Lake Kivu Methane Extraction: Evaluation of Scenarios

Alfred Wüest
Lukas Jarc, Martin Schmid, Natacha Pasche
Kongens Lyngby DK, 14 May 2009
Overall conclusions (general)

- Dilution
  many disadvantages $\rightarrow$ Avoid dilution
- Reinjection to Biozone
  Nutrient pollution $\rightarrow$ NOT acceptable
- Reinjection below IZ $\rightarrow$ is acceptable
- “Safe” CH$_4$ extraction $\rightarrow$ is possible!
  maintaining stratification / low nutrient prize: $\sim$4% of the CH$_4$ resource
  and 2 withdrawals / reinjections
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Content

• Background information
• Goal of the analysis / study
• Approach
• Results
• Conclusions
• Recommendations
Lake Kivu vertical structure

Salinity [g l$^{-1}$] and O$_2$ Concentration [mg l$^{-1}$]

Depth [m]

Temperature [$^\circ$C]

Gas Concentrations [mol l$^{-1}$]

T

S

CH$_4$

CO$_2$
**Overall extraction numbers**

- Total / extractable CH$_4$ 60 / 46 km$^3$
- Total power 46 $\times$ 400 MWyr
- Power (if CH$_4$ used in 46 yr) 400 MW
- Water flow 100 m$^3$/s
Density stratification

Salinity guaranties stability!

CO2 is second
Lake Kivu – gas pressure

130 m to saturation

55% of saturation

CO₂, CH₄, CH₄+CO₂

hydrostatic pressure
Nutrients: vertical P profile (N same structure)

Major chemocline

Oxycline

Deep water: 200 times more nutrients than surface water

5 g/L
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Goal of the scenarios study

• Find extraction scenario fulfilling the three *Guiding Principles* (constraints)

First: Reduce risk of eruption
Second: Minimize effect on lake ecology
Third: Maximize methane output
Objectives for Lake Kivu methane harvesting

Priority

First Minimize probability of eruption
  → keep profile stable
  → reduce gas content in lake
  → increase activation energy for bubbles

Second Minimize impact on lake ecology
  → minimize nutrient upward flux to Biozone

Third Maximize methane harvest
  → minimize CH$_4$ loss
  → allow build-up of new deep-water CH$_4$
  → no dilution of CH$_4$ resource
<table>
<thead>
<tr>
<th>Guiding Principles</th>
<th>Objectives</th>
<th>Attributes Quantifying Objectives</th>
</tr>
</thead>
</table>
| Safety             | • Keep stratification  
                      • Reduce gas  
                      • Reduce risk | 1) Schmidt stability  
                      2) CO2 Content  
                      3) CH4 Content  
                      4) Bubble forming energy |
| Lake ecology       | • Minimize nutrient input to *Biozone* | 5) P flux to *Biozone*  
                      6) N flux to *Biozone* |
| Economic viability | • Minimize CH4 loss  
                      • Accumulation of newly formed CH4  
                      • no CH4 dilution | 7) harvested CH4  
                      8) harvested plus harvestable CH4 |
What can be adjusted?

five “crews”: Design Parameter

• Extraction depth (+ depth range)
• Dilution water (%) (+ intake depth)
• Release depth (+ depth range)
• % CH$_4$ removed (to turbine)
• % CO$_2$ removed (to atmosphere)
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Scenario definitions

- Biozone
- Intermediate Zone
- Potential Resource Zone
- Resource Zone
- Intermediate Zone Re-injection (A, B)
- PRZ
- Re-injection (C)
- Extraction intake
- Resource Zone Re-injection

- Methane to turbines
- ~40 to 60 m
- Scrubbing (wash) water
- ~40 to 80 m
- ~260 to 460 m
Conductivity $k_{20} \text{[mS/cm]}

\begin{array}{c}
\text{Depth [m]} \\
\text{15 cm/yr} \\
\text{Residence time} \\
800 – 1000 \text{yr}
\end{array}

\begin{array}{c}
\text{15 m}^3/s \\
\text{22 m}^3/s
\end{array}

\text{CH}_4 \text{ production:}
\begin{array}{c}
\text{historic 32 gC/m}^2/\text{yr} \\
\text{recent: } \sim 100 \text{ gC/m}^2/\text{yr} \\
\text{total 4.5 m}^3/s
\end{array}
150 MW plant with intermediate reinjection
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<td>Safety</td>
<td>• Keep stratification</td>
<td>1) Schmidt stability</td>
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<tr>
<td></td>
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<td>2) CO2 Content</td>
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<td>3) CH4 Content</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4) Safety tolerance</td>
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<td>• Minimize nutrient input to <em>Biozone</em></td>
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<td></td>
<td>• no CH4 dilution</td>
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150 MW - intermediate re-injection

Phosphate

Depth (m)

PO₄ (mol m⁻³)

Dilution source depth

Reinjection depth

Intake depth

2004
2014
2024
2034
2044
2054
2104
## Problems related to intermediate re-injection

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Objective “Safety”</th>
<th>Objective “Ecology”</th>
<th>Objective “Economic benefit”</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>KP1</td>
<td>61% of max. after 100 yr</td>
<td>1.6-fold of natural after 50 yr</td>
<td>92 % of maximum</td>
<td>84 % of maximum</td>
</tr>
<tr>
<td>KP2</td>
<td>82% of max. after 100 yr</td>
<td>1.2-fold of natural after 100 yr</td>
<td>93 % of maximum</td>
<td>83 % of maximum</td>
</tr>
<tr>
<td>MH</td>
<td>48% of max. after 100 yr</td>
<td>2.6-fold of natural after 50 yr</td>
<td>96 % of maximum</td>
<td>89 % of maximum</td>
</tr>
</tbody>
</table>
Resource Zone intake / reinjection
(Ext = Re-in = 375 +/- 105 m)
Methane extraction concentration

![Graph showing methane extraction concentration over time. The x-axis represents time in years, ranging from 2004 to 2104. The y-axis represents methane concentration in mol m$^{-3}$. Two lines are shown: one for primary extraction and one for secondary extraction. The primary extraction line starts higher and decreases more sharply than the secondary extraction line, which decreases more gradually.](image-url)
Methane / Carbondioxide ratio

Time (year)

CH₄ / CO₂

primary extraction
secondary extraction
## Advantages of Resource Zone / reinjection

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<tr>
<td>B</td>
<td>48% of max. after 100 yr</td>
<td>2.0-fold of natural after 50 yr</td>
<td>100 % of maximum</td>
<td>100 % of maximum</td>
<td>failed on Obj. “Safety” and on Obj “Ecology”</td>
</tr>
<tr>
<td>C</td>
<td>81% of max. after 100 yr</td>
<td>natural</td>
<td>97 % of maximum</td>
<td>92 % of maximum</td>
<td>option</td>
</tr>
<tr>
<td>D</td>
<td>100% of max. after 100 yr</td>
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</tr>
<tr>
<td>F</td>
<td>87% of max. after 100 yr</td>
<td>natural</td>
<td>98 % of maximum</td>
<td>96 % of maximum</td>
<td>option</td>
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<td>G</td>
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<td>natural</td>
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<td>88 % of maximum</td>
<td>option</td>
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<tr>
<td>H</td>
<td>85% of max. after 100 yr</td>
<td>natural</td>
<td>98 % of maximum</td>
<td>89 % of maximum</td>
<td>option</td>
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<tr>
<td>GH</td>
<td>87% of max. after 100 yr</td>
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• Reinjection below IZ \(\rightarrow\) is acceptable

• “Safe” CH\(_4\) extraction \(\rightarrow\) is possible!
  maintaining stratification / low nutrient
  prize: \(\sim\)4% of the CH\(_4\) resource
  and 2 withdrawals / reinjections
Specific conclusions (scenarios)

- **Intermediate Zone reinjection (< 200 m) (Scenario A,B, KP1, MH)**
  - drives huge P, N fluxes
  - increase CH$_4$ loss
  - reduce stability → NO OPTION

- **PRZ re-injection (Scenario C)**
  - little change to nutrients and stability
  - “dilutes” PRZ → loss of 3 to 8% (If Extraction works ideal)
  → Simple for panning, no short-circuiting

- **Deep re-injection (stacking) (Scenario D)**
  - minimum change to the lake functioning
  → Simple for panning, no short-circuiting, up to 10% loss

- **Deep re-injection (homogenizing) (Scenario E,F, GH)**
  - minimum change to the lake functioning
  → more complex, short-circuiting(?) , only 4% loss
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