Concepts for efficient hydrogen liquefaction

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The Role of Large-Scale Hydrogen, Hyper closing seminar

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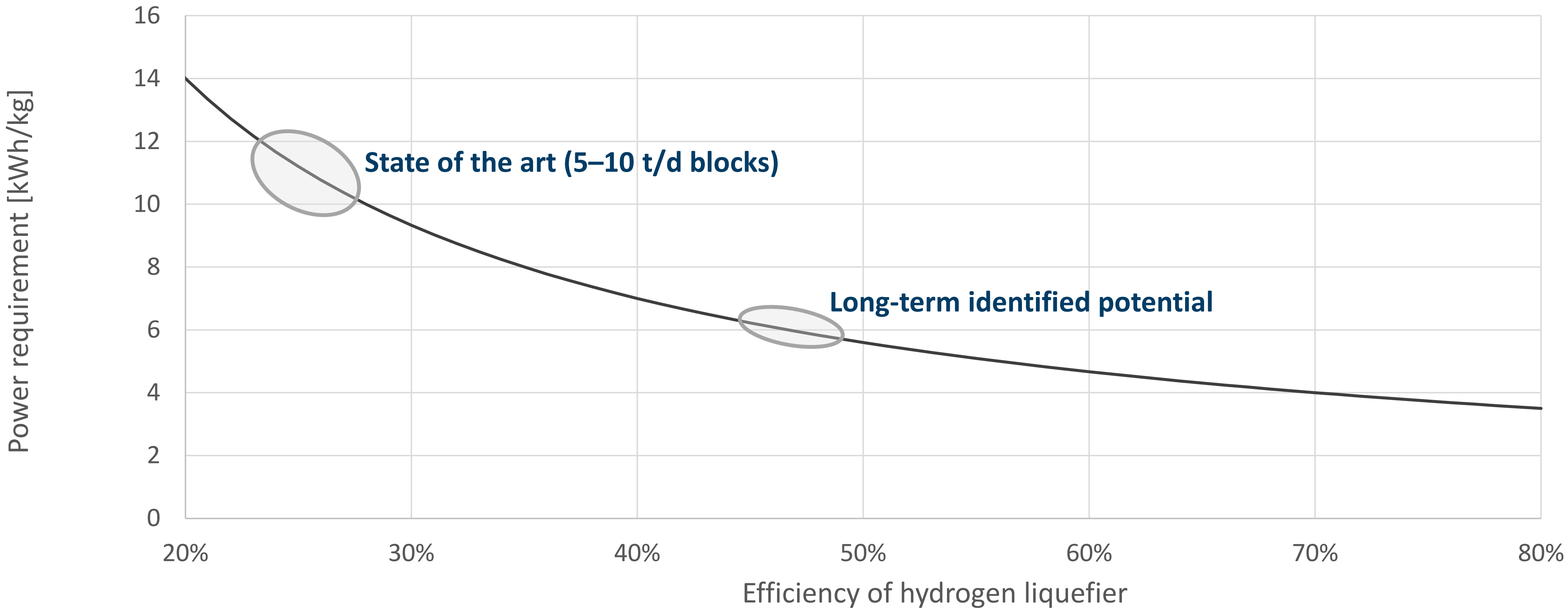
Overview of the presentation

- A look at the present and beyond-present state-of-the-art for LH_2 generation.
- Dissecting the loss of efficiency – where does it come from?
- How do we realize the potential of LH_2 generation? – the next steps

Power requirement vs exergy efficiency of liquefier



In perspective:

Full-scale LNG plants: 10 000–20 000 t_{LNG}/d

Rational (exergy) efficiency: Up to 48 %

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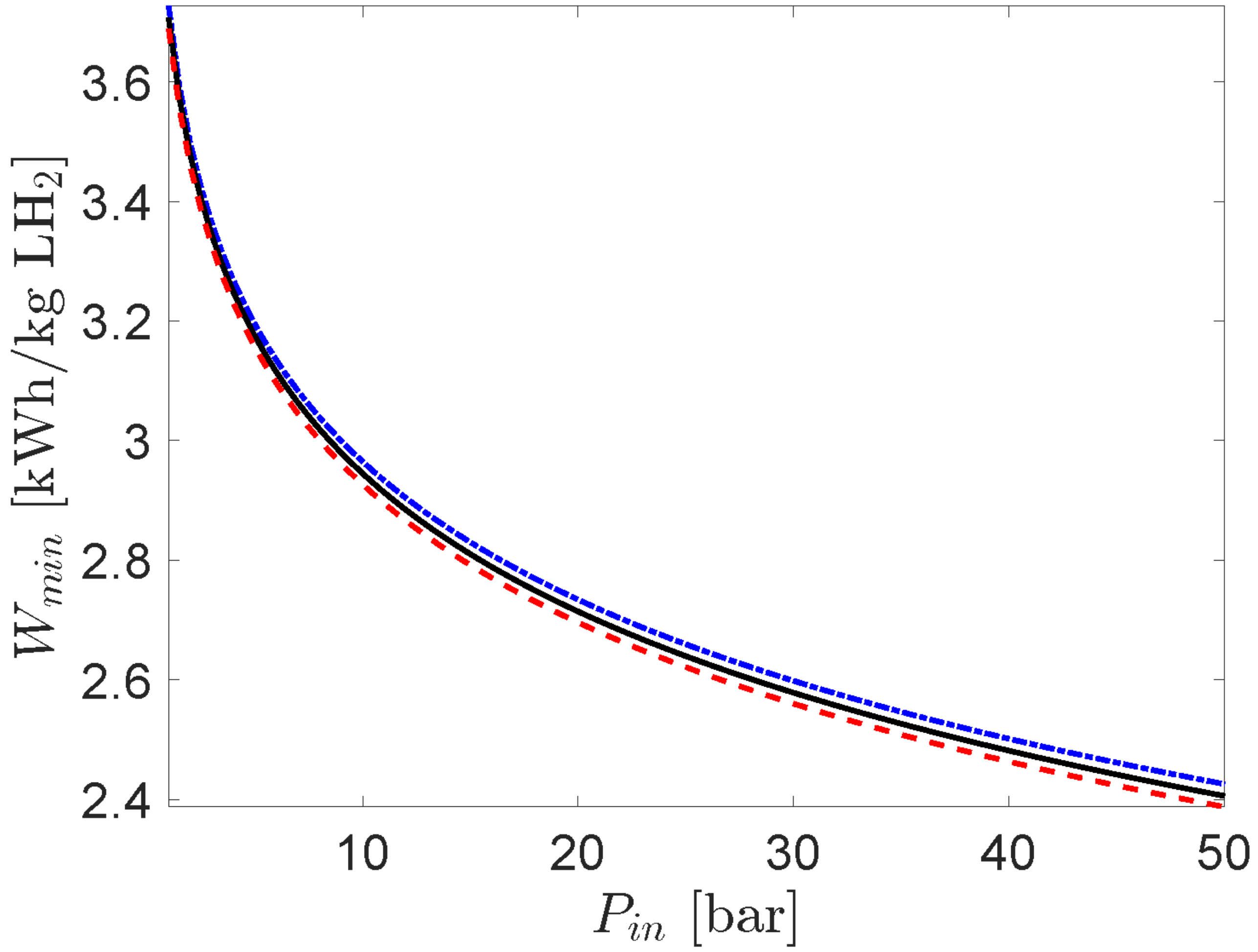
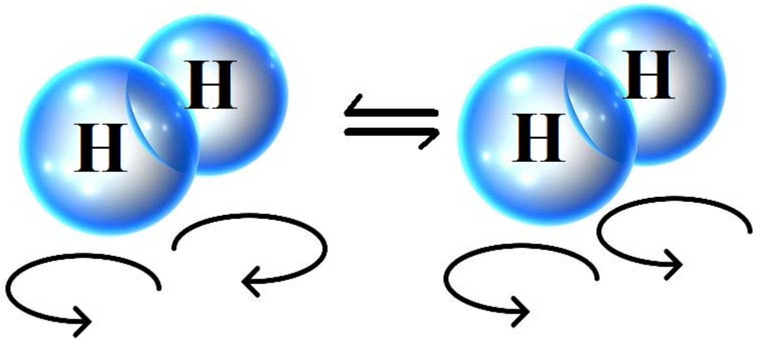
Minimum liquefaction work

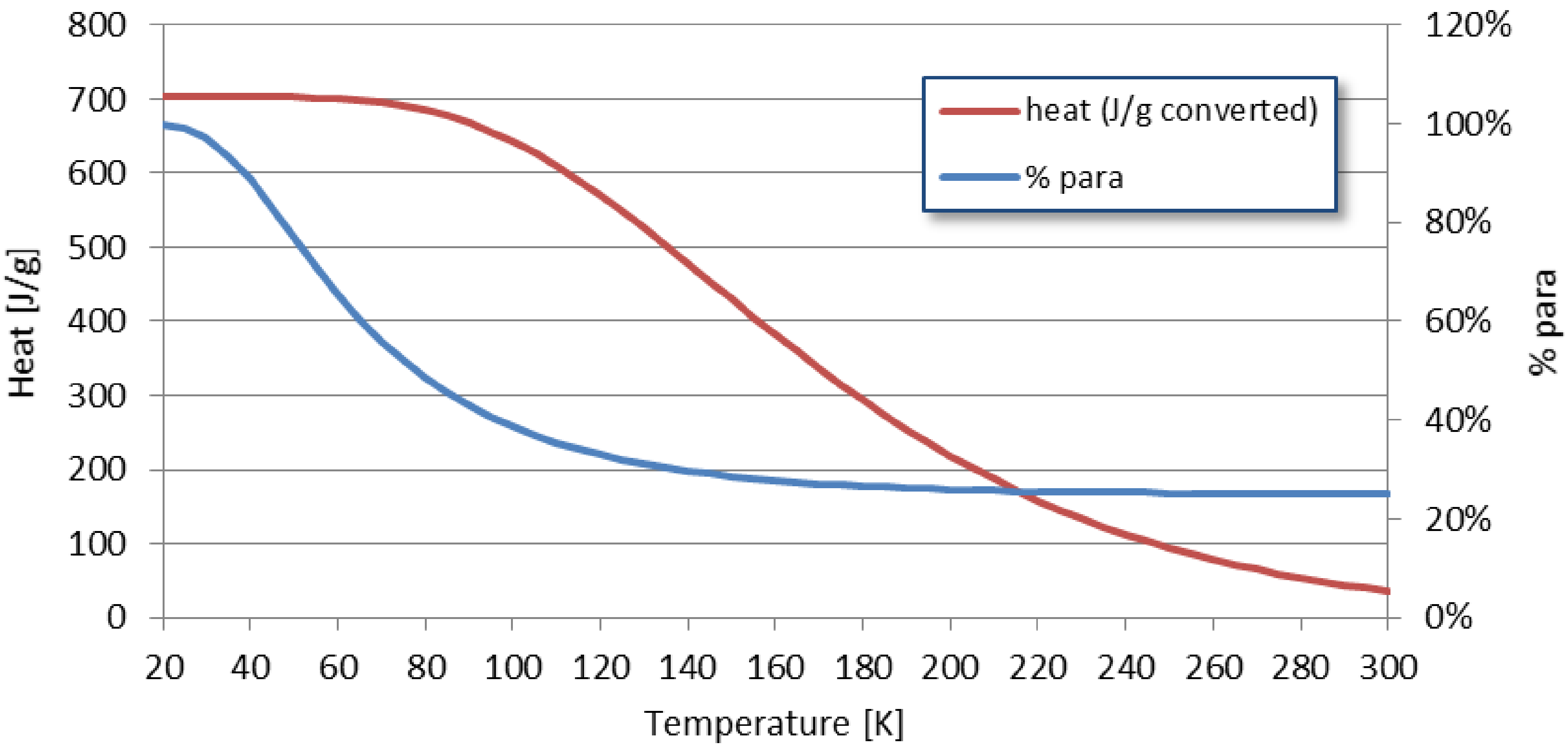
- Main influence:
  - Feed pressure
- Key influences:
  - Final liquid storage pressure
    - 1.3 bar (blue dotted)
    - 1.5 bar (black)
    - 1.7 bar (red dashed)
  - Target para-hydrogen concentration
  - Ambient temperature



Conversion of ortho to para-hydrogen

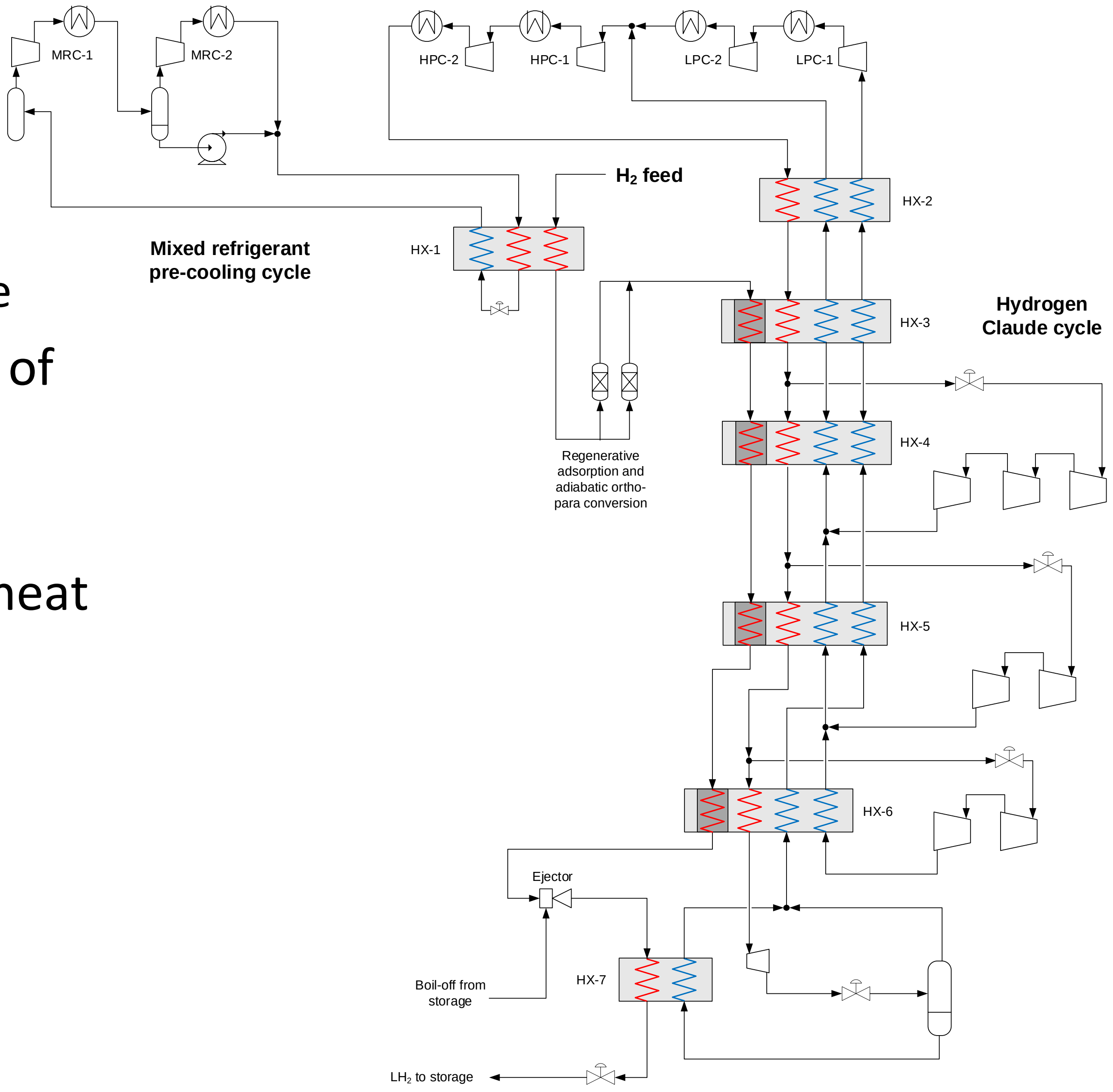


para-hydrogen ortho-hydrogen



Process overview

- Assumed capacity: 125 t/d
  - Additionally 7.1 t/d BOG from storage
- Mixed-refrigerant "PRICO" precooling of feed hydrogen to 114 K
- Hydrogen Claude cooling to 30 K
- Continuous ortho-para conversion in heat exchangers between 114 K and 30 K
- Expansion and BOG recompression to 1.85 bar with ejector
- Condensing and subcooling before transfer to final LH2 storage
- Storage pressure: 1.50 bar



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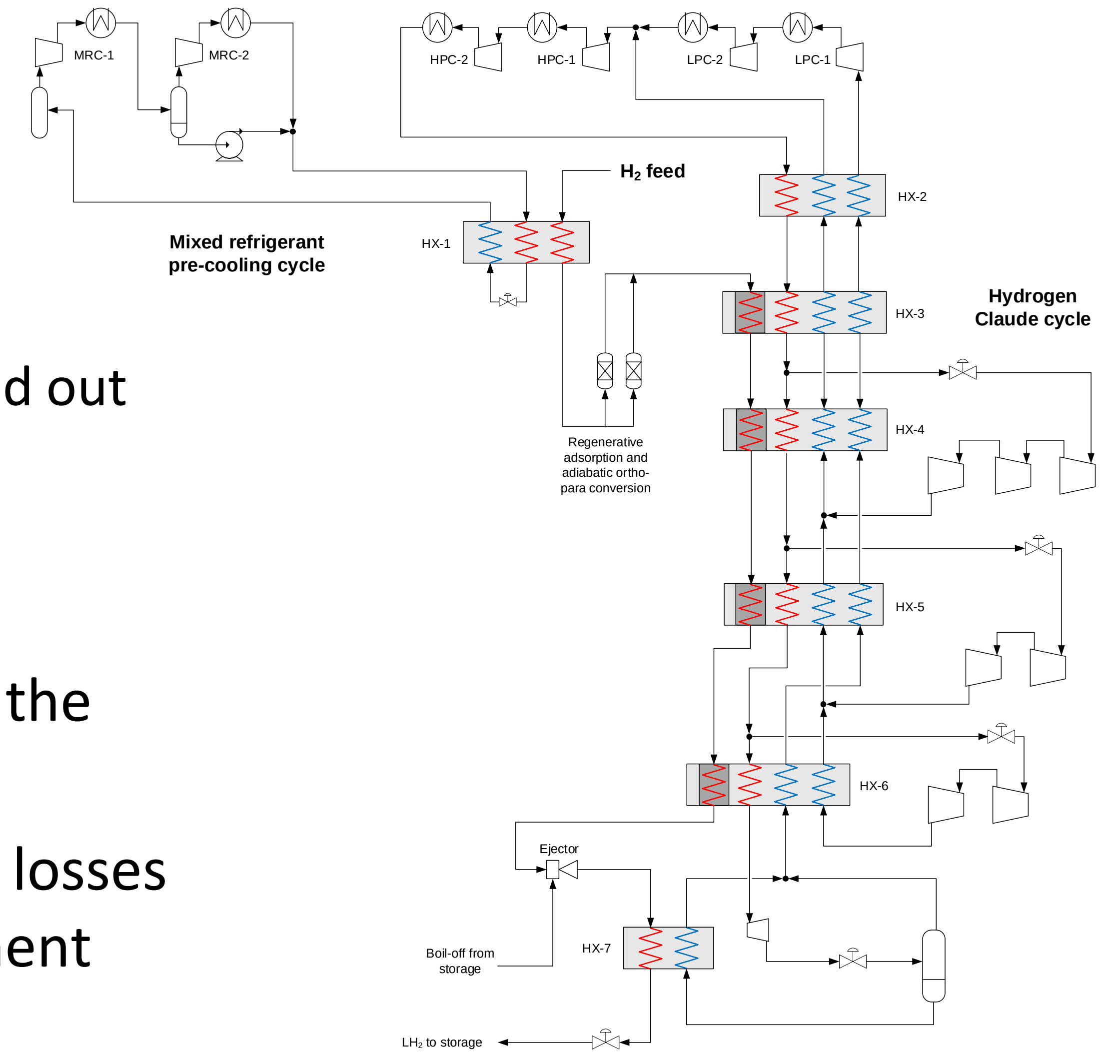
Overall liquefier efficiency

- Two independent ways to calculate the overall efficiency (and to verify the calculations):
  - Overall, top-down. Based on exergy flows in and out of the system boundaries
  - Detailed, bottom-up. Calculating the exergy destruction in each single process component
- The former method is sufficient for calculating the overall efficiency of the plant
- The latter method gives a full breakdown of all losses and gives directions as to where the improvement potentials lie



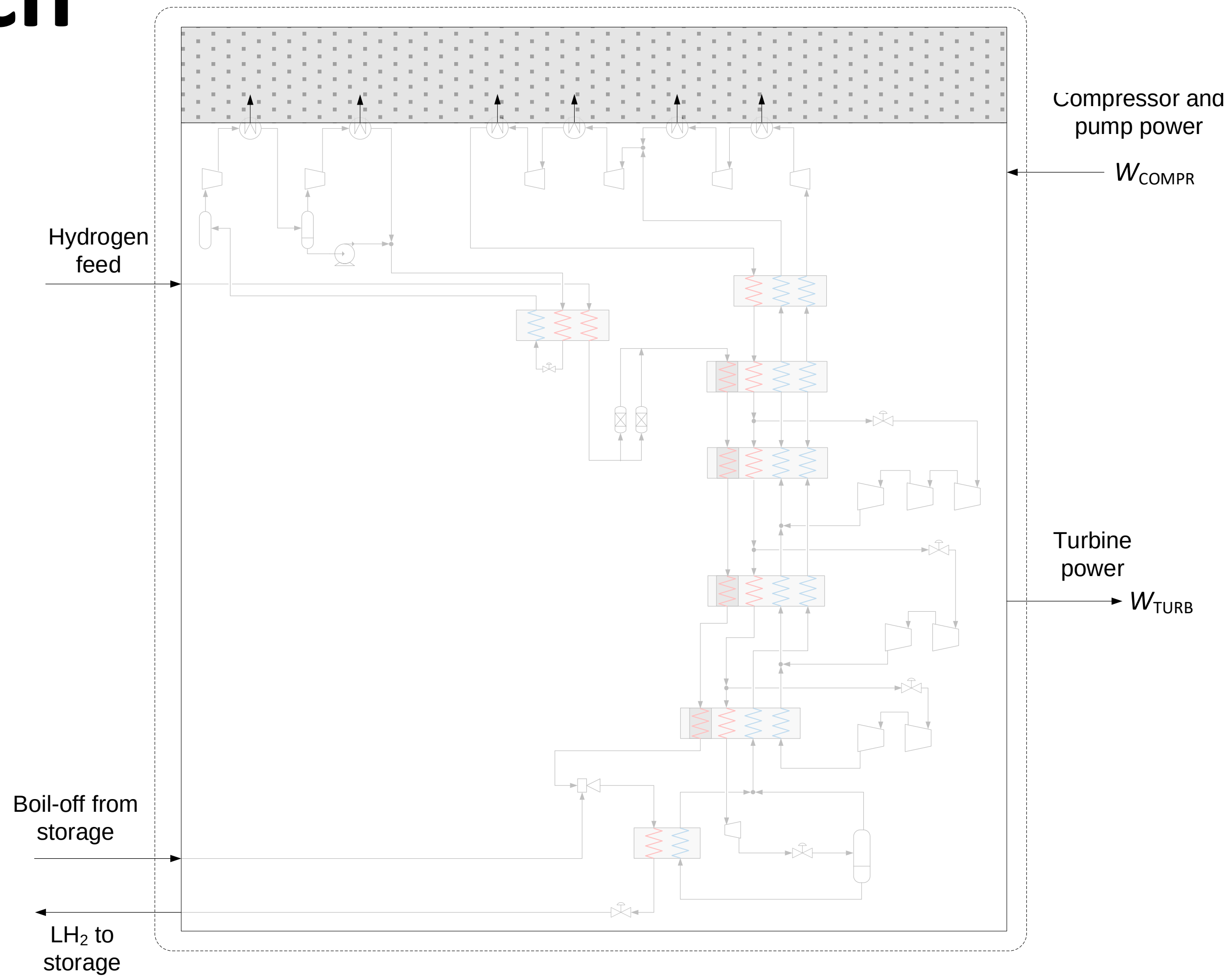
Overall, top-down approach

- Only considers exergy streams crossing the system boundaries
  - Hydrogen feed flow exergy
  - BOG flow exergy
  - LH_2 product flow exergy
  - Compression power
  - (Turbine power, assumed dissipated)
  - (Intercooler heat, assumed dissipated)
- Exergy efficiency:

  $= (E_{LH2\ prod} – (E_{H2\ feed} + E_{BOG})) / W_{compr}$

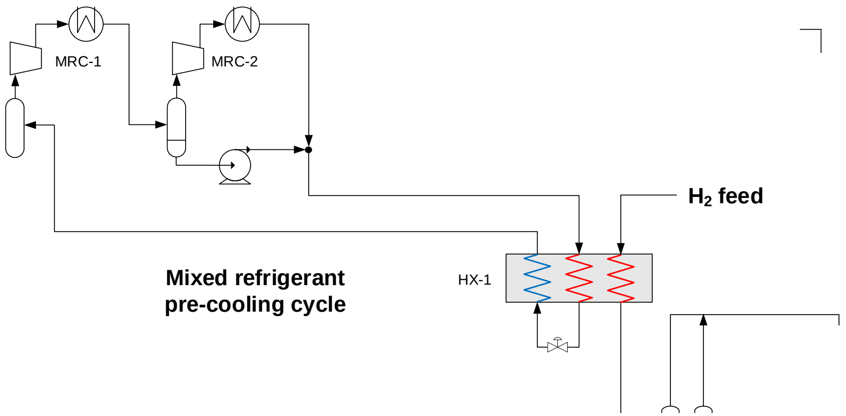
  $= (14\ 361\ kW / 36\ 729\ kW)$

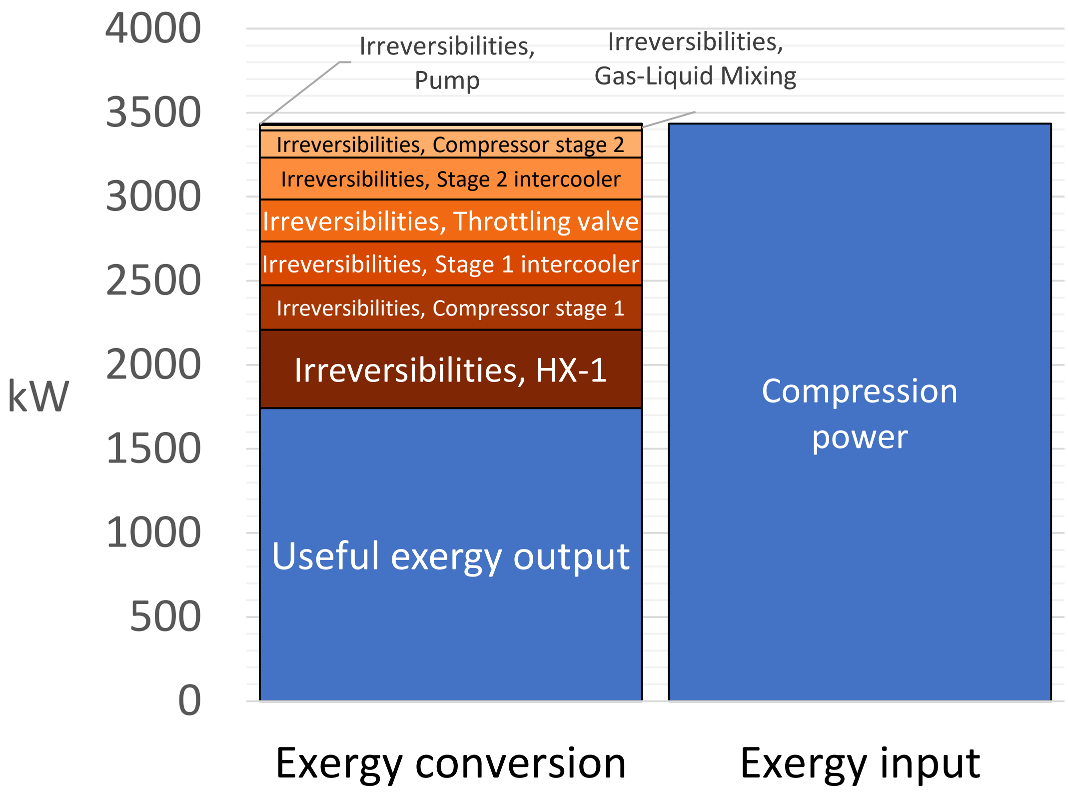
  $= 39.1\ \%$



Pre-cooling cycle to 114 K

- Single, 5-component refrigerant mixture
- Estimated stand-alone exergy efficiency for pre-cooling to 114 K: 50.75 %
- Further efficiency improvements can be made:
  - Replacing throttling valve with a liquid expander, or expander in series with throttling valve
    - Reduces entropy in expansion process and leads to savings other places in the process
  - Dual-mixed refrigerant cycle:
    - Tailored refrigerant mixtures for two temperature ranges instead of a single one
    - Allows even deeper precooling, possibly down to 80 K





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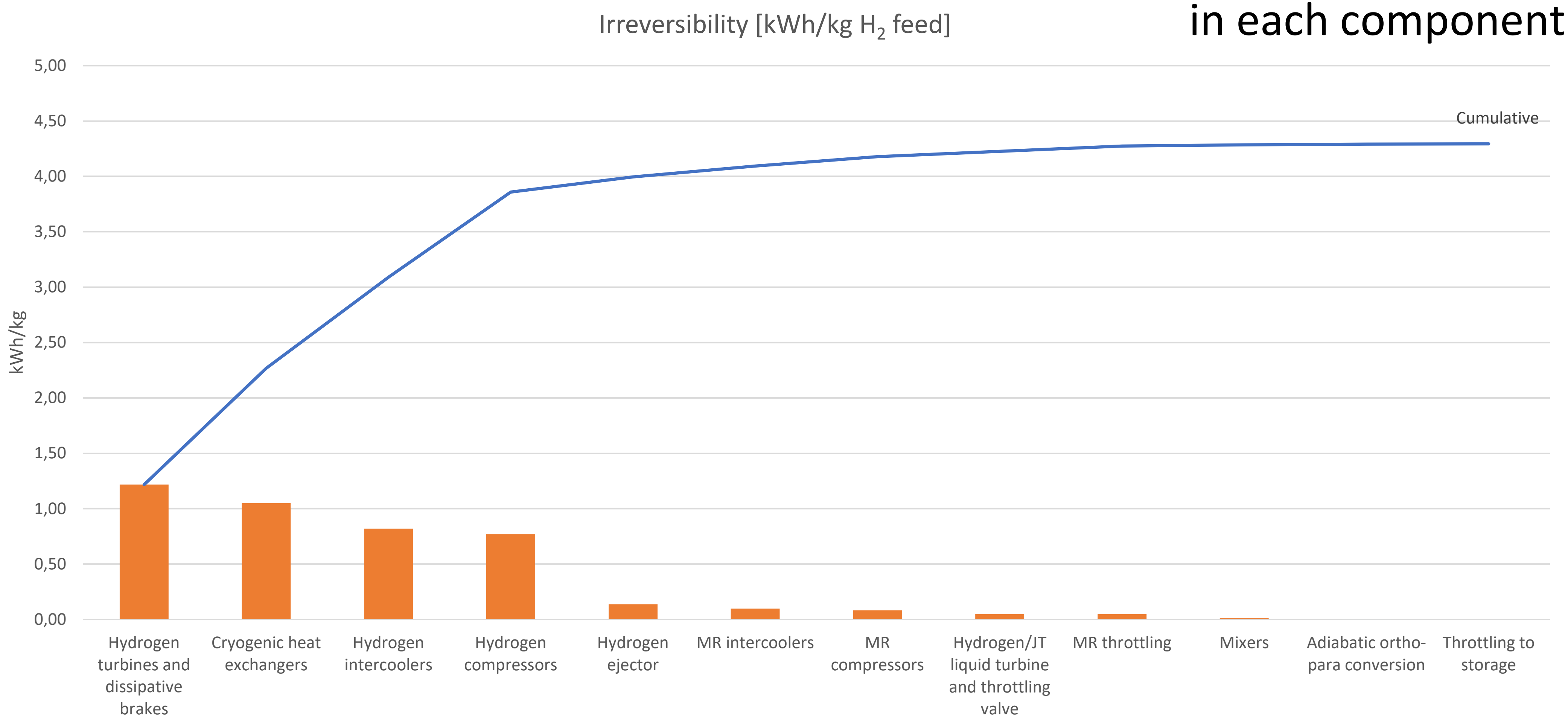
Detailed, bottom-up approach

Calculating the irreversibility rate (exergy destruction rate) in each component (40+)



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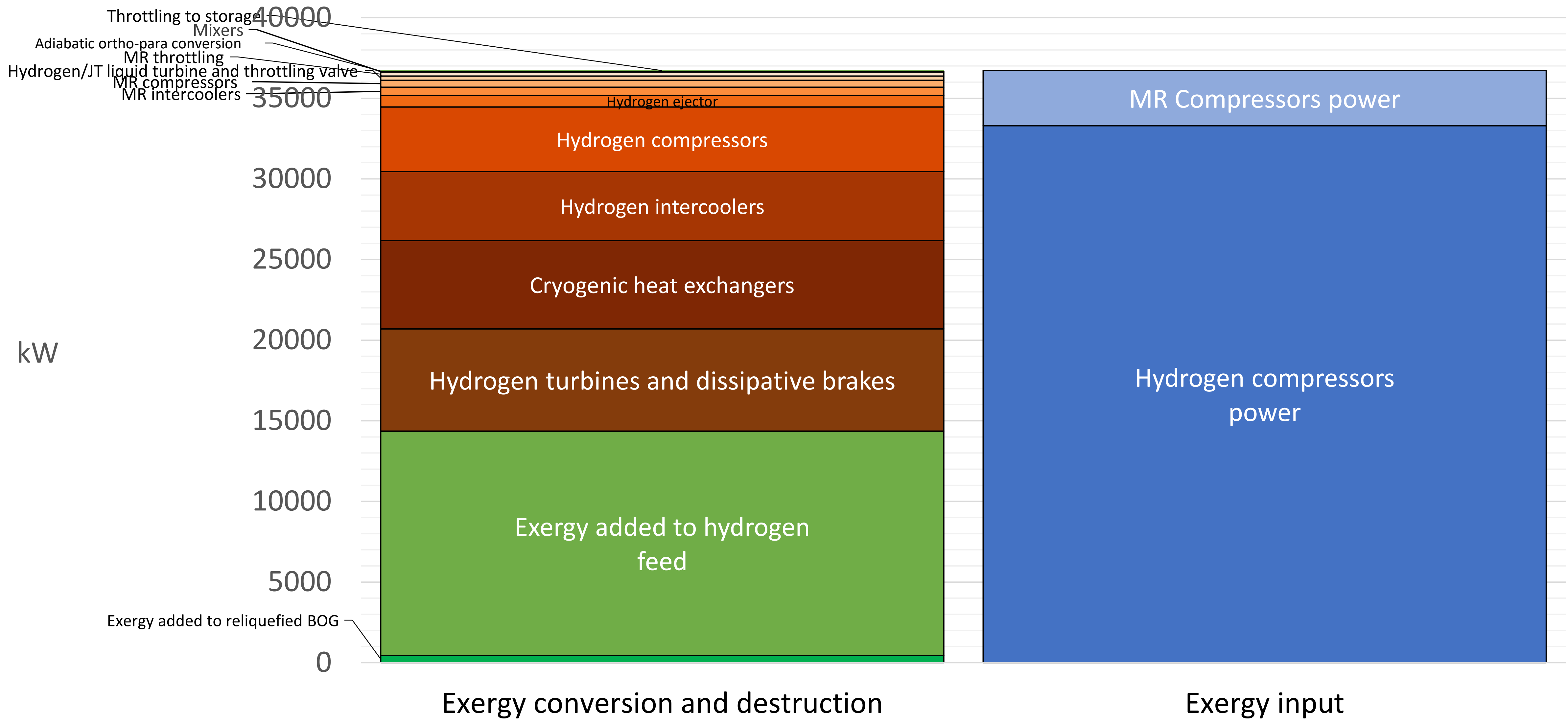
Verification of top-down and bottom-up approaches



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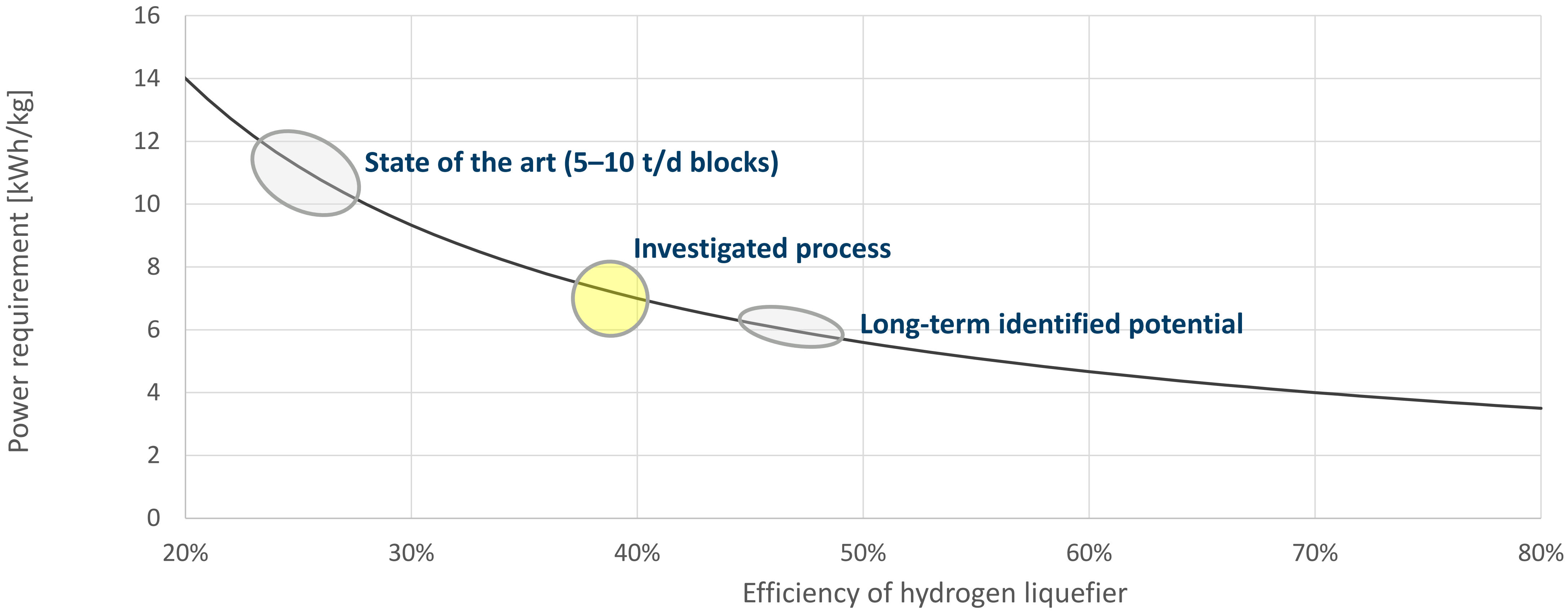
Improved efficiency from recovering turbine power

- Efficiency of the liquefaction process without power recovery:
  - Exergy efficiency: **39.1 %**
  - **7.05** kWh/kg scaled with hydrogen feed rate (125 ton per day)
  - **6.67** kWh/kg scaled with hydrogen feed rate + boiloff gas reliquefaction rate
- For these numbers, 2769 kW of hydrogen turbine shaft power is assumed to be dissipated
- If, e.g. 80 % of this power is recovered with electric generators the improved efficiency figures will be:
  - Exergy efficiency: **41.6** %
  - **6.62** kWh/kg scaled with hydrogen feed rate (125 ton per day)
  - **6.27** kWh/kg scaled with hydrogen feed rate + boiloff gas reliquefaction rate

Power requirement vs exergy efficiency of liquefier



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Further improvements

- High capacity shifts the cost weighting more towards OPEX, hereunder energy cost, while the impact of CAPEX decreases. This motivates for, and necessitates, more advanced and integrated process designs
- **Precooling**: Dual mixed refrigerant to also extend the range from 114 down towards 80 K. Will shift power consumption over from hydrogen to MR compression
- **Feed expansion from 30 K:** Possibility for a liquid expander upstream of the ejector
- **Subcooling process**: Can be two-stage instead of single-stage to improve efficiency
- **H_2 feed pressure:** Autothermal reforming as well as some electrolysers can supply hydrogen at e.g. 30–40 bar. There are several means for taking advantage of this for improving the efficiency
- Turbocompressors and novel cryogenic refrigerant: More easily scalable, boiling at low temperatures.

For more: See D. Berstad, Ø. Wilhelmsen, K. Banasiak. Hydrogen liquefaction. Influence of ejector and expander configuration. Hyper Technical Seminar. Trondheim, 15 May 2019

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