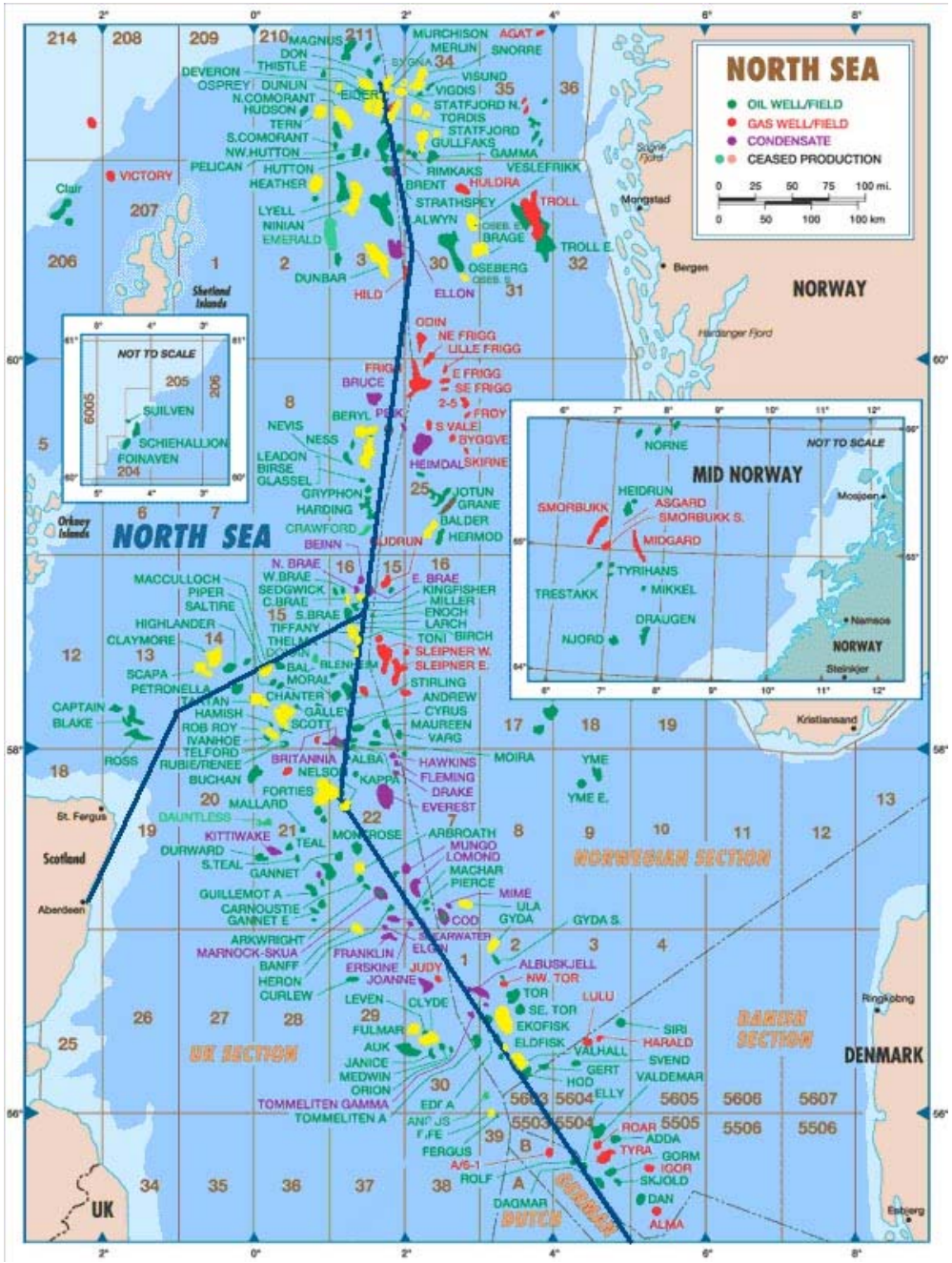
NORTH SEA
OIL WELL/FIELD
GAS WELL/FIELD
CONDENSATE
CEASED PRODUCTION
NORWAY
MID NORWAY
NOT TO SCALE
NORTH SEA
UK SECTION
NORWEGIAN SECTION
DANISH SECTION
DENMARK
UK
Scotland
Shetland Islands
Orkney Islands
Bergen
Stavanger
Kristiansand
Aberdeen
St. Fergus
Ringkjobing
Esbjerg
MAGNUS
MURCHISON
AGAT
MERLIN
SNORRE
VISUND
VIGDIS
STATFJORD N.
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GULLFAKS
GAMMA
VESLEFRIKK
HULDRA
TROLL
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BRAGE
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HEATHER
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ALWYN
DUNBAR
HILD
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BRUCE
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SKIRNE
JOTUN
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LEADON
BIRSE
GLASSEL
GRYPHON
HARDING
CRAWFORD
BEINN
SUILVEN
SCHIEHALLION
FOINAVEN
VICTORY
Clair
LYELL
NINIAN
EMERALD
PELICAN
DEVERON
OSPREY
DUNLIN
N.COMORANT
HUDSON
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S.COMORANT
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TYRIHANS
MIKKEL
TRESTAKK
DRAUGEN
NJORD
MACCULLOCH
PIPER
SALTIRE
SEDGWICK
C.BRAE
N. BRAE
W.BRAE
E. BRAE
KINGFISHER
MILLER
ENOCH
LARCH
TONI
BIRCH
SLEIPNER W.
SLEIPNER E.
S.BRAE
HIGHLANDER
TIFFANY
THELMA
CLAYMORE
SCAPA
PETRONELLA
TARTAN
CAPTAIN
BLAKE
HAMISH
ROB ROY
IVANHOE
TELFORD
RUBIE/RENEE
BUCHAN
ROSS
BAL
MORAL
BLENHEIM
CHANTER
GALLEY
SCOTT
STIRLING
ANDREW
CYRIUS
MAUREEN
VARG
BRITANNIA
ALBA
NELSON
KAPPA
HAWKINS
FLEMING
DRAKE
EVEREST
MOIRA
YME
YME E.
FORTIES
MALLARD
GAUNTLESS
KITTIWAKE
TEAL
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S.TEAL
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COD
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ELGIN
FRANKLIN
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MARNOCK-SKUA
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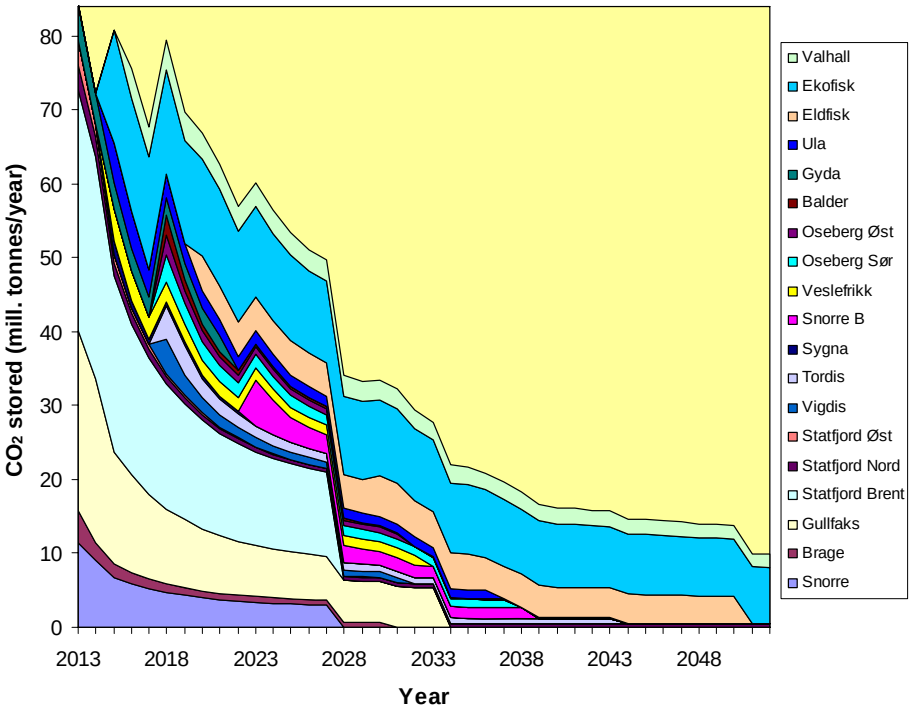
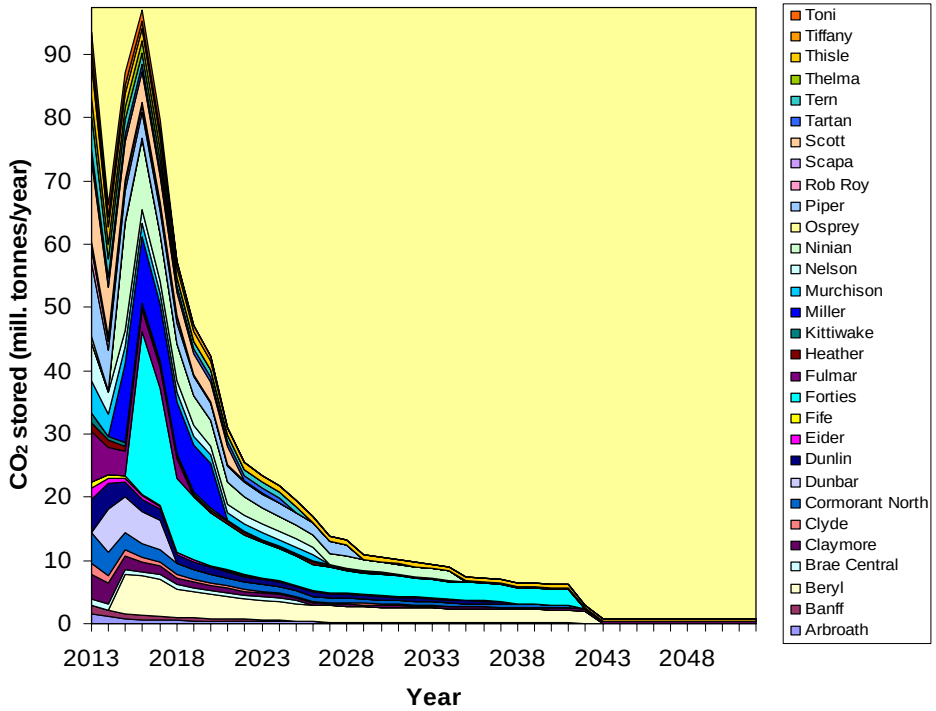
CO_2 storage profiles in oil fields

60 USD/bbl, 40 years injection



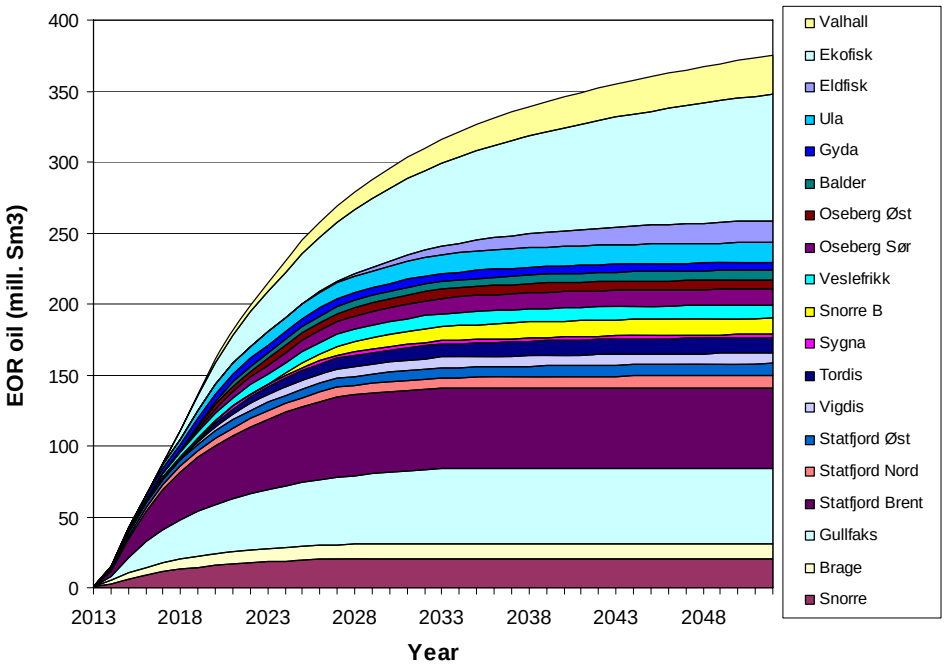
Norwegian fields



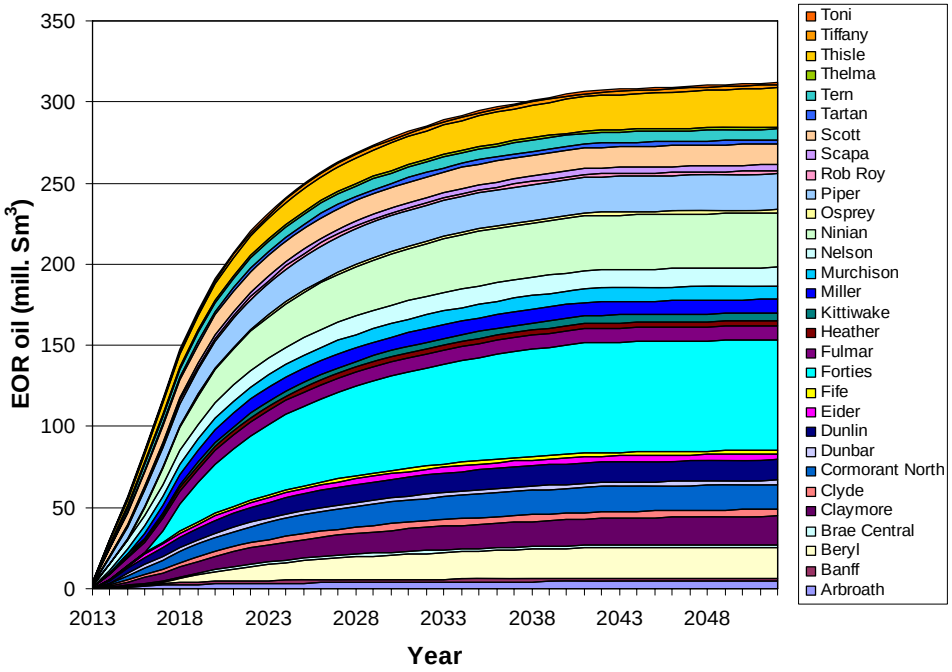
UK fields

Incremental oil production

60 USD/bbl, 40 years injection



Norwegian fields



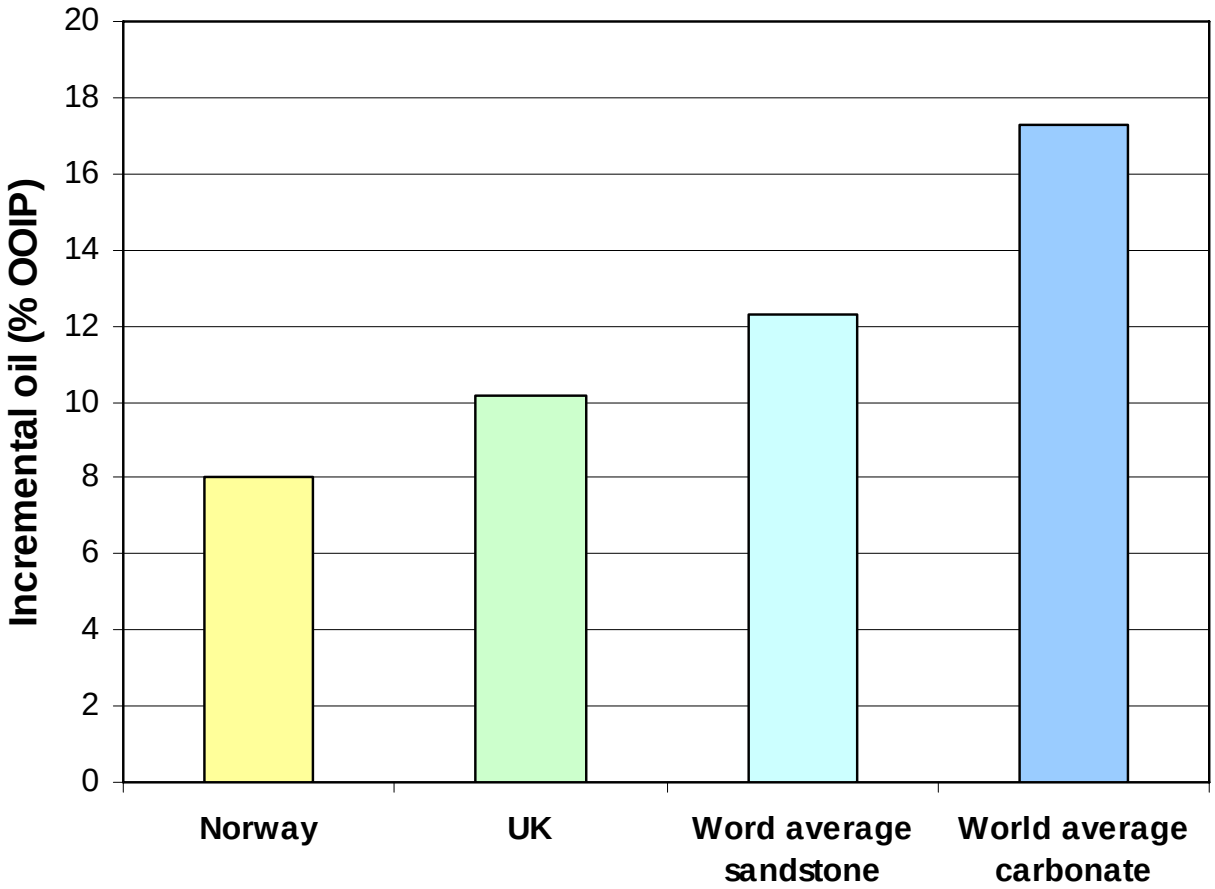
UK fields

Summary of EOR project performance

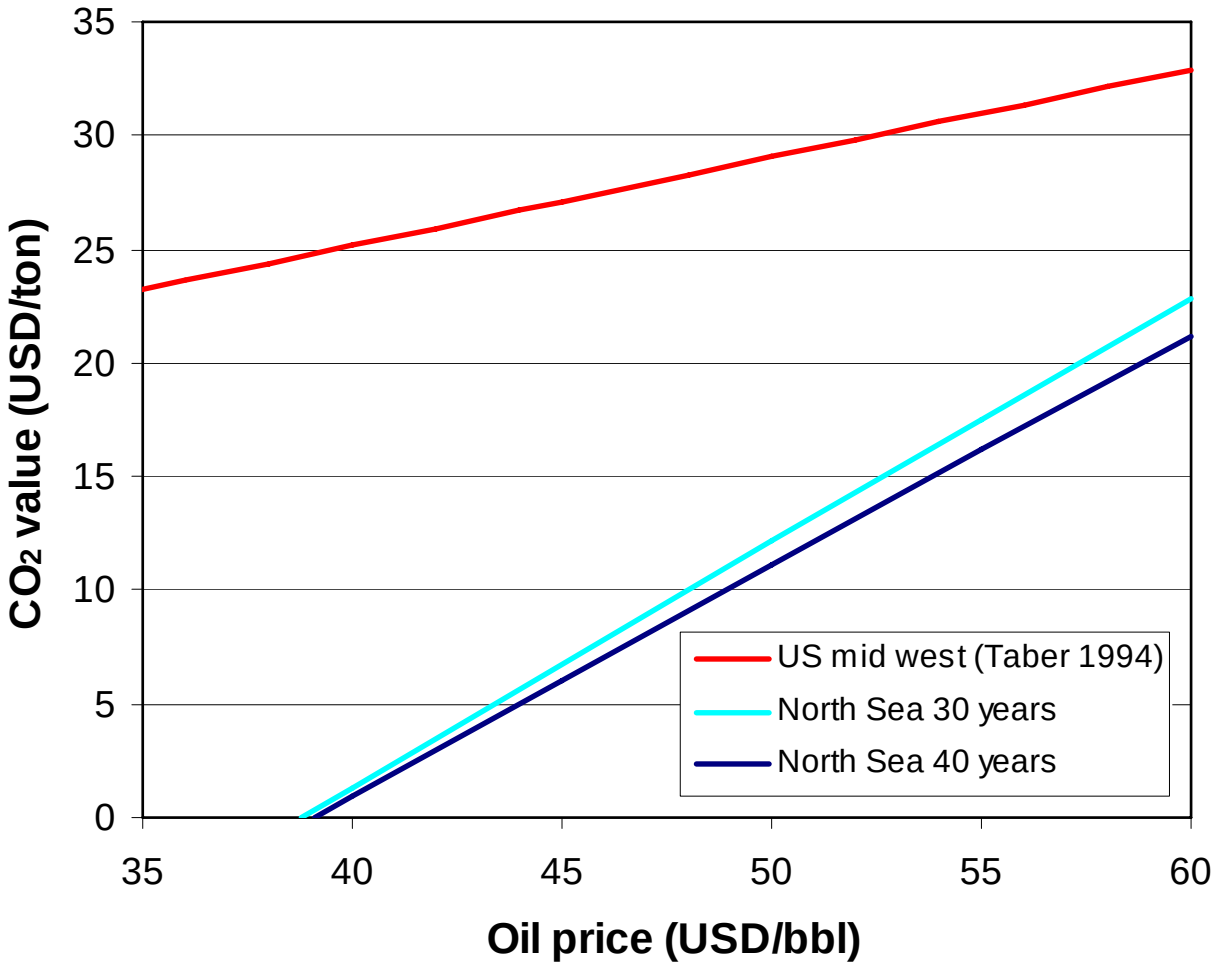
60 USD/bbl, 40 years project lifetime

Item	Norway	UK	Total
Investment costs (mill. USD)	28400	30832	59232
Operating costs (mill. USD/year)	1104	1234	2338
Total oil (mill. Sm^3)	2664	2054	4718
Oil recovery (% OOIP)	56.7	67.1	60.8
EOR oil (mill Sm^3)	375	312	687
Incremental oil recovery (% OOIP)	8.0	10.2	8.8
Total stored CO_2 (mill. ton)	3373	3881	7254
Stored CO_2 in oil reservoirs (mill. ton)	1479	853	2332

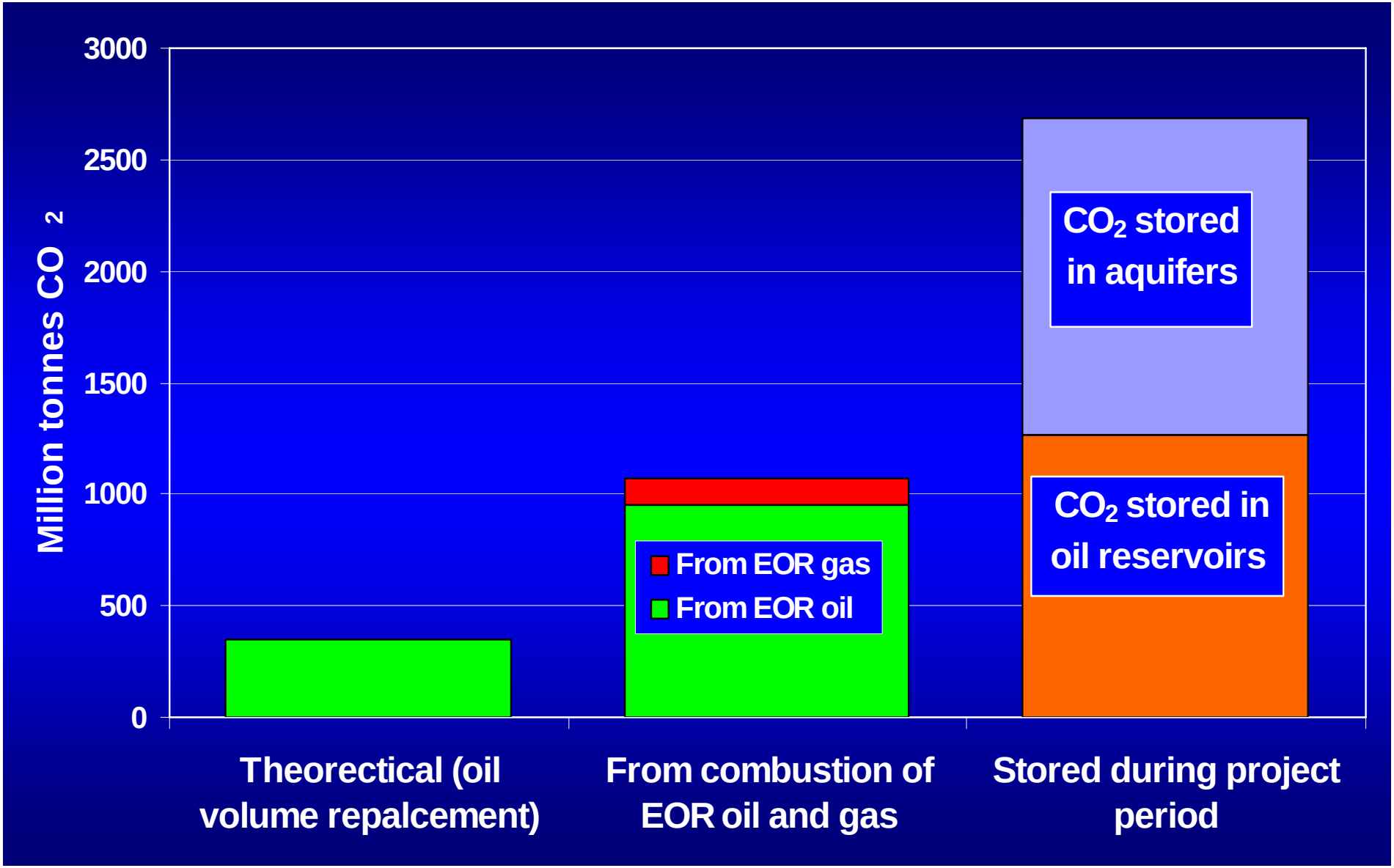
Incremental oil recovery for tertiary CO_2 injection



The value of CO_2

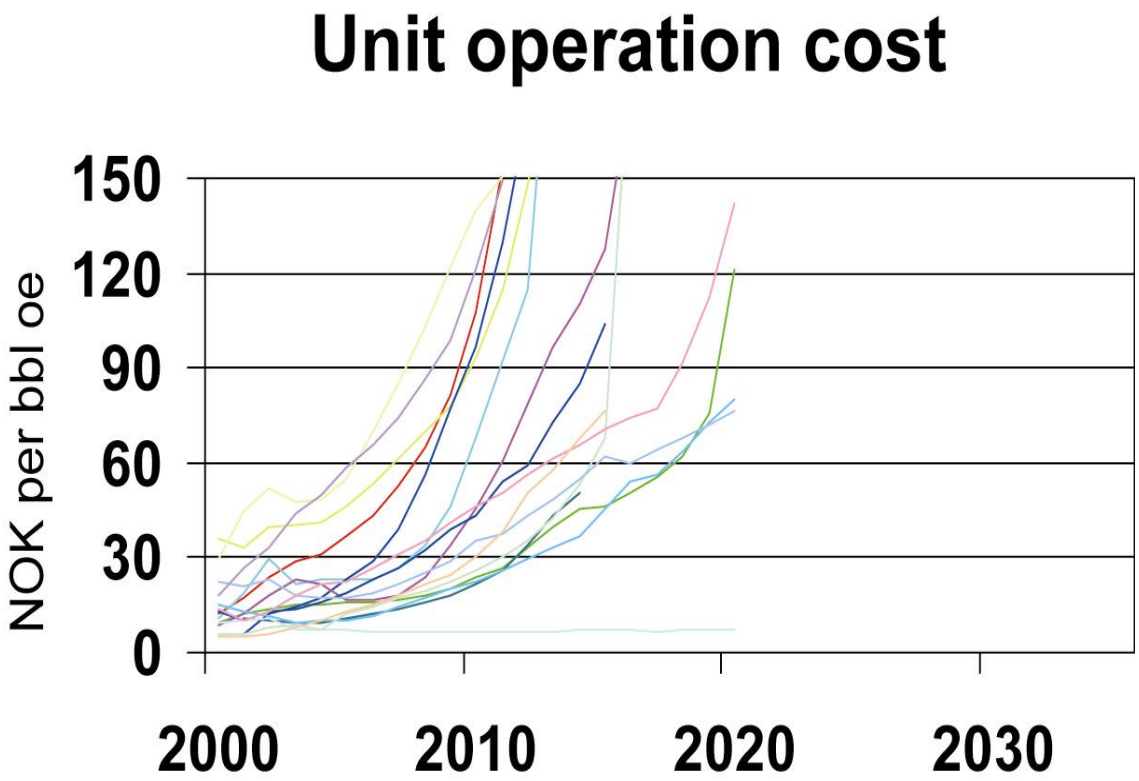


CO_2 balance for 19 Norwegian CO_2 EOR projects



The time-window for EOR projects

- The implementation of EOR projects must be done before operation of the field becomes unprofitable
- For many fields this time limit may be reached before a CO_2 infrastructure is established in the North Sea
- The benefits of CO_2 injection may therefore be lost



Future operation costs for North Sea oil reservoirs

Source: www.Petoro.no

Conclusions

- CO_2 based EOR can contribute to reduce GHG emissions
- The use of CO_2 for EOR gives a value to CO_2 that can cover parts of the capture and deposition costs
- The storage potential for CO_2 in North Sea oil reservoirs in in the order of two billion tonnes
- The EOR potential is estimated to 600 to 700 mill. Sm^3
- These potentials can only be realised if a CO_2 infrastructure to the North Sea oil reservoirs is established within a few years and if the oil fields are not permanently shut down in the meantime