Final design of a cost-optimized 100 tpd H₂ liquefier. CEC 2017 Madison.

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Introduction.
Why Liquefaction?
### Estimated number of fuel cell vehicles based on typical hydrogen fuel consumption rates

<table>
<thead>
<tr>
<th>Fuel Cell Vehicle Type</th>
<th>H\textsubscript{2} consumption (tpd)</th>
<th>Hydrogen production</th>
<th>Trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 tpd</td>
<td>50 tpd</td>
</tr>
<tr>
<td>Car</td>
<td>0.0004</td>
<td>12’500</td>
<td>125’000</td>
</tr>
<tr>
<td>Bus / Truck</td>
<td>0.03</td>
<td>167</td>
<td>1667</td>
</tr>
<tr>
<td>Train</td>
<td>0.25</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Large ship</td>
<td>10</td>
<td>0.5</td>
<td>5</td>
</tr>
</tbody>
</table>

- US DoE’s future cost target on hydrogen delivery is 4-6 USD/kg H\textsubscript{2}
- EU cost target is 5-7 €/kg H\textsubscript{2} (FCH JU 2014)
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Concept A: HP-Hydrogen cycle.

MR Precooling

H₂ Cycle Compression

Feed H₂

Ortho- to Para-H₂ Conversion

Precooling Coldbox

H₂ Turbines

Ortho-Para Catalyst Filled

Feed Gas

To storage

Precooling Coldbox

Liquefier Coldbox

MR precooling cycle (Joule-Thomson)

HP-H₂ cryogenic cycle (Claude)
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Impact of liquefaction capacity on process design

Concept A: HP-H₂ Claude cycle

Improved State-of-the-art

Concept B: H₂-Ne Mix cycle

Mixed-Refrigerant cycle (MRC)

Nitrogen Expander cycle

Liquid N₂

Cryogenic Refrigeration

Precooling

Hydrogen liquefier train capacity in tpd LH₂
Process optimization for 100 tpd LH₂.
Specific energy consumption (SEC).

Conventional H₂ Claude cycle with LN₂ vs. optimized HP-H₂ cycle with MRC

Spec. Energy Consumption (SEC) in kWh/kg LH₂

- Conventional w/ LN₂ 5 tpd LH₂
- Energy-optimized 100 tpd LH₂
- Cost-optimized 100 tpd LH₂
Impact of plant capacity
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Large-scale hydrogen liquefaction

— Optimal process design dependent on liquefaction capacity & boundary conditions

— Specific energy consumption from 10 kWh/kg to about 6 kWh/kg LH₂ feasible within 5 years

— Specific liquefaction costs reduced by nearly 60% (50 tpd) or 70% (100 tpd) vs. 5 tpd LH₂

— Specific liquefaction costs ≈ 1 €/kg LH₂ feasible

— Large-scale LH₂ supply can reach the future cost targets for hydrogen mobility
Thanks for your attention.