Trends in global and regional utilization of EOR technologies

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Worldwide EOR Outlook

- EOR could help to unlock 300 billion more barrels of oil, equal to 10 years’ production at today’s levels.
- Each reservoir requires a tailor-made approach to EOR.
- 2/3 of world oil production comes from mature oil fields (with over 30 year production).
- How to improve the performance of brownfields?

- 75 million b/d of capacity additions needed by 2030.
- 8.5 million b/d is to be supplied by additional EOR in 2030.
Examples for IOR/EOR effects on field life cycles

Weyburn EOR project
Operated by EnCana – Canada, Saskatchewan

Weyburn Unit Historical Production
Courtesy of Encana

Effect of CO₂ gas injection into Budafa-Lovászi fields from late 60’s
Classification of Oil Recovery Processes

Primary Recovery
- Original well-inflow
  - Natural flow
  - Artificial lift
- Production control
  - Infill drilling
  - Horizontal well etc.
- Corrected well-inflow
  - Simulation
  - Acidation
  - Fracturing etc.

Secondary Recovery
- Water flooding
- Gas flooding
- Pressure maintenance

Tertiary Recovery
- Gas
  - Hydrocarbon
  - CO2
  - N2
  - Flue gas
  - Air
  - WAG etc.
- Thermal
  - Steam soak
  - Steam drive
  - Hot water
  - Combustion
  - Electromagnetic etc.
- Chemical
  - Polymer
  - Micellar-polymer
  - Caustic
  - Foam etc.
- Other
  - Microbial etc.
Schematics of different EOR methods

**CO₂ injection (miscible)**

- Purchased CO₂, Anthropogenic and/or Natural Sources
- Injected CO₂
- Recycled CO₂, Production Well

**CO₂ injection (immiscible)**

**Phases of artificial CO₂ gas cap EOR process**
1. Create an artificial gas cap
2. Gas with water
3. Oil displacement with water

**Thermal EOR:**
- Hot water
- Steam flood
- Huff 'n' puff
- SAGD
- Combustion, etc.

**Chemical EOR (polymer, surfactants, etc.)**
EOR projects in the world

- 3.5% of world production

EOR PROJECTS IN DIFFERENT COUNTRIES

- Brasil: Steam, CO₂, MEOR
- Indonesia: Steam
- Saudi Arabia: Steam, CO₂
- Egypt: Cyclic steam
- Germany: Steam
- Netherlands: Steam
- Trinidad: Steam, CO₂
- Turkey: Steam
- Venezuela: Steam, SAGD, HC, Surfactant, Combustion
- Colombia: Steam
- Kuwait: Steam
- China: Steam, Polymer
- Mexico: N₂
- Albania: Steam
- Ecuador: Steam
- Oman: Steam, Sour gas, Polymer
- Abu Dhabi: CO₂

- EOR oil doubled from 1982 to 1990 (1.2 million BPD) and doubled again to 2.5 million BPD in 2006.
- By 2030, EOR Oil will reach 8.5 million BPD.

- Out of 331 commercial world’s EOR projects, only 2 projects in the ME.
- There are 133 producing CO₂ EOR projects, mainly in the United States.

Ref. 2012 worldwide EOR survey - Oil & Gas Journal
### EOR projects in the world

| Key players in USA active EOR projects  
37 operator company |
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal</strong></td>
</tr>
<tr>
<td>Chevron, ExxonMobil, Occidental, Encone, Area Energy, Dereck Oil and Gas, Seneca, Stockdale, etc.</td>
</tr>
</tbody>
</table>

| Key players in Canadian active EOR projects  
12 operator company |
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Thermal</strong></td>
</tr>
<tr>
<td>Apache Canada, Devon Canada, Conoco, ExxonMobil, Husky Oil, Imperial Oil, Cultus, Pengrowth, Penn West Energy</td>
</tr>
</tbody>
</table>

### Middle East: Huge potential - possible business development target

- Brazil: Petrobras (CO2, MEOR, Steam)
- Germany: Wintershall (steam)
- Austria: OMV (polymer)
- Indonesia: Caltex (steam)
- Turkey: TPAO (CO2)
- Venezuela: PDVSA E&P (gas, surfactant, steam)
- India: ONGC (combustion)
- Albania: Bankers (steam)
- Russia: LUKoil (WAG, thermal, chemical)
- Middle East, China (CO2, chemical)
- and other countries.

Source: Society of Petroleum Engineers
Influencing factors

Managerial factors

- Long term commitment
- Profit margin
- Reserve replacement, reporting
- High tech environment
- Knowledge & experience
- Strategic focus
- SD
- Operational experience

Resources

- Financial (CAPEX, OPEX)
- HR capacity
  (Well trained staff, brain aggregation)
- Services
- Access to technology
Oil price effect on number of EOR projects

Planned Domestic EOR Projects

<table>
<thead>
<tr>
<th>Planned Domestic EOR Projects</th>
<th>Resources (kt)</th>
<th>CAPEX (MFt)</th>
<th>CAPEX (MUSD)</th>
<th>NPV (MFt)</th>
<th>PI (Ft/Ft)</th>
<th>CAPEX/Resource (USD/bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demjén - Demjén Nyugat</td>
<td>36,0</td>
<td>748,4</td>
<td>3,4</td>
<td>486,7</td>
<td>1,7</td>
<td>11,8</td>
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<tr>
<td>Öttömös – Kelet, Ött-K-I, Ött-K-II telepek</td>
<td>89,7</td>
<td>3314,6</td>
<td>14,8</td>
<td>1125,4</td>
<td>1,4</td>
<td>21,1</td>
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<tr>
<td>Ortháza mező - Ederics rétegcsoport, Ortháza-1</td>
<td>165,6</td>
<td>5650,8</td>
<td>25,3</td>
<td>3113,7</td>
<td>1,6</td>
<td>19,4</td>
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<tr>
<td>Sávoly DK triasz olajtelepek</td>
<td>101,4</td>
<td>2073,3</td>
<td>9,3</td>
<td>1187,3</td>
<td>1,6</td>
<td>11,6</td>
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<tr>
<td>Ásotthalom</td>
<td>90,4</td>
<td>2703,9</td>
<td>12,1</td>
<td>1094,9</td>
<td>1,6</td>
<td>17,0</td>
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<tr>
<td>Budafa / Zala-Kerettey</td>
<td>181,0</td>
<td>515,6</td>
<td>2,3</td>
<td>4134,9</td>
<td>9,4</td>
<td>1,6</td>
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<tr>
<td>Bajánsenye-Őriszentpéter Dél /Őriszentpéter Dél gázcsapadék</td>
<td>33,6</td>
<td>783,5</td>
<td>3,5</td>
<td>242,5</td>
<td>1,3</td>
<td>13,3</td>
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<tr>
<td>Üllés miocén alaphelység 2</td>
<td>517,5</td>
<td>2103,9</td>
<td>9,4</td>
<td>7740,3</td>
<td>5,6</td>
<td>2,3</td>
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<tr>
<td>Szank - miocén alaphelység</td>
<td>79,3</td>
<td>268,5</td>
<td>1,2</td>
<td>1552,9</td>
<td>6,8</td>
<td>1,9</td>
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<tr>
<td>Nagylengyel Barabásszeg (IX blokk)</td>
<td>265,2</td>
<td>7017,1</td>
<td>31,4</td>
<td>99,1</td>
<td>1,0</td>
<td>15,1</td>
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<tr>
<td>Kiskundorozsma</td>
<td>229,2</td>
<td>7468,2</td>
<td>33,5</td>
<td>3087,8</td>
<td>2,0</td>
<td>18,6</td>
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<tr>
<td>Budafa / Budafa-3 K Kelet</td>
<td>29,0</td>
<td>3232,8</td>
<td>14,5</td>
<td>-2064,2</td>
<td>0,3</td>
<td>63,5</td>
</tr>
</tbody>
</table>

Data from Oil & Gas Journal, EIA and other sources

Production cost curve (not including carbon pricing)
Production tendency in Pannonian basin

Production decline in Hungary

Production decline in Croatia

Gas production
Oil production

Mtoe

Domestic Oil Production (Mt/year)

Year

0 1 2 3 4
IOR / EOR application in MOL’s and INA’s practice

**IOR Application**

- Two sided / simultaneous water injection (GOC and WOC)
- Multifunctional application of horizontal well technology
- In-fill drillings
- Conformance control in oil and gas wells
- Fracturing in low perm reservoirs

**EOR Application**

- CO₂ flooding in carbonate and sandstone reservoirs (Nagylengyel, Szank oil fields)
- CO₂ flooding combined with water injection in sandstone reservoirs (Budafa, Lovászi oil fields)
- CO₂ pilot injection and implementation in Ivanič-Zutica oil field
- Methane injection into an extra light oil reservoir (Algyő field, Tisza-1 reservoir)
- Ethane rich gas injection into a light oil reservoir (Algyő field, Tisza-2 reservoir)
- Nitrogen injection into a fractured metamorphic type oil reservoir (experimental, Kiskundorozsma field)
- Thermal methods (In-situ combustion, steam injection) in Demjén oil field
- Microbiological EOR in Demjén-W field
**Primary Recovery**

- **Original well-inflow**
  - Natural flow
  - Artificial lift
  - Production control
  - Infill drilling
  - **Horizontal well etc.**

- **Corrected well-inflow**
  - Stimulation
    - Acidation
    - Fracturing
    - etc.
  - **Profile modification**
    - Polymers
    - Gels
    - etc.

**Secondary Recovery**

- **Water flooding**
  - Pressure maintenance

**Tertiary Recovery**

- **Gas**
  - Hydrocarbon
  - CO₂
  - N₂
  - Flue gas
  - Air
  - WAG
  - etc.

- **Thermal**
  - Steam soak
  - Steam drive
  - Hot water
  - Combustion
  - Electromagnetic
  - etc.

- **Chemical**
  - Polymer
  - Micellar-polymer
  - Caustic
  - Foam
  - etc.

- **Other**
  - Microbial
  - etc.

**Production by reservoir energy**

**Displacement by Injected water and gas**

**Application of sophisticated energy**

**Contribution of different oil recovery processes (Hungary)**

- **Water injection** 36%
- **CO₂ injection** 4%
- **Natural depletion** 59.2%
  - (**Horizontal Wells** 4%)
  - (**Chemical treatment** 0.5%)
Share of Production from EOR in Total Hungarian Production

- EOR production in 2011:
  81,131 t – equal 12.95% of total domestic oil production (zero royalty!)

- EOR applications by MOL resulted in near to 5 million tons of oil from the beginning (from 1969)

- This ≈ 38-million-bbl exercise means an average of 10% increase in Recovery Factor (IOR/EOR fields)

- RFo is currently 32% (including EOR), Ultimate Recovery is also below 40%

- There is a further room for future improvement.

- Long term strategy is to increase the URF above

- Entering into the international EOR arena:
  - Past:
    - OKGT/SzKFI contract with ONGC for in-situ combustion project in Mehsana field, India (1990)
    - Investigation of participation opportunities for international EOR projects (Albania, Iran, etc.)
  - Present:
1953 – Laboratory-scale CO₂ flooding tests
1960’s – Pilot tests of CO₂ injection in Lovászi and Budafa fields
(with the CO₂ gas gained from flue gas of central boiler battery, then with liquefied CO₂ transported from Répcelak in Lovászi field, and with the CO₂ gas produced from Budafa-Deep formation in Budafa field)
1972 – Field-scale CO₂ injection started in Budafa Field
(in Budafa-West formation, with the CO₂ produced from Budafa-Deep formation)
1975 – Field-scale CO₂ injection started in Lovászi Field
(in Lovászi-East formation, with the CO₂ produced from Budafa-Deep formation)
1980 – Pilot tests of CO₂ injection in Nagylengyel field
(in Blocks V-VI South-Triassic, with the CO₂ produced from Budafa-Deep formation)
1988 – Field-scale CO₂ injection started in Nagylengyel Field
(in Blocks I-IV Rudistid, with the CO₂ produced from Budafa-Deep formation)
1989 – Pusztaföldvár WAG
1992 – Field-scale CO₂ injection started in Szank Field
(in Szank-NE and Szank-SE formation, with the CO₂ separated in Szank Sweetening Unit - more source fields)
2003 – CO₂ Pilot Injection Ivanić
2007 – Screening of new fields New target field for CO₂ injection
2011 – Nagylengyel-III phase Implementation, Ivanic Zutica implementation
MOL-INA EOR projects in 2012

Methane gas injection to Tisza-1 reservoir (Algyő) was finished in May 2012.
• Cum. Oil with primary recovery: 0.66 MMm³
• Cum. Oil on 31 December 2012: 1.40 MMm³
• 13% RF increment in C3-C6 components

CO₂ injection to Szank oil field
• CO₂ from the Szank gas sweetening plant (max. 40000 m³/h)
• 5.6% RF increment

Ivanic-Zutica CO₂ injection project
• Successful pilot in 2003-2005
• Forecasted incremental oil for the whole project (feasibility study):
  ➢ 3,94 MMm³
  ➢ 5.9 % OOIP

Microbiological EOR experiment in Demjén-W field
• Bacterial treatment on De-32,-35,-55 wells
• Good results on De-35,-55,-56 wells
• 275 t incremental production in 1 year
EOR R&D sub-projects

- **EOR mobility control with CO2 (2006-2015):**
  - Decrease the CO2 mobility with newly developed polymer or tenside composition to reach better oil recovery in the CO2 injection tests
  - Development of compositions are ongoing

- **Polymer-tenside flooding pilot in Algyő (2001-2014):**
  - Develop a polymer-tenside composition for polymer-tenside flooding in high temperature and high pressure conditions
  - First injectivity test at pilot well was successful

- **Profile control and EOR applying biotechnology methods (2002-2014):**
  - Develop a bio-polymer and bio-tenside composition for oil-viscosity decreasing and production efficiency improvement as Microbiological EOR
  - Demjén-West huff and puff test results are positive with increased oil production with lower oil viscosity

- **Analysis of EOR opportunities on gas condensate wells (2006-2013):**
  - Develop a process to stop the production decline of Baján-Őri hydrocarbon condensate field
  - First pilot well test was finished with increased production
1. **Synthesis of new type chemicals for HTHP reservoirs** ($Tr=98\, ^\circ C, Pr=170-190\, \text{bar}$)
   - Surfactants (anionic) & cosurfactants (nonionic)

2. **Selection of surfactant & cosurfactant**
   - CMC and IFT measurement
   - Sulubilization ratio
   - Surfactant/cosurfactant ratio
     - Adsorption capacity of chemicals
     - Wetting angles and properties

3. **Polymer-surfactant coposition formulation**
   - Polymer/Surfactants/cosurfactants ratio
   - Filter and mobility ratio, viscosity, long time thermal stability test

4. **Coreflood oil recovery tests by PSC:**
   - 1.0 PV injected aqueous solutions of polymer-surfactant composite (PSC)
   - Tertiary Oil Recovery, $E_{\text{rin}}=15-37\%$
Microbial Enhanced Oil Recovery (MEOR)

1. Selection and growth of microbes
   - Production of biosurfactant-biopolimer composites. (BSBPC)

2. Laboratory study of BSBPC:
   - Flow characteristics (viscosity)
   - Emulsification, demulsification capacity
   - Heavy hydrocarbon (paraffin, asphaltene, wax) decomposition capacity.

3. Coreflood oil recovery tests by BSBPC:
   - 1.0 Pore Volume Injected BSBPC
   - Tertiary Oil Recovery, $E_{rin}=15-21\%$.

4. Huff and Puff treatment of production wells:
   - BSBPC injection
   - 7 days progression (well shutdown)
   - Producing (production increased twice)
Cyclic Screening Process

Portfolio analysis by sub-regions – fine screening

Systematic screening of fields and technologies – coarse screening

Target: 1,500 – 1,800 koe additional oil production

Repeating the cycle in 5-6 years
Future EOR/IOR Plans in Hungary

- Screening of Hungarian fields for future enhancement projects in 2007.
- 36 fields/reservoirs have been chosen for IOR/EOR/EGR applications.
- 4 groups were identified as different project categories on the basis of NPV and technical risks.

**Categories:**
1. Ready to start projects.
2. Necessary to supplement projects.
3. Weak pay-back projects.
4. Do not start projects.

- Modified project list in 2010 (no yellow category, only 26 fields).
- Other new mid-/longterm project ideas.

<table>
<thead>
<tr>
<th>Modified portfolio</th>
<th>Planned operation</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mezősas - Pt/Pz-2</strong></td>
<td>IOR Implementation of gas lift system</td>
<td>Completed</td>
</tr>
<tr>
<td>Ásotthalom-É</td>
<td>IOR Drilling of 1 new well</td>
<td>1 old well was perforated and completed as producer</td>
</tr>
<tr>
<td><strong>Ruzsa</strong></td>
<td>IOR Fracturing of 2 wells</td>
<td>Ru-19 well was fractured and completed as producer - no commercial production</td>
</tr>
<tr>
<td>Pusztaföldvár - Békés szint</td>
<td>IOR Increasing fluid production of producers</td>
<td>Technical preparation of the project is partly completed</td>
</tr>
<tr>
<td><strong>Sávoly-Dél</strong></td>
<td>IOR Decreasing gathering pressure by compressor</td>
<td>Completed</td>
</tr>
<tr>
<td><strong>Endröd - I., III.</strong></td>
<td>IOR Perforation modifications; sidetrackings; increasing numbers of producers by perforating other wells penetrating the target reservoirs</td>
<td>Project is in progress</td>
</tr>
<tr>
<td><strong>Algyő mező olajtelepei</strong></td>
<td>IOR Sidetracking of 1 old well</td>
<td>Under preparation</td>
</tr>
<tr>
<td><strong>Görgeteg-Babócsa (GBK-2)</strong></td>
<td>IOR Drilling of 2 new wells; perforation modifications; periodical production of old satellite wells</td>
<td>Project is under re-evaluation</td>
</tr>
<tr>
<td>Kiskunhalas - ÉK Északi metamorf</td>
<td>IOR CO₂ injection</td>
<td>Field development plan is already prepared</td>
</tr>
<tr>
<td>Öttömös – Kelet, Ótt-K-I, Ótt-K-II telepek</td>
<td>EOR Drilling of 2 new wells; CO₂ injection</td>
<td>Project has not been started</td>
</tr>
<tr>
<td>Ortaháza mező - Ederics rétegcsoport, Ortaháza-1</td>
<td>EOR CO₂ injection</td>
<td>Project starting is still not planned</td>
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<tr>
<td>Sávoly-DK tráss olajtelepek</td>
<td>EOR CO₂ injection</td>
<td>Field development plan is already prepared</td>
</tr>
<tr>
<td>Ásotthalom</td>
<td>EOR CO₂ injection</td>
<td>Implementation of the project is questionable</td>
</tr>
<tr>
<td><strong>Budafa / Zala-Kerettye</strong></td>
<td>EOR CO₂ injection</td>
<td>Field development plan is already prepared</td>
</tr>
<tr>
<td>Barcs-Nyugat gázkondenzátum telep</td>
<td>IOR Drilling of 1 new well</td>
<td>Under preparation</td>
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<tr>
<td>Bajánsenye-Öriszentpéter Dél /Öriszentpéter-Dél gázsapadék</td>
<td>EGR Gas injection</td>
<td>Under preparation</td>
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<tr>
<td>Üllés miocén alaphegység 2</td>
<td>EGR CO₂ injection</td>
<td>Project is delayed</td>
</tr>
<tr>
<td>Szank - miocén alaphegység</td>
<td>EGR CO₂ injection</td>
<td>Cancelled</td>
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<tr>
<td>Demjén-Demjén Nyugat</td>
<td>EOR Hot water injection</td>
<td>Project is under preparation and planning</td>
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<tr>
<td><strong>Endröd-Észak</strong></td>
<td>EOR Drilling of 1 new well</td>
<td>Cancelled</td>
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<tr>
<td>Kiskundorozsma</td>
<td>EOR CO₂ injection</td>
<td>Cancelled due to lack of CO₂ source</td>
</tr>
<tr>
<td>Nagylengyel-Barabásszig (IX blokk)</td>
<td>EOR CO₂ injection</td>
<td>Under preparation</td>
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<tr>
<td>Inke - IB - Vese és Lízoló</td>
<td>FD Drilling of 3+1 wells</td>
<td>Project is delayed</td>
</tr>
<tr>
<td>Végegyháza - Nyugat</td>
<td>FD Drilling of 1 new well</td>
<td>Not economical</td>
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<tr>
<td><strong>Forráskút</strong></td>
<td>IOR Copletion of one well and fracturing</td>
<td>Not economical</td>
</tr>
<tr>
<td><strong>Budafa / Budafa-3 K Kelet</strong></td>
<td>EOR Gasoline and CO₂ injection</td>
<td>Not economical</td>
</tr>
</tbody>
</table>
Future EOR/IOR Plans in Croatia

<table>
<thead>
<tr>
<th>Field</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ivanic-Zutica</td>
<td>CO₂ injection - EOR</td>
</tr>
<tr>
<td>Sumecani</td>
<td>Steam Huff 'n' Puff - EOR/IOR</td>
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<tr>
<td>Okoli</td>
<td>CO₂ or water injection - EGR</td>
</tr>
<tr>
<td>Struzec</td>
<td>CO₂ injection - EOR</td>
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<tr>
<td>Benicanci</td>
<td>CO₂ injection - EOR</td>
</tr>
<tr>
<td>Kozarica</td>
<td>Infill drilling - IOR</td>
</tr>
<tr>
<td>Kalinovac</td>
<td>CO₂ injection - EOR</td>
</tr>
</tbody>
</table>

Full-field numerical simulation of Ivanić field.

CO₂ injection site at Ivanic field.

Injection well Iva-28

Kalinovac field

Kalinovac CO₂ injection - EOR
**Conclusions**

- EOR related oil production has relatively low rate compared to total world oil production, however it will have growing importance in the future world oil production.
- High demand for oil maintains the crude price - promising economics of EOR applications.
- In EOR applications USA is a dominant player significantly with CO₂ and thermal technologies.
- All the relevant factors have to be considered as one integrated unit in EOR projects.
- In the Pannonian basin CO₂ gas injection play important role in EOR utilization (HTHP environment). Miscibility is a hard task.
- Application of different chemical systems on selected wells generated significant extra oil production (above 2 Million bbl)
- 40 year production operation practice in CO₂ flooded assets. Strict cost management is the part of company’s „culture”
- Cyclic, systematic screening of existing fields always generates new oil
Thank you for your attention!