ETH zürich

epse
ENERGY & PROCESS SYSTEMS ENGINEERING

Dekarbonisierung der Industrie

Welche technologischen Durchbrüche erwarten wir?

André Bardow
ETH Zurich

Food for thought & discussion

⇒ Heat pumps

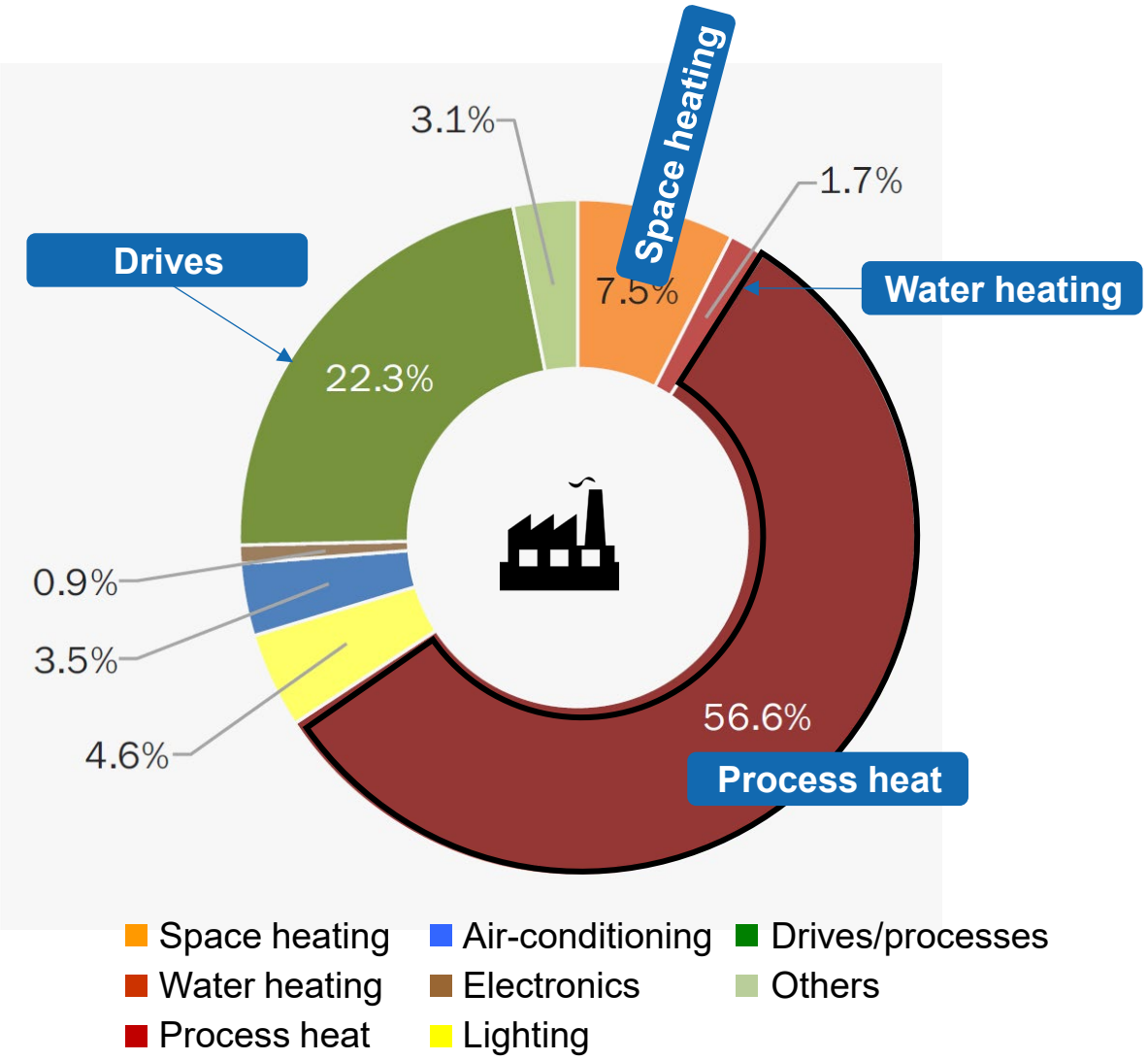
⇒ Synfuels & Hydrogen

⇒ Direct air capture

⇒ Scope 3

⇒ Circular economy

Energy demand of Swiss industry

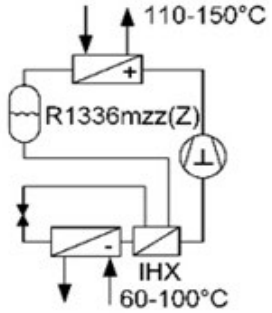


- Heat = 2/3 of energy demand
- Electricity = 1/3 of energy demand

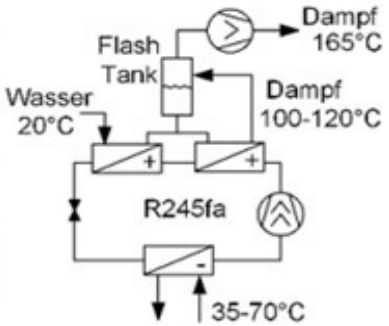
Source: SFOE/Prognos 2024

Industrial heat pumps are becoming available

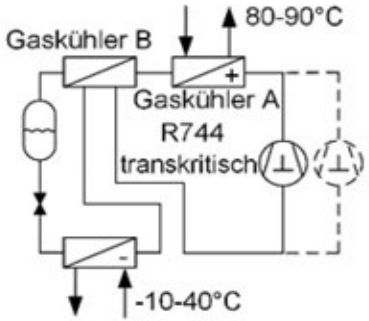
Viking Heat Engines
HeatBooster S4



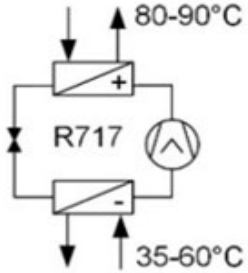
Kobe Steel
Kobelco SGH 120/165



ENGIE (ex-Dürr Thermea), thermeco$_2$ HHR1000
mit 6 Hubkolbenverdichtern bis 1100 kW



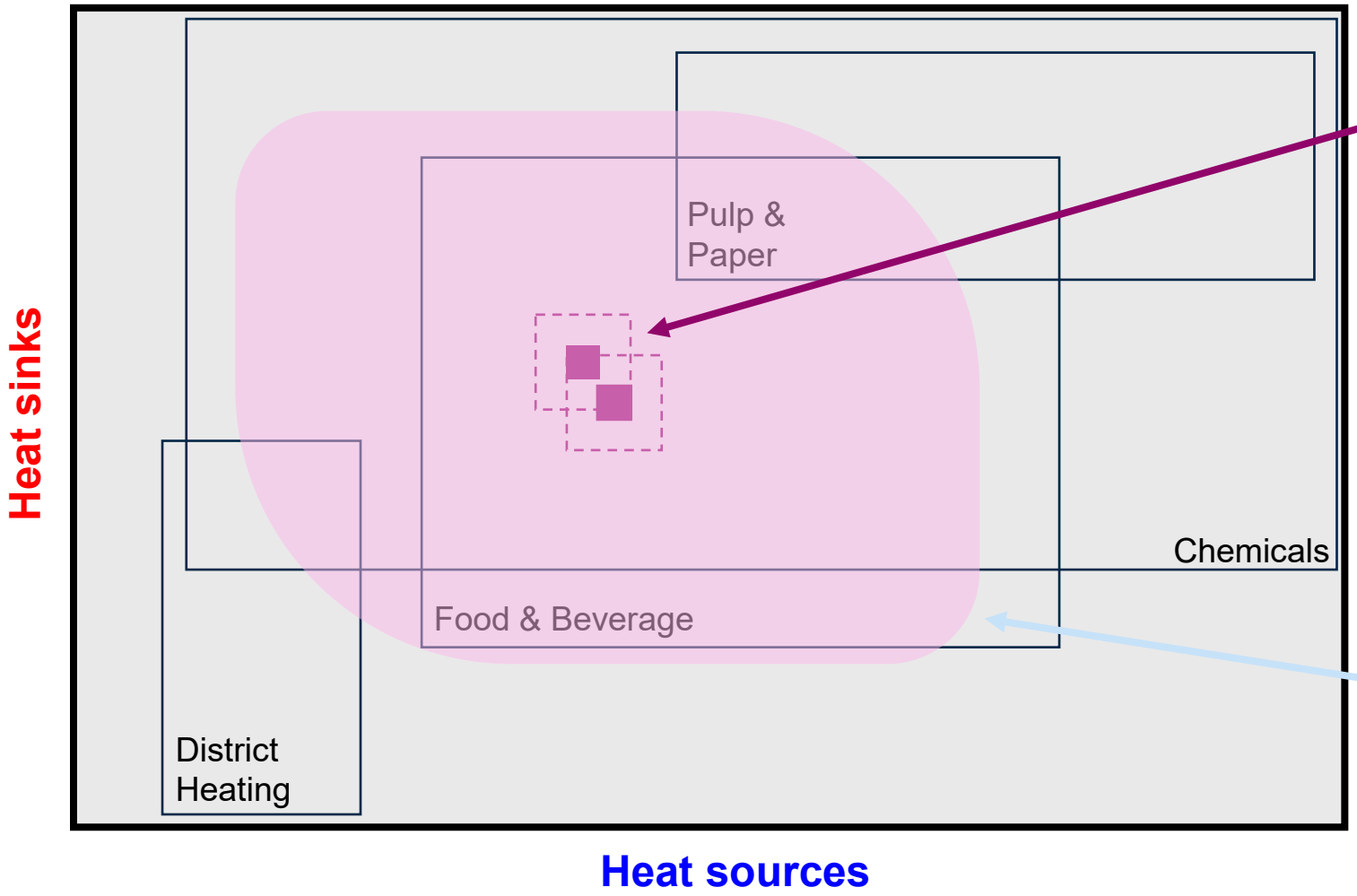
Star Refrigeration, Neatpump NP601,
Vilter VSSH Schraubenkompressor 76 bar



Each product is tailored to exactly one application

High-Temperature Heat Pumps Address Narrow Markets

High-Temperature Heat Pump Market
Projected market value by 2031: USD 150 bn



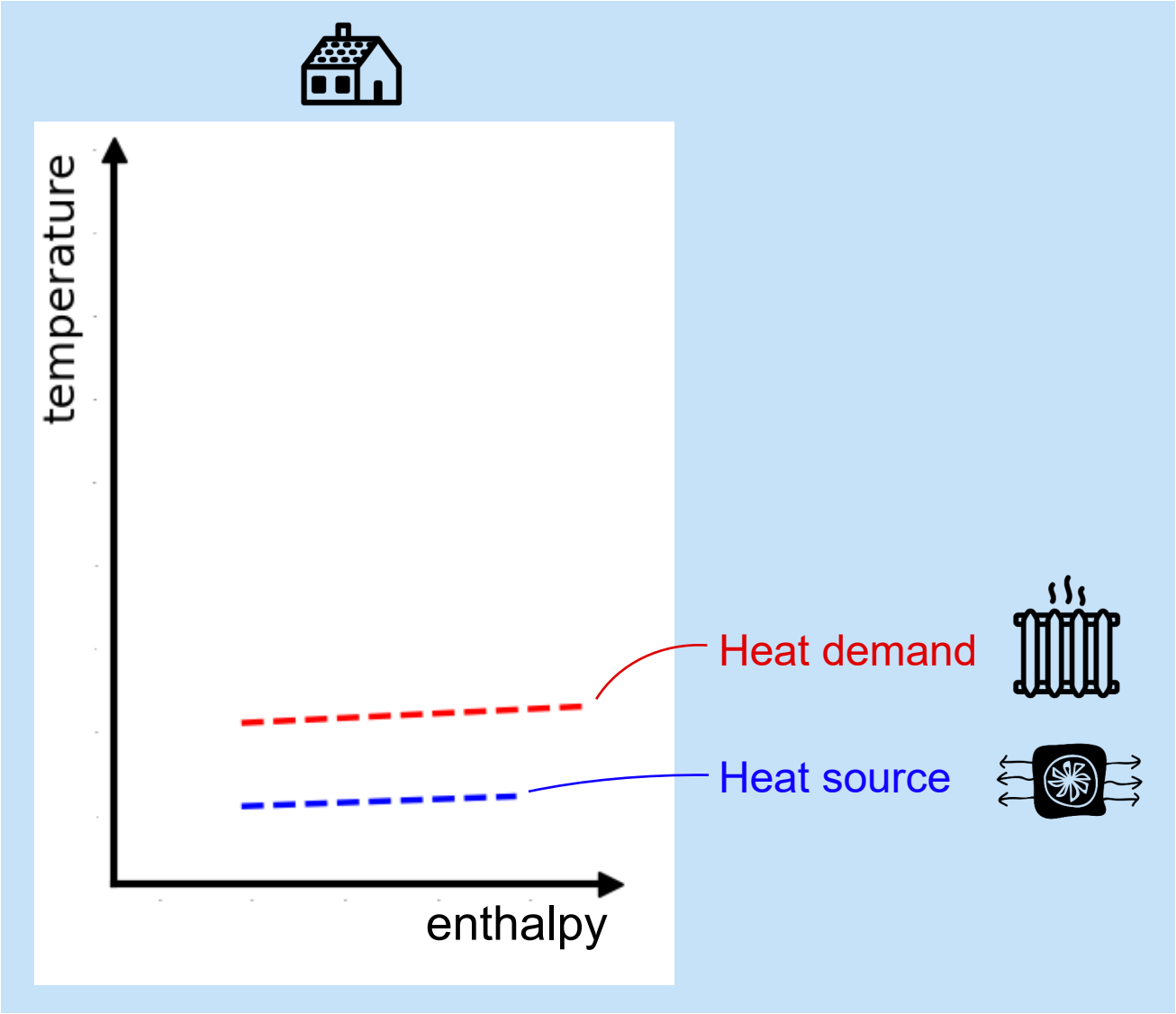
SPECIALISTS

- often **costly** plant engineering needed
- **hampers** efficient **commercialization**

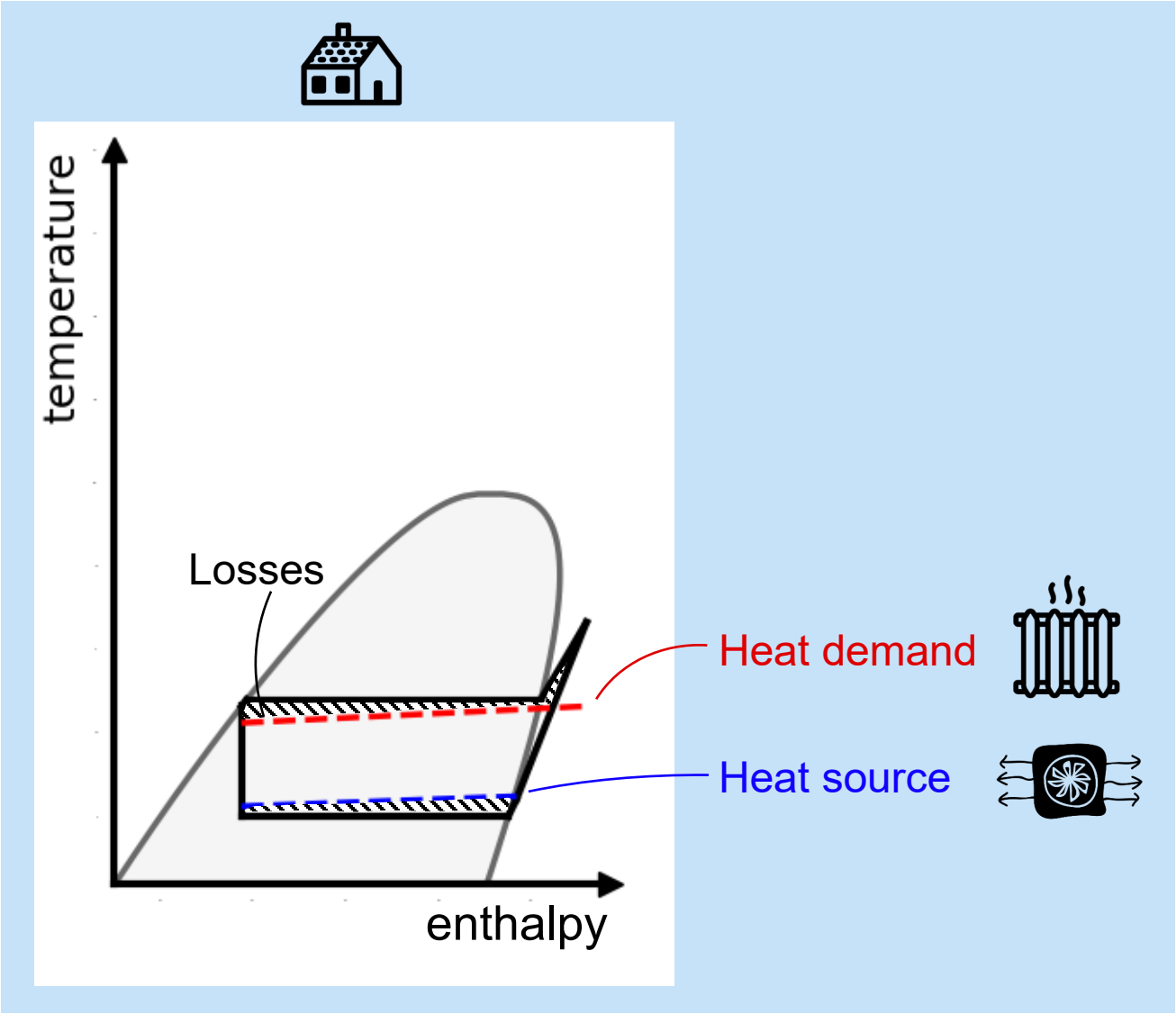
ALLROUNDER

One flexible and highly efficient product to address large shares of the market

The Industrial Needs are Many and Varied



The Industrial Needs are Many and Varied



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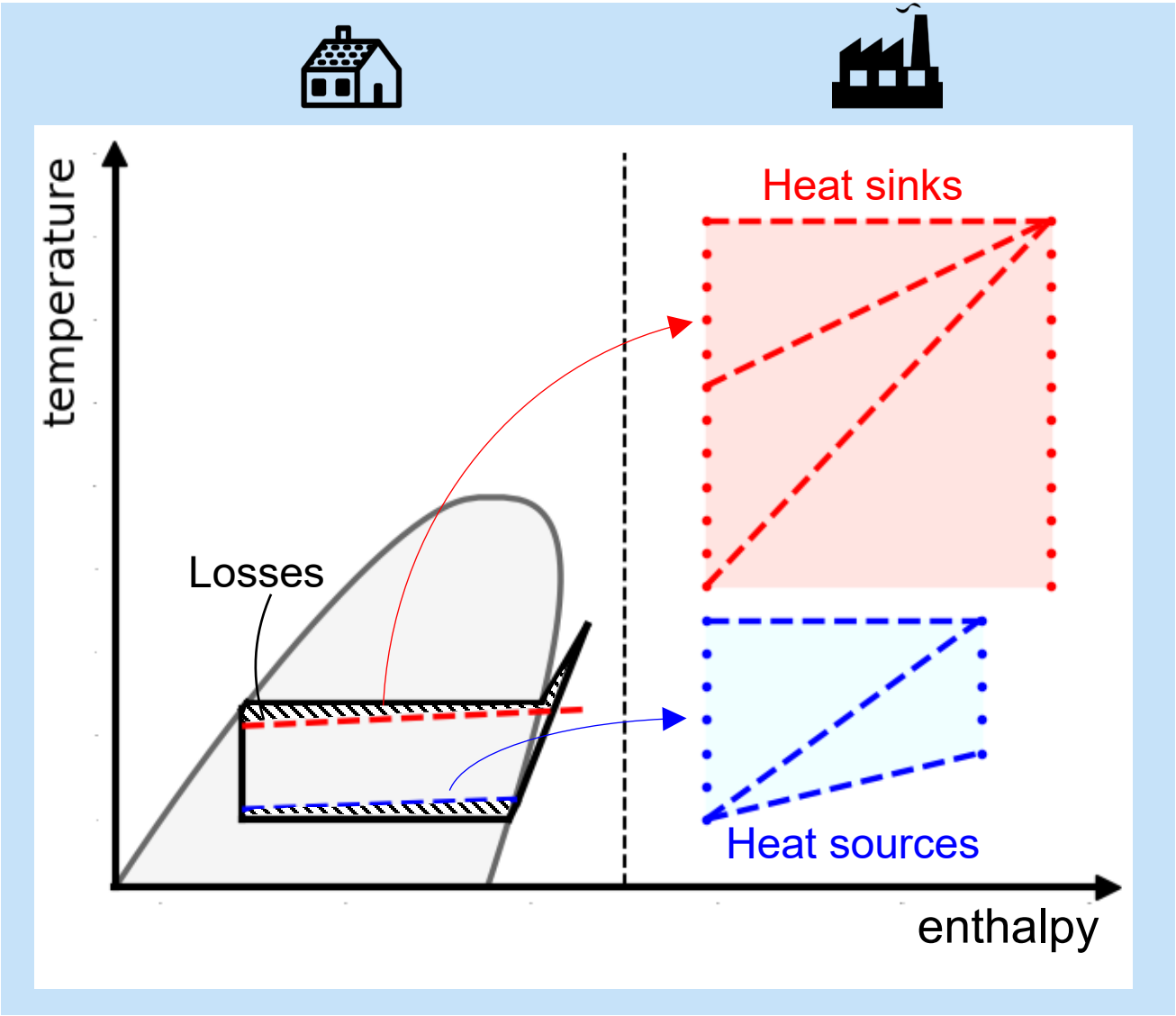
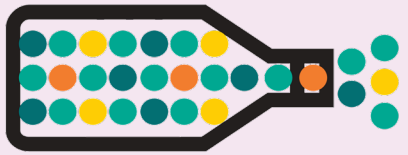


- Higher temperatures
- Sinks and sources:
  high **variability** in temperature **glide**

→ Decreased efficiency

→ Lack of flexibility:

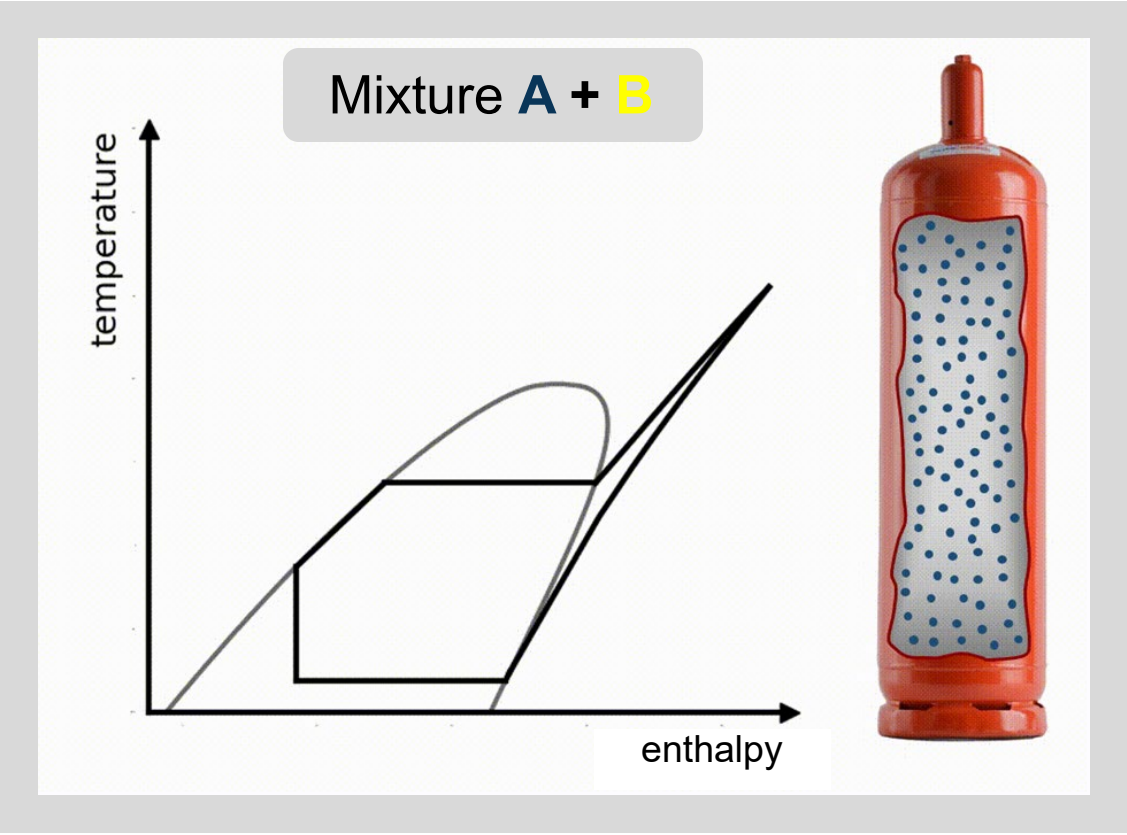
- heat pump design
  is **specific to application**

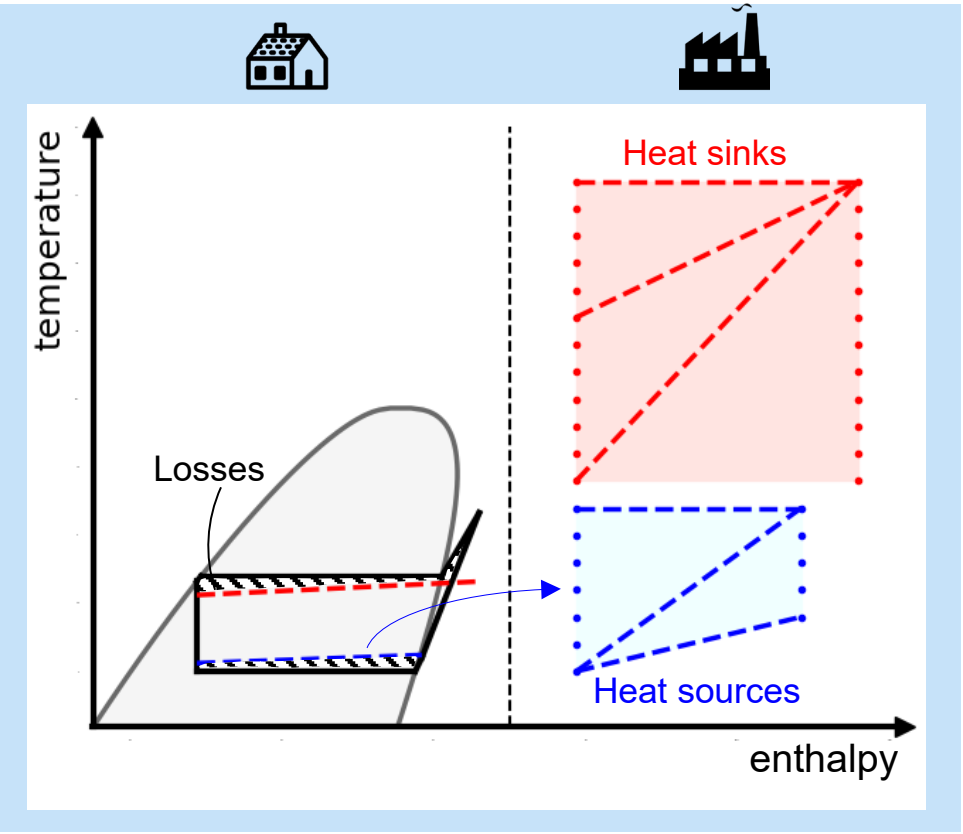


Refrigerant is the bottleneck

The Solution: Refrigerant Mixtures with Glide?

One mixture → **many** options





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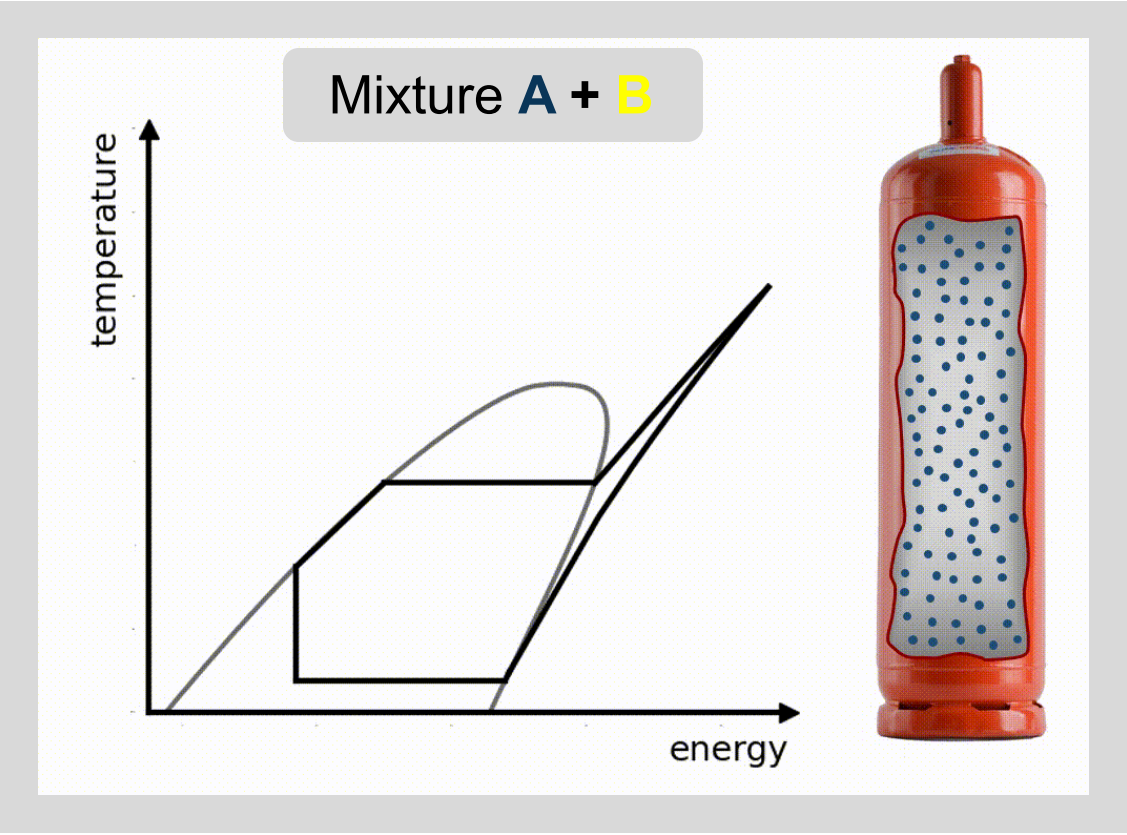

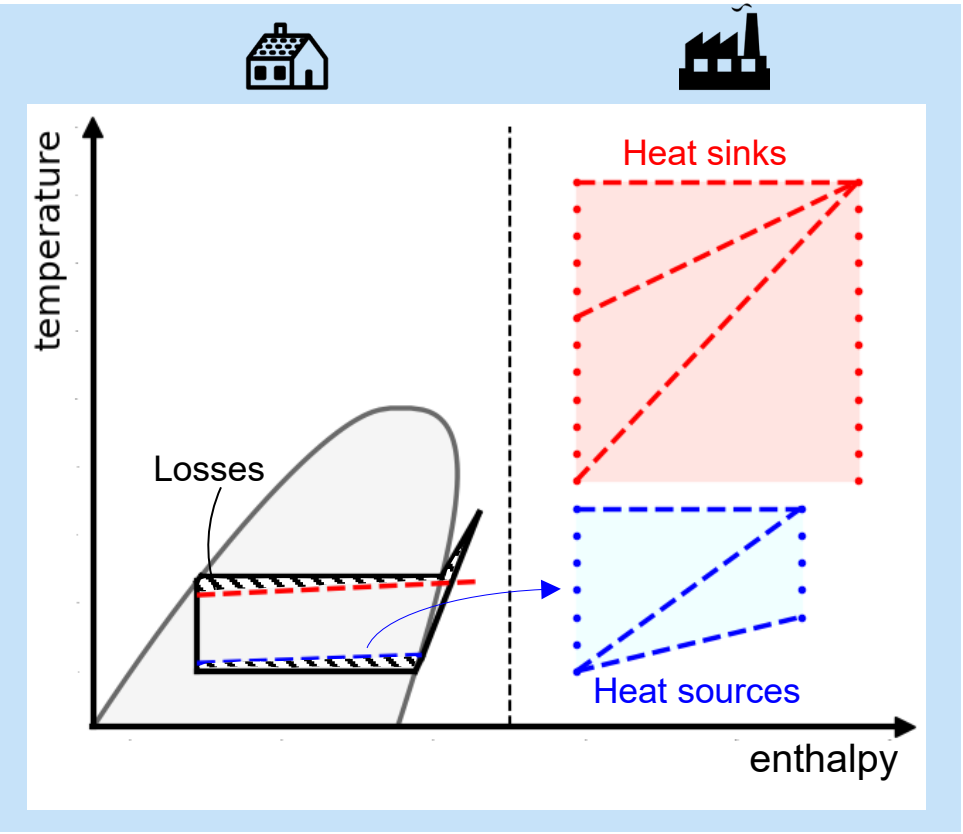

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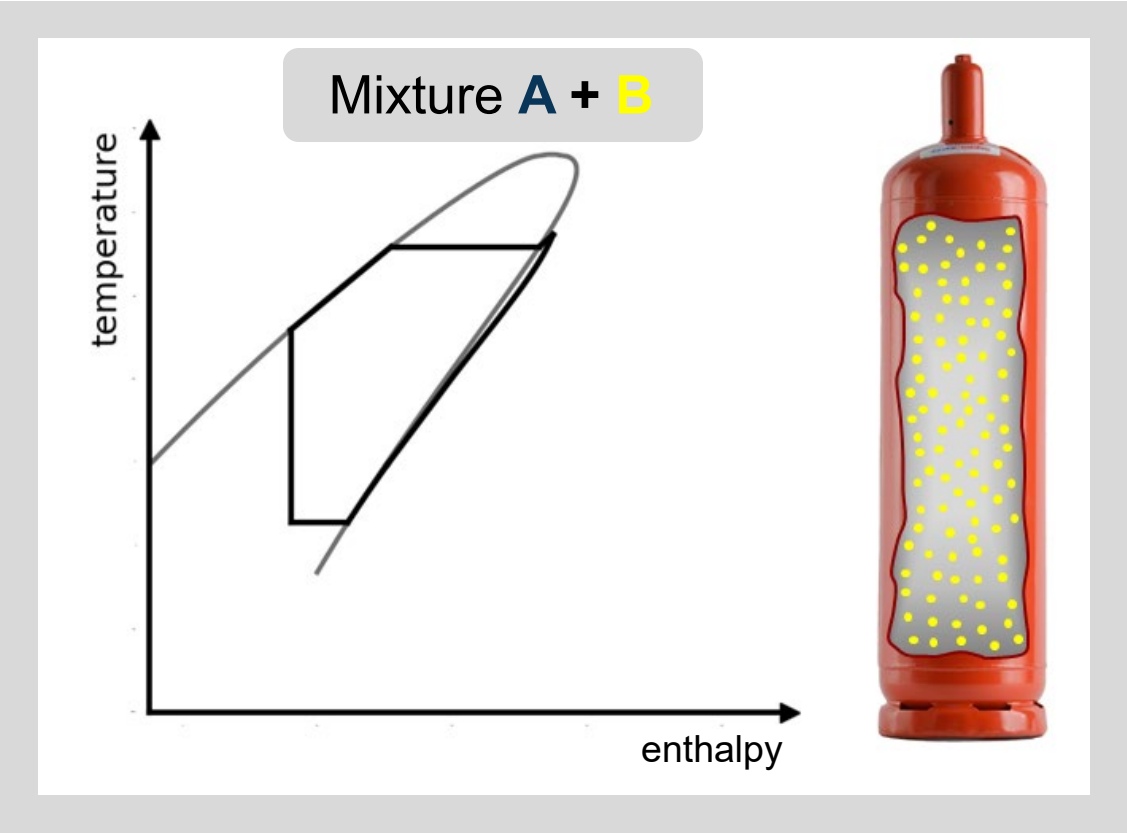

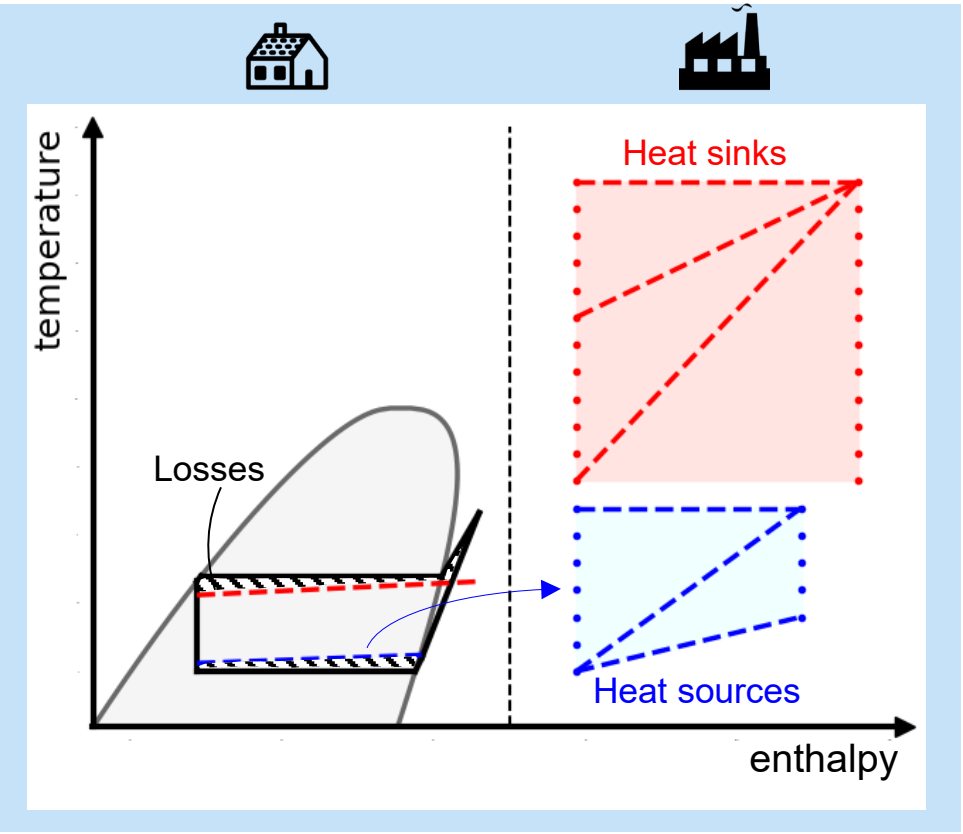

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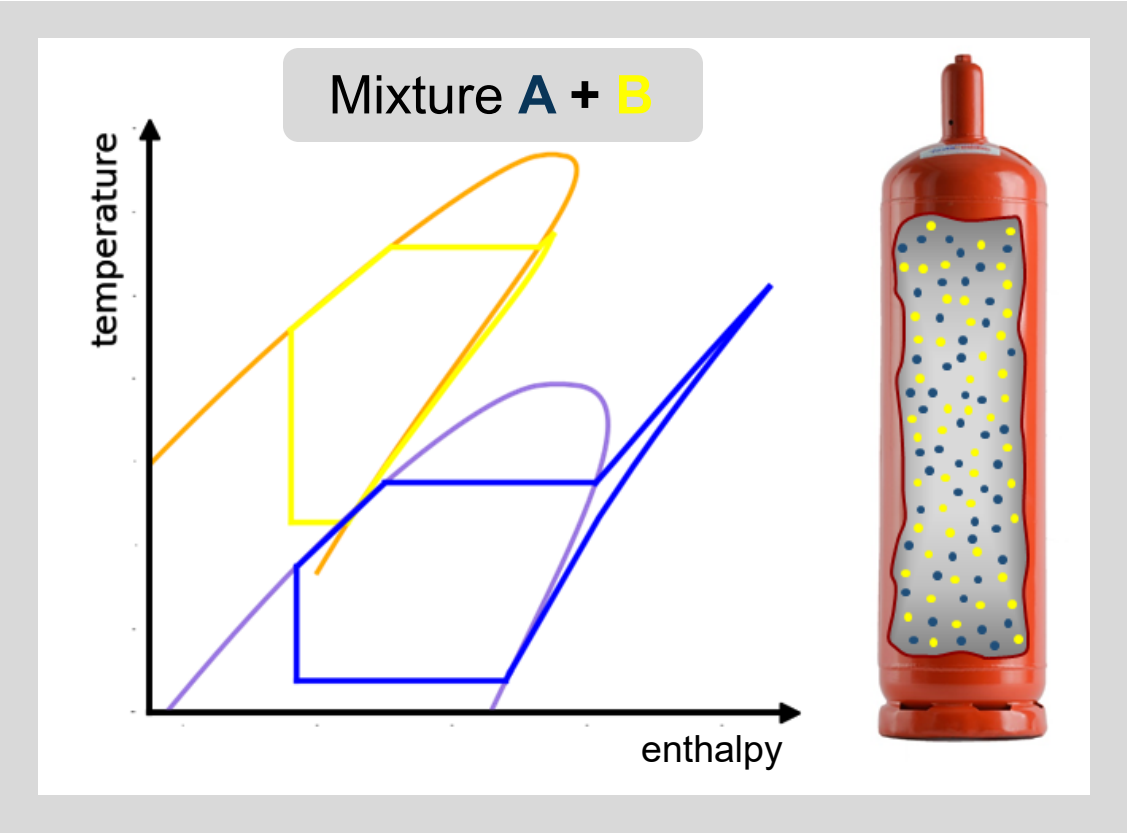

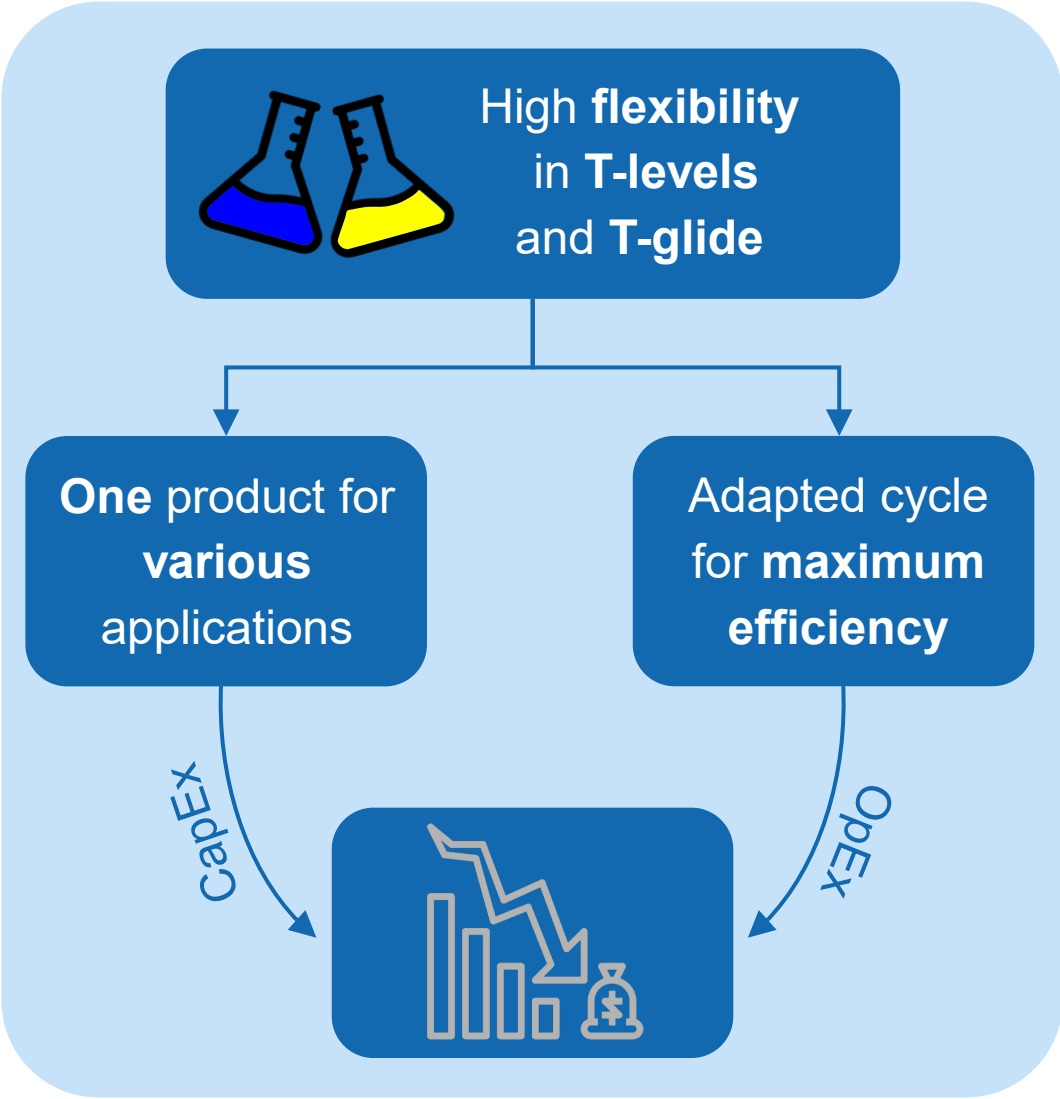

Experiments Confirm Simulations

SPECIALISTS

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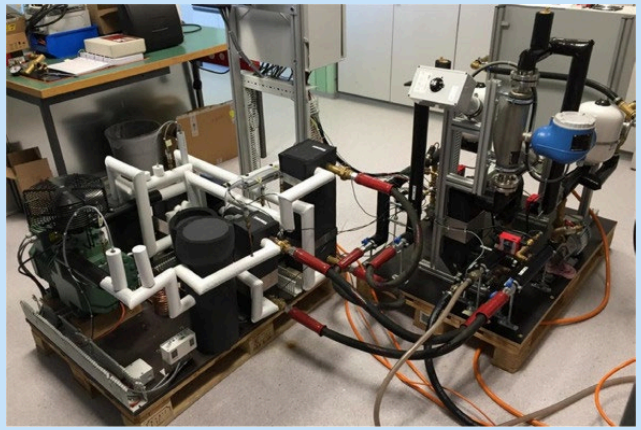
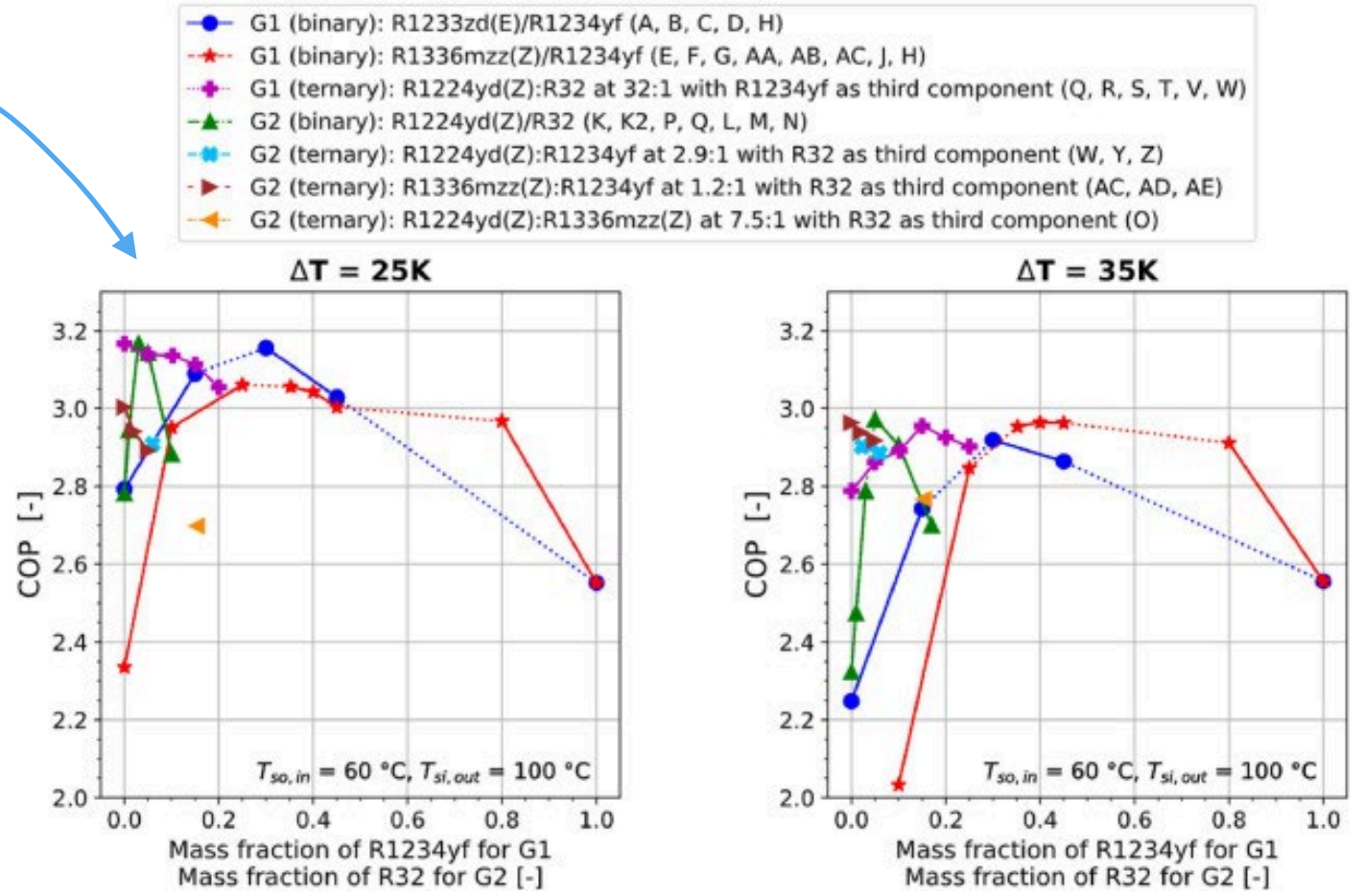


>500 data points
across **40** refrigerant mixtures



Philip Widmaier

Dennis Roskosch

Mixtures significantly increase heat pump COP

Brendel, Bernal, Widmaier, Roskosch, Arpagaus, Bardow, Bertsch, IJR 2024, 165
Brendel, Bernal, Hemprich, Rowane, Bell, Roskosch, Arpagaus, Bardow, Bertsch IJR 2024, 165

Full Steam Ahead ?

SPECIALISTS

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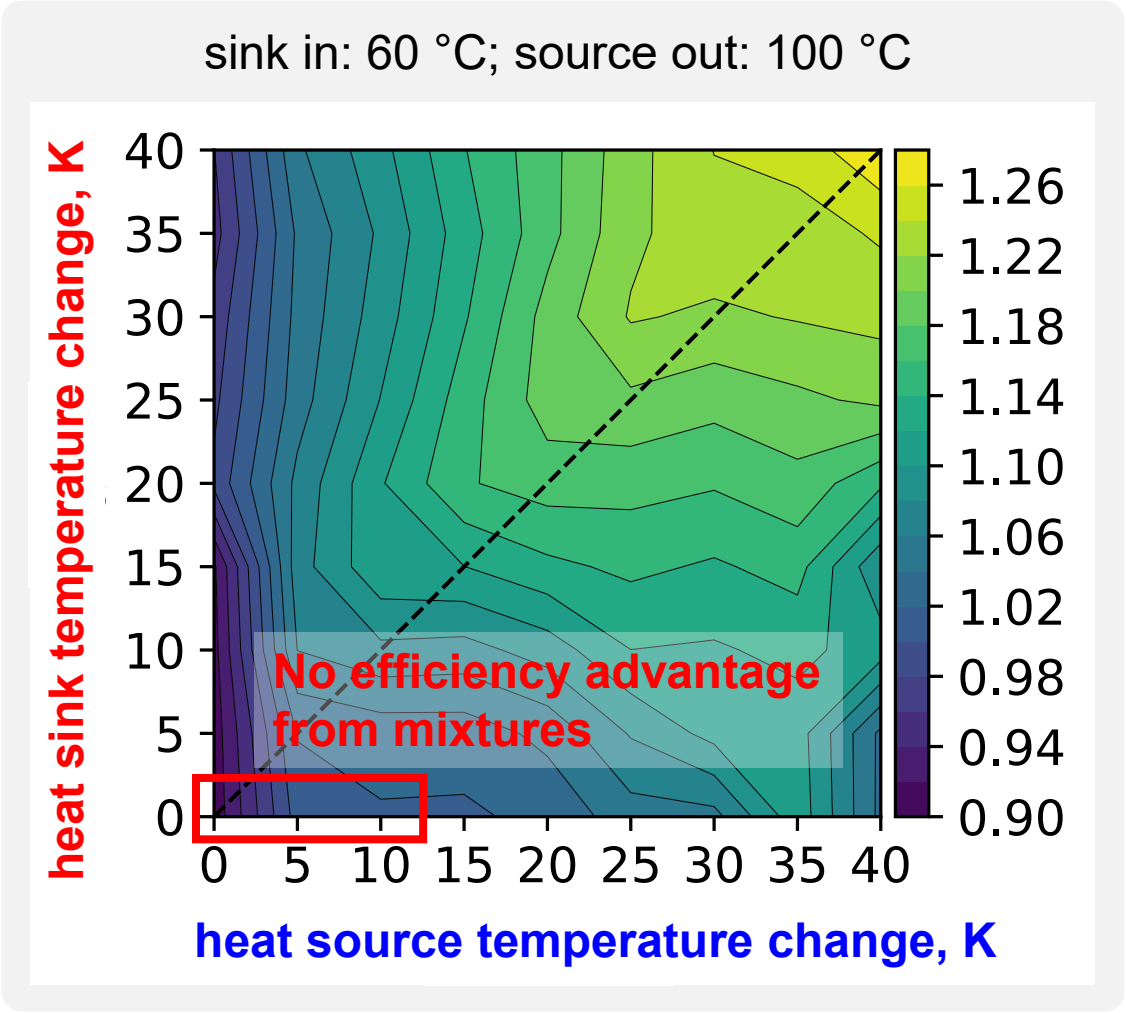


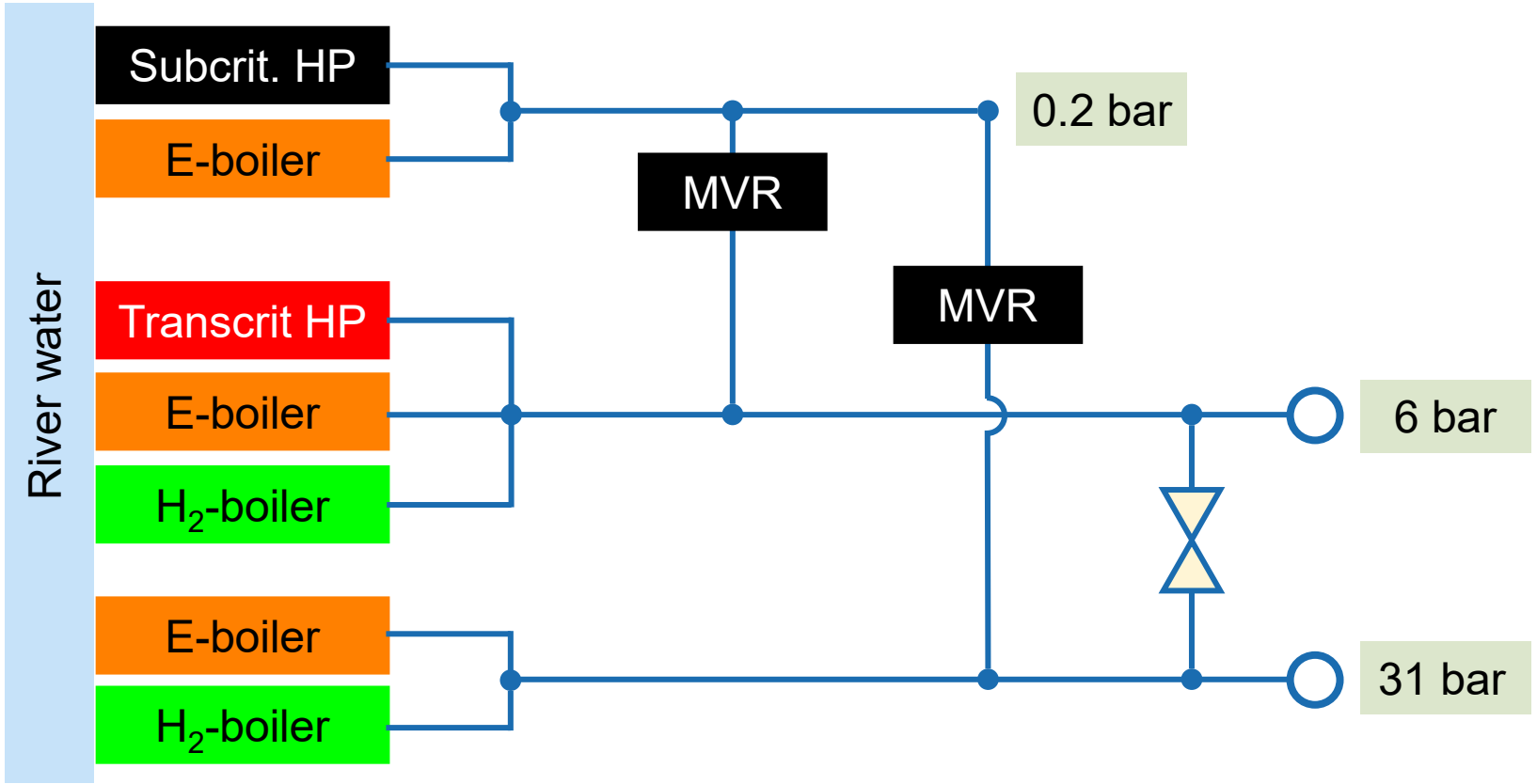
Typical conditions for process steam!

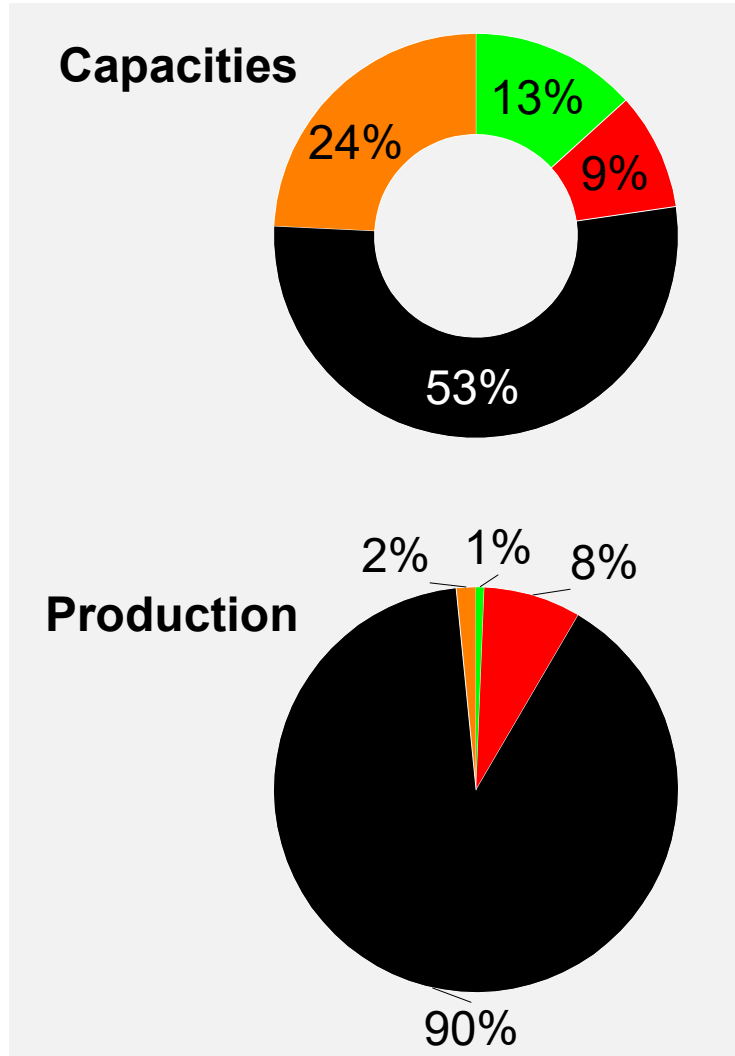
- EU: **40%** of industrial process heat is supplied **by steam**
- BASF Ludwigshafen: 18 mio. tons / year

https://www.portofantwerpbruges.com/en/business/industry/chemicals

Base Case Results

$\bar{C}_{\text{elec}} = 96.85\ €/\text{MWh}$, $C_{\text{H}_2} = 144\ €/\text{MWh}$





- **Heat pumps provide base load**
- **H_2 and E-boiler only for peak loads and protection against failure**

Nolzen, Baader, Dessiex, Evering, Schmid, Bardow, Roskosch, *submitted*

Base Case Results

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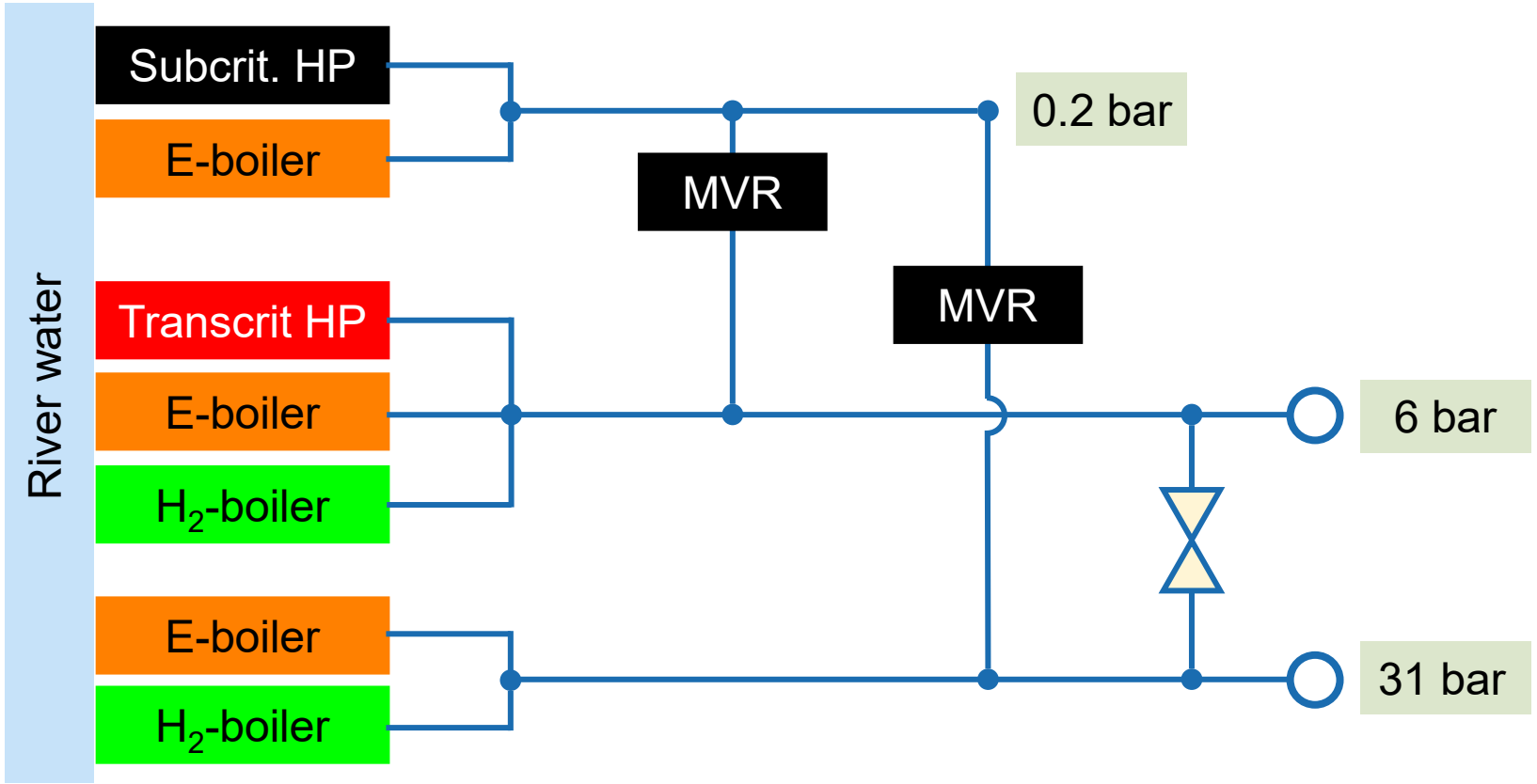
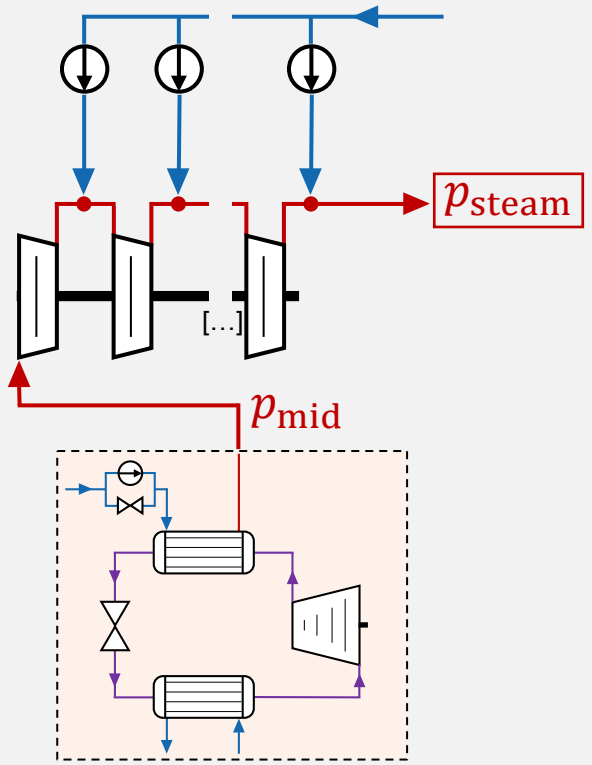


Nolzen, Baader, Dessiex, Evering, Schmid, Bardow, Roskosch, *submitted*

- **The best high-temperature heat pump is a low-temperature heat pump**

Direct evaporation HP + MVR



Subcrit. direct+ MVR

Food for thought & discussion

⇒ Heat pumps

⇒ Synfuels & Hydrogen

⇒ Direct air capture

⇒ Scope 3

⇒ Circular economy

So, what about synfuels & hydrogen?

nature energy

Article

https://doi.org/10.1038/s41560-024-01581-z

Towards carbon-neutral and clean propulsion in heavy-duty transportation with hydroformylated Fischer–Tropsch fuels

Received: 30 November 2023

Accepted: 14 June 2024

Published online: 08 July 2024

Check for updates

Simon Voelker[1], Niklas Groll[1], Marvin Bachmann[1], Leonard Mueller[1], Marcel Neumann[2], Theodoros Kossioris[2], Paul Muthyala[2], Bastian Lehrheuer[2], Marius Hofmeister[3], Andreas Vorholt[4], Katharina Schmitz[3], Stefan Pischinger[2], Walter Leitner[4,5] & André Bardow[6,7]

https://www.nature.com/articles/s41560-024-01581-z

Bild

BILD-KI INFOS ZU BILDPLUS WETTER BILDPLAY MARKTPLATZ ZEITUNG SUCHE ANMELDEN

STARTSEITE NEWS POLITIK REGIO UNTERHALTUNG SPORT FUSSBALL LIFESTYLE RATGEBER GESUNDHEIT SEX & LIEBE AUTO SPIELE DEALS

BILD › Leben & Wissen › Weniger Feinstaub und CO2: Synthetischer Sprit für Lkw hilft dem Klima

Jetzt fährt er fast so klimafreundlich wie Elektro

Deutsche Forscher strecken Diesel mit Alkohol

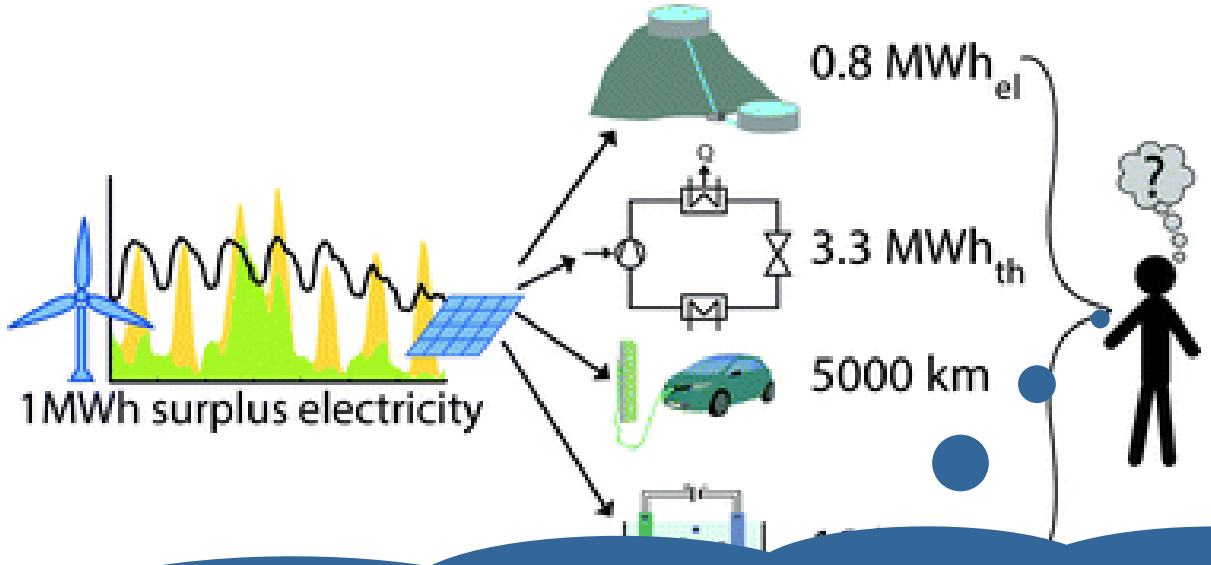
https://www.bild.de/leben-wissen/weniger-feinstaub-und-co2-synthetischer-sprit-fuer-lkw-hilft-dem-klima-6698ca67ebb1b2592aa975f4

Power-to-What ?

André Sternberg

Sarah Deutz

Renewable energies = limited resource



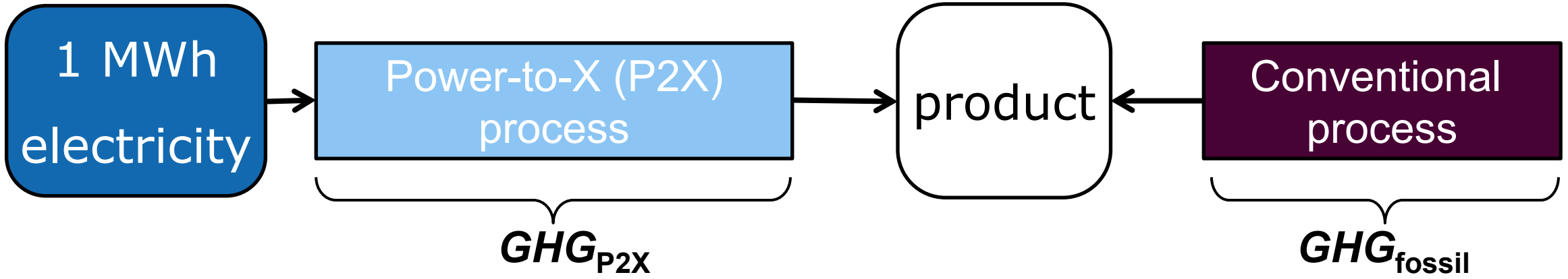
Which Power-to-X route uses electricity best?

Sternberg, Bardow, *Energy Environ. Sci.*, 2015, 8, 389

P2X-Efficiency

Which Power-to-X route uses electricity best?

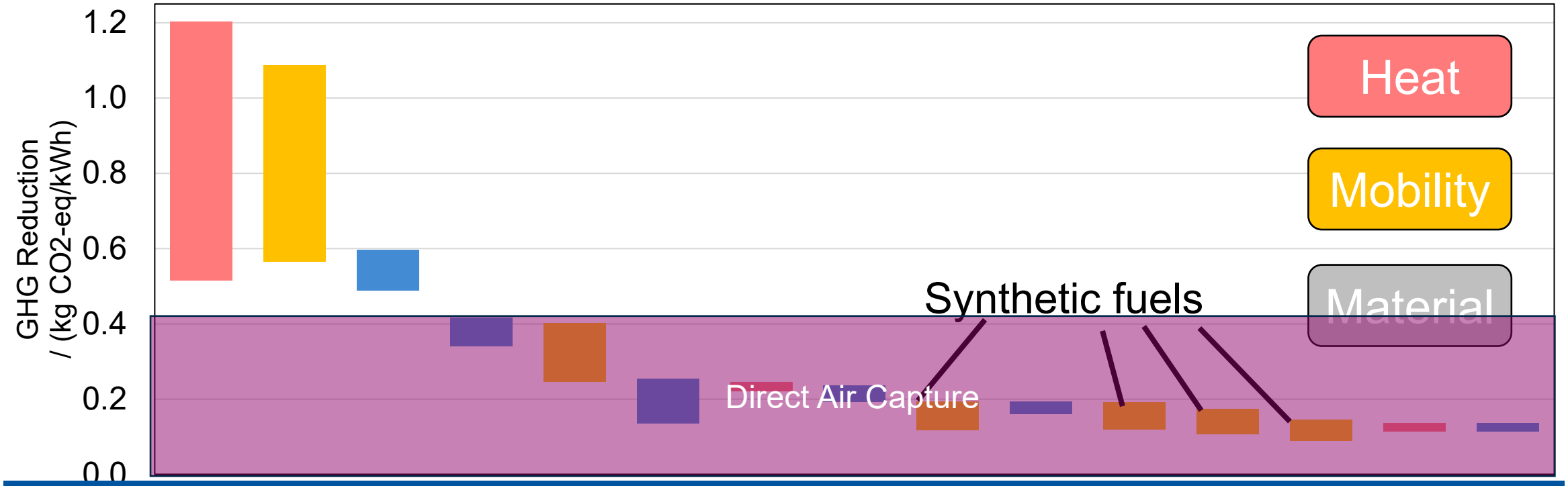
$$\text{P2X-Efficiency} = \frac{\text{Reduction of greenhouse gas (GHG) emissions}}{\text{per MWh electricity used}}$$



$$GHG_{Reduction} = GHG_{fossil} - GHG_{P2X}$$

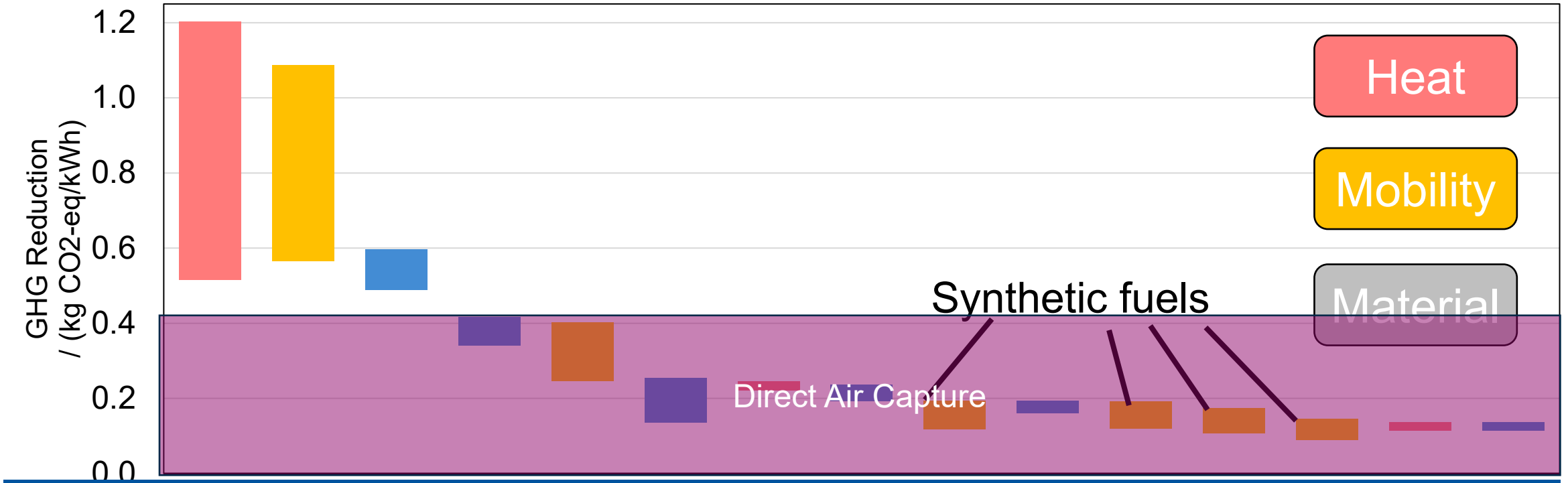
Sternberg and Bardow, *Energy Environ. Sci.*, 2015,**8**, 389-400.

Power-to-X efficiency – GHG savings per electricity used



- Winners: direct routes replacing inefficient fossil routes
- Heat pumps wherever possible
- P2X efficiency of fuels low

Power-to-X efficiency – GHG savings per electricity used



- Winners: direct routes replacing inefficient fossil routes
- Heat pumps wherever possible
- P2X efficiency of fuels low
  - even lower than direct air capture

Food for thought & discussion

⇒ Heat pumps

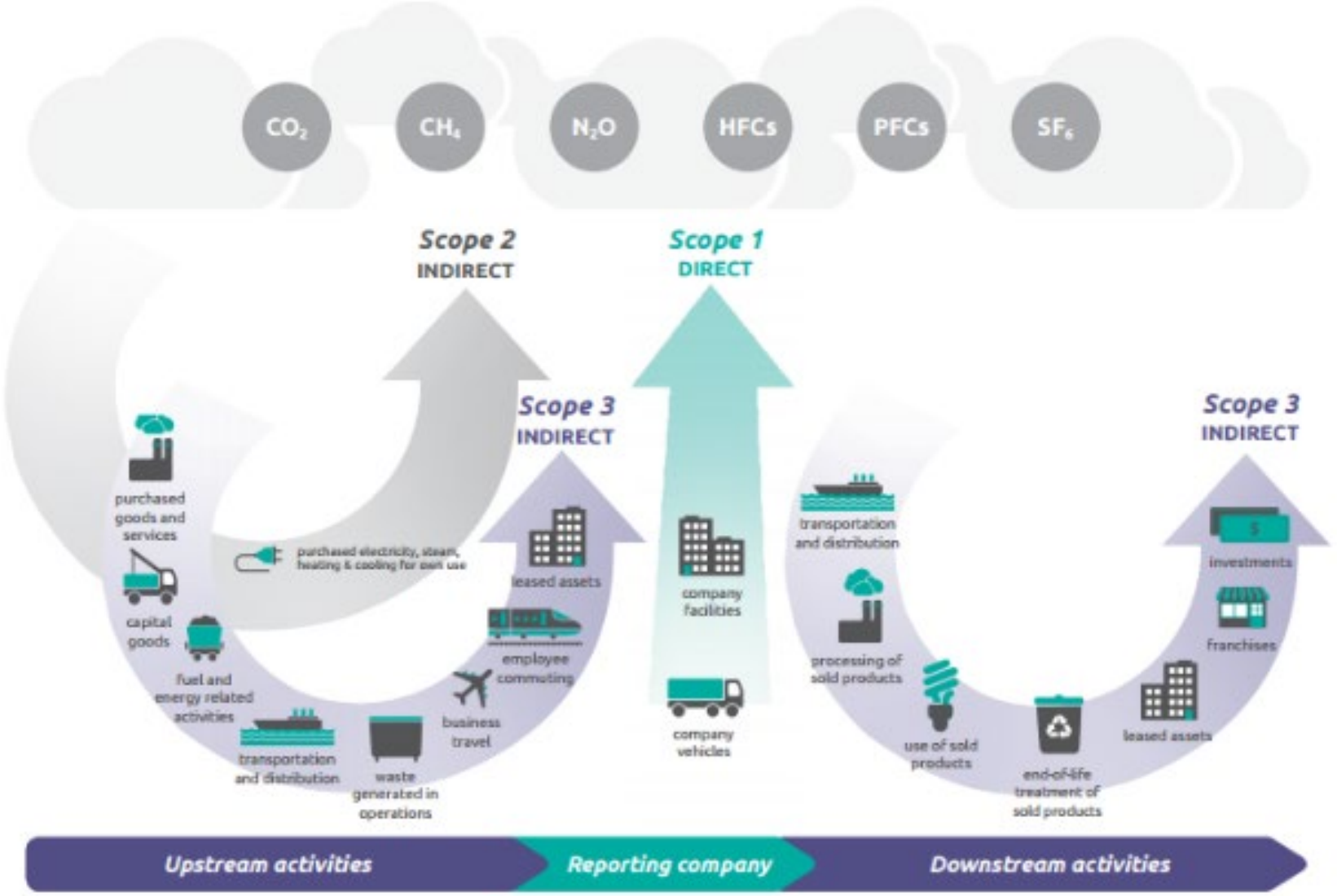
⇒ Synfuels & Hydrogen

⇒ Direct air capture

⇒ Scope 3

⇒ Circular economy

The scopes of decarbonisation



Source: GHG Protocol

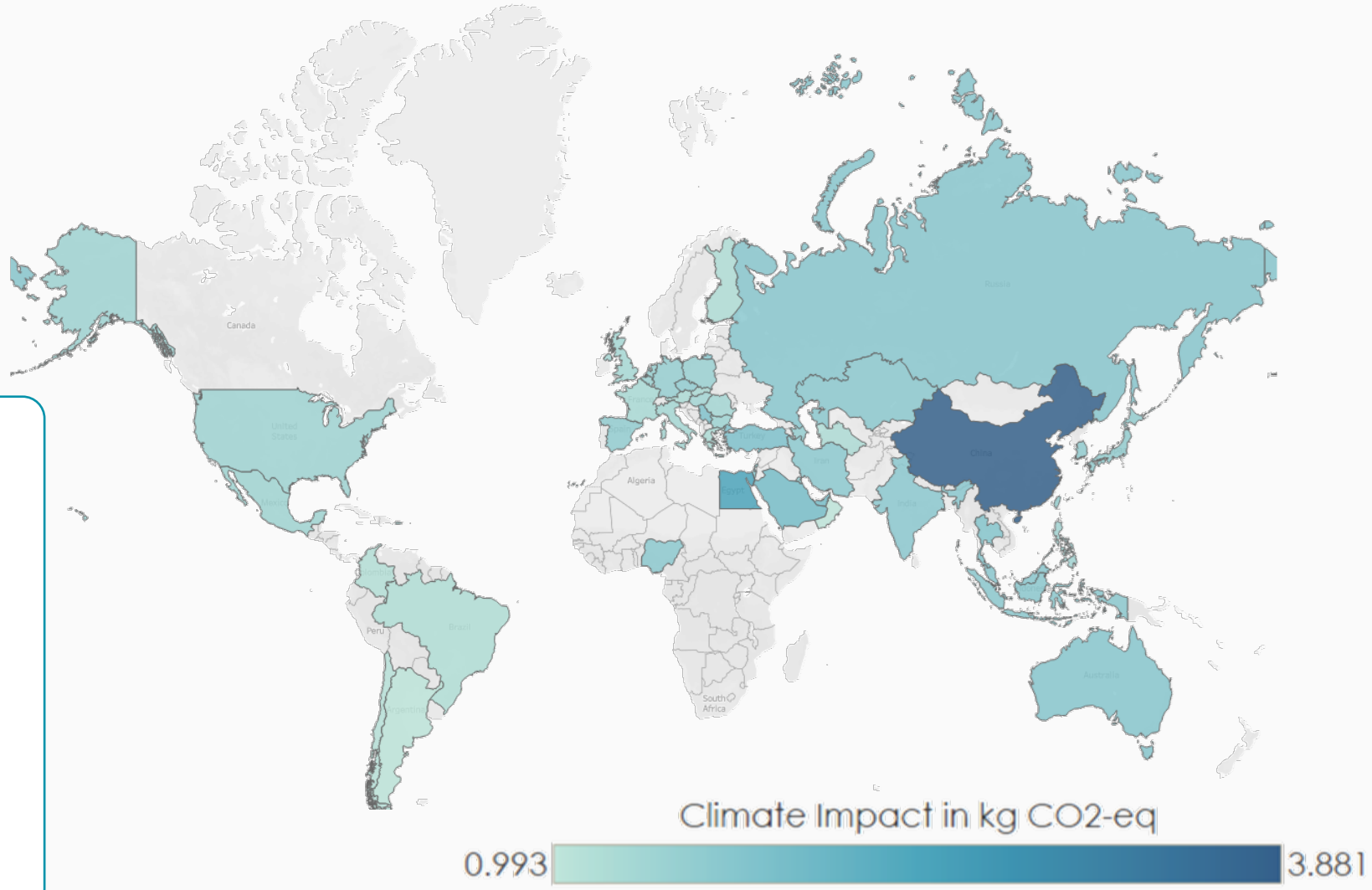
Scope 3 = 75% of corporate GHG emissions

Climate goals need to include all scope 3 emissions

Source: Science-based Targets using CDP data

Supplier-specific data for scope 3 ? Climate impact of polypropylene

Country averages

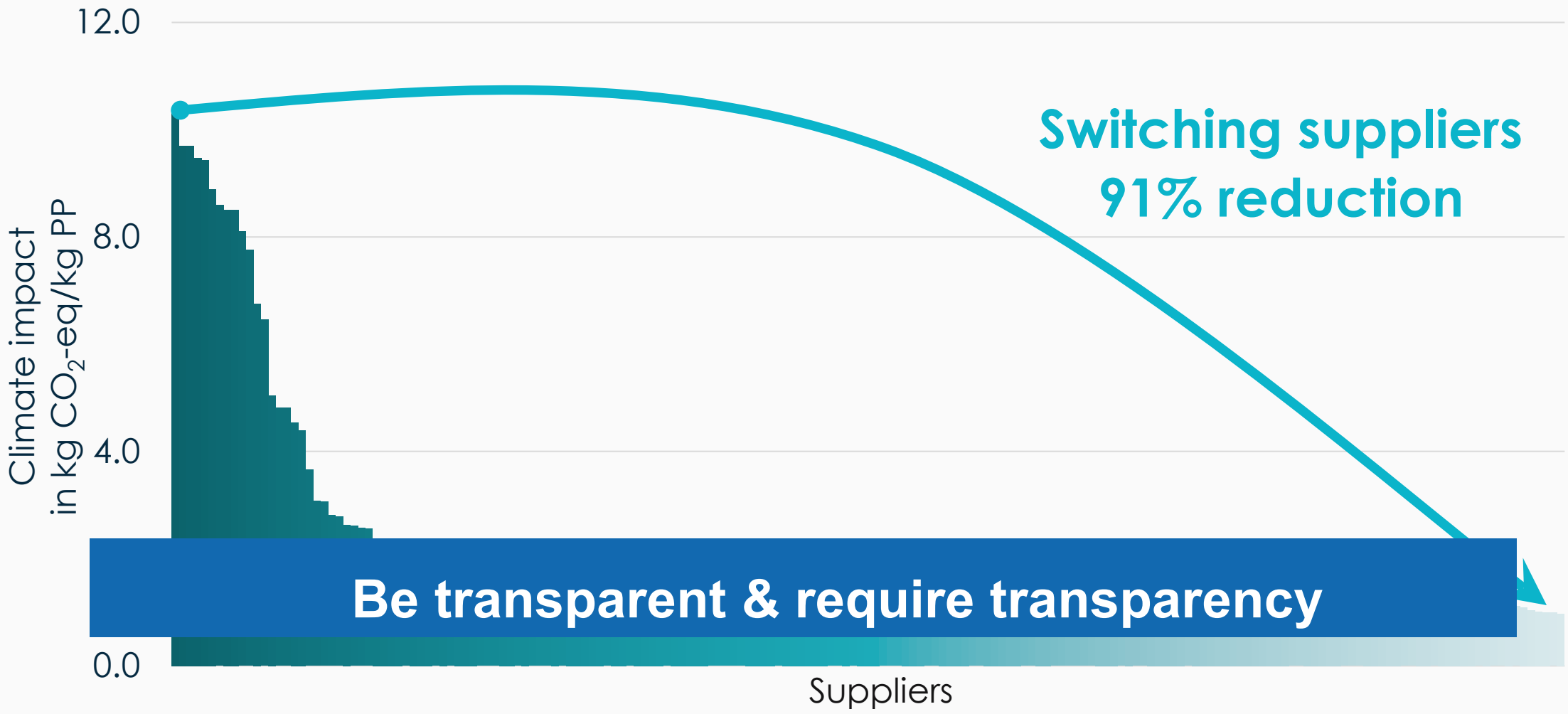


Large differences in climate impacts

- Feedstock use
- Technologies
- Energy

Supply Chain Data impacts Environmental Decision-Making

Variation of company specific carbon footprints (regionalized)



Food for thought & discussion

⇒ **Heat pumps**

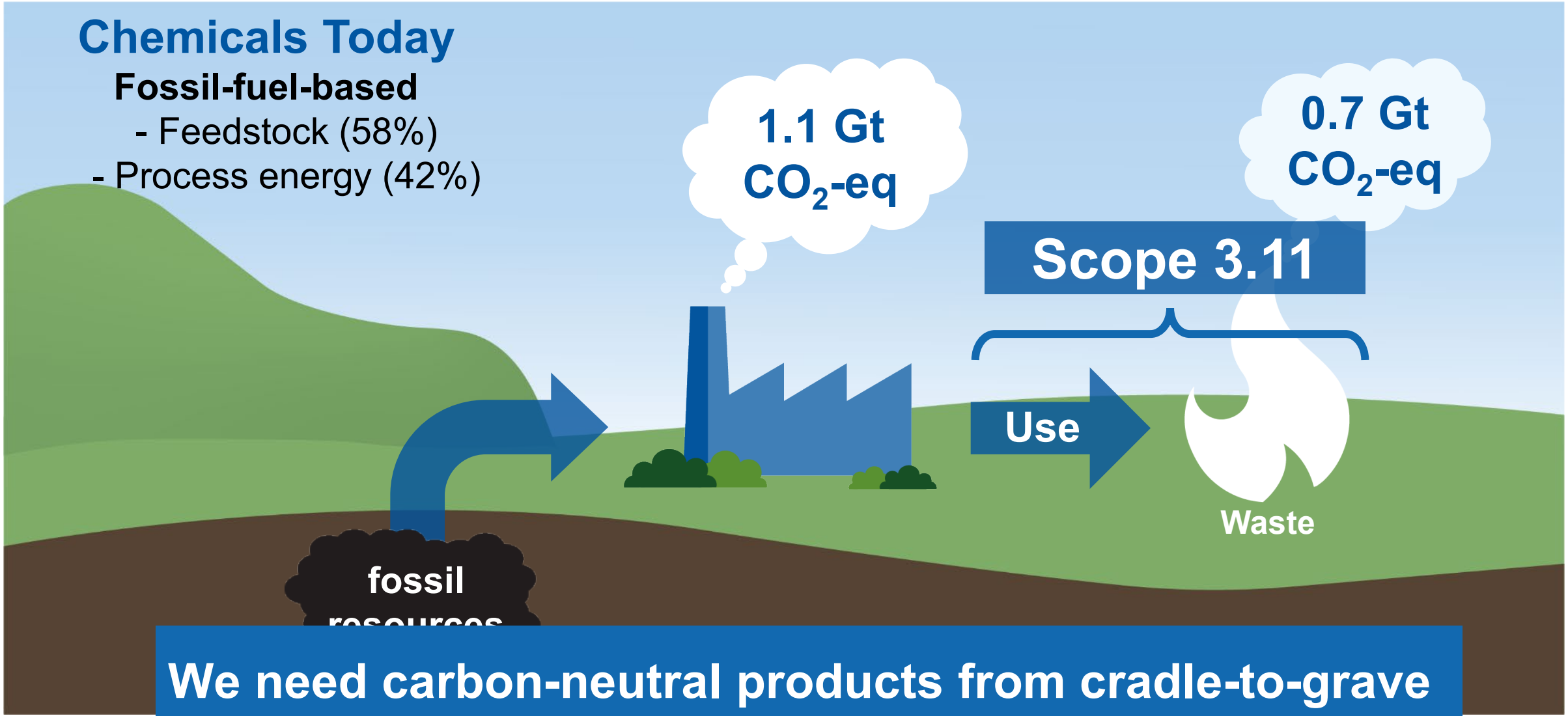
⇒ **Synfuels & Hydrogen**

⇒ **Direct air capture**

⇒ **Scope 3**

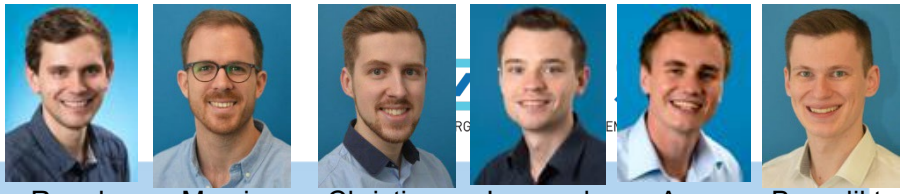
⇒ **Circular economy**

Scope 3: more than upstream emissions

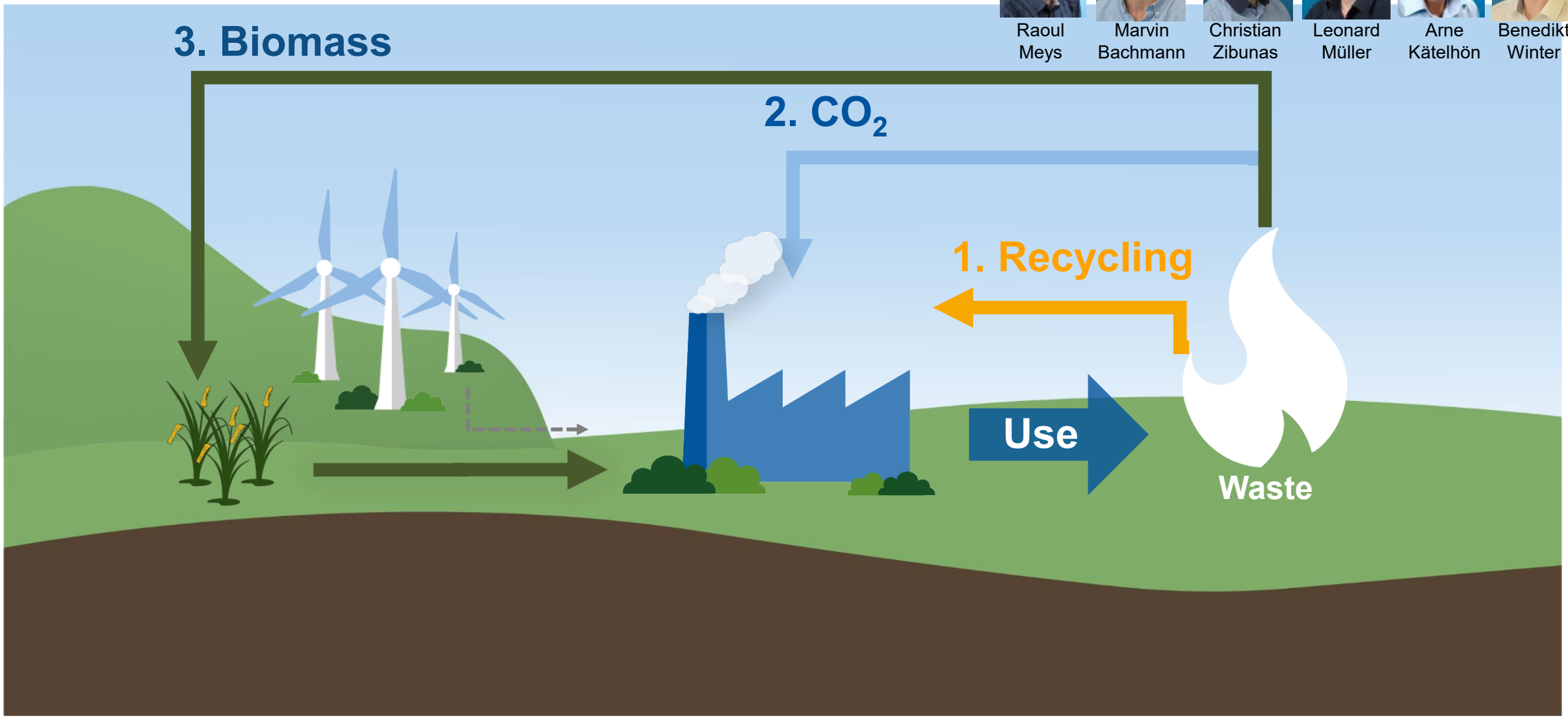


[1] IEA, DECHEMA, ICCA (2013), Technology Roadmap
[2] Zheng and Suh. *Nature Climate Change*. 2019. https://doi.org/10.1038/s41558-019-0459-z

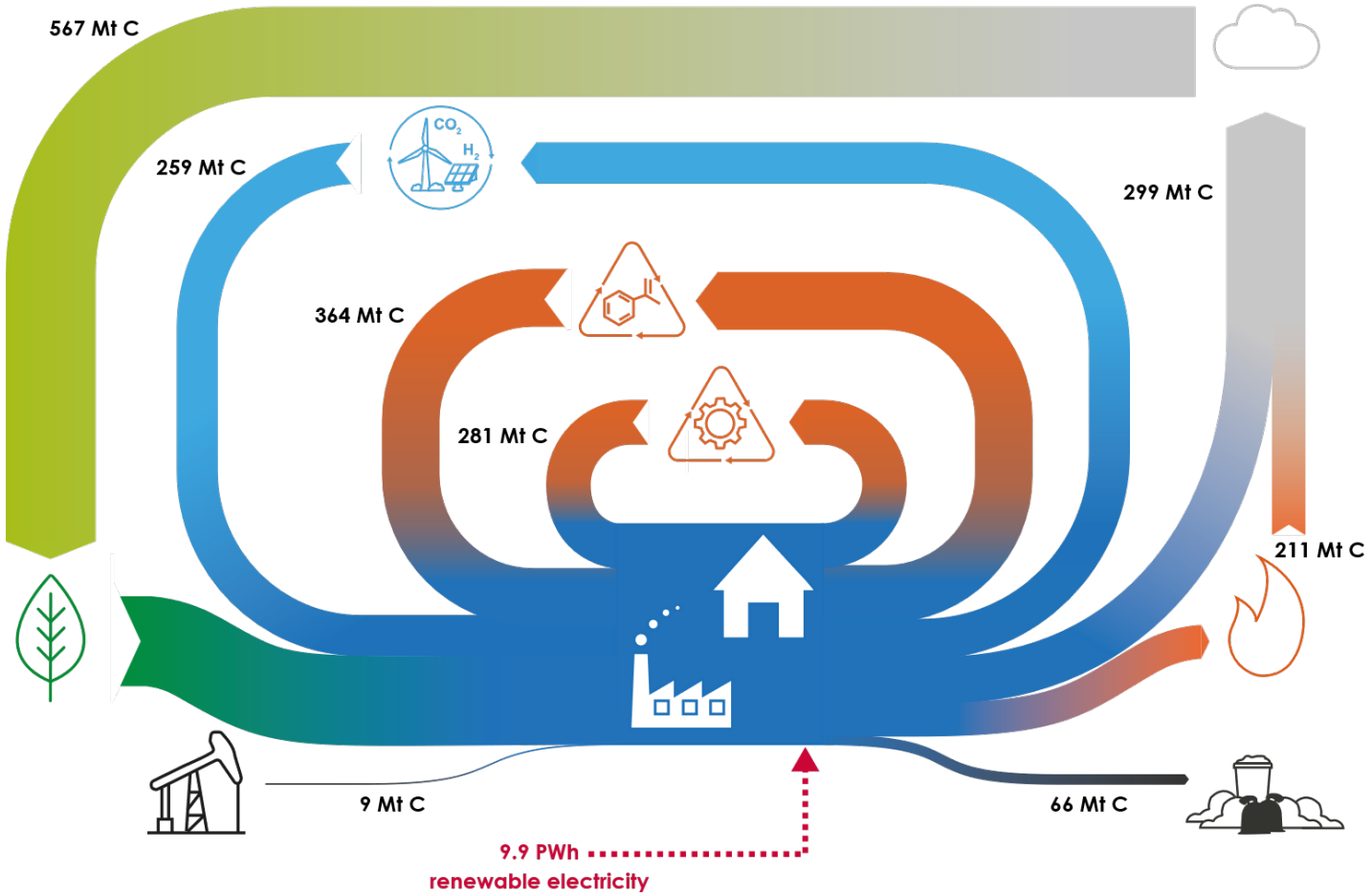
Circular carbon



Raoul Meys | Marvin Bachmann | Christian Zibunas | Leonard Müller | Arne Kätelhön | Benedikt Winter



Carbon-neutral circular carbon economy



Meys et al., *Science*, **2021**

Combining **all circular technologies**
achieves **carbon-neutral** plastics*
using **less energy** than linear the fossil-based benchmark.

Food for thought & discussion

⇒ Integrate all Scope 3 in your targets

⇒ Heat pumps wherever possible

⇒ Synfuels have low Power-to-X efficiency

⇒ Be transparent & require transparency

⇒ The circular economy is the most efficient route to net-zero industries

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