

MEOR Spells MORE OIL



NC STATE UNIVERSITY



Polish Oil & Gas Company



Polish Oil & Gas Institute



RAM Biochemicals, Inc.

WELCOME TO
Praxis Interactive Technology Workshop
9th Global Edition

MEOR Spells MORE OIL

***A Systematic Approach to Microbial Enhanced Waterflooding
for Smaller Scale Projects.***

Presented by
RAM Biochemicals, Inc.
&
The Polish Oil and Gas Institute

MEOR Spells MORE OIL

- Plawowice Project - Cooperative Partners
 - Design, Development, Implementation & Monitoring
 - Results
 - Summary
- MEOR Basic Approaches
- Maturity of Various EOR / MEOR Processes
- EOR / MEOR Cost per Incremental Barrel
- Conclusion



Plawowice Cooperative Partners



INiG / POGI – Polish Oil & Gas Institute

Laboratory Evaluations Pre- and Post-treatment
Microbial System Scale-up / Processing
Collaborated on Project Design / Development / Implementation
Project Monitoring

POGC – Polish Oil and Gas Company

Oil Producer / Geophysical & Geochemical Data
Microbial System and Nutrient Injections
Monthly Production Data and General Observations

BTEC / NC State University Department of Microbiology

Produced Microbial System Inoculum from RAM Seed Stock

RAM – RAM Biochemicals, Inc.

Provided Microbial Materials / Batch Records & Protocols for
All Laboratory & Field Work
Collaborated on Plawowice Project Design / Development /
Implementation & Monitoring
Project Coordination

Producer's life cycle

Discovery, Estimation, Development

Primary recovery

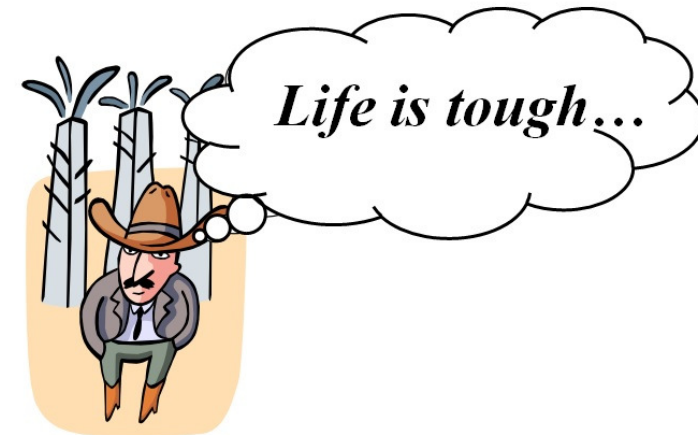
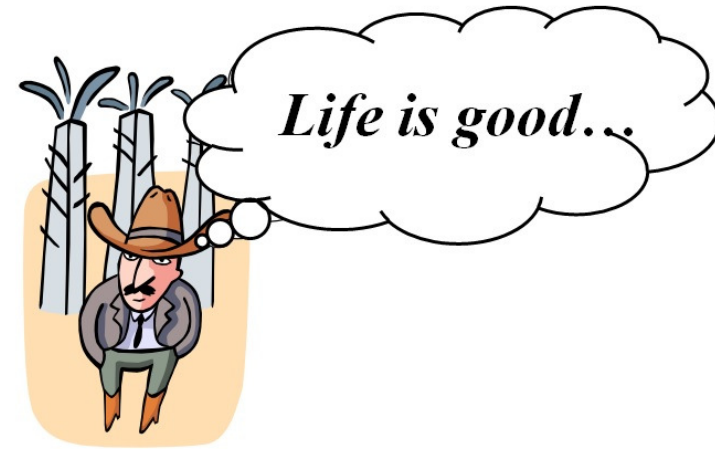
...doesn't

Secondary recovery

Battles physics and loses

- poor sweep efficiency
- poor displacement efficiency

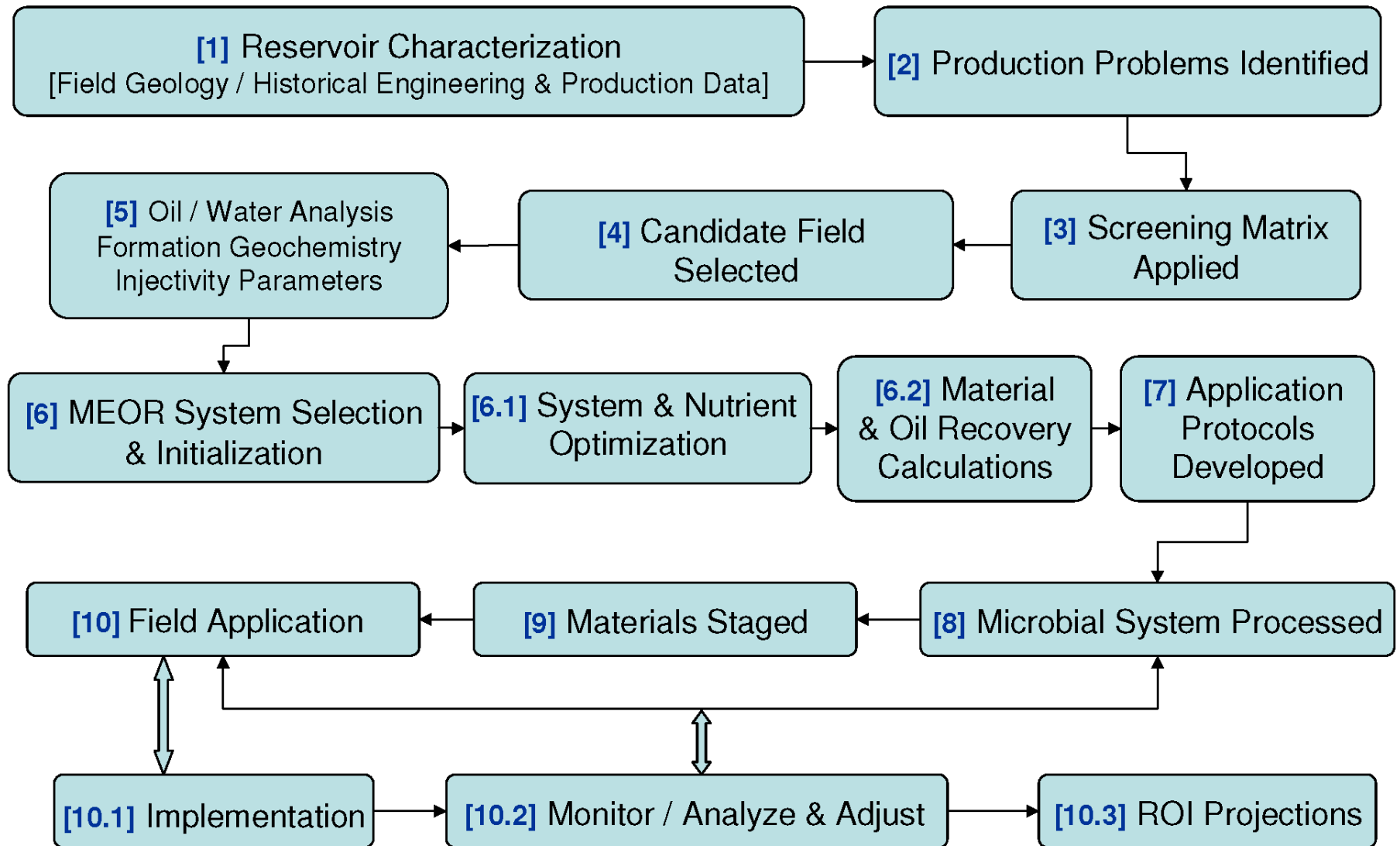
Tertiary recovery – MEOR delivers EOR performance at waterflood cost



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**Development of Microbial Enhanced Oil Recovery Solutions
To Address Oil Production Problems in Mature Fields**



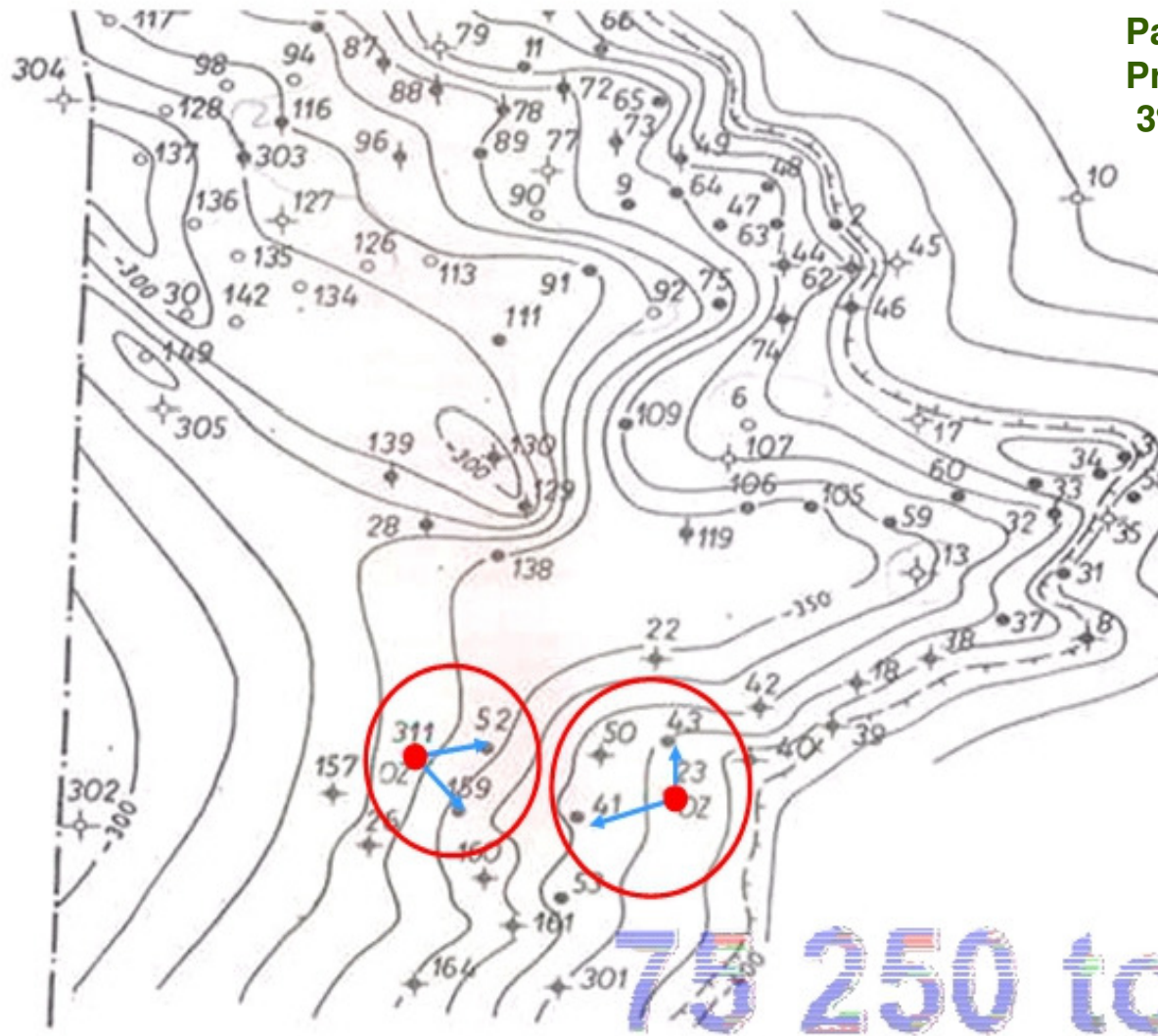
Systematic Approach Applied to RAM/POGI Plawowice MEOR Project

Plawowice Oil Field Location



Plawowice Oil Field

Plawowice Injector Producer Systems



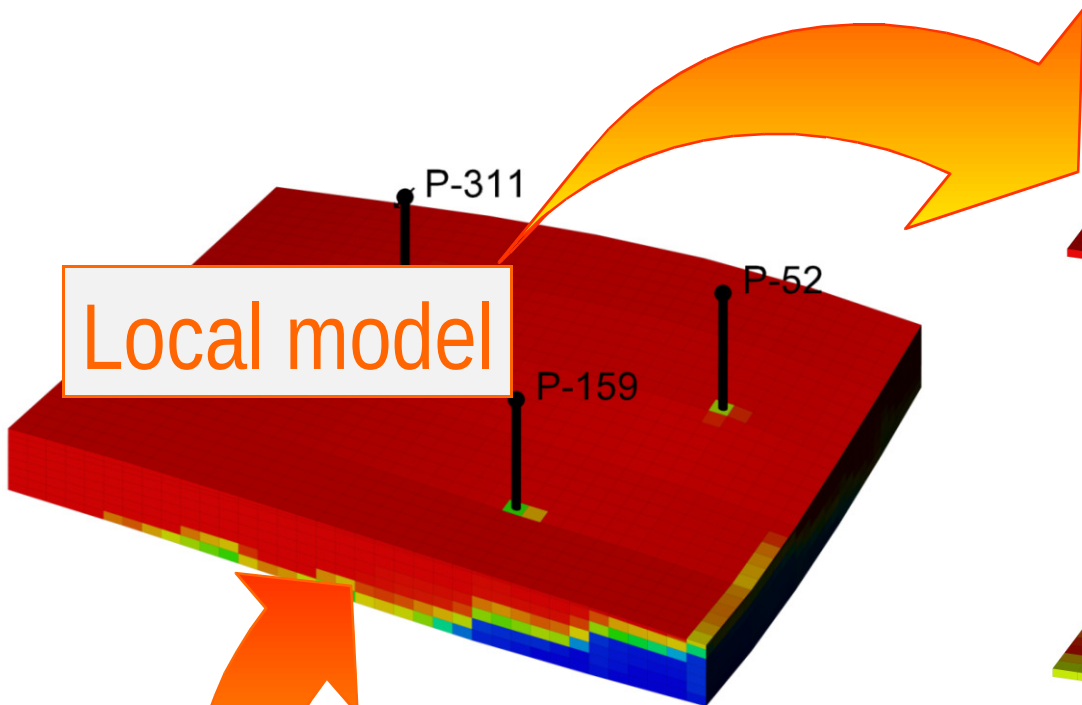
Paraffinic oil; API 38°; 836 kg / m³
Produced brine ranges between
3% and 6% TDS

First drilled in 1954, total oil
production to date from the
Plawowice oil field is about
602,000 metric tones.

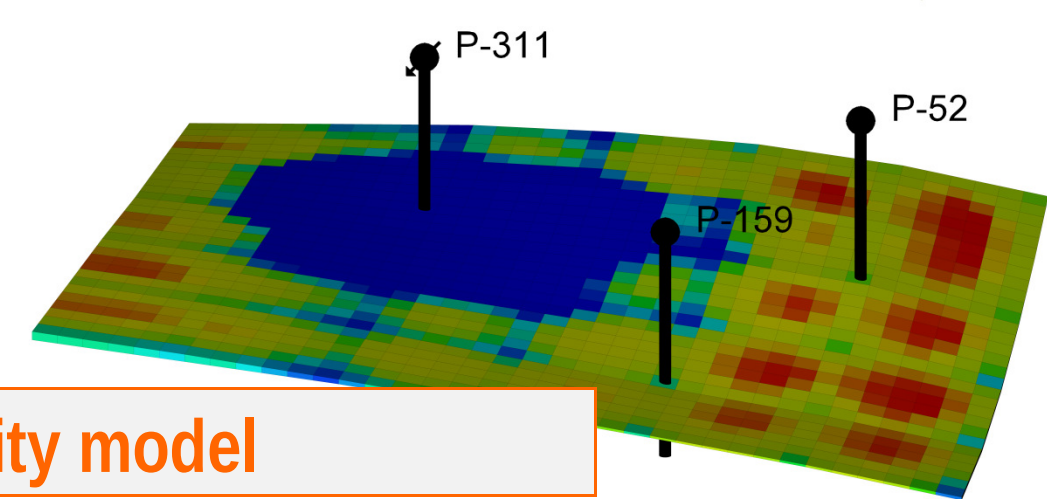
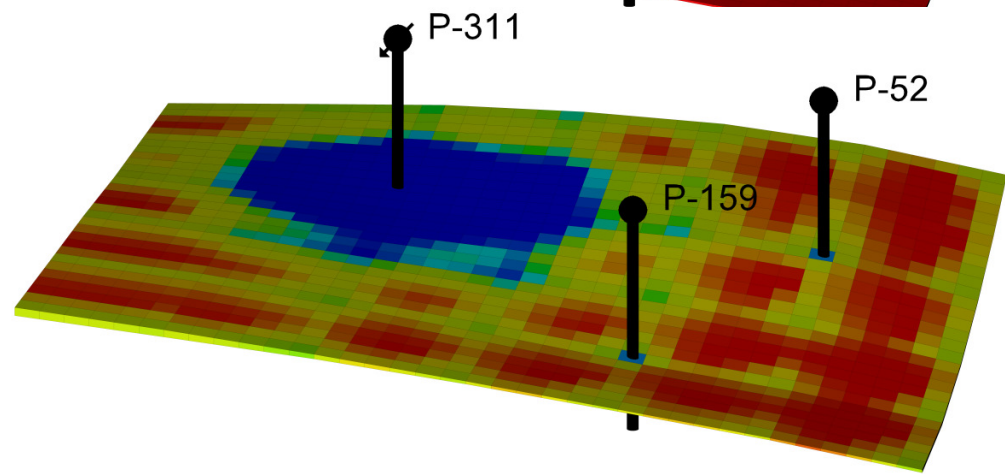
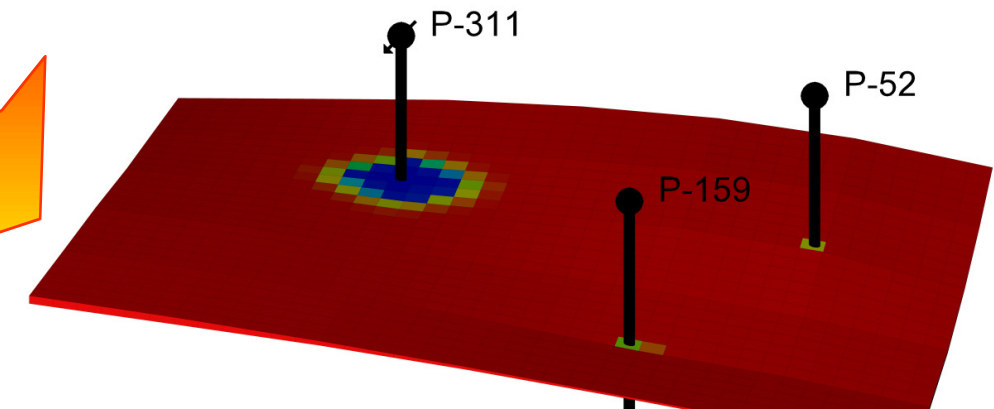
The Polish Oil and Gas
Company began water
flooding in 1986 by
injected produced water
into the production zone
through two injection
wells. Four producing
wells were observed to
be impacted by
connectivity to the
injectors.

Plawowice deposit – simulation model

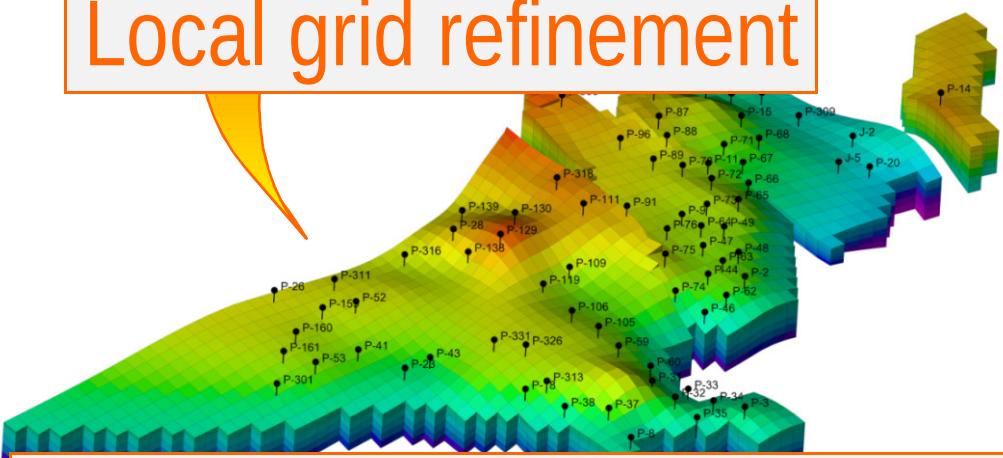
Reservoir simulation



Local model



Local grid refinement



History matched global dual porosity model

Ławowice Project Wells – Basic Data

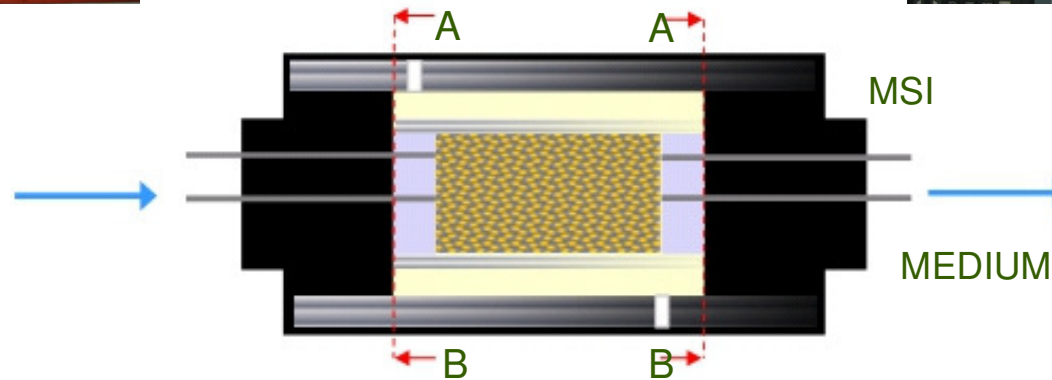
Injection well PI-23 was shut-in in November 2011 due to mechanical problems. This removed the PI-23 / 41 & 43 system from the MEOR project.

Well Name	Ławowice 41	Ławowice 43	Ławowice 52	Ławowice 159
Symbol	PI-41	PI-43	PI-52	PI-159
temperature ° C producing zone	23	23	24	24
reservoir pressure [Mpa]	0,13	0,13	0,1	0,6
oil production [tonns/day]	4,4	0,6	2,3	1,8
water production [tonns/day]	0,3	0,4	0,05	0,2
formation thickness [m]	9	3,5	8,5	6
perforations [m]	11	5,5	10	7

Production data from PI-41 is shown as a control (treated vs. untreated)



Core Study / Recovery Factor [RF] Determination



Core study apparatus

In 2011, INiG's oil engineering laboratory conducted core studies to determine the recovery factors [RF] for the microbial systems proposed by RAM Biochemicals.

Laboratory core testing of Microbial System effectiveness

Core	Permeability [mD]	Effective permeability S(or) [mD]	Pore volume [cm3]	Oil volume [cm3]	Waterflooding		
					Oil displaced [cm3]	Oil Remaining [cm3]	RF _{wf} [%]
1- Kontrola	267	4,1	4,36	3,0	1,0	2,0	33,3
2	295	1,82	4,30	2,8	1,1	1,7	39,3
3	424	5,64	4,15	2,6	1,1	1,5	42,3
4	344	5,4	4,17	2,6	1,2	1,4	46,2
5	335	4,3	4,21	2,2	1,3	0,9	59,1
14	81	0,73	6,54	3,8	0,9	2,9	23,7
15	97	0,85	6,52	4,3	0,9	3,4	20,9

$$E_{mwf} = RF_{mwf} - RF_{wf}$$

6,8%

Core	RF _{wf} [%]	Injected MS [PV]			Total time	RF _{mwf} [%]	E _{mwf} [%]
		Pore volume injected	Second injection [days]	Third injection [days]			
1- Kontrola	33,3	X	X	X	3	33,3	0,0
2	39,3	0,5	1	2	3	55,4	16,1
3	42,3	0,5	1	3	3	53,8	11,5
4	46,2	0,5	X	X	10	50,0	3,8
5	59,1	0,5	1	7	10	61,4	2,3
14	23,7	0,5	X	X	10	27,6	3,9
15	20,9	0,5	1	7	10	24,4	3,5

SELECTION METHODOLOGY



Biotreatability Analysis

$$NI = \frac{\mu_{without _ treatment, \min \ shearrate} - \mu_{without _ treatment, \max \ shearrate}}{\mu_{inoculated, \min \ shearrate} - \mu_{inoculated, \max \ shearrate}}$$

$$DV = \frac{\sum_{i=\min VC}^{\max VC} (\mu_{without _ treatment} - \mu_{inoculated})_i}{\sum_{i=\min VC}^{\max VC} \mu_{without _ treatment, i}}$$

$$EOR = \frac{1}{1 - DV}$$

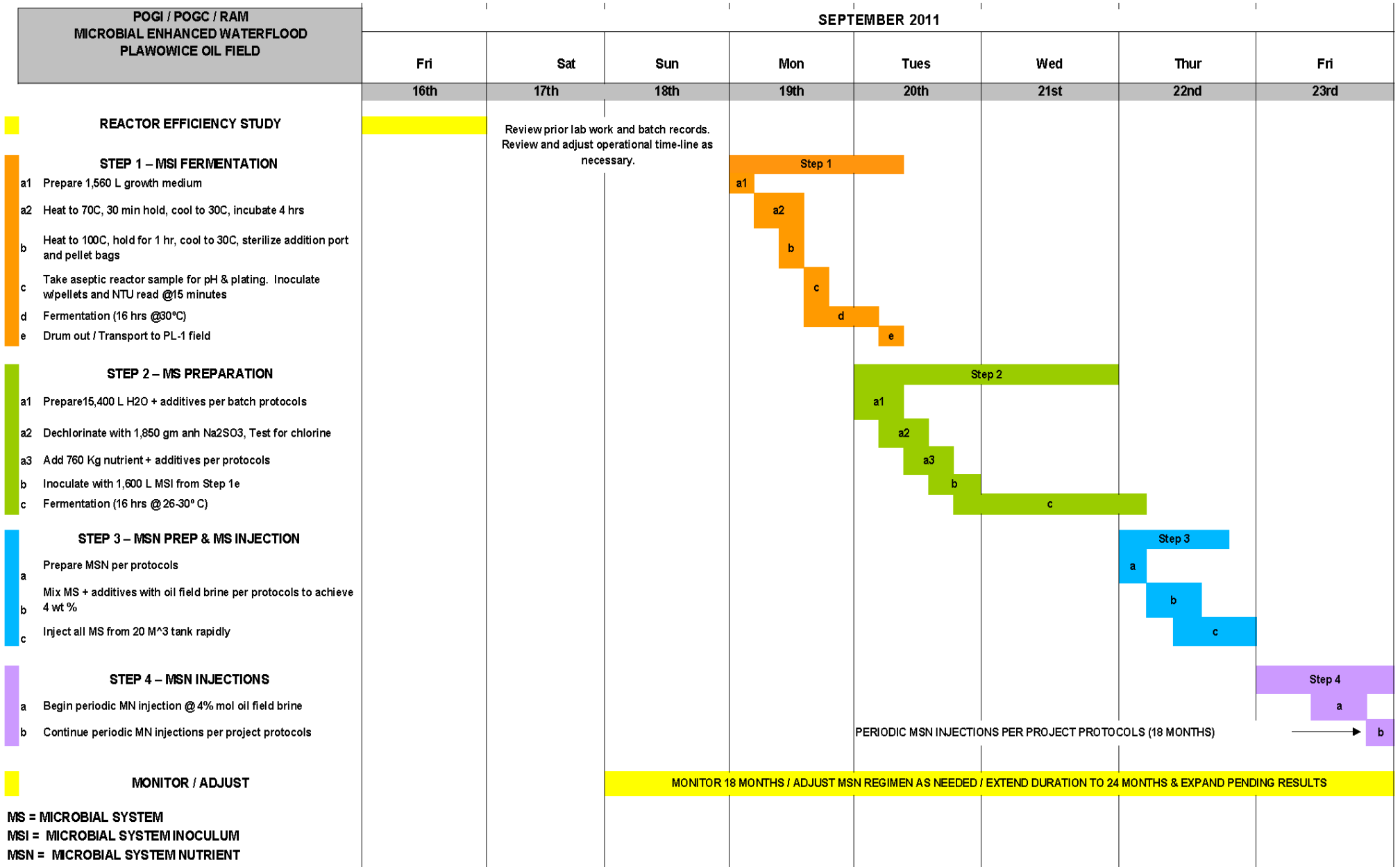
Biotreated Oil:

NI > 1.10

DV > 0.1

EOR > 1.15

Operational Plan - Pławowice MEOR



Microbial System Inoculum [MSI] - Phase I Scale-up

MEOR materials prepared and optimized in BTEC's laboratory

MEOR Inoculum Preparation



Six 5 ml vials each contain
1 ml lyophilized microbes

Three 250 ml bottles contain high
CFU microbial broth

BTEC 30 liter reactor

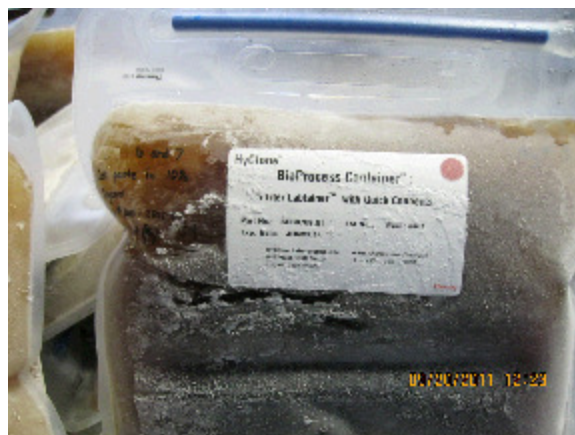


BTEC 300 liter reactor



Frozen MSI concentrate
pellet bag \approx 6 kg

8 bags / 50 kilograms
shipped to Poland
for Phase II Scale-up



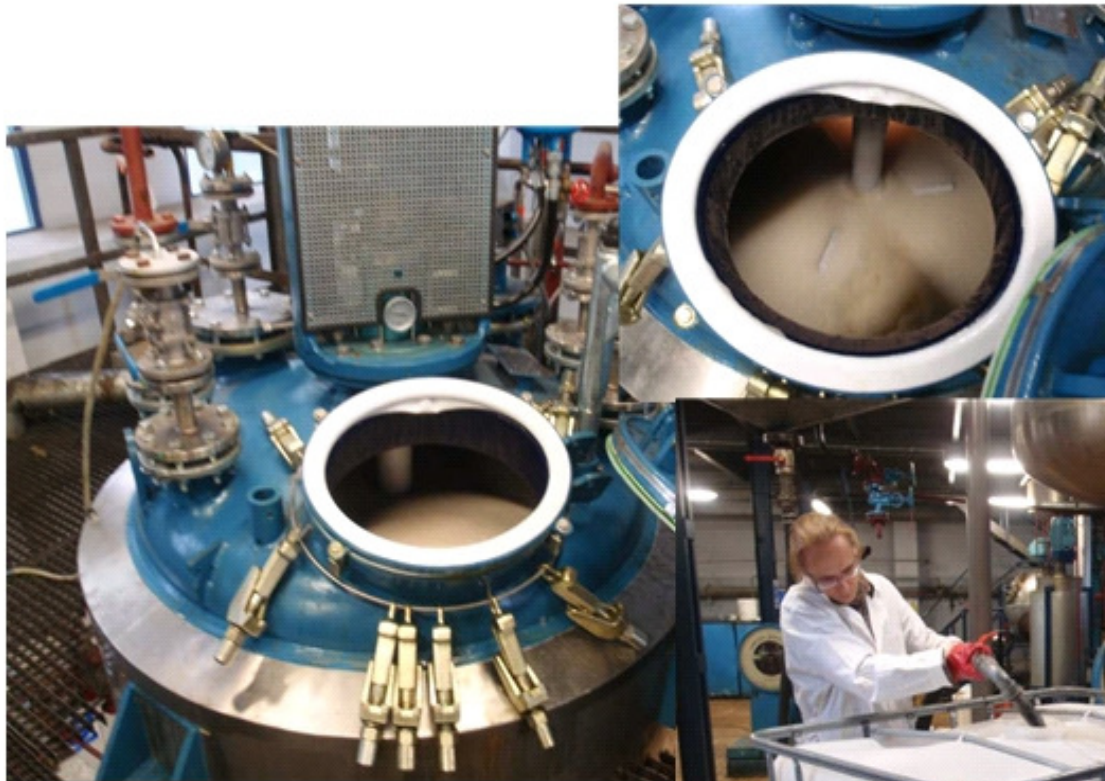
Rick Lawless
BTEC Bioprocess Services

Phase II Scale-up at IniG / POGI

Bio-preparation of 1,500 liters (1.5 m³)



Phase II – Drum Out After 24 hrs 1,500 liters (1.5 m³)



**INiG Facility
Reactor Port**

**MSI Drum Out
By Facility Staff**



Phase II Shipment to Plawowice Oil Field



**Loading 1,500 liters MSI at INiG
Facility**



MSI Delivery / Plawowice Oil Field



Phase III – Microbial System [MS] Preparation at Plawowice Oil Field



Final MS preparation

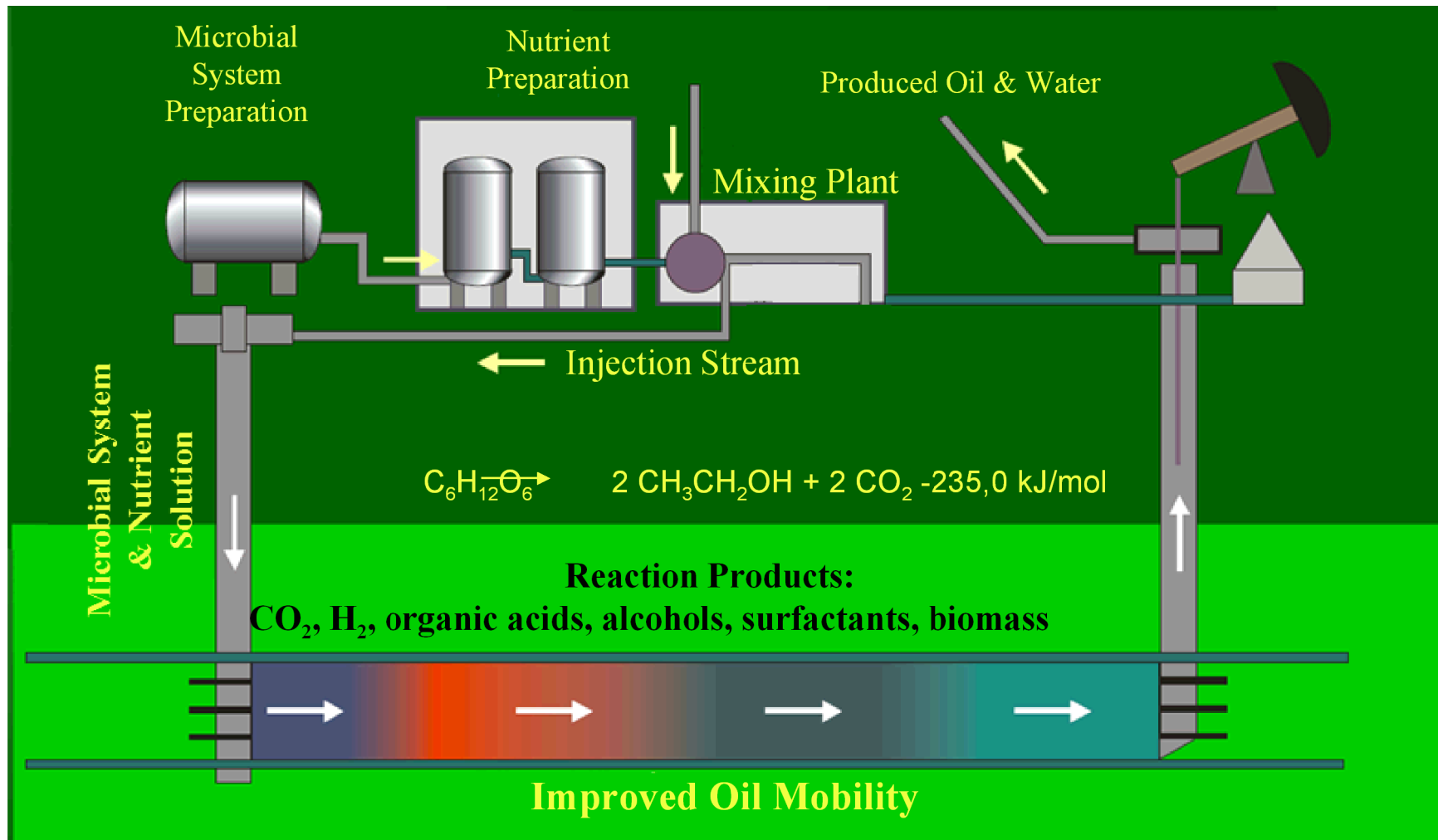
1.5 m³ MSI fed into 20 m³
prepared media

Microbial Nutrient [MN]
Staged at Plawowice



Microbial System [MS]
20 cubic meters (~ 20 MT)
Injected on 22 Sep 2011

Microbial Enhanced Waterflood Process



Treatment process involves a specially selected **Microbial System (MS) injection** into the oil bearing formation, followed by **regular / periodic nutrient injections**.

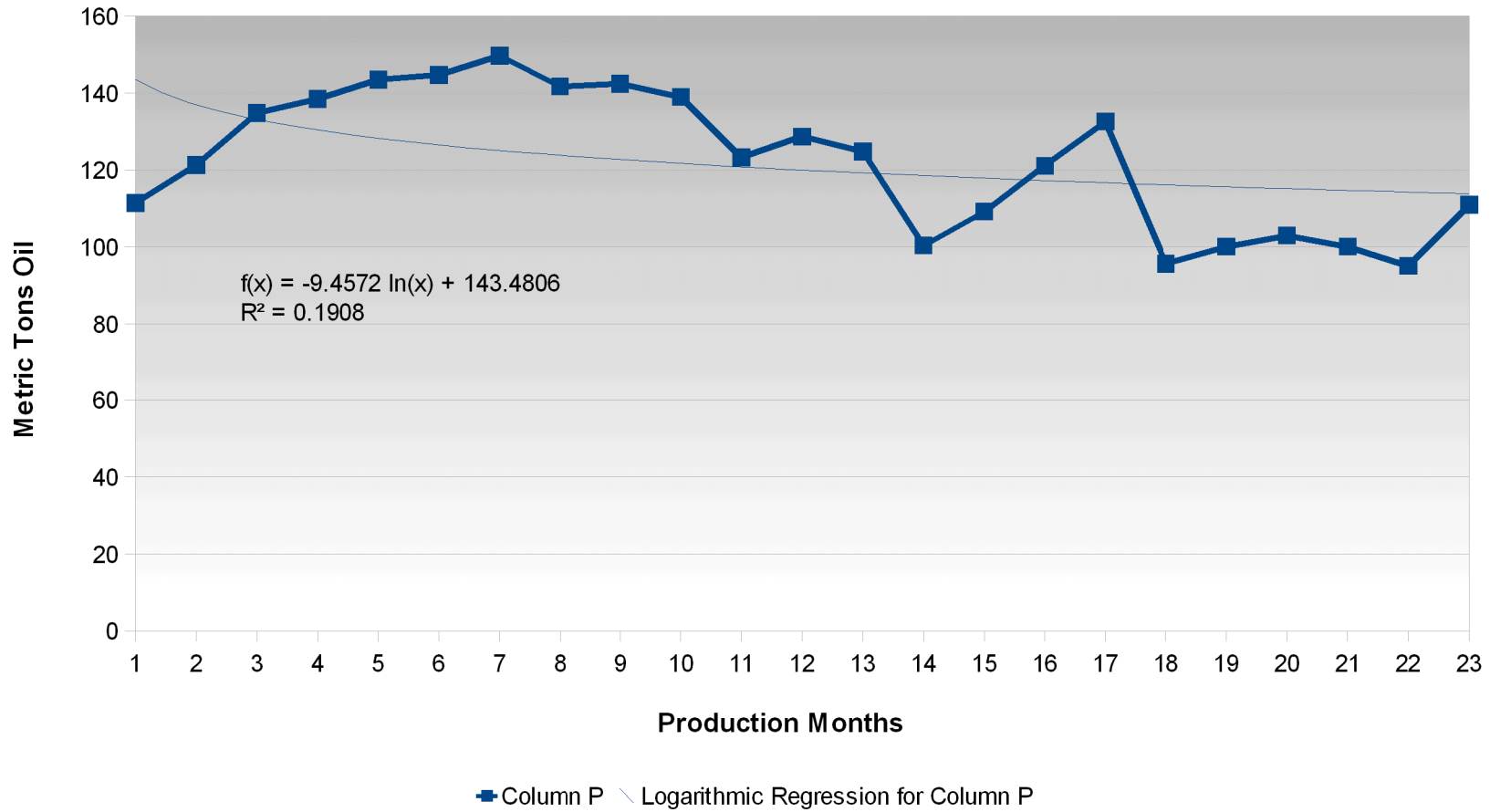
The Pławowice project used augmented beet molasses to sustain MS growth *in situ*. Other inexpensive nutrients can be used depending on the MS bacteria composition.

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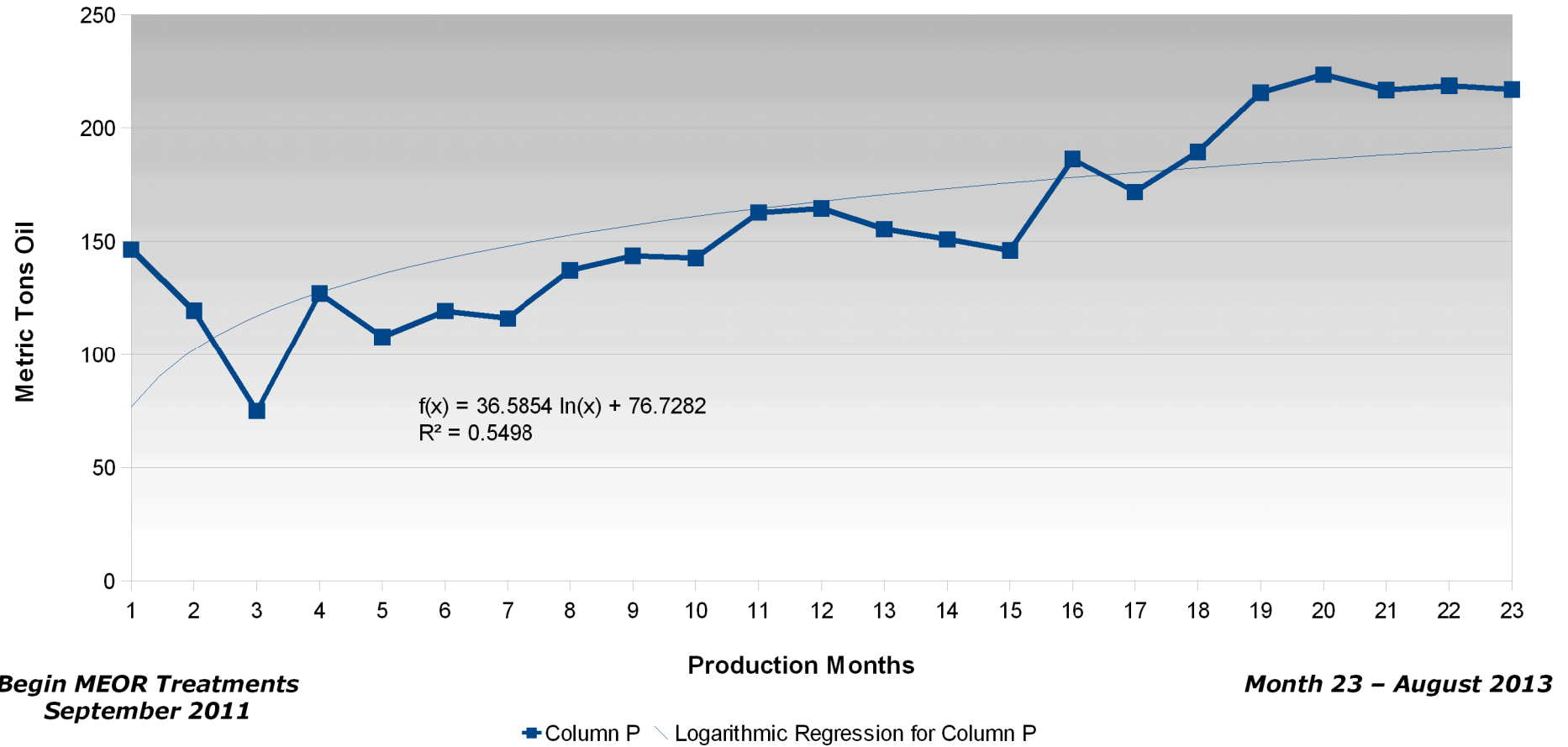
PI-52 & PI-159 Combined Pre-treatment Production

23 Months with Trend Line



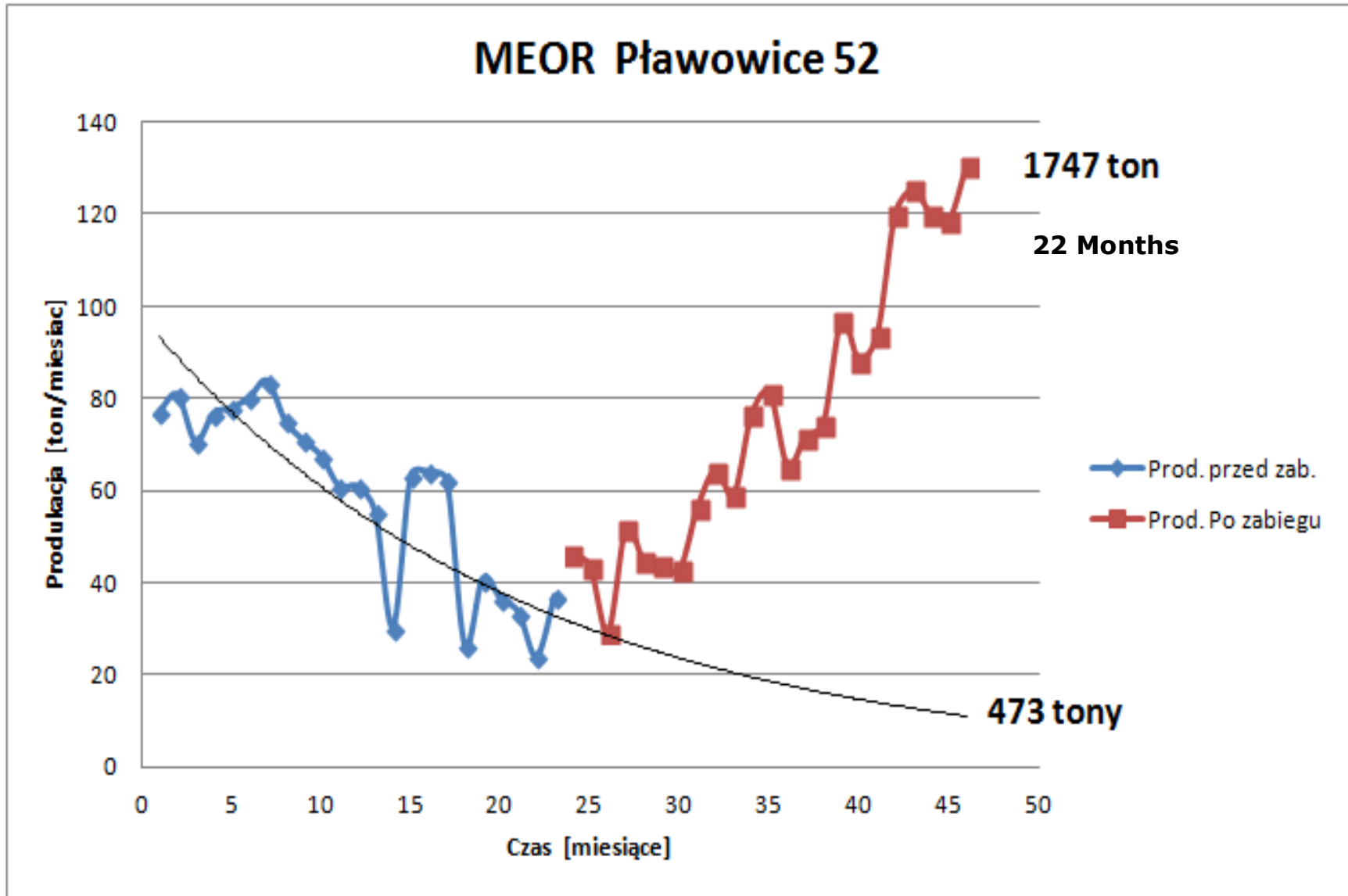
PI-52 & PI-159 Combined Post-treatment Production

23 Months with Trend Line



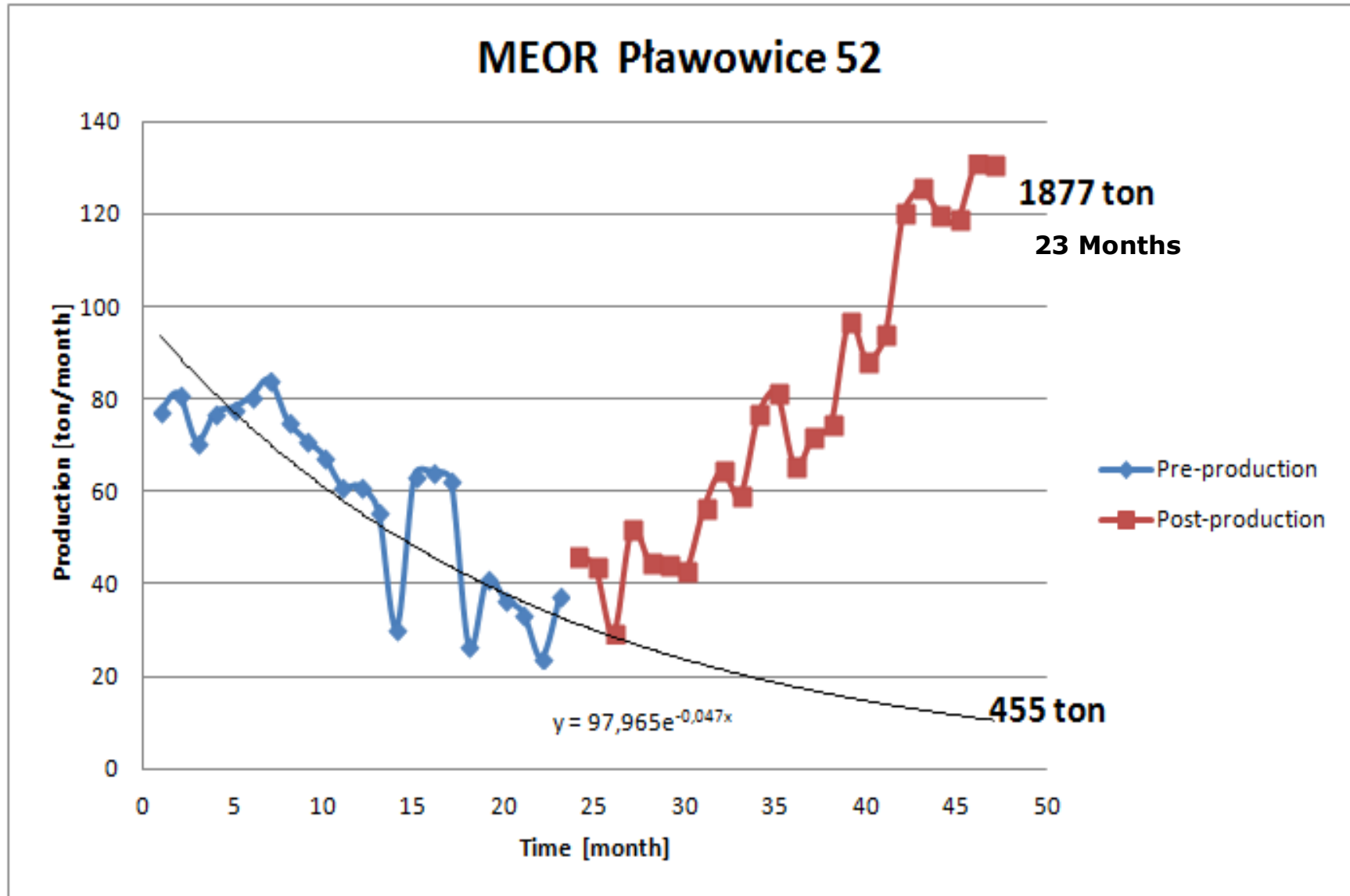
PI-52 Producer

Pre-treatment 23 Months / Post-treatment 22 Months



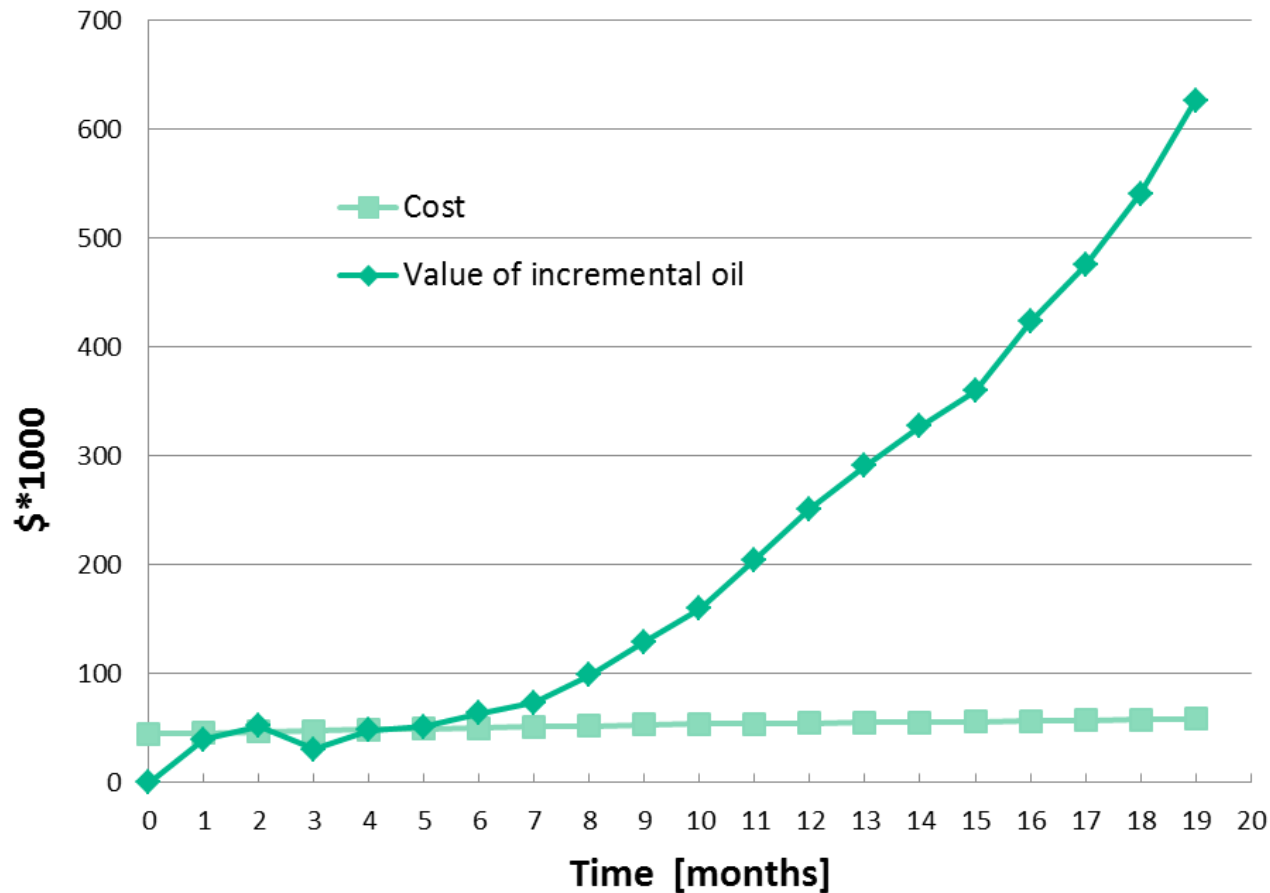
PI-52 Producer

Pre-treatment 23 Months / Post-treatment 23 Months



PI-52 Producer – 23 Months Pre- and Post-treatment Production

Limited Economic Analyses of Plawowice MEOR 19 Months



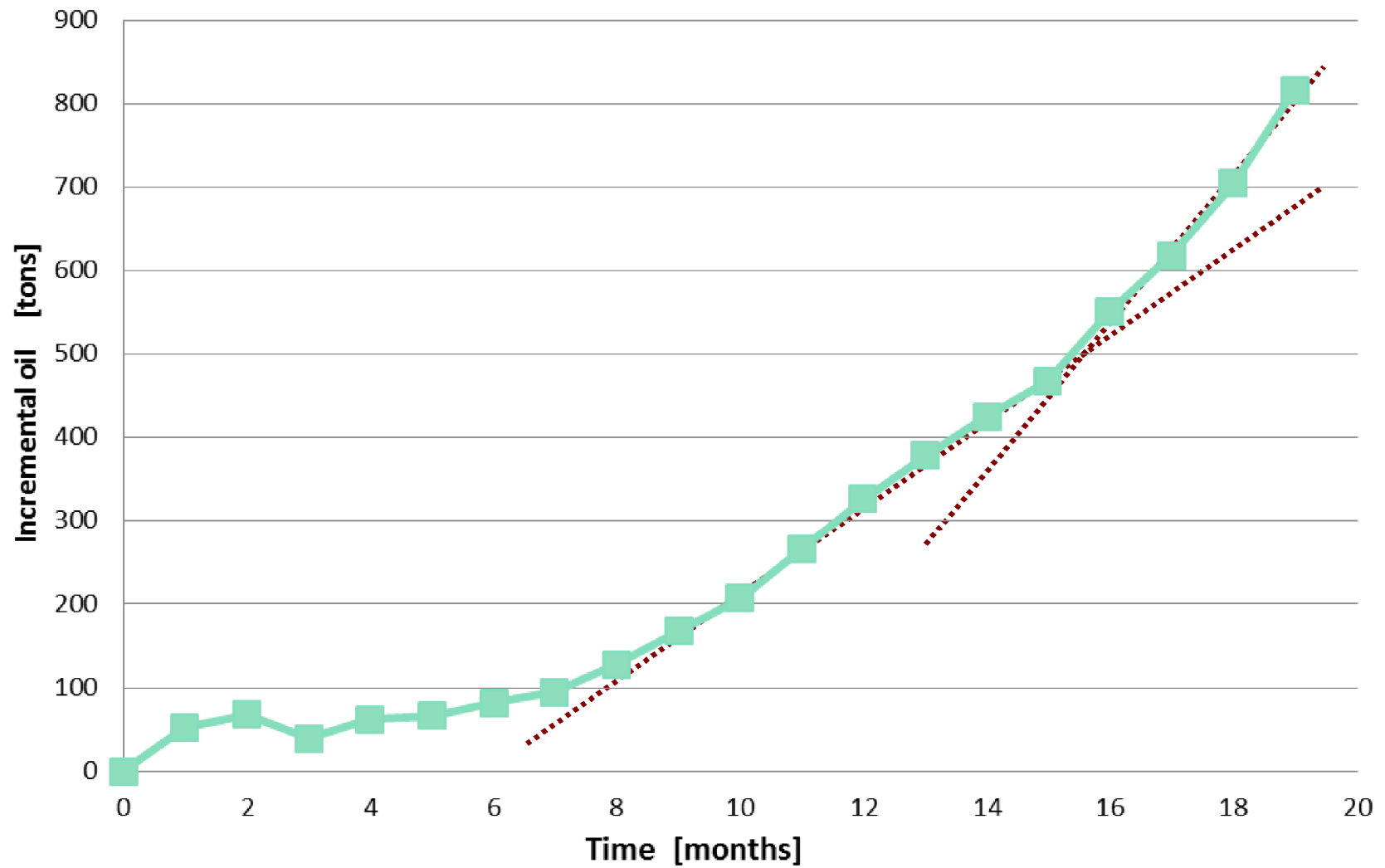
Nutrient cost per incremental barrel < \$2.50 US

Total MEOR cost per incremental barrel < \$11.00 US

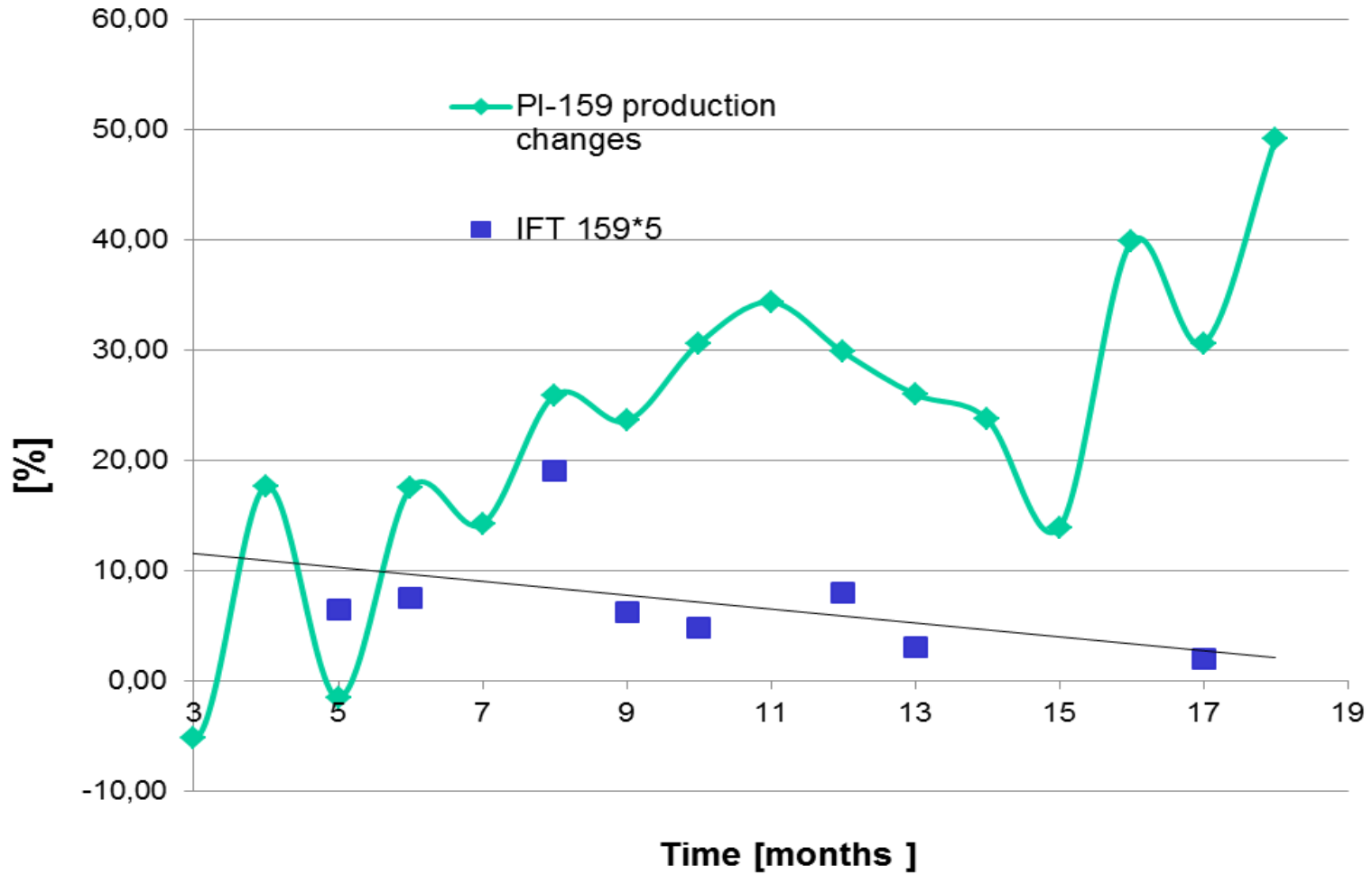
Projected MEOR per barrel costs at 32 months < \$6.00 US

MICROBIAL ENHANCED WATERFLOODING RECOVERS OIL STRANDED IN MATURE FIELDS

Pł-52 and Pł-159 Combined Incremental Oil Production
Trend Lines at 19 Months



IFT and production of PI-159 well comparison



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Pławowice - Summary

- ◆ Significant production increases from both project wells > 1,400 metric tons (~ 10,500 barrels) in 23 months
- ◆ MEOR production cost at 23 months < \$8.00 /bbl incremental oil
- ◆ Per barrel production cost decreases over time – **provided increases are sustained**
- ◆ Systematic approach to MEOR project development proved cost-effective at small scale (1-injector / 2-producers)
- ◆ Project used existing infrastructure, no specialized field equipment required
- ◆ Easily expanded to other injector / producer systems
- ◆ Improved injectivity reported at the PI-311 injector
- ◆ No formation damage or environmental problems observed

Based on these results, the Polish Oil & Gas Institute:

- ♥ Recommends project continuation through May 2014, and expansion in 2014 to include other connected injector / producer systems.
- ♥ Recommends POGC screen other mature oil fields for compatibility with this Microbial Enhanced Waterflooding Technology.

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Basic MEOR Approaches

MEOR technology is implemented by the following **basic approaches with variations**:

1. Stimulate beneficial indigenous microbial populations
 - A) sample production fluids
 - B) screen for indigenous microbial strains
 - C) periodically inject specially prepared nutrients and/or bio-catalysts

2. Inject and stimulate microbial strains isolated from production fluids
 - A) sample production fluids
 - B) isolate beneficial microbial strains and grow up high colony forming units (CFU's)
 - C) inject as one or more slugs
 - D) periodically inject specially prepared nutrients / bio-catalysts

3. Inject and stimulate a microbial system proven to improve oil production
 - A) use strains naturally selected for injectivity, transport and growth under reservoir conditions
 - B) inject as one or more high CFU slug(s)
 - C) periodically inject specially prepared nutrients / bio-catalysts

4. Inject biologically produced products and/or bio-catalysts (with or without microbial strains)
 - A) use commercially available MEOR products (enzymes, bio-catalysts, surfactants, etc.)

The history of Microbial EOR; its present and future role in enhanced oil recovery:

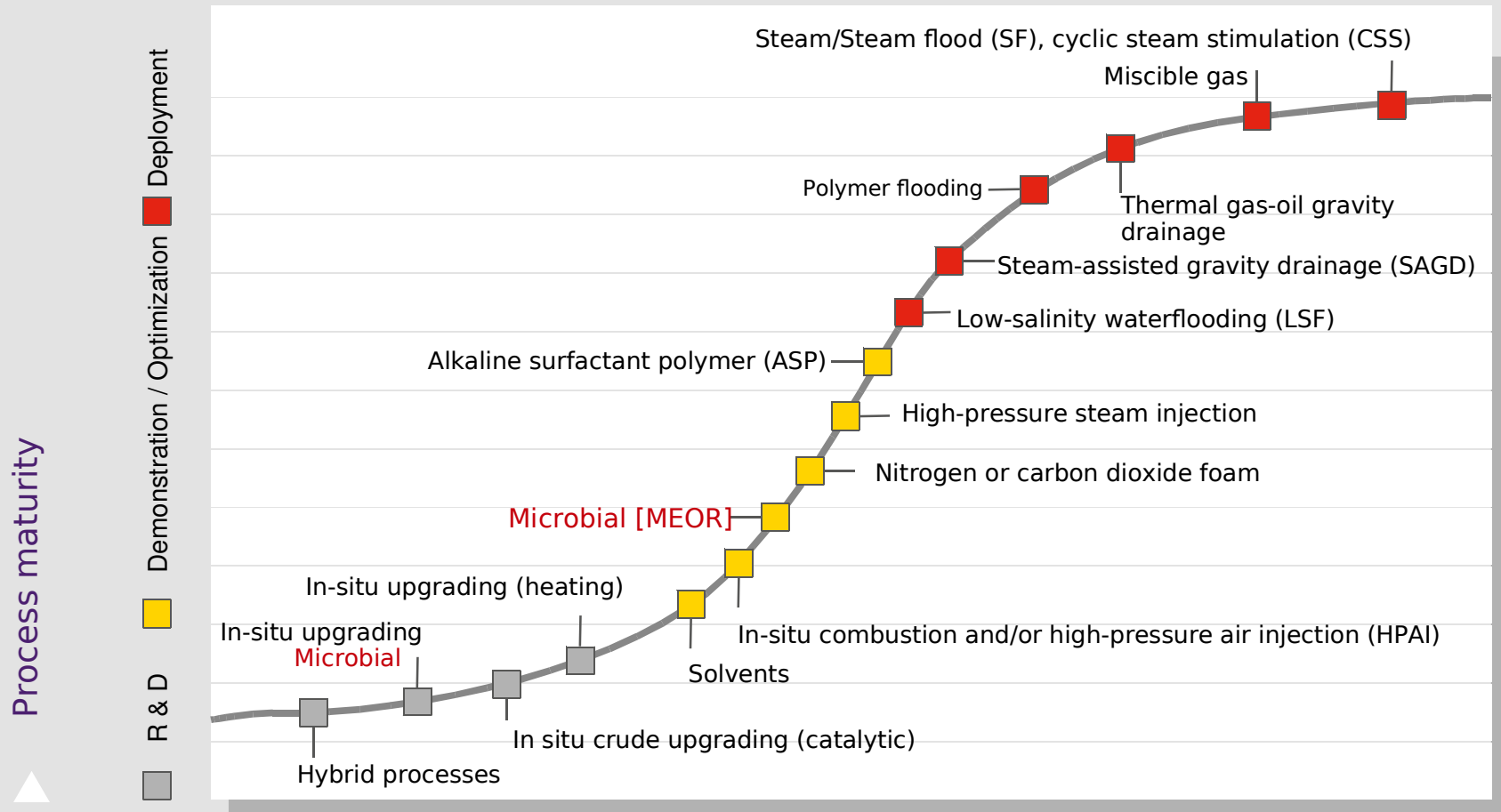
<http://www.rambiochemicals.com/docs/meor.html>

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Maturity of Various EOR / MEOR Processes

EOR Process Development



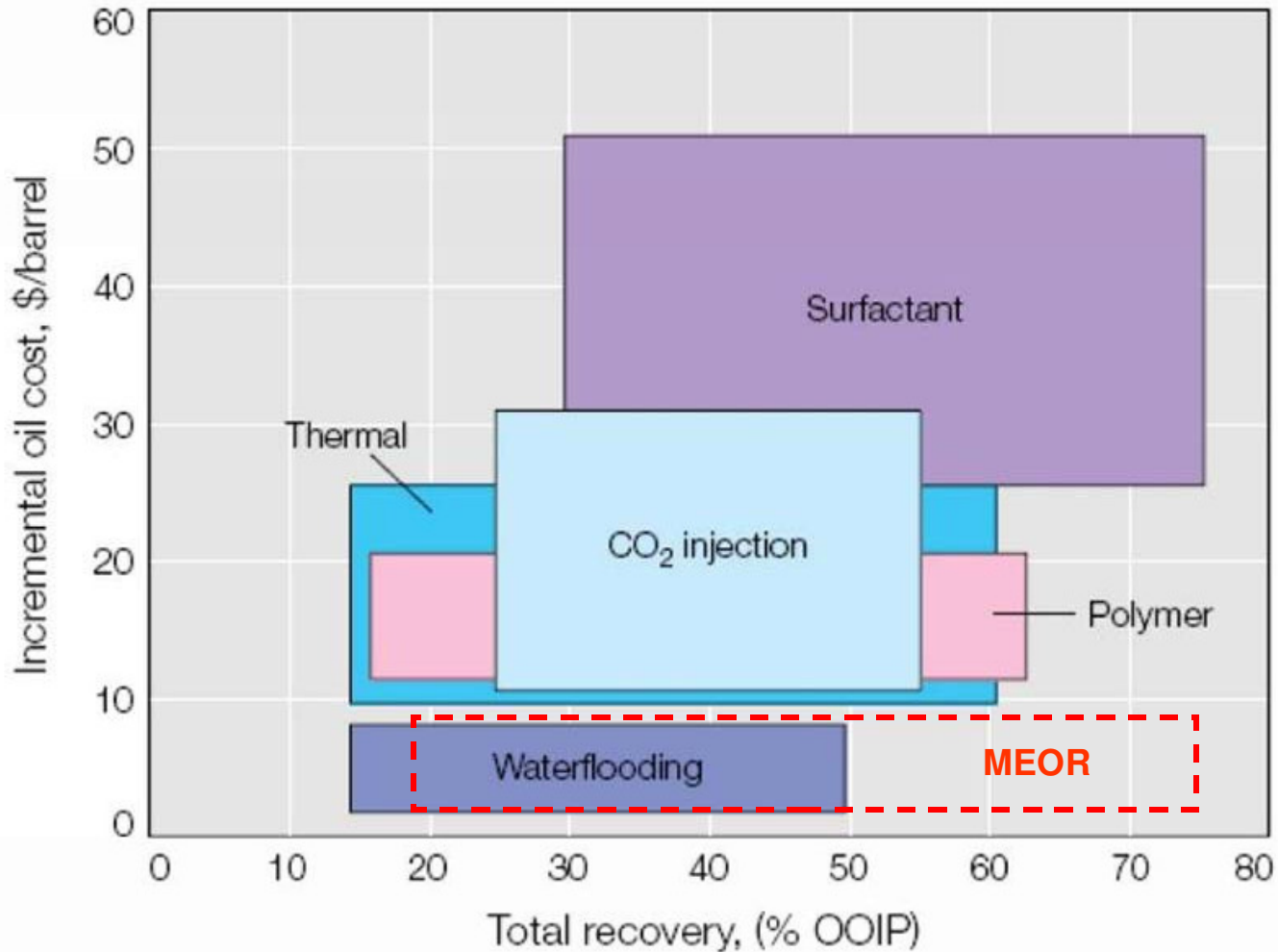
▶ Process development time

Primary and secondary recovery methods recover 30-40% of the oil in a reservoir. EOR / MEOR techniques target the remaining 60-70% left stranded in the ground.

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Costs Comparison and Potential of Various EOR Methods



Comparison of various EOR process costs.

Ref: Simandoux *et al.* "Managing the Cost of Enhanced Oil Recovery." IFT Journal, vol 1.

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Conclusion

- **Microbial Enhanced Oil Recovery [MEOR] technology can be applied successfully in smaller scale projects.**
- **Economies of scale predict that larger scale projects will return larger ROI's.**
- **MEOR can prolong the productive life of marginal oil fields.**
- **A systematic approach to project design, development, implementation and monitoring is essential for reducing risk and maximizing oil recovery.**
- **MEOR cost per barrel, even at small scale, is competitive with other EOR processes.**

Mature oil fields world-wide with suitable geochemical and geophysical characteristics are viable candidates for

Microbial Enhanced Oil Recovery

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9th Global Edition

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*A Systematic Approach to Microbial Enhanced Waterflooding
for Smaller Scale Projects.*



Engineering Details
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Inquiries Welcome



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