Early **O**r **R**egret

Eey**OR**e

Imperial College London

Screening for EOR and Estimating Potential Incremental Oil Recovery on the Norwegian Continental Shelf

SPE190230

Craig Smalley &
Ann Muggeridge

(Imperial College London)

Mariann Dalland,
Ole Helvig,
Eli Høgnesen,
Mari Hetland &
Arvid Østhus

(Norwegian Petroleum Directorate)

NORWEGIAN PETROLEUM DIRECTORATE

Overview

- Background
- New EOR screening methodology
- Results: screening applied to the Norwegian Continental Shelf (NCS)
- Conclusions and implications

Background

What is a Screening Tool?

- Fast method for ranking opportunities
  1. Which fields are suitable for EOR?
  2. Which processes might work in each field?
  3. How much incremental oil could we recover?
  4. Perform detailed technical, environmental, operational and economic assessment on top candidates
- Why?
  - Too costly and time-consuming to fully investigate each field initially
    - Further reservoir characterisation
    - Laboratory studies
    - Detailed numerical simulation

Objectives

- Develop simple transparent screening methodology and supporting toolkit
- Apply to the largest fields on the NCS
- Determine applicability of various IOR/EOR methods:
    - which methods would work in which fields?
- Estimate increased technical recovery potential by field and in total

Processes considered:

Hydrocarbon miscible gas/WAG
Hydrocarbon immiscible gas/WAG
Nitrogen and flue gas/WAG
CO_2 miscible/WAG
CO_2 immiscible/WAG
Alkaline
Polymer
Surfactant
Surfactant/polymer
Low salinity
Low salinity/polymer
TAP (thermally activated particles)
Gels

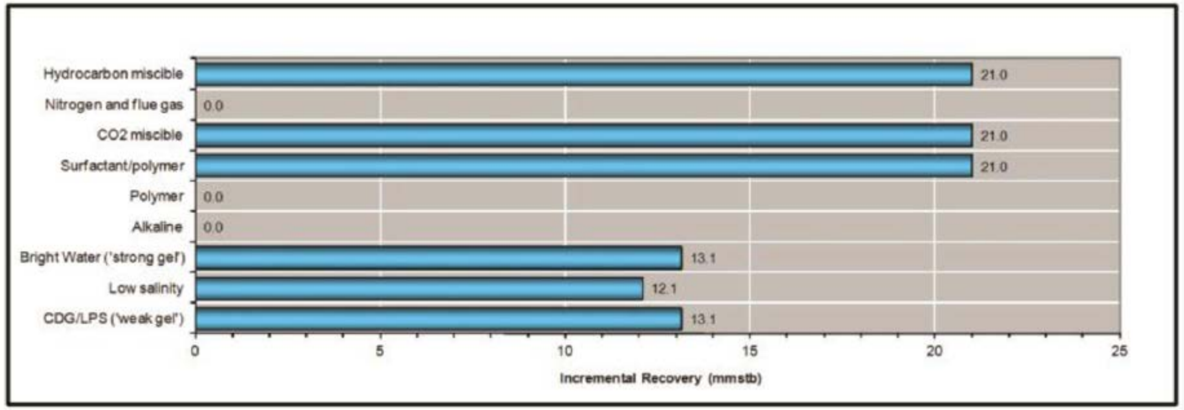
Background

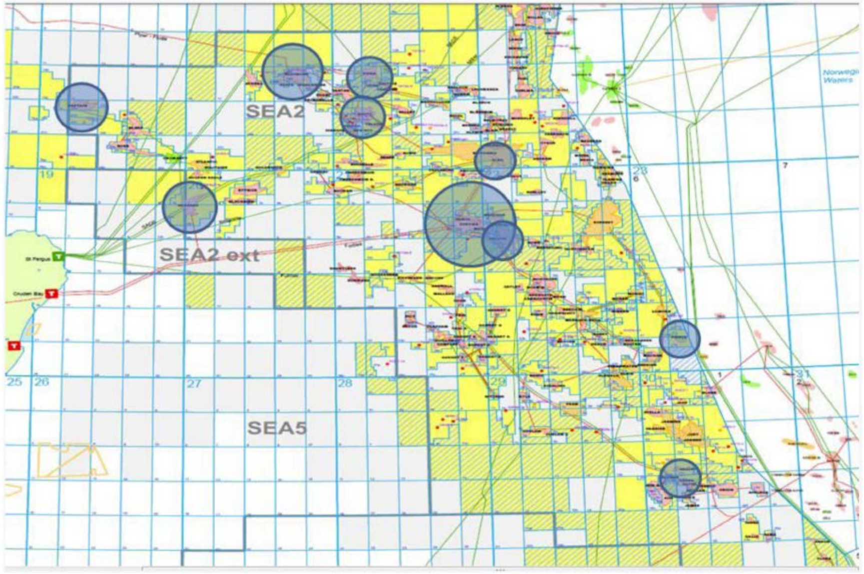
Desired comparability with recent study on the UKCS

McCormack et al. (2014). Maximising Enhanced Oil Recovery Opportunities in UKCS Through Collaboration, SPE 172017

	TECHNICAL PARAMETERS												FIELD MATURITY				
	STOIIP (MMstb)	Depth (ft)	Pressure (psia)	Permeability (mD)	Oil Viscosity (cP)	Temperature (degC)	Acid number (mg KOH/g)*	Amott-Harvey Wetting Index	Frac Clays	Hetrogeneity (0 none, 1 lot)	Injection water salinity	Result	RF to date	EURF	Field Maturity	Result	Incremental Oil (MMstb)
Input Data >>>>>>	315	7872	3720	250	0.29	110	0.1	0	0.045	0.35	36000		53%	55%	96%		
Hydrocarbon miscible																	21.0
Nitrogen and flue gas																	0.0
CO2 miscible																	21.0
Surfactant/polymer																	21.0
Polymer																	0.0
Alkaline																	0.0
Bright Water ('strong gel')																	13.1
Low salinity																	12.1
CDG/LPS ('weak gel')																	13.1
													Maximum Incremental Recovery				21.0

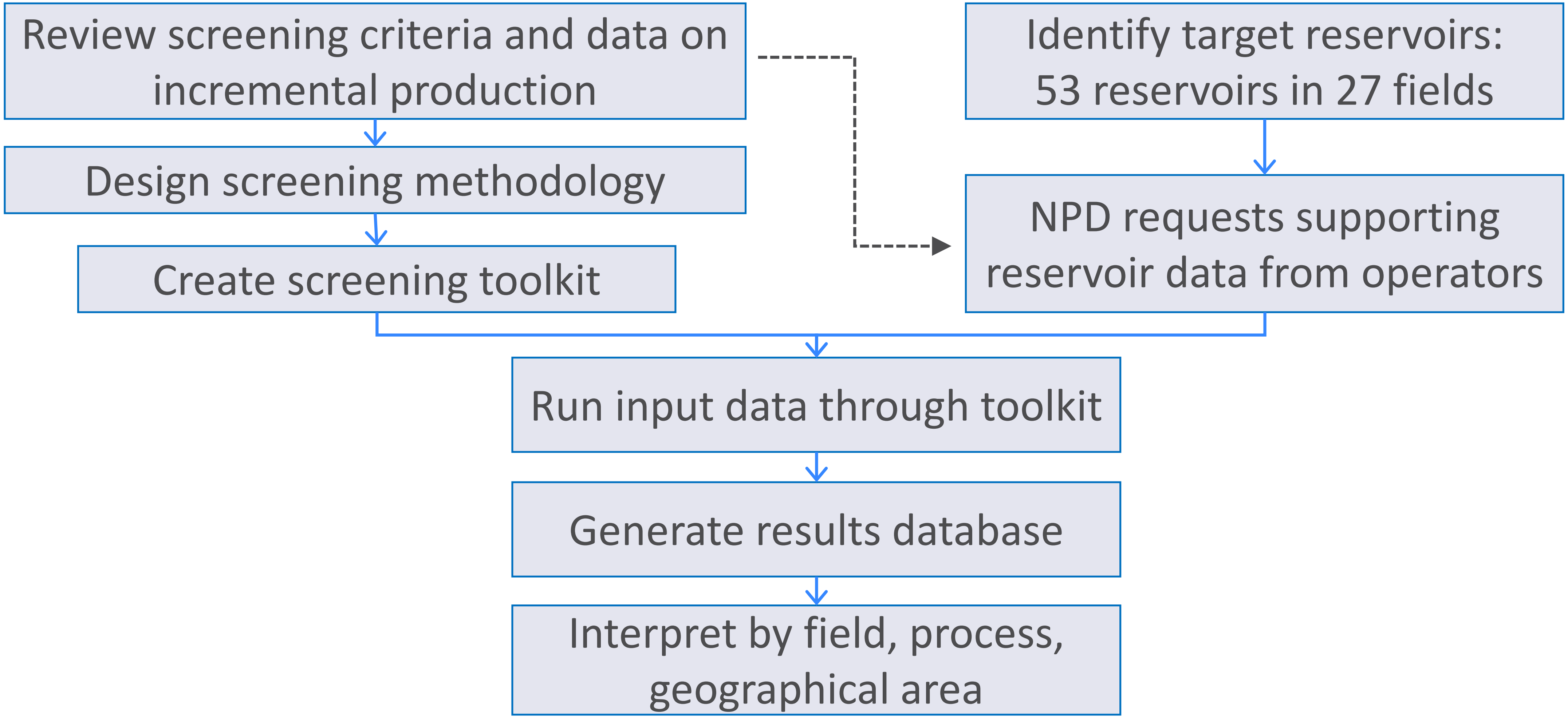
*this was not screened due to lack of readily available data





Screening Methodology

Screening Process



Screening Methodology

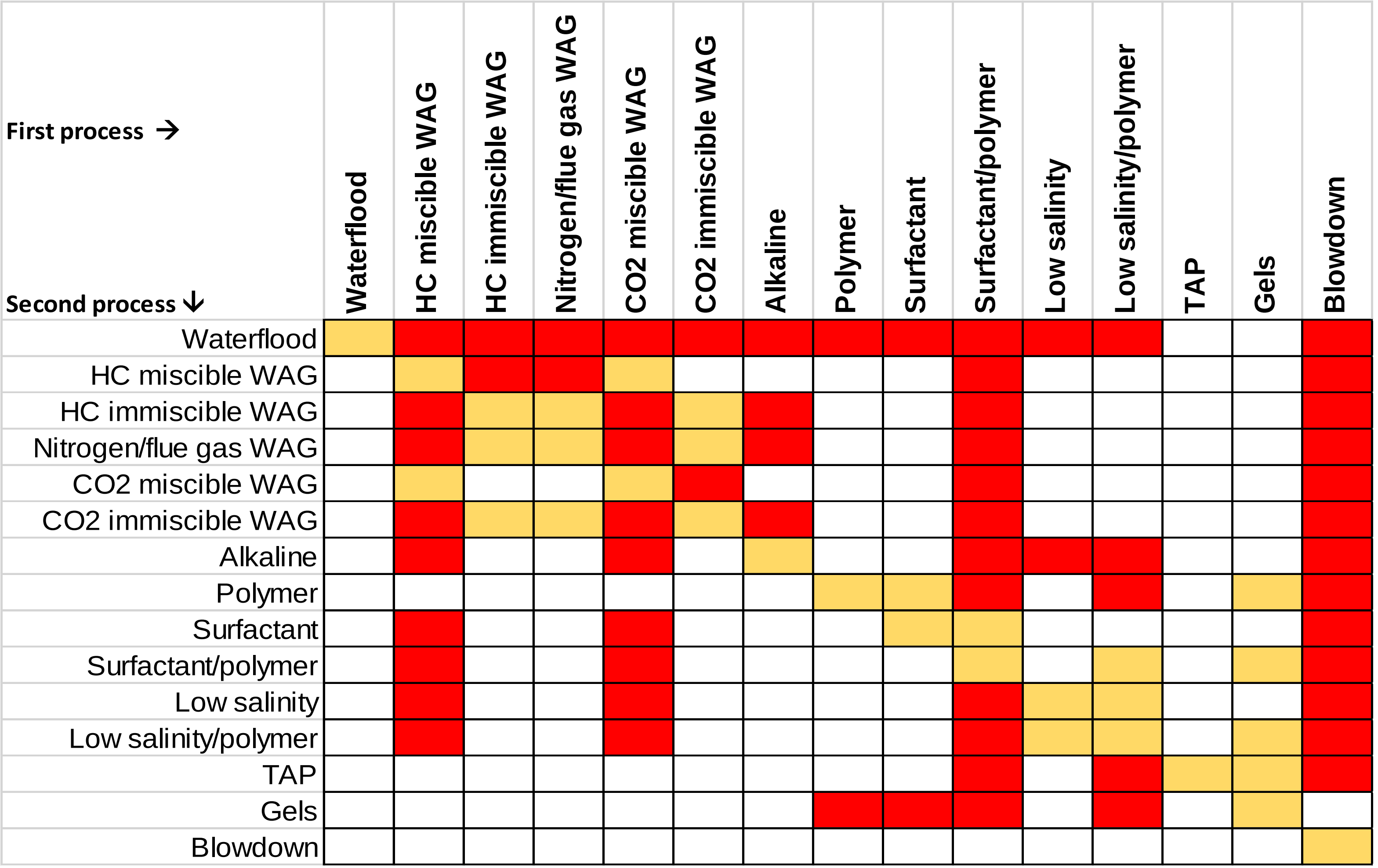
Screening criteria: > 30 publications reviewed

Recovery processes	Lithology	Depth	Pressure	Temperature	API gravity	Viscosity	Crude acidity (TAN)	Wetting behaviour	Porosity	Permeability	Thickness net	Fracturing	Hetrogeneity	Clay content	Clay type	Salinity formation water	Salinity injection water	Remaining oil	Current process
HC miscible gas/WAG																			
HC immiscible gas/WAG																			
Nitrogen and flue gas/WAG																			
CO2 miscible/WAG																			
CO2 immiscible/WAG																			
Alkaline																			
Polymer																			
Surfactant																			
Surfactant/polymer																			
Low salinity																			
Low salinity/polymer																			
TAP																			
Gels																			

Screening Methodology

Impact of current process

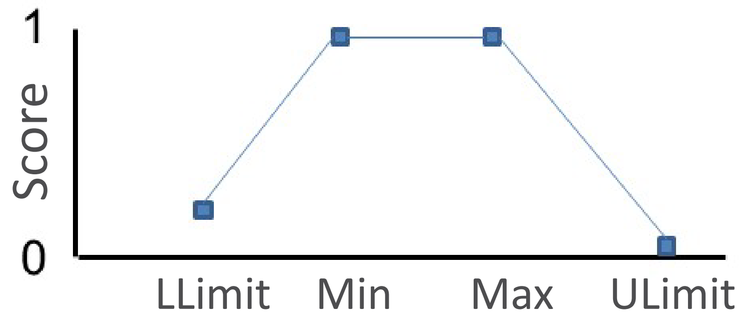
- Three types of process relationship
  - Second process is compatible with first and full increment expected (white)
  - Processes technically compatible but reduced increment (orange)
  - Processes not compatible (red)



Screening Methodology

Screening scores for individual criteria

- Represent how well the field properties meet each screening criterion for each recovery process
- Range between 0 (process not viable) and 1 (process fully viable)
- Calculated via four threshold values: Min, Max, ULimit, LLimit
  - Value between Min and Max. Optimal: screening score = 1
  - Value outside LLimit and ULimit.
    - — Hard thresholds. Process not possible: score = 0
    - — Soft thresholds. Process technically viable, but strongly disadvantaged: score assigned a low but non-zero value
  - Value between LLimit-ULimit but outside Min-Max. Process is viable but not optimal: score assigned on a sliding scale



Screening Methodology

Overall suitability scores for each process

- Scores are weighted, summed and normalised to give an overall suitability score
- Dashboard shows results for individual reservoirs

Field A: Reservoir 1	SCREENING CRITERIA																			
	Lithology	Depth	Pressure	Temperature	API gravity	Viscosity	Crude acidity	Wetting behaviour	Porosity	Permeability	Thickness net	Fracturing	Hetrogeneity	Clay content	Clay type	Salinity fm water	Salinity inj water	Remaining oil	Current process	Suitability score
Units		m	bar	C		cP			frac	mD	m					mg/l	mg/l	frac		
Field Data	Sst	3200	350	130	41	0.4	High TAN	Weakly oil wet	0.2	175	80	No fracture flow	Some layering	10-15% clays	Kaolinite, Smectite	120000	35000	0.80	Wflood	
Recovery processes																				
HC miscible WAG		1	1	1	1	1			1	1	0.6	1	1					1	1	0.9
HC immiscible WAG		1			1	1					0.6	1	1					1	1	0.9
Nitrogen/flue gas WAG		1	0.2	0.6	1	1				1	0.6	1	1					1	1	0.9
CO2 miscible WAG		1	1	0.7	1	1			1	1	0.6	1	1					1	1	0.9
CO2 immiscible WAG		0.4	0		1	1					0.6	1	1					1	1	0
Alkaline	1	0.5			0.8	1	0.5		1	1				0.5		0.1		1	1	0.7
Polymer	1			0.1	1	0			1	1	1	1	1	0		0		1	1	0
Surfactant	1			0.4	1	1			1	1	1		1	0		0.1		1	1	0
Surfactant/polymer	1			0	1	0			1	1	1		1	0		0.1		1	1	0
Low salinity	1					1	0.5	1		1		1	1	1	1	1		1	1	1.0
Low salinity/polymer	1			0.1	1	0	0.5	1	1	1	1	1	1	0.5	1	0.7		1	1	0
TAP	1			0.7		1			1	1	1	1	0.5			1	1	1	1	0.9
Gels				0.5		1				1		1	1				0.3	1	1	0.8

1 (green): Optimal process with maximum recovery increment. 0 (red): Unsuitable with zero recovery increment. Intermediate: Technically feasible but with reduced recovery increment

Screening Methodology

Recovery increments

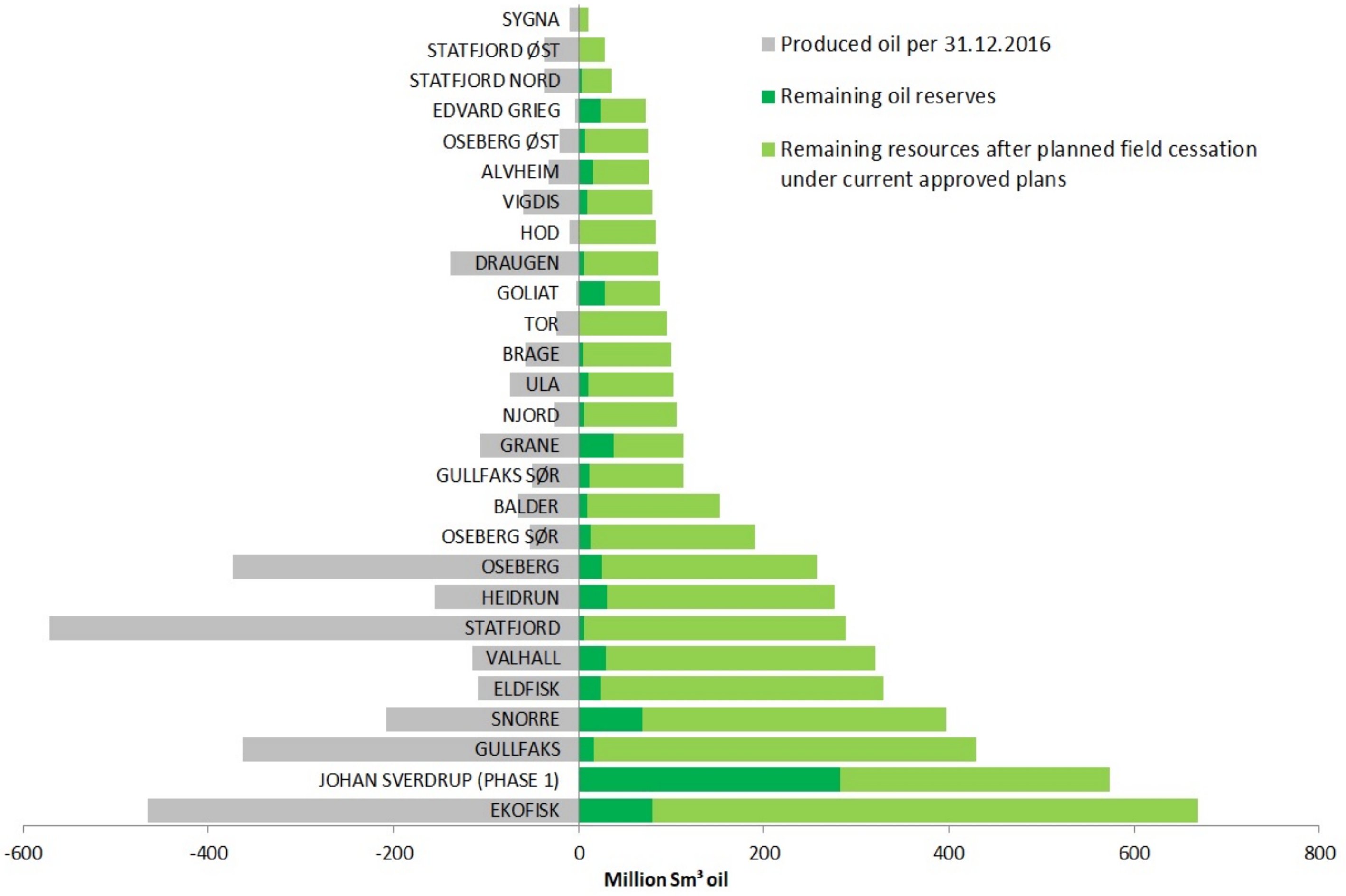
- Derived from analogues
  - Based on literature review, including field and lab data
  - Estimated lower, mid and upper increments
    - based on variability in the analogue data
  - Scaled by screening score
  - Capped by theoretical maximum recovery factor
    - Estimates of microscopic displacement and macroscopic sweep efficiencies

Recovery processes	Theoretical maxima
Waterflood	0.70
Hydrocarbon miscible gas/WAG	0.70
Hydrocarbon immiscible gas/WAG	0.71
Nitrogen and flue gas/WAG	0.70
CO_2 miscible/WAG	0.70
CO_2 immiscible/WAG	0.71
Alkaline	0.73
Polymer	0.77
Surfactant	0.73
Surfactant/polymer	0.86
Low salinity	0.77
Low salinity/polymer	0.81
TAP	0.84
Gels	0.77

Screening Methodology

The analysis

- 53 studied reservoirs from 27 NCS fields
    - o wide range of maturity
- All data imported into toolkit
- Processed as a batch
- Results stored in a worksheet
- Plotted and interrogated using pivot tables and charts

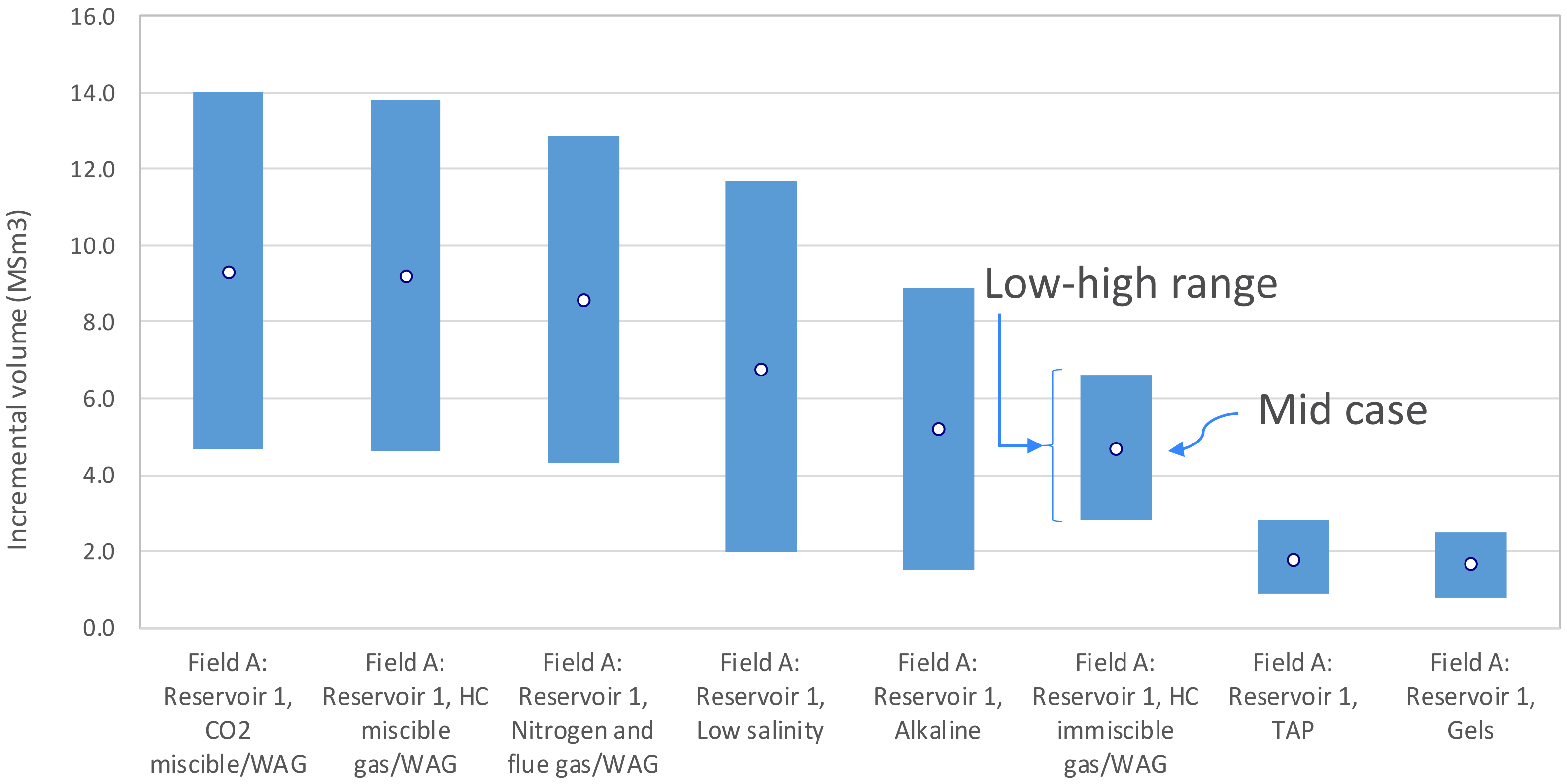


Note: 1 Sm^3 = 6.29 barrels

Results

Field by field analysis

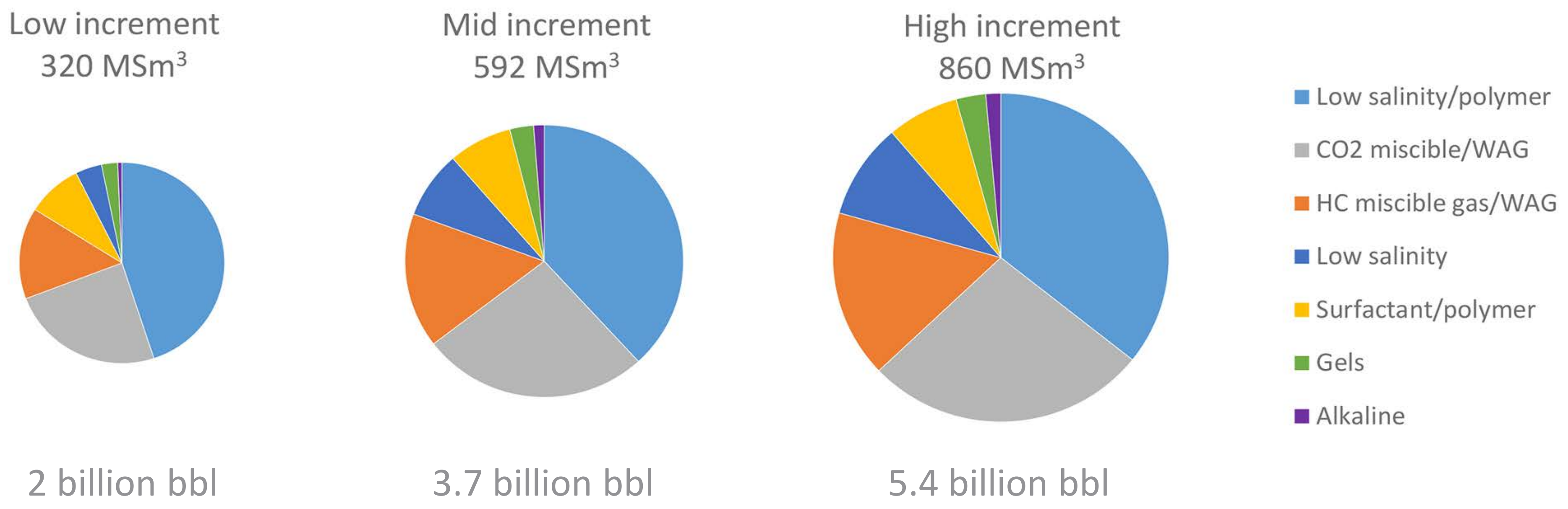
- Estimated a view of the increment each process might add in each reservoir



Results

Overall technical potential incremental recovery

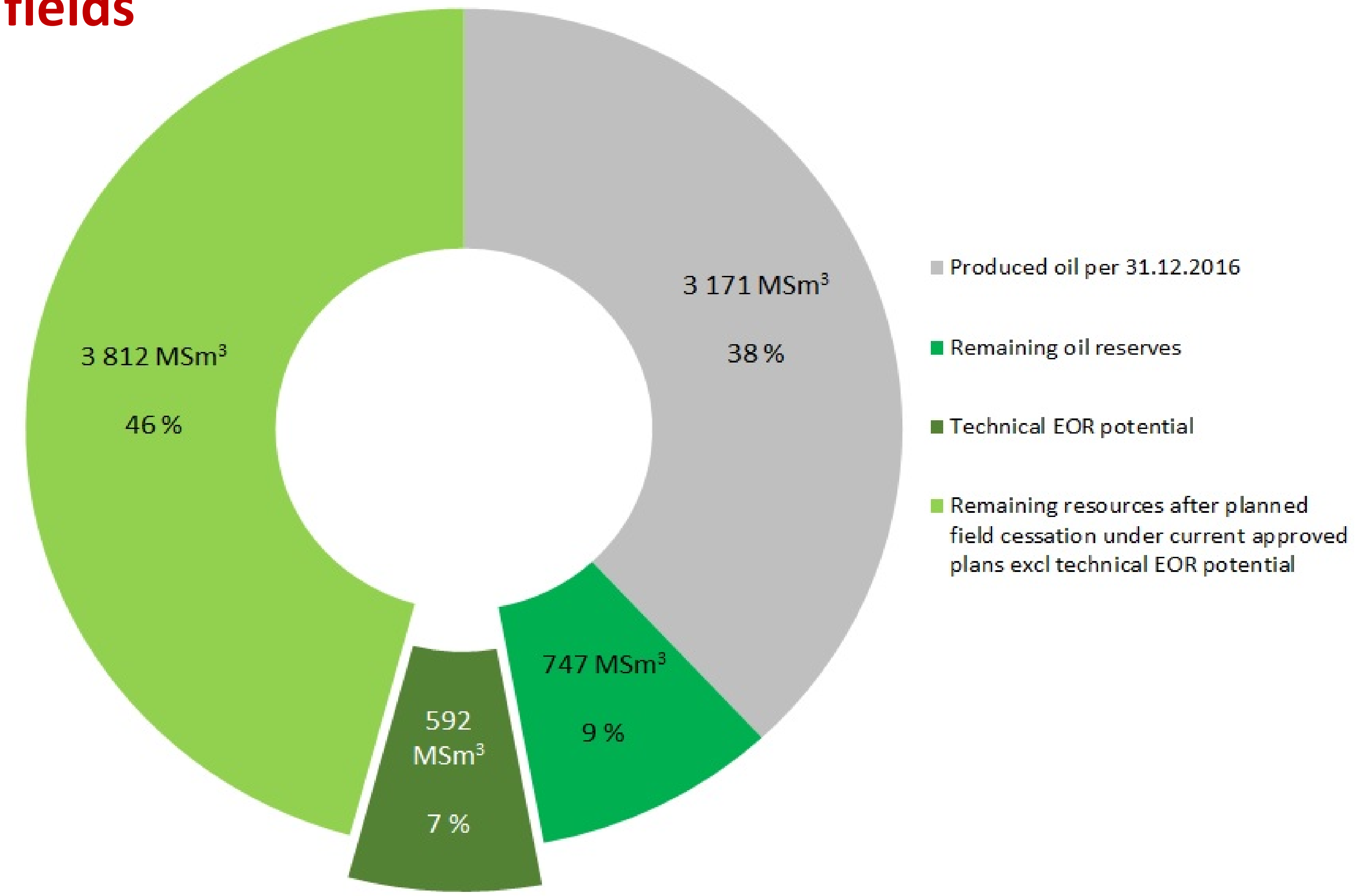
- Sum the top processes at the field level
  - the selected EOR process may be sub-optimal in some reservoirs,
  - operational simplicity leads to a higher chance of successful implementation



Results

Resource overview of the 27 fields

- Increase average recovery factor by 7%
  - From 47% to 54%
  - Mid-case



Results

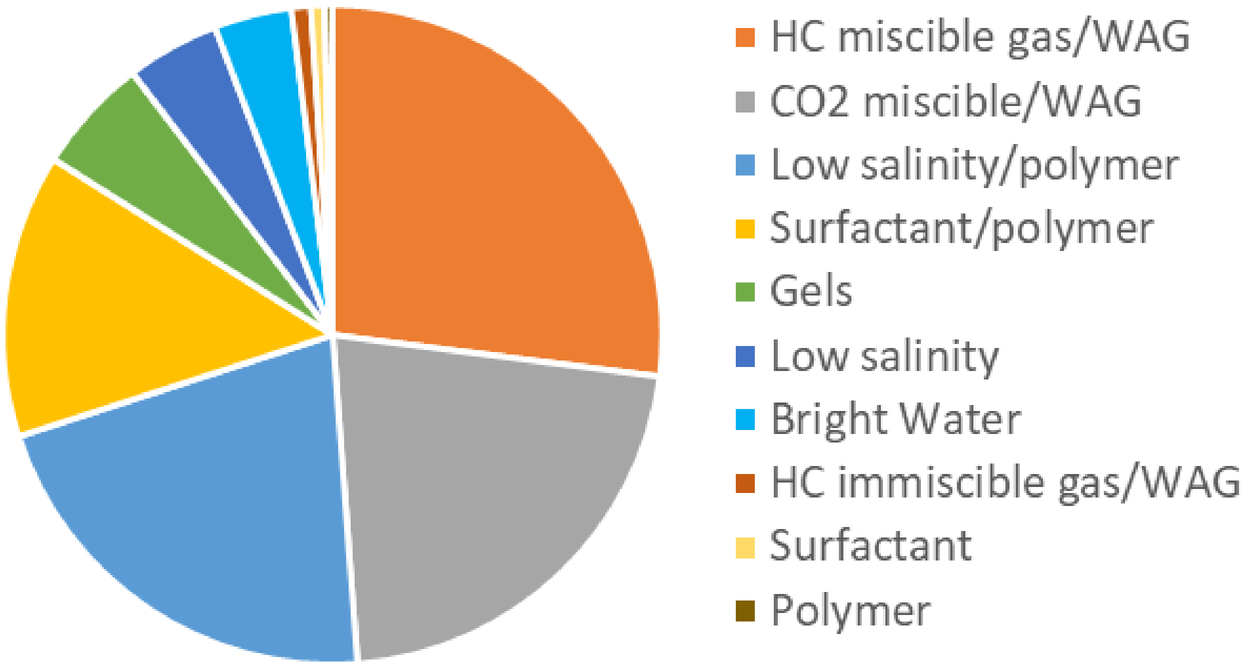
Application of multiple processes

Identify

1. best EOR process
2. the next best <u>compatible</u> process, and then the next….

➢ Optimistic view of volumes
  - Operationally difficult to implement multiple processes in one field

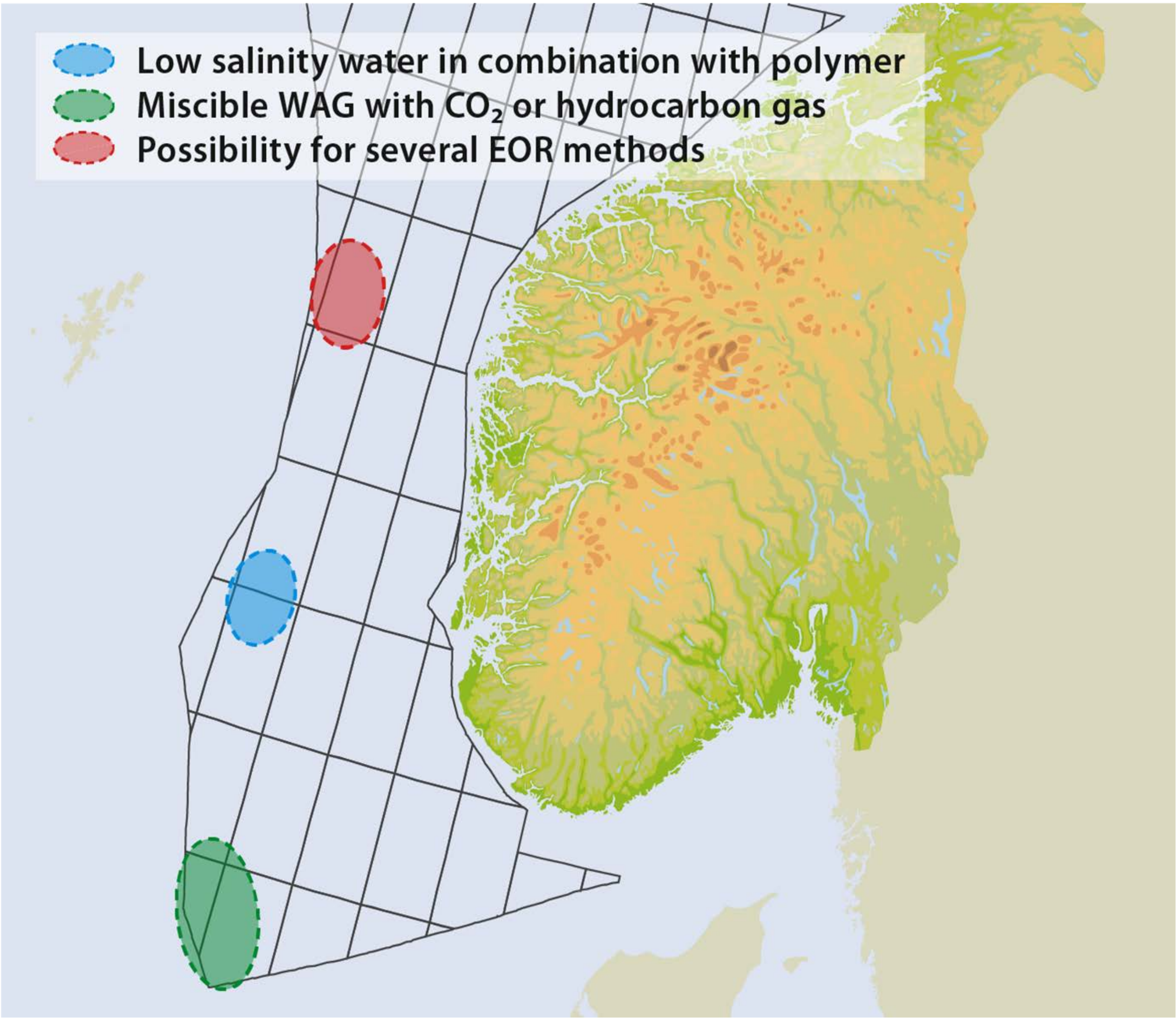
➢ Better view of applicability of each process



Results

Geographical analysis

- Clusters of similar opportunities revealed
- Could provide economies of scale
- Tampen area: various processes
- Utsira High: Low salinity (or surfactant) with polymer
- Chalk fields: Miscible WAG



Conclusions and implications

- Updated screening methodology:
  - More criteria; hard and soft thresholds; sliding score scales; criterion weighting
- ~600 million Sm^3 technical potential in the 27 analysed NCS fields
  - Top processes: low salinity/surfactant + polymer; miscible HC/CO_2 injection
- NPD able to advocate focused EOR technical studies, including field pilots
  - Such pilots are important in verifying process feasibility:
    - provide more analogue data for screening

Future work:

- Explicit incorporation of economic, operational and environmental criteria

EAGE European IOR Symposium 2019

- April 8th-10th
- Pau Pyrenees
- Main sponsor: Total

- Deadline for Abstracts: September 2018