Enhanced Oil Recovery
North Sea Case Studies

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Framework

- ‘North Sea’ is a catch-all label covering North Sea, West of Shetland and Norwegian Sea
- EOR projects reviewed were either on UK Continental Shelf, UKCS, or on Norwegian Continental Shelf, NCS
- Both producing regions are considered mature, but also have areas in which significant new developments are occurring:
  - for UKCS - West of Shetland
  - for NCS - Norwegian Sea
- UKCS oilfields are predominantly sandstones
- NCS fields are mostly sandstones but a significant chalk play exists

Orientation

- Water depth ca.100-400m, deepens as move North
- Initial large fields developed with fixed platforms
- FPSO more common in deeper and less sheltered water

North Sea - Potted History

- **Geological ages** of developed oil reservoirs, in declining order of historic recovery, were
  - For UKCS: Jurassic, Tertiary, Cretaceous
  - For NCS, Jurassic, Cretaceous (chalk) and Tertiary
- **Waterflooding** has featured in the majority of oil field developments
- Initial, large field developments typically preceded gas evacuation
- **Gas injection** (GI) adopted as
  - Large volumes of gas
  - structural relief
  - rock quality
  - a need to replace reservoir voidage (production)
- Oilfields that used GI include **Brent, Beryl, Fulmar** (all UKCS) and **Ekofisk, Statfjord, Gullfaks, Oseberg, Snorre** (all NCS)

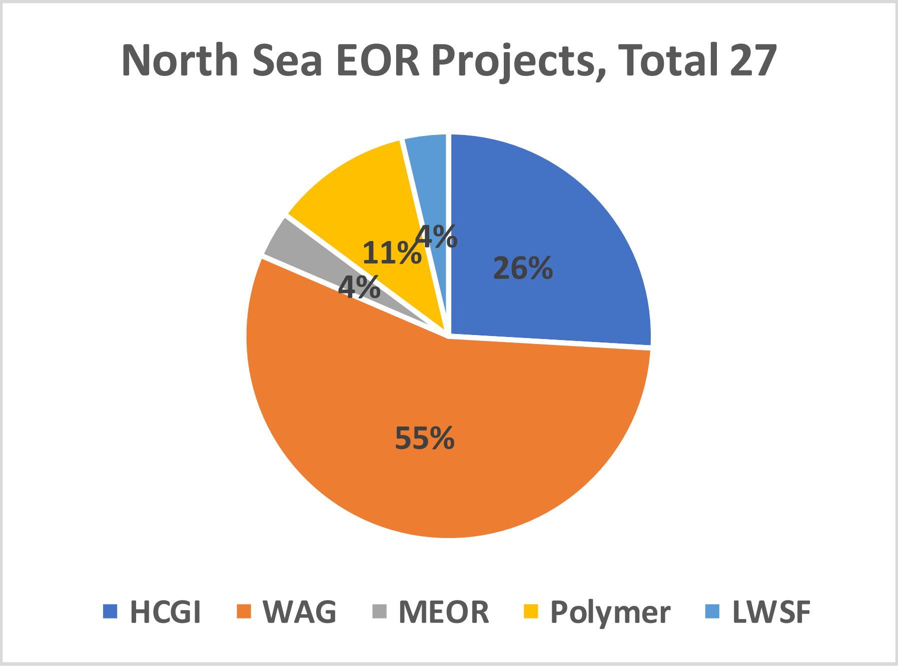
North Sea - Gas Market Effect

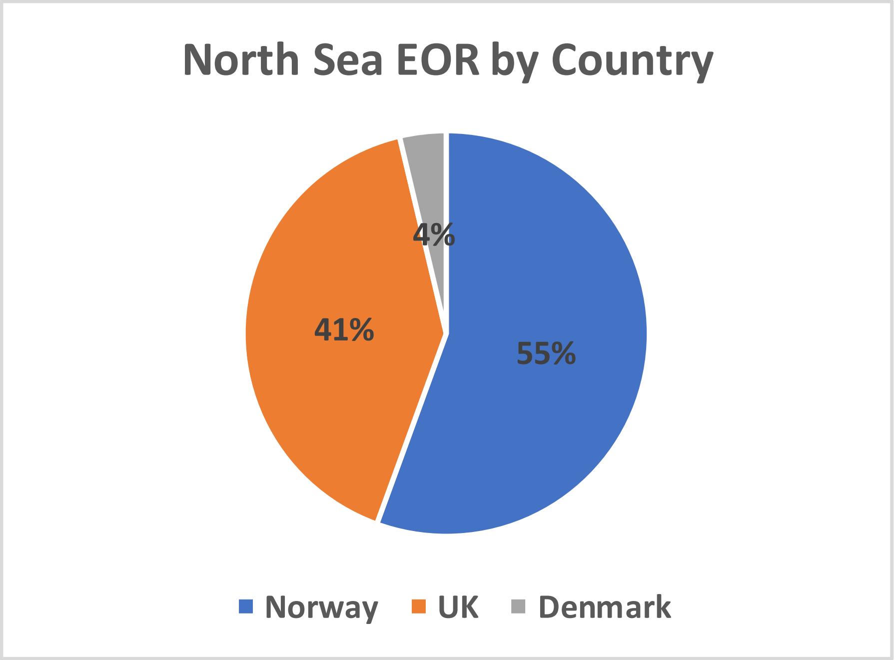
- **Since early 1990's GI has not featured** in initial field developments in UKCS
  - UK switched to natural gas for power generation and domestic consumption and associated gas was increasingly diverted there
  - UK is gas deficient and imports over 50% of its requirements
- NCS saw more gradual build-out of pipeline and market
  - Norway internal markets are small and dispersed, fully supplied by hydroelectric
- For NCS, GI continues to feature in some new field developments dependent on gas export options, area gas sales agreements etc.
  - Potential for CO_2 as part of Carbon Capture and Storage (CCS)

North Sea - Recovery Factor Snapshot

- Both **UKCS and NCS oilfields have enjoyed very high recovery factors**
- High cost environment with limited, high-cost wells meant focus on:
  - Reservoir characterisation (3D seismic then 4D, geological modelling)
  - Reservoir management strategies (solution gas drive not used)
  - Well construction (extended reach drilling, smart wells, flow assurance)
- Favourable geology, light oil translated into good waterflood recovery and, where used, from gas flood
- Estimated **ultimate recovery for UKCS and NCS oilfields 46%**

UKCS and NCS EOR

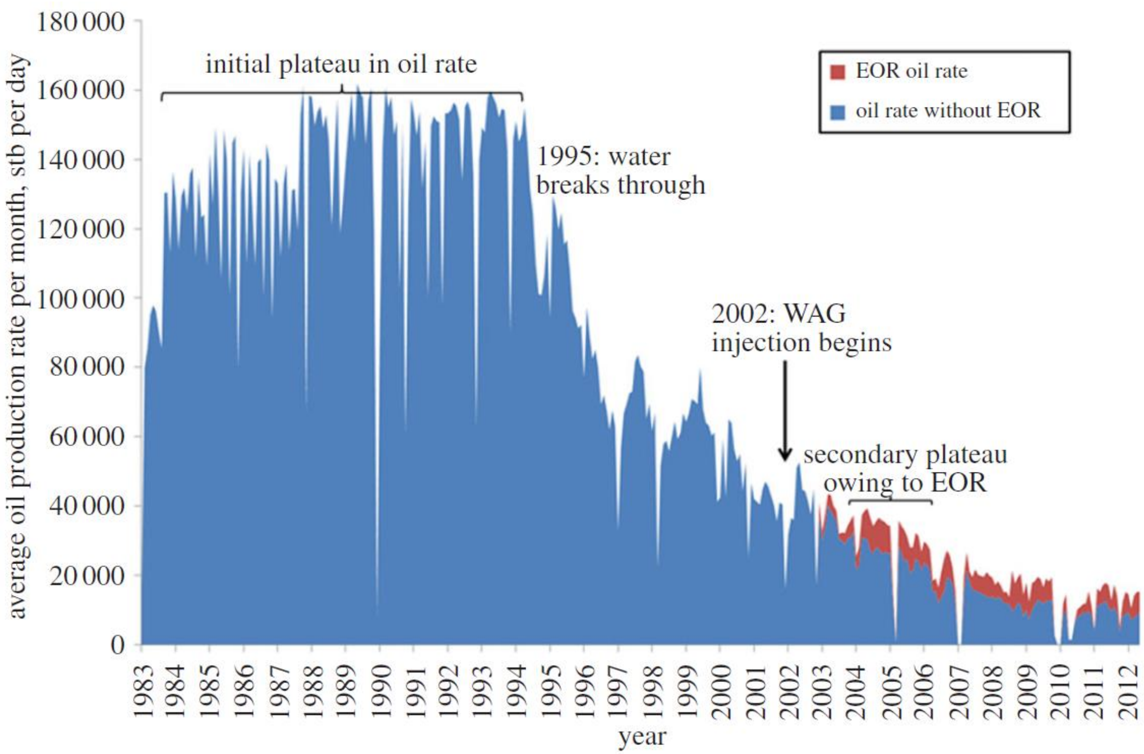




North Sea - WAG Schemes

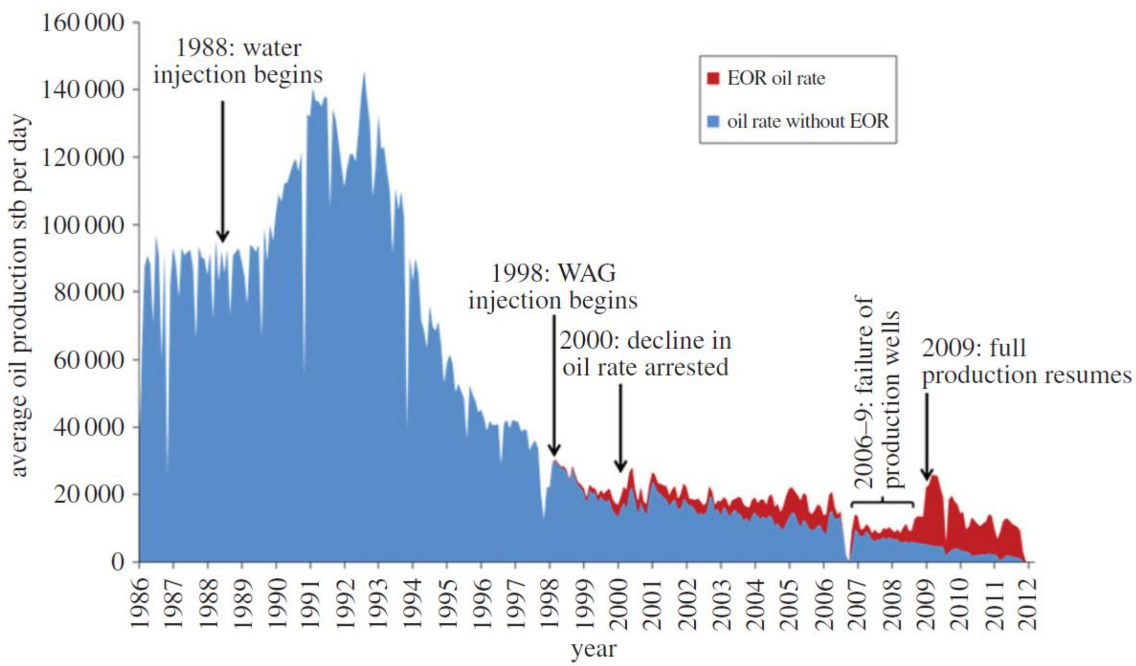
- **Water Alternating Gas (WAG)** is a hybrid scheme that combines water and gas flooding
- Features
  - A compartment/ fault-block is injected with water for a set volume typically then the injector is switched to gas injection for a set volume
  - Sequence performed multiple times to maximise incremental oil
  - Limits gas cost burden but changeover adds operational complexity
  - Preceded by core floods to establish incremental recovery target and detailed reservoir modelling to scale up lab results (or field pilots)
- **Applied successfully** in several North Sea fields - cycles ca.6-12 months
- Currently by
  - **BP - Magnus (UKCS) and Ula (NCS)**
  - **Statoil - Gullfaks, OsebergE, Snorre, Veslefrikk; W'shall - Brage**

Magnus Field Production Plot



- Built on learning from Miller, Ula, S.Brae
- Imports associated gas from West of Shetland
- Increased contribution from WAG as more fault blocks added
- Long payback often a feature of EOR

Ula Field Production Plot



- Built on Miller, S.Brae, onshore experience
- Imports associated gas from nearby fields
- Increased contribution as WAG widened

North Sea - Polymer Assisted Water Flooding

- **Recovery by water flooding impacted by viscosity difference** with oil
  - For typical light N.Sea oil, >30°API, 1-10cP contrast not significant
  - Where oil heavier and more viscous, making injection water (<1cP) more viscous **introducing polymers may improve recovery** vs seawater
- UKCS pilot scheme by **Chevron in Captain** (ca.100cP oil), NCS pilot by **Statoil in Heidrun**, long running Total project in Dalia, offshore Angola:
  - Identifying best polymer, temperature and salinity constraints
  - Logistics and supply chain getting chemical to offshore wellsites
  - Onsite QC ensuring intended quality is injected in reservoir

Polymer Assisted Water Flooding (continued)

- **Results encouraged incorporation of facilities for polymer flooding in asset development planning**
  - **Captain** late life development planning
  - Redevelopment planning for BP's **Schiehallion field,** West of Shetland
  - Final FID pending for both
- EOR favours companies with
  - 'long time perspective' as offshore EOR project risk mitigation reflected in v.long time frames
  - R&D resources
  - ability to move opportunities out of the laboratory and into field
  - access to cheaper, proving grounds
  - Collaborative approaches to shared risk mitigation e.g. for polymer BP+Statoil partners in Dalia

Emerging EOR Methods

- Emerging EOR methods
  - **Microbial EOR (MEOR)**
  - **Low Salinity Water Flooding, LSWF**

- Both reduce residual oil saturation in rock
  - In MEOR bacteria is introduced and nourished in reservoir to effect a reduction in surface tension and reduce oil trapping in pores
  - Science behind low salinity effect is still under debate

- ‘Cheap’ proving grounds have been important
  - Statoil - ongoing MEOR trial in Norne, NCS, but have collaborated on N.American field trials with Glori Energy (early Gullfaks pilot too)
  - BP – at forefront of evaluation of Low Salinity WF, have progressed the technique through a succession of field trials initially onshore Alaska

- LSWF/ LoSal® has been adopted by BP for field-wide deployment in the next development phase of Clair, West of Shetland (under construction)

Offshore EOR

Challenges:

- Remoteness, weather, sea-state
- Space and weight limitations
- Expensive wells, wide well spacing
- Reservoir understanding
- Seawater main resource
- Flow assurance
- Mature field: old wells, commingled
- Pilot testing
- Access to experienced specialists

Resourcing:

- Integrated team incl.wells, facilities from outset for early ID of issues
- Location/ nature of unswept oil coupled with geology
- Supplementary core analysis to confirm EOR opportunity
- Additional PVT analysis
- Flow assurance provision
- Monitoring and surveillance plan
- People: continuity, long term

Offshore EOR Incremental Recovery

- **Reporting sporadic**, estimates not always consistent/ comparable
  - N.Sea regional average RF 46% but range is wide ca.20%-70%
  - Similarly incremental RF from EOR has range ca.2%-15%
- **Localised EOR dilutes incremental field recovery** e.g. if EOR adds 10% RF from a 200MMstb fault block of a 1000MMstb field, field RF +2%
- Field specifics incl. development history impact EOR increment also size of field, nature of reservoir (sandstone/ carbonate), temperature
- **EOR understanding, practises steadily evolving** – collaboration and information dissemination/sharing important
- **UKCS review identifies GI probably as WAG (possibly incl.CO_2), polymer EOR and LSWF as most applicable**

Questions?

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