BP North Sea EOR lessons learned

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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
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1. North Sea context
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4. Future
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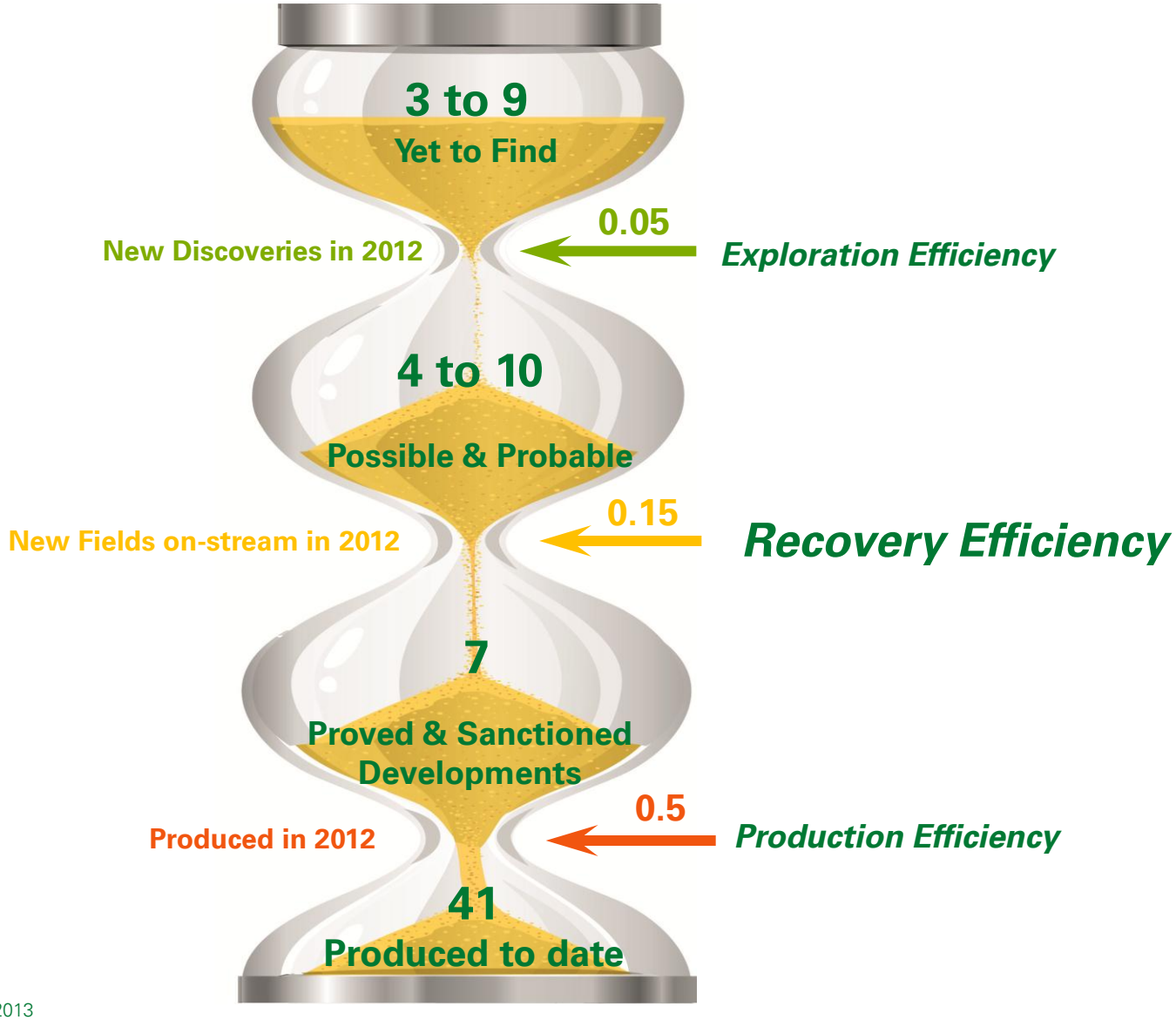
Themes here are:

- 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

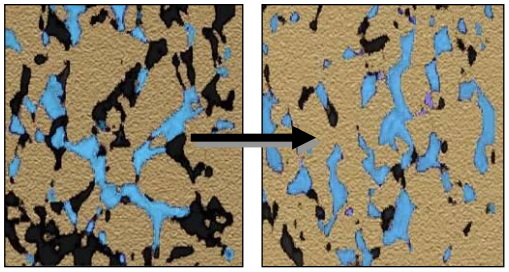
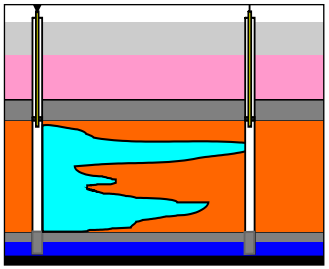
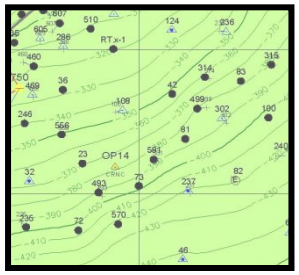
Context
North Sea Reserves & Resources (billion boe)



Source: Oil & Gas UK Economic Report 2013

Delivering EOR

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


Recovery Factor = **Pore scale displacement** x **Sweep** x **Drainage** x **Cut - offs**

Subsurface Delivery of EOR

LoSal® EOR
Miscible Gas / CO_2

Polymer
Bright Water®

Practical EOR Delivery

New wells
Effective patterns

Logistics & Longer field life
Plant & well efficiency

Delivering EOR

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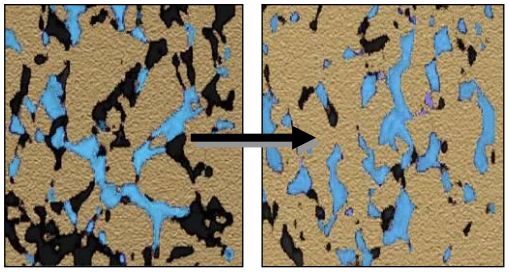
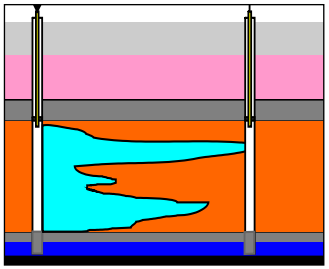
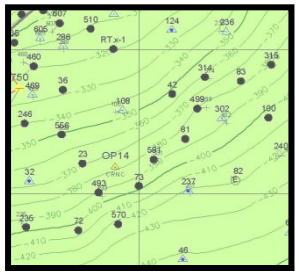


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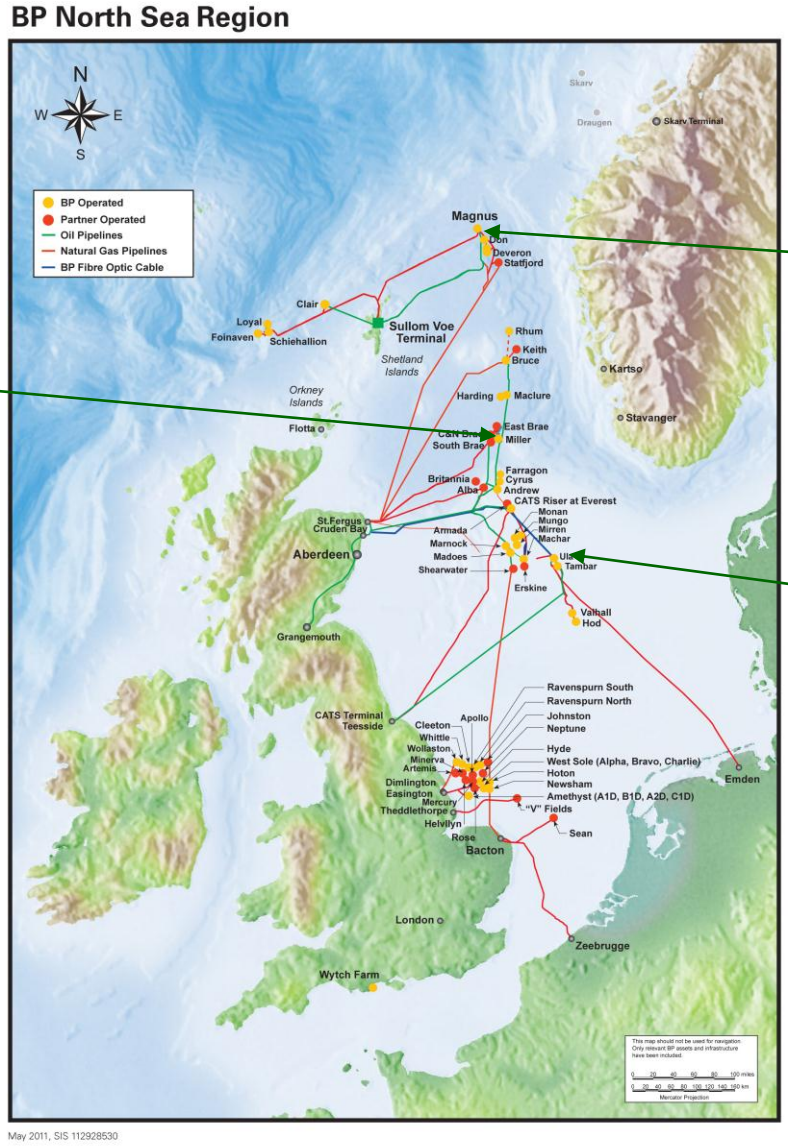
CONFIDENCE / STRATEGY ALIGNMENT

North Sea EOR Project History

BP EOR Focus Areas in North Sea
Field locations with current & future projects



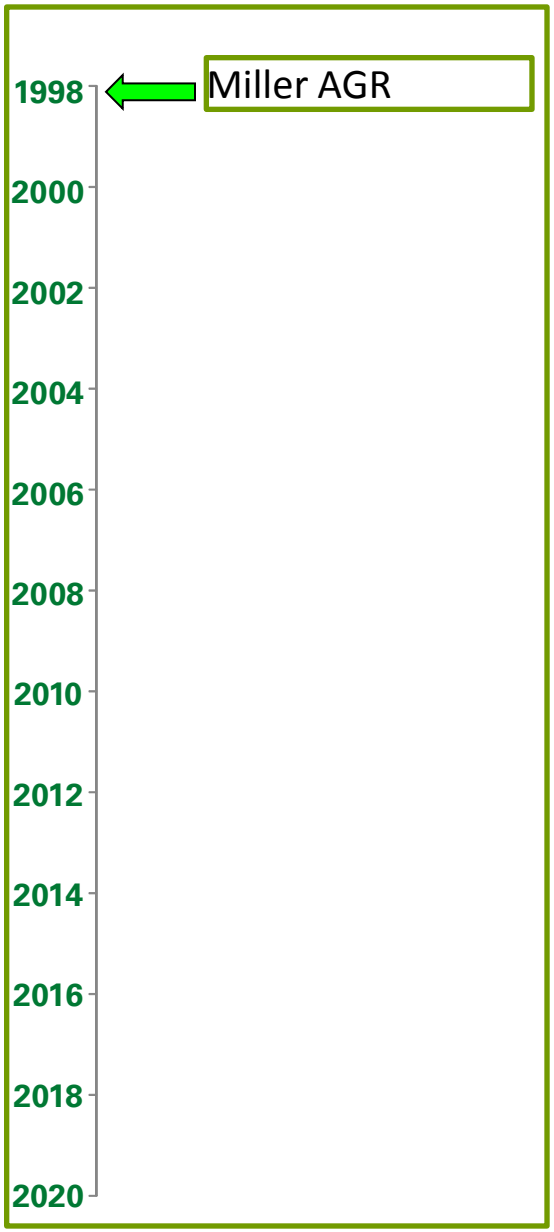
Miller

Magnus

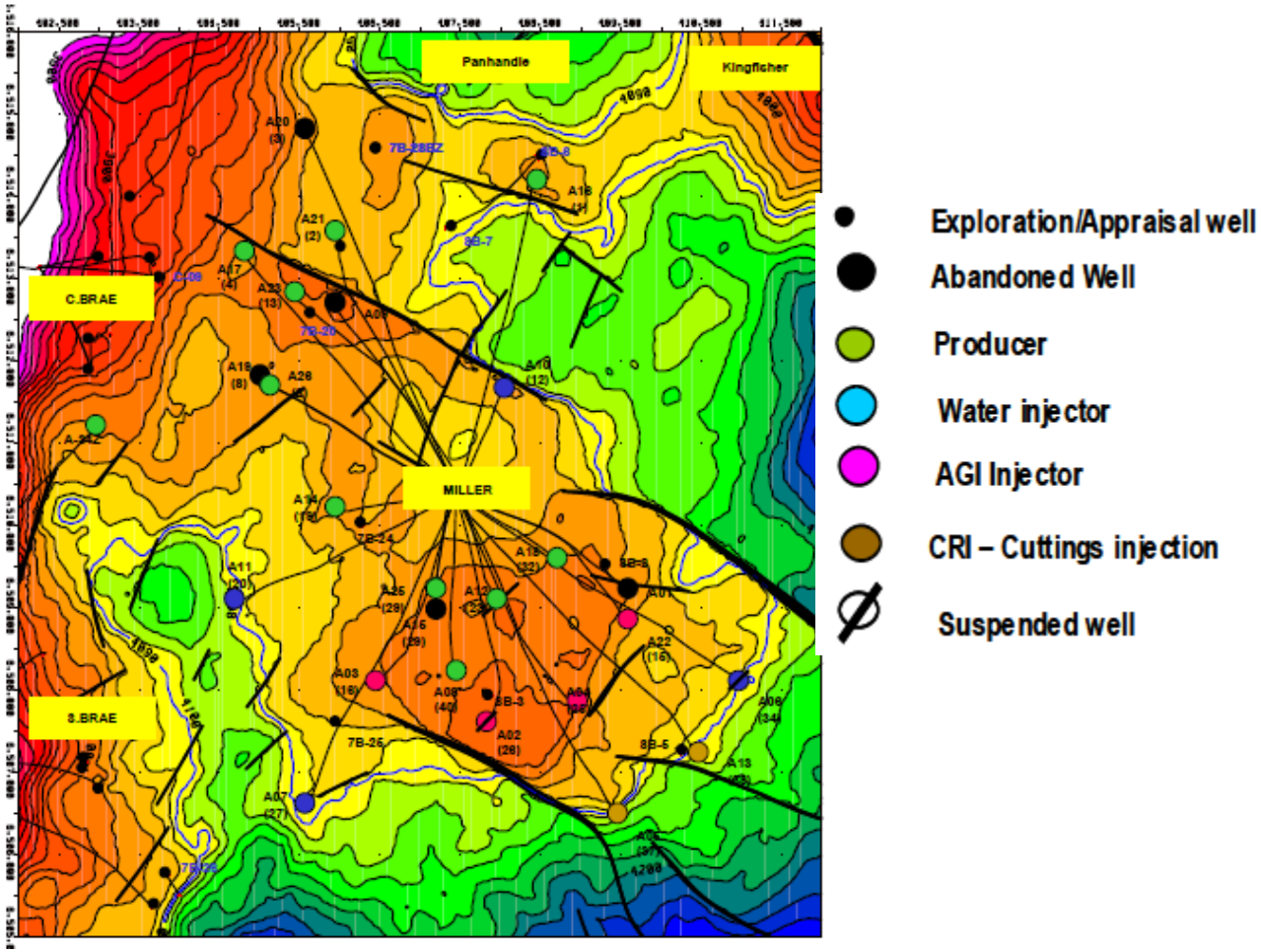
Ula

LoSal is a trademark of BP plc

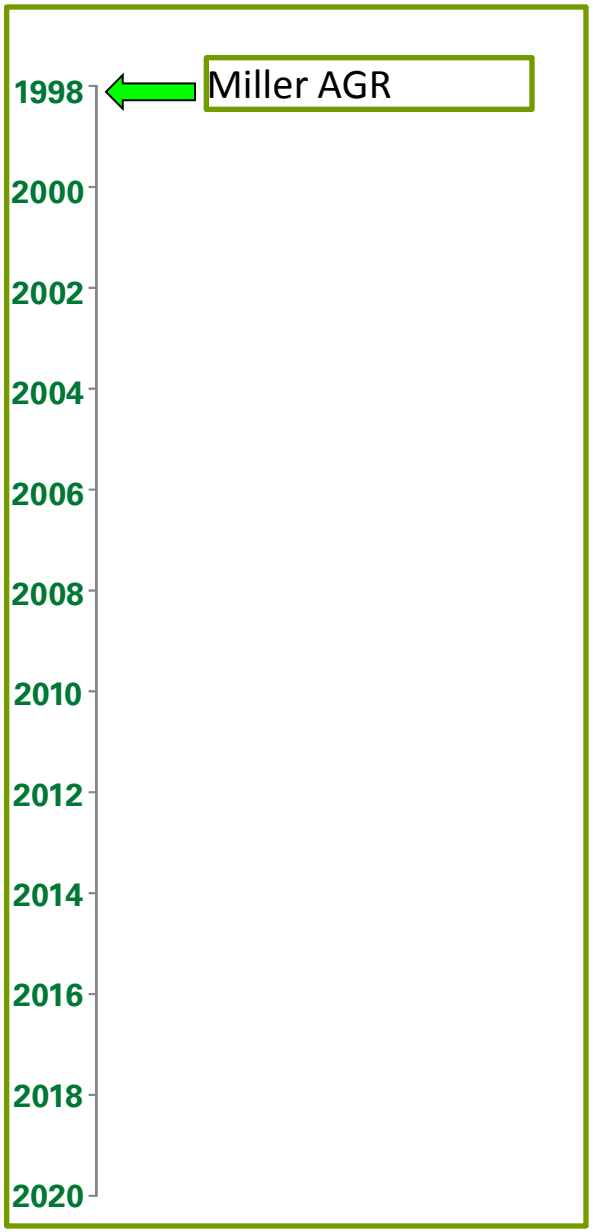
Miller Associated Gas Re-injection



- New WAG compressor installed
- 3 wells converted to a limited WAG scheme



Miller Associated Gas Injection



Critical Enablers

- BP Alaska WAG experience
- Good reservoir sweep & high Sorw

Lessons Learned:

- Compression performance
- WAG subsurface success
- Modelling workflow
- Too late

Miller Associated Gas Injection

1998 Miller AGR
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020

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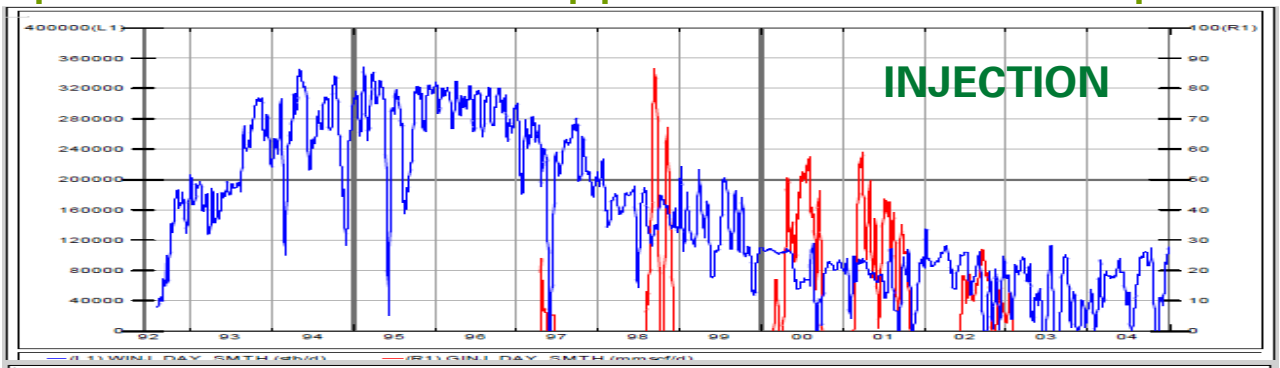
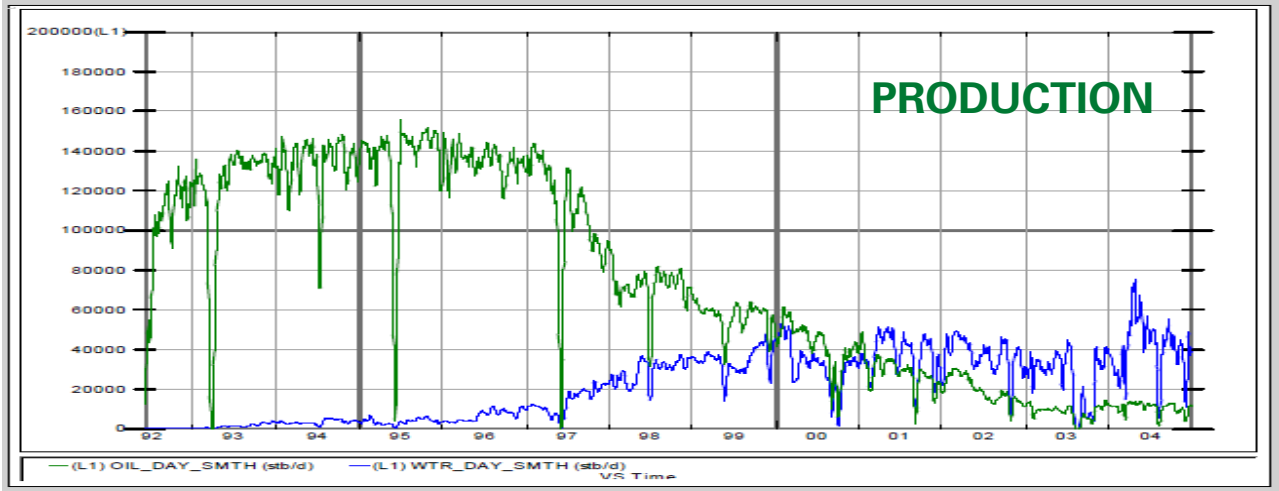
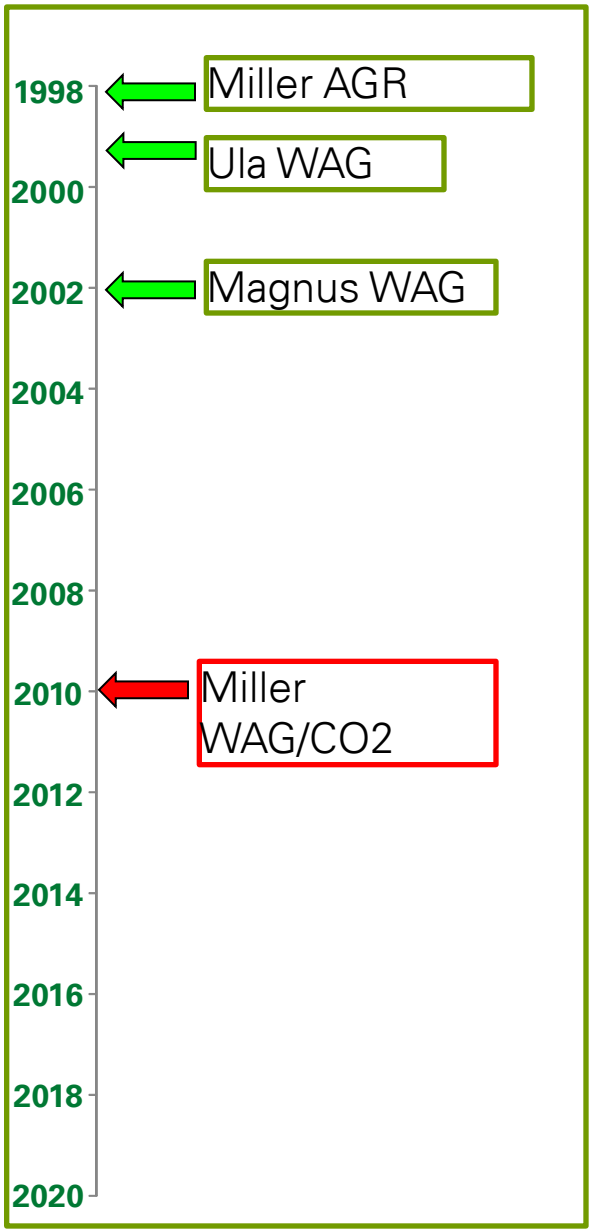
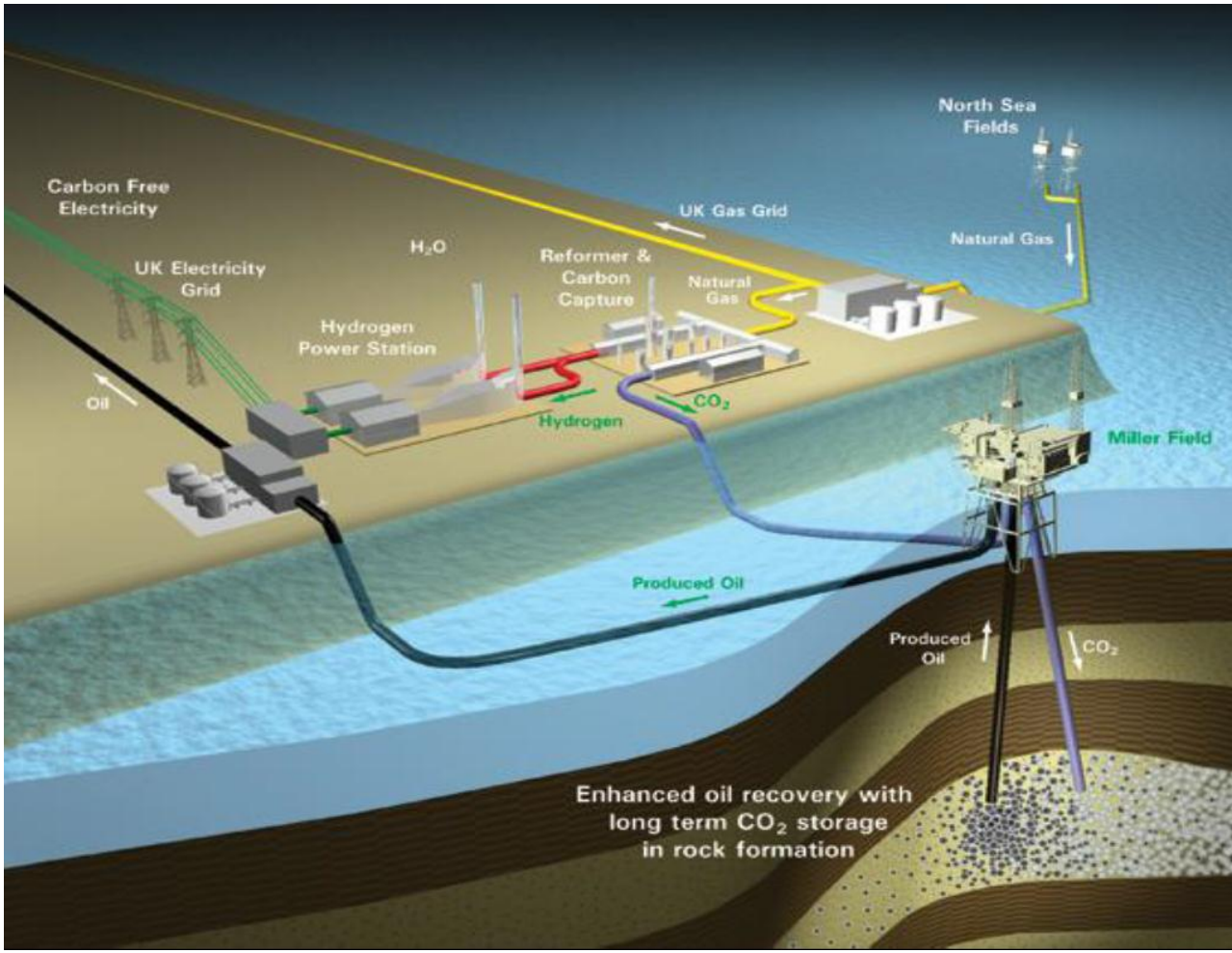


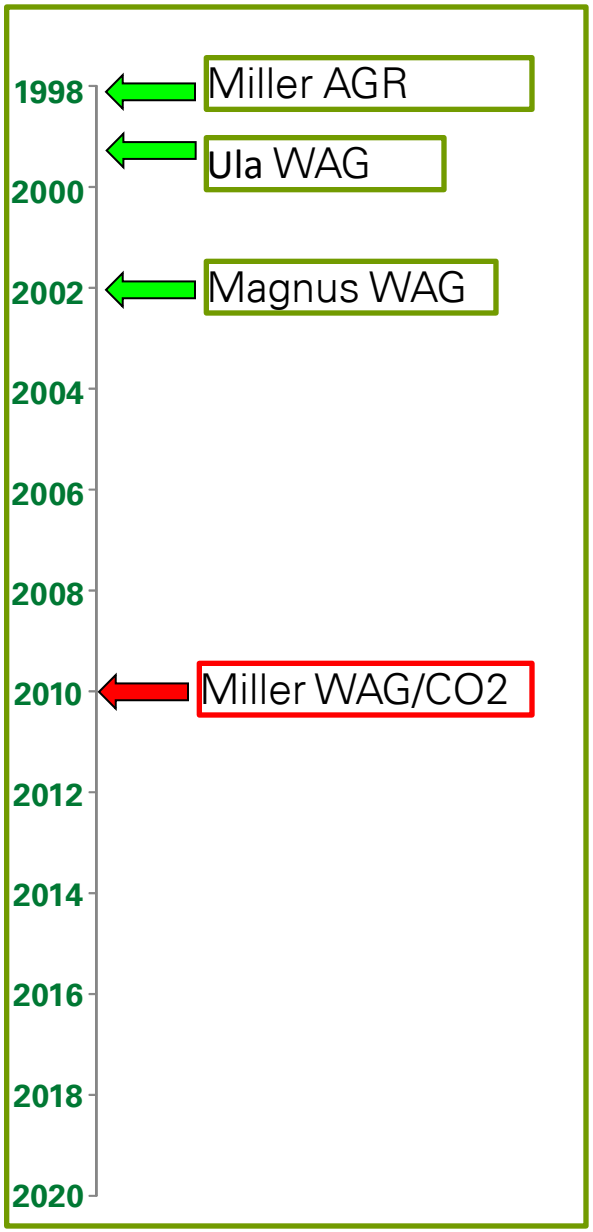


Miller CO_2 project





Miller CO_2 Injection

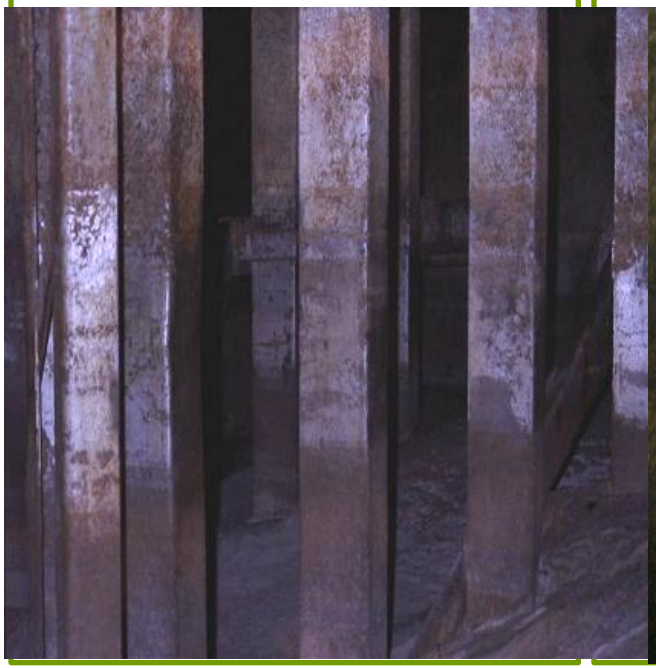


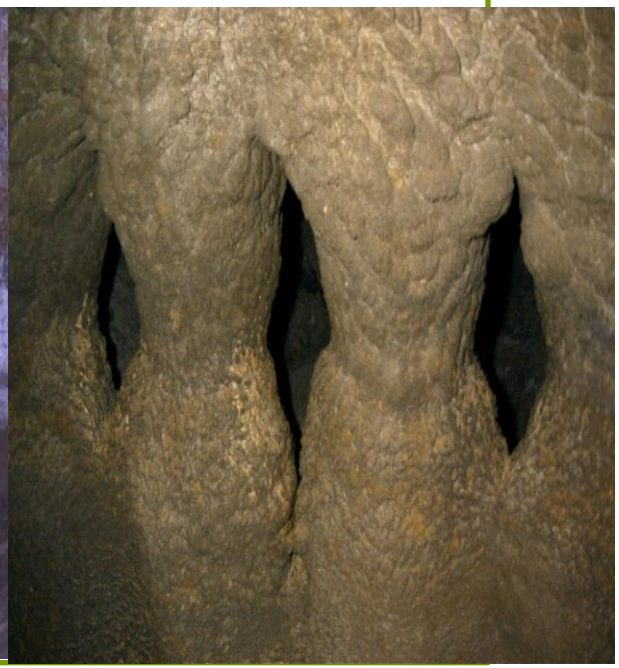
Critical Enablers

- Infrastructure & Injectant supply

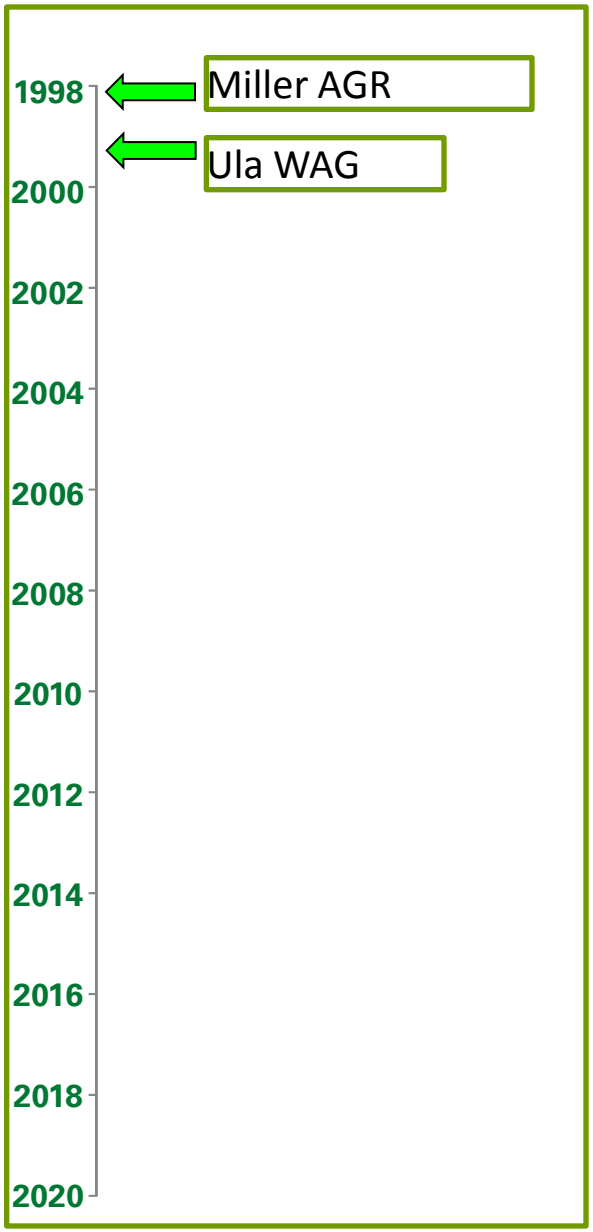
Lessons Learned:

- EOR cannot pay for full platform costs
- Step too far for new technologies
- No fiscal regime at the time for CO_2, too late in field life, low oil price

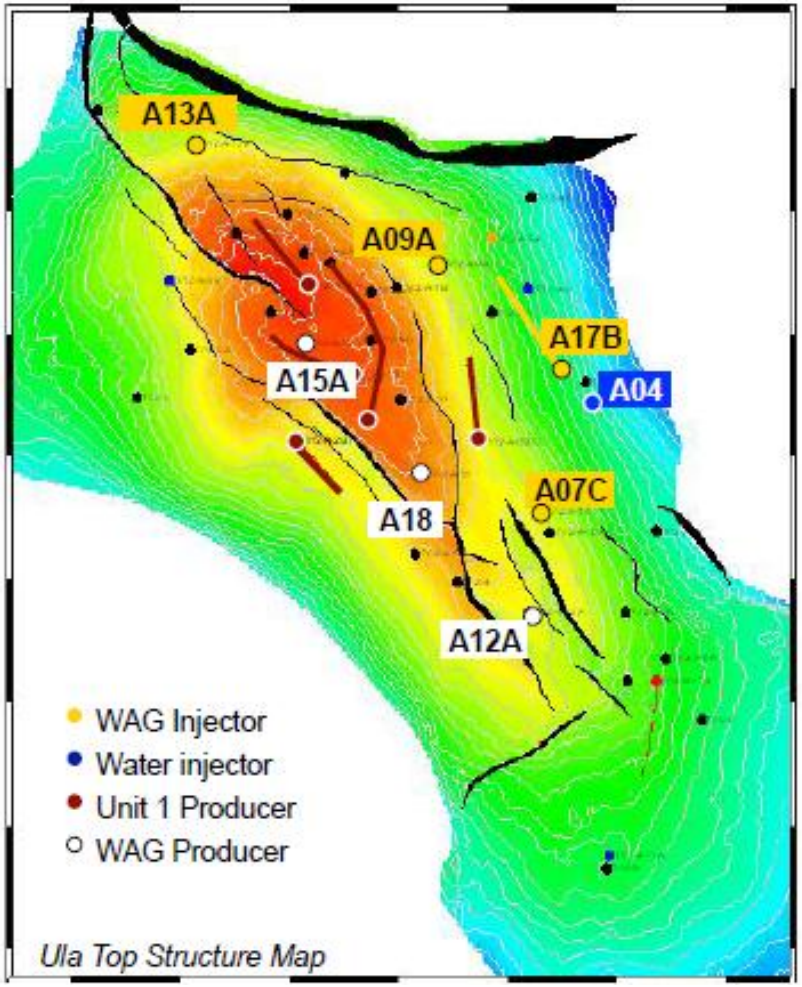




Ula behind flood front pilot



- New WAG compressor installed
- 2 WAG injectors in 1999 to 4 in 2005
- Increased gas capacity & further WAG wells in 2009

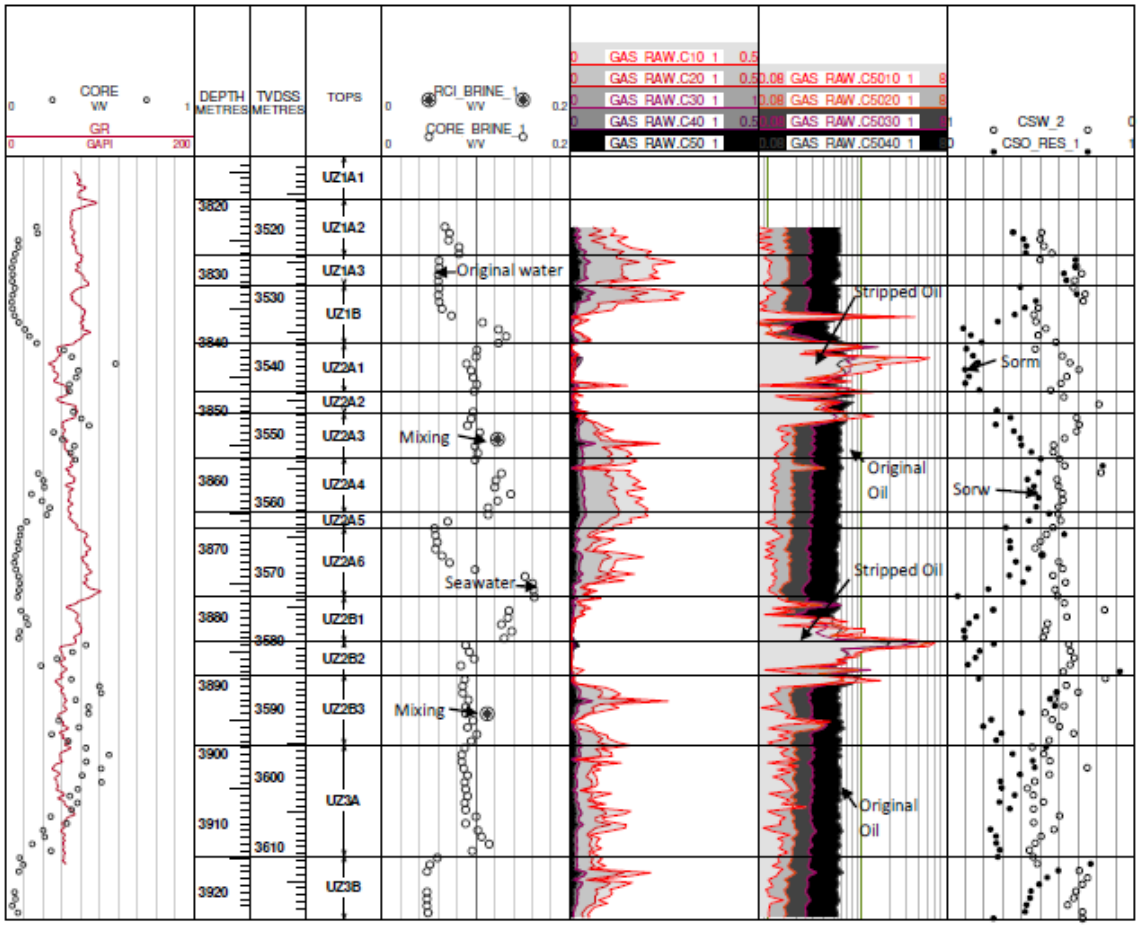


Surveillance Data – behind flood front pilot

1998 Miller AGR

Ula WAG

2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020



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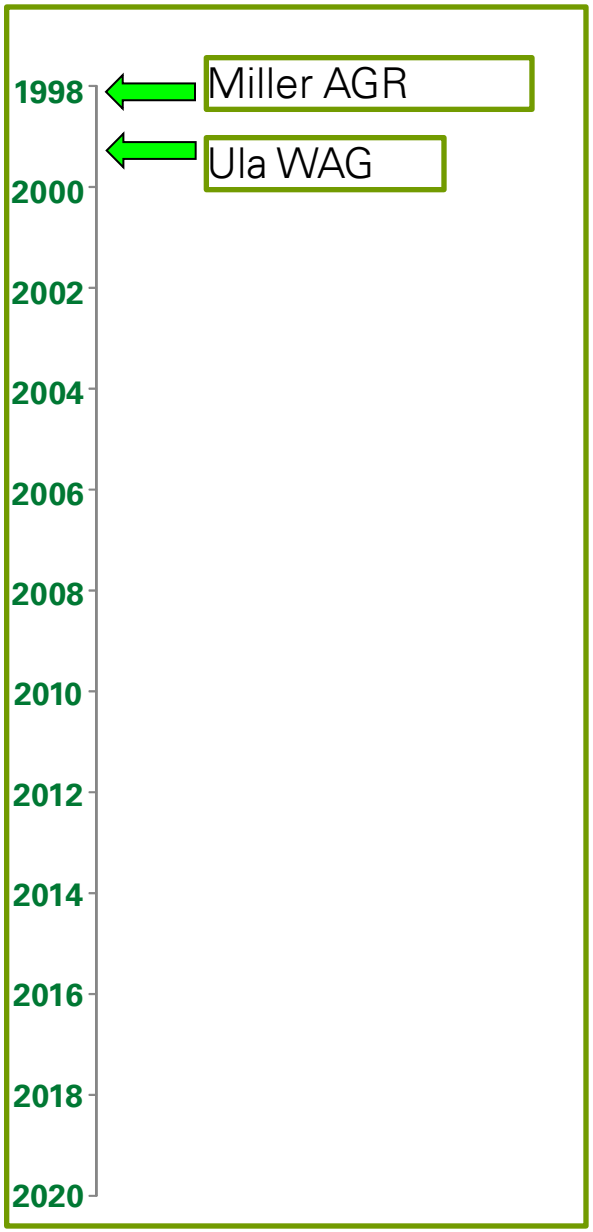
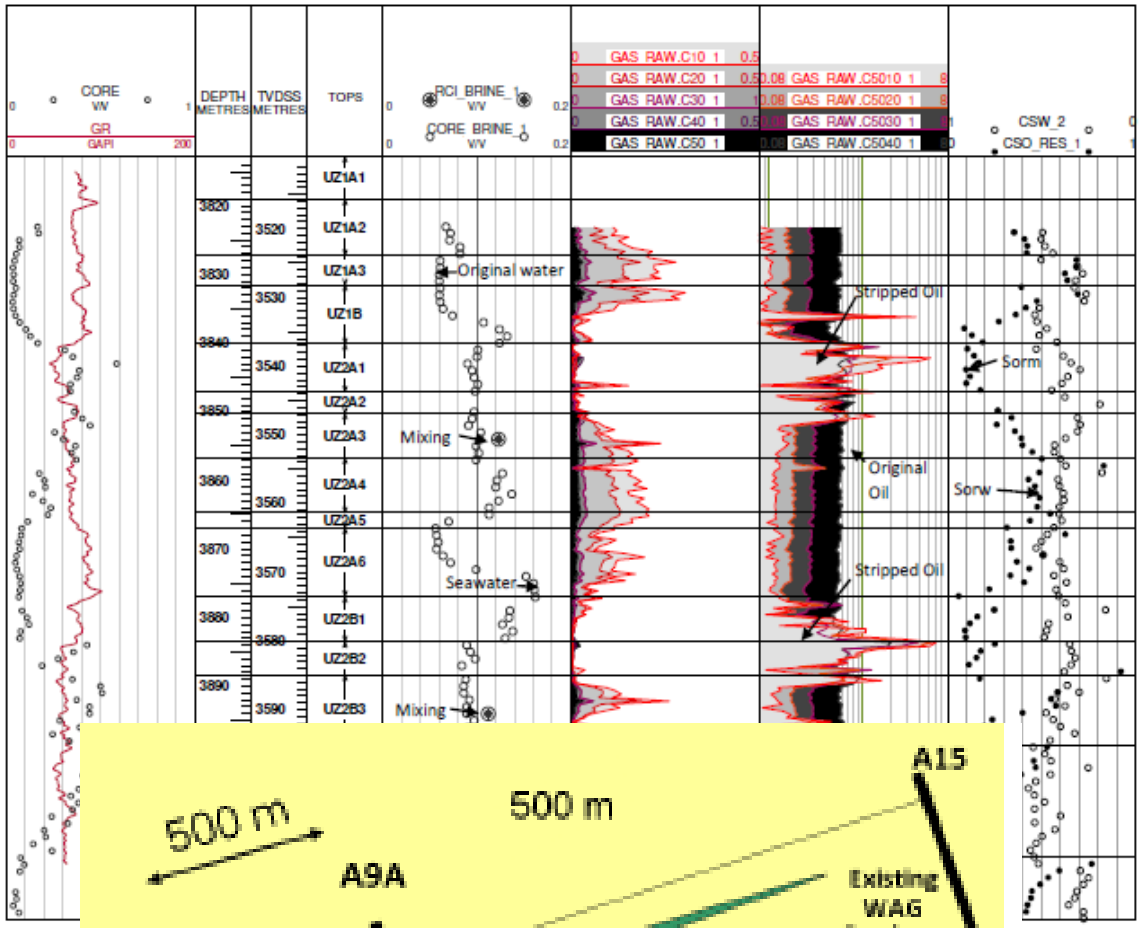
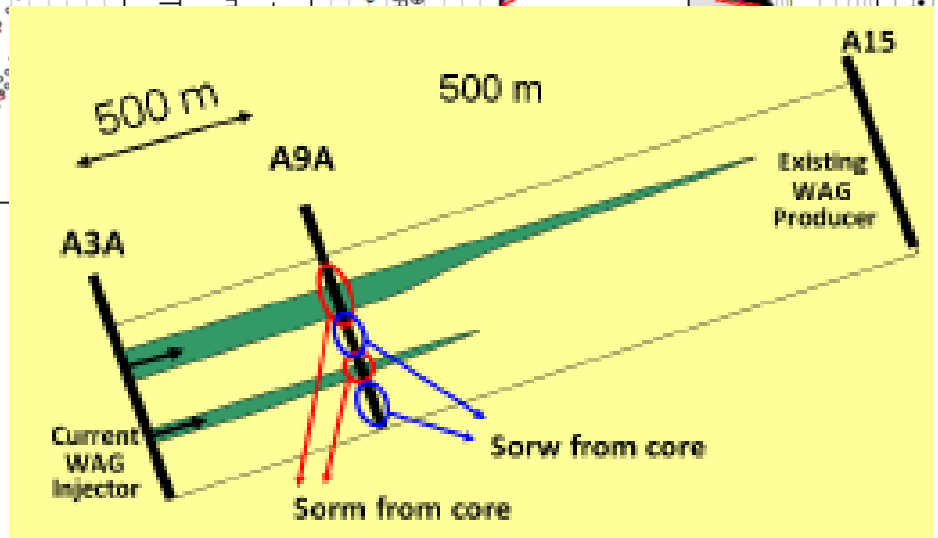






Ula future

1998 ← Miller AGR

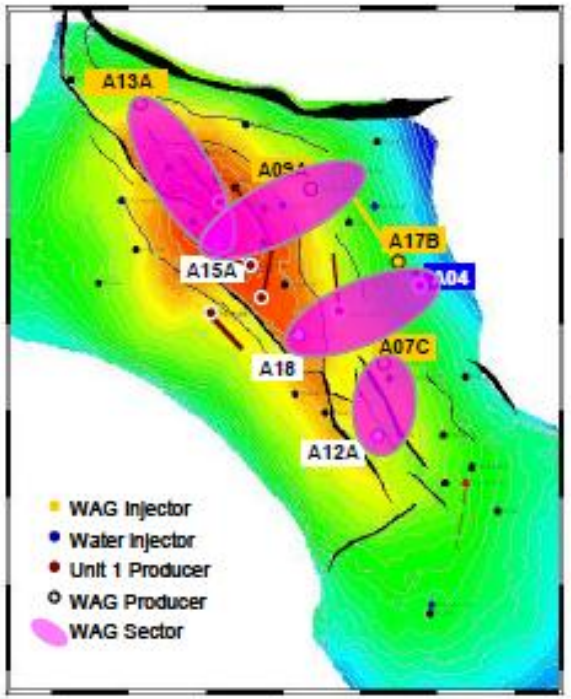
1998 ← Ula WAG

2010 ← Blane gas & more wells

2012 ← Oselvar gas & more wells

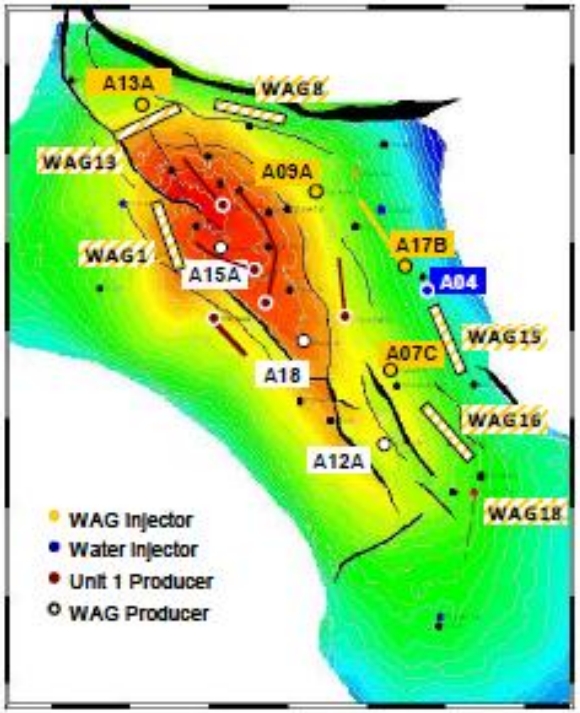
2018 ← Expanded WAG

2000 2002 2004 2006 2008 2014 2016 2020

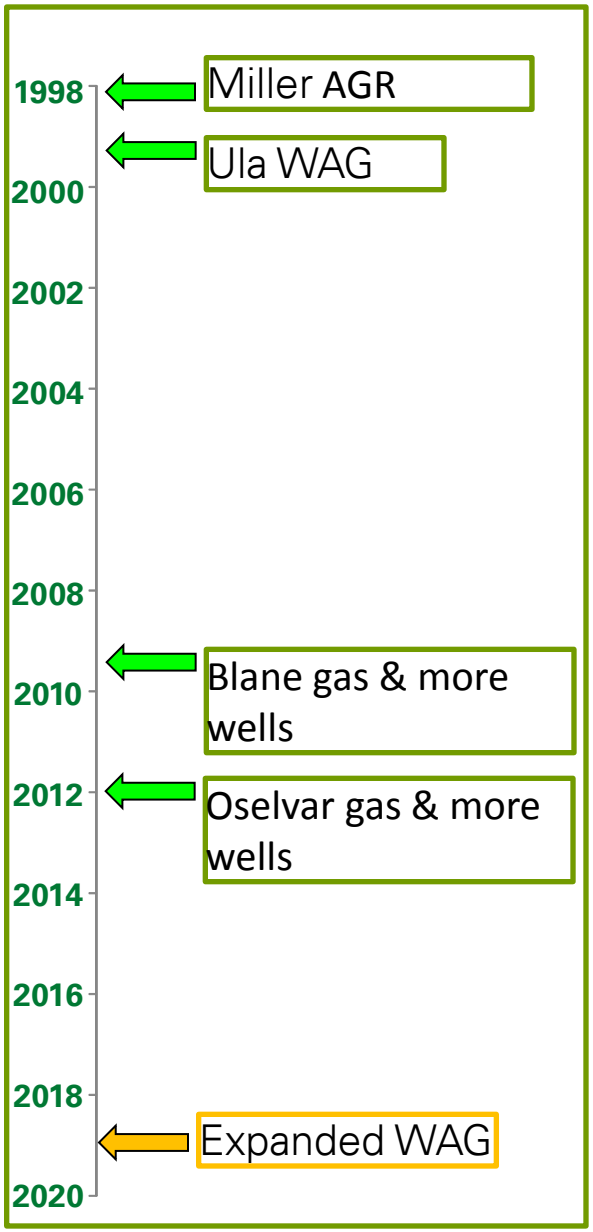


Current WAG

Expanded WAG



Ula WAG Scheme



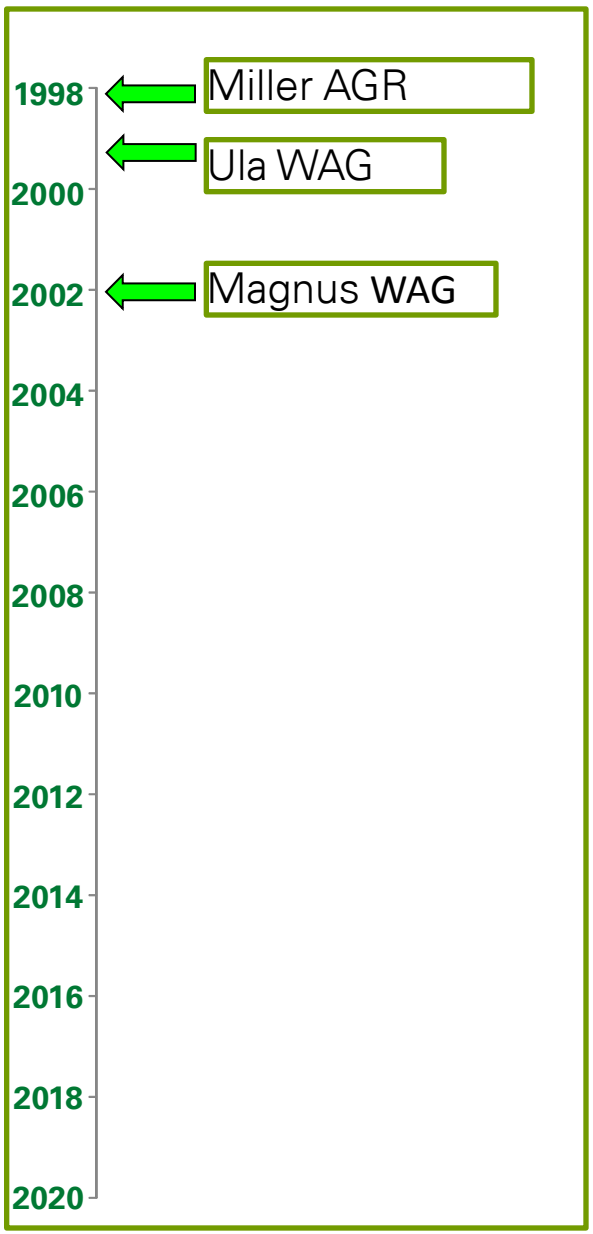
Critical Enablers

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

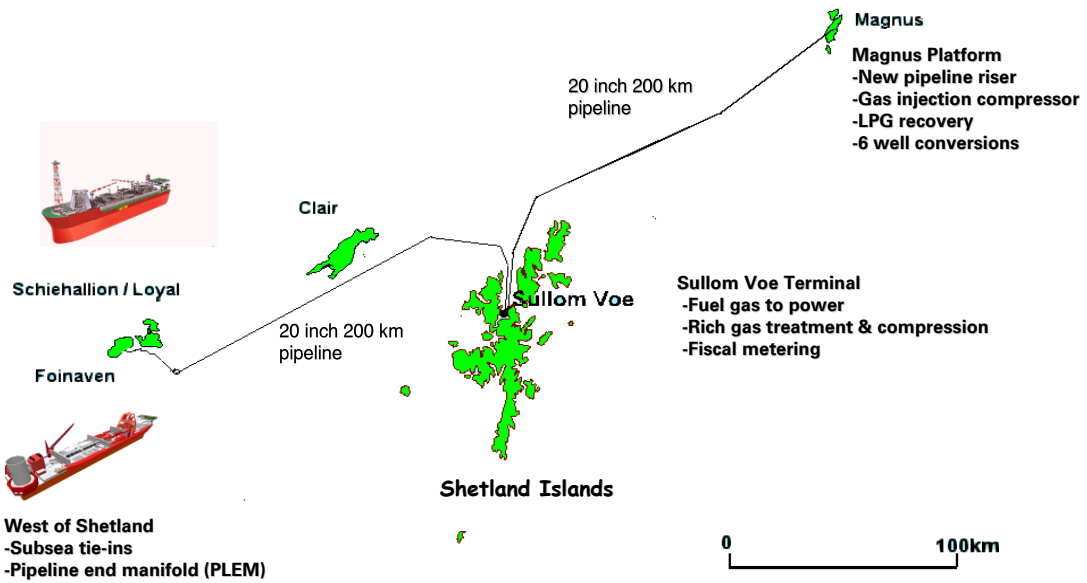
Lessons Learned:

- Gas injector integrity
- Timing WAG bank is difficult – Needed surveillance to understand

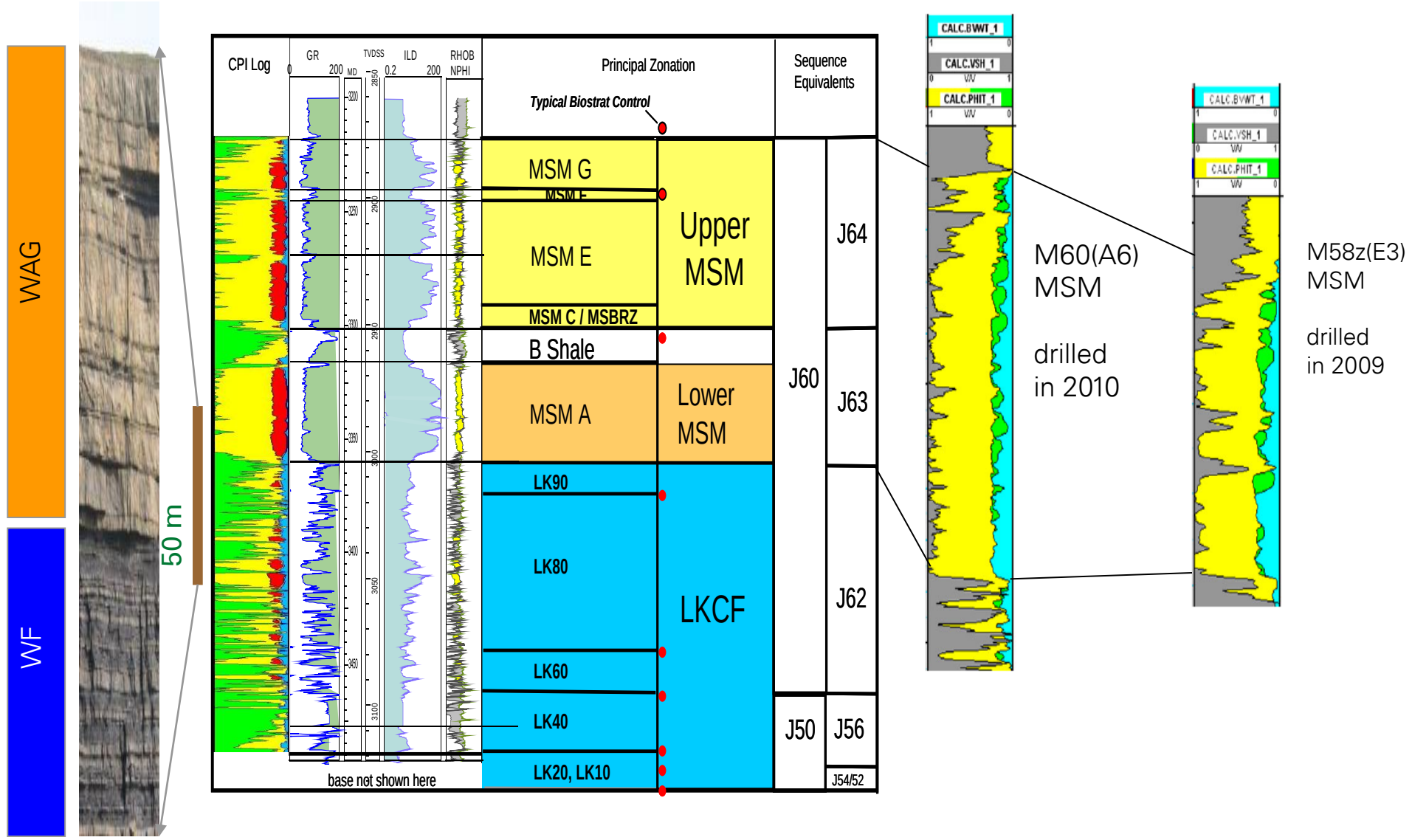
Magnus WAG Scheme



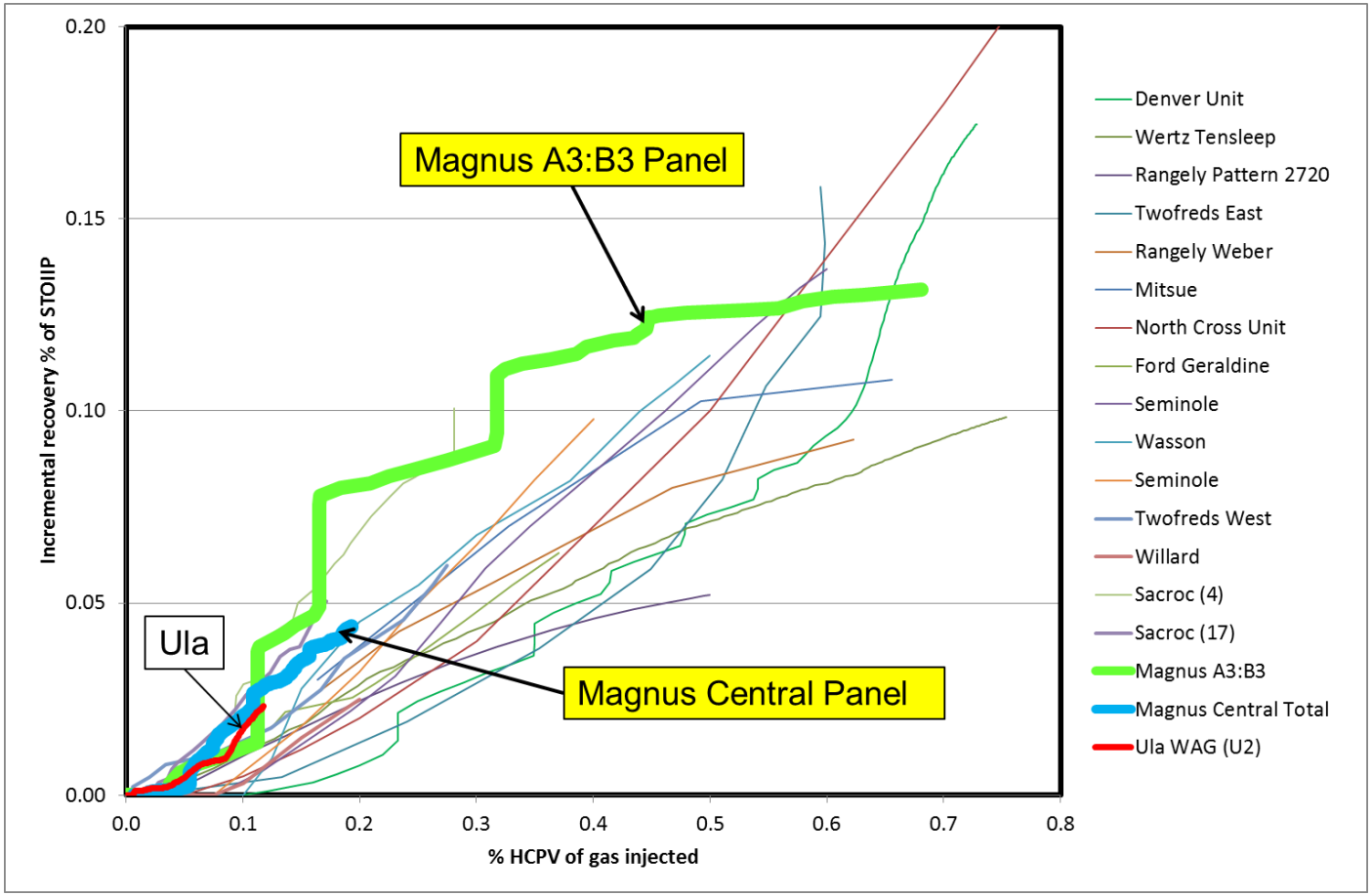
- New WAG compressor installed
- Gas import from stranded West of Shetland gas



Magnus Understanding the WAG target

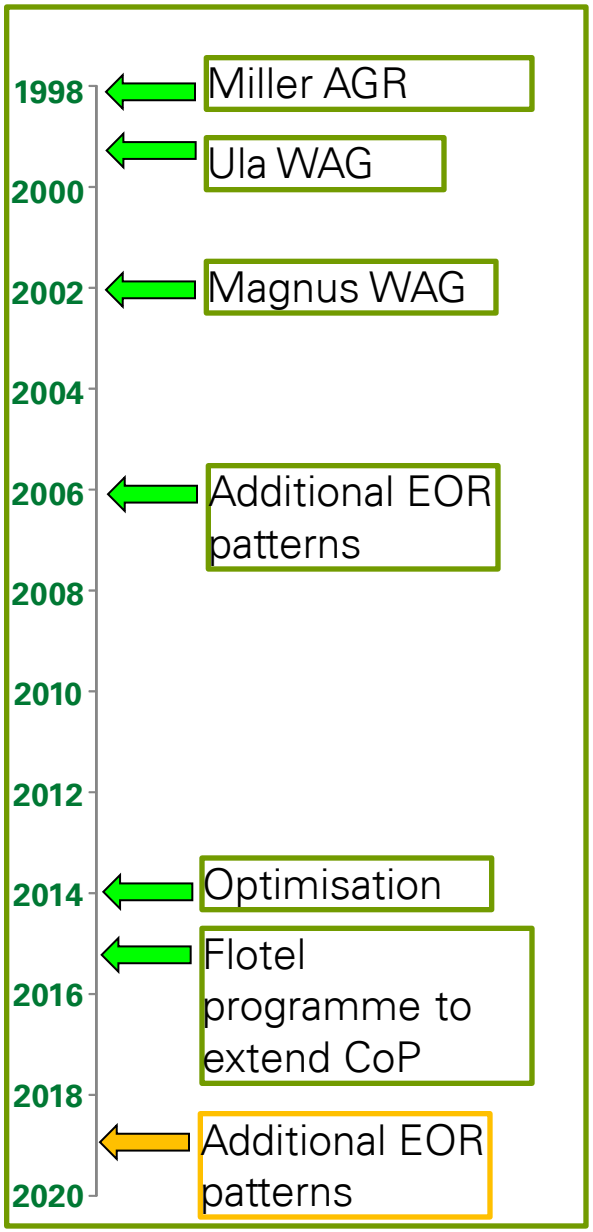


WAG Benchmarking with Industry Data



- 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

Magnus WAG

1998 ← Miller AGR

1998 ← Ula WAG

2002 ← Magnus WAG

2006 ← Additional EOR patterns

2014 ← Optimisation

2016 ← Flotel programme to extend CoP

2020 ← Additional EOR patterns

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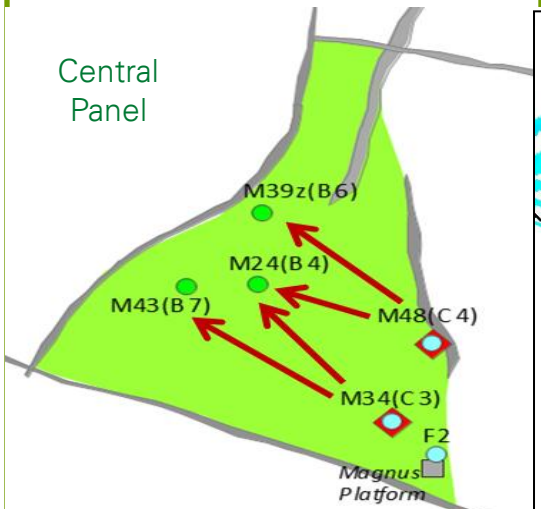
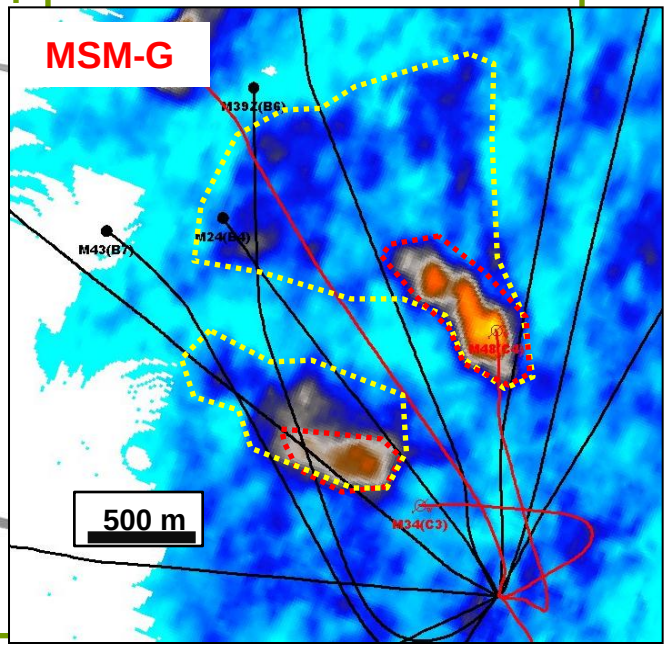
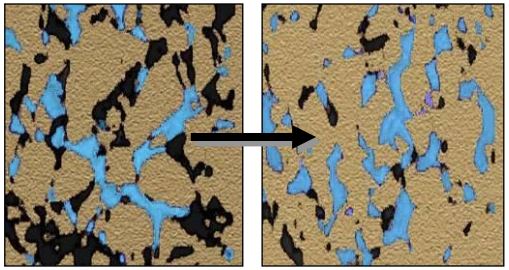
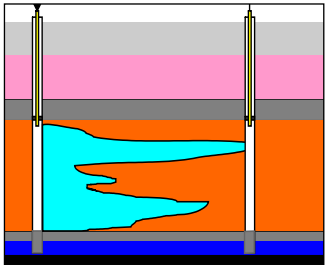
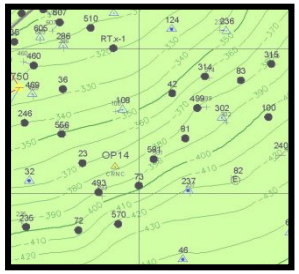




Lessons learned from four EOR projects

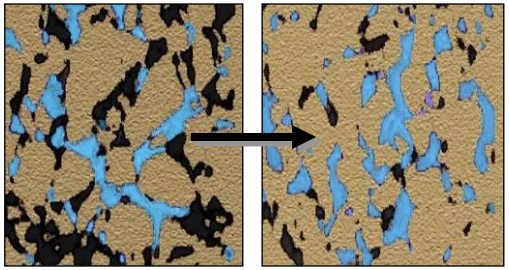
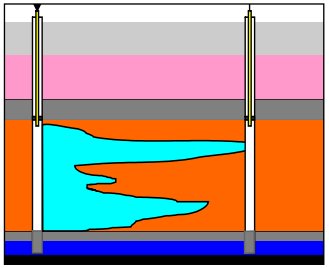
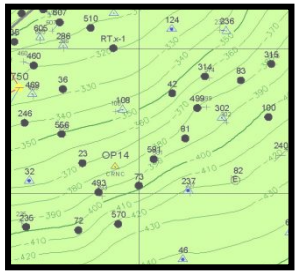

Recovery Factor = **Pore scale displacement** x **Sweep** x **Drainage** x **Cut - offs**

CONFIDENCE

Subsurface Delivery of EOR

Subsurface Workflow knowledge
Surveillance: Seismic, Sorm & Sorw etc

Lessons learned from four EOR projects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CONFIDENCE

Subsurface Delivery of EOR

Subsurface Workflow knowledge
Surveillance: Seismic, Sorm & Sorw etc

Practical EOR Delivery

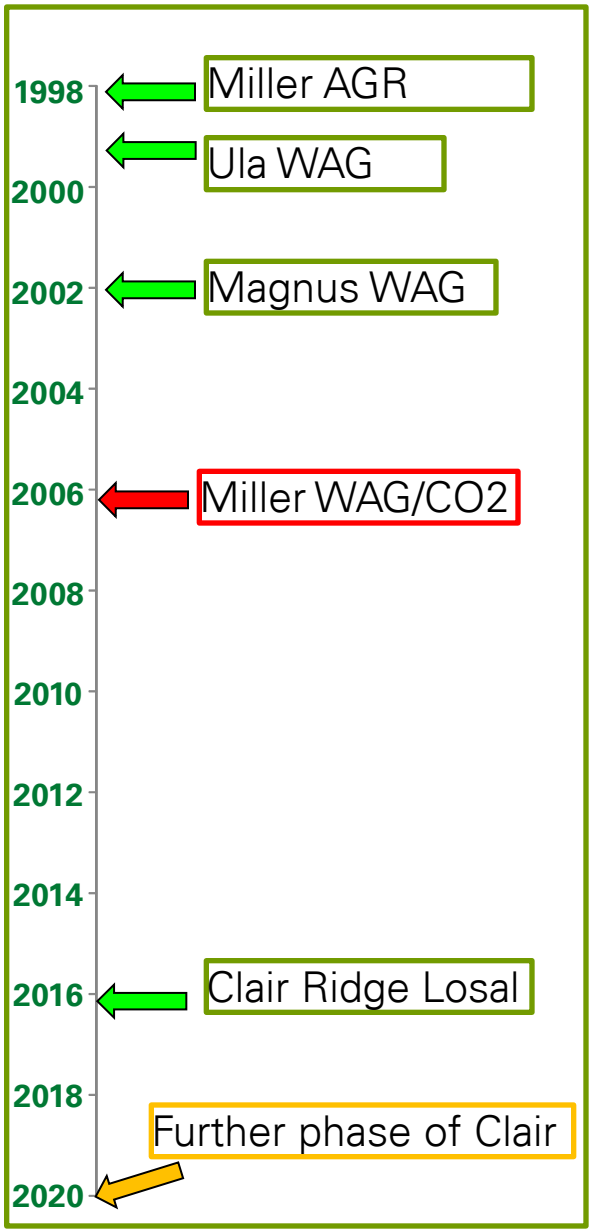
Well integrity

- Injectant supply
- Understanding changes to plant process critical
- Fiscal Relief

- Multiple phases of EOR

Future Projects

Clair Ridge *LoSal* ® EOR

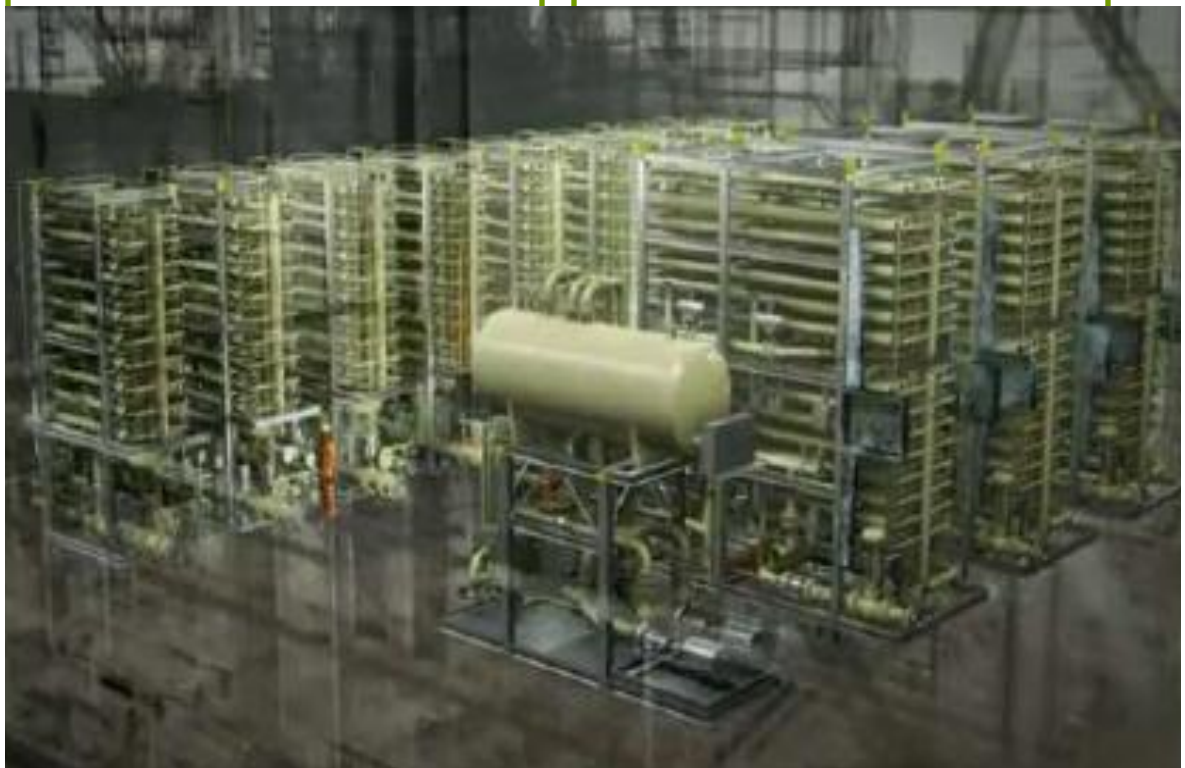


Critical Enablers

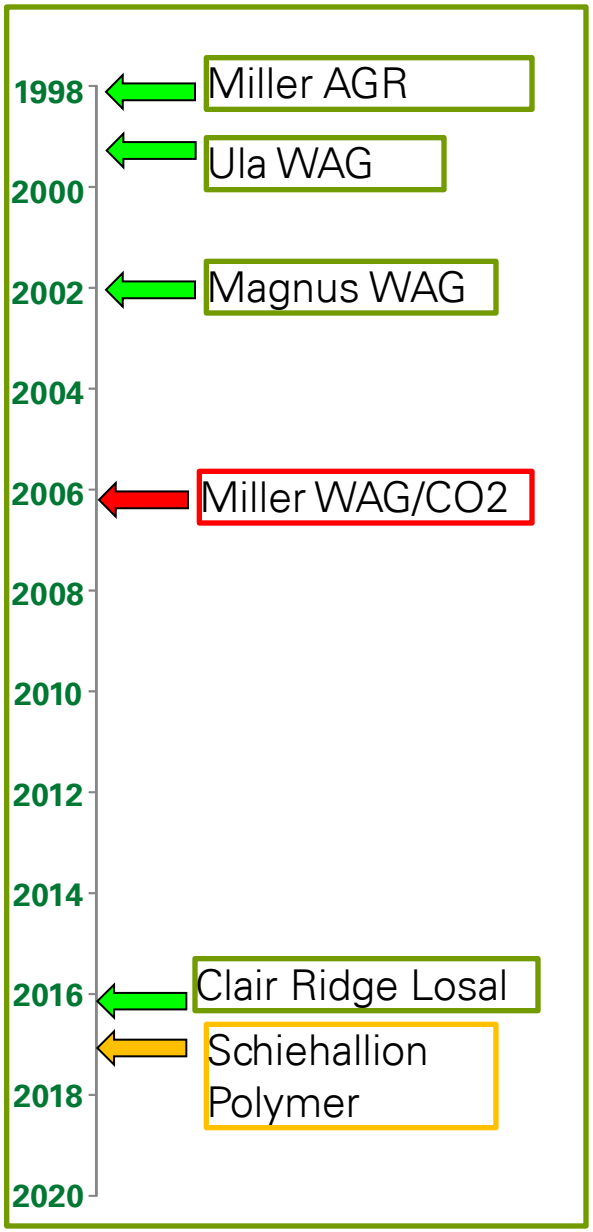
- BP Alaska *LoSal®* EOR experience
- Big STOIIP
- Other benefits (scale & H2S)

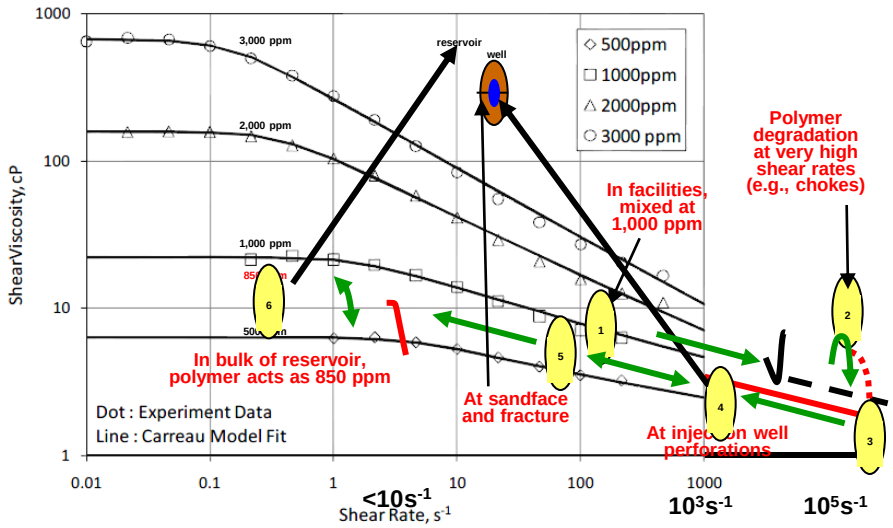
Lessons Learned:

- Align partnership
- Need big development for standalone *LoSal®* EOR … *collaboration?*



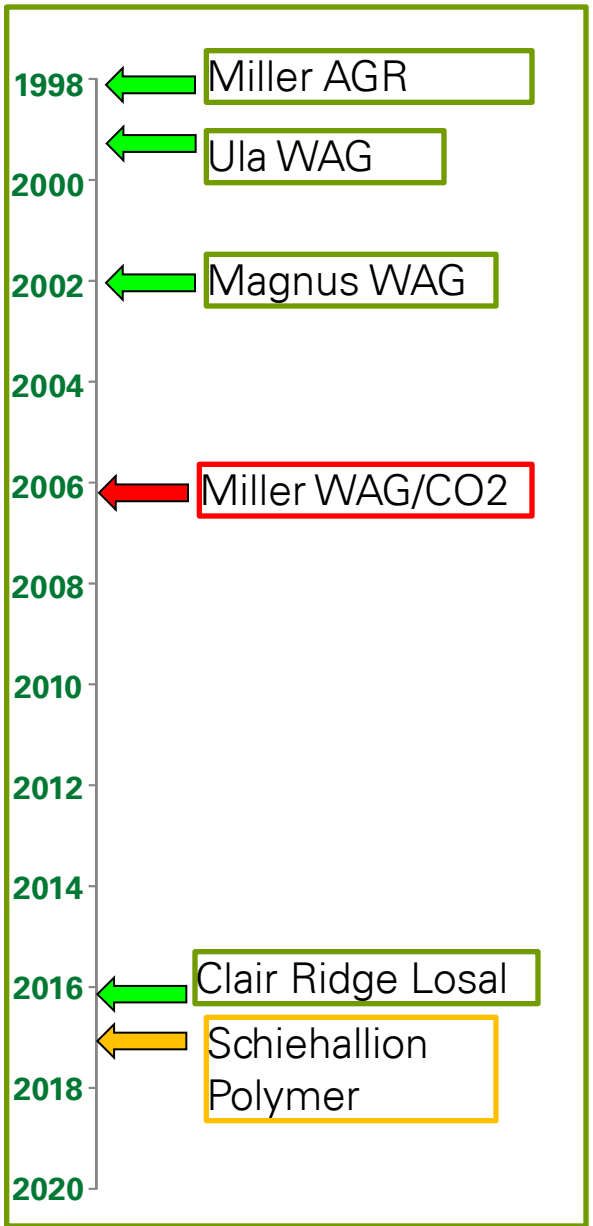
Schiehallion Polymer

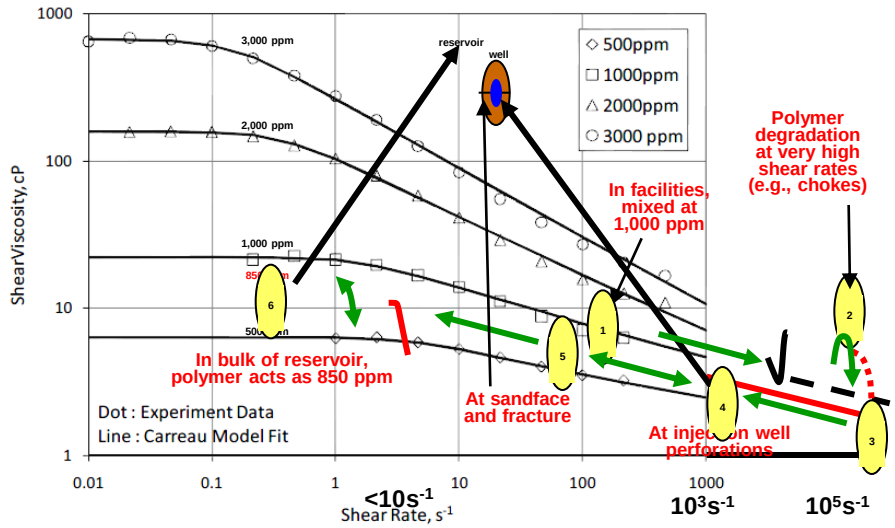




Effect of polymer concentration on shear viscosity (3630S in 1% NaCl at 25 °C).

Schiehallion Polymer





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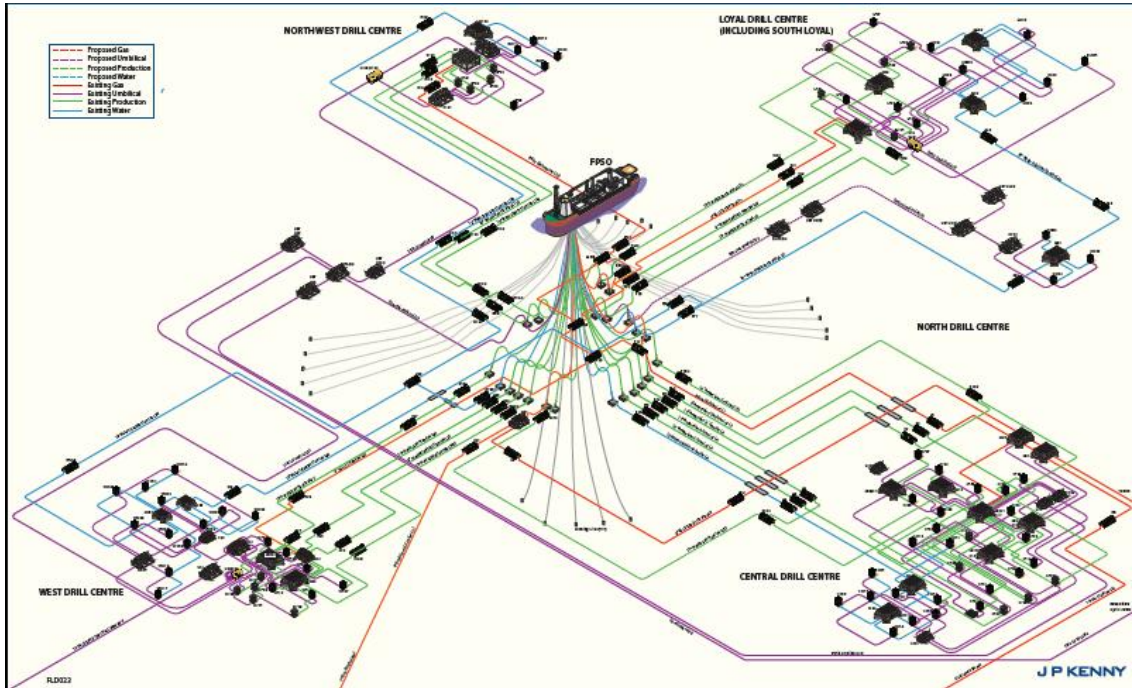
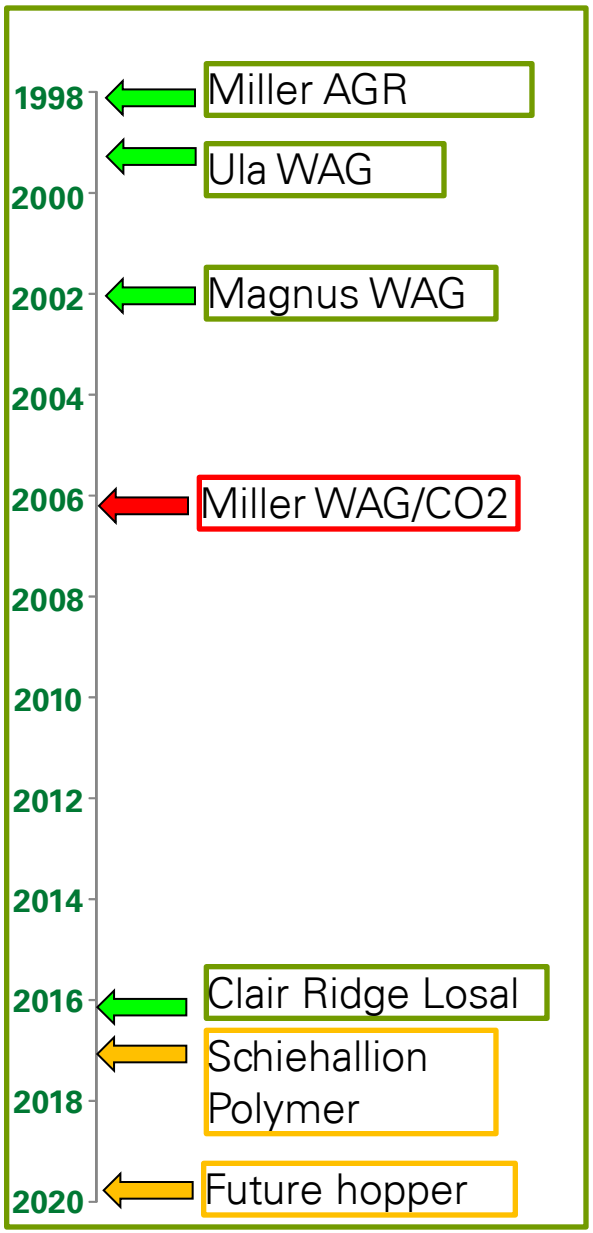


Schiehallion polymer lessons



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

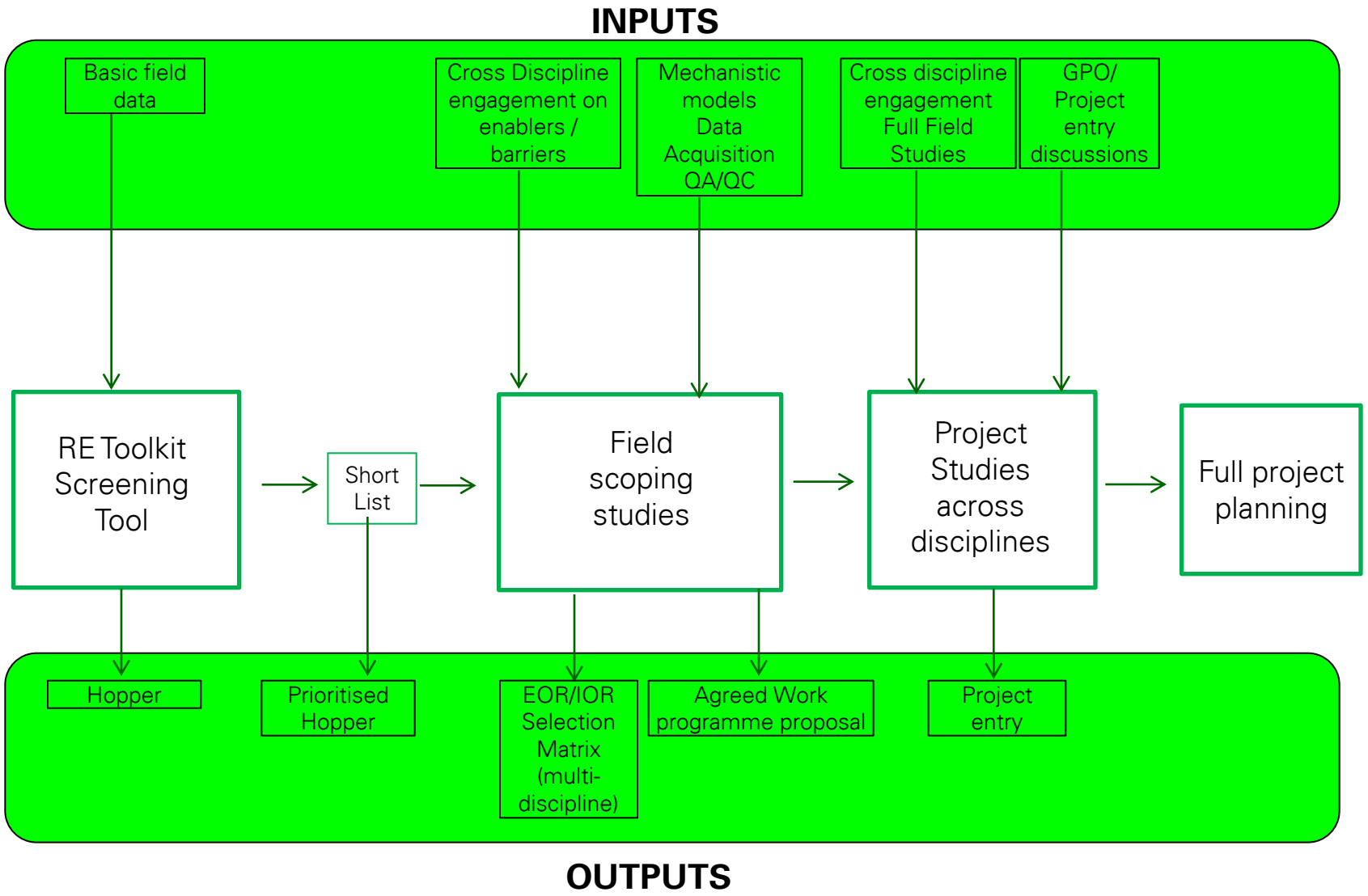
So, what are we doing now?

Brackish water or losal

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



High level screening

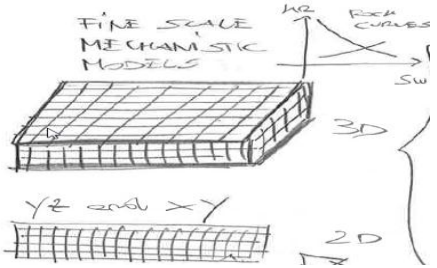
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10	Field 11	Field 12	Field 13	Field 14	Field 15
N2/Flue	R	R	R	Y	Y	Y	R	R	R	R	R	R	Y	R	R
H/C Miscible	R	G	R	G	G	G	G	Y	R	R	R	R	G	G	R
CO2 Miscible	R	G	R	G	G	G	G	Y	R	R	Y	Y	G	G	R
Immiscible	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Waterflood	G	G	G	R	G	Y	G	G	Y	Y	G	G	G	G	G
LoSal	G	G	Y	R	G	R	Y	G	Y	Y	G	G	G	G	G
Brightwater	G	G	R	R	G	R	R	G	Y	Y	G	G	G	G	G
Alkaline (Caustic)	Y	R	R	R	R	R	R	R	G	G	G	G	Y	R	Y
Surfactant	Y	R	R	R	R	R	R	R	Y	G	G	G	G	R	Y
Polymer	R	R	R	R	R	R	R	R	Y	G	G	G	Y	R	R
Alkaline-Surfactant	Y	R	R	R	R	R	R	R	Y	G	G	G	Y	R	Y
Alkaline-Polymer	R	R	R	R	R	R	R	R	Y	G	G	G	Y	R	R
Polymer-Surfactant	R	R	R	R	R	R	R	R	Y	G	G	G	Y	R	R
A-S-Polymer	R	R	R	R	R	R	R	R	Y	G	G	G	R	R	R
Viscous: CHOPS	Y	R	R	R	R	R	R	R	Y	Y	Y	Y	R	R	Y
Viscous: Air (Combustion)	G	R	Y	R	Y	R	R	Y	R	G	G	G	Y	Y	G
Viscous: Steam	Y	R	R	R	R	R	R	R	R	Y	R	R	R	R	R
Brine data	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N

Mid case barrels by field by option type

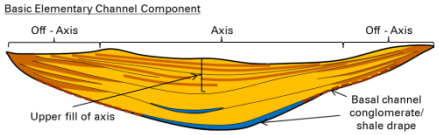
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Field 9	Field 10	Field 11	Field 12	Field 13	Field 14	Field 15
N2/Flue															
H/C Miscible															
CO2 Miscible															
Immiscible															
Waterflood															
LoSal															
Brightwater															
Alkaline (Caustic)															
Surfactant															
Polymer															
Alkaline-Surfactant															
Alkaline-Polymer															
Polymer-Surfactant															
A-S-Polymer															
Viscous: CHOPS															
Viscous: Air (Combustion)															
Viscous: Steam															

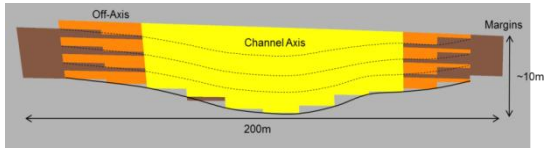
Standardise Modelling Workflow

1. Fine Scale Mechanistic model with rock curves



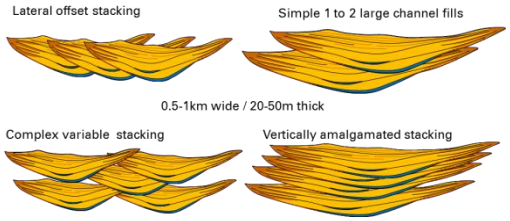
2. Fine Scale Geological element model with rock curves

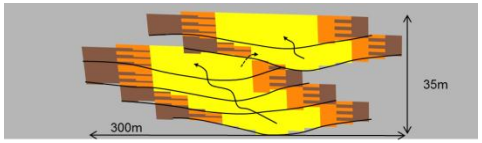




Upscale rel perms if neccessary

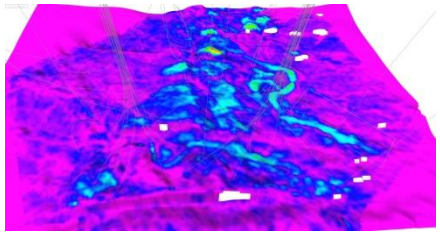
3. Fine Scale Depositional system Geological model with upscaled to pseudos

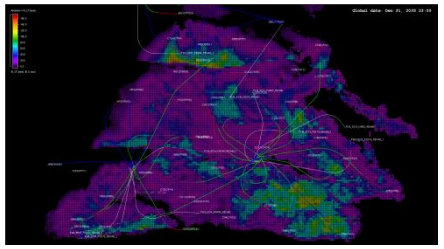




Upscale rel perms if neccessary

4. Full field model with areal pseudos & potentially EOR process pseudos





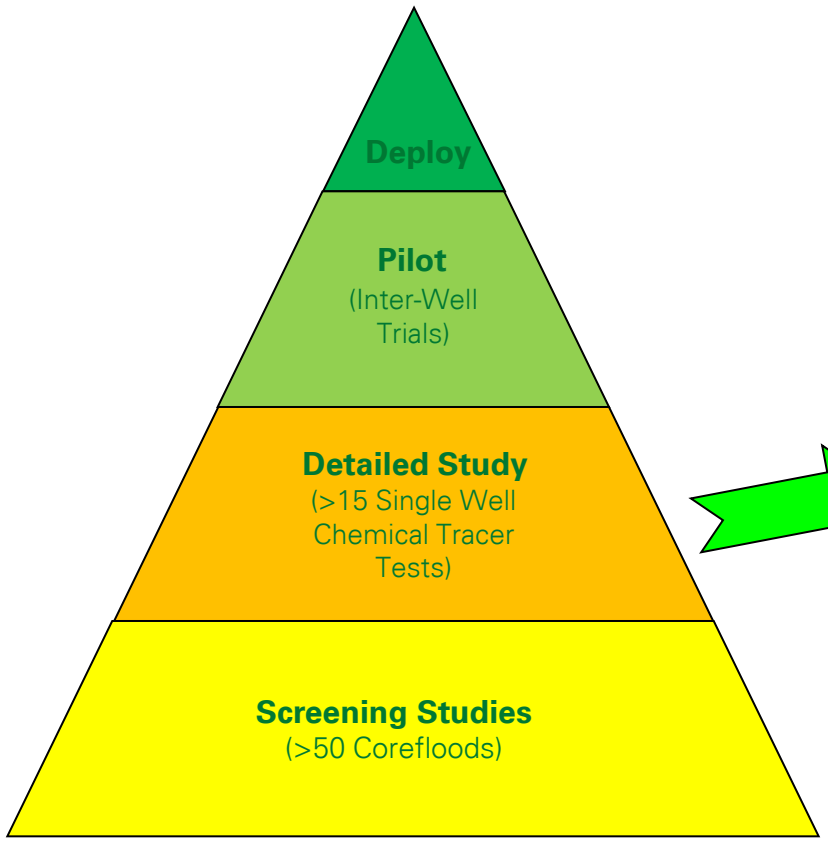
Screening Process: Summary of EOR project status

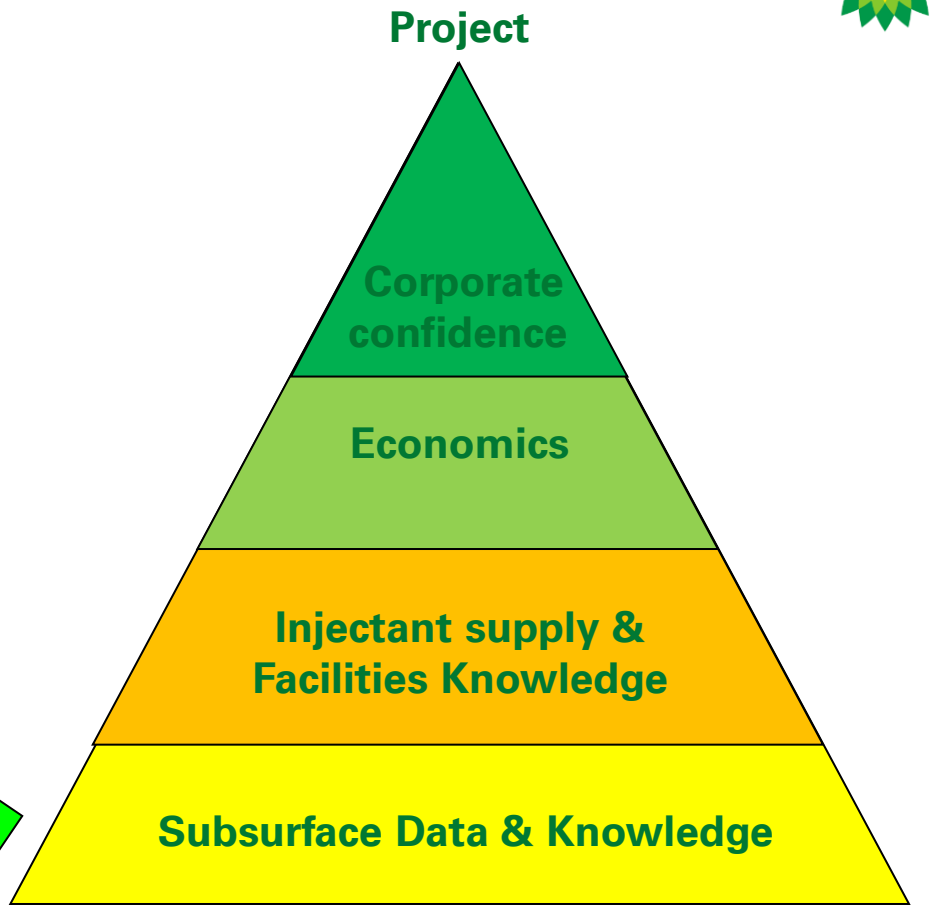
- Communication tools to understand status

Field	EOR Screening	SCAL	Production Forecast	Injectanat Supply	Facilities Design	Project Economics	Chance of Success	Comments
Field 1 EOR Optimsation								
Field 2 Polymer								
Field 2 Optimisation								
Field 3 Polymer								
Field 4 EOR						?		
Field 5 *Losal*								
Field 6 Hisal						?		
Field 7 EOR optimisation								
Field 8 Hisal						?		
Field 5 upsides						?		

Green	Complete	Complete	Complete	Complete	Good NPV	>50%
Yellow	In Progress	In Progress	In Progress	In Progress	Marginal	10-50%
Red	Not Started	Not Started	Not Started	Not Started	Negative NPV	<10%

Building Confidence : Pyramid of proof





…. PLANNING INTEGRATION

EOR challenges & possible solutions

Key Success Factors	Challenges	Solutions

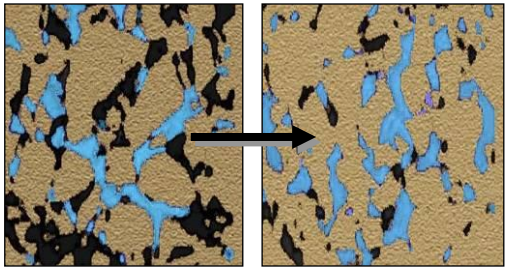
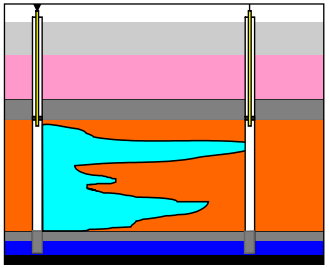
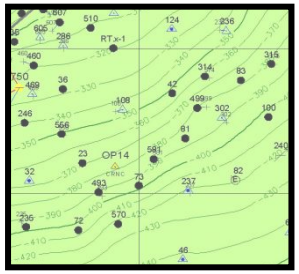
Low Cost Injectant	• Source
	• Cost of supply or purchase
		• Engage with CCSA to develop CO_2 EOR / CCS strategy.
		• Collaboration
		  • supply chain
		  • shared facilities (eg ITF call)

Subsurface Understanding	• Awareness of EOR. • Understanding mechanisms • Confidence	• DECC PILOT (screening, workshops, coreflood planning) • "Pyramid of Proof".
Facilities	• Lack of space / weight	• ITF: Low Salinity facilities for brownfields. • Include capacity for EOR within BoD's for new developments (FDP consent).
Economics	• "High" front-end & increased OPEX costs.. • Time to CoP. • Pace!!	• "Clusters" formed for knowledge/cost sharing • EOR hopper awareness. • Potential for fiscal relief.

pilot the right course for oil and gas success

Department of Energy & Climate Change

Lessons learned from four EOR projects


Recovery Factor = **Pore scale displacement** x **Sweep** x **Drainage** x **Cut - offs**

CONFIDENCE

Subsurface Delivery of EOR

Subsurface Workflow knowledge
Surveillance: Seismic, Sorm & Sorw etc

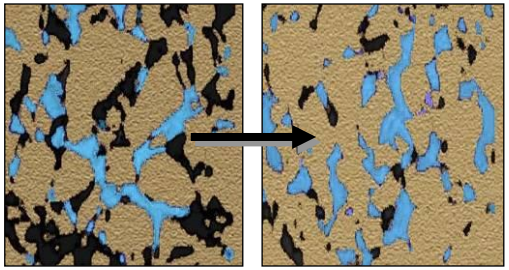
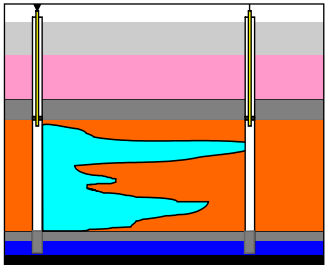
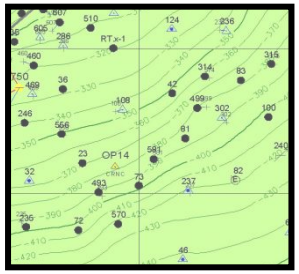
Practical EOR Delivery

Well integrity

- Injectant supply
- Understanding changes to plant process critical
- Fiscal Relief

- Multiple phases of EOR

Lessons learned from BP EOR projects


Recovery Factor = **Pore scale displacement** x **Sweep** x **Drainage** x **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

- Injectant supply
- Understanding changes to plant process critical
- Fiscal Relief

- Multiple phases of EOR

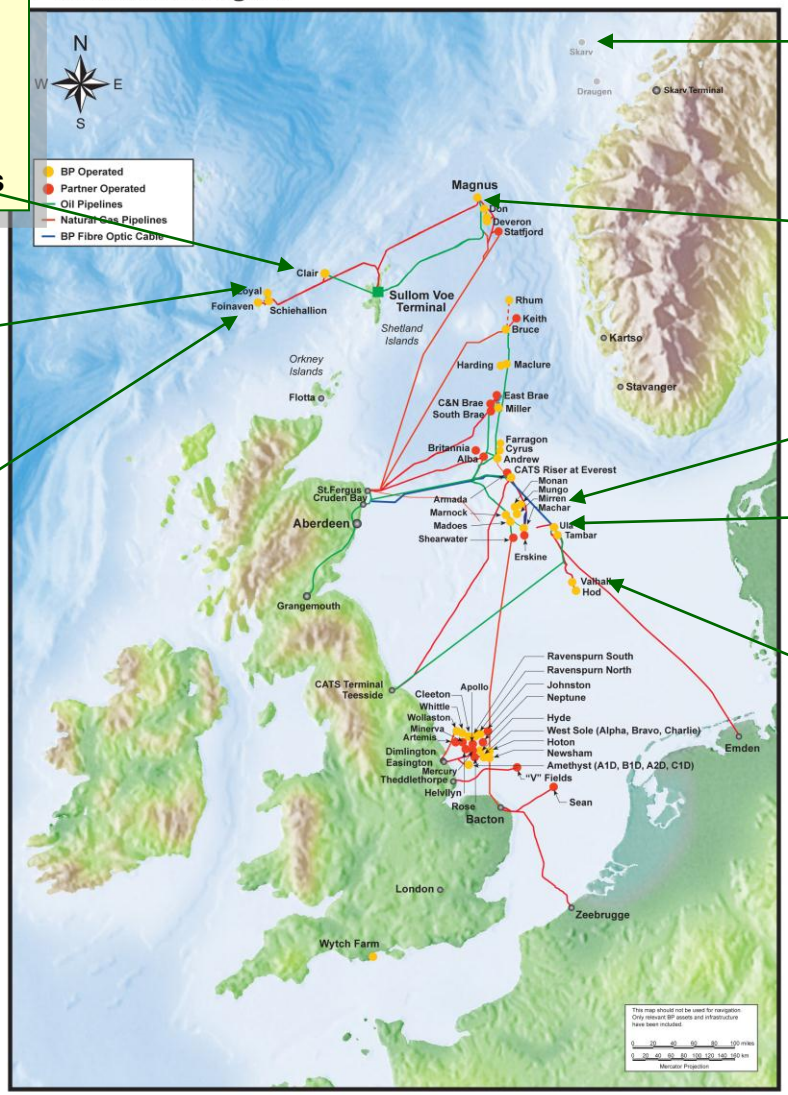
BP EOR Focus Areas in North Sea
Field locations with current & future projects

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?

BP North Sea Region



May 2011, SIS 112928530

Skarv
Crestal gas Injection
Started-up 2013

Magnus
WAG since 2002
Optimisation

ETAP
Potential for water IOR

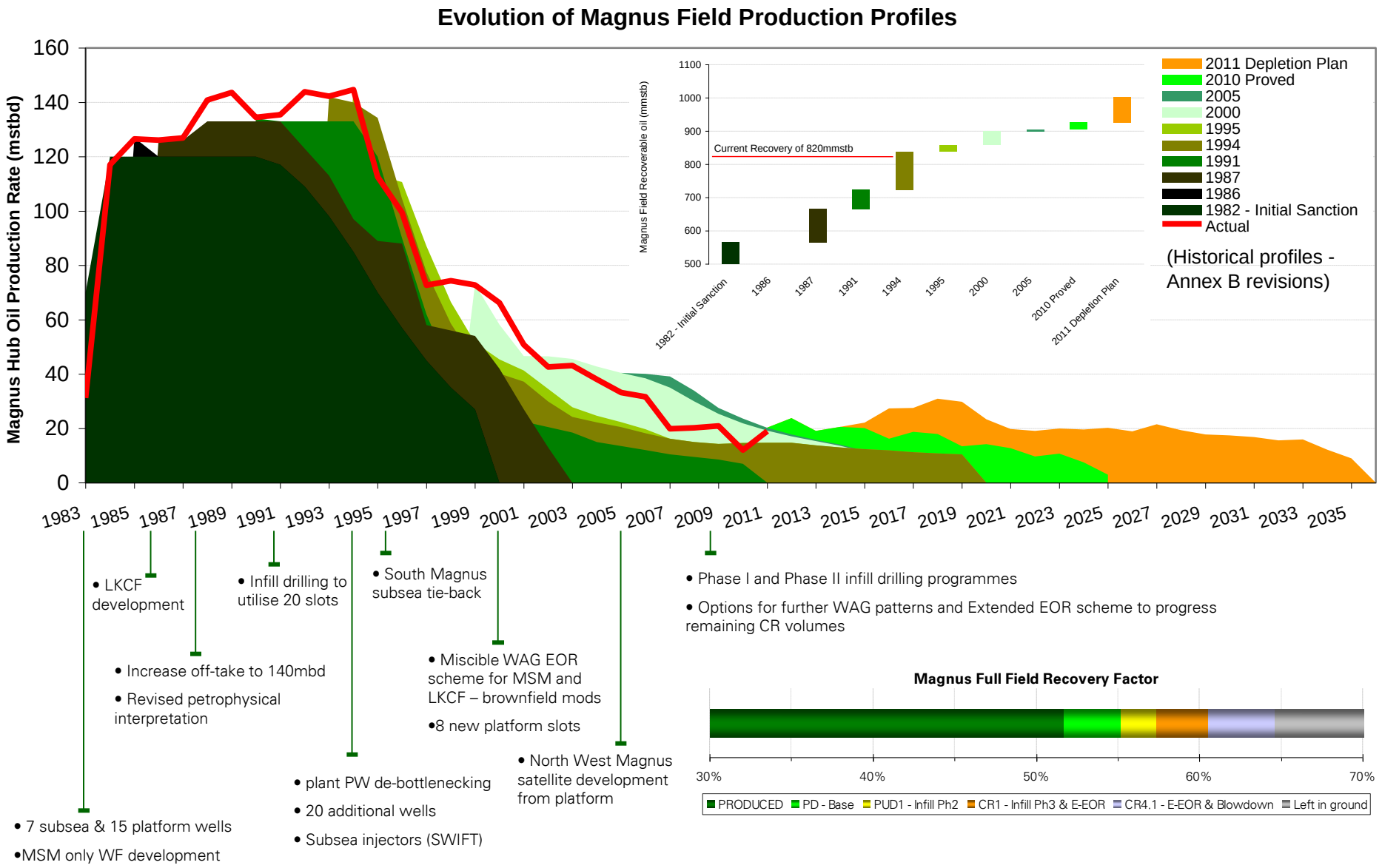
Ula
WAG since 1999
Large upside potential

Valhall
Sulphate injection research

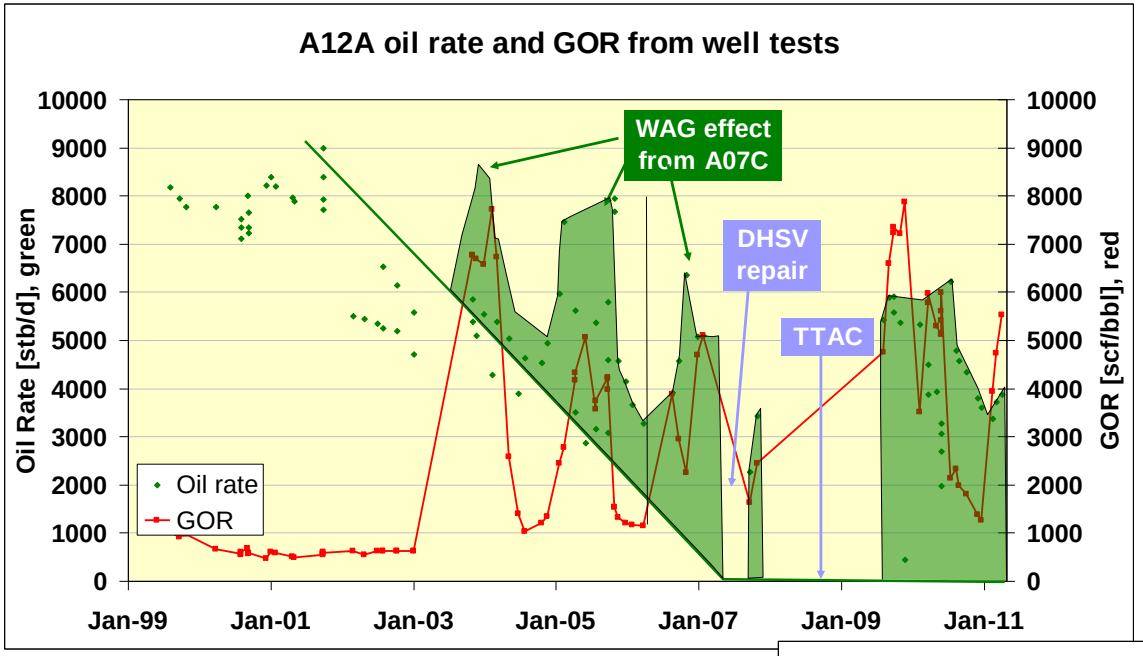
LoSal® is a registered trademark of BP plc

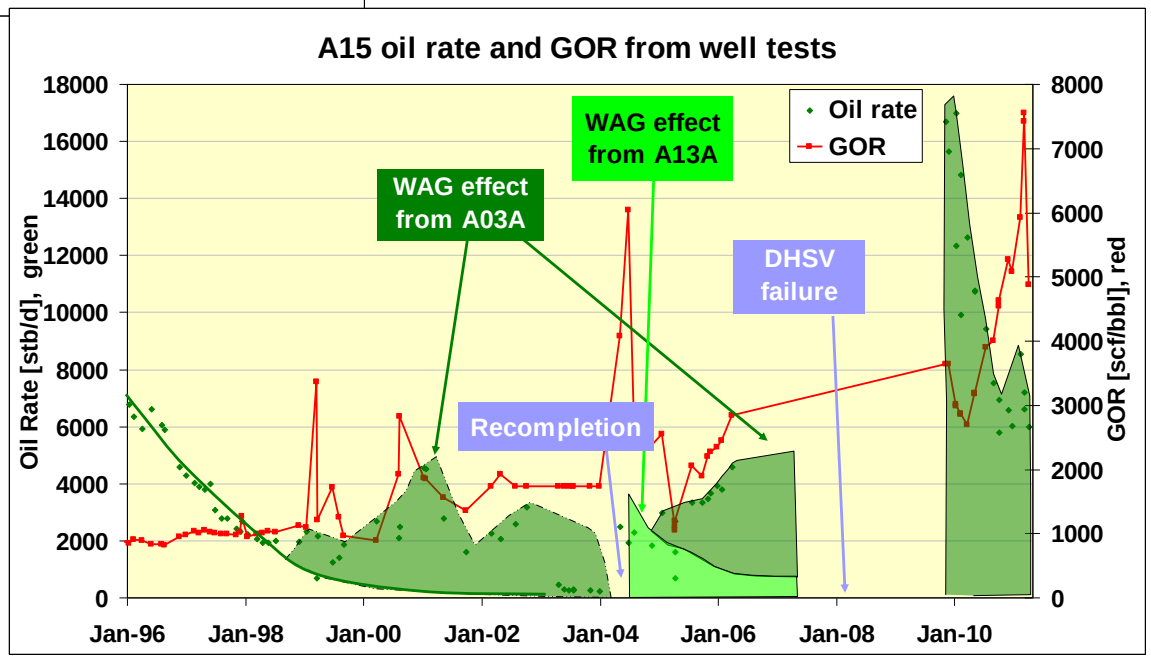
End

Summary: Magnus Development phases



Ula WAG Increment





Schiehallion Q204 Polymer

Separation flow loop – Opus Plus