Reservoir Souring Challenges and Solutions from the Operators Perspective

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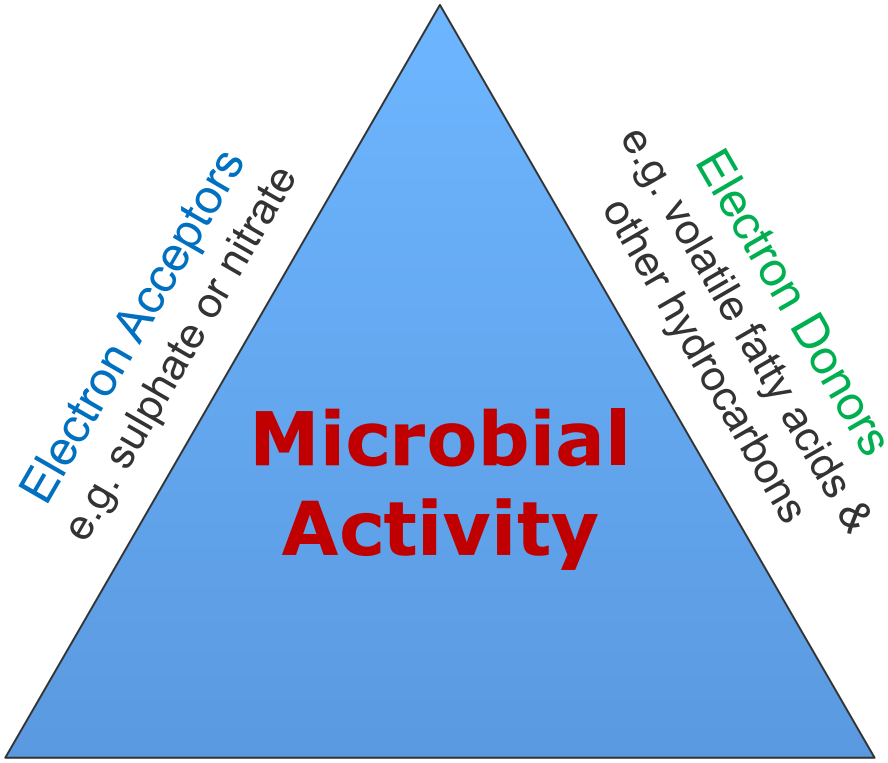
Introduction

Presentation Outline

- Reservoir Souring Introduction
- Impact of reservoir souring
- Reservoir souring management
- New Field development
- Conclusions

Introduction

Microbial Activity



Environment
- Physical
- Chemical
- Biological

Sulphate Reducing Bacteria (SRB)

Organic compound electron donors + SO_4^{-2}

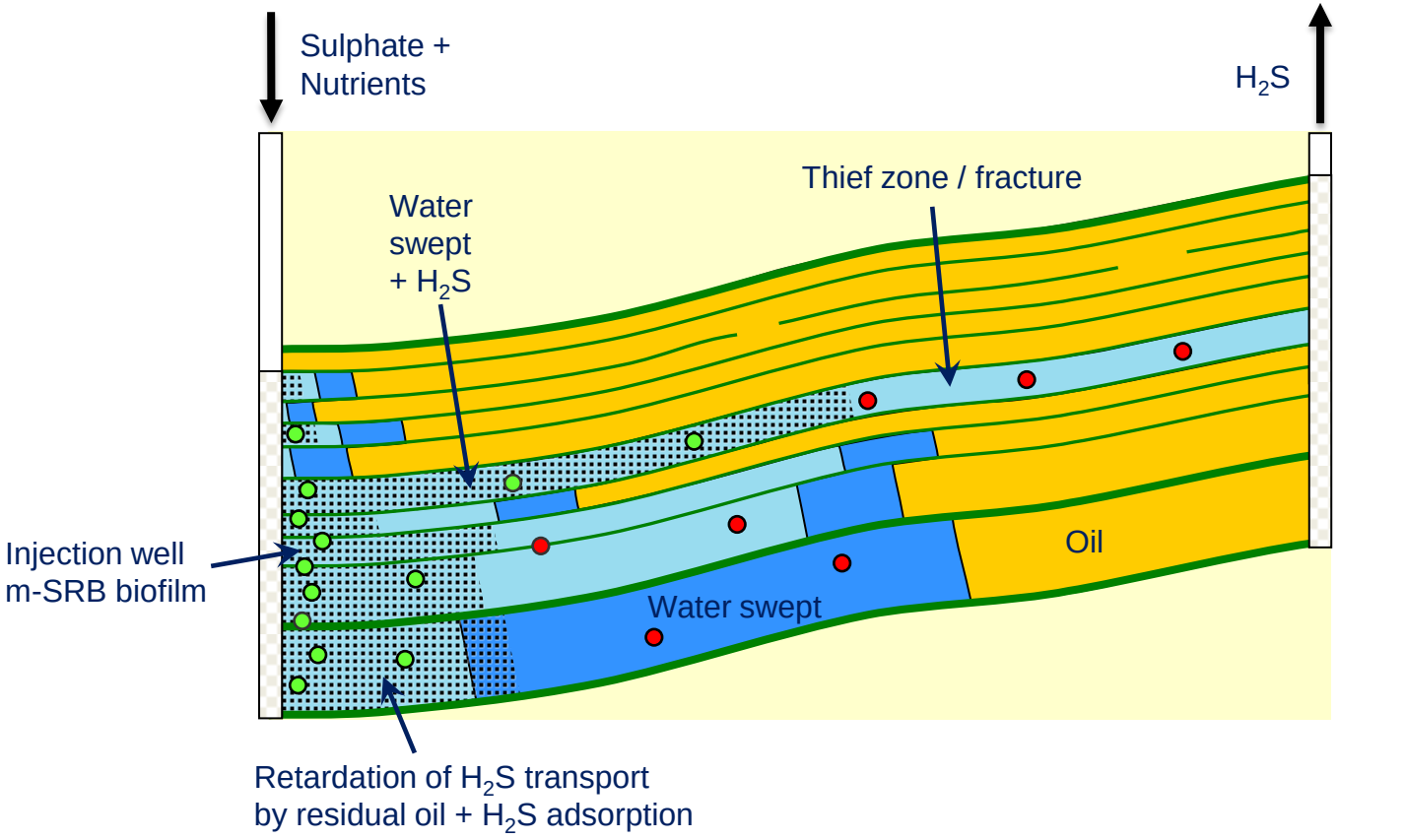
= CO_2 + H_2S

Nitrate Reducing Bacteria (NRB)

Organic compound electron donors + NO_3^-

= CO_2 + NO_2^-, N_2

Reservoir Souring Schematic



Impact of Reservoir Souring

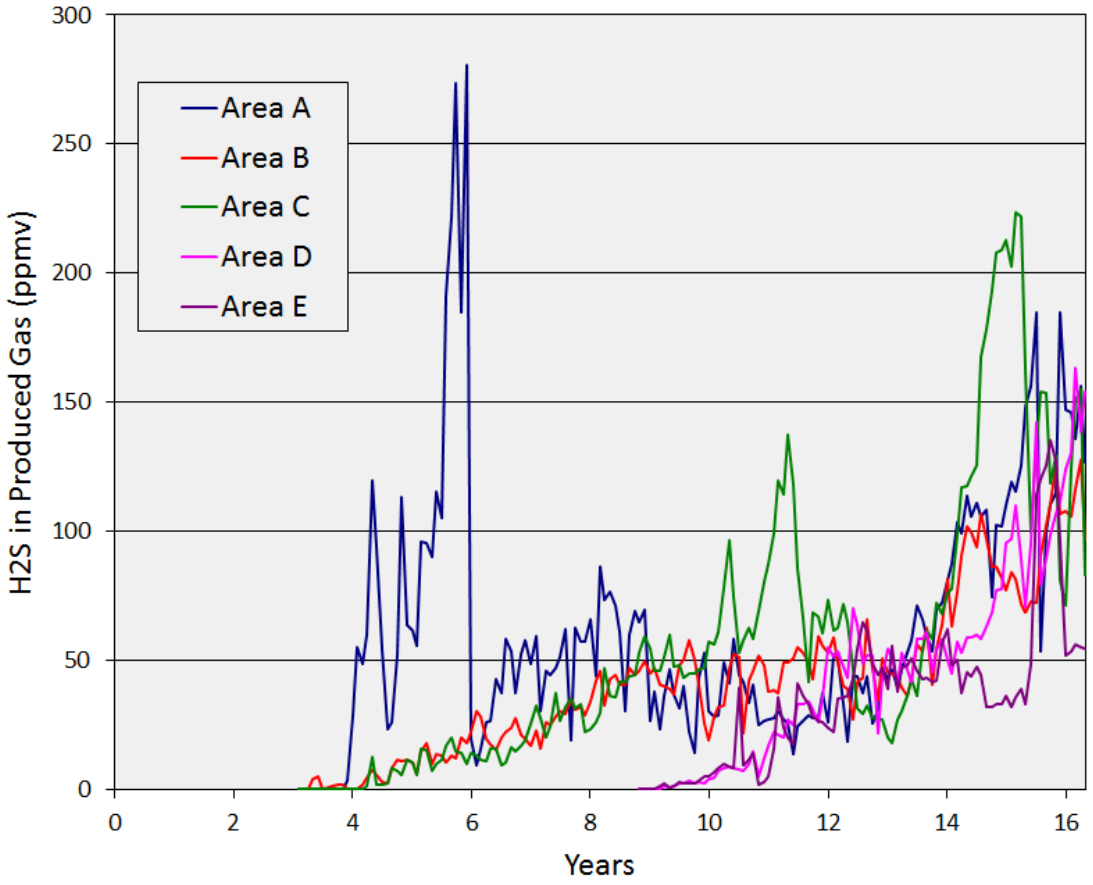
- HES impact of producing a toxic gas
- Achieve export gas H_2S specification
- Sizing / selection of H_2S scavenging equipment
- H_2S partial pressure, NACE and metallurgy selection
- Knock down factors for riser fatigue allowance
- Injection water treatment for souring mitigation

- Multi-million dollar economic implications
  - Shut-in of production
  - Replacement of equipment for metallurgy upgrades
  - Treatment chemical costs

Agbami FPSO, 4,700 ft water depth

Example of Souring Development

- Offshore field with seawater injection
- Injector-producer transit time of several years
- Progressive deployment of seawater injection across the field
- H_2S profiles are combined production for 5 to 10 wells
- Spikes in H_2S correspond to high H_2S levels in individual wells



Souring Prevention

- Batch biocide treatment of injection water
  - Chevron experience is that batch biocide dosing does not reliably prevent reservoir souring
  - Required to control biofilm development in water injection system
  - Low dose continuous biocide? (NACE 11219, 2011)

- Nitrate treatment
  - Complex modes of action, but competition for electron donor appears to be the dominant mechanism
  - Typically dosed continuously
  - High dose rates (>200 ppm chemical) may be required for PWRI or low temperature reservoirs
  - Large volumes of chemical may be required
  - Mixed experience with nitrate in the oil industry

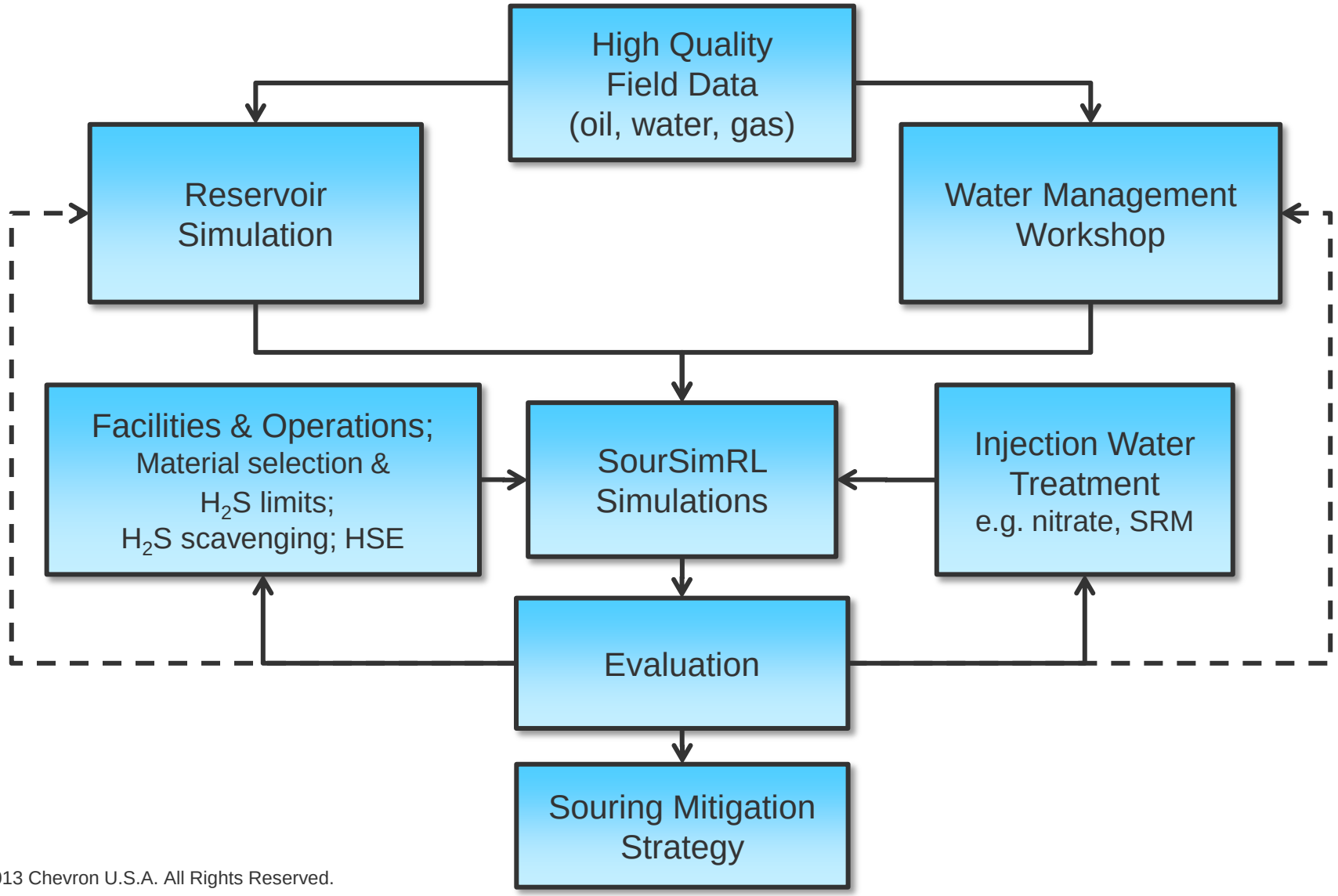
Souring Prevention

- Sulphate removal
  - Reduce injection water sulphate to 10-40 mg/l
  - Highest confidence mitigation strategy
  - Large footprint process equipment
  - Sulphate removal more difficult for produced waters
  - Should not inject “off-spec” water, and this can lead to shut-in of water injection system
  - Must treat the injection water from the start of injection
- Choice of injection source water
  - Choose low sulphate or low dissolved organic carbon source water
  - Seawater, PWRI, aquifer, river, lake
- Perchlorate?

Tombua-Landana Platform with SRM

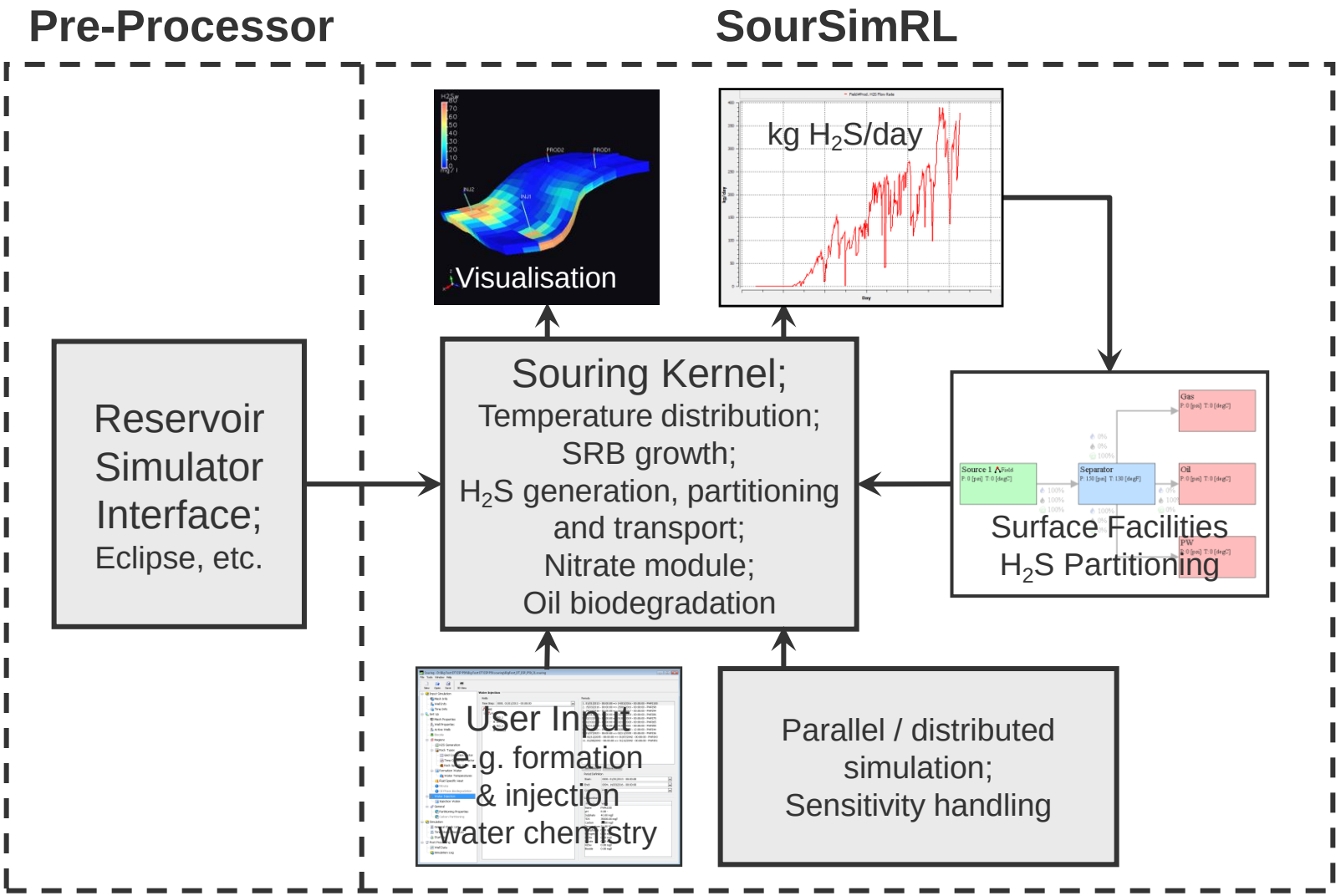
Souring Study Workflow

Development of Souring Mitigation Strategy



Souring Study Workflow

SourSimRL (SSRL) Souring Simulator



New Field Development

Subsurface Properties

- Offshore, deep water development
- High API, low oil viscosity
- Reservoir pressure close to bubble point
- Good waterflooding properties
- Important to maintain pressure via water injection voidage replacement

Lithology / Depositional Type	Siliciclastic sandstone deposited in a fluvial to shallow marine environment
Seawater Depth	4,000 ft
Reservoir Depth	9,100 ft
Reservoir Temperature	79 C

Reservoir Oil	Mol%
N_2	0.29
CO_2	0.03
H_2S	0.00
C1	52.7
C7+	35.8

Formation Water	(mg/l)
Chloride	7,160
Sulphate	50
VFA (acetate, etc.)	430
Barium	6
Calcium	1,291
TDS	12,866

New Field Development

Facilities and Commercial

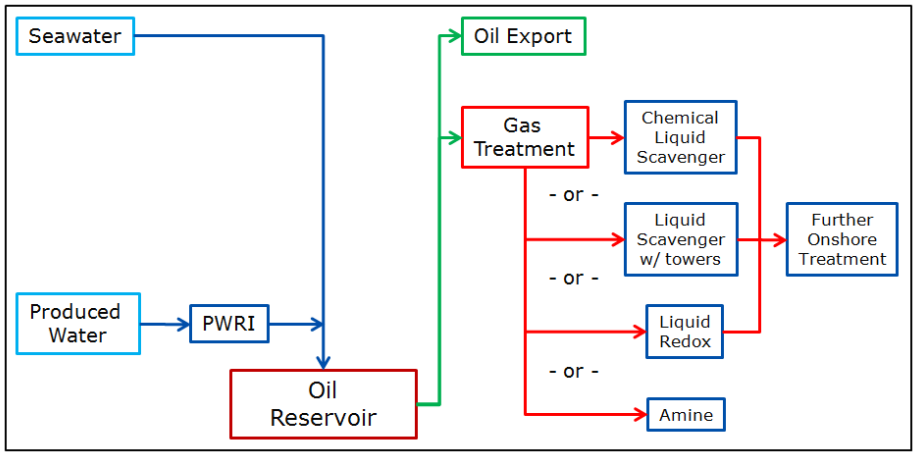
- Limits of between 240 and 400 ppmv H_2S on flexible risers
- Commercial consideration
  - Low delivery H_2S specification
- Options for seawater pre-treatment
  - Sulphate removal unit (nanofiltration)
  - Reverse osmosis unit (hyperfiltration) – low salinity waterflood
    - EOR potential application
  - Continuous nitrate dosing
  - Biocide batch dosing is required for MIC control
- Options for gas treatment
  - Liquid scavenger
  - Offshore and / or onshore amine unit

Example onshore amine plant

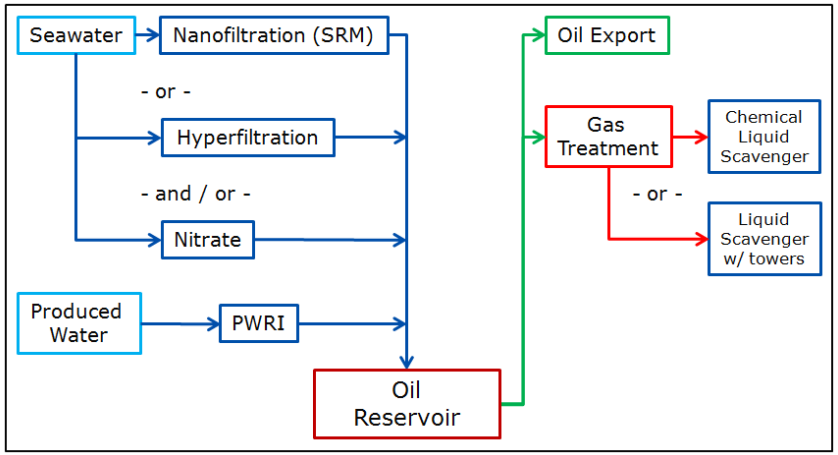
New Field Development

Treatment Options

Options without Water Pre-Treatment



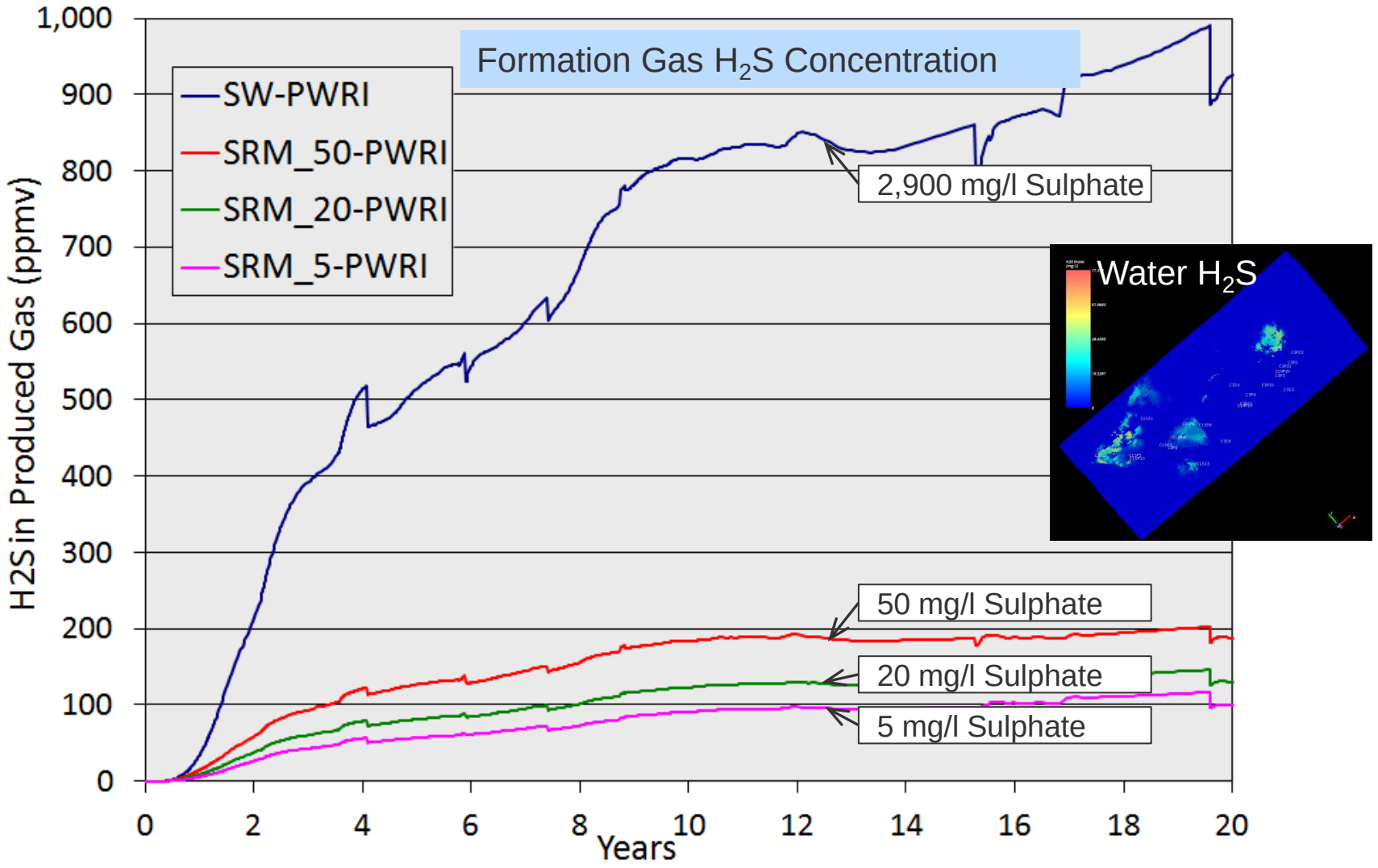
Options with Water Pre-Treatment



- Two different approaches:
  - Inject water without pre-treatment, and deal with H_2S in production facilities
  - Pre-treat the injection water to minimise H_2S scavenging requirements
- Project selected PWRI in alignment with Chevron Environmental Performance Standard
- SourSimRL cases run to evaluate different injection water treatments and associated H_2S scavenging requirements

New Field Development

P90 Field H_2S Profiles



New Field Development

Nitrate Treatment Simulations

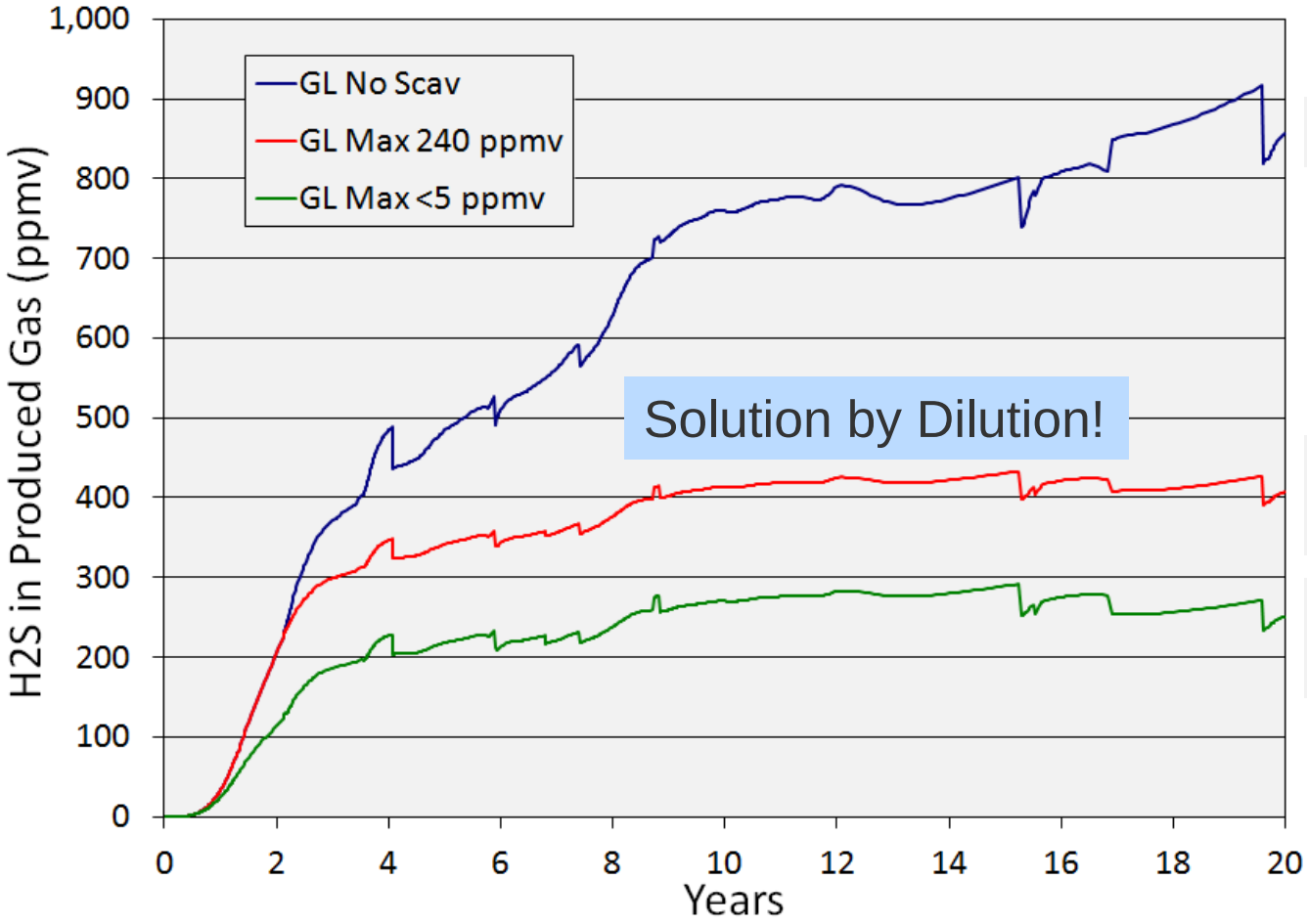
Injection Water	Nitrate Ion Dose (mg/l)	P90 H_2S Conc. (ppmv)	% Reduction in H_2S Conc. with Nitrate
SW-PWRI	0	991	0%
SW-PWRI	100	593	24%
SRM_20-PWRI	0	146	0%
SRM_20-PWRI	100	144	1%

- SourSimRL model setup is conservation (pessimistic) with respect to the effectiveness of nitrate treatment
- Very low impact on SRM-PWRI (20 mg/l sulphate) because sulphate is the limiting factor and nitrate treatment acts on carbon availability

New Field Development

Lift Gas H_2S Scavenging

Impact of Gas Lift H_2S Scavenging



No H_2S Scavenged

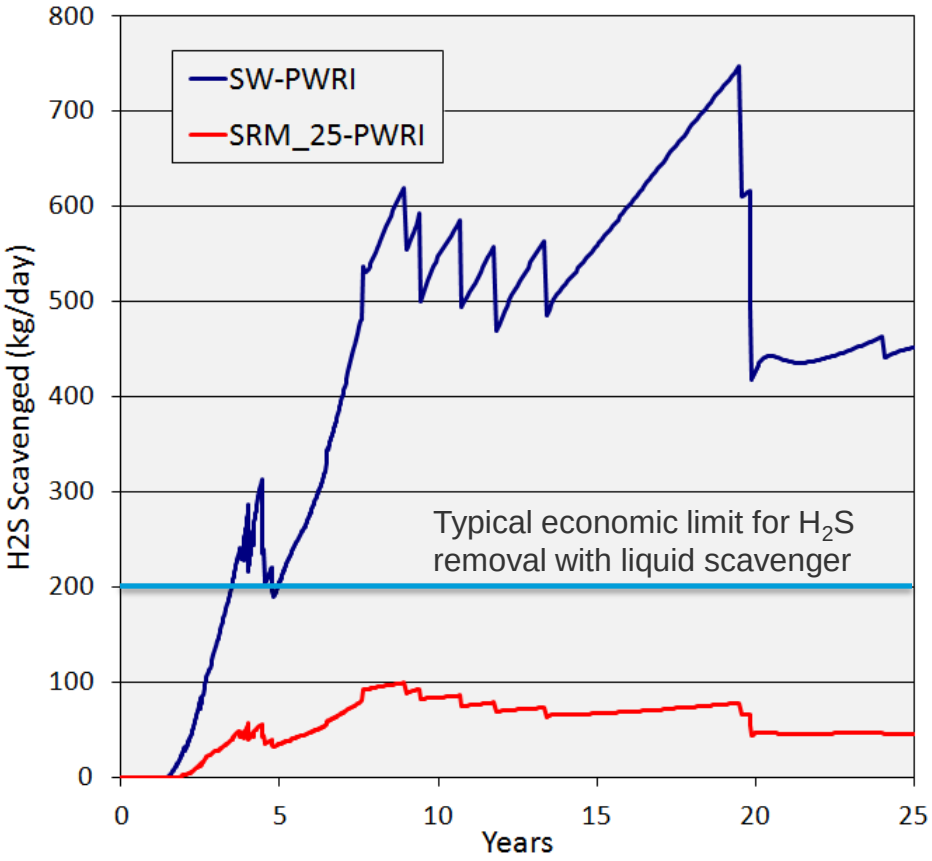
H_2S Scavenged to max 240 ppmv

H_2S Scavenged to max 2.3 ppmv

New Field Development

H_2S Scavenging Rate

- SW-PWRI
  - Requires process equipment offshore to meet export gas flexible riser requirement
- SRM_25-PWRI
  - H_2S limits can be achieved with liquid scavenger
- SRM treatment of injection water means that:
  - No need for costly offshore treatment equipment i.e. amine plant
  - Tight gas H_2S export specification can be met **reliably** and existing export pipelines can be used



SRM_25 denotes sulphate removal membrane treated seawater with a target sulphate concentration of 25 mg/l

Conclusions

- Essential to development of microbiological souring management plan during field development phases
- Management plan must include injection water treatment, metallurgy of construction and H_2S removal requirements in production system
- Reservoir souring simulations are key to techno-economic evaluation
- Souring simulations need to consider:
  - Gas lift and H_2S scavenging
  - H_2S limits from materials, especially riser fatigue life
- Low sulphate water injection limits souring development, but doesn't necessarily prevent it entirely