eor by SNF
Enhanced Oil Recovery

Reducing Carbon Intensity
While Maximizing Oil Recovery

EOR – Reducing Carbon intensity while maximizing oil recovery

February 2023

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SNF
WATER SCIENCE

POLYMER FLOODING

A MATURE TECHNOLOGY CONTINUOUSLY IMPROVED

More than 320 chemical injections in the US

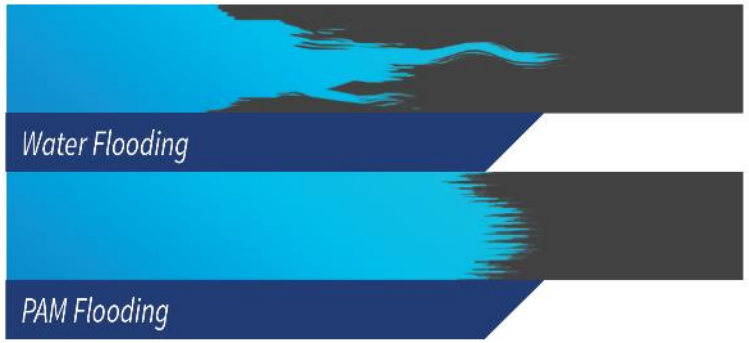
1976 - 1982

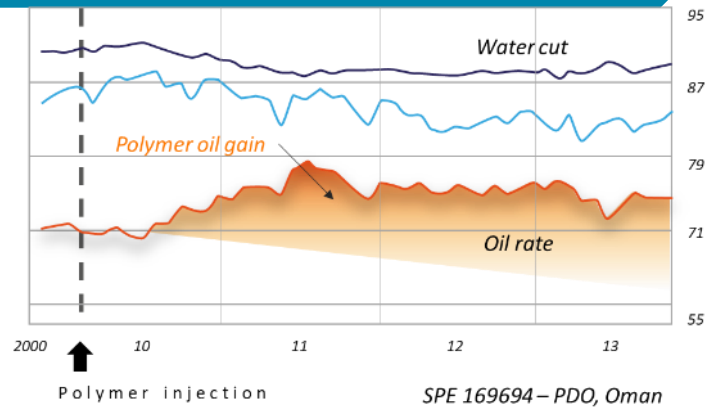
Large successes in China

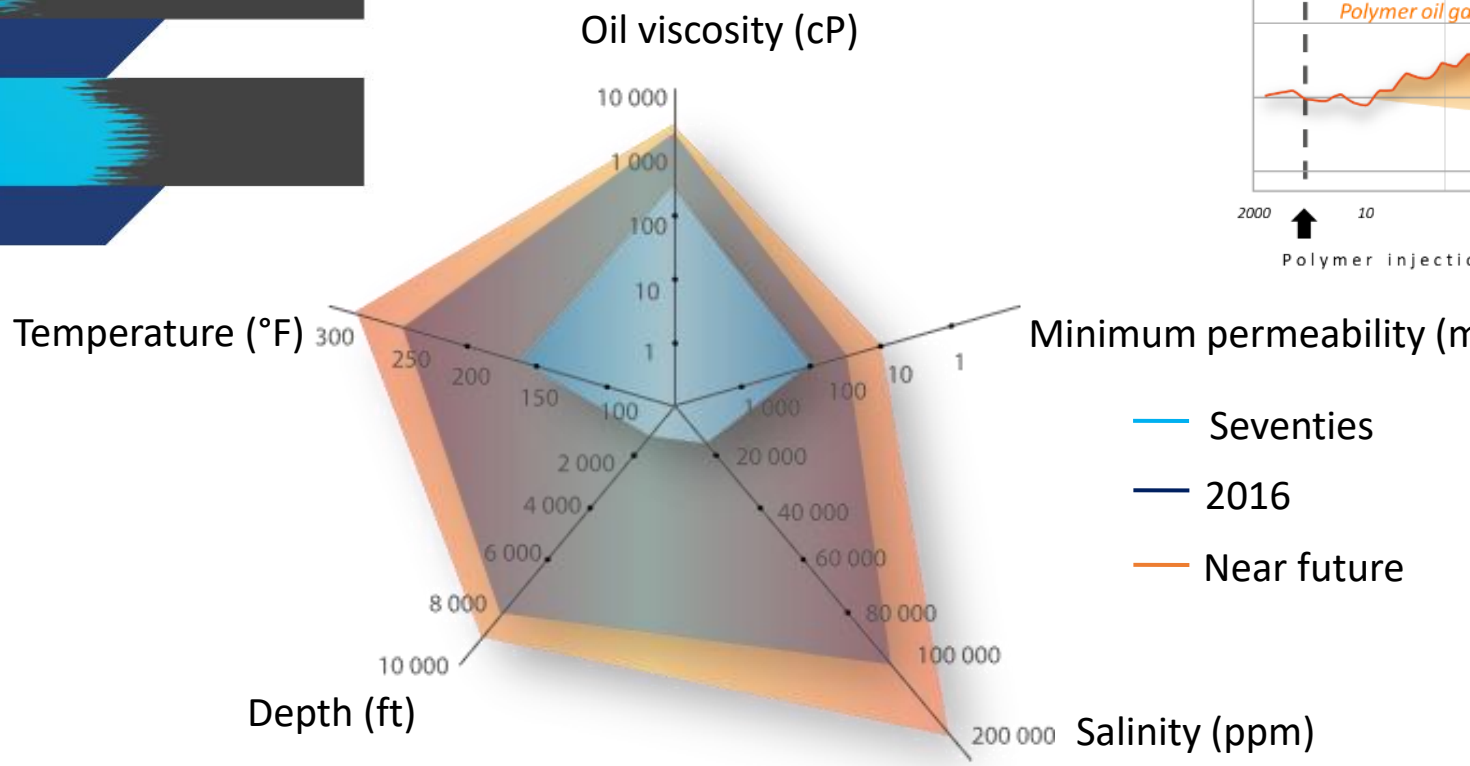
1989 -2000

More than 350 projects all around the word

2010 - …







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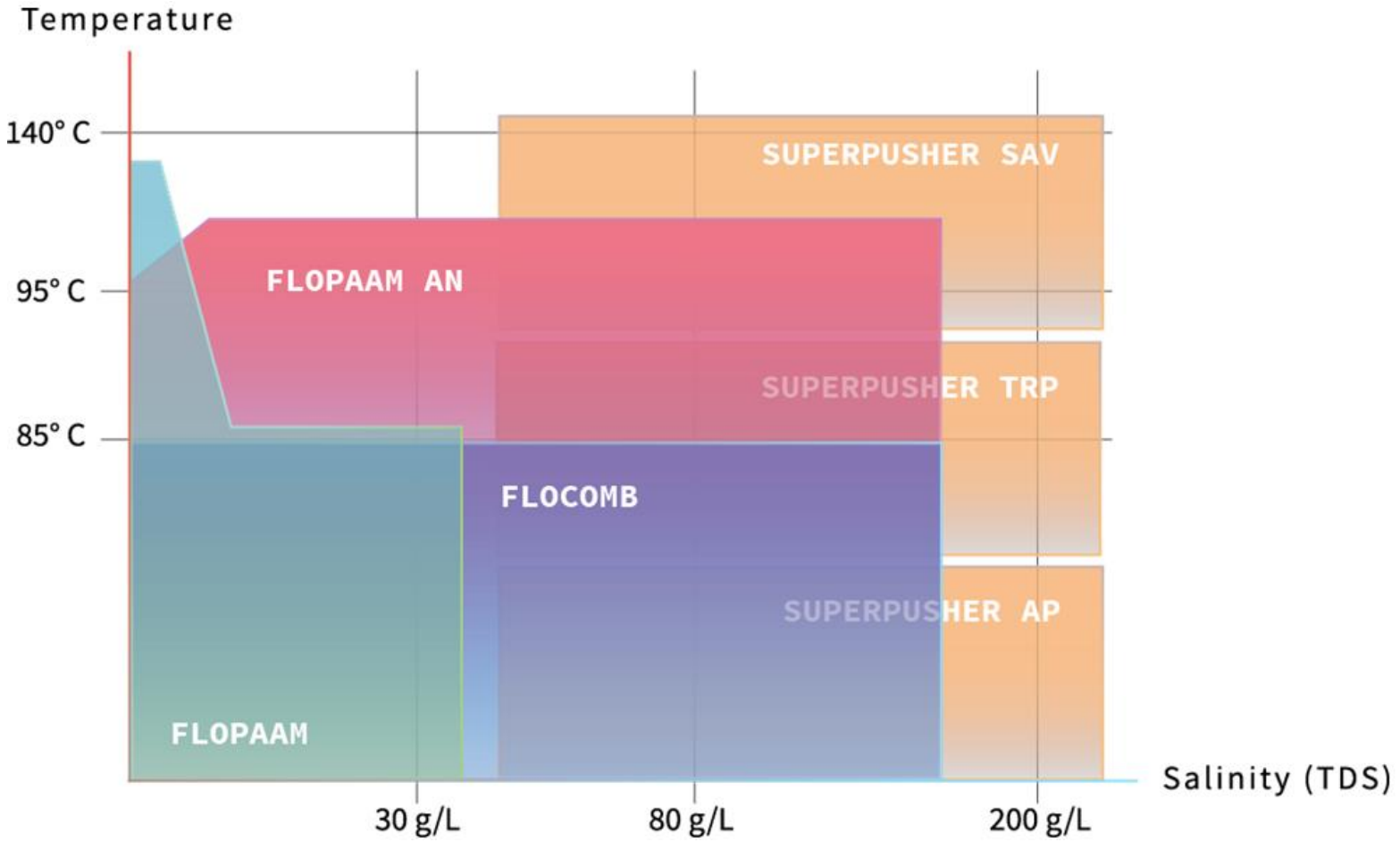
EOR POLYMER RANGES

- **ANIONIC POLYACRYLAMIDE**
  Up to 75°C - 85°C
- **SULFONATED CO & TER POLYMERS**
  Up to 100°C – 105°C
- **SUPERPUSHER SAV POLYMERS**
  Up to 140°C
- **ASSOCIATIVE POLYMERS**
  Higher viscosities up to 75°C
- **FLOCOMB POLYMERS**
  High salinity, up to 85°C - 90°C
- **THERMORESPONSIVE POLYMERS**
- **F3P - PROTECTED POLYMER PACKAGE**
  Up to 120°C with O_2, Iron and H_2S



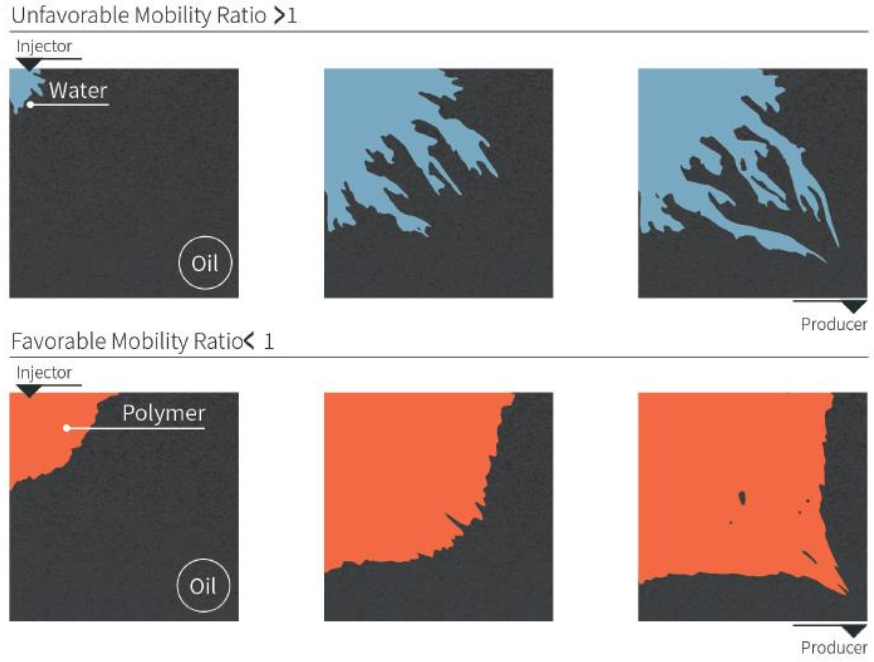
POLYMER FLOODING – A PROVEN TECHNOLOGY

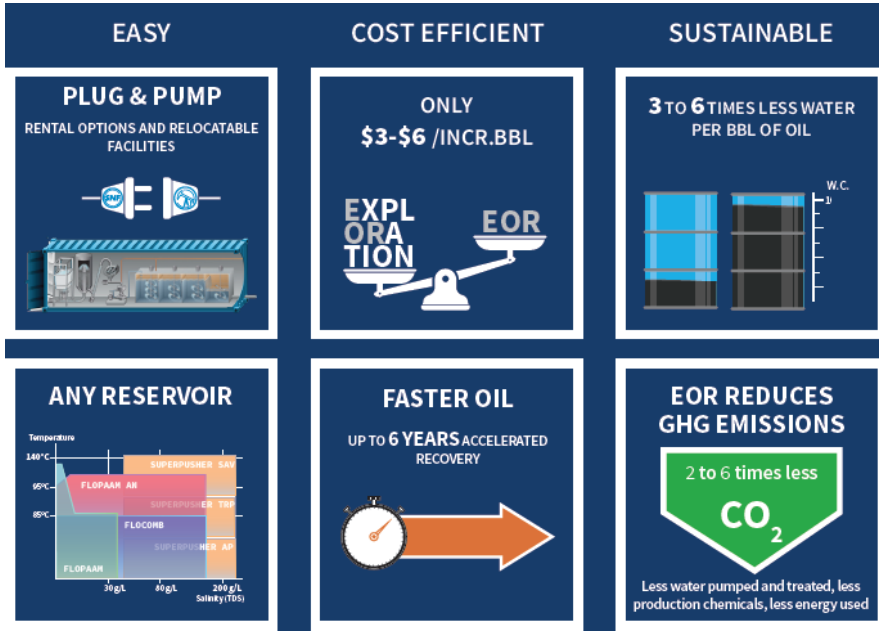
- Proven EOR technology with more 350 applications worldwide
  - First applications in the US in the 70's / 80's
  - China polymer flood in the 90's
  - Worldwide pilot and full field since 15 years

- Improves reservoir sweep efficiency
  - Improves mobility control ratio between water and oil
  - Promotes crossflow to increase oil recovery

- Cost is limited to $3 to $6 per incremental barrel
  - Polymer EOR allows recovery of **8 to 20% incremental oil**
  - Cheaper than Exploration & Production activities

- Accelerates oil recovery / **Reduce CO_2 footprint / Save water**
  - Operators reports up to 6 years acceleration in recovery
  - Main driver: **Water cut reduction**
  - Extra Oil production from un-swept area





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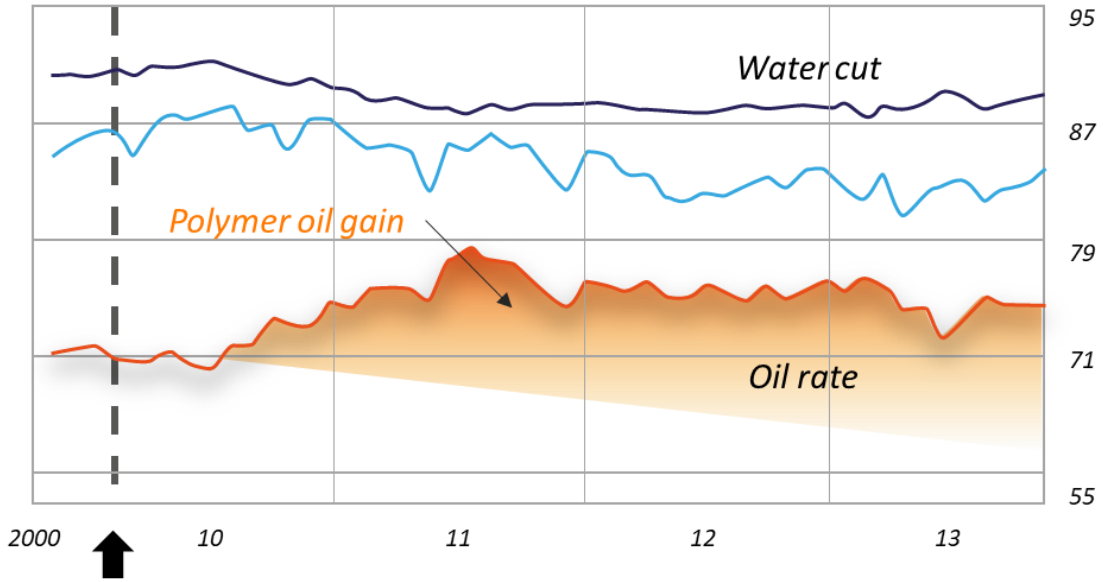
POLYMER FLOODING – A PROVEN TECHNOLOGY



SPE 169694 – PDO, Oman

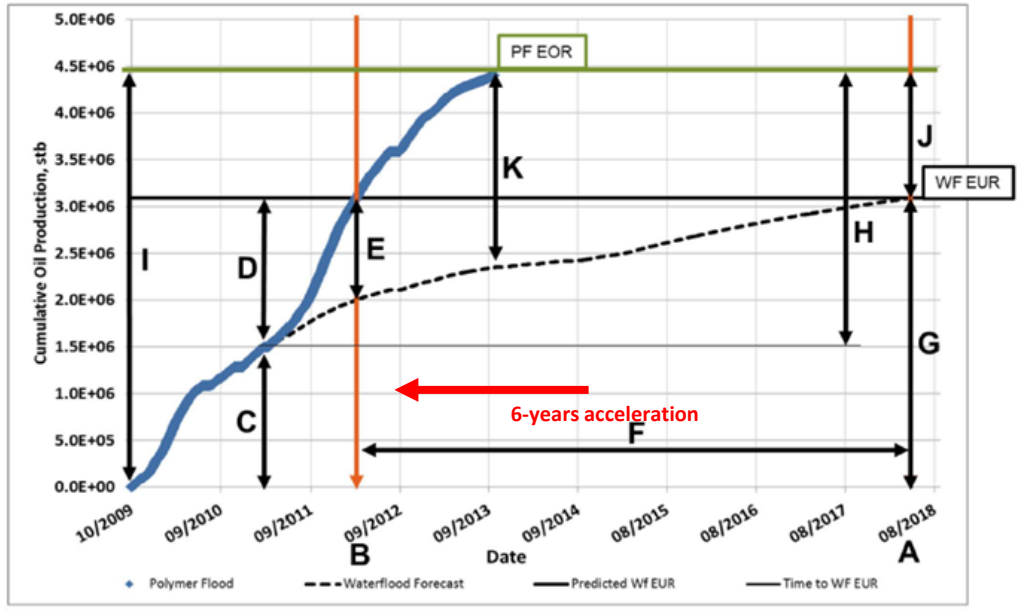


Figure 10—Captain EOR Pilot production and EOR terminology designations to report chemical flood performance

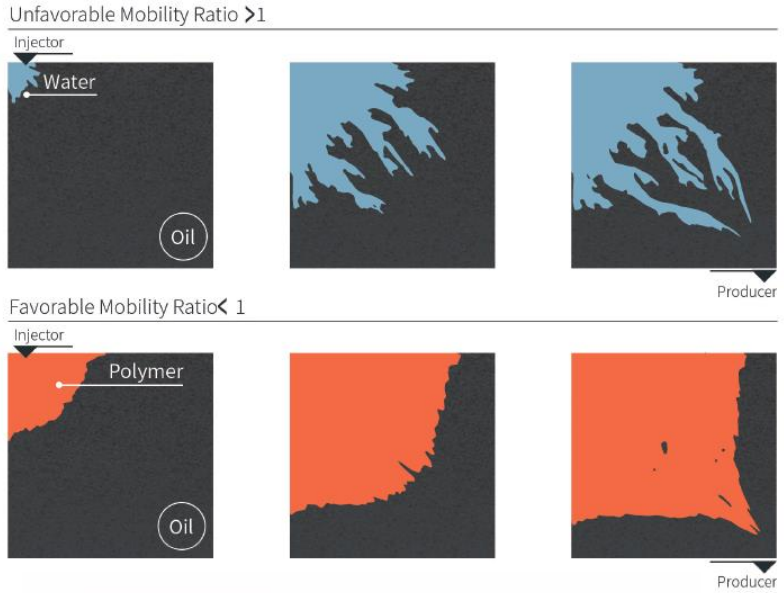
SPE 190175 – Chevron, Captain (UK)

POLYMER FLOODING

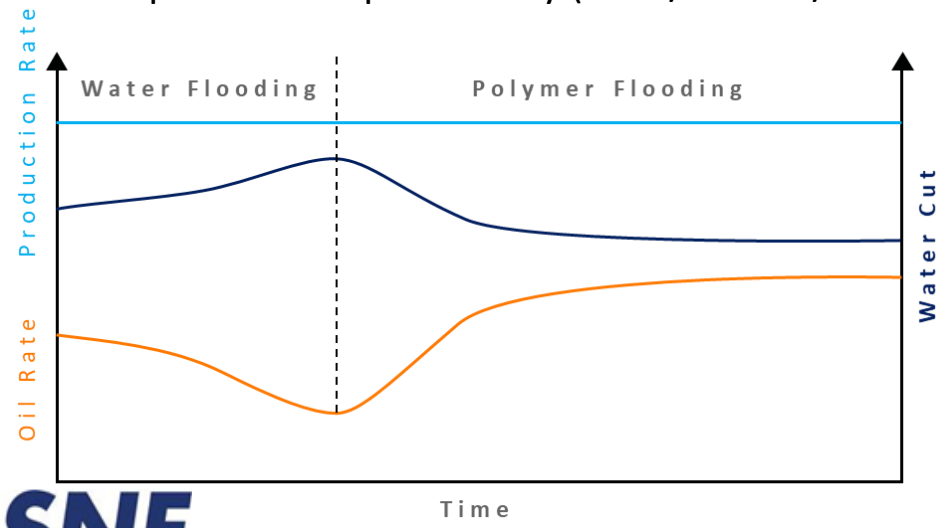
- PF improves mobility ratio between water and oil

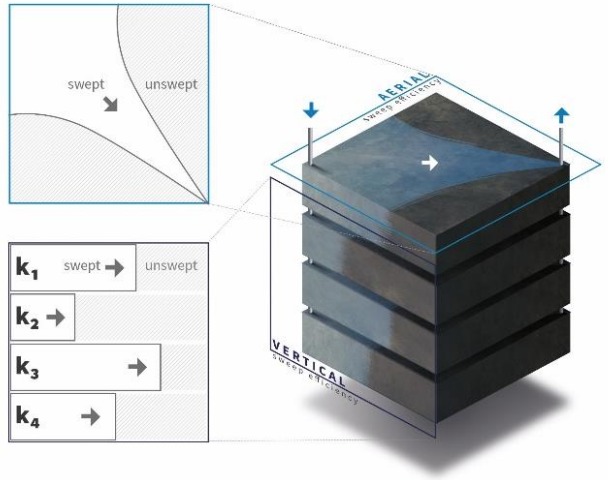
$$Mobility\ ratio = \frac{\lambda_{water}}{\lambda_{oil}} = \frac{\kappa_{water} / \mu_{water}}{\kappa_{oil} / \mu_{oil}}$$

- PF limits or prevents water fingering



- PF improves sweep efficiency (areal/vertical/microsco

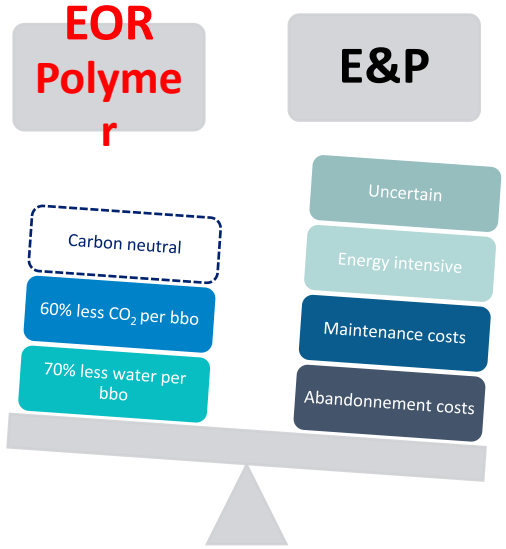




HOW TO SATISFY THE OIL DEMAND?

- Main contribution = mature conventional reservoir → declining production
  - 60% of the reservoir under water injection and produce at high Water Cut
  - Excessive water production => main factor responsible for excessive CO_2 emissions
- Two options:
  - Getting more from existing field / assets
  - Looking for and developing new reservoir

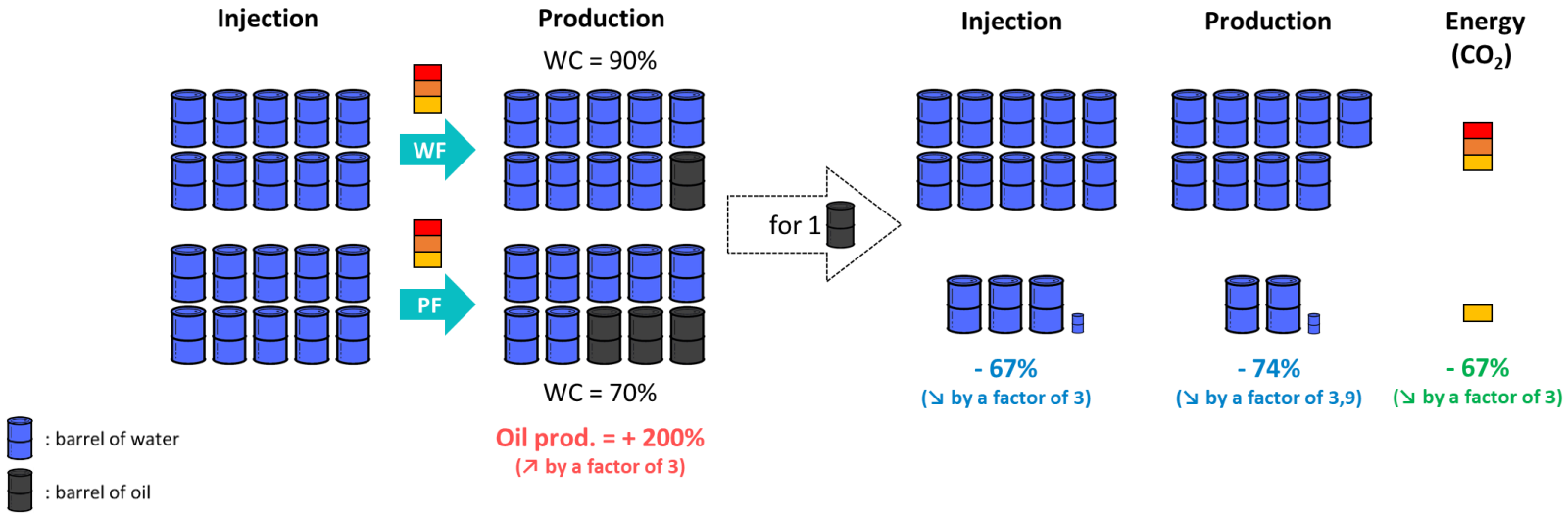
- 3 to 6 $/inc. bbo
- Cleaner and faster oil
- Existing infrastructures



- 7 to 10 $/inc.bbo
- Could suffer from thougher legislation

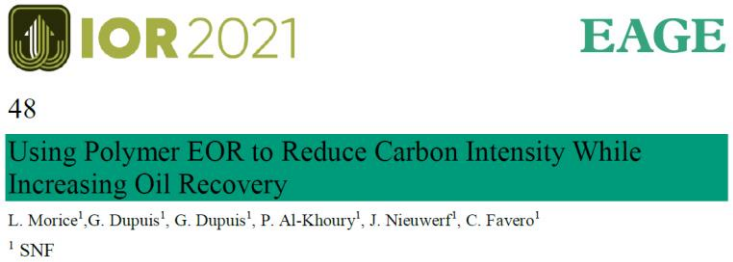
ENVIRONMENTAL IMPACT OF POLYMER FLOODING

- Main driver = reduction of water cut making fluid injection more efficient



- **Reduction of 67% of the CO_2 emission** per extra barrel of oil

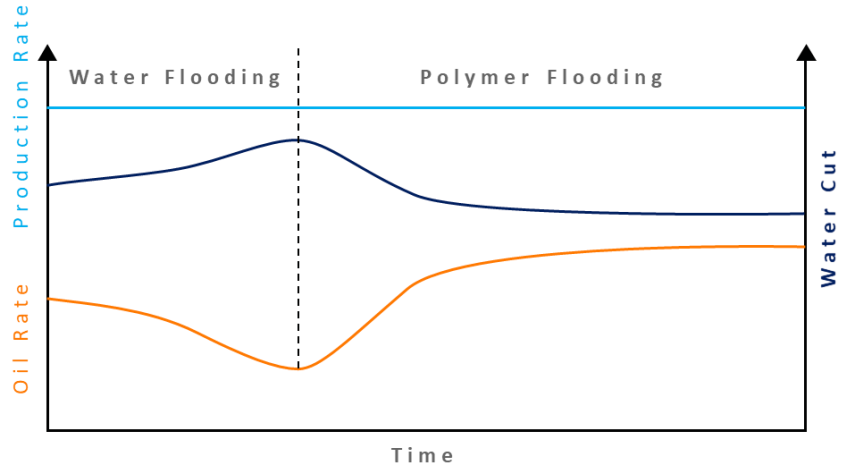
- Related publication:

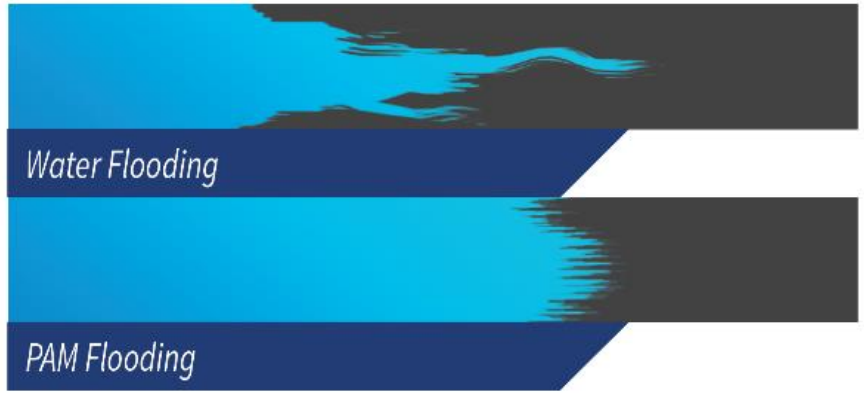


Polymer Flooding : A Sustainable Technology

- **Objective = Demonstrate the environmental benefits of polymer flooding**
  - Less 60% of CO_2 per barrel of oil produced in average
  - Less 70% to 80% of water use per barrel of oil produced in average
  - Polymer flooding is carbon neutral from a chemical point of view

- Main driver = water cut reduction
  - 60% of the reservoir under water injection and produce at high WC
  - Excessive water production => main factor responsible for excessive CO2 emissions





Polymer Flooding : A Sustainable Technology

System boundaries

- Energy consumption determination of each elements of the WF and PF operations
  - Water treatment
  - Lifting system
  - Polymer dissolution/preparation unit

- Determination of CO_2 emissions related to both process
  - Energy consumption converted in emission factor using local Energy emission factor
  - Oil field chemicals (manufacturing + transport)
  - Polymer (manufacturing + transport)

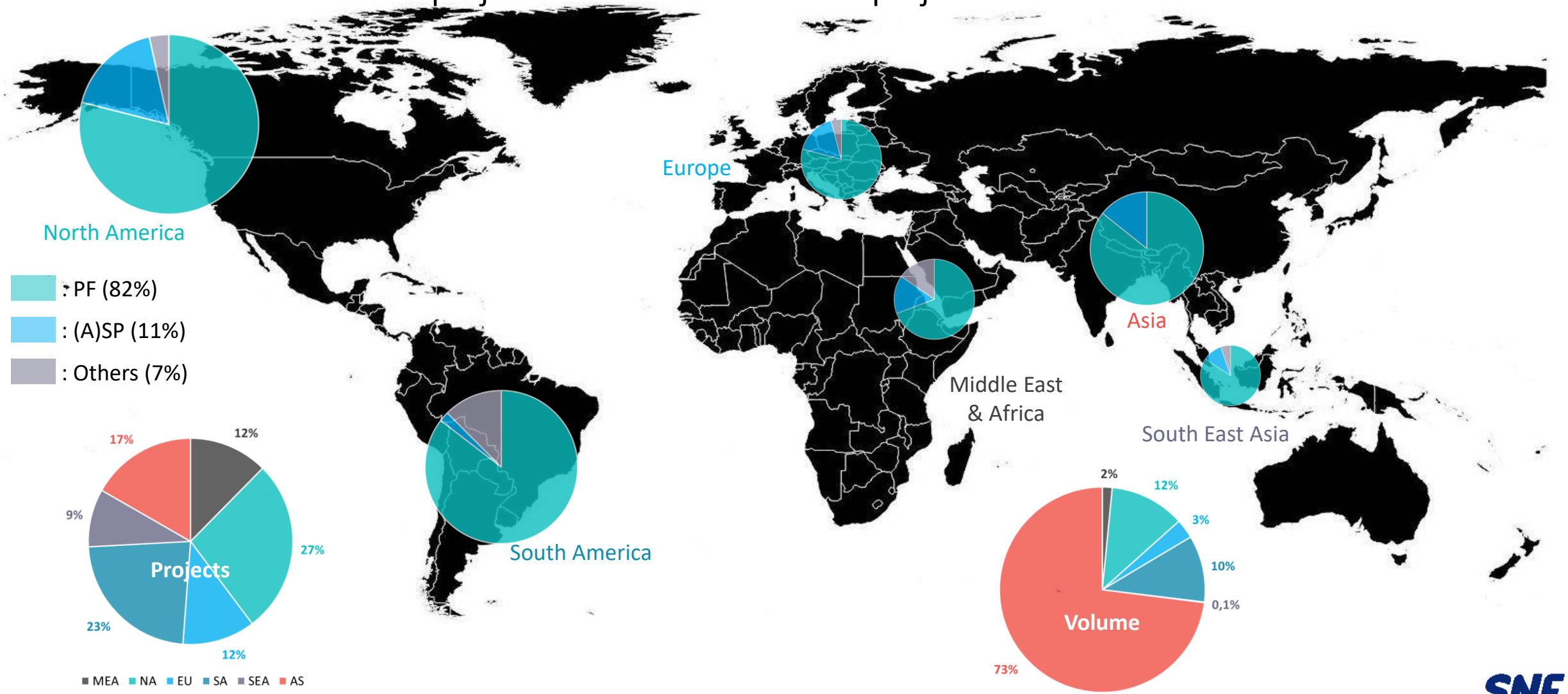
- Assumptions :
  - No gas production
  - Produced water disposal not considered

CHEMICAL EOR – AN EXPANDING ENVELOPPE OF APPLICATION

Parameter	Yesterday	Today	
Oil viscosity	<200 cP	<10 000 cP	Canada, Venezuela
Temperature	<95°C	<140°C	Brazil, Middle-East …
Permeability	>100 mD	>10mD	Middle-East …
Salinity	Low	<250g/l TDS	Kazakhstan, Middle East
Cost at iso-viscosity	1500 ppm@$4/kg	1000 ppm@$2/kg	Higher MW improved chemistries

FIELD PROVEN TECHNOLOGY

- More than 200 active projects over about 350 C-EOR projects



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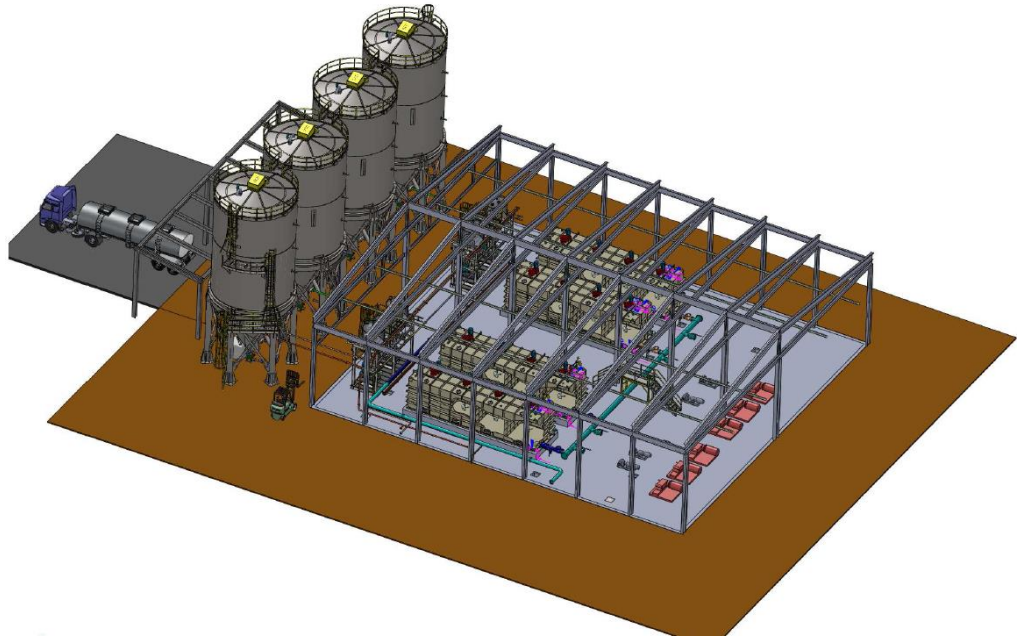
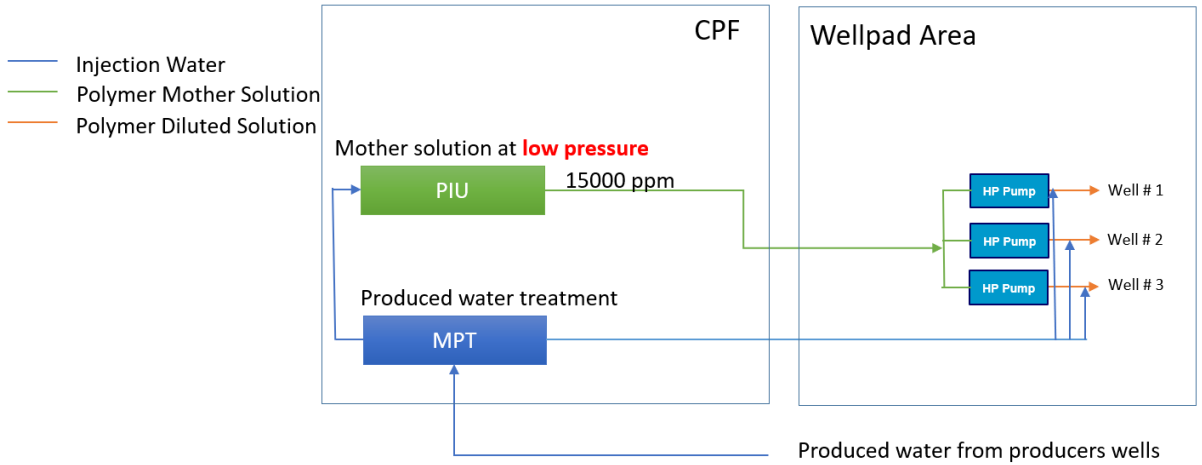
FIELD DEVELOPMENT STRATEGY – CENTRALIZED POLYMER FACILITIES

- Description
  - Polymer Facilities for the full field capacity
  - Centralized polymer mother preparation
  - Injection pumps located at well pad or at centralized facilities
- Main features of centralized development
  - Optimized footprint
  - Significant site preparation
  - Design based on site specific constraints





- 1 HP pump per well, pumping concentrated solution
- Dilution of mother solution in high pressure water

SOME OF THE LARGEST PROJECTS OVER THE WORLD

- INDIA – CAIRN MBA: 600,000 bpd / 200 injectors
- CHINA – DAQING / SHENGLI
- ARGENTINA – YPF / CAPSA: 200 injectors
- CANADA – CNRL
- ALSKA – HILCORP
- Large scale developments in middle east (PDO / KOC / ADNOC, …)
- AFRICA is ramping up

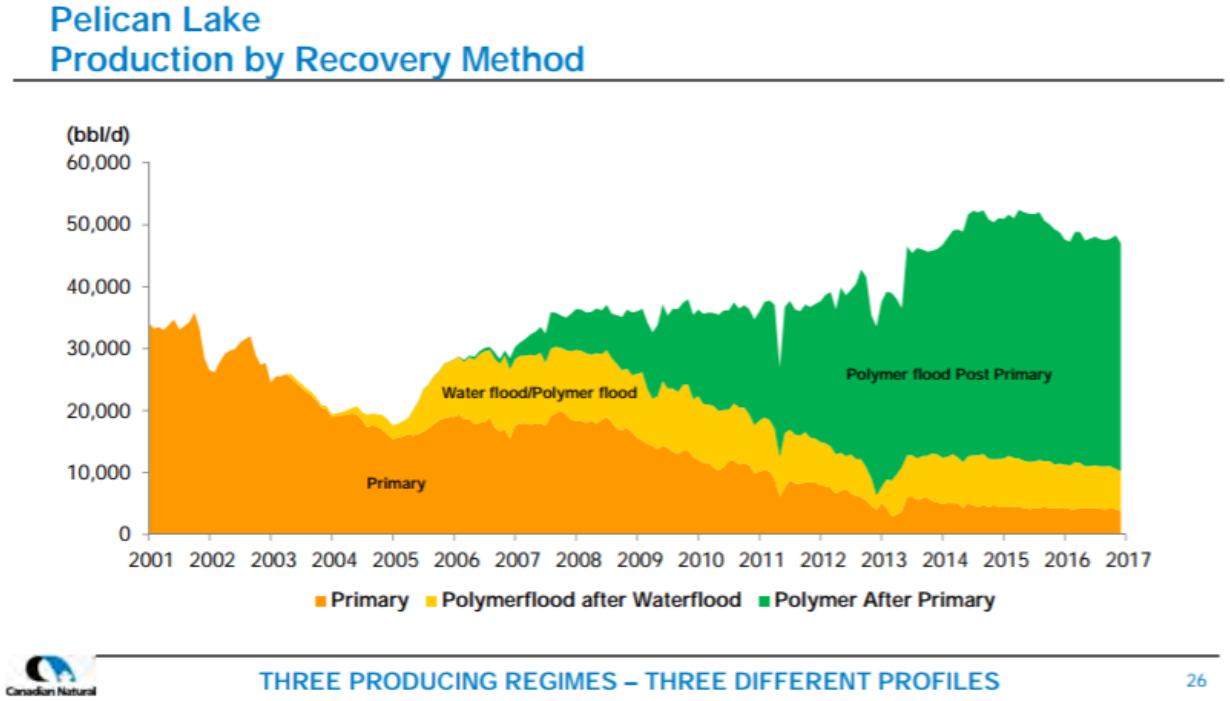
and… CAPTAIN!

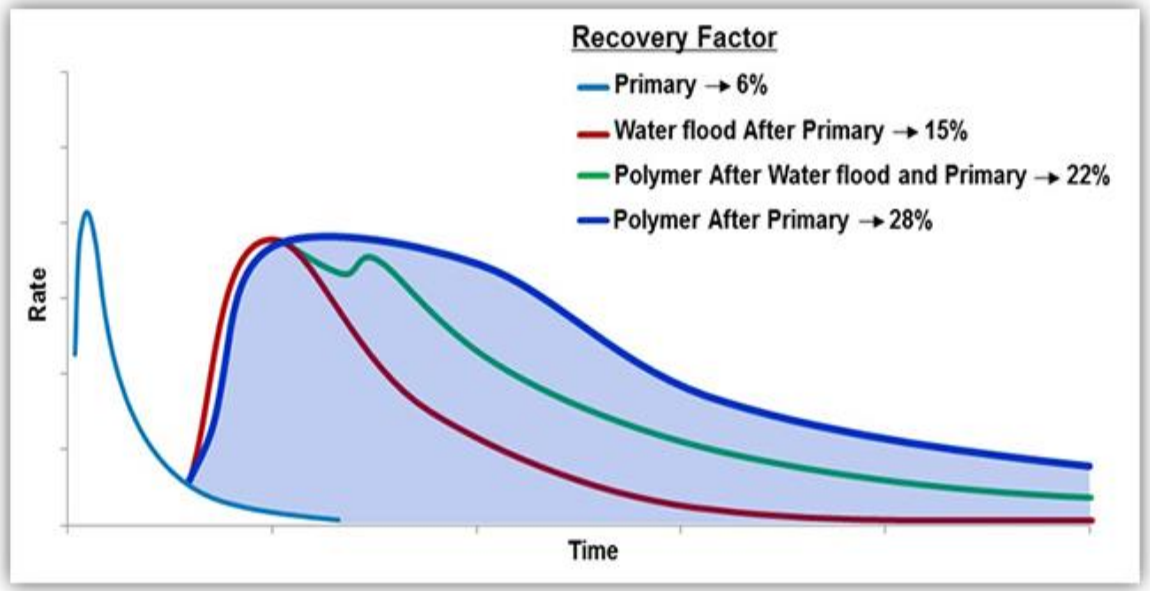
IFP EOR Workshop (September 2022):

“Polymer EOR is now mature enough to go straight to large scale field application”

CANADA

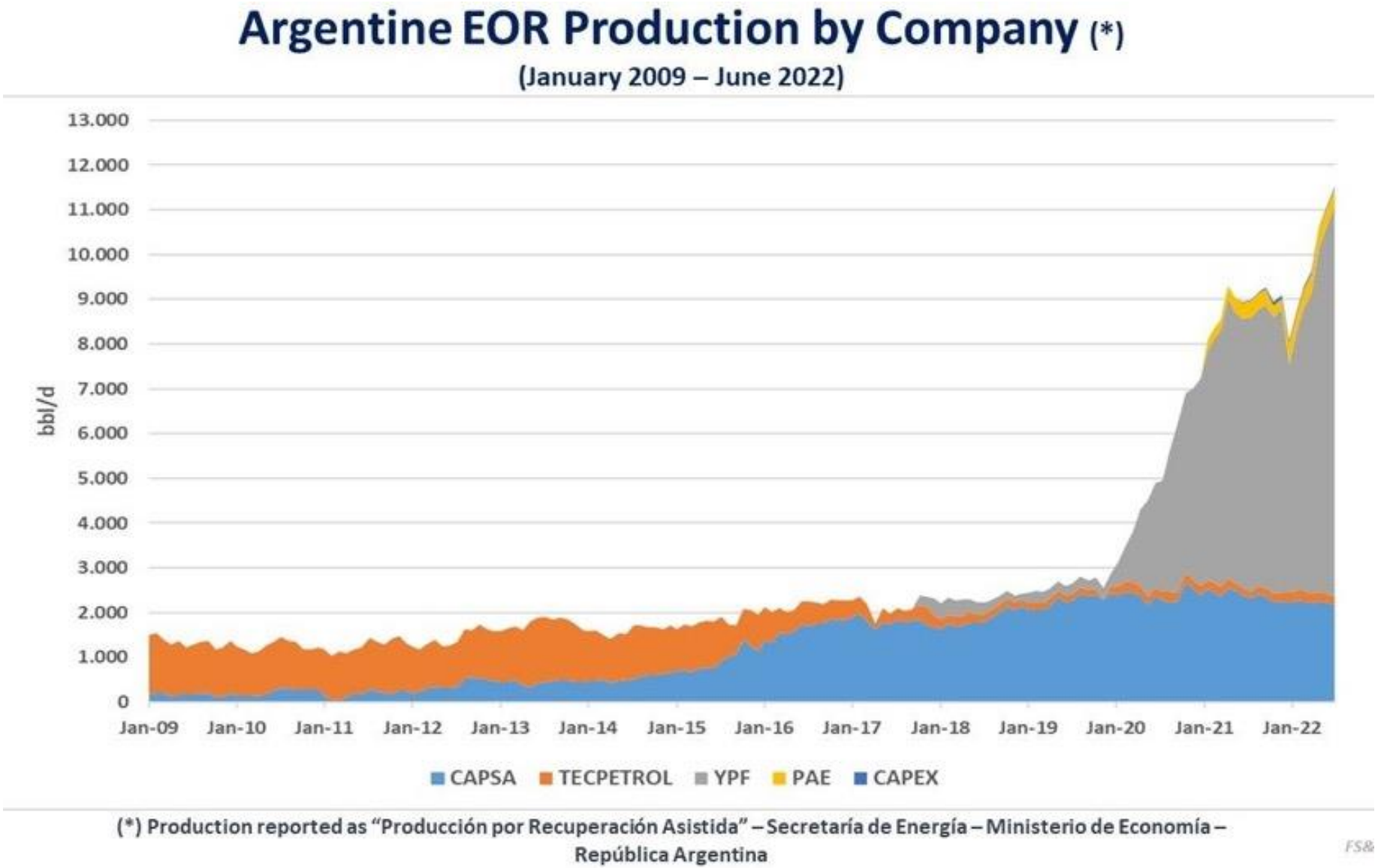
- Heavy oil pools
- Polymer is now considered right after primary production
- Polymer / ASP projects implemented since 15 years





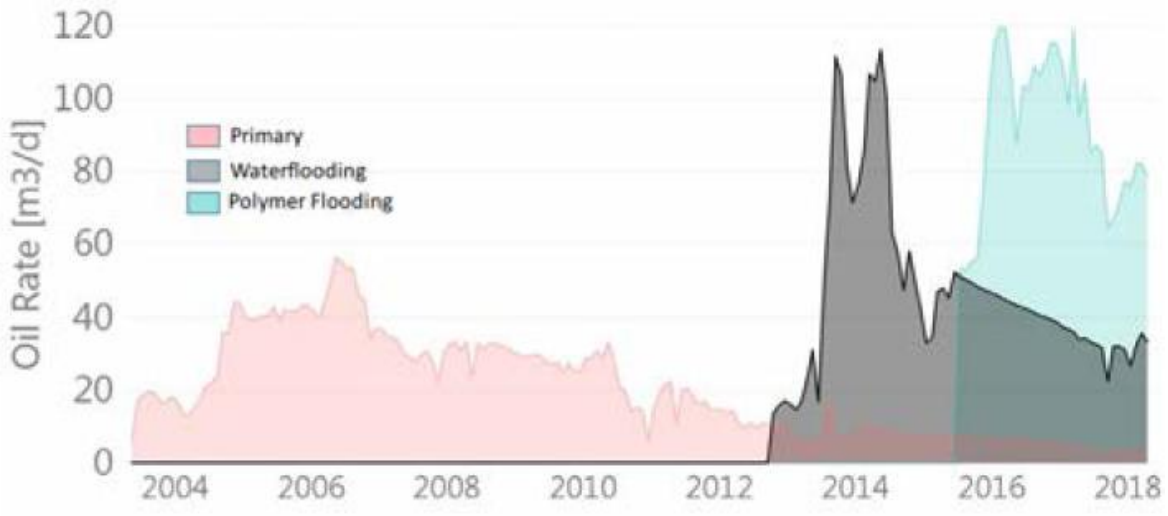
https://www.cnrl.com/operations/north-america-exploration-and-production/north-american-crude-oil-and-ngls/pelican-lake-crude-oil

ARGENTINA



YPF - ARGENTINA

- Progressive deployment of large-scale polymer flooding in several fields
  - 20 PIU containerized units, deployed in various oil fields in Argentina (more units under construction)
  - Total of 154 injection wells
  - Start-up: progressive from 2019 to 2023

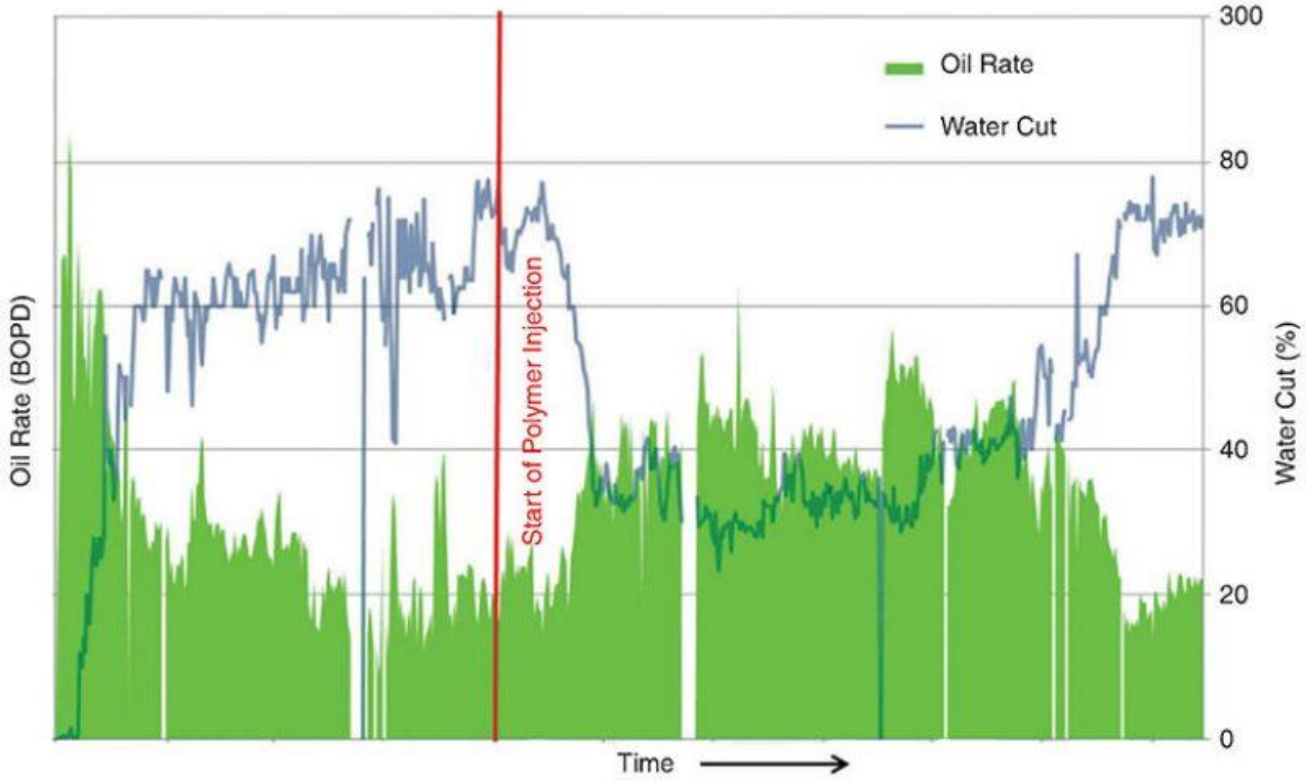


Ref. paper : "SPE 200355 - A Successful Polymer Pilot of 18%Stooip Drives a Fast Sweet-Spot Based 80-Injectors Modular Polymer Expansion", SPE Improved Oil Recovery Conference 2020

CAIRN MBA - INDIA

- Mangala contains waxy sweet crude oil - 20 °API / in-situ oil viscosity of 9 –22 cp
- Average reservoir temperature of 65°C.
- Full Field Polymer Injection from 2015
- 600,000 bpd of polymer solution injected – 200 injectors

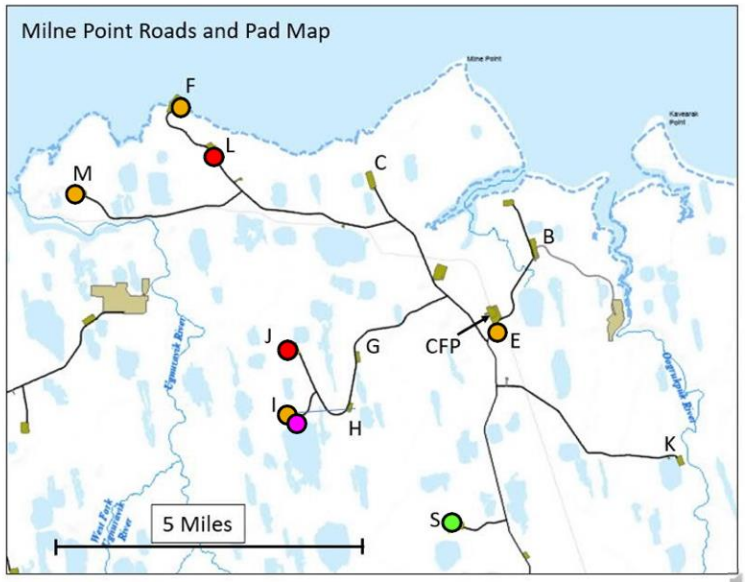
Oil cut increased from approximately 25% at the end of the water-injection phase to 70% at its highest during the polymer flood, followed by a reduction back to 25% and lower



HILCORP - ALASKA

- "Whereas the waterflood was estimated to achieve 19–21% recovery rate, the polymer flood is expected to net up to 39% of the oil in place by 2050. […] By 2035, modeling from the privately held Hilcorp showed that by 2035 the EOR project may yield an incremental increase of 5.9 million bbl vs. the 2.9 million bbl it expected under the waterflood.
- "In addition, each dollar invested yields $5.05, and each barrel of oil produced over the project duration costs about $8.35 to produce," reads the paper. The authors said even at $40/bbl prices, all the economic simulations predicted "a positive and robust" net present value as the result of the polymer flood."

- 2017 (screening)
  - Lab studies
  - Pilot patterns simulation
    - 1 tertiary flood (J Pad)
    - 1 secondary flood (L Pad)
  - Injection well test
- 2018
  - Design and install two pilot facilities
  - J and L Pads – 5,000 bwpd
- 2020
  - 4 expansion facilities – 25,000 bwpd
  - Most remaining horizontal waterflood patterns
- 2021
  - I Pad II – 4,000 bwpd (new patterns)
- 2022
  - S Pad – 7,500 bwpd (new patterns)
- Current ~40,000 bwpd
  - 95% of horizontal injectors
  - 66% total Schrader Bluff injection

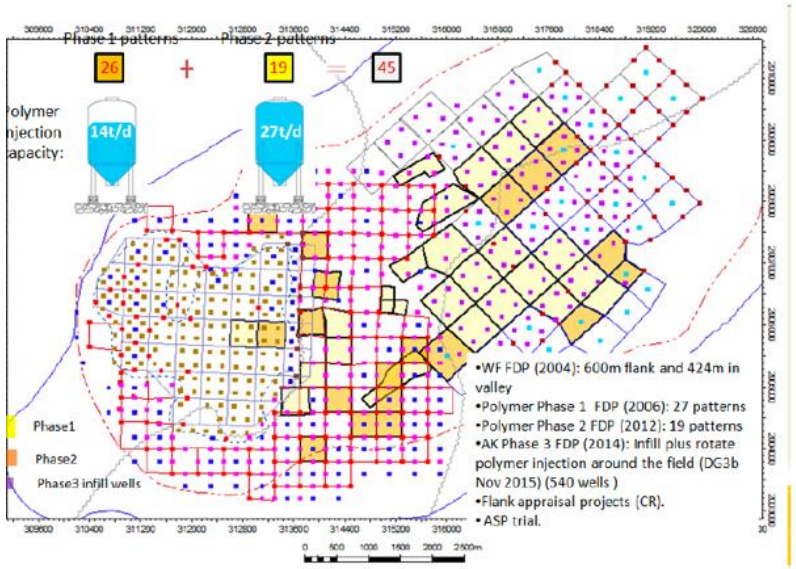


https://jpt.spe.org/first-ever-polymer-flood-in-alaska-hailed-as-a-heavy-oil-breakthrough

PDO - OMAN

- PDO: chemical EOR in Marmul, Haima West, Nim-r, Thayfut

  - **PH1:** Started in 2010 with 27 polymer patterns mostly in the flank
  - **PH2:** Started in 2015 with additional 19 polymer patterns
  - **PH3:** infill + polymer rotations (over 400 infill wells to be drilled and polymer to be rotated across the field)



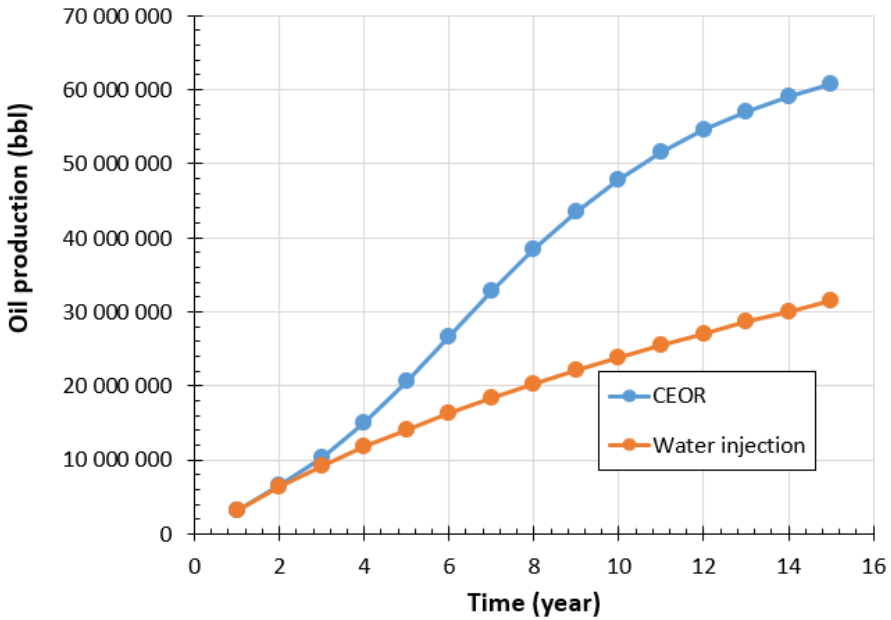
DAQING - CHINA

- μ oil= 11cP, no aquifer
- 2427 polymer injection wells, 60% of PV injected
- Extra-oil recovery +12% OOIP, 1.58.108 tons of oil as of 2011
- Volume of produced fluid per barrel of oil is 40% lower for polymer flooding because of decreased water-cut
- Volume of fluid injected per bbl of oil is 65% lower for polymer flooding compared to waterflooding
- Economic evaluation show that OPEX for polymer flooding are up to 2,83$/bbl lower than waterflooding (SPE164595)

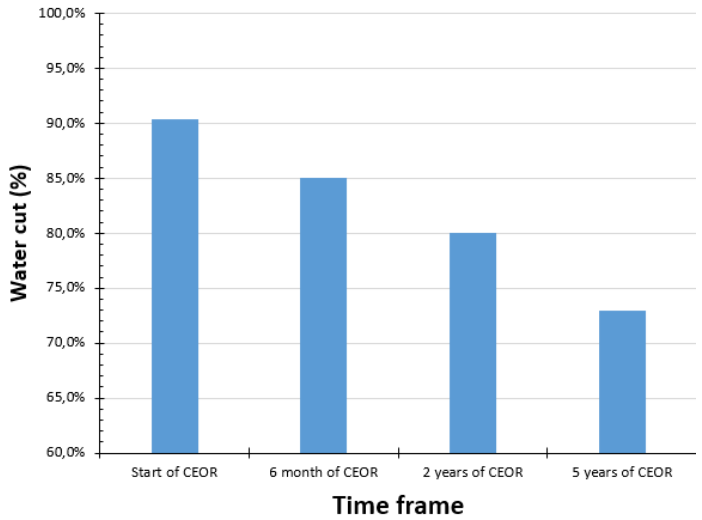
SHENGLI OFFSHORE - CHINA

- Project running for 3 years months, uptime >98%
- Positive results, confirming the projections:
  - Oil recovery: +11.6%
  - CO2 emissions reduced by 64%
  - Recovery rate to reach 50.8% at the end of injection
- Limited CAPEX, optimized OPEX and reduced footprint requirement
- Two new projects to be implemented
- After 15th years of polymer injection : Planned oil production increases by 29 340 744 bbl
- Acceleration in oil recovery = 8 years

Extra Oil production



Evolution of the water cut during the first 5 years of CEOR pilot in CB22F Area



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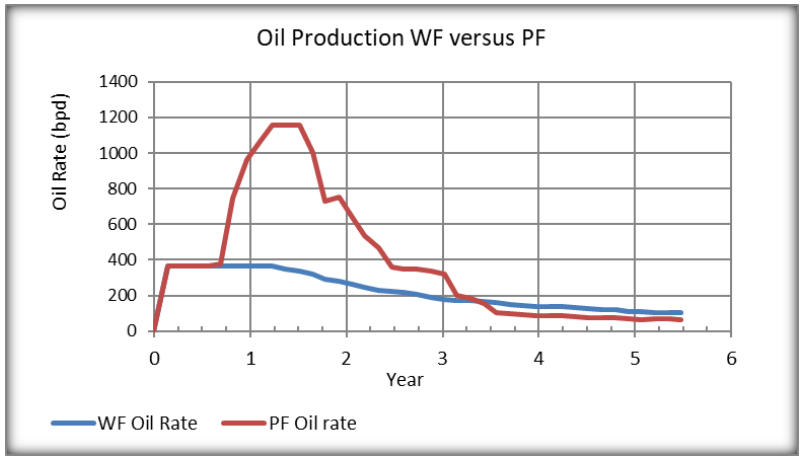
ALWAYS A GOOD TIME FOR A PILOT!

- Cost-efficient
  - Cheaper than exploration, less risks
  - Known reserves and reservoirs
  - Maximize the use of existing infrastructures

- Simple implementation
  - Getting more from existing field / assets
  - « Just viscous water », low cost, improved polymer quality
  - Skid-mounted, pre-designed equipment
  - Fast and easy deployment



- Innovative injection & deployment strategies
  - Deployment based on modular approach with several skids to minimize CAPEX (leasing options)

- Pilot objectives
  - Check injectivity, rates, viscosity
  - Evaluate injection equipment
  - Assess oil recovery for extrapolation, economics
  - Evaluate the back-produced water treatment options

FIELD CASE #1 - ARGENTINA

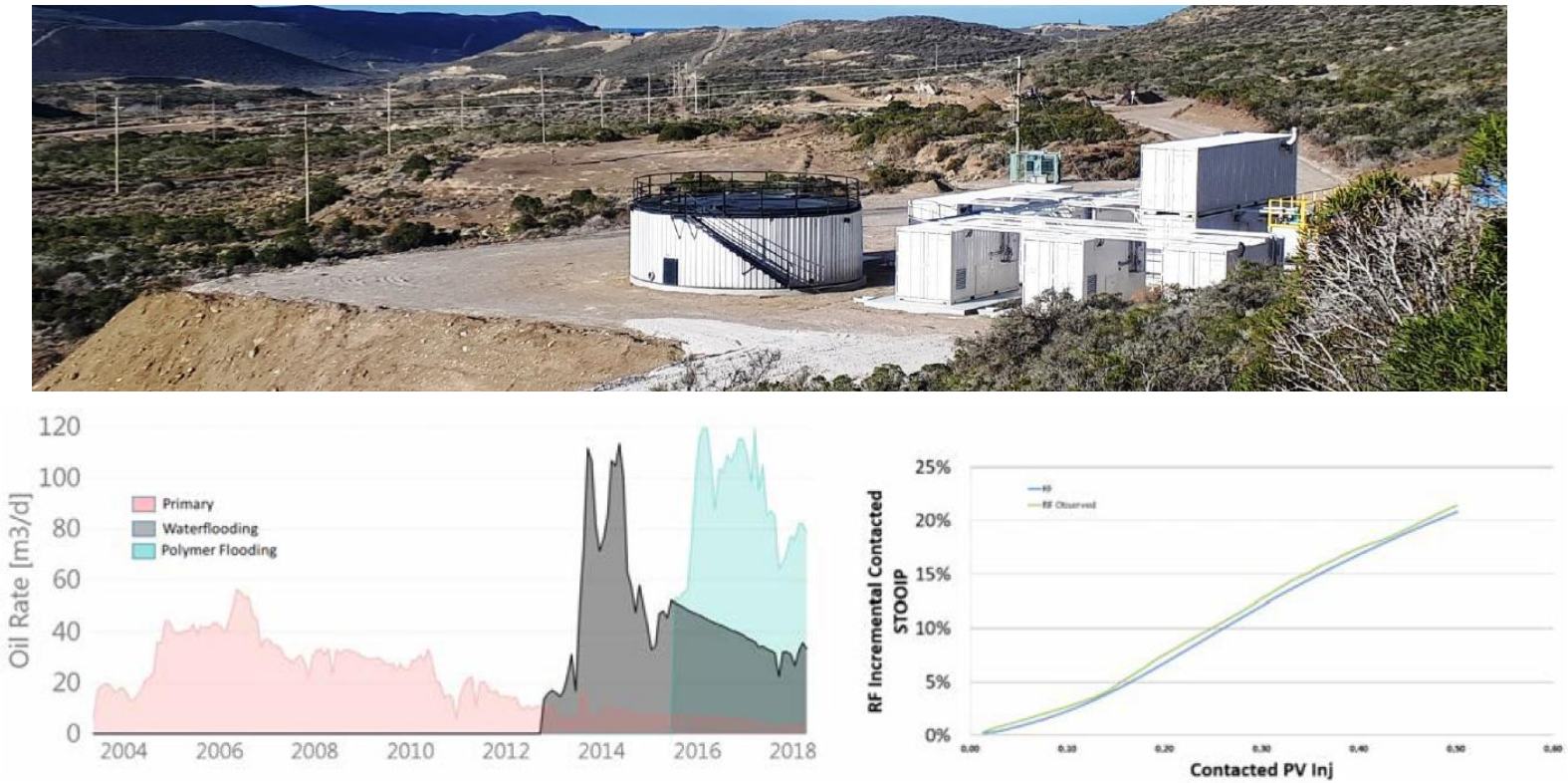


Figure 3—a) Observed production profile for the three recovery processes, primary, waterflooding and polymer flooding. b) Polymer injection incremental recovery factor versus pore volumes ofpolymer injected. The green line is the simulation increment forecast and the blue line is the observed production increment.

Grimbeek, 2020_IPTC_20285

FIELD CASE #2 - CANADA

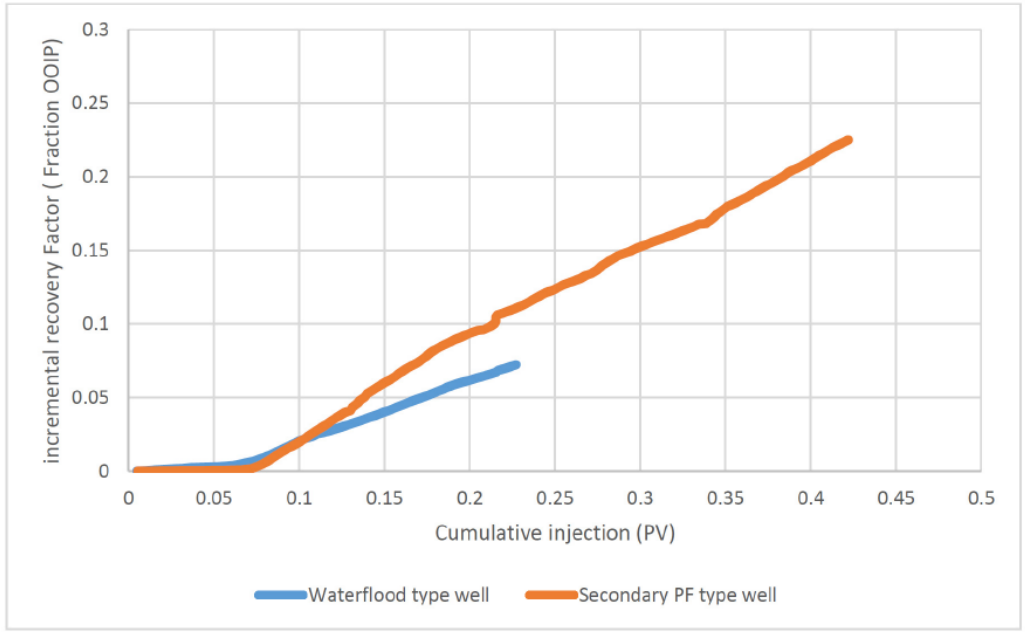
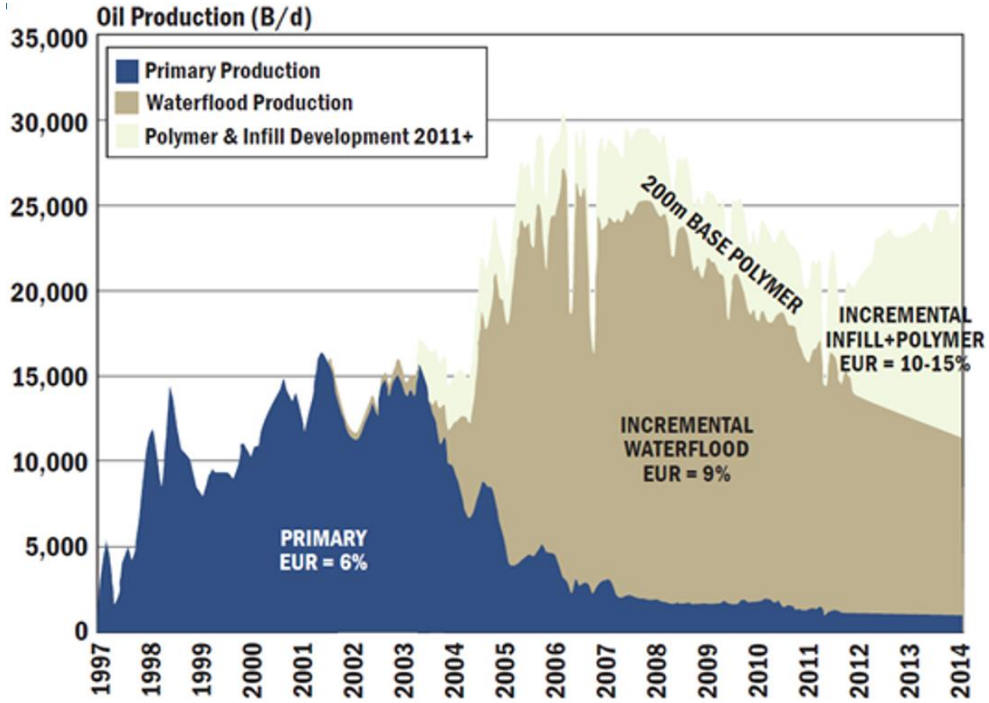


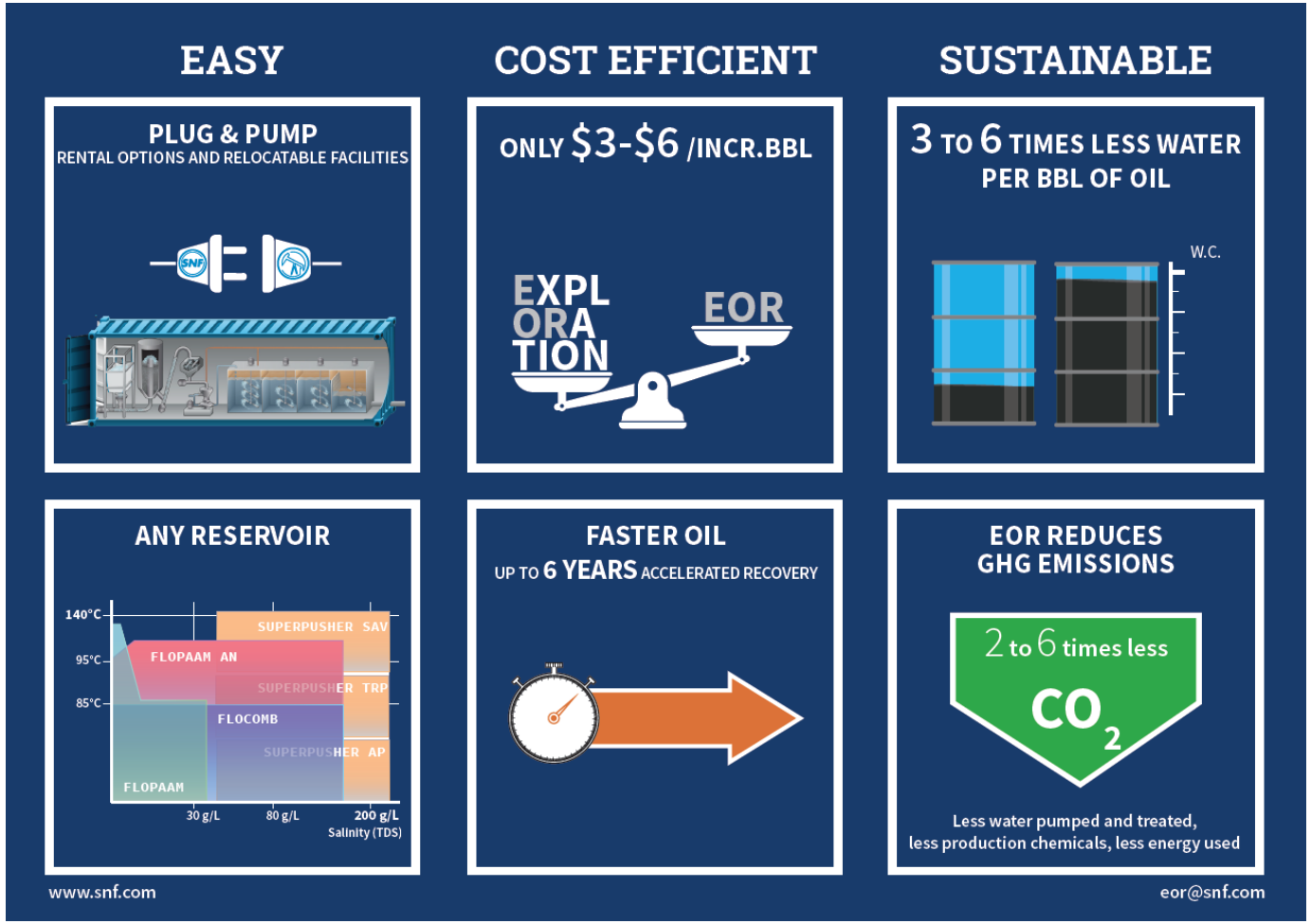
Figure 22—Type wells for secondary polymer flood and waterflood



Source: Cenovus Energy, "Performance Review of In Situ Oil Sands Scheme Approval 9404V", April 2014.

Pelican Lake, SPE 180852

CONCLUSION



Thank you

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