

NC Museum of Natural Sciences

BEST FEST: Science Talks Series

Welcome To

MEOR Spells MORE OIL[®]

Presented by
RAM Biochemicals, Inc.

With Special Thanks To:

Polish Oil & Gas Institute [INiG-PIB], Polish Oil & Gas Company [PGNiG]
North Carolina Museum of Natural Sciences
BTEC and NC State University

NC Museum of Natural Sciences

BEST FEST: Science Talks Series

Microbial Enhanced Oil Recovery Spells MORE OIL

We hope to give you a better understanding of:

- What crude oil is – What its made of
- How its formed and Produced
- Primary and Secondary Oil Recovery
- Enhanced Oil Recovery [EOR] & Microbial [EOR]
- Practical Application of MEOR
- Project results - Early Phase I
- Conclusion

What is crude oil made of?

Crude oil is considered a *fossil fuel* and classified by the type and relative percentages of its hydrocarbon content. Oil varies chemically from reservoir to reservoir, but is typically composed of:

Element	Weight %	Hydrocarbon	Avg Weight %	Weight % Range
Carbon	83-87	Paraffinic	30%	15 - 60%
Hydrogen	10-14	Naphthenic	49%	30 - 60%
Nitrogen	0.1 - 2	Olefinic / Aromatic	15%	3 - 30%
Oxygen	0.1-1.5	Asphaltic	6%	Remainder
Sulfur	0.5-6			
Metals	< 0.1			
Hydrocarbon weight % values are averages.				

There are hundreds of grades and types of crude oil. Oil is named after the reservoir from which it is produced. A partial list of the world's many grades and types:

Alaska North Slope, Algerian Condensate, Arab Extra Light, Arab Heavy, Arab Medium, Azadegan, Bakken, Balder, Belayim Blend, Beryl, Bonny Light, Brass River, Brent Blend, Brunei Light, Champion, Cinta, Cold Lake Blend, Dubai, Eagle Ford, Escalante, Foroozan Blend, Fulmar, Gryphon, Hidra, Hoops Blend, Isthmus, Jasmine, Kuwait, Light Louisiana Sweet, Liverpool Bay, Mars Blend, Maya, Napo, Nile Blend, Oman, Poseidon Streams, Qatar Marine, Rabi, South Arne, Tapis, Tempa Rossa, Terra Nova, Troll, Turkmen Blend, Upper Zakum, Urals, Vasconia, West Texas Intermediate (WTI), Western Canada Select, Xikomba, Yoho, Zakum, Zuata Sweet, Zueitina

Where does crude oil come from / how does it form?

Crude oil: Mysterious Origin?

1. Biogenically: The prevailing view among geo-scientists is that crude oil is the biologically transformed remains of long dead plants and tiny marine organisms (zooplankton and algae). Larger animals may have also contributed to a much lesser extent.^[1]

2. Abiogenically: Proposed in the 1950's, this theory holds that petroleum forms “naturally” through geochemical processes deep inside the Earth.^[2]

Indeed, the genesis of crude oil may prove to be both biogenic and abiogenic. But in the oil business where the oil comes, how it is formed and what it is made of has little if any impact on:

How Crude Oil is Produced

Kansas oil well log



Well Profile
Glen Marcellus #B-1

C-SE-NE
1980'S, 660'W, FNEC.
Sec: 36 - T32S - R35W
Stevens County, KS

API No: 15-189-20653
Spud date: 4/21/1983
RTD date:
Completion: 7/15/1983
Longitude: -101.06951
Latitude: 37.22271
Field: Shuck Northwest

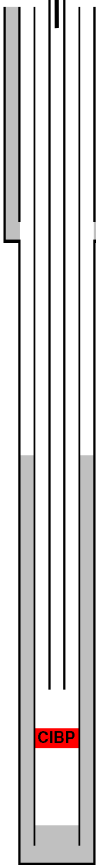
Lufkin Mark II 228.
64"Stroke

11/4x22'PRw/12'Liner.
8'6"2'x7/8 subs.
81-7/8 rods.
165-3/4 rods.
2'x3/4 sub.
2x11/2x16'RWTC.
23/8x6' sub.
193 jts 23/8 tbg.
23/8x51/2 AC@6028'.
9 jts 23/8 tbg.
SN @ 6247'.
1 jt 23/8 tbg.
3'Perf sub, Bullplugged@6280'.

20" Conductor at 86'.

Tops		
Chase	2618'	332
KB	2950'	-3
DF	3431'	-481
GL	4499'	-1549
Atoka	5602'	-2652
Morrow	5627'	-2677
Chester	5999'	-3049
St.Gen	6221'	-3271
St.Louis	6355'	-3405

95/8@1691'w/500sx.



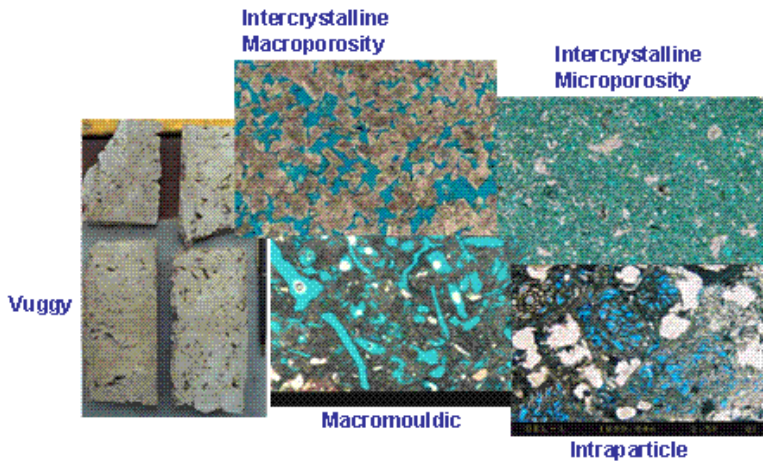
Chester -3184
6134' to 6142', 2spf. 1983.
3284', Could be sand.

6400'PBD.
51/2@ NA.
6500'RTD.

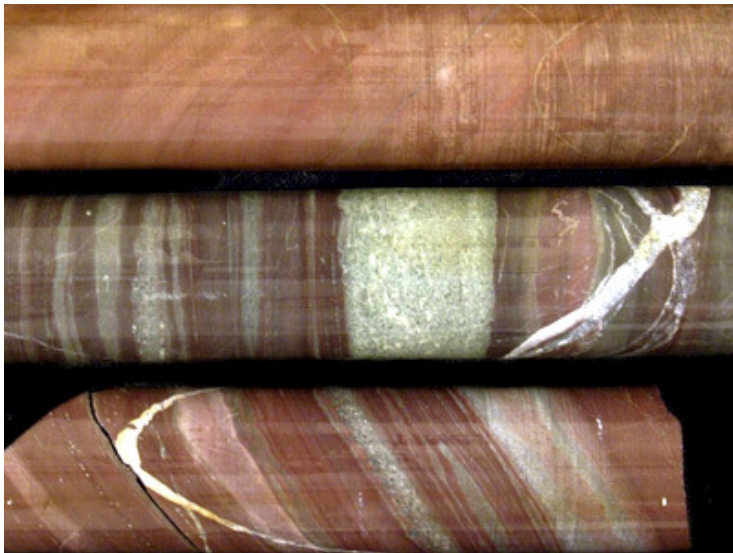
The origin of crude oil, how it is formed or what it is made of has little if any impact on:

How Crude Oil is Produced

Crude oil flows through oil bearing rock!



Carbonate formation rock



Consolidated & unconsolidated sandstone and granite cores

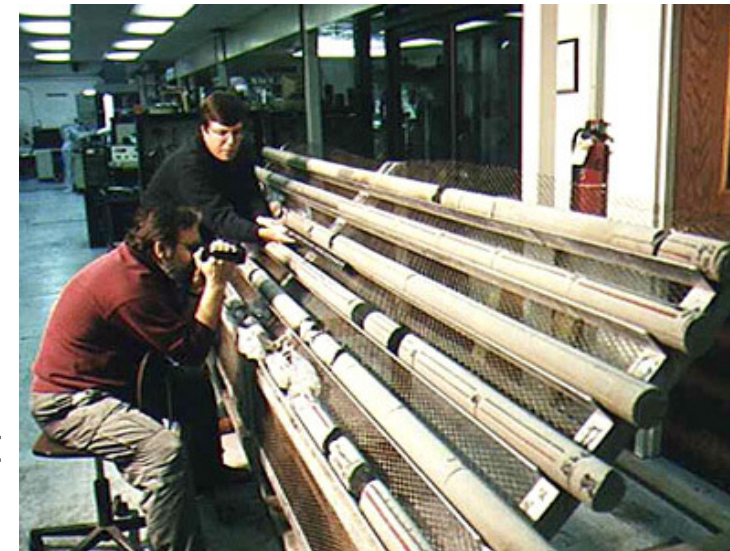
Small cores used for laboratory studies of Recovery Factor (RF)



Standard core size is 1" diameter x 4" height
Pore volume is measured by removing water with heat and replacing under pressure until saturated

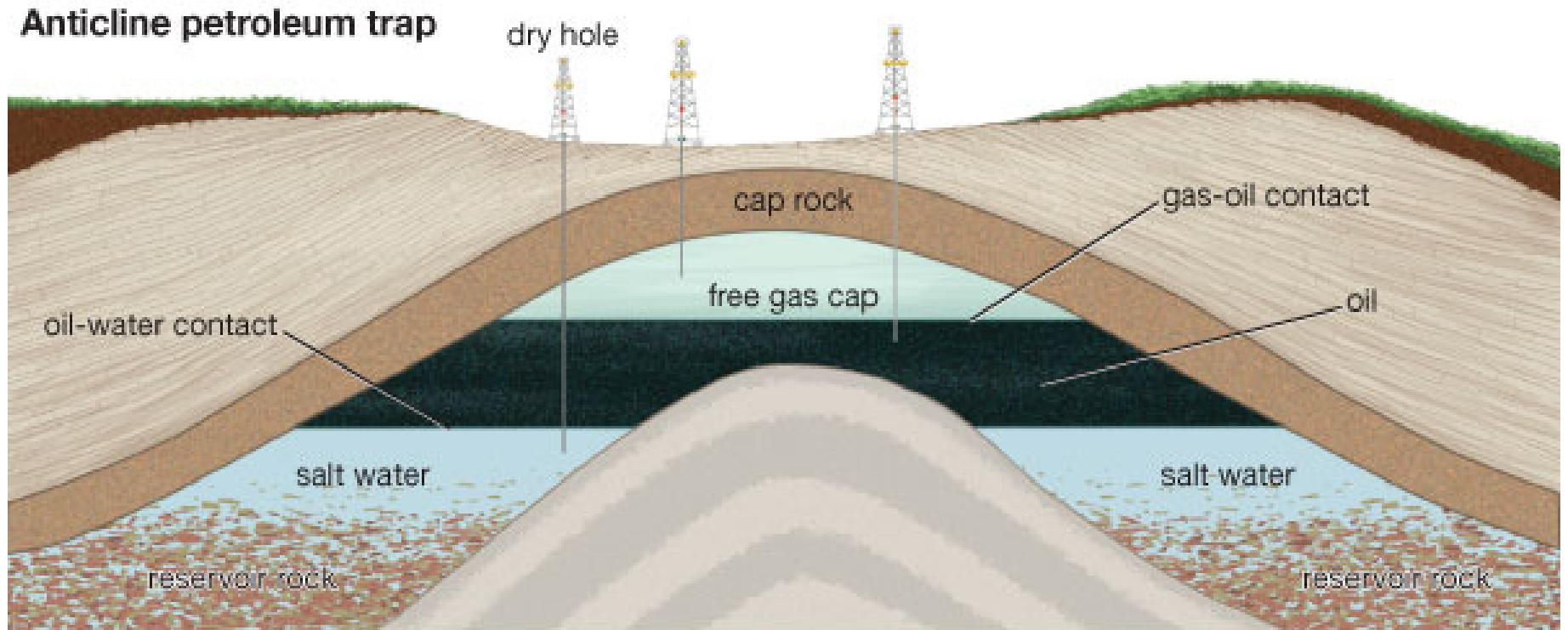


Core drill bit



Well logging 'tube' cores

Crude oil trap



© 2010 Encyclopædia Britannica, Inc.

West Texas Intermediate, Brent Blend, and Dubai are *benchmark crudes* used as chemical and physical reference markers to 'grade' hundreds of crude oils produced around the world. Other benchmarks include the **Opec basket, Tapis Crude** and **Bonny Light**.

West Texas Intermediate is used primarily in the U.S. It is light (high API gravity) and sweet (low-sulfur) thus making it ideal for producing products like low-sulfur gasoline and diesel fuel.

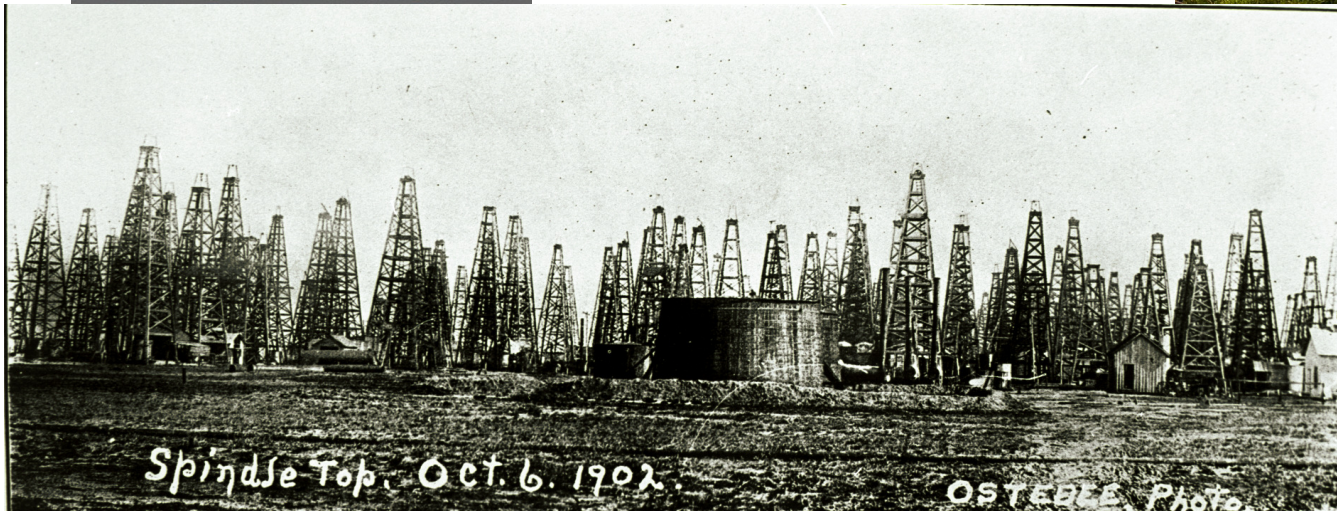
How crude oil is produced – (Primary Recovery)

Three distinct recovery phases: primary, secondary, and tertiary (or enhanced)

Primary recovery – natural reservoir pressure (gas drive) moves oil through the formation and into the production tubing. Gravity drainage begins to take over as the reservoir's natural pressure decreases.



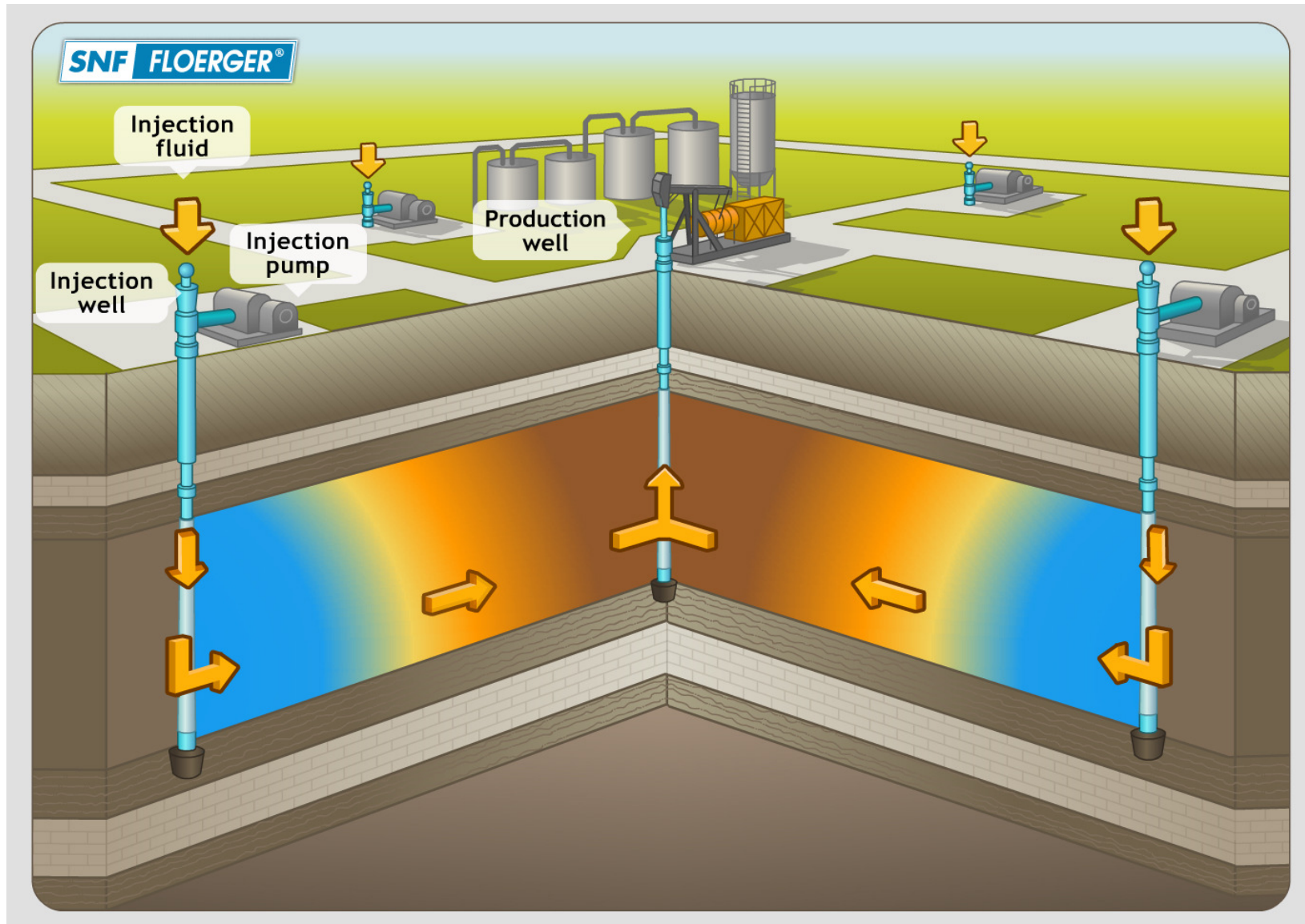
Pump jacks are installed to lift oil up the production tubing and move it along surface lines and into stock tanks when gas drive is depleted.



Primary recovery typically produces about 10% to 20% of the original oil in place (OOIP) in a reservoir.

How crude oil is produced – (Secondary Recovery)

Secondary recovery – injects water or gas to displace and drive oil to the producing wells



Secondary recovery will produce another 20 to 40% - leaving as much as 60 - 70% still in the reservoir.

How crude oil is produced - (Tertiary Recovery)

Tertiary recovery – enhanced oil recovery (EOR) is comprised of a suite of technologies

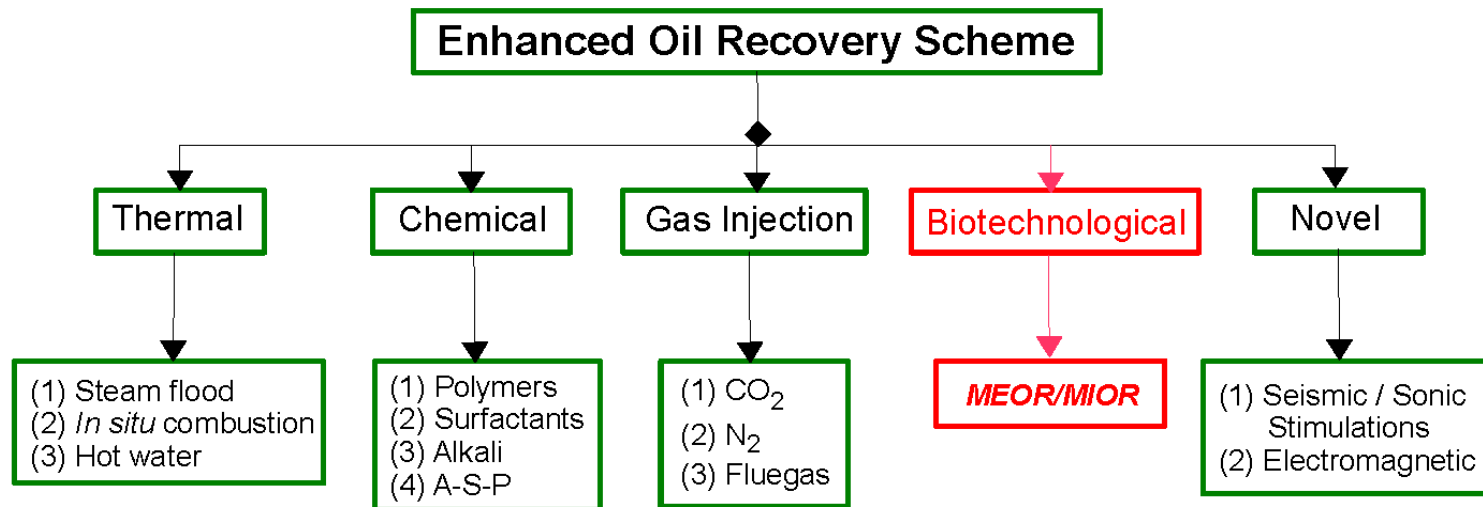
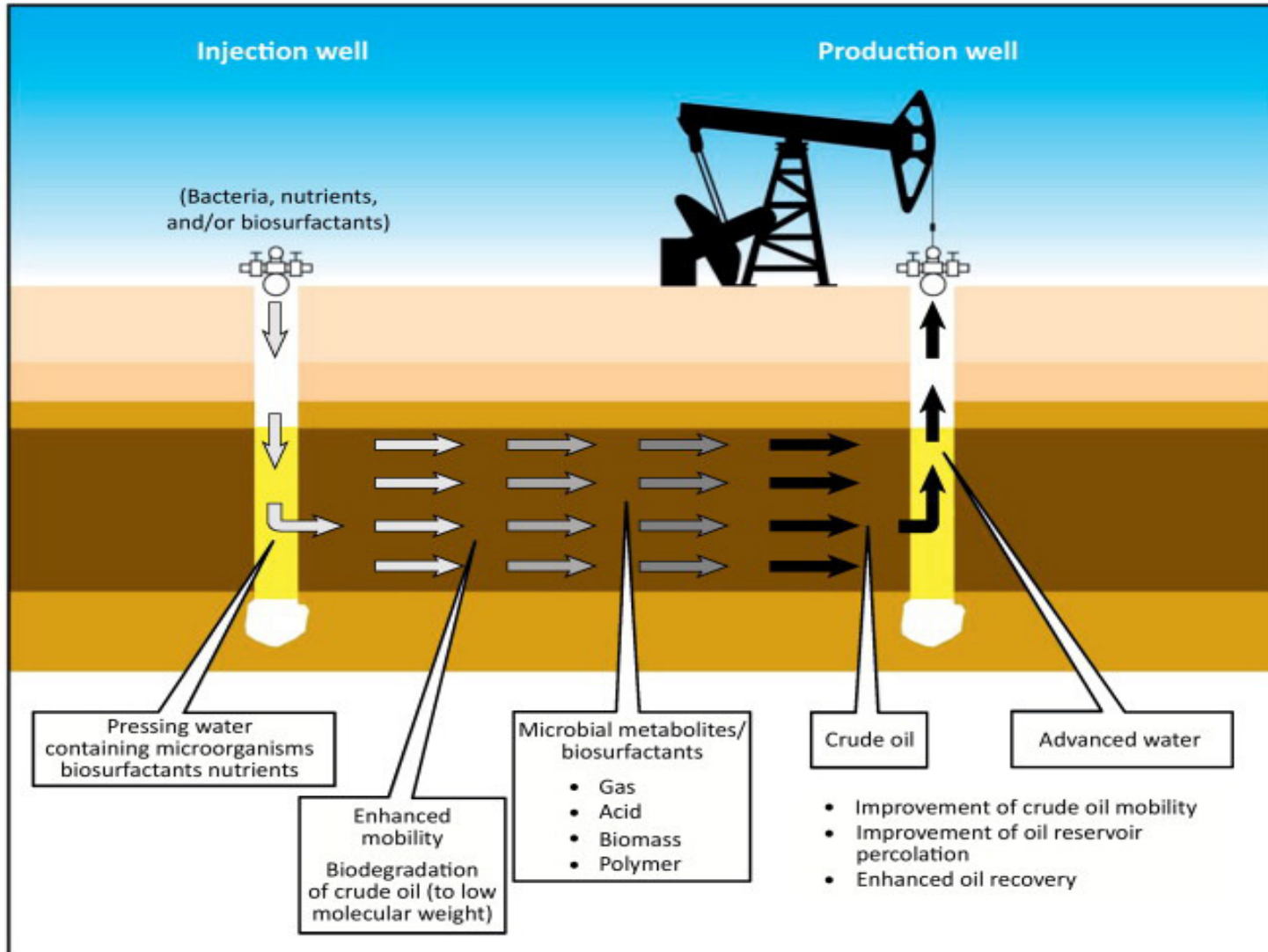


Fig. 1 Diagram of current enhanced oil recovery techniques

Tertiary recovery targets the remaining 60 to 70% of OOIP still left stranded in the reservoir.

MEOR – Biological EOR

What exactly is MEOR and why does it spell MORE OIL?

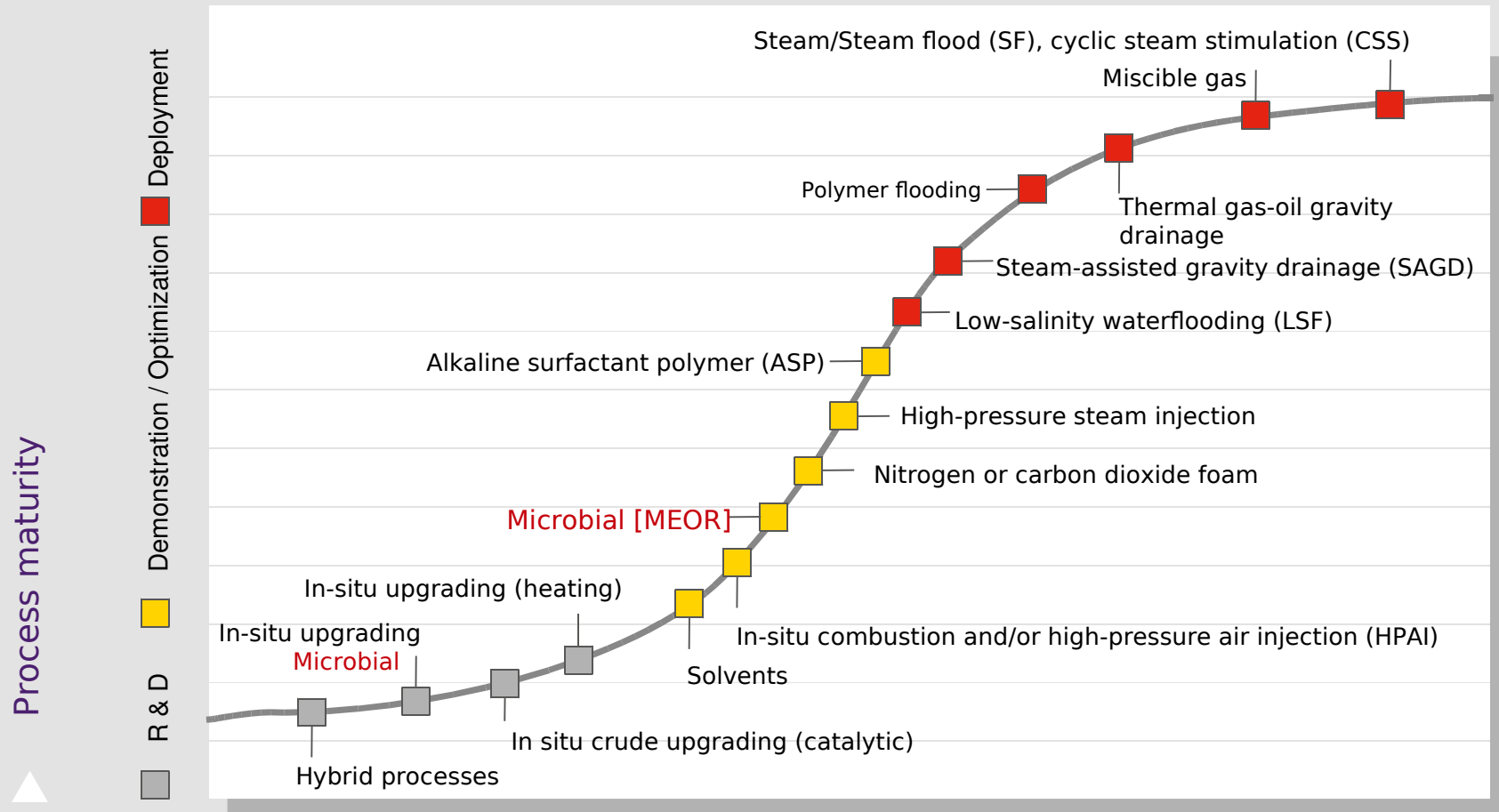


TRENDS in Biotechnology

MEOR is a biological approach to EOR. But rather than injecting EOR chemicals or gases, microbes produce them *in situ* (in the reservoir's oil bearing matrix).

Maturity of various EOR technologies

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.

MEOR Goes to Poland



Pławowice MEOR Project



INSTYTUT NAFTY I GAZU



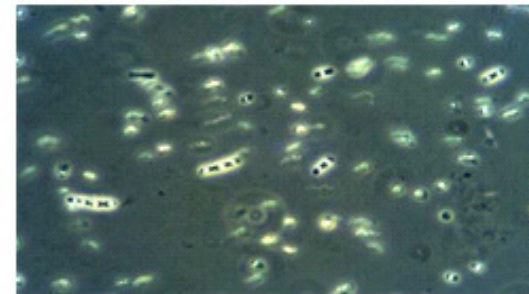
Microbial Waterflooding as a Method to Increase Oil Production in Mature Fields

Presented By:

Sławomir Falkowicz, Renata Cicha-Szot
Institute of Oil and Gas [INiG]

Witold Wójcicki
PGNiG S.A. Branch in Sanok

Marcin Rogaliński
PGNiG S.A. Warsaw





Cooperative Partners

INiG – Polish Oil & Gas Institute

Laboratory Evaluations
Project Design / Development / Implementation
Monitoring & Oversight (following initial MS injection)

PGNiG – Polish Oil and Gas Company

Oil Producer
Microbial System (MS) and Nutrient Injections
Production Data

BTEC / NCSU Department of Microbiology

Produced MS Inoculum from RAM Seed Stock

RAM – RAM Biochemicals, Inc.

Produced Microbial System Materials
Project Design / Development / Implementation
Developed Application Protocols
Project Coordination & Oversight (through MS injection)

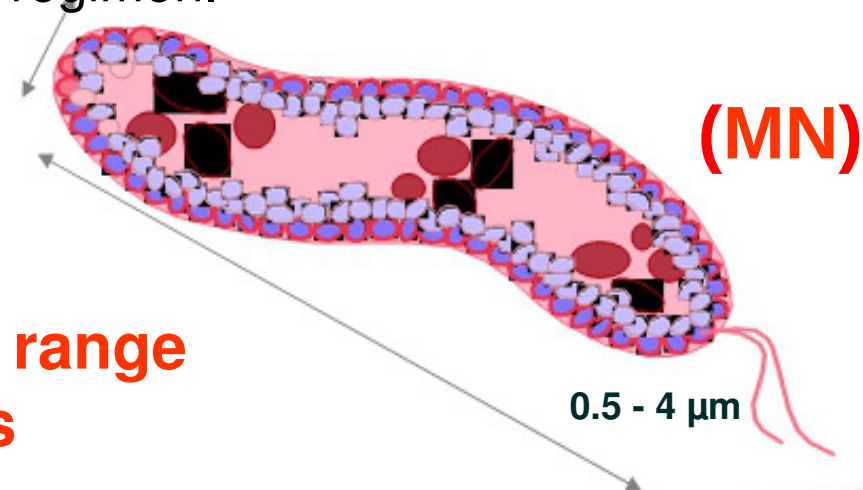




Presentation of Microbial Oil Recovery (MN) Bacterium do the Work!



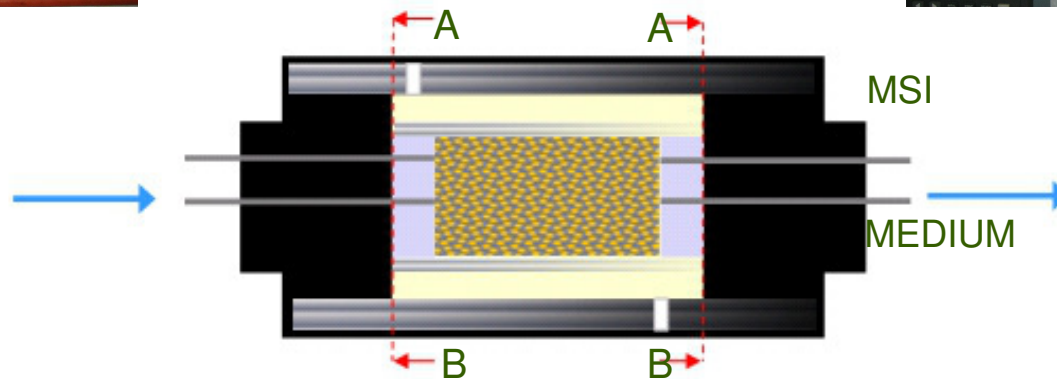
- Living / self-replicating organisms
- Factories producing bio-products useful for conformance control
- Not genetically modified, ubiquitous in nature
- Naturally selected for injectivity, transport through porous media, and the proven ability reproduce under reservoir conditions when provided with the proper nutrient regimen.



**Formation pore diameters range
from 2 – 200 microns**



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 system proposed by RAM Biochemicals, Inc.



Laboratory testing of MS effectiveness

Core Number	Permeability [mD]	Permeability skuteczna S(or) [mD]	Volume Porosity [cm3]	Oil Volume [cm3]	Waterflooding		
					Oil Displaced [cm3]	Oil Remaining [cm3]	RFwf [%]
1- Control	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 Number	RFwf [%]	Initial MS Injected	Additional MS Injected		Total Time	RFmwf [%]	Emwf [%]
			Pore Volume Injected [PV]	Second Injection [Day]			
1- Control	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

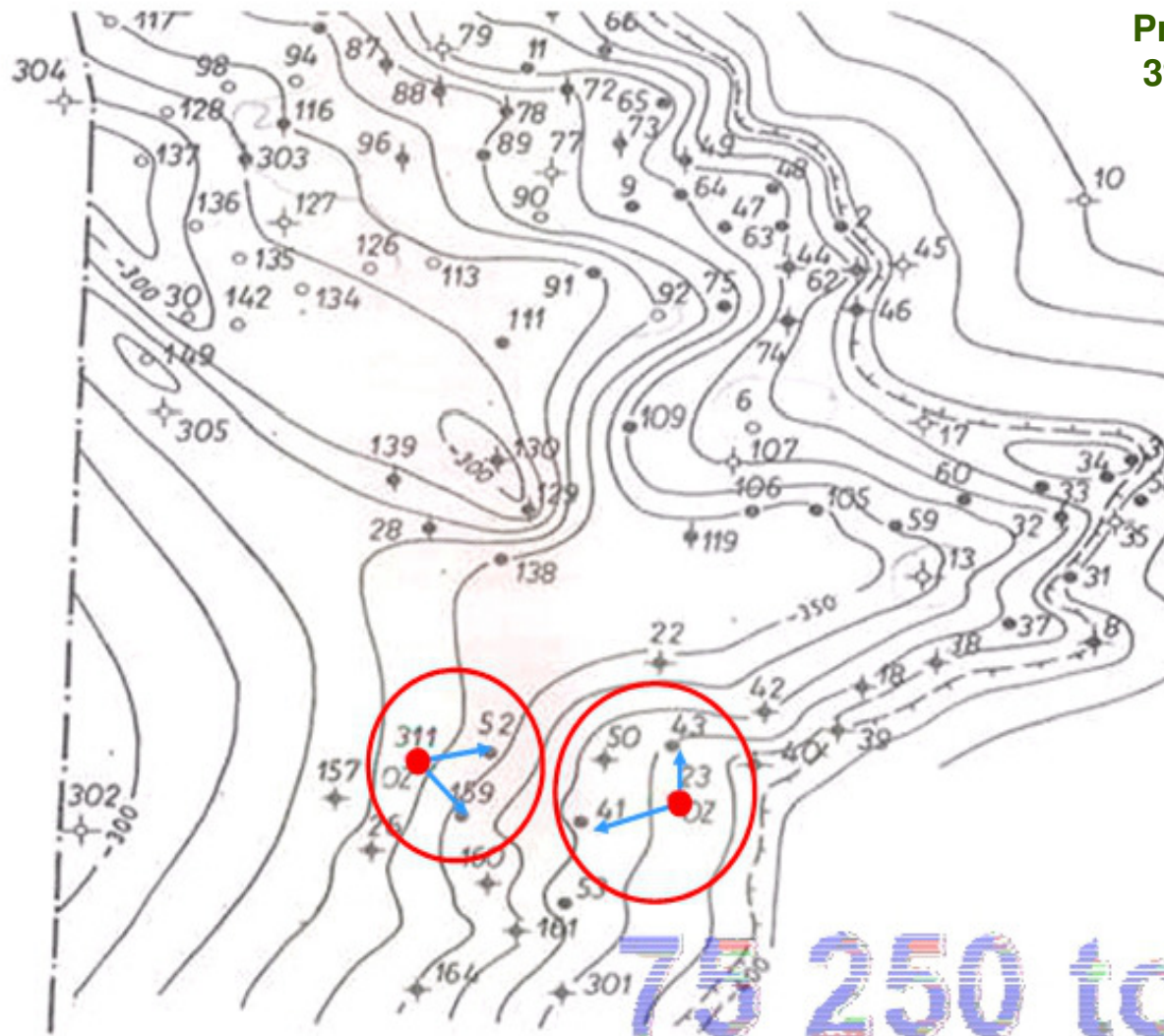


Plawowice Oil Field Selected for Microbial Enhanced Waterflood Project

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.

From 1978 to 1986 the
Polish Oil and Gas
Company injected
produced water into the
production zone through
two injection wells.
Four producing wells
were observed to be
impacted by connectivity
to the injectors.



75 250 ton

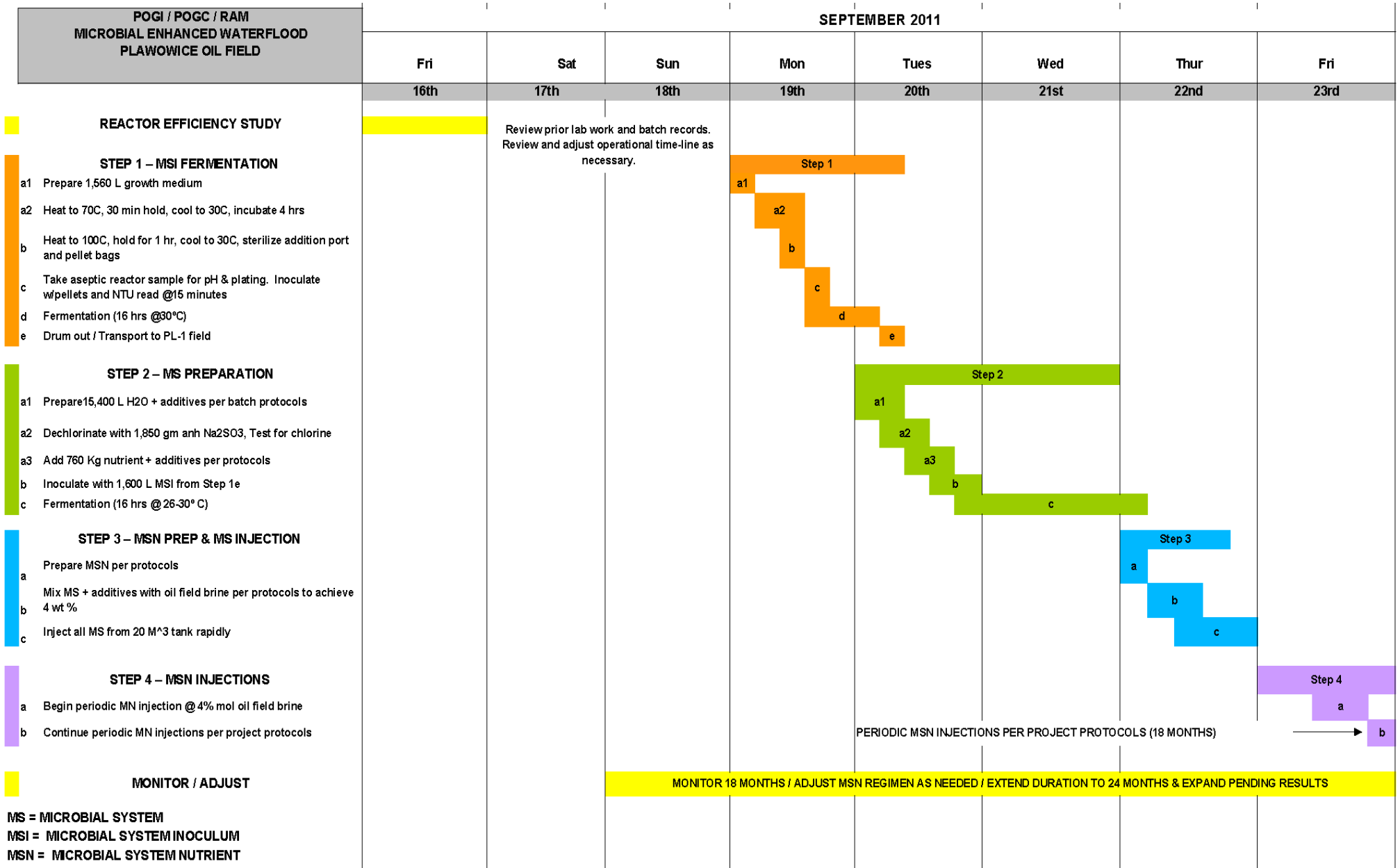


Ławowice MEOR Project Wells

Well Name	Ławowice 41	Ławowice 43	Ławowice 52	Ławowice 159
Symbol	Ł-41	Ł-43	Ł-52	Ł-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



Operational Plan for Plawowice MEOR



Microbial System [MS] 1st Scale-up at BTEC

MEOR project seed materials are prepared and optimized in the laboratory

MEOR Inoculum Preparation



Six 5 ml vials each contain 1 ml lyophilised microbes

Three 250 ml bottles contain high CFU microbial broth

Prepared by:
José M. Bruno-Bárcena, PhD
Assistant Professor of Microbiology,
NC State University

BTEC 30 liter fermentor



BTEC 300 liter fermentor



Frozen pellet bag \approx 6 kg

8 bags / \pm 50 kilograms
Received in Poland
still frozen



Rick Lawless
Associate Director of Strategic Programs
BTEC 23



Second scale-up in Poland Bio-preparation Amplification to (1,500 liters)

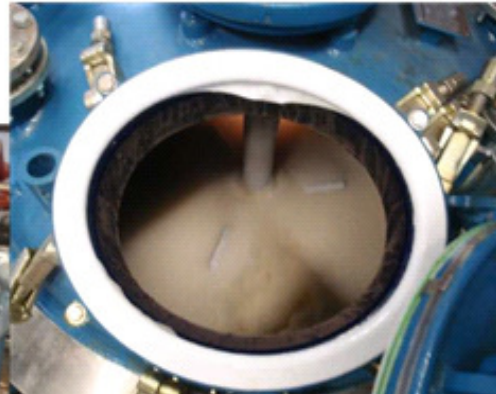




Drum Out at INiG-PIB Fermentation Facility 1.5 m³ (1,500 liters)



**INiG Facility Reactor
Port**



**MSI Drum Out
By Facility Staff**





Microbial System Shipment and Arrival at Plawowice Oil Field



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



**MSI Delivery @ Plawowice Oil
Field**





Microbial System Preparation for Injection at Plawowice Oil Field



**1,500 liters MSI Pumped Into
Tank Prepared with 20 cubic meters
oil field brine + augmented nutrient**

**Produced 20 m³ (20,000 liters) of
microbial system [MS]
ready for injection**

**1,500 liters (396 gallons)
Microbial System Inoculum [MSI]**





Microbial System - Final Amplification [MS] Injected September 2011



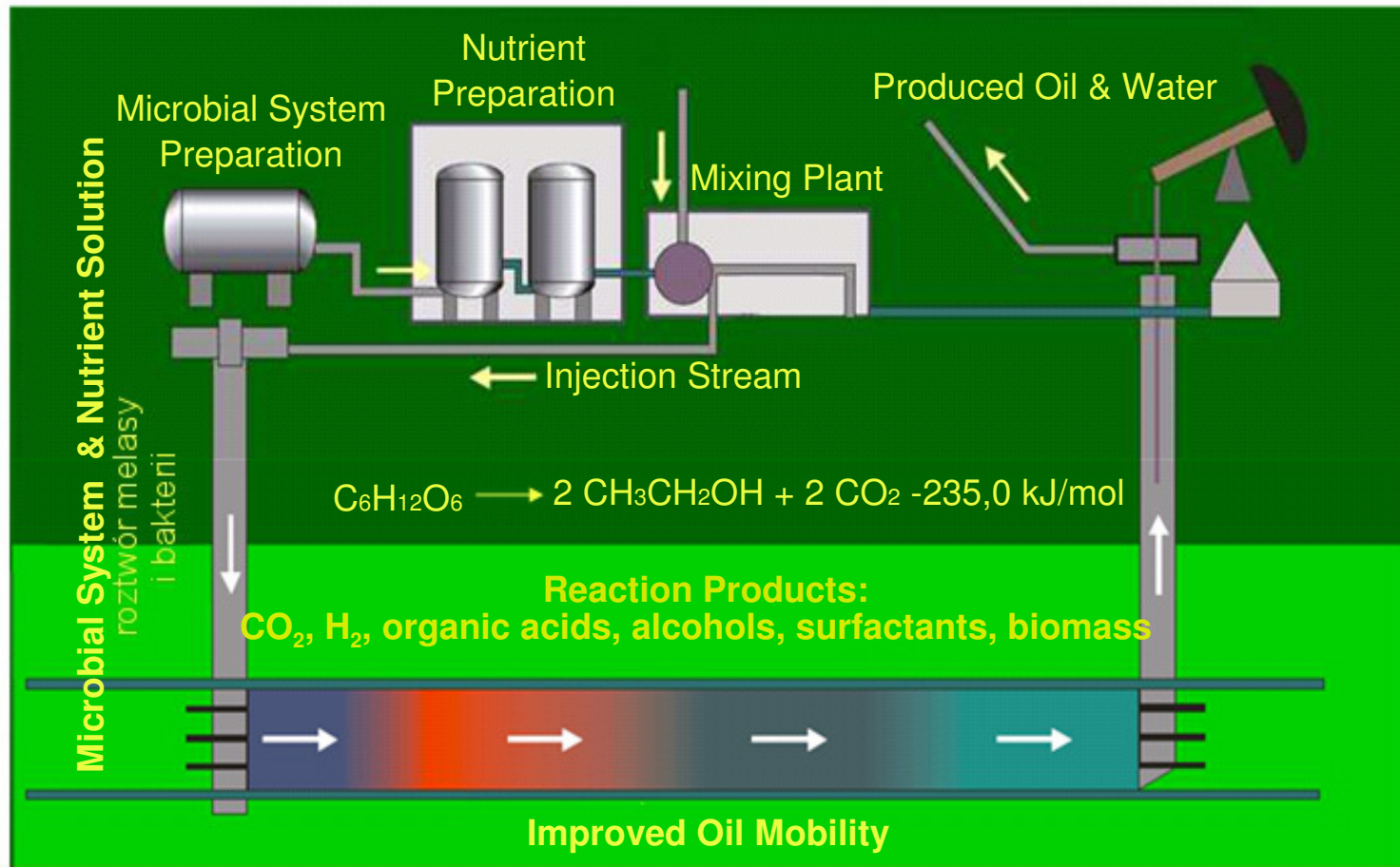
**Augmented Microbial Nutrient
[MN]
Staged at Plawowice**

**Final Microbial System
Preparation
20 cubic meters
(~ 20 metric tons)**





Microbial Enhanced Waterflood Process

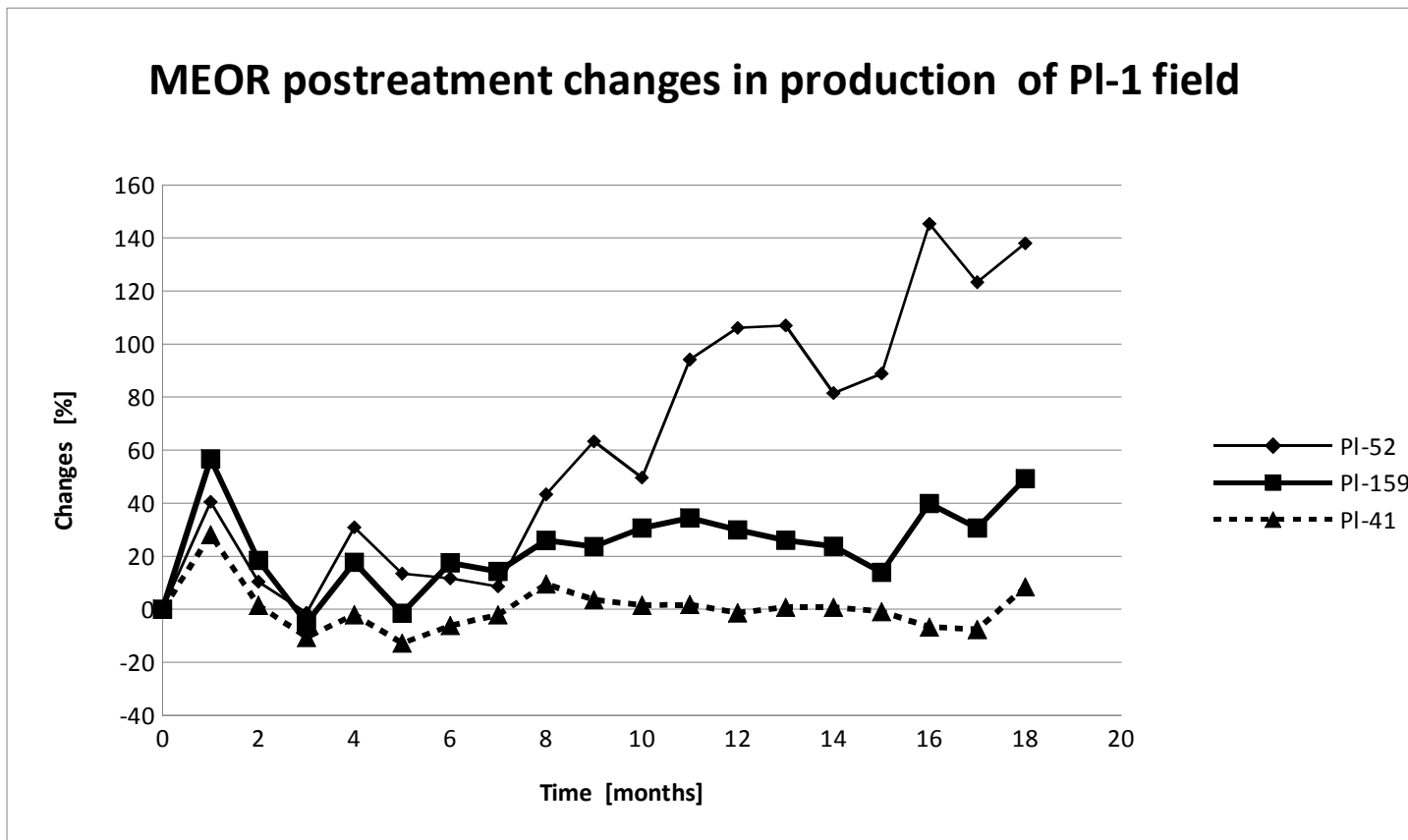


Treatment process involves a specially selected Microbial System (MS) injection into the oil bearing formation, followed by regular / periodic nutrient injections. The Pławowice project used augmented beet molasses to sustain MS growth *in situ*. Other inexpensive nutrients can be used depending on the MS bacteria composition.

Pławowice 18 Month Post Treatment Production

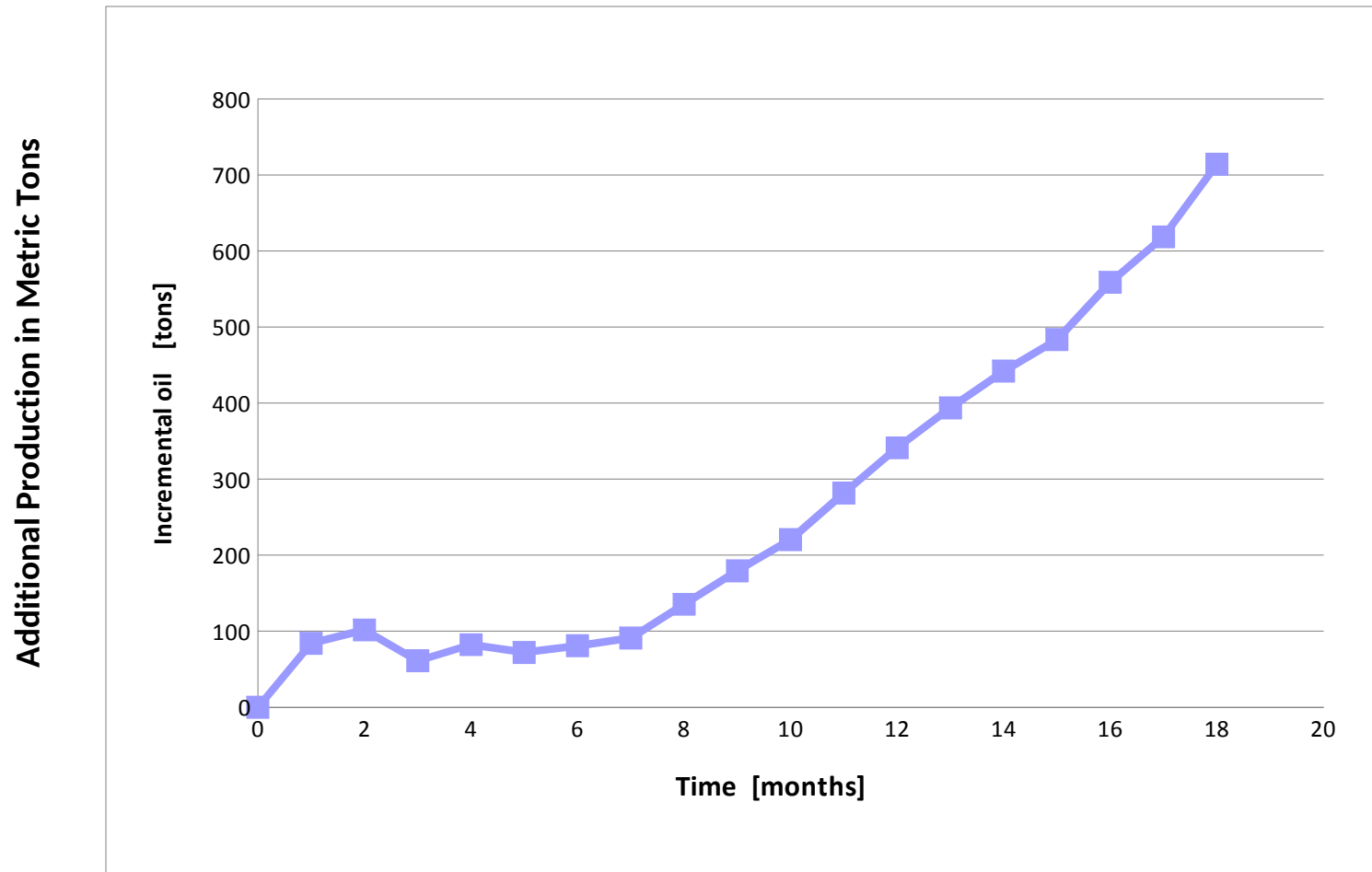
Time [months]	PI-52		PI-159		PI-41		PI-311
	Oil	Water	Oil	Water	Oil	Water	Injected water
1	55.5	0	100.3	7.1	144.8	7.6	187
2	43.6	0	75.8	6.8	114.7	9	208
3	29.3	0	45.6	5.9	101	9.5	169
4	51.7	0	75.3	9	110.7	7.8	182
5	44.8	0	63	6	98.5	5.4	117
6	44.1	0	75.2	8.2	106	8.2	214.5
7	42.9	0	73.1	9	110.6	9	234
8	56.6	0	80.6	9.3	123.7	9.3	195
9	64.5	0	79.1	6.8	117	8.9	143
10	59.1	0	83.6	9.3	114.7	9.3	132
11	76.7	0	86	9.3	115	9.3	72
12	81.4	0	83.1	9	111.5	9	138
13	65.4	0	90	9.3	113.8	9.3	90
14	71.7	0	79.2	8.6	113.9	9	84
15	74.6	0	71.4	7.2	112	8.6	42
16	96.9	0	89.5	7.3	105.4	6.3	156
17	88.2	0	83.6	2.8	104.4	5.6	108
18	94	0	95.5	3.1	122.5	6.2	174
Total	1141.0	0.0	1429.9	134.0	2040.2	147.3	2645.5
Average AT	63.4	0.0	79.4	7.4	113.3	8.2	147.0
Change [%]	60.5		23.7		0.2		
Average BT	39.5	0.0	64.2	5.8	113.2	7.4	

Plawowice 18 Month Post Treatment Production PI-52 – PI-159 & PI-41 (Control)



Plawowice Aggregate Cumulative Surplus Production Pł-52 & Pł-159 Oil Wells

704 metric tons = 5,050 US Barrels @ \$80/bbl = \$404,000



Project Started on September 25, 2011

Time after treatment [months]

Plawowice Findings

- ◆ 704 metric tons (5,050 barrels) of additional oil produced in 18 months
- ◆ Improved injectivity reported at the PI-311 injector
- ◆ No production problems with project wells
- ◆ No damage to reservoir formation observed
- ◆ No environmental problems observed
- ◆ Microbial treatments were cost effective
- ◆ No specialized equipment required to implement treatment regimen

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

- ♥ Recommends expanding the project scope to include other Plawowice oil wells, and advised the Polish Oil and Gas Company to investigate application of this technology to other mature oil fields in Poland.

Mature oil fields world wide with similar geochemical and geophysical properties should be viable candidates for Microbial Enhanced Oil Recovery

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Thank You for Attending

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NC State University
BTEC Bioprocessing Facility
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