BP North Sea EOR lessons learned

Euan Duncan
North Sea Discipline Lead Reservoir Engineer
Enhanced Oil Recovery
BP North Sea lessons learned

1. Current Context
2. History
   • A few pictures
   • Enablers & Lessons
3. Current projects
4. Future
   1. Technology
   2. Unlocking options
Enhanced Oil Recovery
BP North Sea lessons learned

1. North Sea context
2. History
   • A few pictures
   • Enablers & Lessons
3. Current projects
4. Future
   1. Technology
   2. Unlocking options

Themes here are:
• EOR works in the subsurface & tends to grow with time
• Size of prize, access to infrastructure & injectant supply are critical
• Confidence in process is critical

so …. Good planning & Collaboration are potential EOR enablers
Context
North Sea Reserves & Resources (billion boe)

Exploration Efficiency
New Discoveries in 2012: 3 to 9
Exploration Efficiency: 0.05

Recovery Efficiency
New Fields on-stream in 2012: 4 to 10
Recovery Efficiency: 0.15

Production Efficiency
Produced in 2012: 7
Production Efficiency: 0.5

Produced to date: 41

Source: Oil & Gas UK Economic Report 2013
Delivering EOR

- Recovery Efficiency can be increased by making improvements across four levers:

\[
\text{Recovery Factor} = \text{Pore scale displacement} \times \text{Sweep} \times \text{Drainage} \times \text{Cut-offs}
\]

**Subsurface Delivery of EOR**

- LoSal® EOR
- Polymer
- Miscible Gas / CO₂
- Bright Water®

**Practical EOR Delivery**

- New wells
- Logistics & Longer field life
- Effective patterns
- Plant & well efficiency

LoSal® is a registered trademark of BP plc
BrightWater® is a registered trademark of Nalco Company
Delivering EOR

- Recovery Efficiency can be increased by making improvements across four levers:

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**Subsurface Delivery of EOR**

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- Effective patterns
- Plant & well efficiency

CONFIDENCE / STRATEGY ALIGNMENT

LoSal® is a registered trademark of BP plc

BrightWater® is a registered trademark of Nalco Company
North Sea EOR Project History
BP EOR Focus Areas in North Sea Field locations with current & future projects

LoSal is a trademark of BP plc
Miller Associated Gas Re-injection

- New WAG compressor installed
- 3 wells converted to a limited WAG scheme
Critical Enablers
• BP Alaska WAG experience
• Good reservoir sweep & high Sorw

Lessons Learned:
• Compression performance
• WAG subsurface success
• Modelling workflow
• Too late
Critical Enablers
- BP Alaska WAG experience
- Good reservoir sweep & high Sorw

Lessons Learned:
- Compression performance
- WAG subsurface success
- Modelling workflow
- Too late
Miller CO₂ project

- Miller AGR (1998)
- Ula WAG (2000)
- Magnus WAG (2002)
- Miller WAG/CO₂ (2010)
Miller CO₂ Injection

**Critical Enablers**:
- Infrastructure & Injectant supply

**Lessons Learned**:
- EOR cannot pay for full platform costs
- Step too far for new technologies
- No fiscal regime at the time for CO₂, too late in field life, low oil price

Timeline:
- 1998: Miller AGR
- 2000: Ula WAG
- 2002: Magnus WAG
- 2010: Miller WAG/CO₂
Ula behind flood front pilot

- New WAG compressor installed
- 2 WAG injectors in 1999 to 4 in 2005
- Increased gas capacity & further WAG wells in 2009
Surveillance Data – behind flood front pilot

- Miller AGR
- Ula WAG
Surveillance Data – behind flood front pilot

- Miller AGR
- Ula WAG
Ula future

1998
- Miller AGR
- Ula WAG

2000

2002

2004

2006

2008

2010
- Blane gas & more wells

2012
- Oselvar gas & more wells

2014

2016

2018
- Expanded WAG

2020
- Current WAG
- Expanded WAG
Ula WAG Scheme

**Critical Enablers**
- Injectant supply: Gas export lost when Cod field abandoned
- Miller compression experience
- Alaska experience

**Lessons Learned:**
- Gas injector integrity
- Timing WAG bank is difficult – Needed surveillance to understand

**Dates:**
- 1998: Miller AGR
- 2000: Ula WAG
- 2010: Blane gas & more wells
- 2012: Oselvar gas & more wells
- 2018: Expanded WAG
- New WAG compressor installed
- Gas import from stranded West of Shetland gas
Magnus Understanding the WAG target

WAG

CPI Log

Typical Biostrat Control

Principal Zonation

Sequence Equivalents

Upper MSM

MSM G

MSM E

MSM C / MSBRZ

B Shale

Lower MSM

MSM A

MK90

MK80

MK60

MK40

LK20, LK10

LK0

LK10

LK20

LK40

LK60

LK80

LK90

M60(A6) MSM

M58z(E3) MSM

drilled in 2010

drilled in 2009

base not shown here

50 m
Magnus panels & Ula overall performance is better than most of the industry benchmarks.
Magnus WAG

Critical Enablers
- BP Alaska WAG experience
- Ula & Miller compression
- WoS Stranded gas

Lessons Learned:
- Technical Experience
- Injectant supply critical
- System complexity and uptime in mature assets challenging
- Fiscal relief beneficial

1998
- Miller AGR
- Ula WAG

2000
- Magnus WAG

2002
- Additional EOR patterns

2004

2006

2008

2010

2012

2014
- Optimisation

2016
- Flotel programme to extend CoP

2018
- Additional EOR patterns

2020

2022
Critical Enablers

- BP Alaska WAG experience
- Ula & Miller compression
- WoS Stranded gas

Lessons Learned:

- Technical Experience
- Injectant supply critical
- System complexity and uptime in mature assets challenging
- Fiscal relief beneficial

Magnus WAG
Lessons learned from four EOR projects

**Subsurface Delivery of EOR**

Subsurface Workflow knowledge
Surveillance: Seismic, Sorm & Sorw etc

Recovery Factor = Pore scale displacement \( \times \) Sweep \( \times \) Drainage \( \times \) Cut-offs
Lessons learned from four EOR projects

Practical EOR Delivery

Well integrity
- Injectant supply
- Understanding changes to plant process critical
- Fiscal Relief
- Multiple phases of EOR

Subsurface Delivery of EOR
Subsurface Workflow knowledge
Surveillance: Seismic, Sorm & Sorw etc

Recovery Factor = Pore scale displacement \times Sweep \times Drainage \times Cut-offs

CONFIDENCE
Future Projects
Clair Ridge LoSal® EOR

Critical Enablers
- BP Alaska LoSal® EOR experience
- Big STOIIP
- Other benefits (scale & H2S)

Lessons Learned:
- Align partnership
- Need big development for standalone LoSal® EOR … collaboration?

Further phase of Clair
Schiehallion Polymer

Effect of polymer concentration on shear viscosity (3630S in 1% NaCl at 25 °C).

Polymer degradation at very high shear rates (e.g., chokes)

In facilities, mixed at 1,000 ppm

At injection well perforations

In bulk of reservoir, polymer acts as 850 ppm

At sandface and fracture

3,000 ppm

2,000 ppm

500 ppm

100 ppm

0 ppm

1000 ppm

2000 ppm

3000 ppm

5000 ppm

Effect of polymer concentration on shear viscosity (3630S in 1% NaCl at 25 °C).
Effect of polymer concentration on shear viscosity (3630S in 1% NaCl at 25°C).

Polymer degradation at very high shear rates (e.g., chokes)

In facilities, mixed at 1,000 ppm

At injection well perforations

In bulk of reservoir, polymer acts as 850 ppm

At sandface and fracture

At sandface

In bulk of reservoir, polymer acts as 500 ppm

Effect of polymer concentration on shear viscosity (3630S in 1% NaCl at 25 °C).
Schiehallion polymer lessons

Critical Enablers
- Understand reservoir
- Large STOIIP … collaboration?
- Partnership

Knowledge

Lessons Learned:
- Polymer delivery challenge: manufacture, logistics, mixing, degradation needs careful planning
- Significant upsides exists vs current technology

Timeline:
- 1998: Miller AGR
- 2000: Ula WAG
- 2002: Magnus WAG
- 2006: Miller WAG/CO2
- 2016: Clair Ridge Losal
- 2018: Schiehallion Polymer
- 2020: Future hopper
So, what are we doing now?
Brackish water or losal

Breacais losal
Lower Breakish
Technology

1. Developing new Water based IOR technologies:
   - Pore scale
   - Losal® EOR plant

2. Facilities:
   - Integrity management, Field life extension, PoB efficiency
   - Plant & well uptime

3. Wells
   - Cost
   - Surveillance & conformance control
Screening process leading to Project Entry

**INPUTS**

- Basic field data
- Cross Discipline engagement on enablers / barriers
- Mechanistic models Data Acquisition QA/QC
- Cross discipline engagement Full Field Studies
- GPO/Project entry discussions

**OUTPUTS**

- RE Toolkit Screening Tool
- Short List
- Field scoping studies
- Project Studies across disciplines
- Full project planning

**PRIORITISED HOPPER**

- Hopper
- Prioritised Hopper
- EOR/IOR Selection Matrix (multi-discipline)
- Agreed Work programme proposal
- Project entry
## High level screening

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Standardise Modelling Workflow

1. Fine Scale Mechanistic model with rock curves

2. Fine Scale Geological element model with rock curves

3. Fine Scale Depositional system Geological model with upscaled to pseudos

4. Full field model with areal pseudos & potentially EOR process pseudos
### Screening Process: Summary of EOR project status

- **Communication tools to understand status**

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<th>EOR Screening</th>
<th>SCAL</th>
<th>Production Forecast</th>
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<td>Field 7 EOR optimisation</td>
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<td>Field 8 Hisal</td>
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<td>Field 5 upsides</td>
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<table>
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<tr>
<th>Green</th>
<th>Complete</th>
<th>Complete</th>
<th>Complete</th>
<th>Complete</th>
<th>Complete</th>
<th>Good NPV</th>
<th>&gt;50%</th>
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<tbody>
<tr>
<td>Yellow</td>
<td>In Progress</td>
<td>In Progress</td>
<td>In Progress</td>
<td>In Progress</td>
<td>Marginal</td>
<td>10-50%</td>
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<tr>
<td>Red</td>
<td>Not Started</td>
<td>Not Started</td>
<td>Not Started</td>
<td>Not Started</td>
<td>Negative NPV</td>
<td>&lt;10%</td>
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Building Confidence: Pyramid of proof

Subsurface Technical
Losal® EOR example

Deploy

Pilot
(Inter-Well Trials)

Detailed Study
(>15 Single Well Chemical Tracer Tests)

Screening Studies
(>50 Corefloods)

Corporate confidence

Injectant supply & Facilities Knowledge

Subsurface Data & Knowledge

Economics

…. PLANNING INTEGRATION
# EOR challenges & possible solutions

<table>
<thead>
<tr>
<th>Key Success Factors</th>
<th>Challenges</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Cost Injectant</strong></td>
<td>• Source&lt;br&gt;• Cost of supply or purchase</td>
<td>• Engage with CCSA to develop CO₂ EOR / CCS strategy.&lt;br&gt;• Collaboration&lt;br&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• supply chain&lt;br&gt;• shared facilities (eg ITF call)</td>
</tr>
<tr>
<td><strong>Subsurface Understanding</strong></td>
<td>• Awareness of EOR.&lt;br&gt;• Understanding mechanisms&lt;br&gt;• Confidence</td>
<td>• DECC PILOT (screening, workshops, coreflood planning)&lt;br&gt;“Pyramid of Proof”</td>
</tr>
<tr>
<td><strong>Facilities</strong></td>
<td>• Lack of space / weight</td>
<td>• ITF: Low Salinity facilities for brownfields.&lt;br&gt;Include capacity for EOR</td>
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<tr>
<td></td>
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<td>within BoD’s for new developments (FDP consent).</td>
</tr>
<tr>
<td><strong>Economics</strong></td>
<td>• “High” front-end &amp; increased OPEX costs..&lt;br&gt;Time to CoP.&lt;br&gt;Pace!!</td>
<td>• “Clusters” formed for knowledge/cost sharing&lt;br&gt;EOR hopper awareness.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Potential for fiscal relief.</td>
</tr>
</tbody>
</table>
Lessons learned from four EOR projects

Subsurface Delivery of EOR
Subsurface Workflow knowledge
Surveillance: Seismic, Sorm & Sorw etc

Practical EOR Delivery
Well integrity
- Injectant supply
- Understanding changes to plant process critical
- Fiscal Relief
- Multiple phases of EOR
Lessons learned from BP EOR projects

Practical EOR Delivery
- Injectant supply
- Understanding changes to plant process critical
- Fiscal Relief
- Multiple phases of EOR

Recovery Factor = Pore scale displacement $\times$ Sweep $\times$ Drainage $\times$ Cut-offs

Align with strategy, Development Planning & Scale (reservoir & infrastructure)

**Subsurface Delivery of EOR**
- Subsurface Workflow knowledge
- Surveillance: Seismic, Sorm & Sorw etc

**Practical EOR Delivery**
- Well integrity
BP EOR Focus Areas in North Sea Field locations with current & future projects

Clair Ridge
LoSal® EOR
Approved for s/u 2016
Greater Clair
Future EOR & new technologies

Schiehallion & Loyal
Polymer – vessel space
Potential future optimisation

Foinaven
Potential for polymer + other?

Skarv
Crestal gas Injection
Started-up 2013

Magnus
WAG since 2002
Optimisation

ETAP
Potential for water IOR

Ula
WAG since 1999
Large upside potential

Valhall
Sulphate injection research

LoSal® is a registered trademark of BP plc
End
Summary: Magnus Development phases

- **7 subsea & 15 platform wells**
- **MSM only WF development**
- **LKCF development**
- **Infill drilling to utilise 20 slots**
- **South Magnus subsea tie-back**
- **Increase off-take to 140mbd**
- **Revised petrophysical interpretation**
- **Miscible WAG EOR scheme for MSM and LKCF – brownfield mods**
- **8 new platform slots**
- **North West Magnus satellite development from platform**
- **Plant PW de-bottlenecking**
- **20 additional wells**
- **Subsea injectors (SWIFT)**
- **Phase I and Phase II infill drilling programmes**
- **Options for further WAG patterns and Extended EOR scheme to progress remaining CR volumes**

**Evolution of Magnus Field Production Profiles**

- **Magnus Hub Oil Production Rate (mstbd)**
- **Magnus Full Field Recovery Factor**
- **Current Recovery of 820mmstb**
- **Magnus Field Recoverable oil (mmstb) Current Recovery of 820mmstb**

(Historical profiles - Annex B revisions)
Ula WAG Increment

A12A oil rate and GOR from well tests

0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Jan-99 Jan-01 Jan-03 Jan-05 Jan-07 Jan-09 Jan-11
Oil Rate [stb/d], green
GOR [scf/bbl], red

- Oil rate
- GOR

WAG effect from A07C
DHSV repair
TTAC

A15 oil rate and GOR from well tests

0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08 Jan-10
Oil Rate [stb/d], green
GOR [scf/bbl], red

- Oil rate
- GOR

WAG effect from A13A
WAG effect from A03A
DHSV failure
Recompletion
Schiehallion Q204 Polymer Impact on Swivel Design Area for EOR equipment

Impact on Separation and Produced water treatment e.g. Hydrocyclones

Polymer delivered as bulk chemical

Polymer viscosity optimised for max injectivity

Production

Shear in chokes

Separation flow loop – Opus Plus