Shell's EOR Journey: Experiences past to present

ANP Workshop
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Outline

- Shell's EOR Journey
- Maximising economic recovery
- EOR challenges and enablers
- Onshore to offshore
- Offshore CO_2 EOR
- Conclusions

EOR journey - Learning by doing


Steam trials


Thermal EOR pilots


Full scale CO_2 floods.

Thermal growth.


CO_2/thermal optimisation.

Gasification.


Low-salinity water flood.
Smart surveillance.
Unconventional heavy oil.
Innovative solvents.
Offshore EOR.
CO_2 solutions


Steam injection, Peace River Canada.

Miscible gas floods, Oman.

1930 | 1940 | 1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010 | 2016+


Gas injection.

Oil saturation measurement.


1st commercial steam drive.

First successful CO_2 field test.


Permian CO_2 boom.

Chemical trials.

Sour gas injn, Oman


Smart fields.

Oil sands.

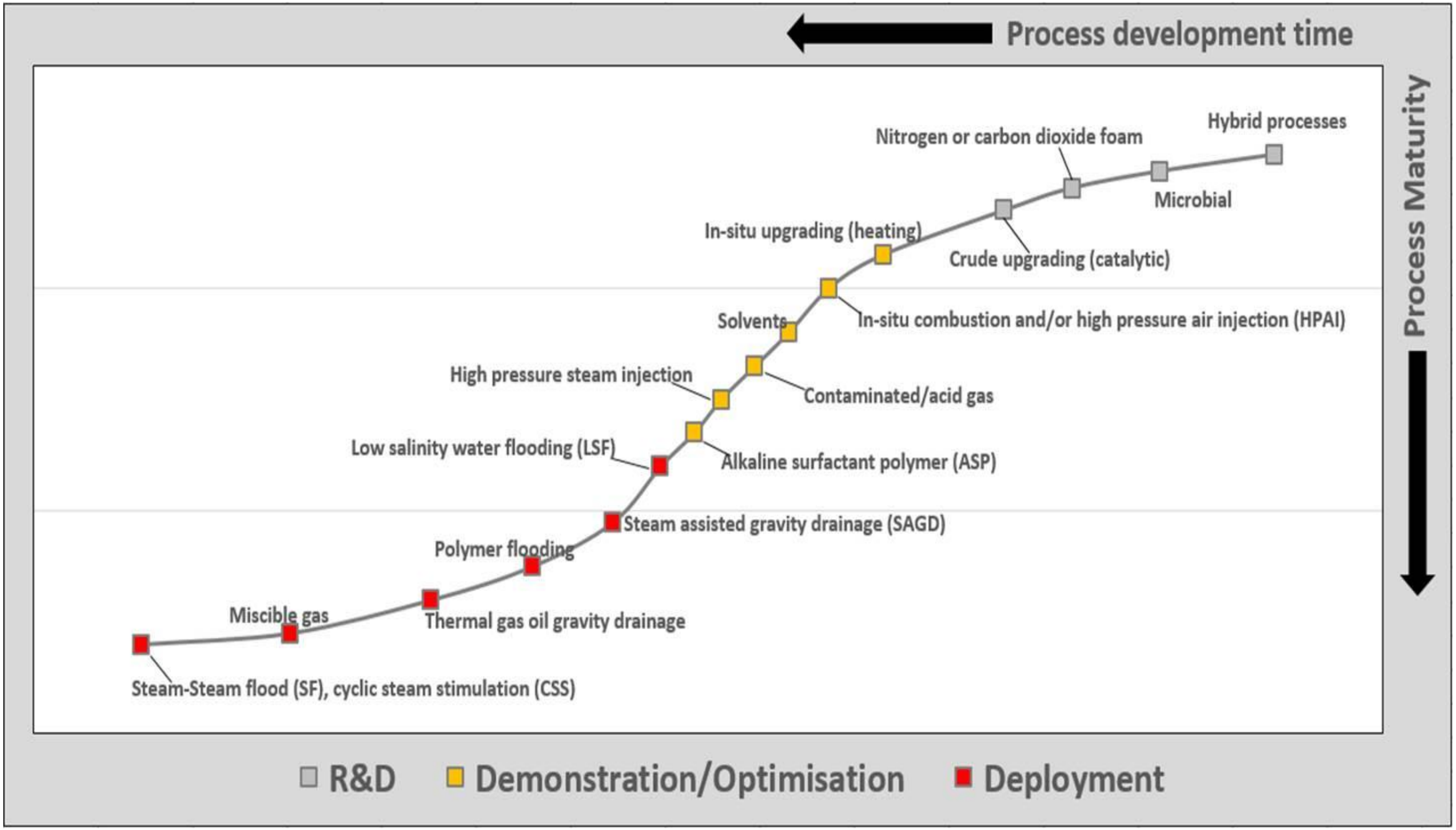

Polymer injection Oman

Steam Assisted Gravity Drainage in fractured carbonate, Oman.

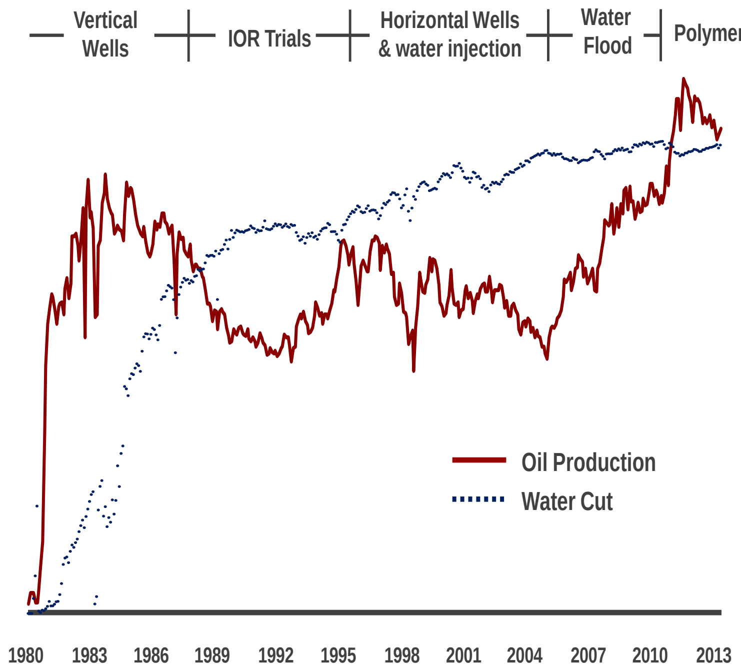

Solar steam, Oman

Re-development project, steam injection Schoonebeek, NL

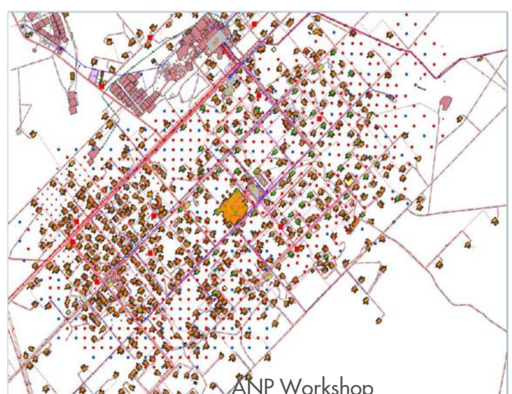
EOR - R&D to Deployment



Polymer flood – Marmul



- Heterogeneous clastic reservoir - 90 cp oil
- Large scale polymer flood on-stream 2010
  - 17,500 m^3/day (polymer)
  - Low salinity injection water (5000ppm TDS)
  - 27 patterns
- Oil Increase/Water cut reversal observed
  - Produced polymer can be handled
- Increase from 27 → 46 injectors since May 2015
- Urban planning, rotation schedule prepared for full field implementation



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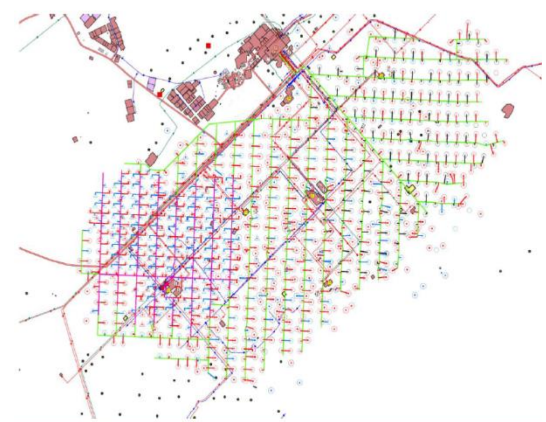

Steam Injection – Belridge and Aera

- Belridge Tulare core of Aera, STOIIP 1.6 bstb
  - Started production 1911, water drive reached watercuts above 90% before conversion to steam flooding
  - Large scale steam injection began 1982
  - Ongoing conversion of deeper reservoirs from waterflood to steamflood
  - Manages a stock of some 15000 wells at an average production rate of <10bopd.
  - In current environment Aera still able to make a profit

AME Manufacturing Excellence Award

Aera Energy LLC – Development Team

10000 Ming Ave. Bakersfield CA 93311

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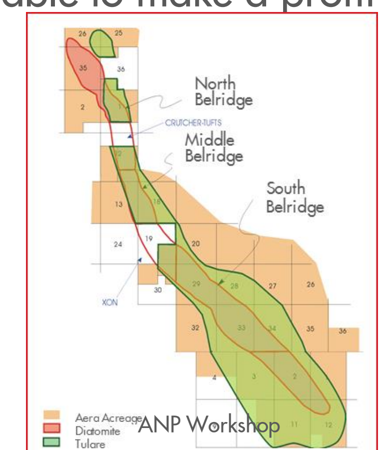

CO_2 EOR – Denver Unit

Largest CO_2 EOR project in the world, developed by Shell

- more than 400 MMscf/d sustained CO_2 injection in >100 patterns
- over 200 MMscf/d gas processing/recycling on site
- surveillance and management of CO_2 EOR

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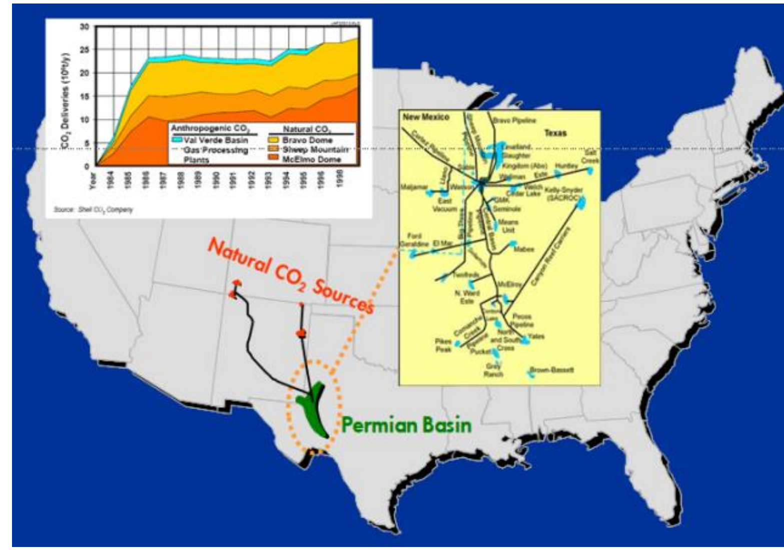
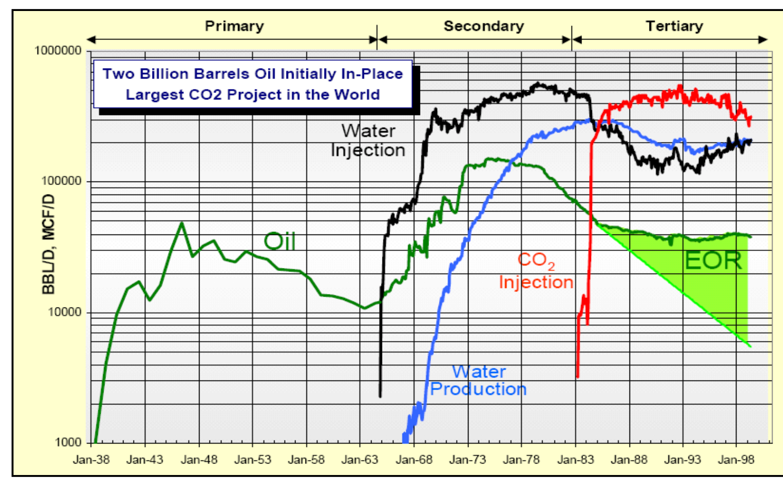
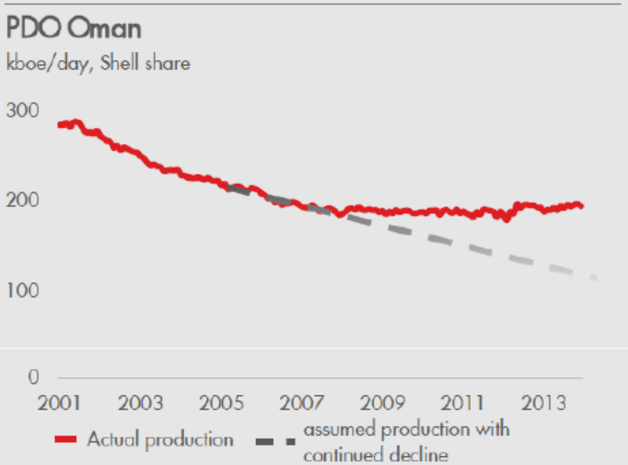
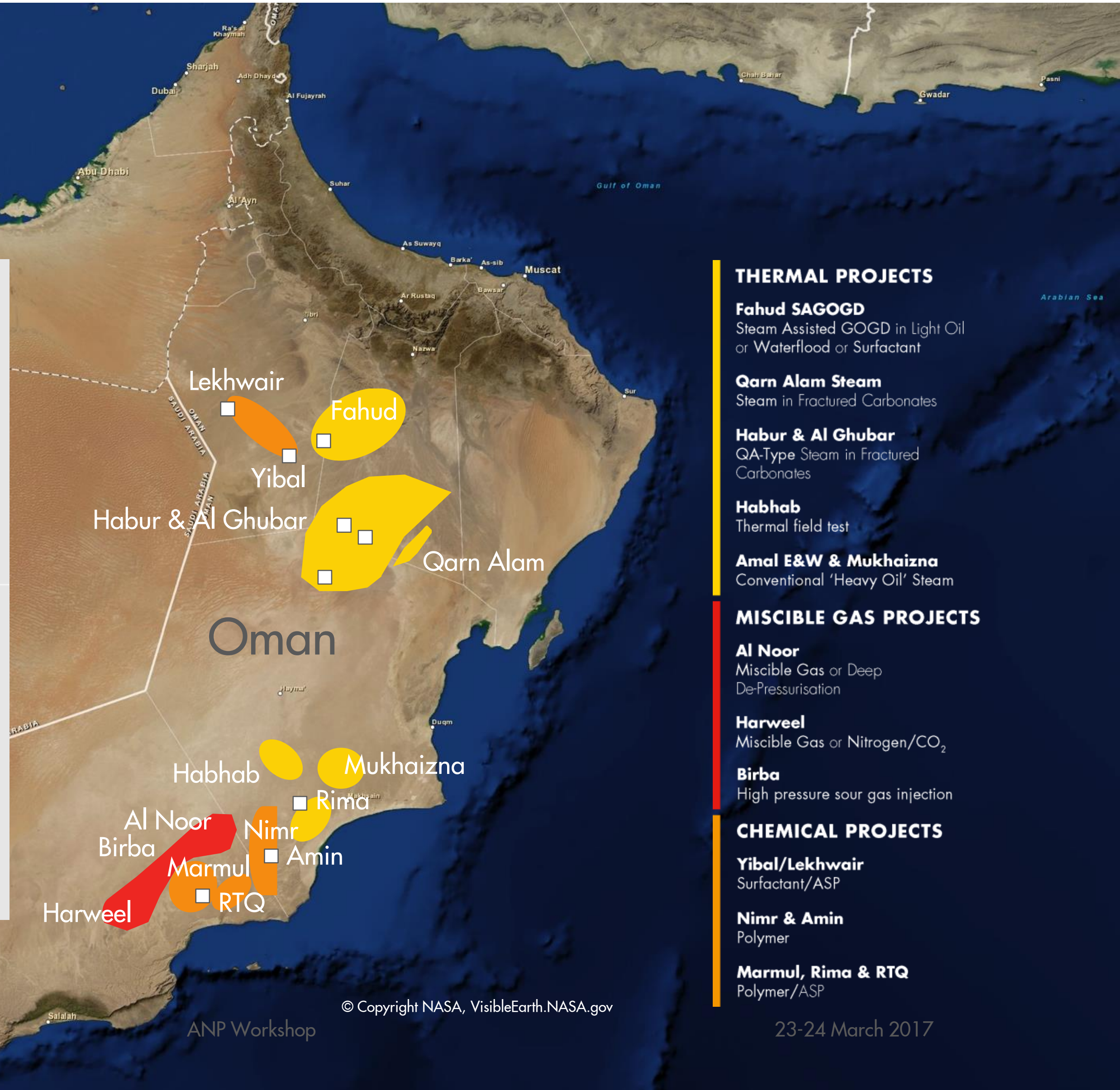




EOR projects in Oman



- Production decline halted
  - focus on up-time
  - reservoir development
  - sub-surface dynamics
- Innovative EOR schemes



THERMAL PROJECTS

Fahud SAGOGD
Steam Assisted GOGD in Light Oil or Waterflood or Surfactant

Qarn Alam Steam
Steam in Fractured Carbonates

Habur & Al Ghubar
QA-Type Steam in Fractured Carbonates

Habhab
Thermal field test

Amal E&W & Mukhaizna
Conventional 'Heavy Oil' Steam

MISCIBLE GAS PROJECTS

Al Noor
Miscible Gas or Deep De-Pressurisation

Harweel
Miscible Gas or Nitrogen/CO_2

Birba
High pressure sour gas injection

CHEMICAL PROJECTS

Yibal/Lekhwair
Surfactant/ASP

Nimr & Amin
Polymer

Marmul, Rima & RTQ
Polymer/ASP

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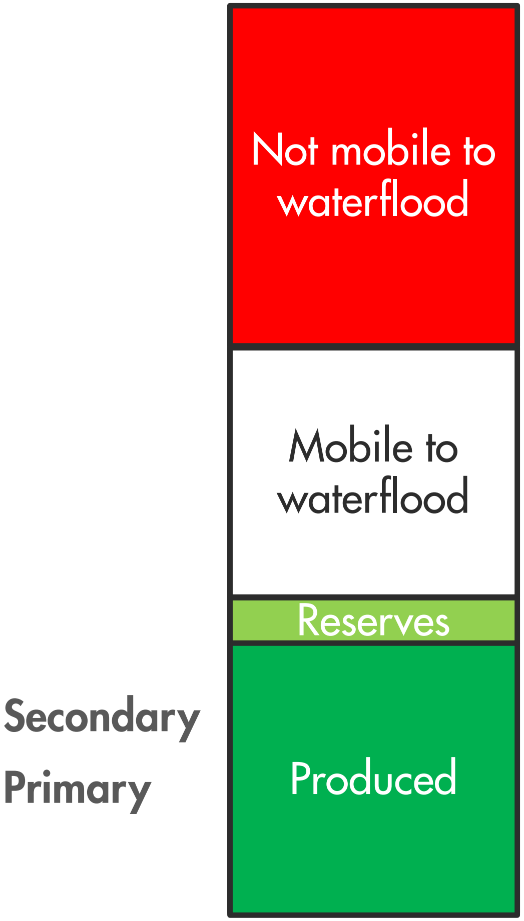
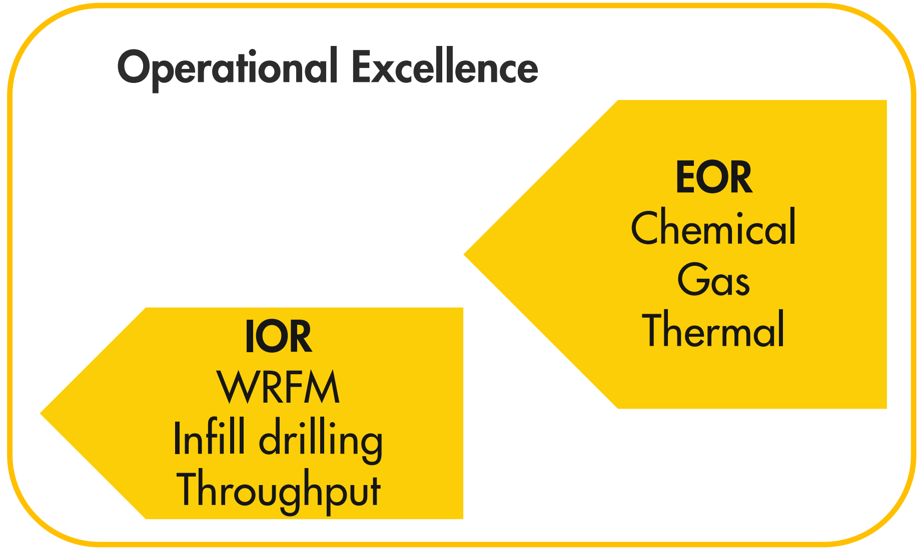
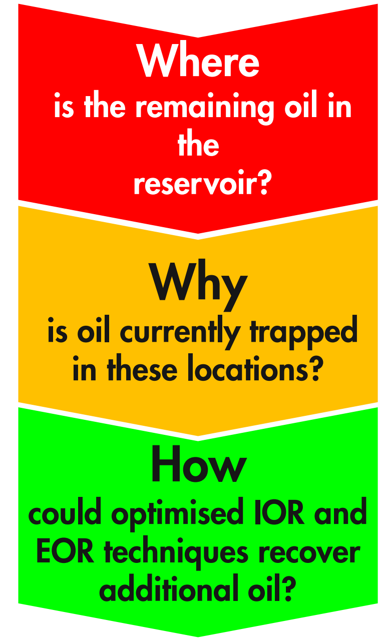
Maximising economic oil recovery







- A field with 35% ultimate recovery leaves almost twice as much oil in the ground as we have produced

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The EOR challenge and enablers

EOR is not business as usual, it is hard work technically and commercially

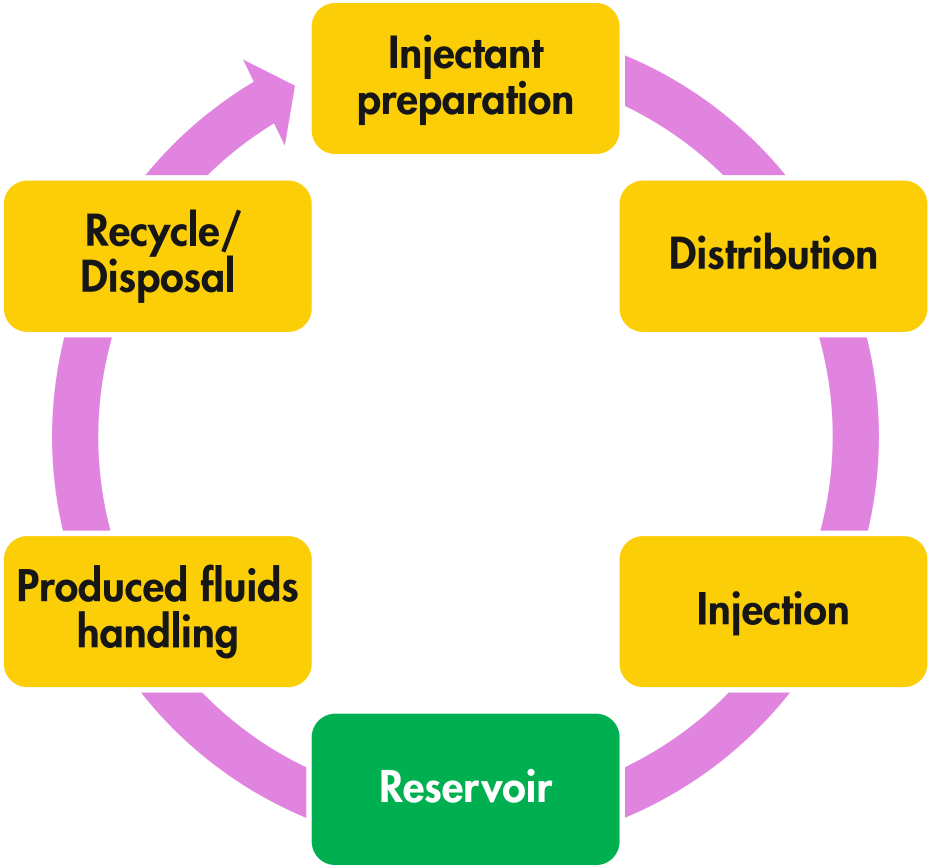
- Less oil to go after
  - 10-20% EOR incremental, vs 30-60% primary/secondary recovery
- Slower response times
- More expensive injectants
- Requirement for more surface facilities with added complexity

Enablers

- Lifecycle planning and surface subsurface integration
- Step up in surveillance capability to drive performance
- Contracting and procurement framework and standardisation
- Excellent stakeholder management
- Appropriate fiscal and regulatory structures needed

EOR systems: Integration

- Integration of subsurface and surface underpins successful EOR projects
  - Work on full injection/production cycle
- Injection system to achieve injectant at design specification in reservoir and flexibility to optimise EOR performance
- Production system robust to changes in fluid streams through EOR project lifecycle



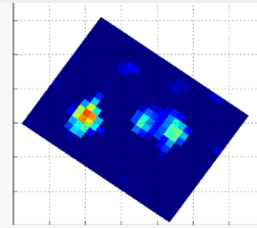
EOR reservoir surveillance

Fahud – Thermal Gas Oil Gravity Drainage

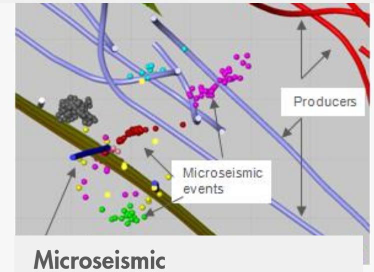
Caprock integrity
Interpretation of microseismic events
Traffic light classification
Geomechanical modeling to support interpretation

Steam front conformance
Geomechanical inversion of deformation data

Steam Distribution and Caprock Integrity Monitoring



Surface deformation



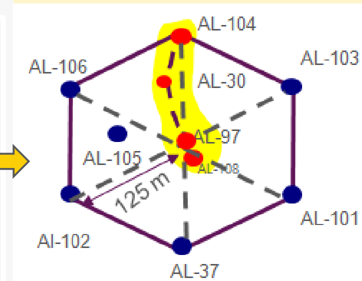
Microseismic

Amal – Steam Drive

Steam front conformance: Integrated interpretation of seismic, petrophysical (log) and geological data

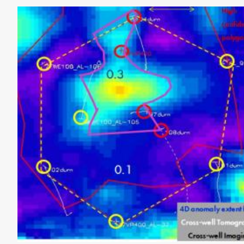
Understanding of preferential steam direction caused by intra Haradh channel system

Steam Distribution Monitoring



Temperature Logging

Integrated Interpretation of all data

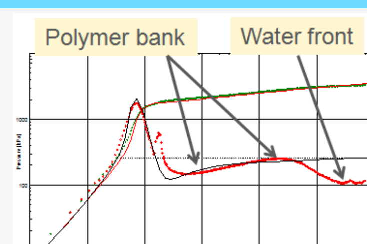


Steam outline Constrained by data

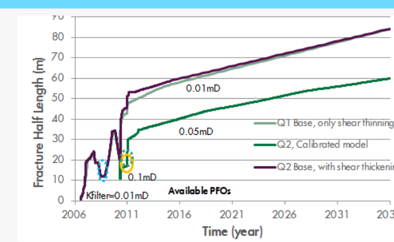
Marmul – Polymer Injection

Fracture monitoring and control
Classification of wells in traffic light
surveillance priority
well test interpretation
calibration and modeling
leading to water treatment decisions

Frac Length Monitoring



Pressure fall off test – Identification of Polymer Front



FracIT Modelling of frac length

Greater - Birba Miscible Gas Injection

Gas inflow monitoring
DTS feasibility and design

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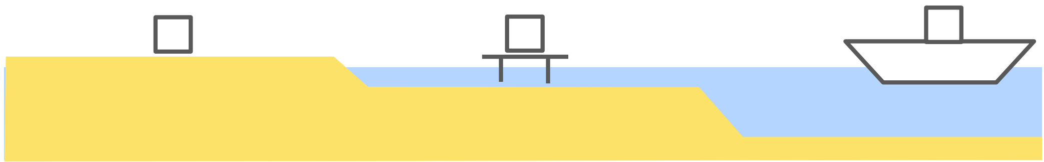
Moving EOR offshore



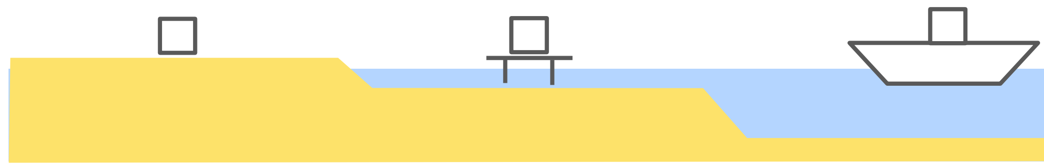
Additional challenges for offshore EOR compared to onshore EOR

- Wider well spacing and slower reservoir processing rates
- Limitations on weight and space for additional facilities or storage
- Impact of EOR injectants on wells/facilities (corrosion, non-metallic materials)
- Impact of wells/facilities on EOR injectants (corrosion products, shear)
- Design life of facilities
- Surveillance challenged, especially for sub-sea wells

Approaches

- Day 1 EOR implementation
- Lifecycle planning to create future EOR optionality
- Brown field modification, potentially supported by additional jackets or vessels
- "Greenfield" EOR redevelopment with new facilities fit for 30+ years production

Status of Shell offshore EOR



	Onshore	Shallow water	Deepwater
Thermal			
Low salinity waterflood			
Polymer			
(Alkaline) Surfactant/Polymer	Producing pilots	Single well test	
Miscible Hydrocarbon Gas			
Miscible CO_2			

- Operating/ In execution
- Concept selected
- Pre-feasibility
- Technology demonstration

St Joseph field:
Surfactant polymer flooding for offshore

- St Joseph field identified as target for chemical EOR
- Full field ASP concept feasibility assessment
  - Water treatment and logistics were large cost and operational challenge
- Shift development concept to SP
  - No need to remove divalents from water, but at expense of higher concentration of polymer and surfactants
  - Proved in a SWCTT that SP has the same oil recovery efficiency as ASP
- Can only make things work by working them in detail

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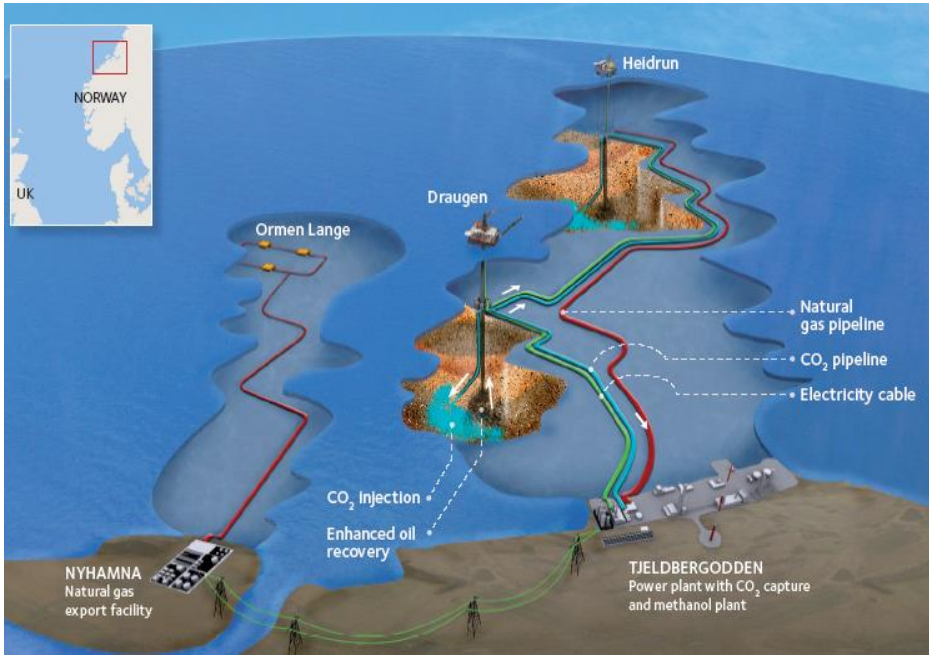
Offshore tertiary CO_2 EOR

- Shell has been active in pushing next generation CO_2 EOR projects
- Studies show offshore CO_2 EOR can be technically and economically feasible
  - HSSE brings new issues
  - Subsurface-surface integration key
  - Innovation needed to simplify facilities and reduce CAPEX and OPEX
- Commercially attractive projects require:
  - Reservoirs with large enough EOR prize
  - CO_2 supply (volume and price)
  - Supportive regulatory and fiscal regimes

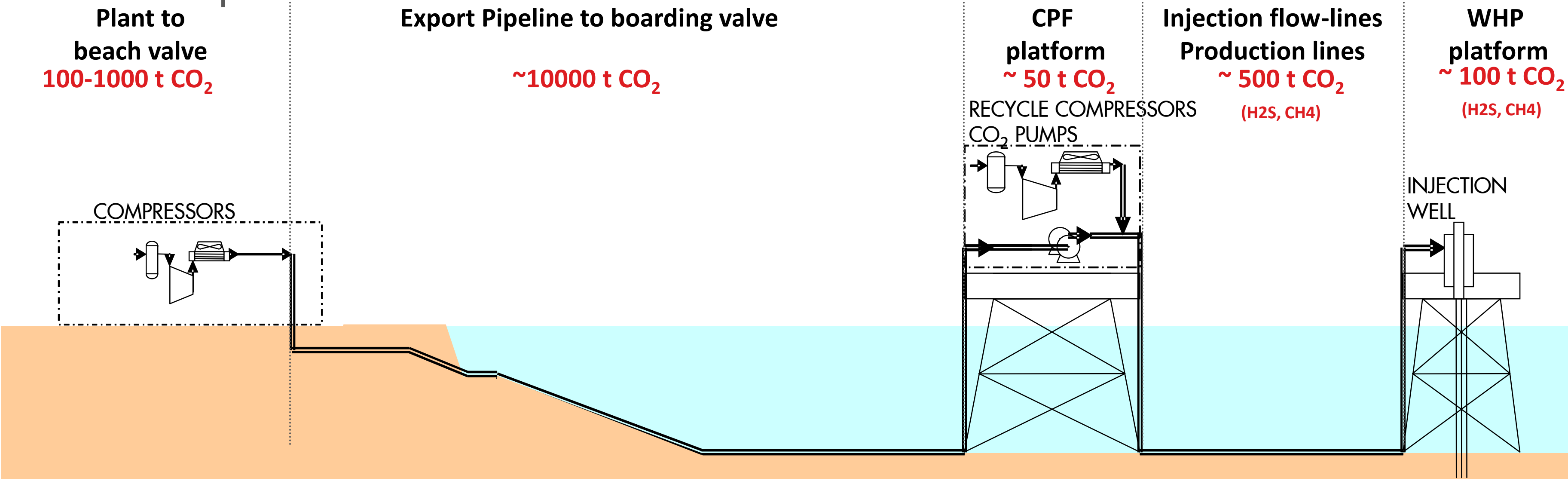
"Brownfield" Halten value chain



CO_2 HSSE offshore

Safe operation first priority

- Significant experience of CO_2 operations for onshore EOR projects
- Operation of CO_2 EOR offshore will introduce new set of challenges
  - Inventory, pressure, confined spaces, evacuation
- Shell CO_2 release testing programme to evaluate and validate hazards consequence models



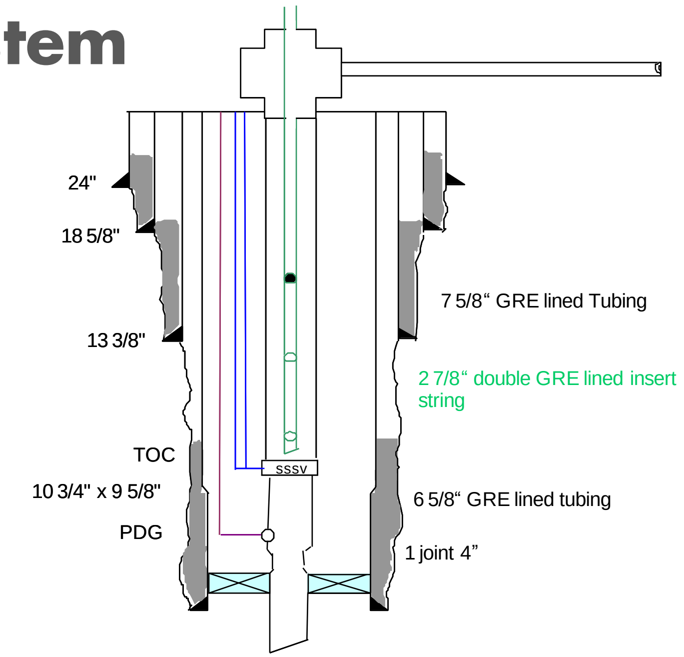
Key messages

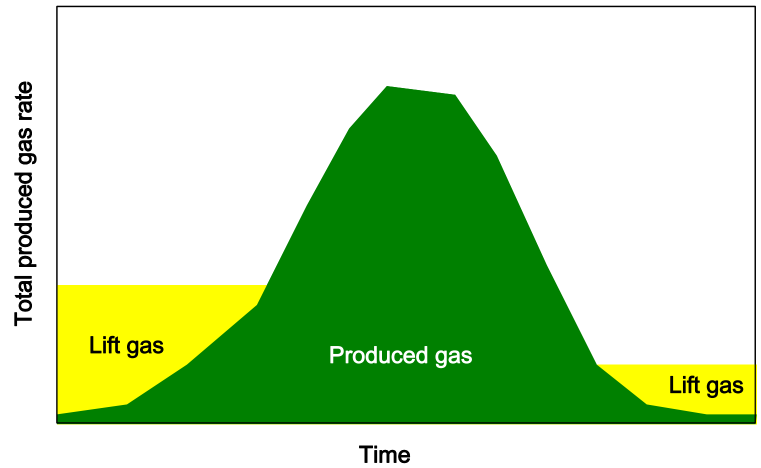
Shell has pioneered EOR technology and continues to innovate to improve existing commercial processes, mature new technology and expand the range of application

- Commercially proven EOR solutions exist for onshore application
  - Technically robust
  - Appropriate regulatory frameworks
- Pushing the envelope of EOR deployment by looking to offshore applications
  - Significant technical and commercial challenges
  - Subsurface-surface integration key
  - Most progress made with gas based EOR in shallow and deep water environments

Shell Integrated CO_2 gas lift system

- Alternative to ESP systems
- Use CO_2 for lift gas, insert string or dual string to protect casing from corrosion
- Lift gas rate adjusted in response to changes in back produced gas
- Advantages
  - Simple and robust system using recycle system, only modest increase in capacity needed
  - Intrinsic risk management, flexibility over number of wells to be gas lifted and response to gas breakthrough timing
  - Reduced requirement for well workovers





Three IOR/EOR questions: Where, Why and How?

Where
is the remaining oil in the reservoir?

Why
is oil currently trapped in these locations?

How
could optimised IOR and EOR techniques recover additional oil?

Redevelopment options need to be based on a proper understanding of the location of the remaining oil saturation

- Describe the location of the remaining oil (after depletion or waterflooding)
- Interpret reservoir performance to understand interplay of geology and balance of viscous and gravity forces
- Infill drilling, waterflood, throughput, deployable EOR processes