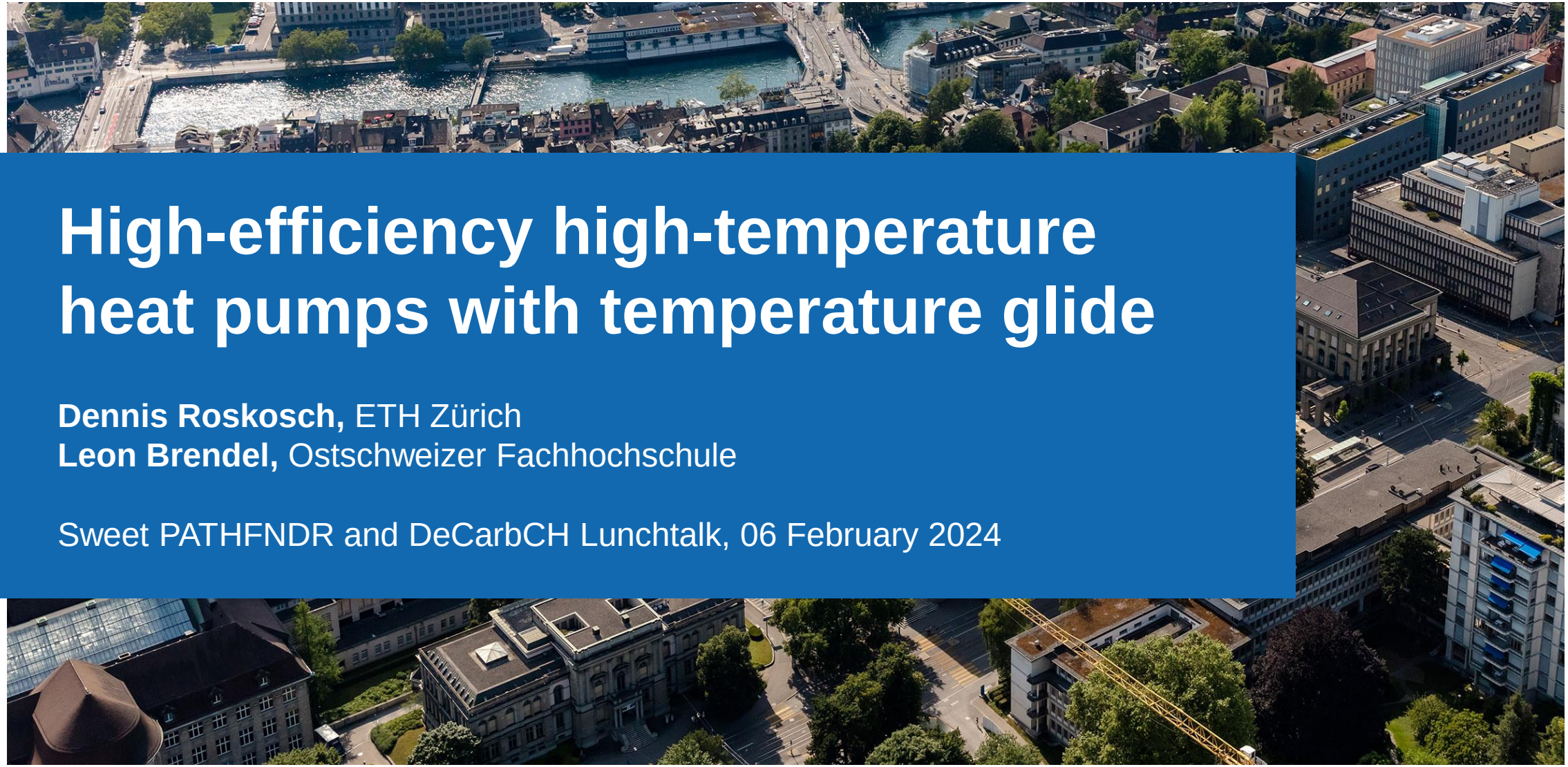


High-efficiency high-temperature heat pumps with temperature glide

Dennis Roskosch, ETH Zürich
Leon Brendel, Ostschweizer Fachhochschule

Sweet PATHFNDR and DeCarbCH Lunchtalk, 06 February 2024

Agenda

Dennis Roskosch (ETH):

- Introduction of the project
- First model-based results

Energy and Process Systems Engineering
Head: Prof. Dr. André Bardow

Leon Brendel (OST)

- First experimental results

Institute for Energy Systems
Head: Prof. Dr. Stefan Bertsch

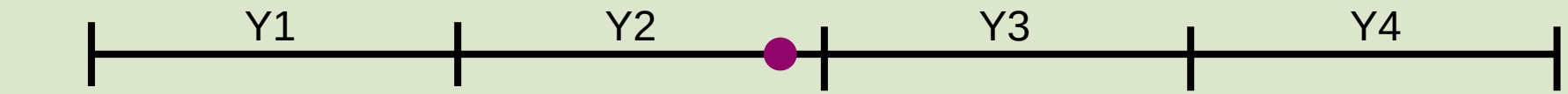
Zürich and Buchs Team up!

Energy and Process Systems Engineering
Head: Prof. Dr. André Bardow

Institute for Energy Systems
Head: Prof. Dr. Stefan Bertsch

Schweizerischer Nationalfonds BRIDGE Innosuisse

“High-efficiency high-temperature heat pumps with temperature glide”



Zürich and Buchs Team up!

Energy and Process Systems
Head: Prof. Dr. André Bardow

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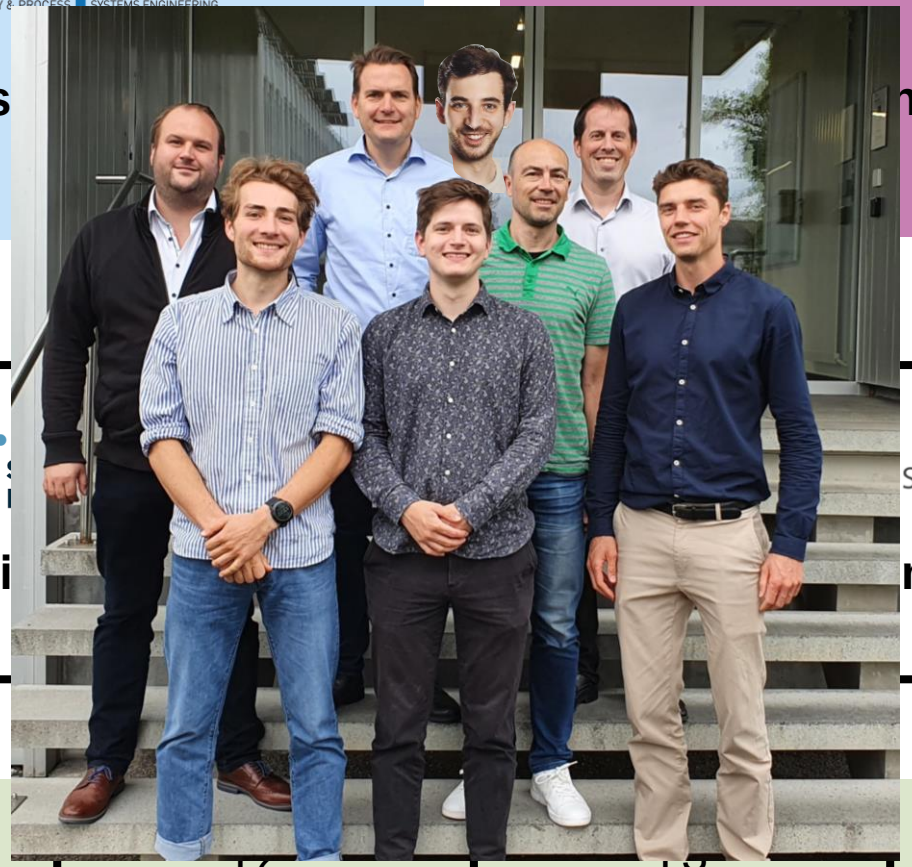
Stefan Bertsch



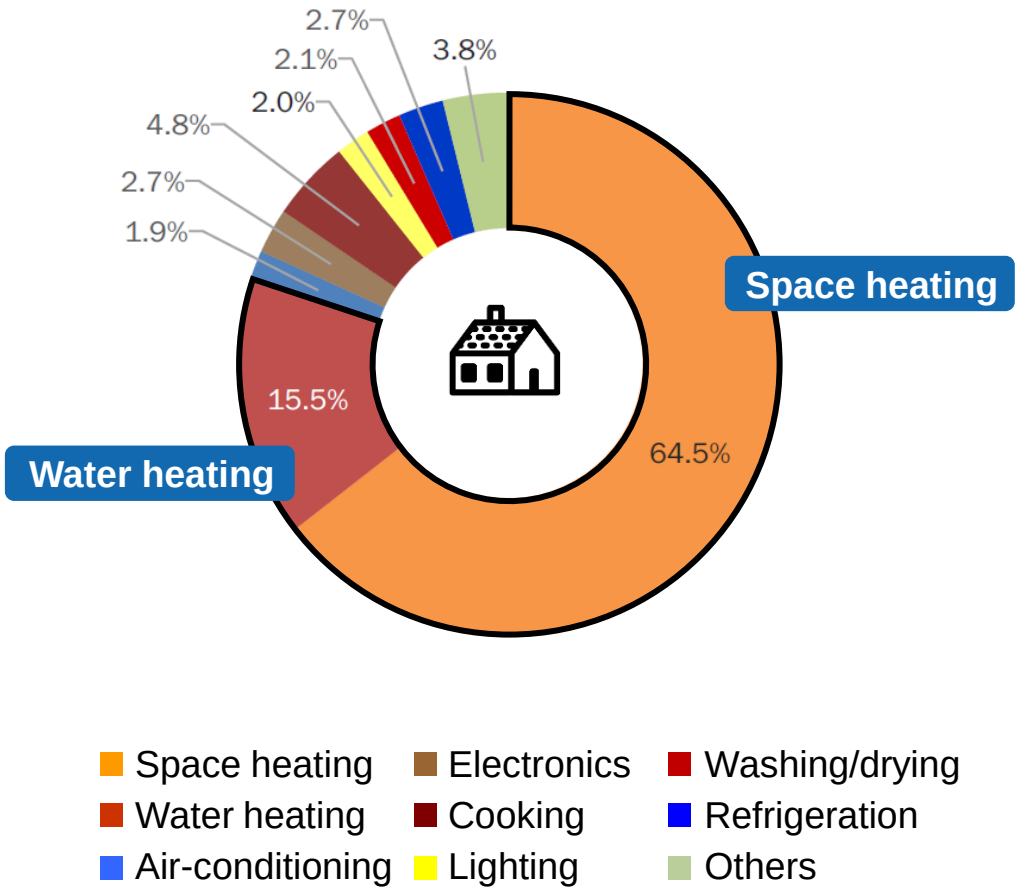
suisse

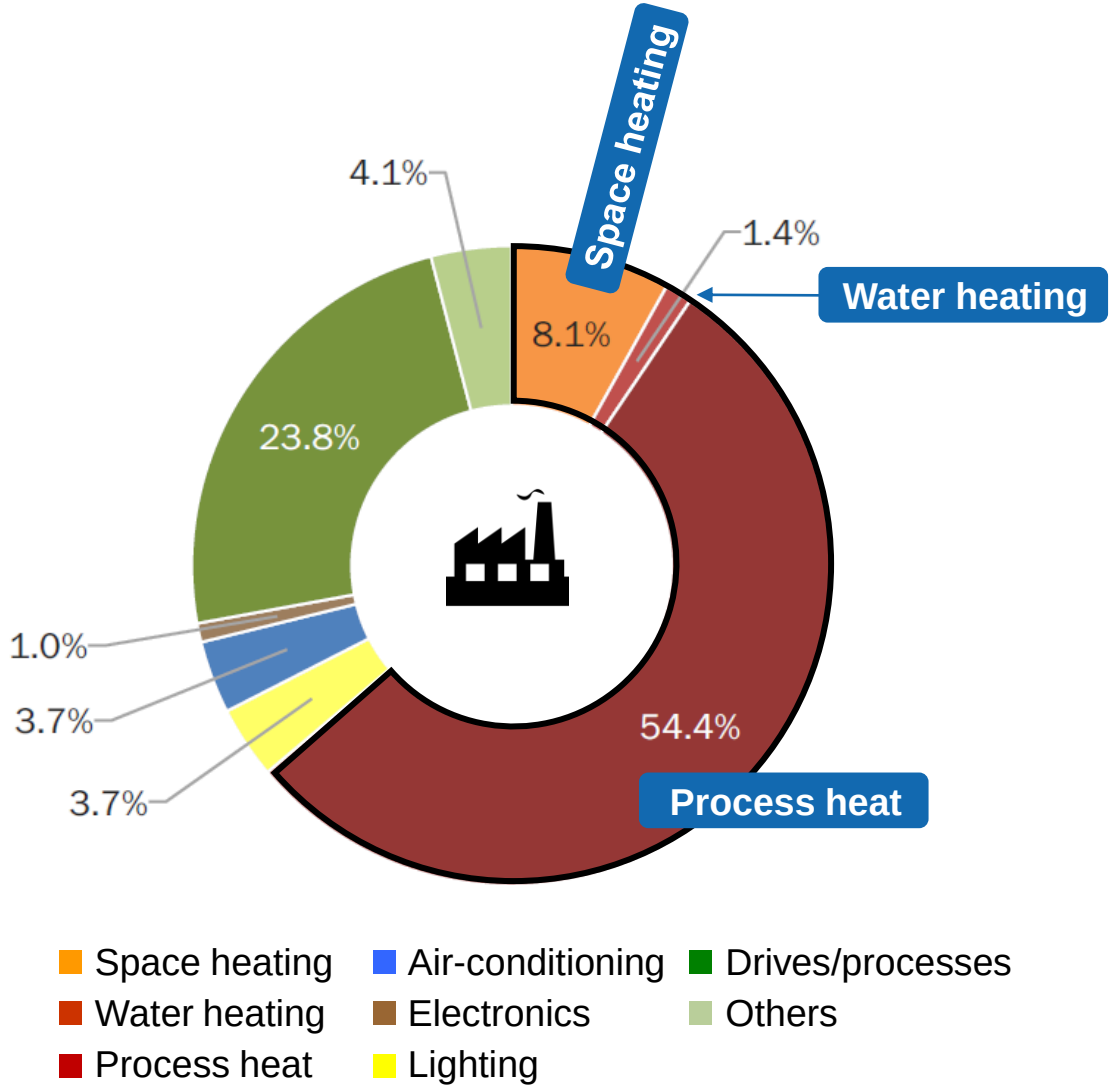
“Hi **mps**

Y1 Y4

Apr. 2022 **Apr. 2026**

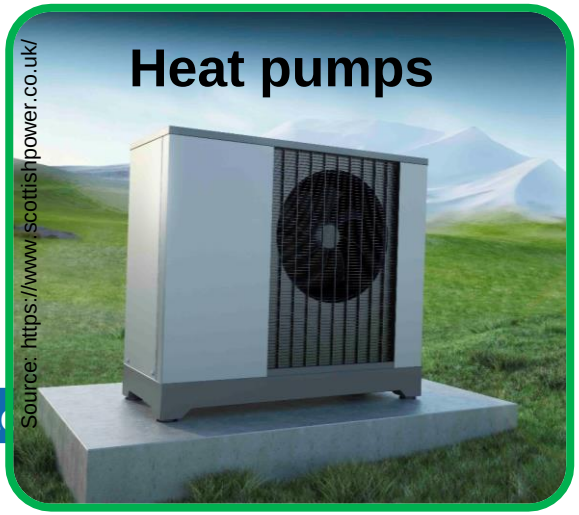
The energy transition is mainly a heat transition

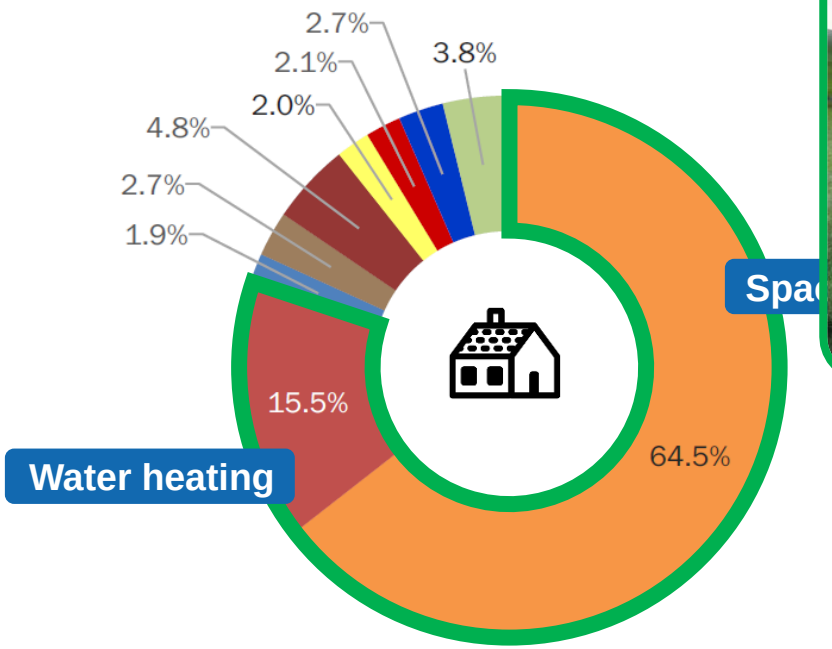


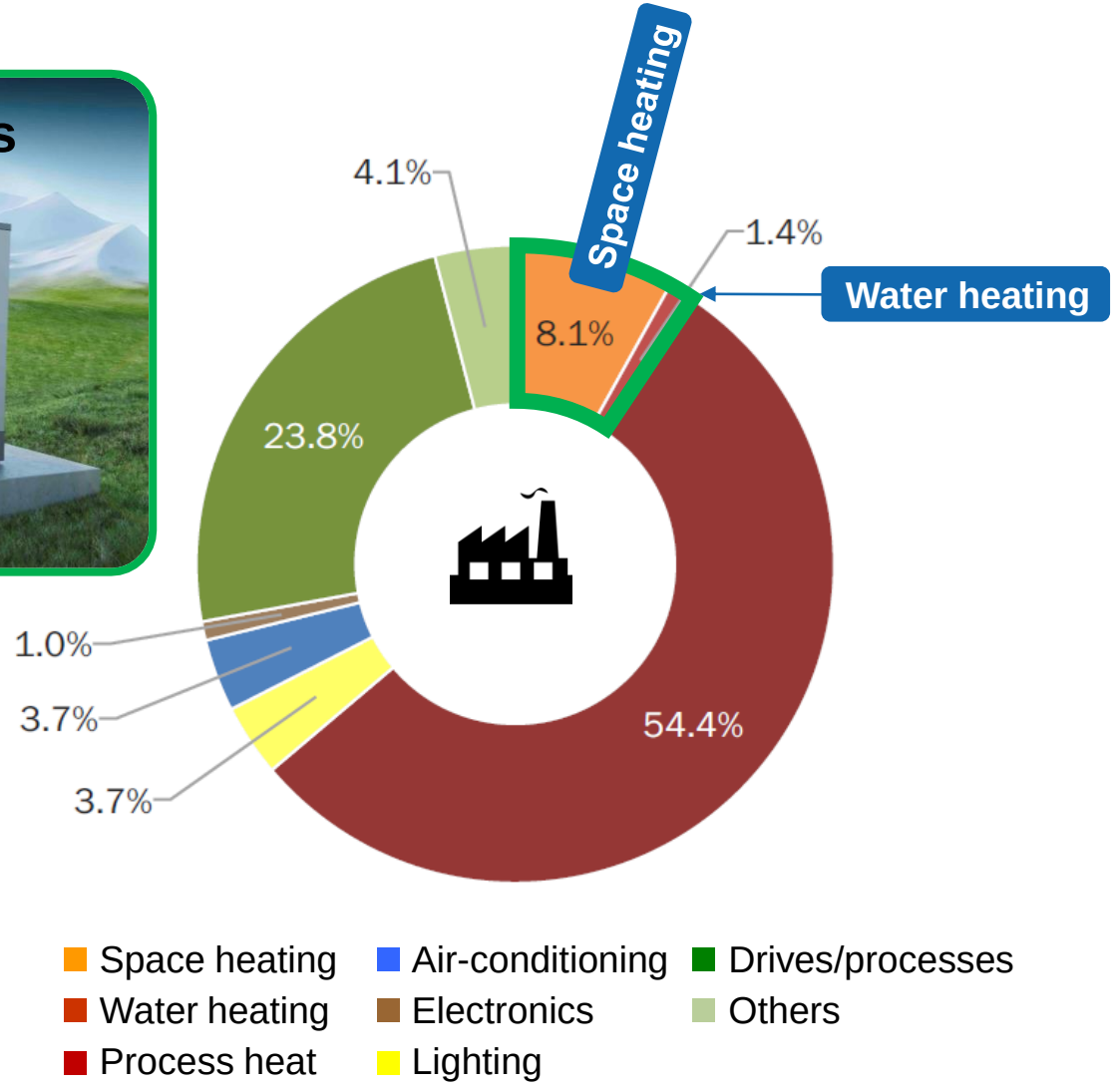


Source: Prognos 2021

Low temperature heat → heat pumps

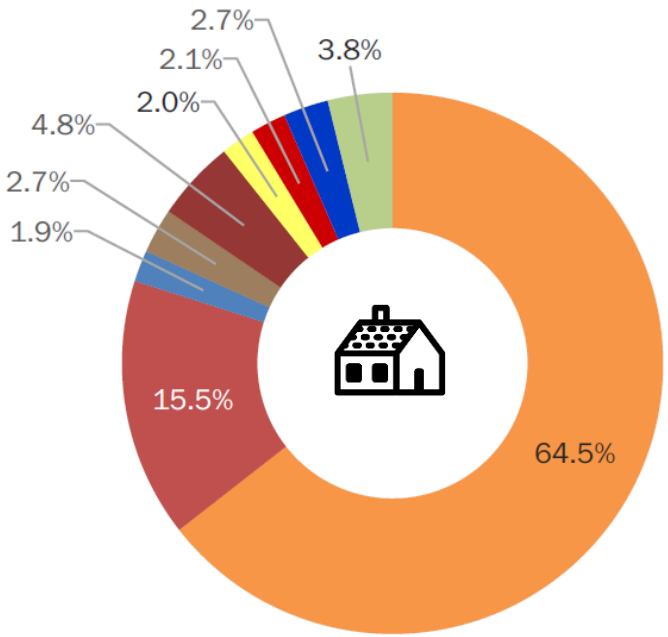


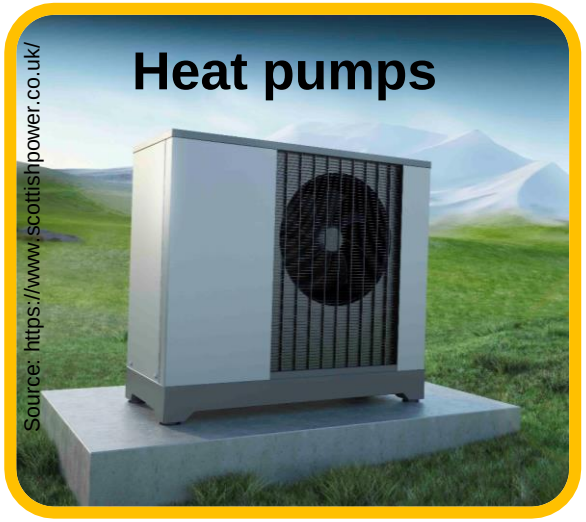




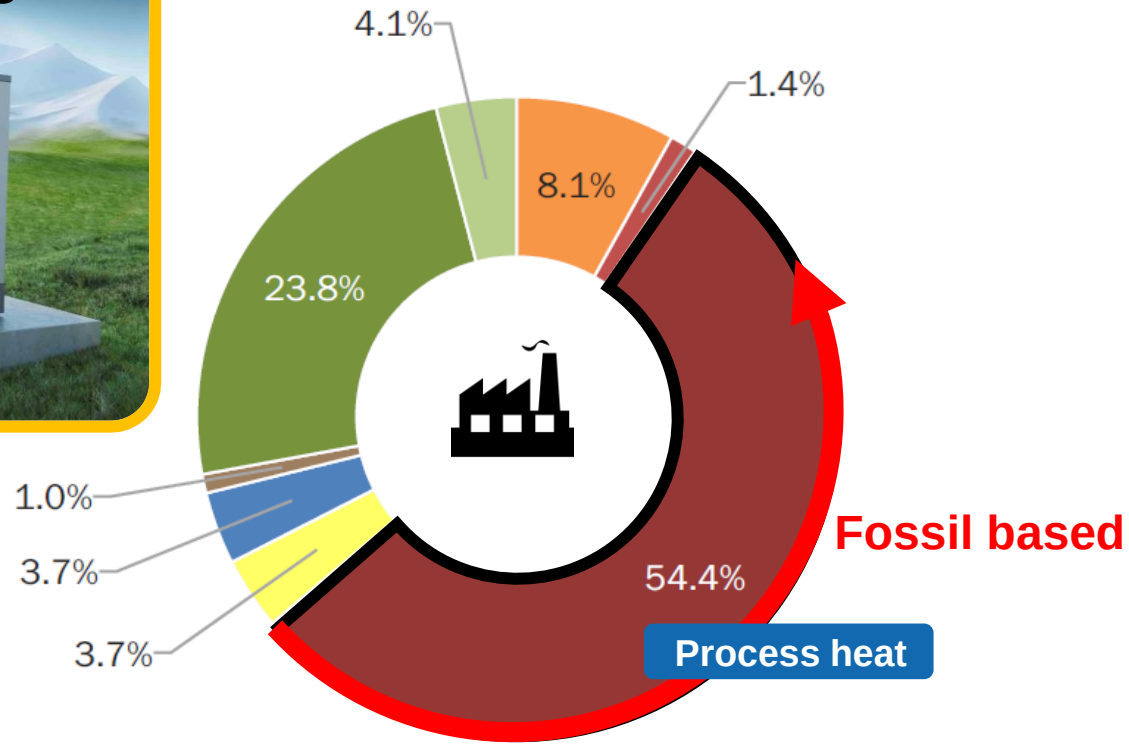
Source: Prognos 2021
Pictures: Colourbox

Process heat still based on fossil fuels





… heat pumps, but…



Space heating, Electronics, Washing/drying, Water heating, Cooking, Refrigeration, Air-conditioning, Lighting, Others

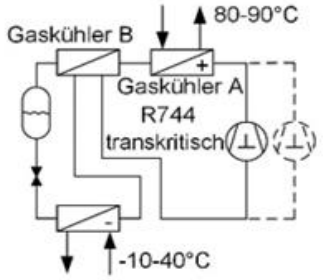
Space heating, Air-conditioning, Drives/processes, Water heating, Electronics, Others, Process heat, Lighting

Source: Prognos 2021
Pictures: Colourbox

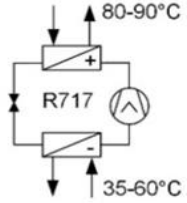
Industrial heat pumps are becoming available

Viking Heat Engines
HeatBooster S4

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



Star Refrigeration, Neatpump NP601,
Vilter VSSH Schraubenkompressor 76 bar



- Various manufacturers have developed high-temperature heat pumps
- Only a few demonstrators in operational environment

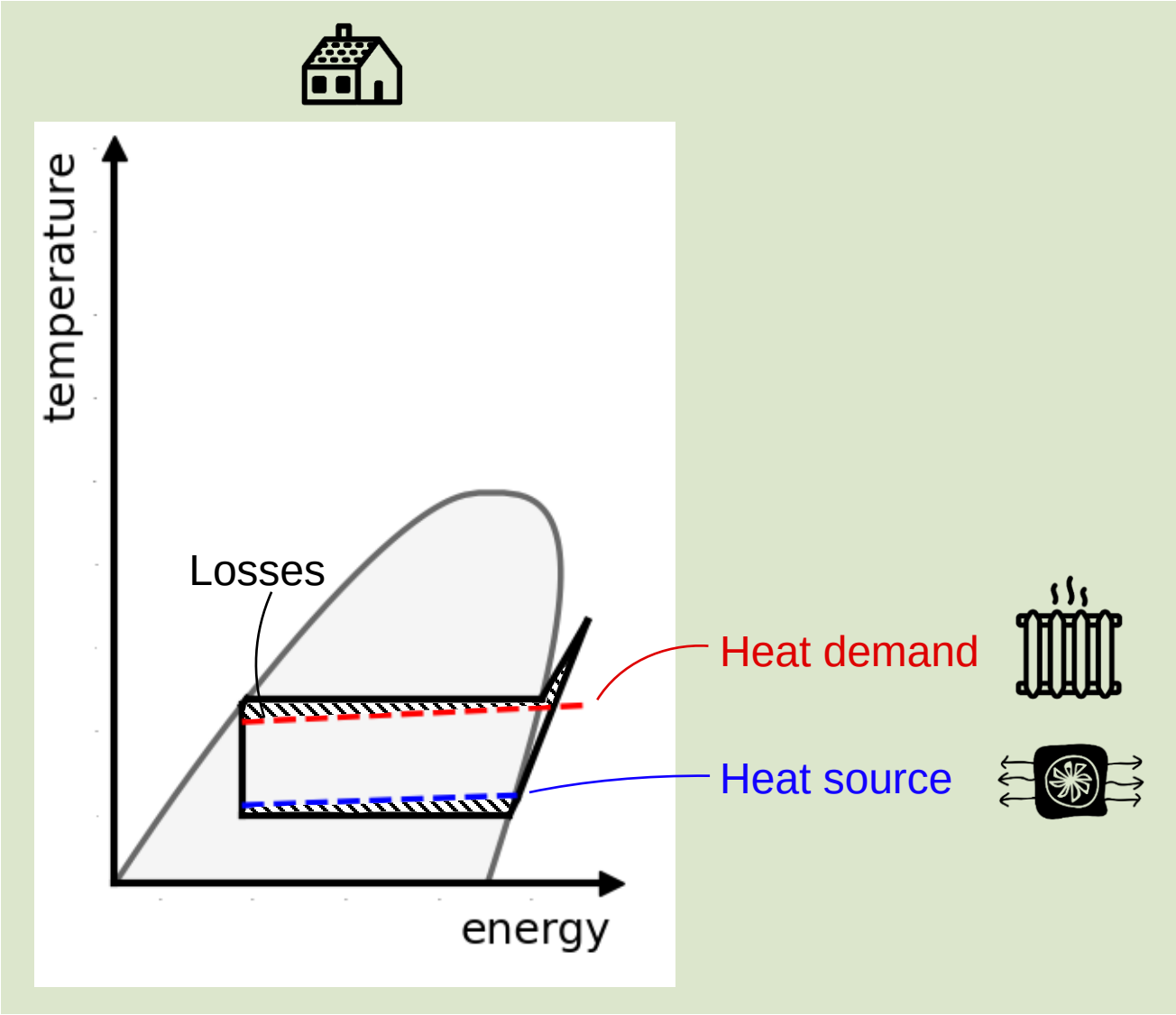
} TRL 5-7

- Each product is tailored to exactly one application
  → often costly plant engineering needed
- Still potential for increasing
  - efficiency
  - maximum temperature

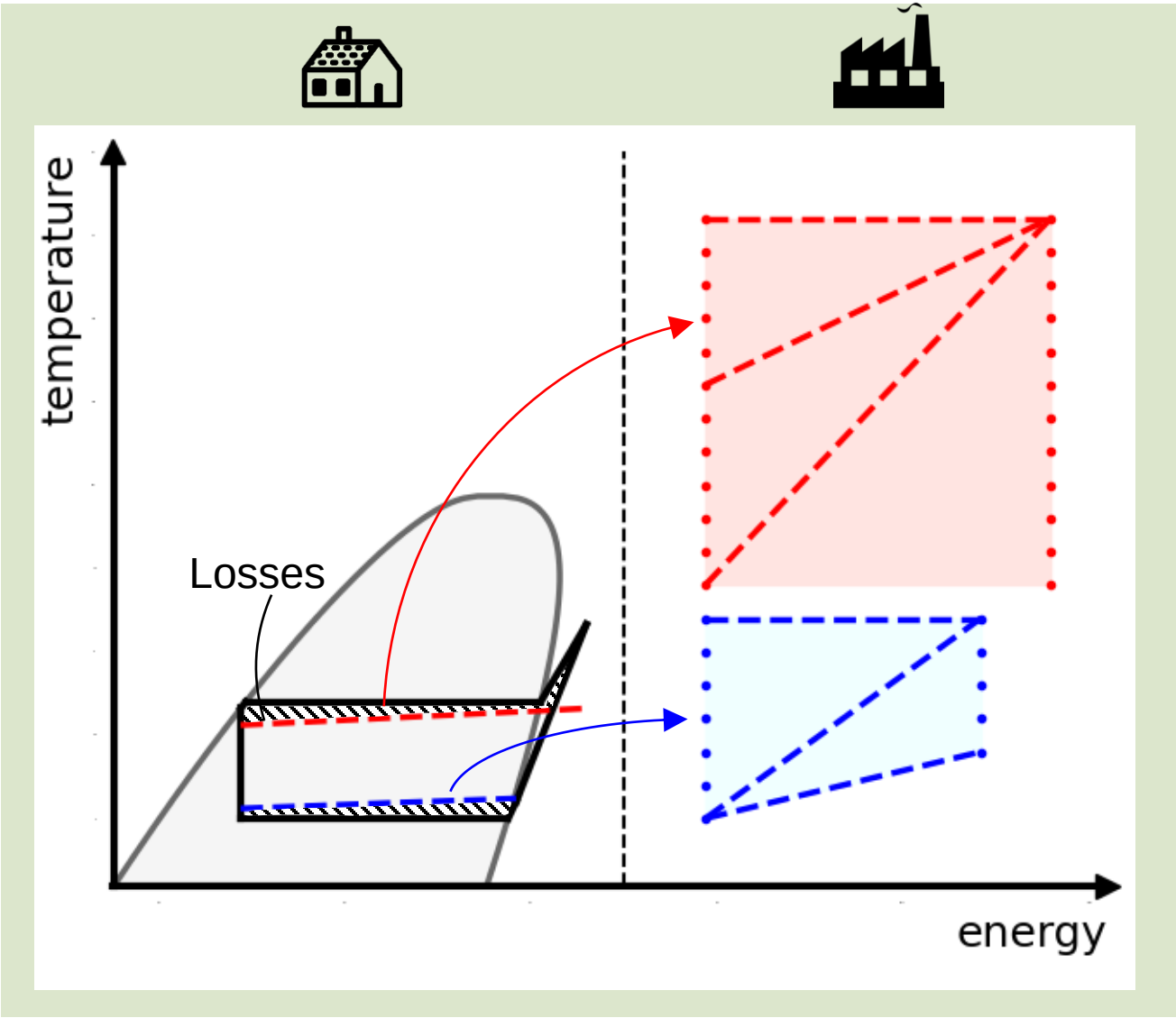
→ **hampers efficient commercialization**

Pictures from Cordin Arpagaus, Hochtemperaturwärmepumpen

The industrial needs are many and varied



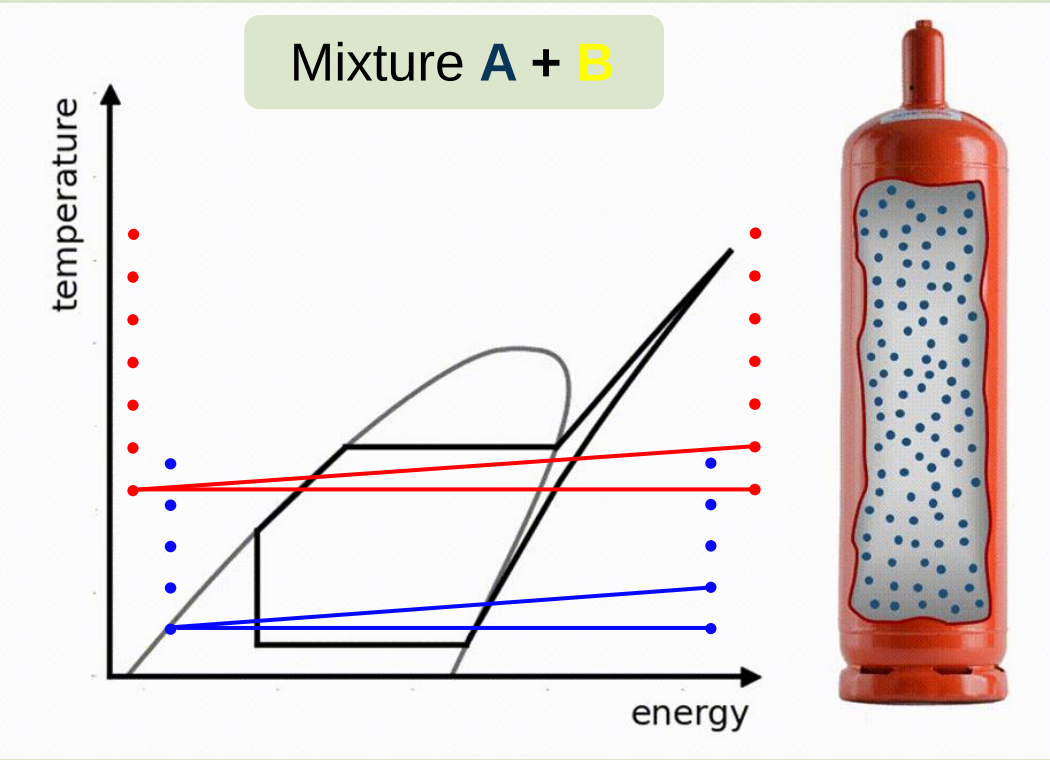
The industrial needs are many and varied



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

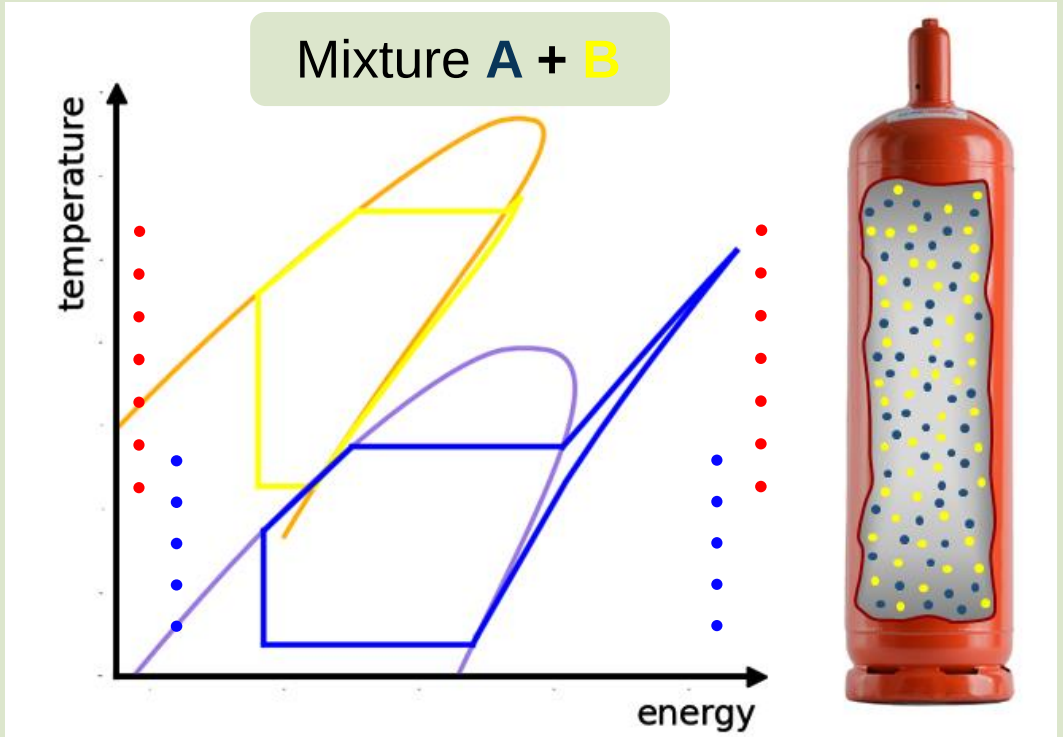
The solution: refrigerant mixtures with temperature glide

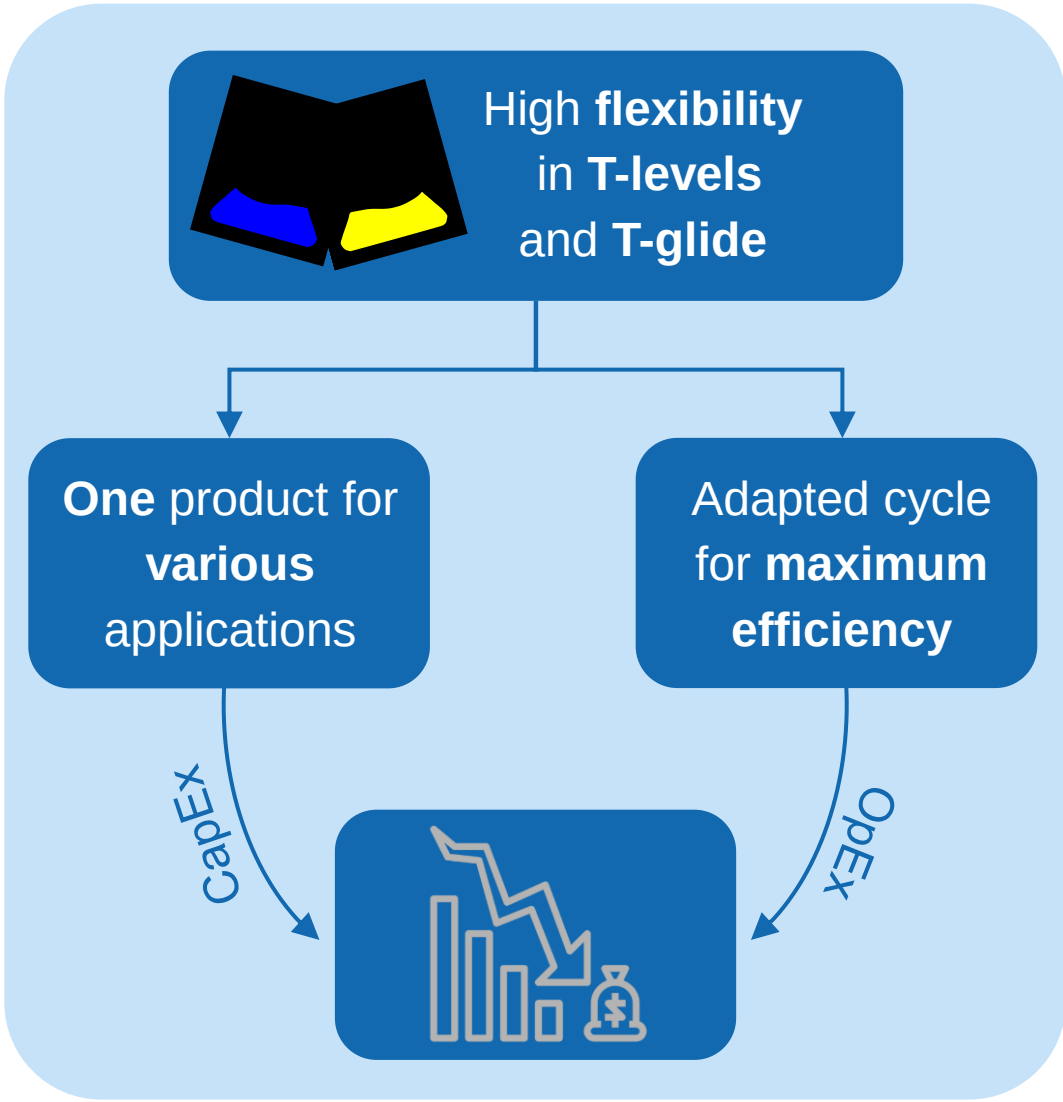
One mixture → **many** options

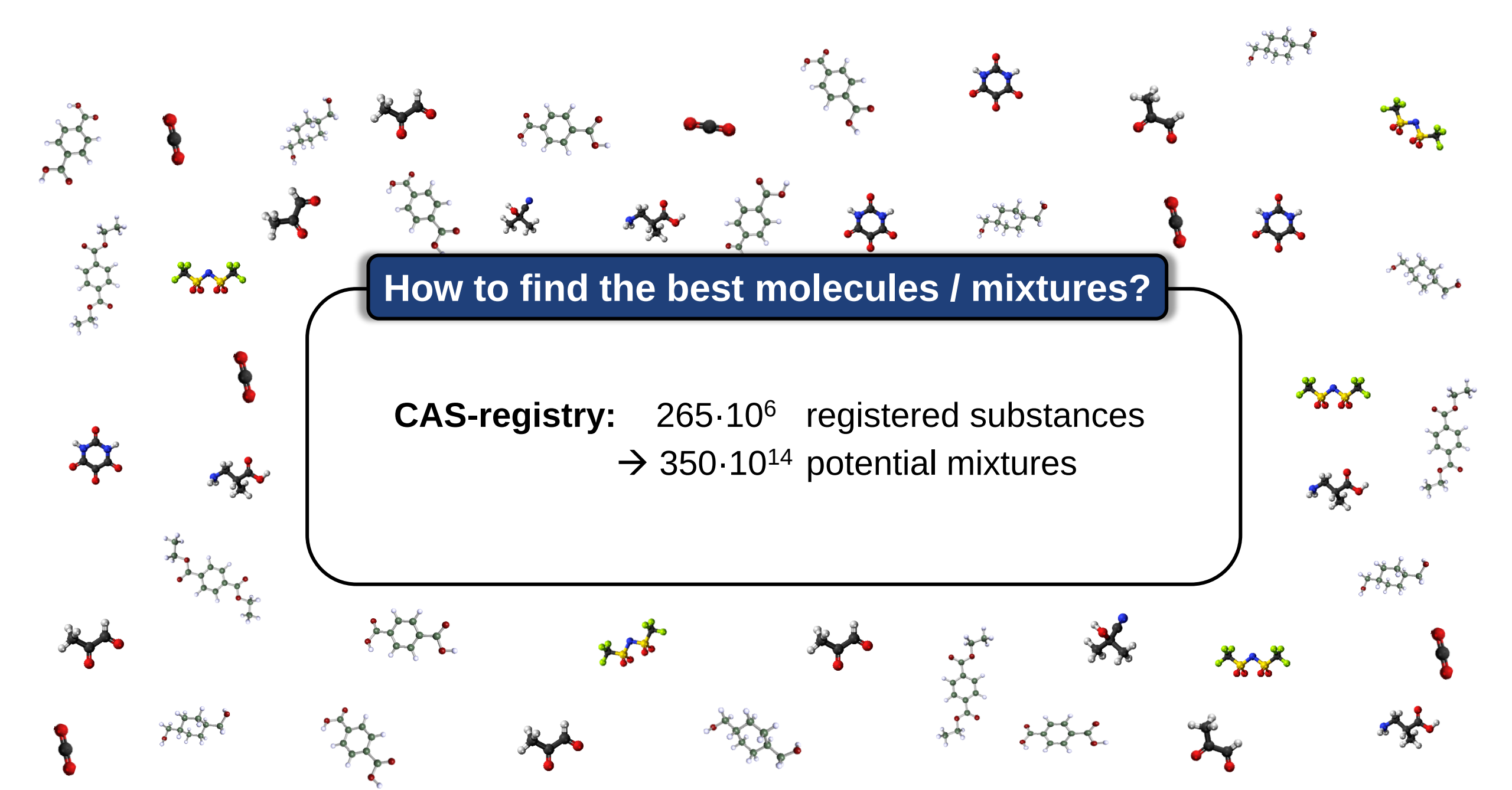


The solution: refrigerant mixtures with temperature glide

One mixture → **many** options







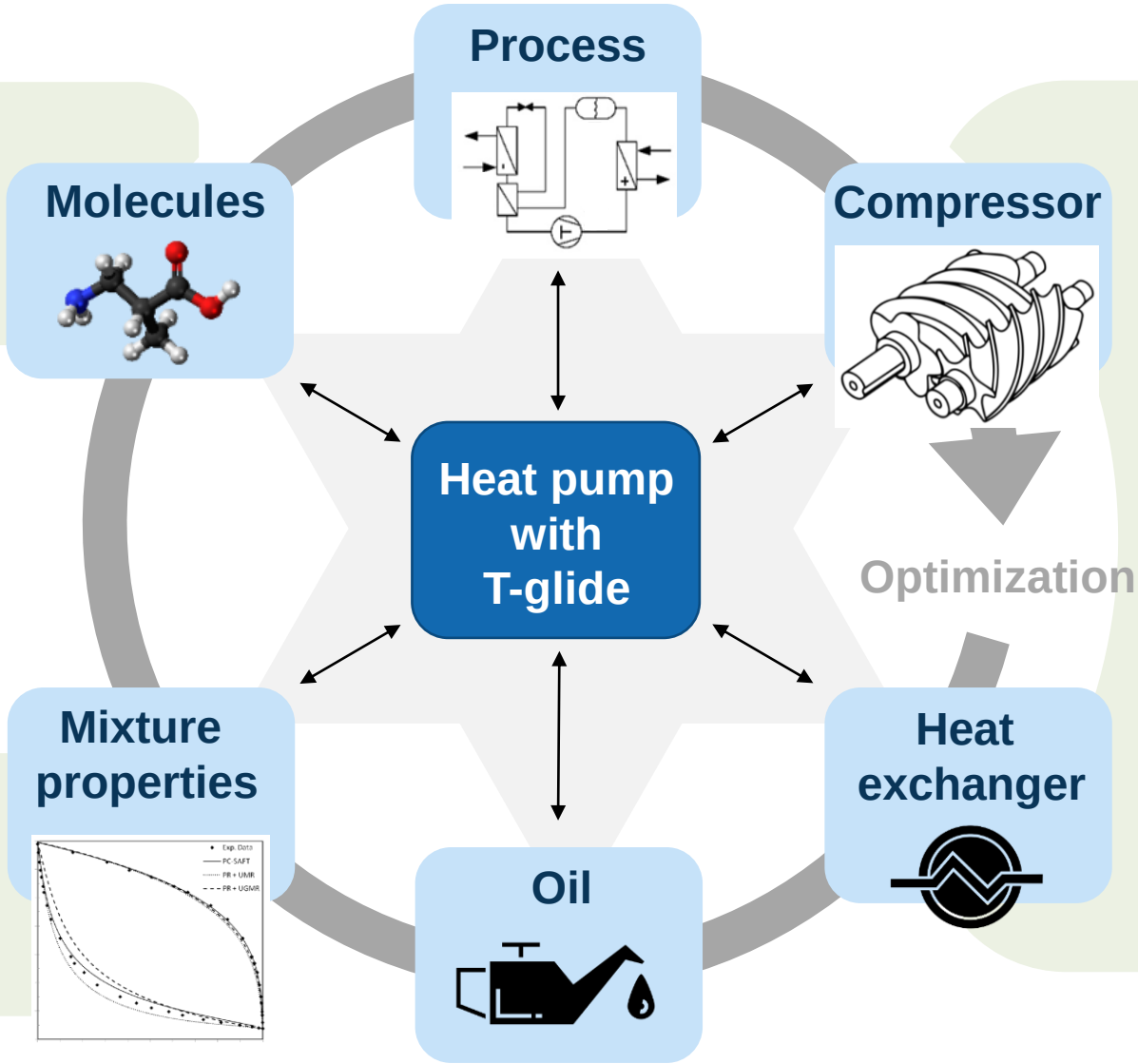
How to find the best molecules / mixtures?

CAS-registry: $265 \cdot 10^6$ registered substances

→ $350 \cdot 10^{14}$ potential mixtures

Mixture in heat pump with T-glide: Open issues

CAS-database:
- 265·**10⁶** molecules
- 351·**10¹⁴** potential mixtures



Process:
- **no** systematic **testing** of high-T heat pumps **yet**
- **no data** with T-glide

Equipment:
- fluid-dependent **models** do **not exist**
- **lack of experimental** data
- **behavior** with mixtures **unknown**

Practice:
- **no experience** with handling mixtures

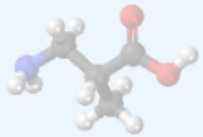
- Dortmund-database ≈100·**10³** VLE data sets
- Current **prediction** methods often **fail**

Mixture in heat pump with T-glide: Open issues

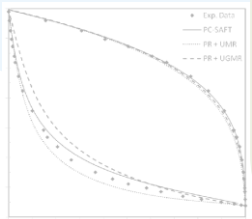
The molecular design space

ETH zürich

Molecules



Mixture properties



inverse problem / optimization

Objective function

Equipment design

Process design

Mixture properties

Mixture behavior

Pure properties

Molecule design

Molecule design

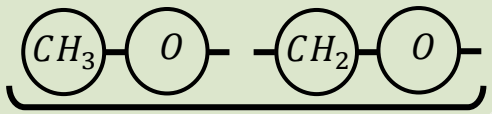
Case-studies
→ CapEx, OpEx

Compressor and heat exchanger models

Thermo-economic process model

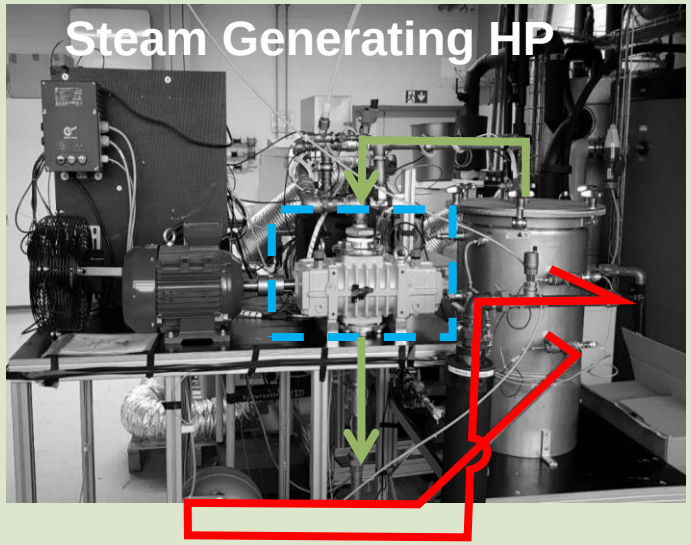
Interaction parameter prediction model

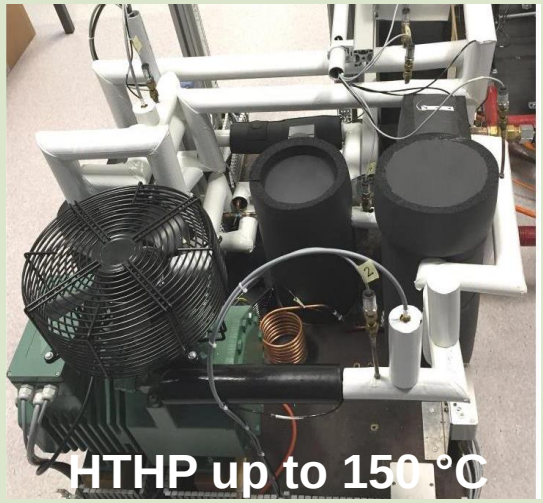
Molecular design

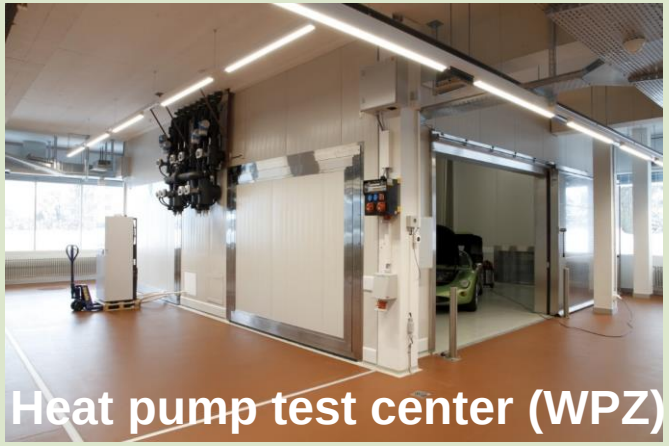


Mixture in heat pump with T-glide: Open issues

Domain know-how and infrastructure







The equipment design space

OST Ostschweizer Fachhochschule

ptimization

Heat
xchanger

Objectives and implementation

Bridging the gap between research and industry towards the faster market introduction of high-efficiency heat pumps with temperature glide

- Experimental demonstration of the benefits
- Clustering of most promising applications
- Providing a guide that maps suitable mixtures to applications
- Providing a guideline for handling in practice
- Establishing a Swiss competence center for industrial heat pumps

Image: Colourbox

Industrial advisory committee

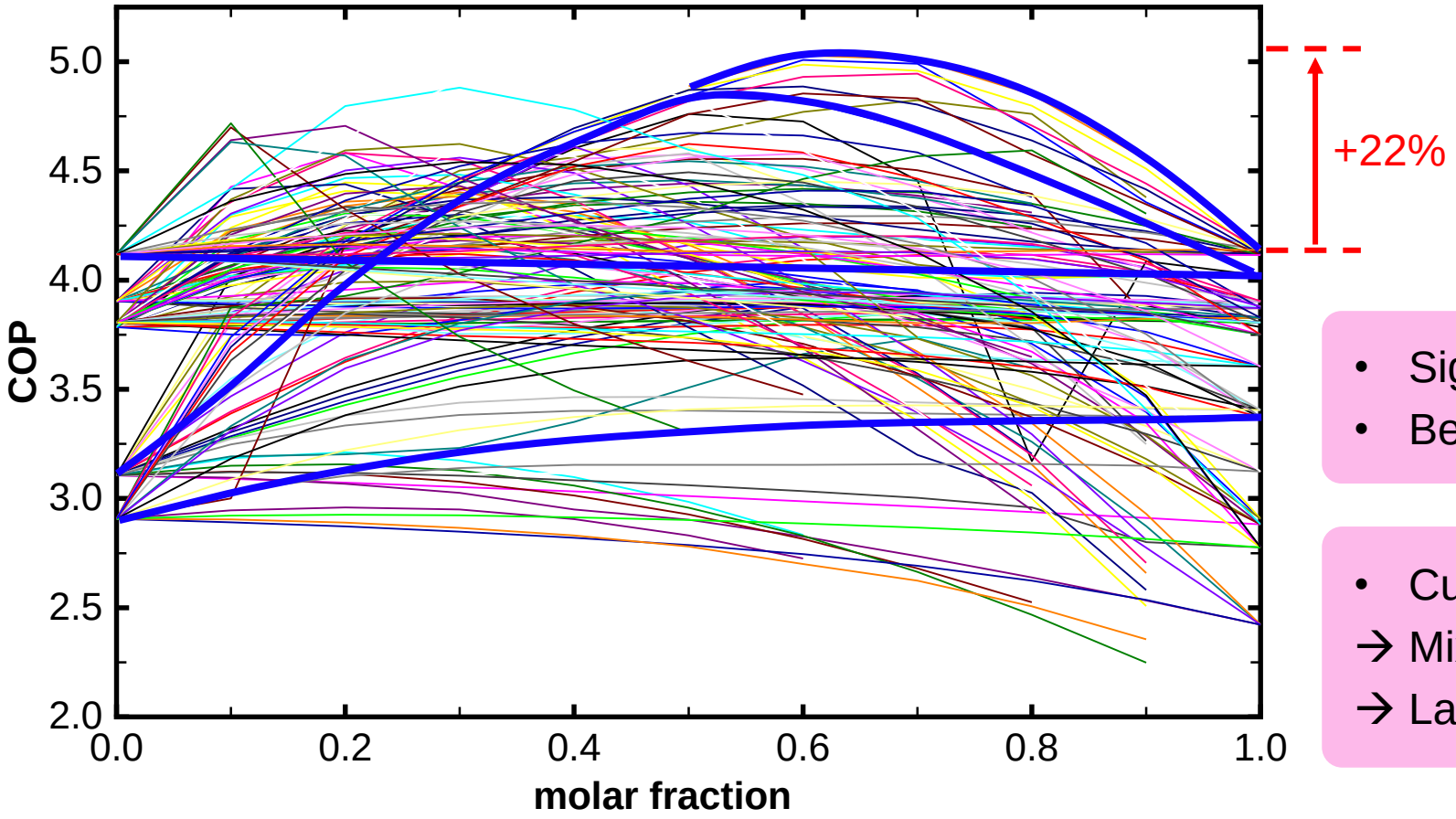
scheco
CTA
MAN Energy Solutions
Oekotherm AG für Energie- und Haustechnik
VIESSMANN
Lenum
YGNIS
FRIGO CONSULTING
Nestlé
DSM

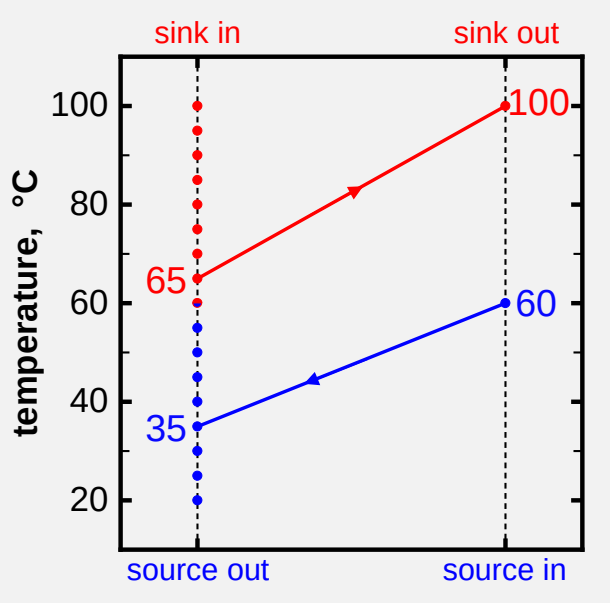
First model-based results

COPs as function of molar fraction

Heat source ΔT = 25 K

Heat sink ΔT = 35 K





- Significantly different COPs
- Best COPs (>4.1): Only mixtures

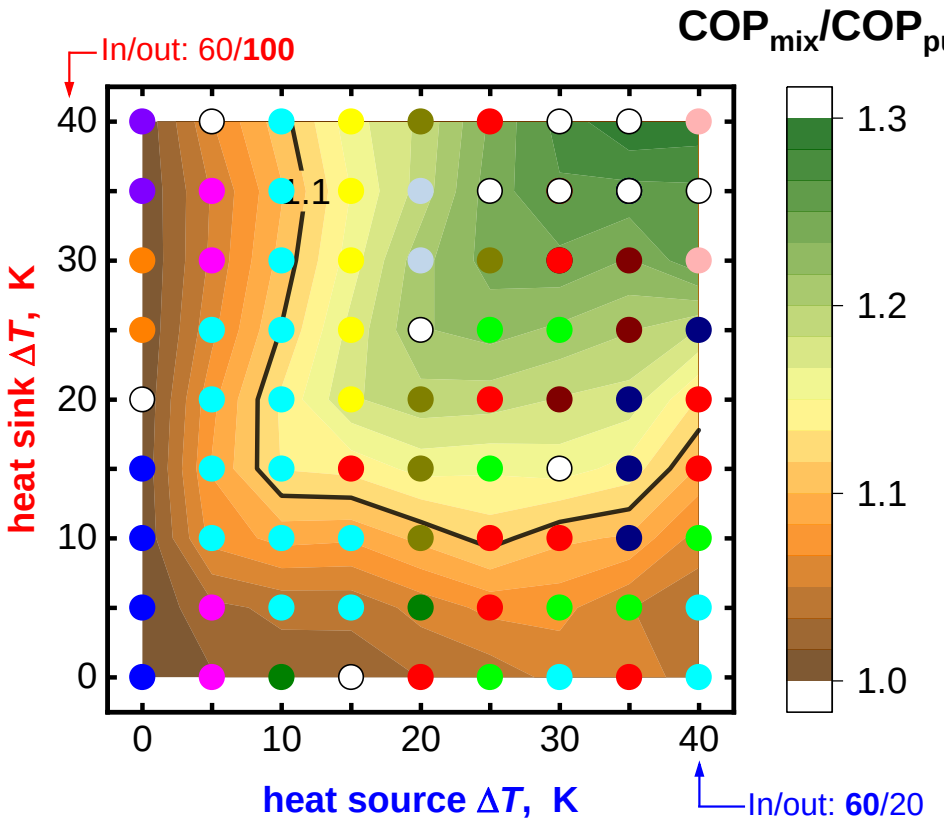
- Curves have different shapes

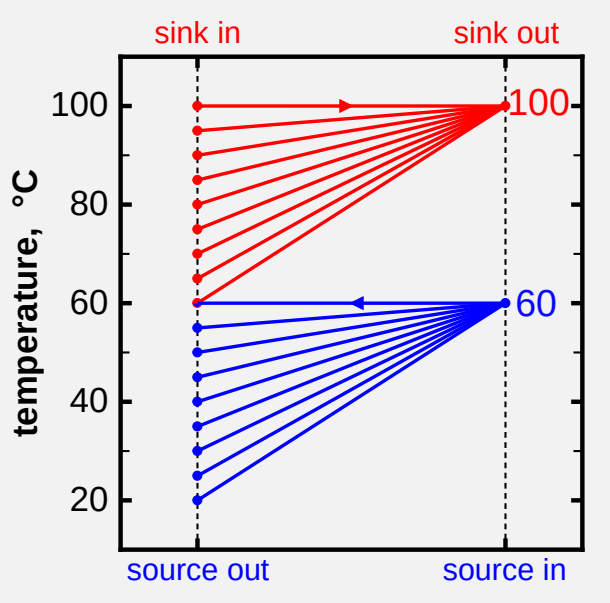
→ Mixtures should be selected thoroughly

→ Large design space needed

COP improvement of mixtures

Best mixture vs. best pure refrigerant





Mixtures are always beneficial or equally efficient

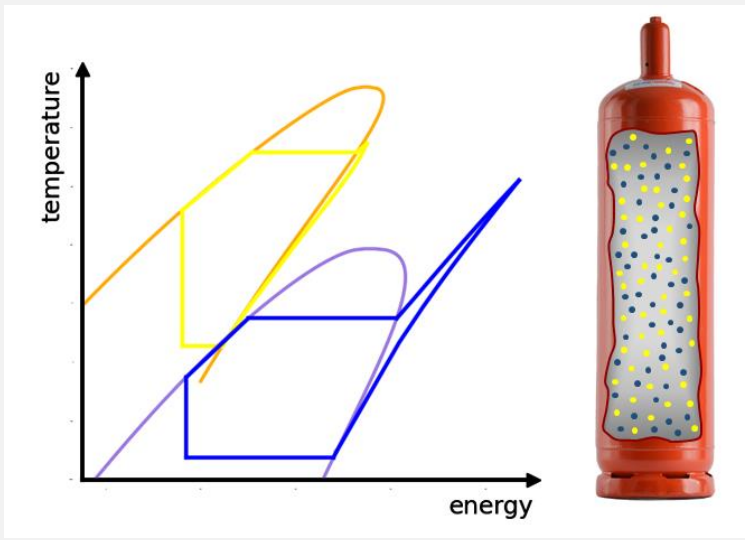
Maximum COP increase of 26%

→ At largest source and sink Δ*T*

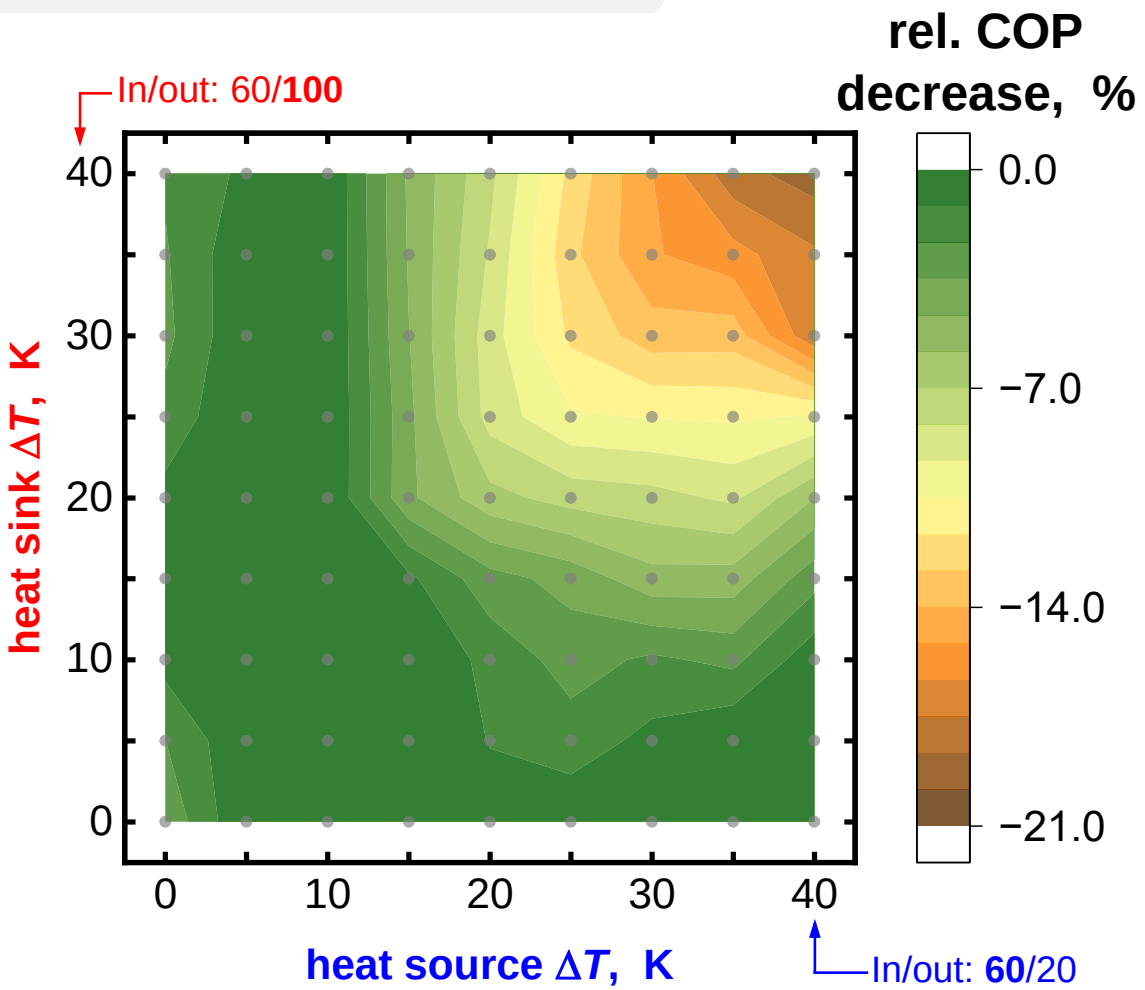
→ Larger Δ*T* → higher improvement expected

Optimal mixtures are highly specific to source and sink

Allrounder mixture vs. best mixture



1-Cyclobutene / Cyclopropane



- Only small COP decrease over a wide range (-4.6%)
- Higher COP decrease for high source and sink Δ*T*

One or two binary mixtures enable high efficiency for many applications

→ Tailoring only through composition change

→ Standardization → cost reduction

Pure refrigerants cannot offer this!

→ Allrounder pure refrigerant: -11.6%