Assessment of hybrid solar-fossil processes
- exemplified by a solar reforming process

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Motivation of Solar Reforming

\[
\begin{align*}
CH_4 + H_2O & \rightleftharpoons 3H_2 + CO \\
CH_4 + CO_2 & \rightleftharpoons 2H_2 + 2CO
\end{align*}
\]

700 – 1000°C

State of the Art / Reference System

Solar Energy \rightarrow Water Steam Cycle 600 °C \rightarrow Electricity

Natural Gas \rightarrow Conventional Reforming 1000 °C \rightarrow Enthalpy Increase

Carnot Efficiency!
Methanol Production via Solar Reforming (SOLME)

\[ f_{\text{split}} = 1 \]  
(All off-gas to reactor)
Methanol Production via Solar Reforming (SOLME)

Evaluation –
\[ \eta = \frac{\Delta H}{Q_{Solar}} \]

How can we evaluate such processes?

\[ \Delta H < 0 ! \]
Proposing an Evaluation Criterion

- Global aim: Reduce GHG-emissions by implementation of renewable energies
- Relevant question: How can we use our renewable energy resources most efficiently?

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Produced Energy (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Energy (SOLME)</td>
<td>1.00</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.97</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.83</td>
</tr>
<tr>
<td>Methanol</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Proposing an Evaluation Criterion

- Global aim: Reduce GHG-emissions by implementation of renewable energies
- Relevant question: How can we use our renewable energy resources most efficiently?

0.83 MWh Methanol
1 MWh Solar Energy
0.97 MWh Natural Gas
0.14 MWh Electricity
0.14 MWh Electricity

SOLME Process
Reference System
Proposing an Evaluation Criterion

- Global aim: Reduce GHG-emissions by implementation of renewable energies
  - Relevant question: How can we use our renewable energy resources most efficiently?

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SOLME System

0.97 MWh Natural Gas
1 MWh Solar Energy
0.14 MWh Electricity

Reference System

1.12 MWh Natural Gas
0.83 MWh Methanol

Methanol Plant

0.004 MWh Electricity
0.83 MWh Methanol
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Proposing an Evaluation Criterion

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  - Relevant question: How can we use our renewable energy resources most efficiently?
Proposing an Evaluation Criterion

• Global aim: Reduce GHG-emissions by implementation of renewable energies
  • Relevant question: How can we use our renewable energy resources most efficiently?

• Two systems with
  • same solar energy input (i.e. Heliostat field size)
  • same methanol production
  • same electricity output
  • different natural gas input

→ Efficiency of solar-hybrid processes:

\[ h_{\text{Hybrid}} = \frac{\Delta E_{\text{Fuel}}}{E_{\text{Solar}}} \]

• Should be maximized and > 0
Results for the SOLME process

And what are the results for the SOLME process???

Results based on process simulation in Aspen.:
• All values > 0
   More efficient utilization of solar energy than in „conventional“ CSP plants
• Clear influence of $f_{\text{Split}}$ on efficiency
  • Optimum value depends on reforming temperature
• “Plateau” with constant efficiency over varying $f_{\text{Split}}$
   Varying ratio of electricity production to methanol production without efficiency loss.

![Graph showing the results with different temperatures and $f_{\text{Split}}$ values.](image-url)
Summary & Outlook

• Process for methanol production via solar reforming (SOLME) proposed
• Solar-Hybrid processes cannot be evaluated with conventional efficiency criteria
  • New criterion proposed
• High efficiency for SOLME process predicted
  → More efficient utilization of solar energy than in solar power plants

• More information:
  • https://doi.org/10.1016/j.apenergy.2016.08.141

Outlook:
• Work is continued in INDIREF project
  • Development of air heated reforming reactor
  • Demonstration of solar reforming in Synlight in 2018
  • And then…

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