IMPROVING WATERFLOODING OFFSHORE USING LOW SALINITY FLOODING

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C. Hernandez, T. G. Sorop, B.M.J.M. Suijkerbuijk, M.T. Looijer

Shell Global Solutions International B.V

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Resources: Our use of the term “resources” in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

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Resources plays: our use of the term ‘resources plays’ refers to tight, shale and coal bed methane oil and gas acreage.

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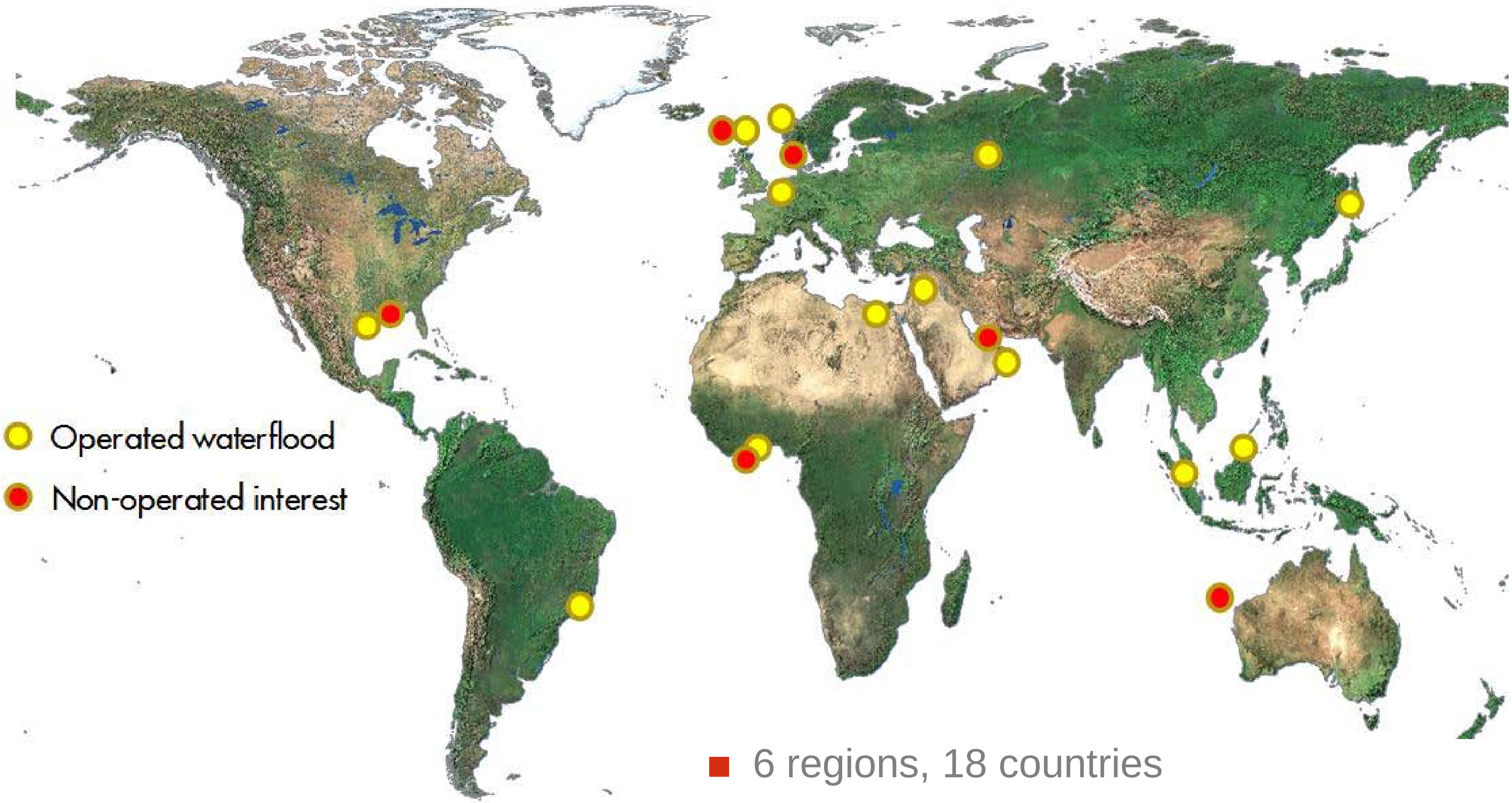
Outline

- Introduction to LSF (Low Salinity WaterFlooding)
- LSF readiness for offshore: laboratory & field evidence
- Managing water quality in offshore WFs
  - Key Shell technologies: ASCET, IFO, PWRI-FRAC, FRAC-IT
  - Improving water quality by LSF
- Subsurface and surface workflows & concepts
- LSF deployment: field examples and learnings
- Summary & Conclusions

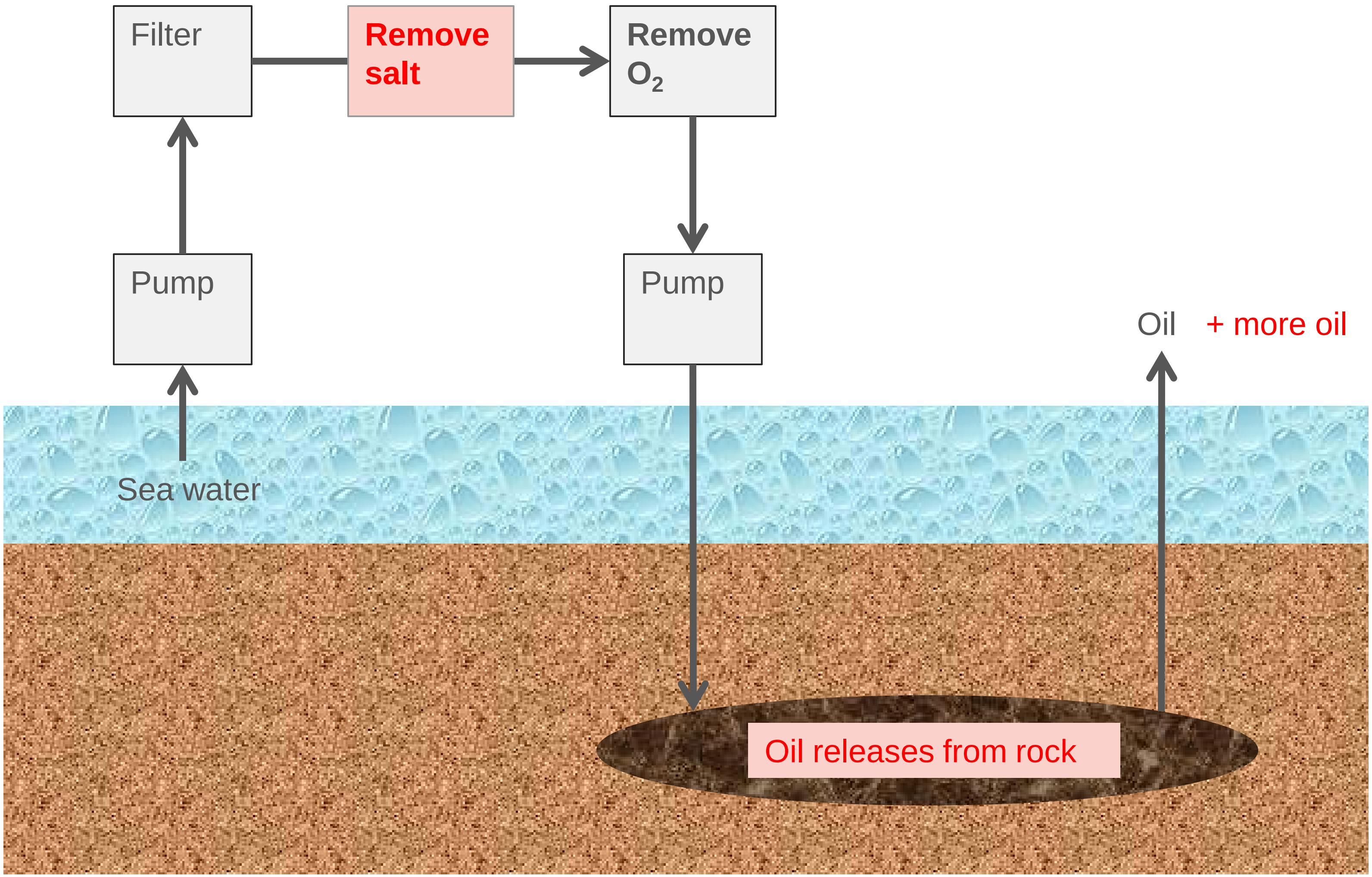
Waterflood in Shell



WF footprint:

- 6 regions, 18 countries
- 7,000+ injection wells, 200+ reservoirs
- More than 30% of Shell liquid production

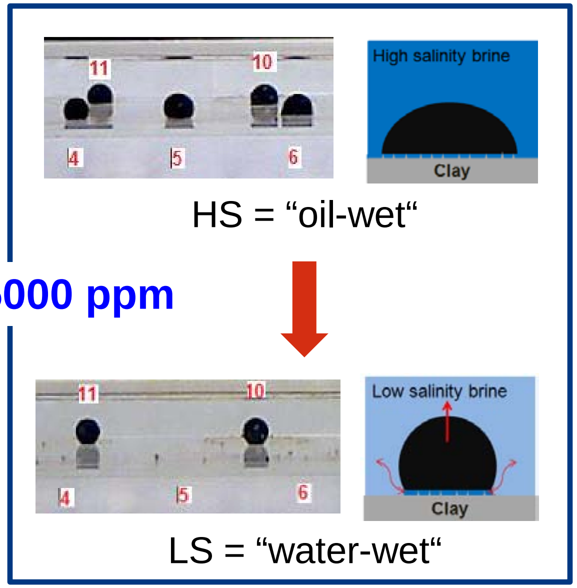
LSF in a nutshell



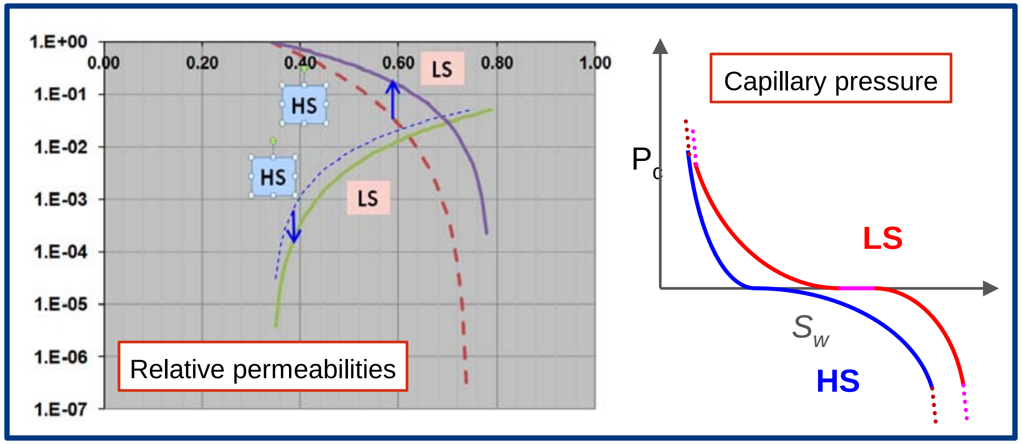
Low Salinity Waterflooding: emerging IOR/EOR technology

A wettability change towards more water-wet…

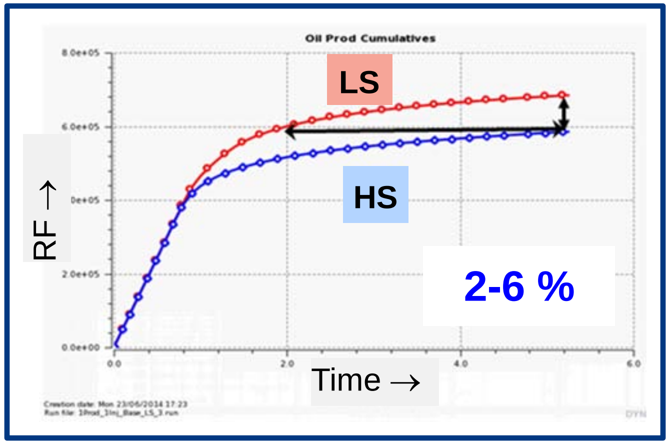
TDS < 5000 ppm



…changes the relative permeabilities, P_c and often S_{or}…



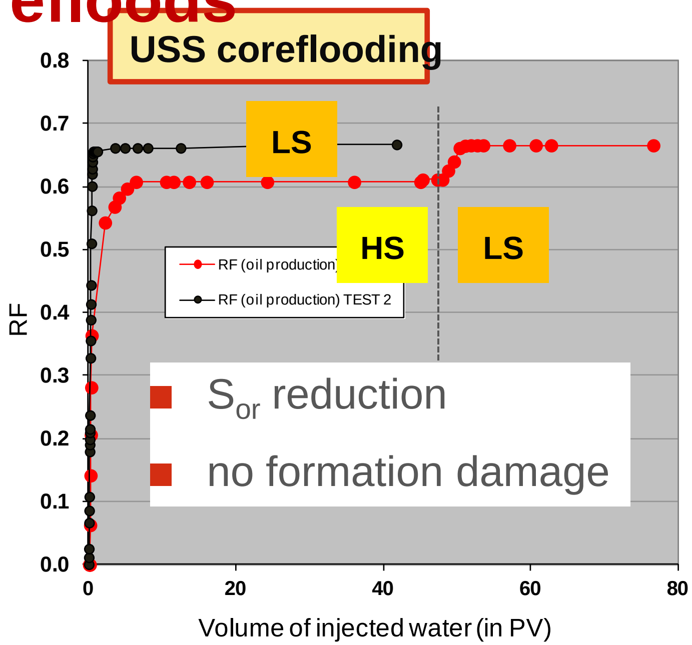
…accelerating oil recovery

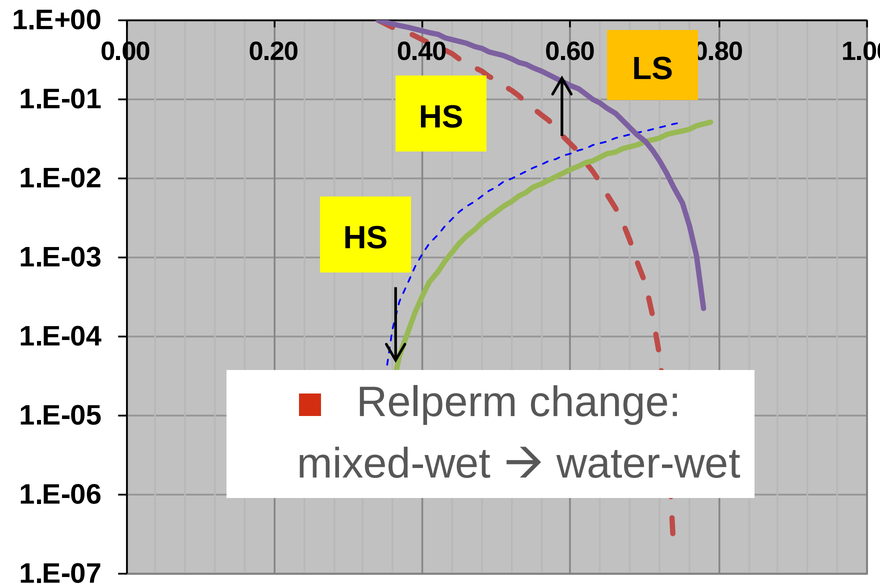


Cense, Berg, Mahani SPE144936, SPE 165255; Ligthelm SPE 119835

LSF in industry: **BP, Saudi Aramco, Statoil, Exxo**

Laboratory evidence: reservoir condition corefloods





- Extensive database on different fields/reservoirs
- In total: 50+ corefloods on reservoir core

Core scale recoveries: 4-11%

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volumetric sweep efficiency, mixing and dispersion

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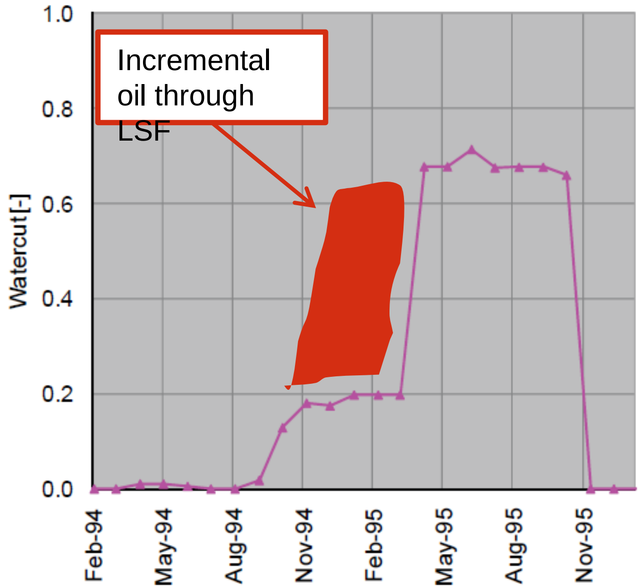
Field scale: 2-6% of STOIIP

Suijkerbuijk et al., SPE 169691

Shell Field Evidence: Omar (AFPC, Syria)

Omar "accidental" field implementation

- TDS (FW) = 90,000 ppm, dominant clay: kaolinite
- WF started initially with river TDS (river) = 500 ppm
- Effectively a LSF for several years before PWRI become available in sufficient quantities



- Production behavior from 15+ wells indicates wettability change: double step in water cut + well logs
- No injectivity loss reported → no formation damage
- Flood front between HS and LS relatively steep with limited mixing
- Incremental RF ~ 5-15% of STOIIP
- Other companies have published valuable work on LSF field trials

BP, Statoil, Saudi Aramco

SPE 129564, SPE 142960

Business Context for LSF Deployment

- Extensive laboratory evidence and convincing onshore field evidences provide confidence that LSF is deployable in all settings

Business need

- Increase recovery factor and (long-term) production (by EOR)
- Improve current WF performance

Business impact

- Increases oil production by up to 6% STOIIP
- Cheapest EOR technique
- Operationally similar to WF → "natural extension to WF"
- Improves waterfloods performance: desalination improves water quality
  - it reduces souring and scaling
  - it reduces injectivity decline & reduces risk of out-of-zone injection
- LSF may be 1st step in the EOR staircase (ex. enables cheaper Polymer Flooding)

Business decision

- Screening of the whole Shell portfolio both onshore & offshore

Water Quality impact on WF performance

- Water quality is a key issue that impacts WF performance.
  - Especially offshore (where usually nr. of injectors is small due to high costs)

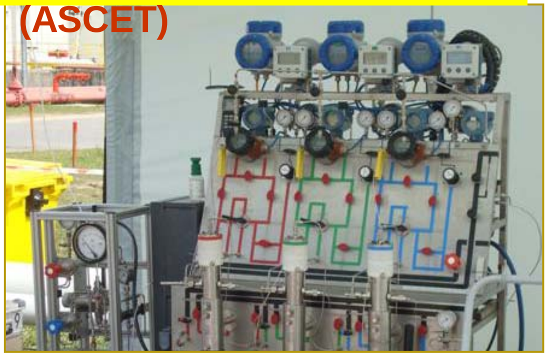
- Possible effects of poor water quality (solids, oiw, composition):
  - Injectivity decline (matrix injection)
  - Promotes induced fractures (most of the time)
  - Increases the risk of out-of-zone injection
  - Negatively impacts areal sweep
  - Increases the risk of souring & scaling

- Water quality has been discussed previously in literature in context of desalination and LSF (Henthorne et al, SPE 144397, Reddick et al., SPE 153933)

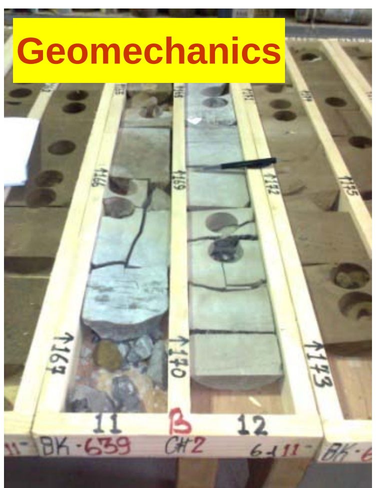
Shell Integrated Workflow For Managing Water Quality

DATA ACQUISITION

On site coreflooding (ASCET)



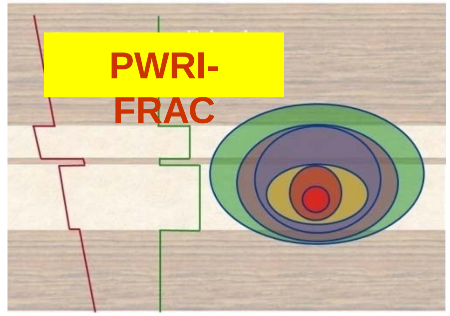
Geomechanics



SPE 121786

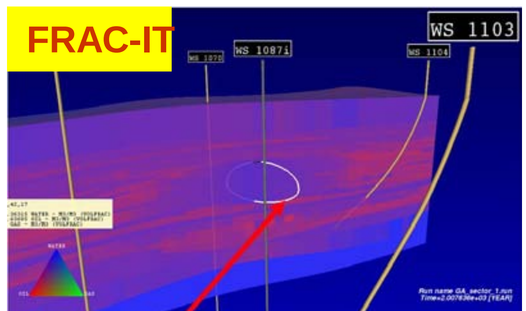
MODELLING

PWRI-FRAC



Stand alone: analytical tool

FRAC-IT



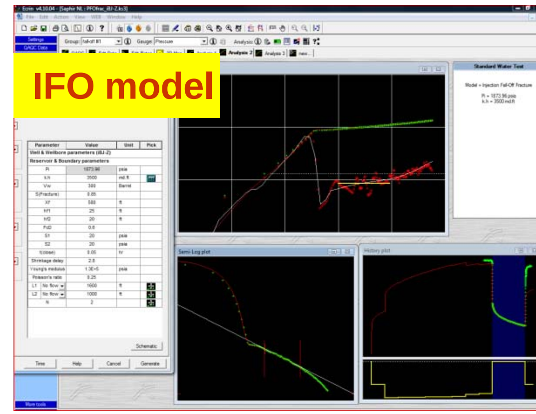
Geomechanics coupled to Fluid Flow as integral part of the MoReS reservoir simulator

SPE 95726, SPE 110379

SURVEILLANCE

- PFO testing
- Step rate testing
- PLT & Temperature surveys

IFO model

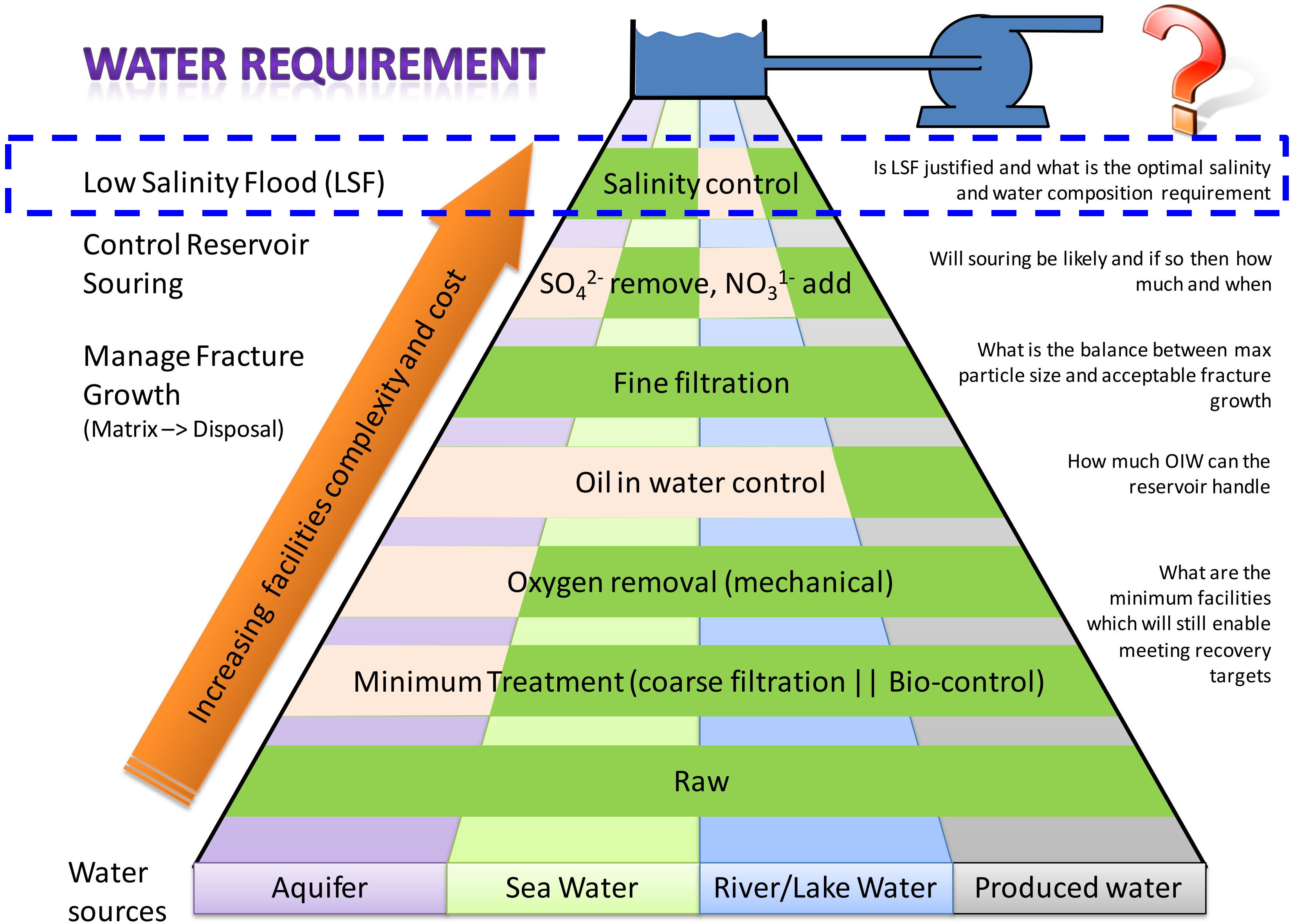


In-house plug-in to PTA software to monitor fracture growth (length & height)

SPE 77946, SPE 84289

Water source treatment option

- Limited cleaning vs. going for the "best quality" water



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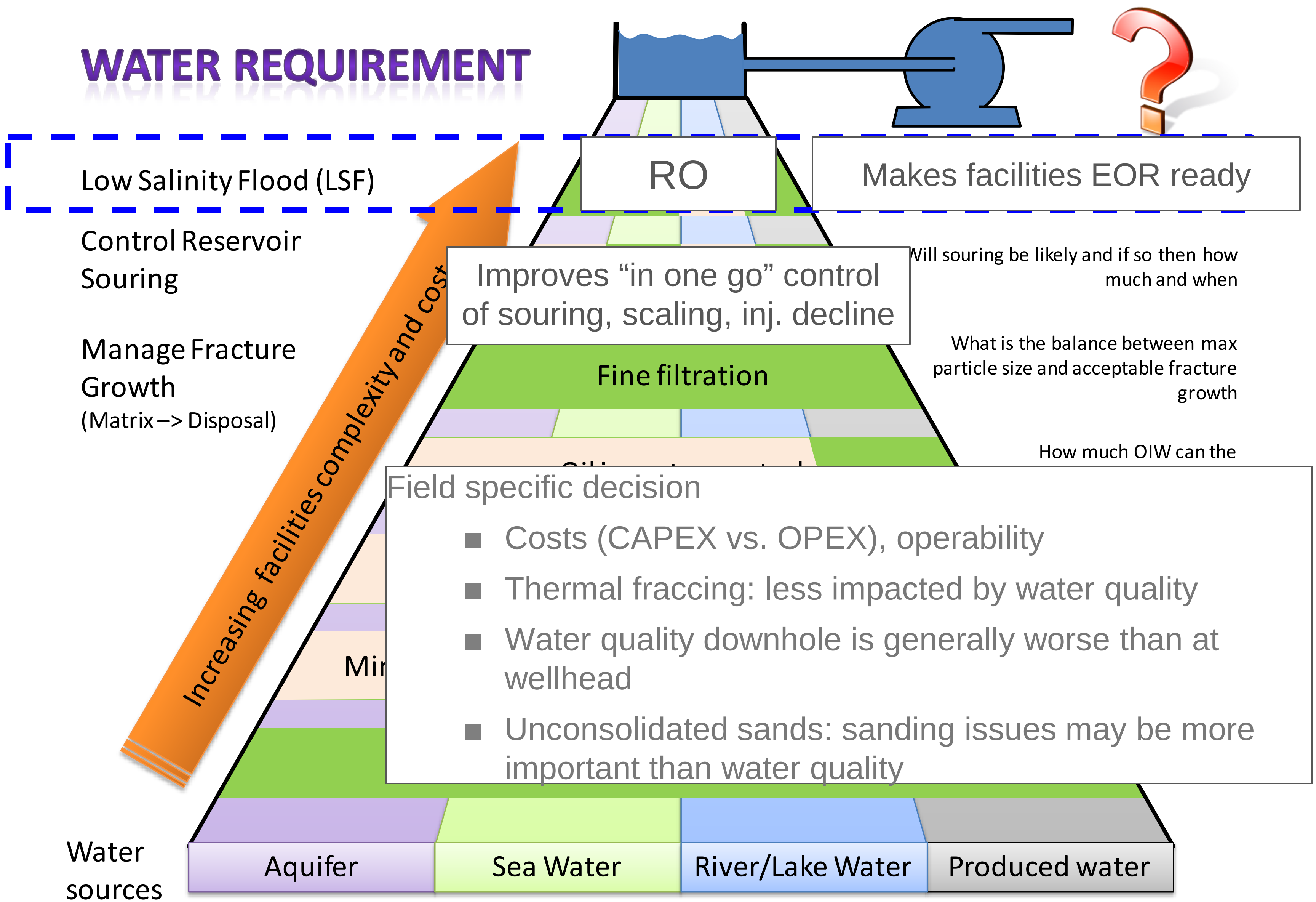


Field specific decision

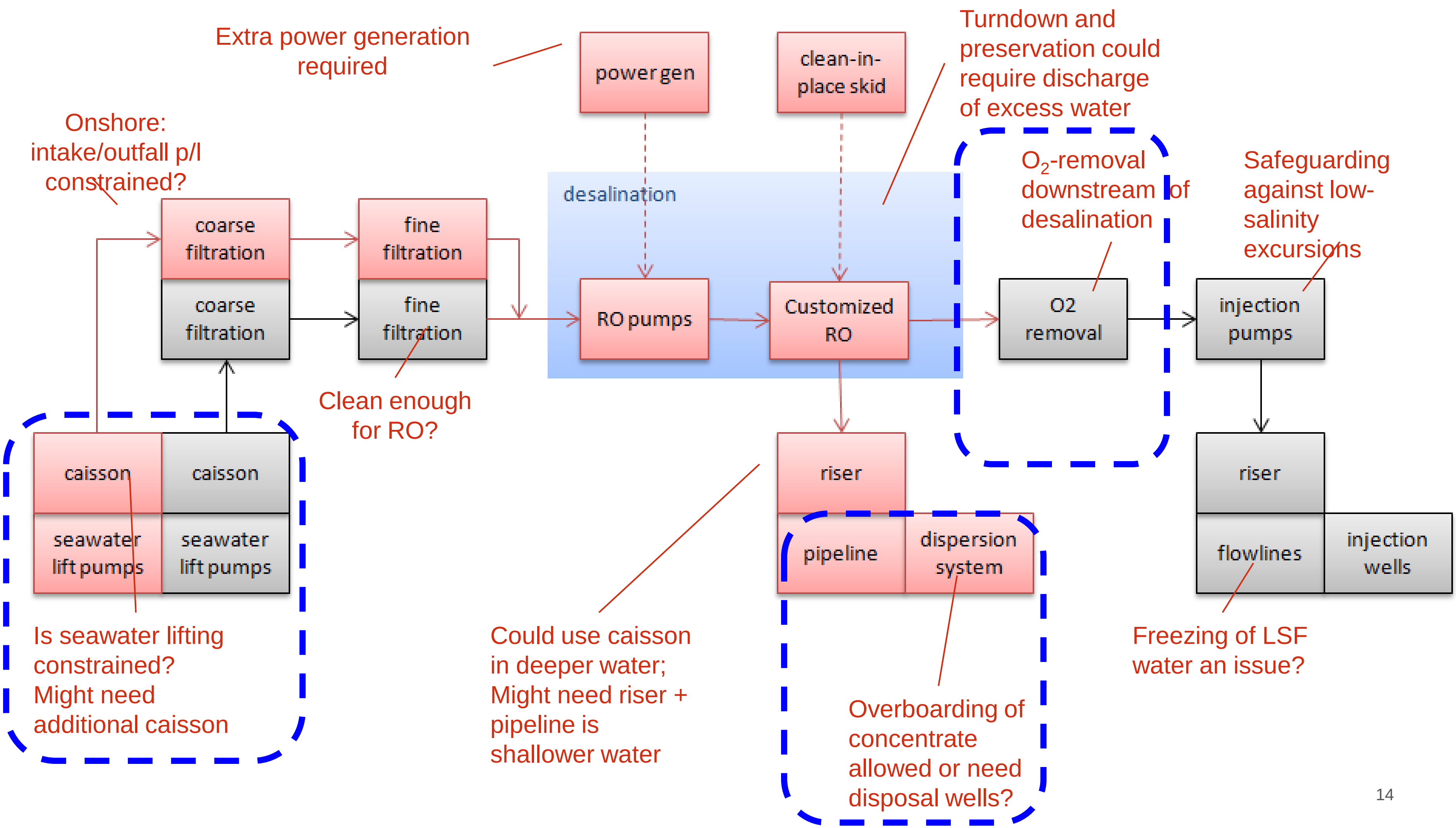
- Costs (CAPEX vs. OPEX), operability
- Thermal fraccing: less impacted by water quality
- Water quality downhole is generally worse than at wellhead
- Unconsolidated sands: sanding issues may be more important than water quality

LSF Facility

- Desalination technology well proven (refineries, power plants and potable water)

- Persons On Board (POB)
- Utilities
- Chemical Injection
- Availability / Sparing
- Substructure bearing capacity (weight)
- Space

- Constructability (production deferment)
- Permit: waste stream, more chemicals
- Fuel (gas) availability



Example of facilities concepts for offshore

- Different facilities concepts for retrofitting

Add-on to existing platform

- Difficult to retrofit
- Installing from day 1 needs to overcome EOR risk aversion

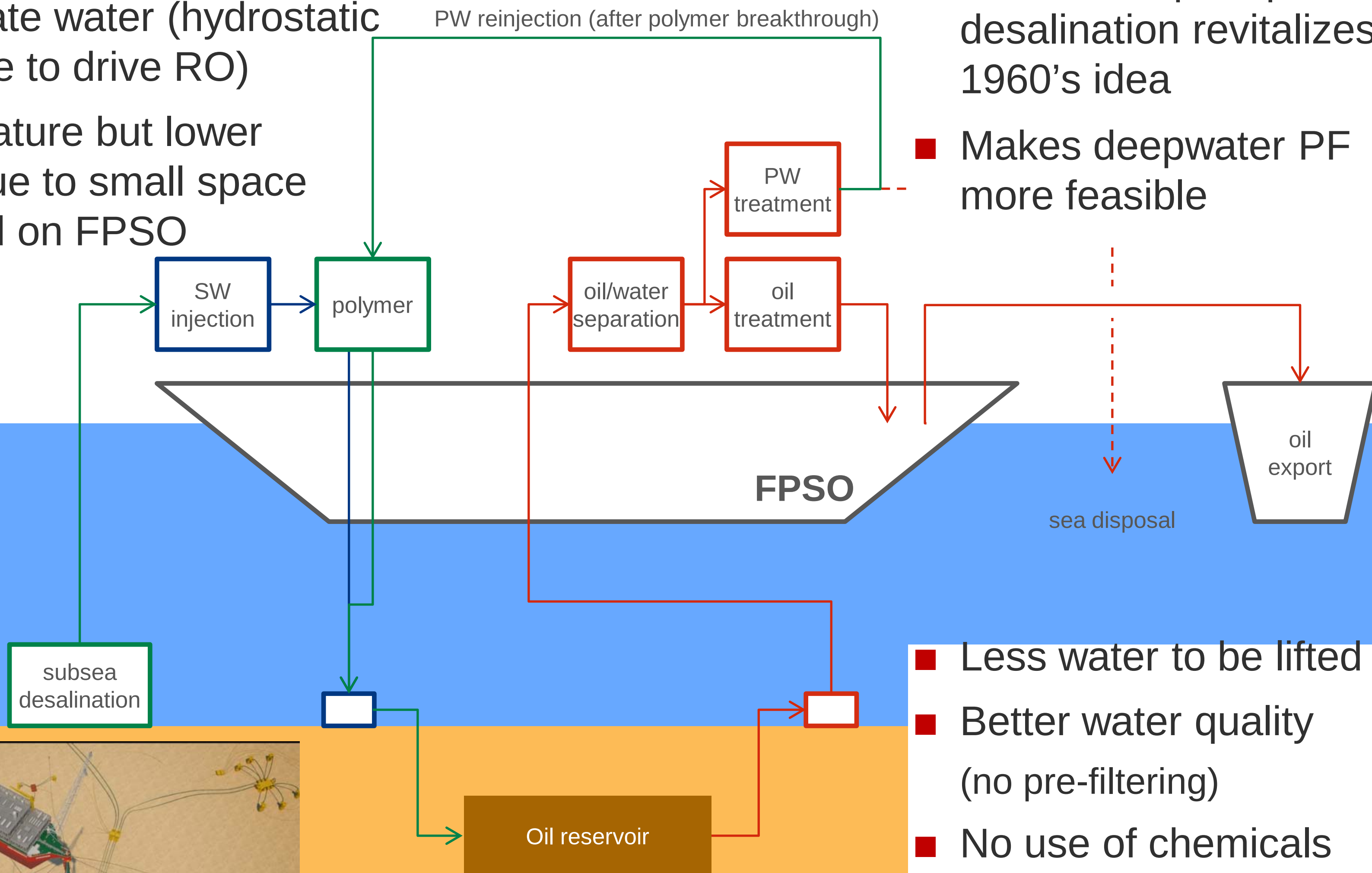
Separate Desalination Vessel

- Easier to retrofit, flexible
- Saves deck space
- May require additional license

New concept: Subsea Desalination for LSF

- Use subsea conditions to desalinate water (hydrostatic pressure to drive RO)
- Less-mature but lower costs due to small space required on FPSO

- Shell concept of passive desalination revitalizes a 1960's idea
- Makes deepwater PF more feasible

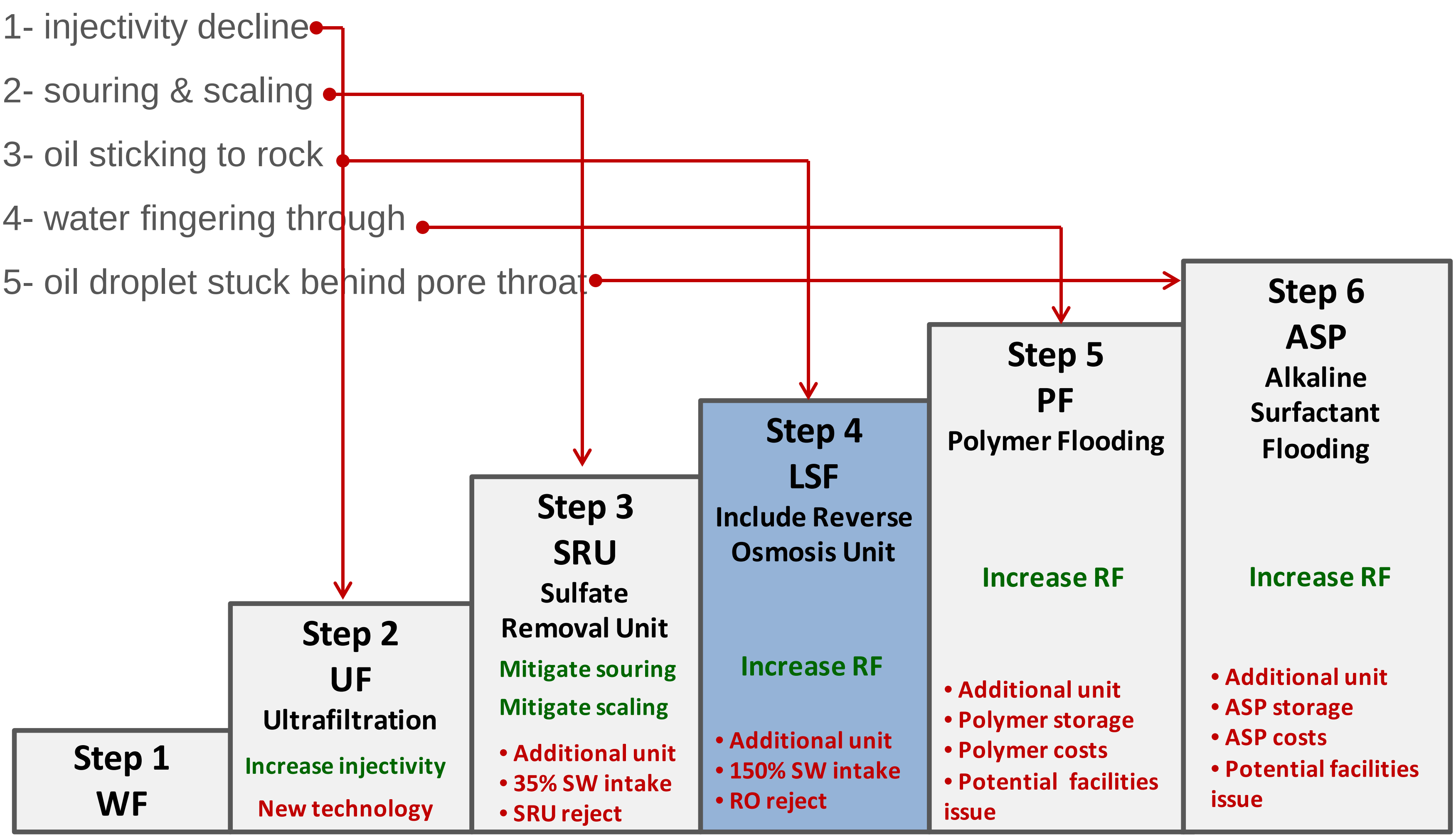


- Less water to be lifted
- Better water quality (no pre-filtering)
- No use of chemicals
- Suited for retrofitting
- Less pump energy required

Water Desalination Report, Vol. 50, issue 18, 2014

Is LSF the end-game?

- Facilities staircase approach from WF to cEOR



Key learnings

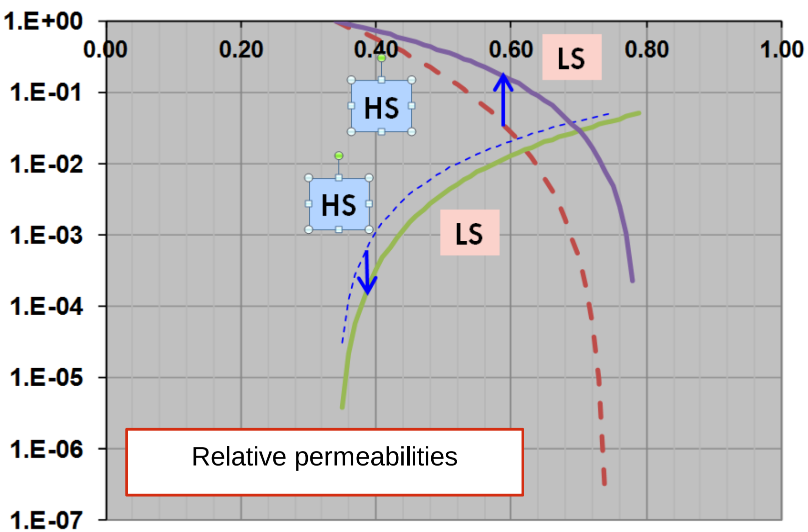
- LSF is ready for offshore deployment (including deepwater)
  - There are no technical showstoppers (risks are ranked low to moderate)
- However: an economic threshold needs to be passed
  - Biggest cost item caused by low efficiency of RO unit
  - Start LSF from day 1 to maximize the economic benefit
  - Retrofitting is expensive but not necessarily uneconomic (if not too late)
  - Well spacing and placing of injectors are critical to the economic success
- LSF is a significant scope increase over conventional WF, but modest relative to SRU

Summary & Conclusions

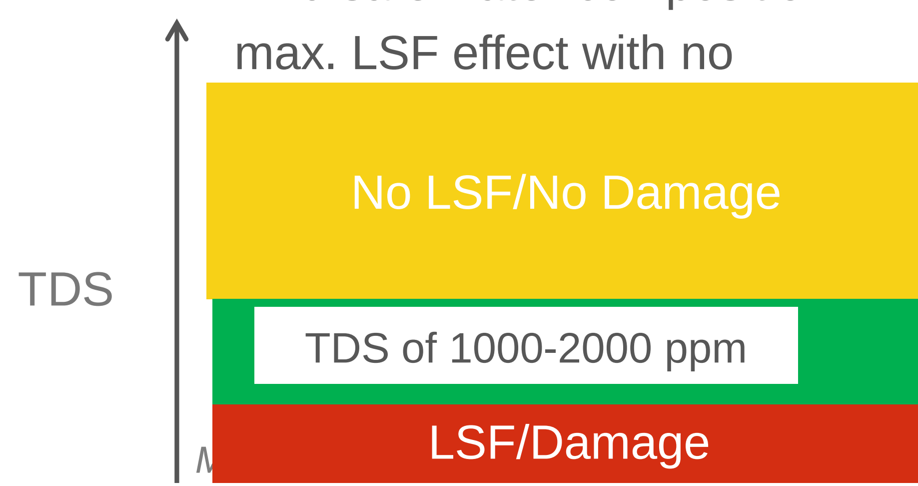
- Water quality has key impact in waterflood performance
- A suite of technologies is used to manage water quality
- LSF provides the “best water quality” improving “in one-go” souring, scaling, injectivity decline, *well longevity* and out-of-zone injection control.
- Laboratory evidence and convincing onshore field evidences provide confidence that LSF is deployable in offshore fields
- Shell wide screening is currently ongoing with 10+ projects progressing in parallel for potential (full) field development. At least half are offshore
- Significant progress has been made in preparing all aspects of implementation: subsurface, surface, risk assessments
- Smart and innovative solutions are developed to reduce costs in moving towards more complex EOR offshore

LSF deployment offshore: subsurface - SCAL testing is key

- For offshore applications:
  - Field testing (LIL/SWCTT): too expensive & too difficult to execute; (injectivity tests could be done → only to de-risk clay swelling)
  - Results close to Sor may not be relevant (not addressing acceleration)
  - Phased implementation offshore is uneconomic
- First step in deployment: raise the quality of SCAL
  - New SCAL protocols rolled out (all WF SCAL include LSF by default)
  - Requires in-situ saturation monitoring + accurate oil production
  - Focus: quantifying LSF incremental oil + de-risk for formation damage



- Find safe water composition: max. LSF effect with no



LSF deployment offshore: subsurface - upscaling

- Offshore field example: retrofitting
- Main factors when upscaling:
  - Volumetric sweep
  - Mixing & dispersion
- Additional:
  - Strong dependence on start LSF: delay leads to lower incremental
  - BSW constraints for producers could play important role (70-80% for some subsea wells)
- In spite of retrofitting the LSF incremental is still significant -- the project is economic (unless it is started too late)

Status of LSF deployment in Shell

- **Business decision** screen the whole Shell portfolio both onshore & offshore
- **Strategy:** All WF healthchecks include screening requirements for LSF
- Priority: cases which require very good water quality to either maintain matrix injection as long as possible or require souring and scaling control
- If SRU is included in the base WF concept then RO has to be screened

Fields/ assets	Type	LSF SCAL testing				LSF projects ORP				
		Started	Completed	Results	Formation damage	Subsurface forecast	Facilities design	Economics	Integration	PRIORITY
Field 1	Onshore			positive	NO					HIGH
Field 2	Onshore			positive	NO					HIGH
Field 3	Offshore									HIGH
Field 4	Offshore									HIGH
Field 5	Offshore									HIGH
Field 6	Onshore			positive						HIGH
Field 7	Onshore									HIGH
Field 8	Offshore									HIGH
Field 9	Offshore			positive						MEDIUM
Field 10	Offshore			positive?						MEDIUM
Field 11	Offshore									MEDIUM
Field 12	Offshore									MEDIUM
Field 13	Offshore			unclear	NO					LOW
Field 14	Offshore									LOW
Field 15	Offshore									LOW