ENGINEERING
TOMORROW

Next Generation Decarbonized Data Center

System Design

Future Data Summit

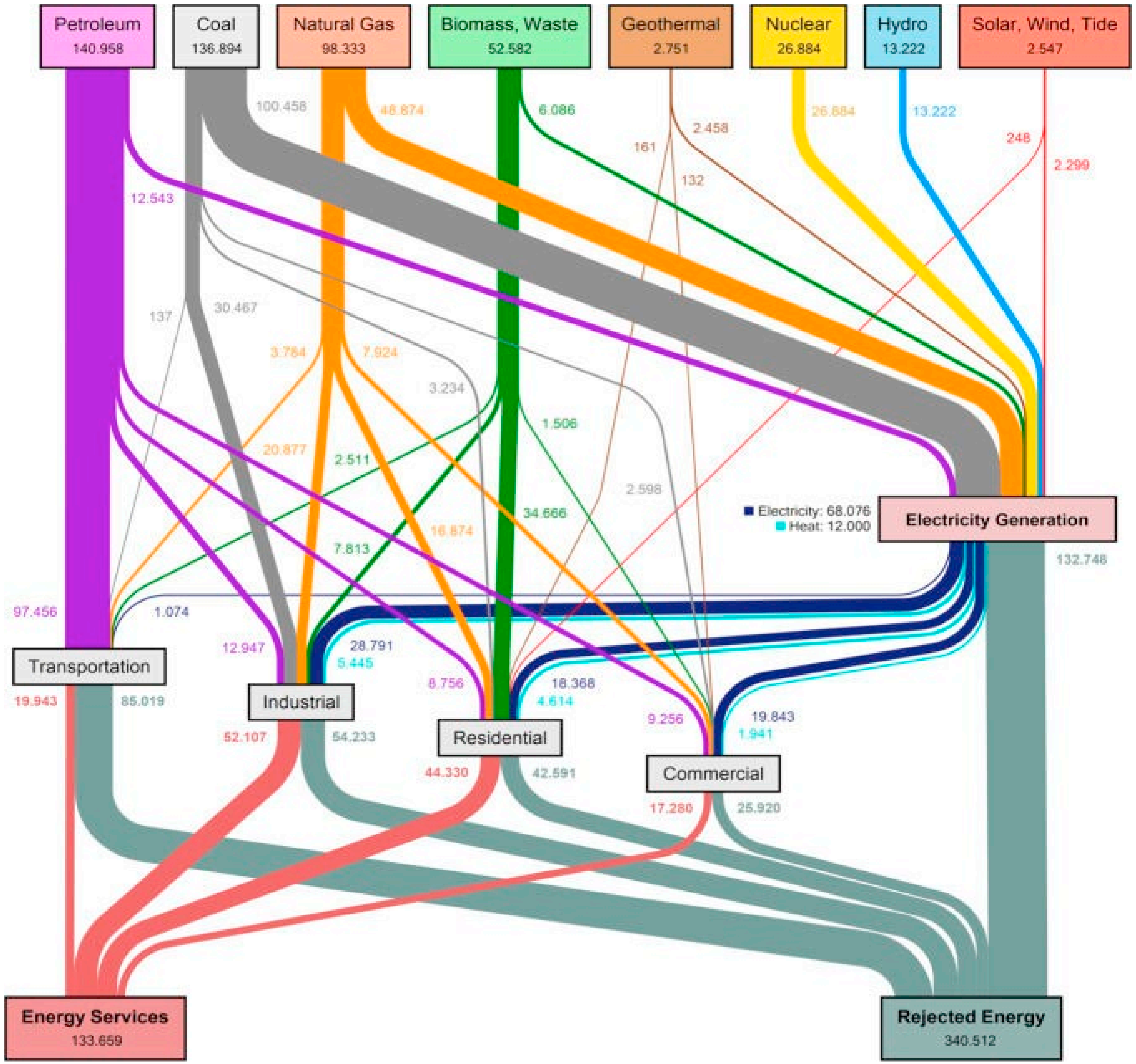
Danfoss Climate Solutions

The Excess Heat Opportunity

”72% of the global energy input (consumed primary energy carriers) is currently lost after conversion.

The future energy system will look radically different and use a lot less primary energy.

Such a system will be characterised by:
a) "electricity-only" renewables (mainly solar and wind),
b) electrification of many end uses that currently rely on burning fossil fuels,
c) reusing unavoidable waste heat,
d) much improved end-use efficiency
e) enhanced flexibility”



[Estimating the global waste heat potential - ScienceDirect]

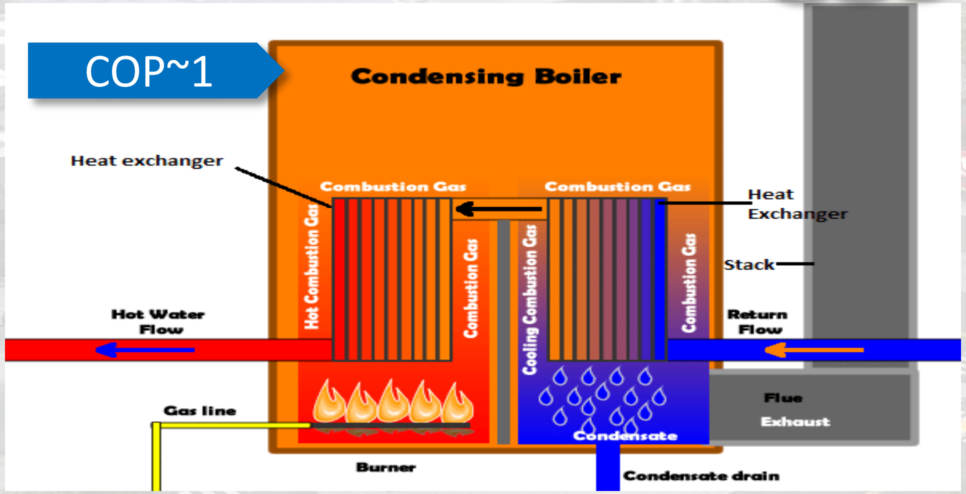
Why is the market focused on Heating Electrification
Efficiency & Decarbonization

Fossil fuels	Heat pumps

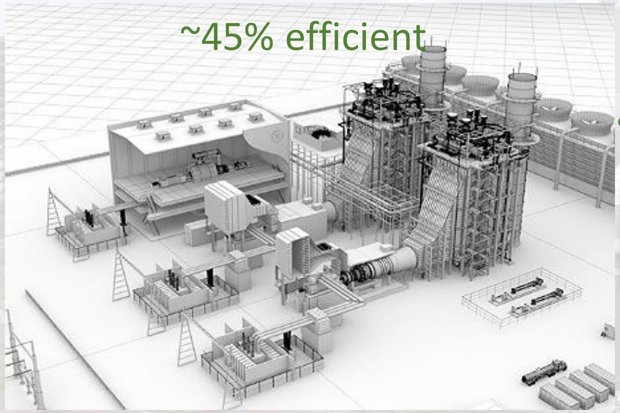
- Inefficient
- Drive CO_2 & other gas emissions impacting environment

CO_2 SO_2 NOx

COP~1



~45% efficient



Transmission & Distribution

-5 - 10%

COP~2.5-3.5

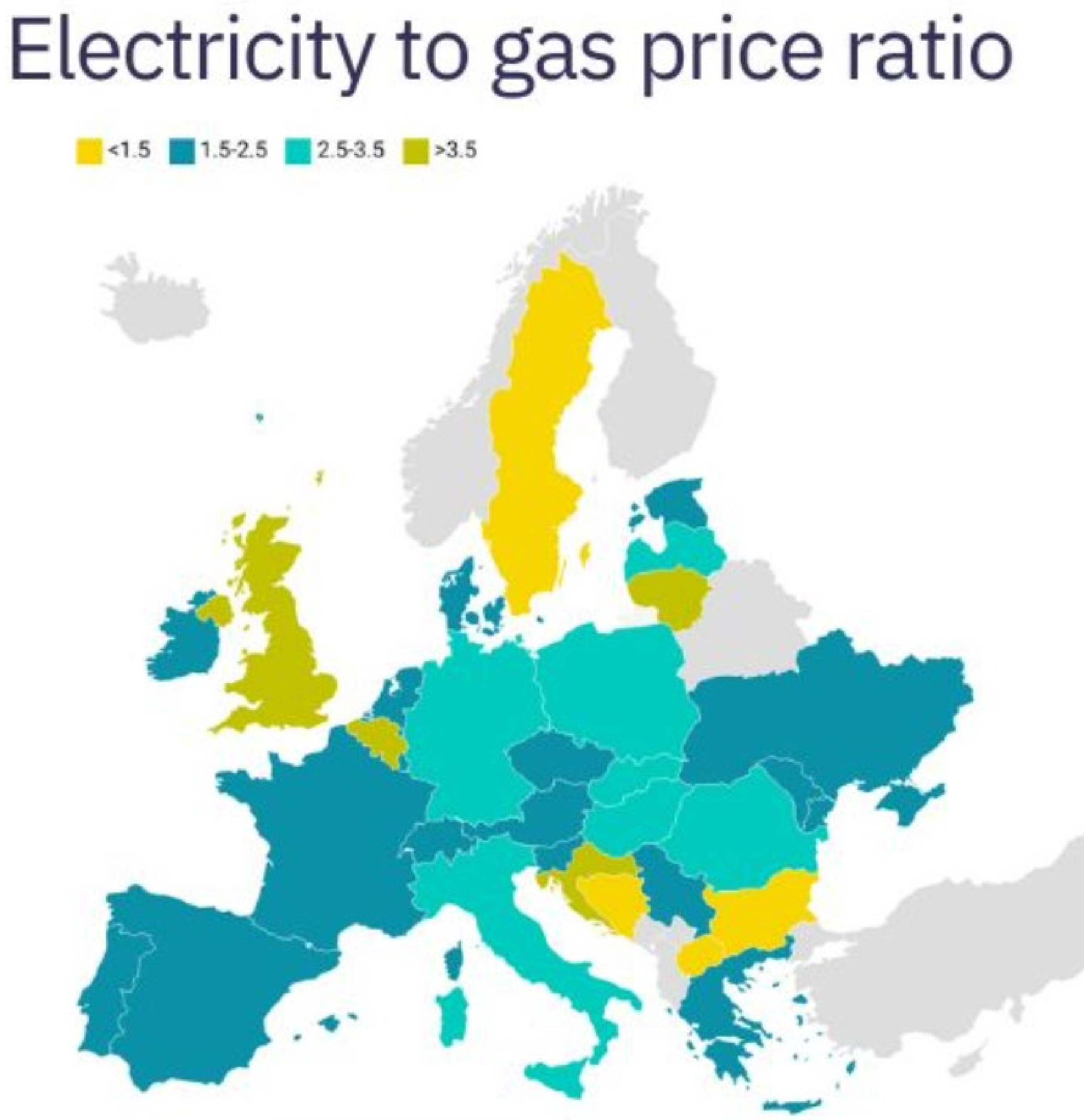
~35% operating cost reduction
~60% emissions reduction

- More efficient
- Efficiency increases at part-load/lift
- Goal is to ***exceed spark spread***

Heat Pump
Part Load
Efficiency

Spark Spread –

EUR 1st Half 2023



- Electrification COP > spark spread = payback
- Ratio driven by both electricity and gas cost
- Wide variation by country
- Variation also in real-time vs average

(3) European Heat Pump Association: Overview | LinkedIn

Sector coupling is the process of optimizing the combination of at least two different sectors of energy demand and production

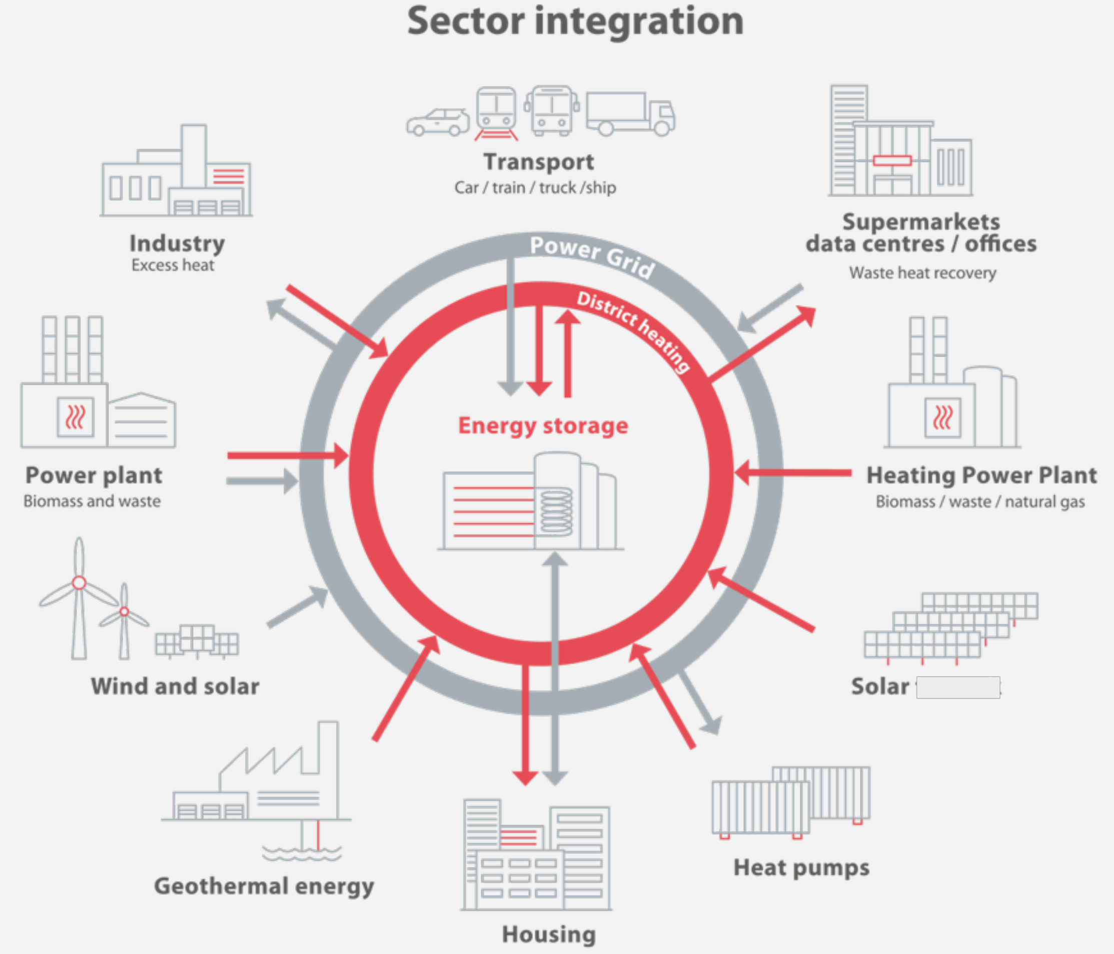
- Can happen on a small scale through urban planning, or it can happen on a larger scale through district energy networks.

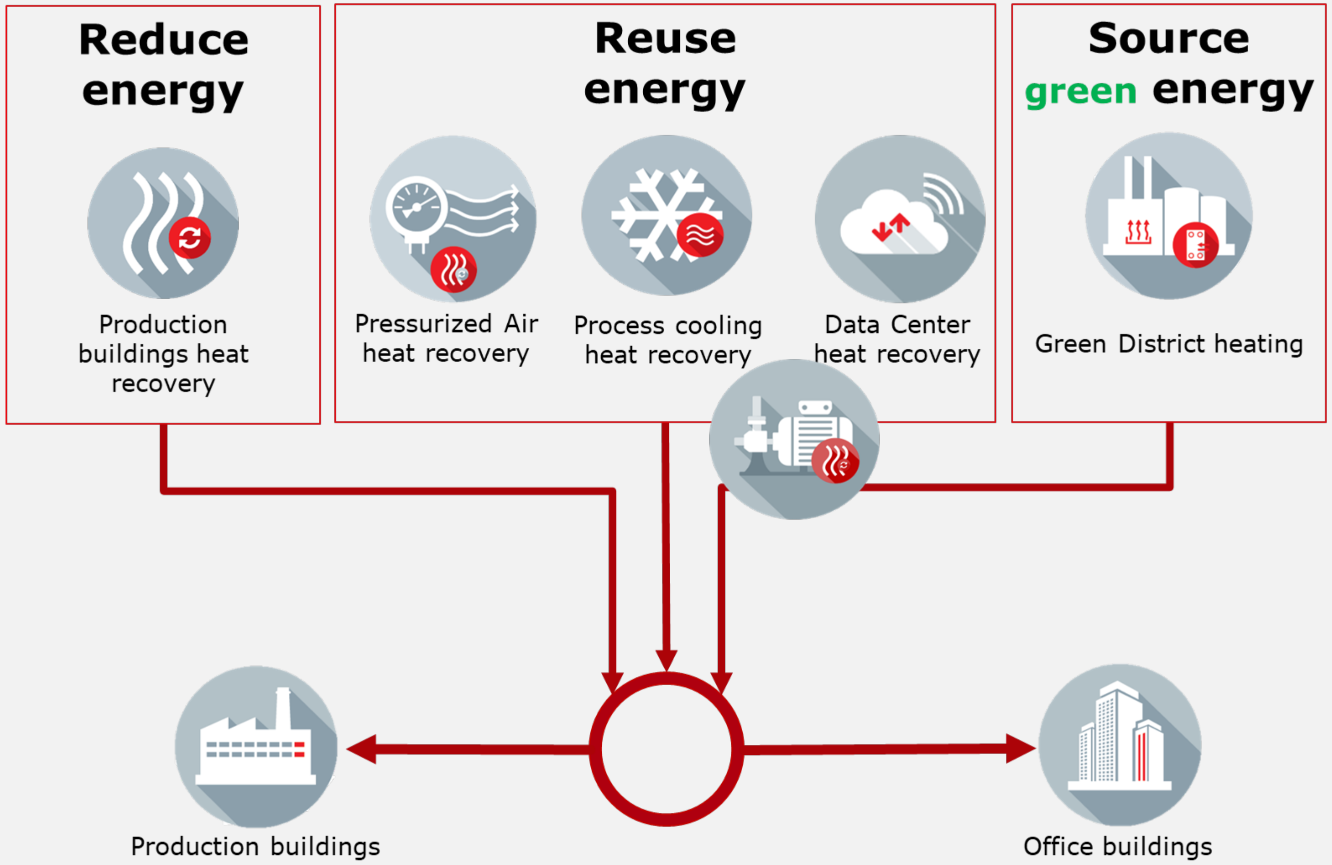
- Large synergies can occur when a producer of excess heat, for instance a data center, is located close to entities that can buy and use large amounts of the excess heat (e.g. horticulture).

- Smart urban planning should consider these synergies between energy producers and users in, for example, industrial clusters. Smart urban planning and sector integration play a vital role in decarbonizing our energy system.

Sector Coupling

Holistic Approach to Efficiency and Decarbonization via Integrated Systems

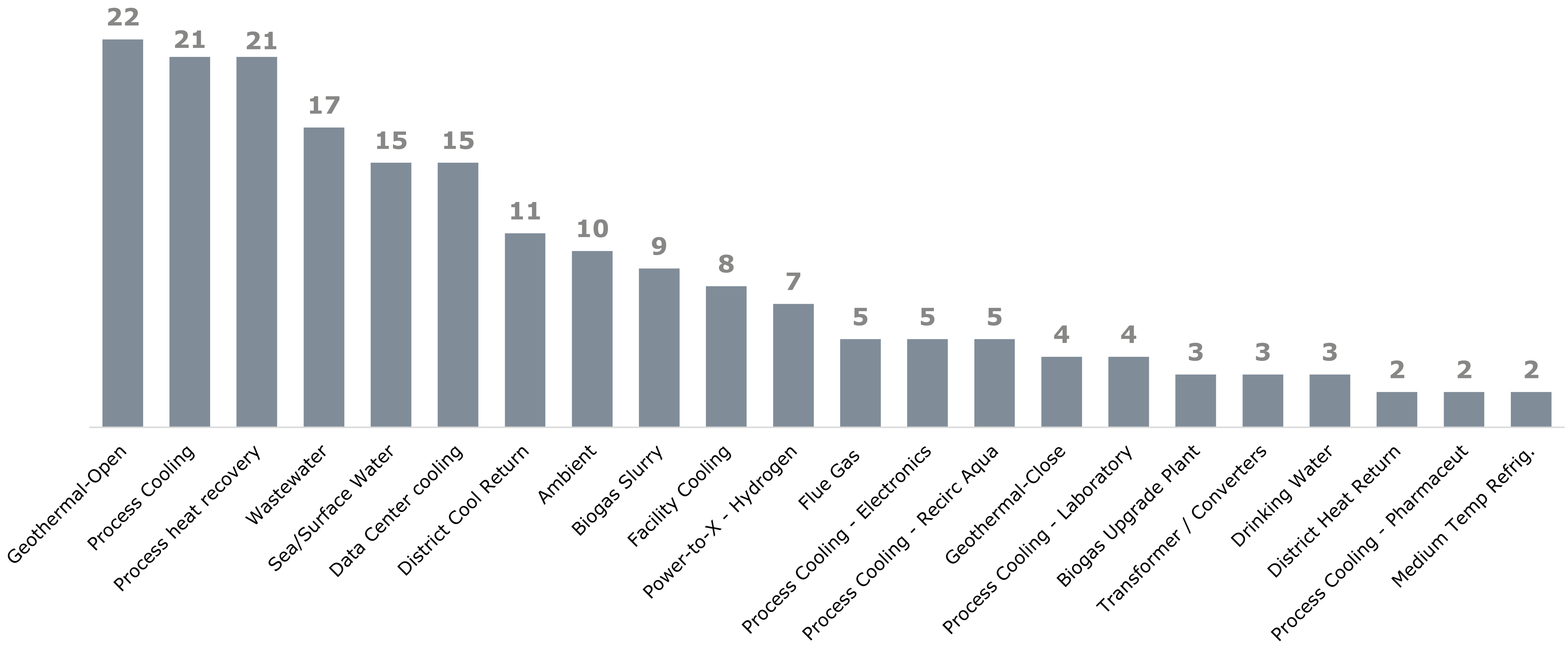




Source, Heat Pump and Demand Analysis

Heat Sources - Projects

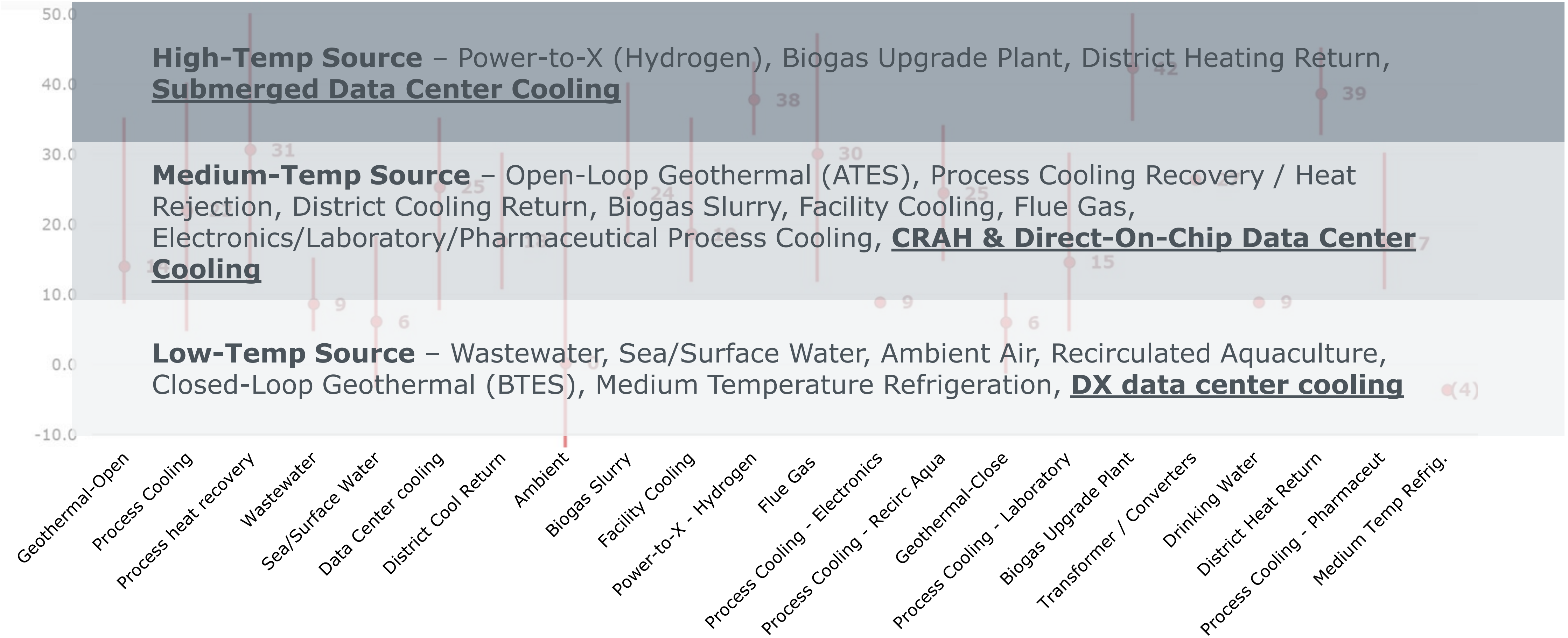
Opportunities by Heat Source (# of projects)



Source, Heat Pump and Demand Analysis

Heat Sources - Quality Grouping

Source Temperature Average/Range



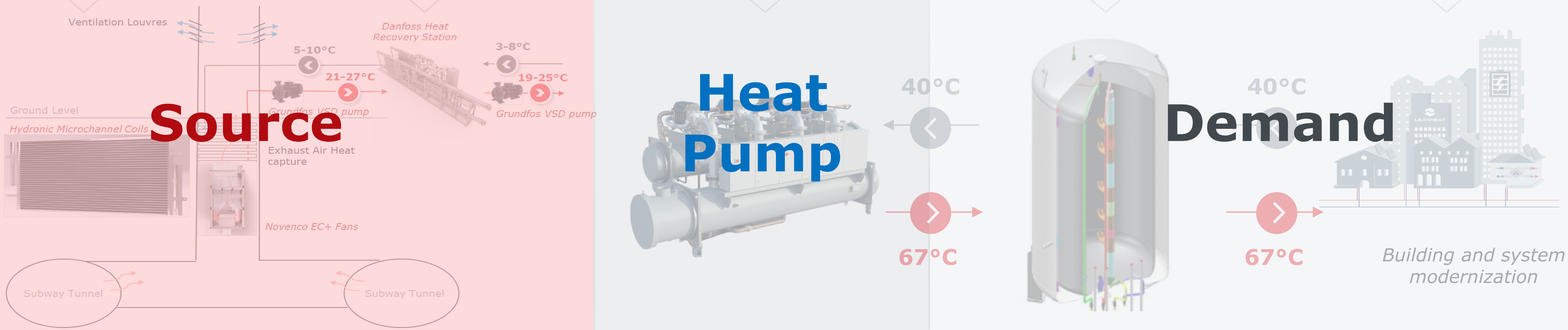
High-Temp Source – Power-to-X (Hydrogen), Biogas Upgrade Plant, District Heating Return, **Submerged Data Center Cooling**

Medium-Temp Source – Open-Loop Geothermal (ATES), Process Cooling Recovery / Heat Rejection, District Cooling Return, Biogas Slurry, Facility Cooling, Flue Gas, Electronics/Laboratory/Pharmaceutical Process Cooling, **CRAH & Direct-On-Chip Data Center Cooling**

Low-Temp Source – Wastewater, Sea/Surface Water, Ambient Air, Recirculated Aquaculture, Closed-Loop Geothermal (BTES), Medium Temperature Refrigeration, **DX data center cooling**

System Design Example – Subway Recovered to District Energy

Heat Recovery	Recovery Loop	Heat Pump	Heat Storage	District Energy
Airside Hydronic Microchannel	**Danfoss Hydronic Station**	**Oil-Free Turbo**	**Accumulator Tank**	**4th Generation DH**



Source

Heat Pump

Demand

(Multiple potential)
Low, medium and high-temp

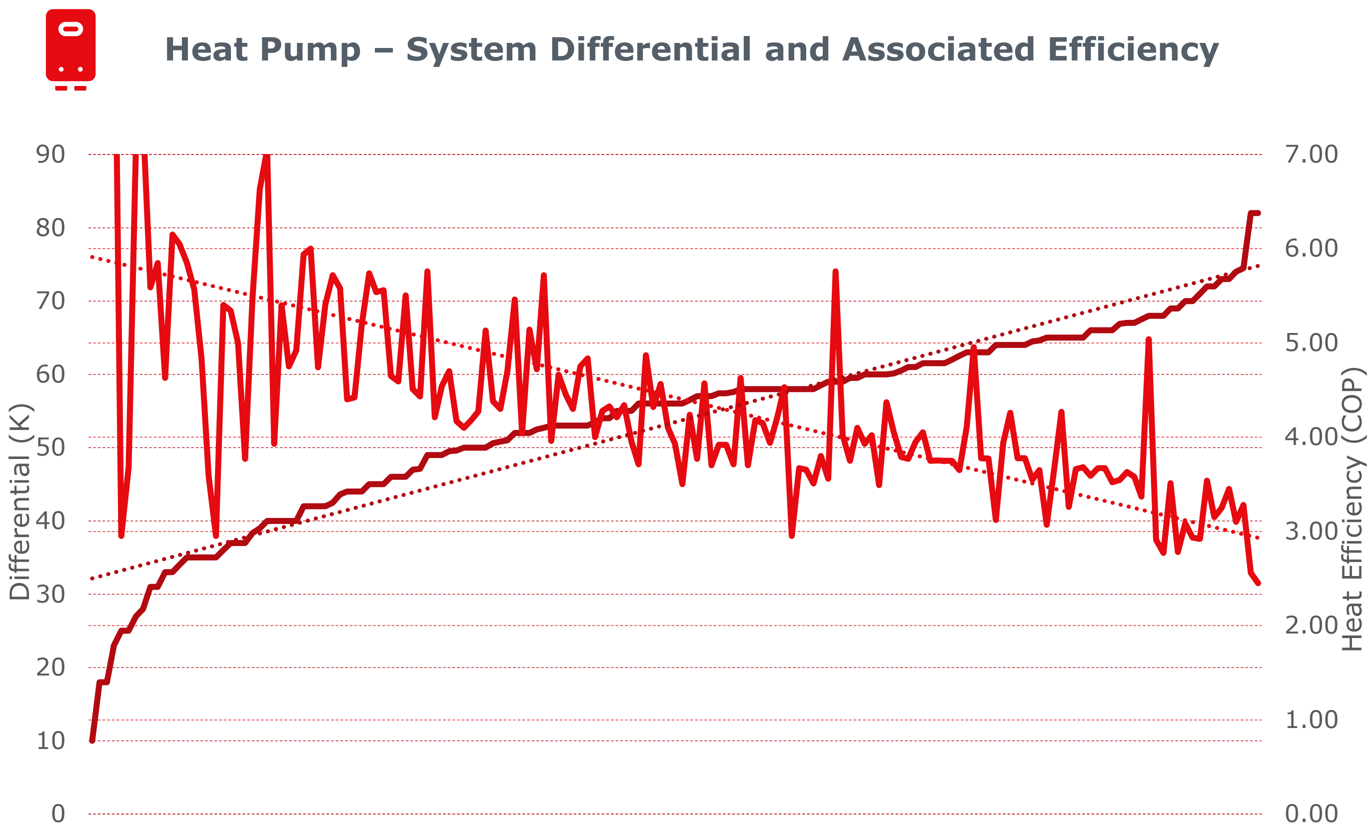
Various compression technologies

(Multiple potential)
Low, medium and high-temp

Sector Coupling
Efficiency & Electrical Load are Critical

- Range of heat source to heat supply differential (K)
- Corresponding heat pump system efficiency (COP)
- 0.3-60MW+ systems

1K differential = **2% heat pump efficiency** = **2% Electrical load**



Source, Heat Pump and Demand Analysis

Variations

Source

High temp (>45C) –

- Power-to-X (hydrogen)
- Biogas upgrade plant
- District heating return
- Very High Temp. Air process
- **Data center cooling - Immersion**

Medium temp (20-45C) –

- Open loop geothermal
- Hydronic process cooling
- Hydronic process rejection
- **Data center cooling – Direct-on-chip**
- **Data center cooling - CRAH**
- Facility cooling
- Biogas slurry
- High Temp. Air process
- Subway exhaust recovery

Low temp (<20C) –

- **Data center cooling - DX**
- Wastewater
- Seawater
- Recirc. Aqua.
- Med. Temp. Air process
- Medium temperature refrigeration

Heat Pump / Station

- Industrial High-Temp
- High Lift Heat Pump
- Medium Lift Heat Pump
- Low Lift Heat Pump

- Heat Recovery Station – Industrial Heat Pump
- Heat Recovery Station – High Lift Heat Pump
- Heat Recovery Station – Medium Lift Heat Pump
- Heat Recovery Station – Low Lift Heat Pump
- Heat Recovery Station - Standalone

Demand / Heat User

High temp (>80C) –

- F&B pasteurization
- F&B cooking
- Process hot water
- 3rd gen District Heat
- Power-to-X
- High Temp Drying

Medium temp (50-80C) –

- 4th gen District Heat
- Fan coil / AHU
- Radiator
- Domestic water
- Boiler feedwater
- Process wash water
- Process pre-heat
- Med temp drying
- Fresh water generation

Low temp (<50C) –

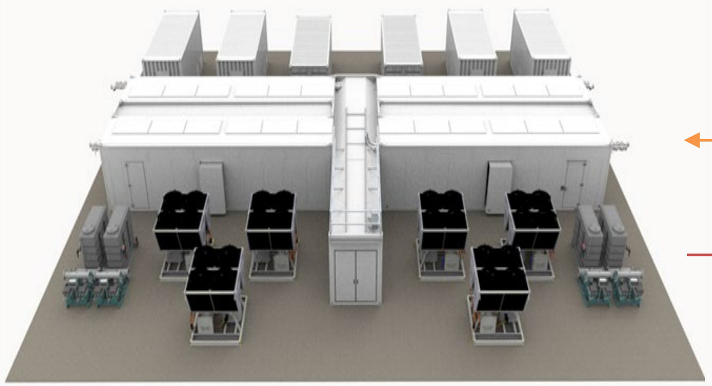
- Greenhouse
- Underfloor heating
- 5th gen District Heat

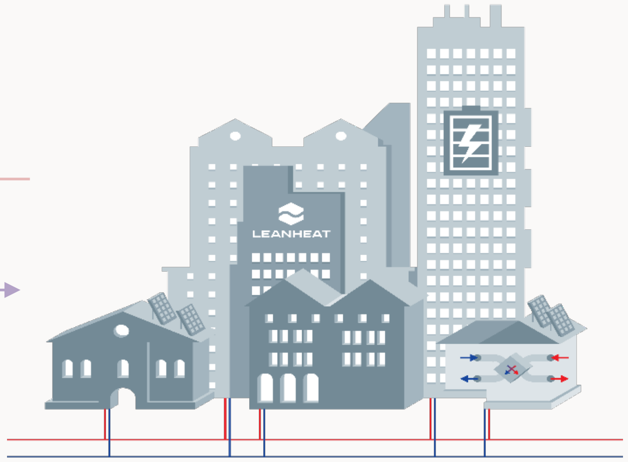
DC - Brewery
DC - Brewery
DC – District Energy
DC – District Energy
DC - Greenhouse
DC - Greenhouse

Sector Coupling Retrofit Options

Baseline - Data Center Cooling / Heat Recovery

Data Center	Heat Pump	District Energy
Chilled Water / Air Cooling	*Centrifugal Water-Water*	*4th Generation Heating*





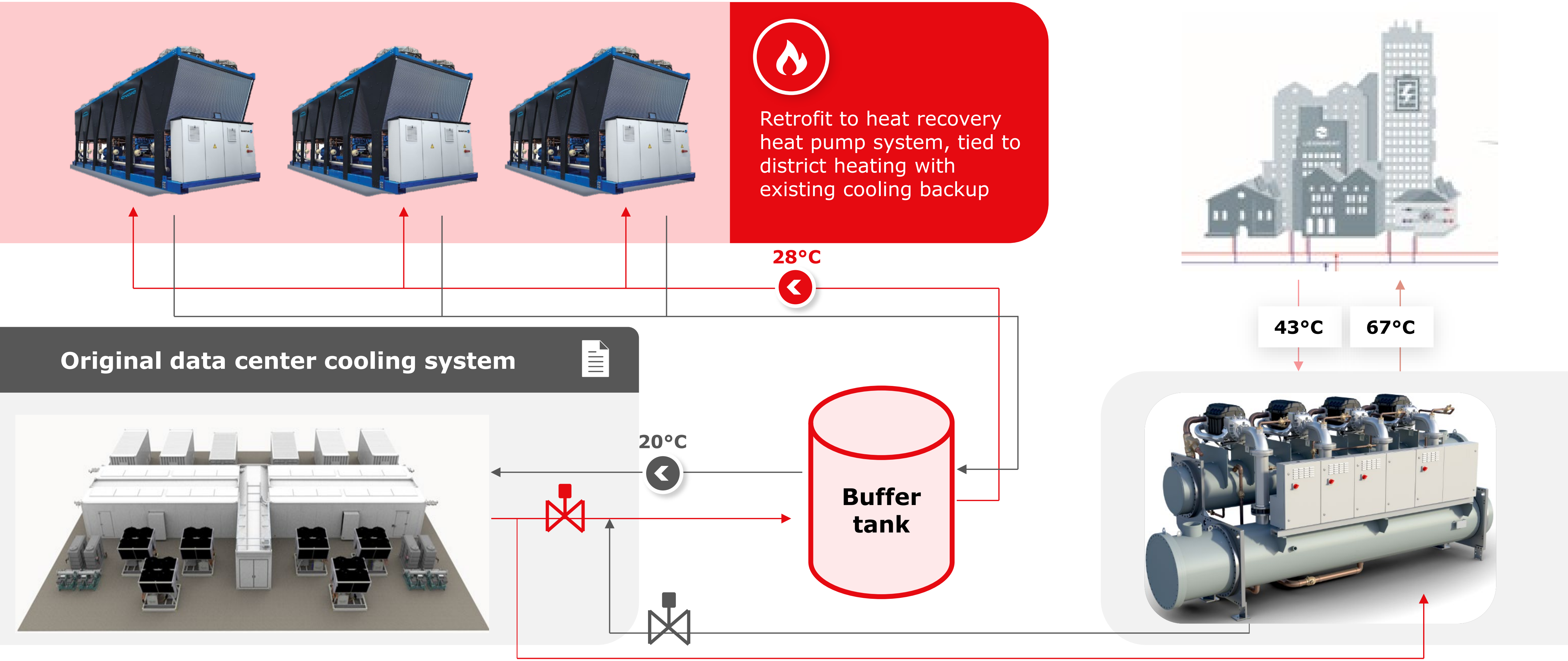
4.0 COP Cooling

250k€/MW Heat

5.0 COP Heating

Retrofit Data Center with Water-Water Heat Pumps

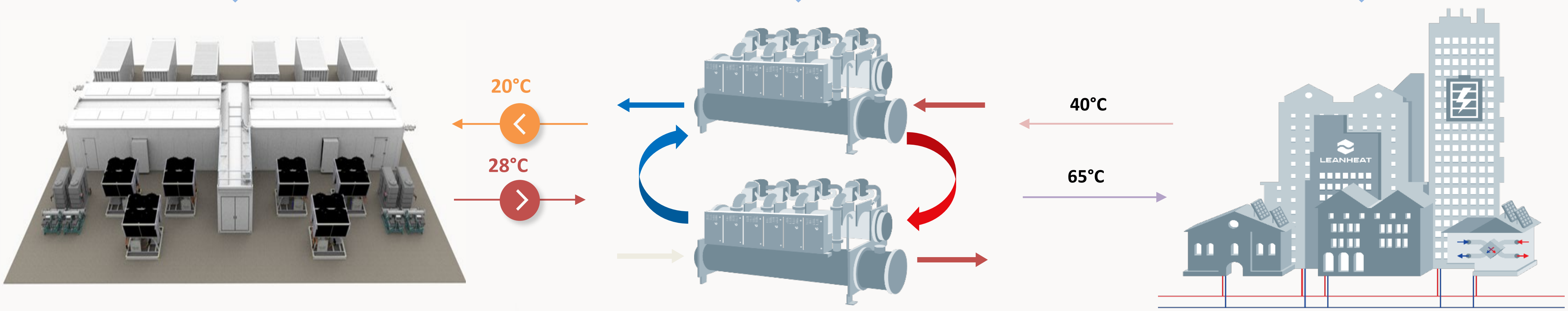
Danfoss data center cooling & heat recovery system digital twin



Sector Integration Retrofit Options

Lower Heat Demand Return Temps Enable Higher Heat Pump Efficiency

Data Center	Heat Pump	District Energy
Chilled Water / Air Cooling	*Centrifugal Series-Series Water-Water*	*4th Generation Heating* *Lower Return Temp*



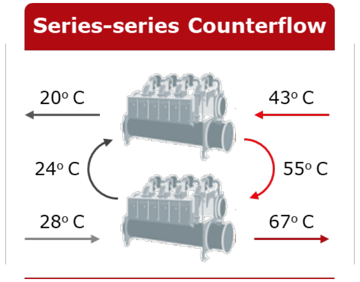
4.8 COP
Cooling

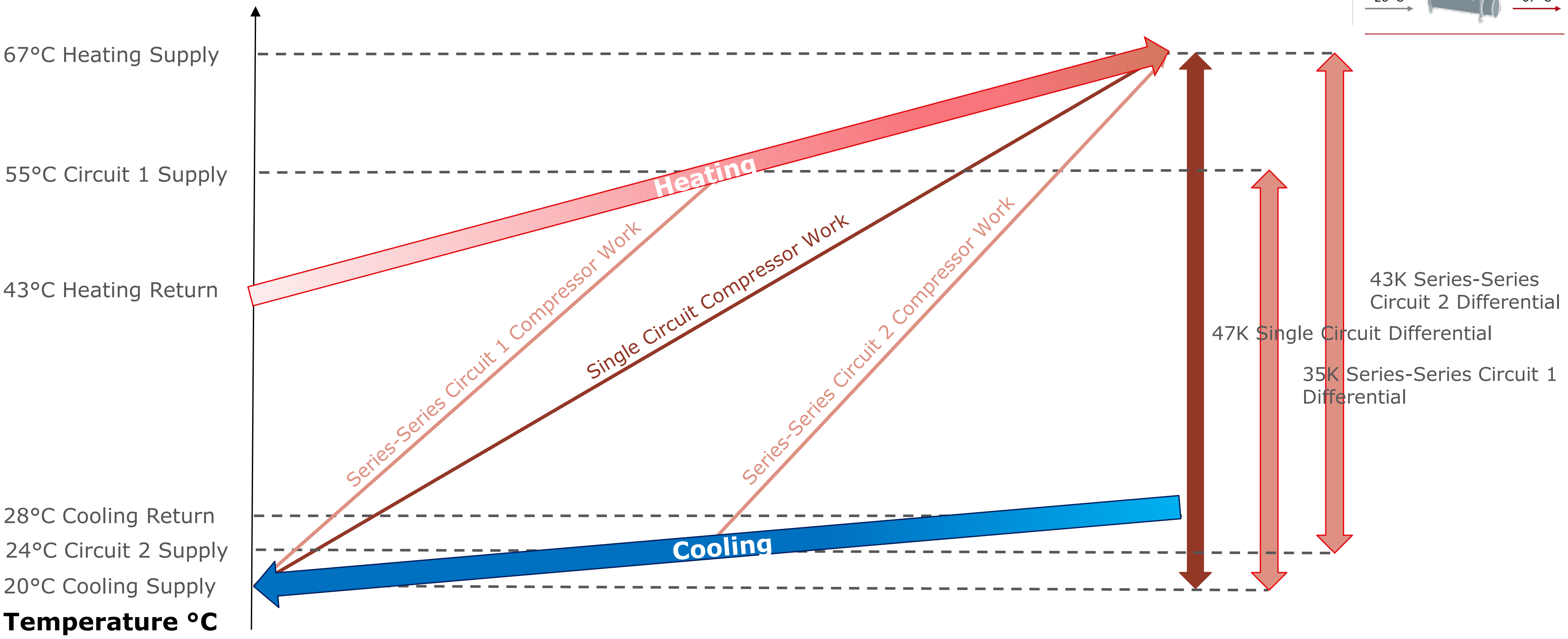
- Lower return temp from variable flow, 2-way PICV and AI control software optimization
- In-turn allows series-series counterflow heat pump - 20% efficiency increase

5.8 COP Heating

Performance

Why Is Series-Series Counterflow More Efficient?



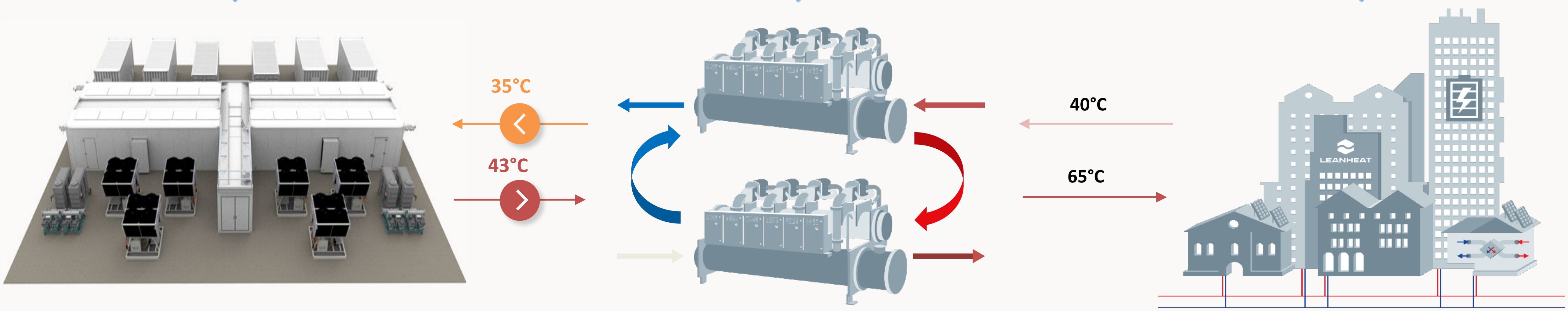


Dividing system into two circuits lowers work and increases efficiency (18% in this case)

Sector Coupling Retrofit Options

Liquid Cooling / Higher Source Temps Allows Max Efficiency

Data Center	Heat Pump	District Energy
Liquid / On-Chip Cooling	*Centrifugal Series-Series Water-Water*	*4th Generation Heating*



6.2 COP
Cooling

15K
differential
decrease

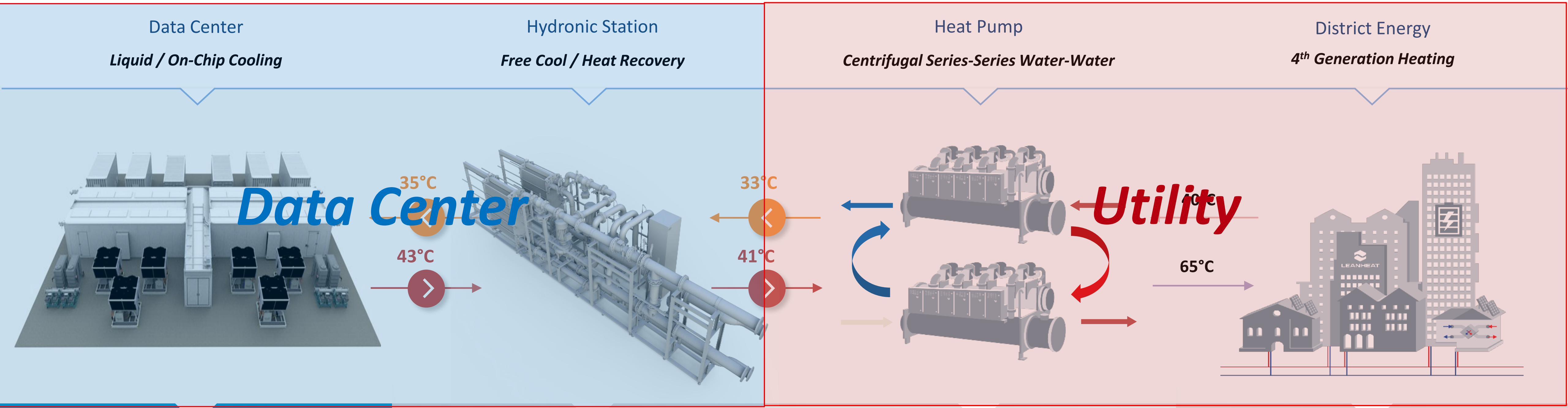
=

30%
efficiency
increase

7.2 COP Heating

Sector Coupling Retrofit Options

Data Center Free Cooling / Heat Reuse – Business Model



Free Cooling

~20 COP

- Data center heat station enables free cooling / heat recovery at 40% heat pump applied cost with minor system heat efficiency impact
- Cooling power limited to supply pumps, driven by recovered heat
- Scenario suited for different data center cooling and heating ownership model

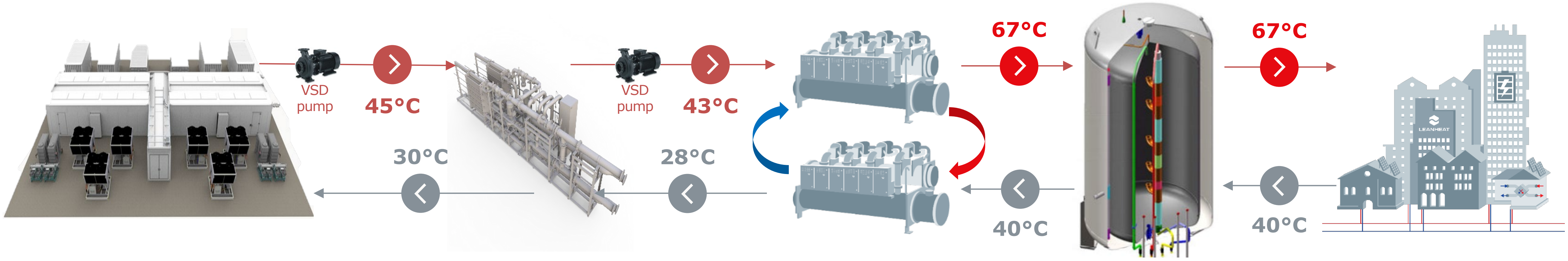
7.0 COP Heating

Source, Heat Pump and Demand Analysis

Source Variation – Data Center

39K Differential = 6.8 COP

Heat Recovery	Recovery Loop	Heat Pump	Heat Storage	District Energy
Treated Wastewater	**Danfoss Station**	**Oil-Free Turbo**	**Accumulator Tank**	**4th Generation DH**

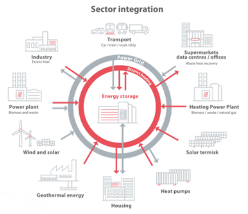


- Data Center direct-on-chip liquid cooling
- Recovered heat to custom hydronic station
- Custom Station data center cooling system isolation
- Supplied to evaporator loop of water-water heat pump

- Centrifugal series-series counterflow heat pump
- Boosting recovered heat directed from custom station
- Boosted to loop for heat accumulator tank

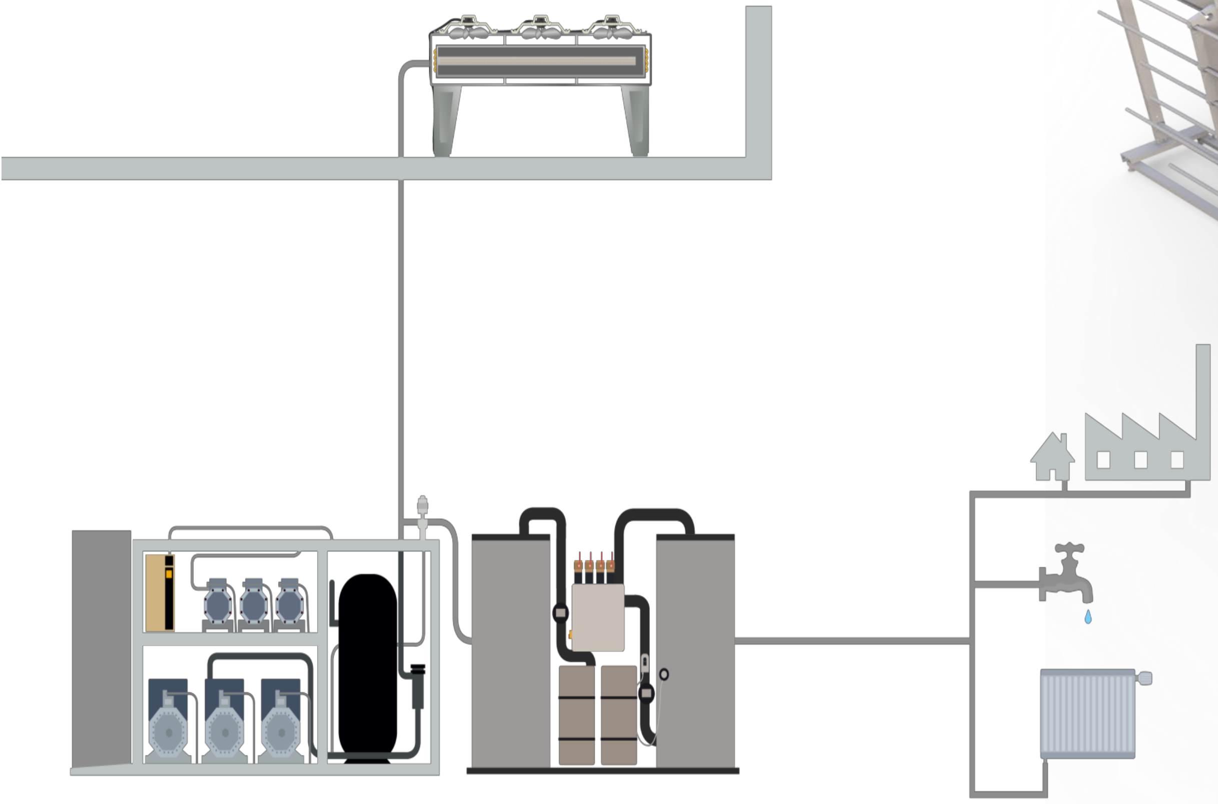
- Heat accumulator tank to store heat at temperature supplied by heat pump
- Storage to district energy per demand / loading
- Supplied to existing district heating network

Heat Recovery Stations – What is It?



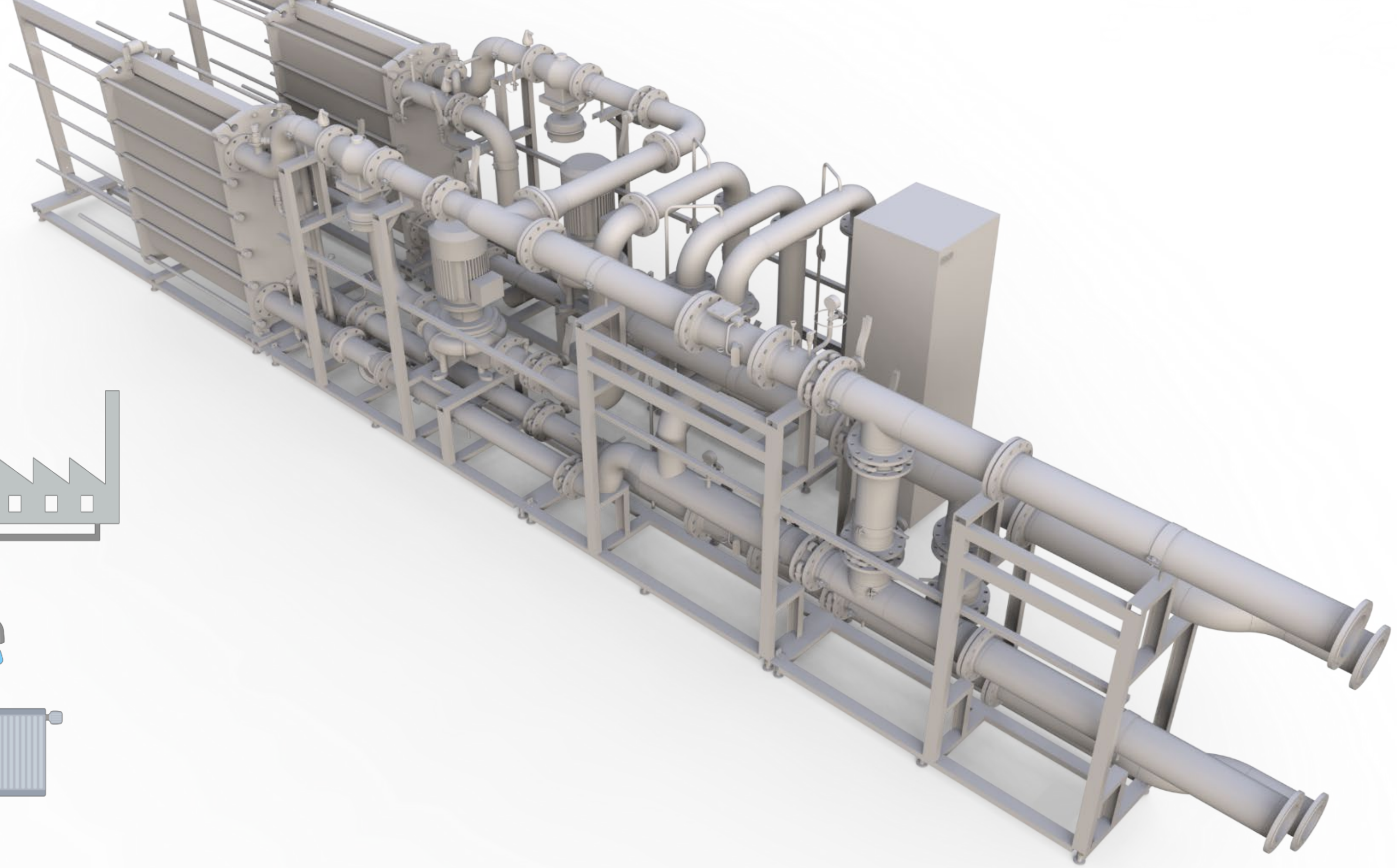
Small-Scale

Refrigeration (~500kW)



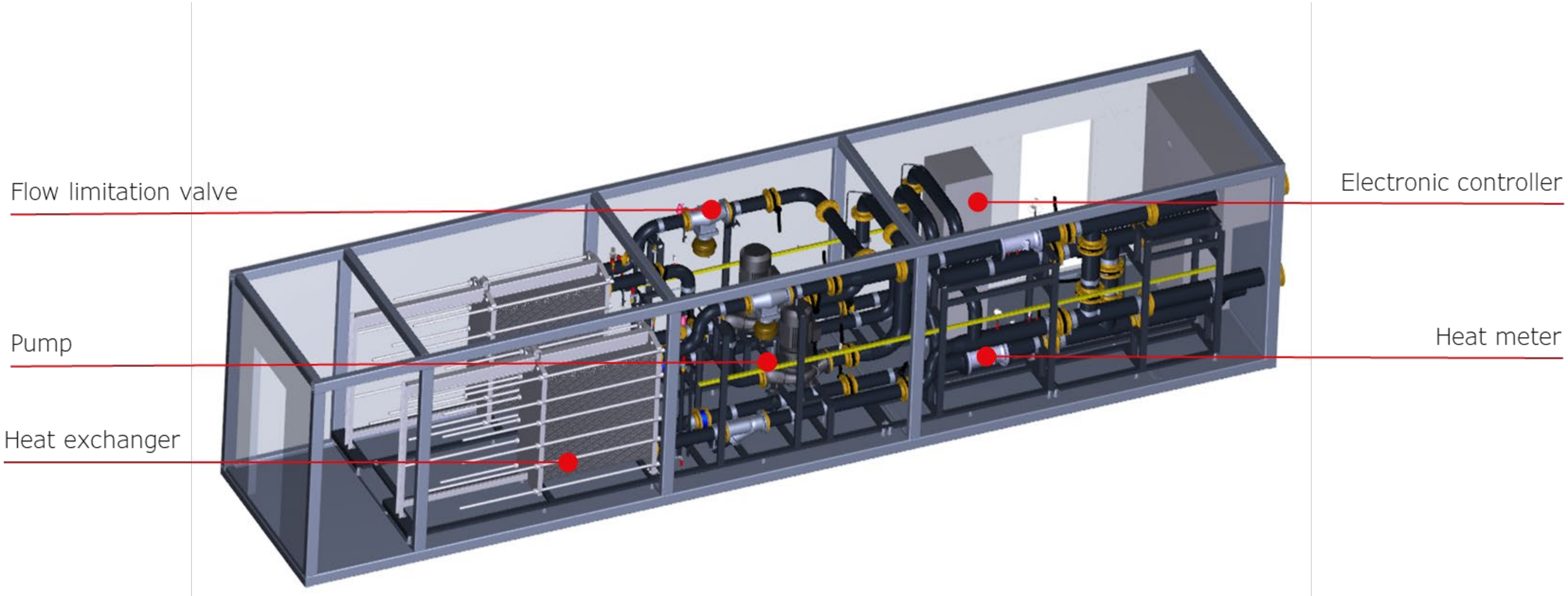
Large-Scale

Data Center, etc (~5MW)



Sector Coupling Retrofits

Heat Recovery Stations – Large Scale

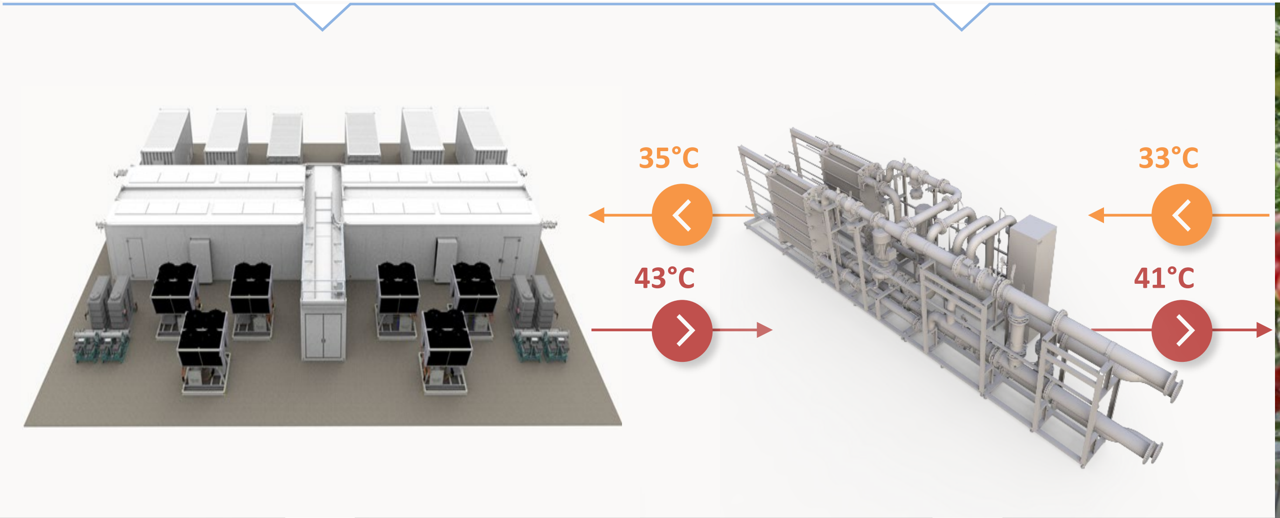


Heat Recovery Station

Sector Integration Retrofit Options

Data Center Free Cooling / Food Production Heat Reuse

Data Center	Hydronic Station	Greenhouse Farming	Indoor Fish Farms
Liquid / On-Chip Cooling	***Free Cool / Heat Recovery***	***Supply Air Heat***	***Supply Water Heat***



Free Cooling

~20 COP

- Greenhouse farms and indoor horticulture as potential heat recovery customers, collocated with data center
- Symbiotic efficiency relationship with data center - Directly use available heat without heat pump boost

Free Heating

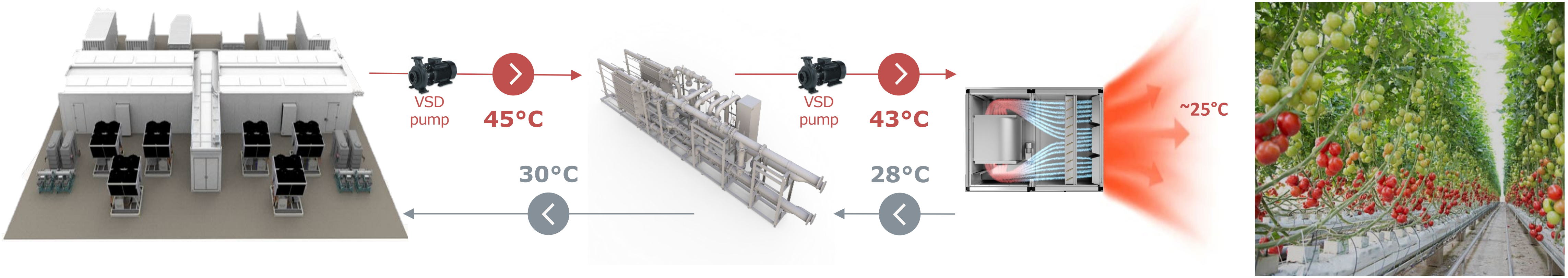
~20 COP

Source, Heat Pump and Demand Analysis

Source Variation - Greenhouse

Negative Differential = 20+ COP

Heat Recovery	Recovery Loop	Air-Handlers	Greenhouse Farming
Liquid Cooled Data Center	**Custom Hydronic Station**	**Pressurization Fans**	**Supply Air Heat**



- Data Center direct-on-chip liquid cooling
- Supplied direct to custom station with no heat pump boost – True symbiosis system
- Data center cooling backup air-cooled chillers or dry cooler heat rejection (when not recovered)

- Recovered heat to custom hydronic station
- Custom Station data center cooling system isolation

- Recovered heat supplied to air-handler for heating of outdoor air
- Heated outdoor air supplied to greenhouse to maintain year -around optimal growing temperature

Source, Heat Pump and Demand Analysis
Heat Pump and Demand Variation – Brewery

57K Differential = 4.7 COP

Heat Recovery	Recovery Loop	Heat Pump	Heat Storage	Brewery
Liquid Cooled Data Center	**Custom Hydronic Station**	**Piston-Based**	**Accumulator Tank**	**Ferment./Pasteur.**

- Data Center direct-on-chip liquid cooling
- Recovered heat to custom hydronic station
- Custom Station data center cooling system isolation
- Supplied to evaporator loop of water-water heat pump

- Piston-based water-water heat pump
- Boosting recovered heat directed from hydronic station
- Boosted to loop for heat accumulator tank

- Heat accumulator tank to store heat at temperature supplied by heat pump
- Storage to brewery fermentation and pasteurization per demand

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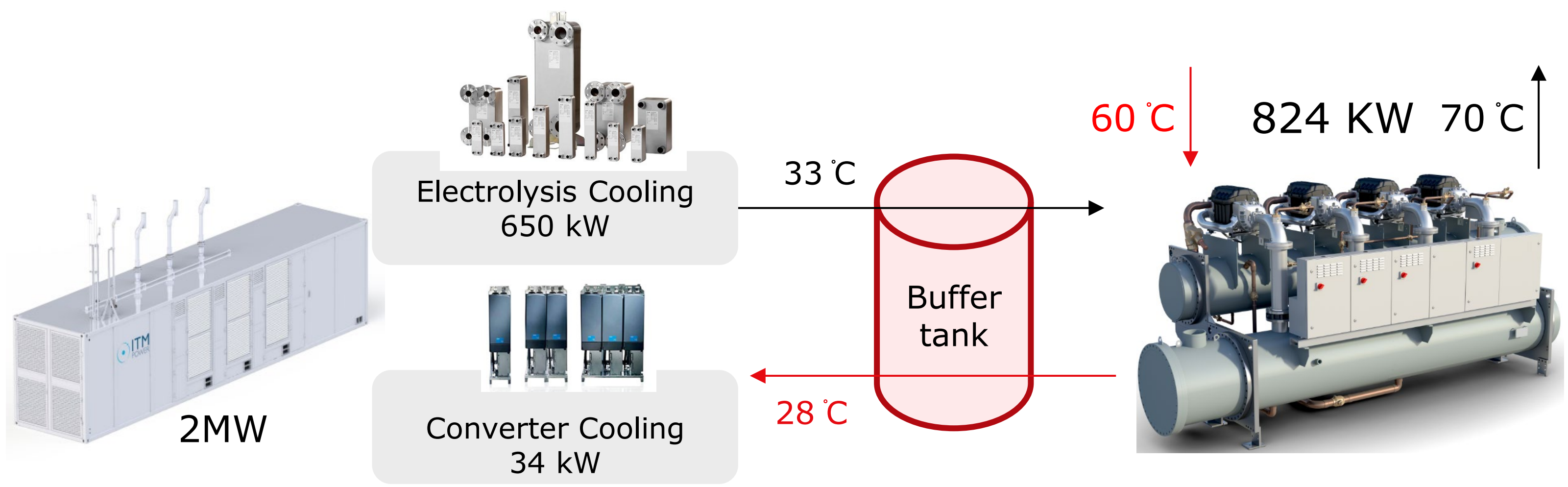
Additional Heat Recovery Opportunity
Data Center Backup Power & Hydrogen Production

Water-Water Heat Pump	Cooling capacity	Heating capacity	Power input	COP Cooling	COP Heating	Chilled water leaving Temp	Chilled water enteri Temp	Hot water return Temp	Hot water supply Temp	Minimum load
	kW	kW	kW	W/W	W/W	℃	℃	℃	℃	
Full load, 28-20C	650	824	174	3.74	4.74	33	28	60	70	18.8%



- 2MW PEM electrolyzer
- 70% electrolysis efficiency / 30% waste heat recovered
- Electrolysis degrades / recovered waste heat increases over time
- Recovered waste heat increases further when paired with hydrogen fuel cell for onsite power

Why Water-Water Heat Pump & High Heat Recovery Temperature are Critical

- **Multiple heat source choices**
- **Large air-water heat pump ~3-3.5 COP**
- **Oil-free water-water recovery heat pumps ~6-7 COP, based mainly on higher source temperature**
- **High electricity price fluctuation**
- **From efficiency & resulting operating cost / heat price**
  - Air-water heat pumps operate when electricity price < 600 DKK/MWh (~300 hours this year)
  - Oil-free heat pumps operate when electricity price < 1200 DKK/MWh (>80% of the year)

Daily electricity price fluctuation – One day (10/21)

Low	~100€/MWh
High	~300€/MWh

For DHU, difference between low-cost baseload heat source with quick payback and peaking plant backup

Conclusions

- Energy system excess heat presents a significant opportunity for efficiency and decarbonization
- Baselining energy transition discussions to current and alternative solutions critical to showing the best path
- The magnitude of efficiency exceeding spark spread ratio governs financial return
- Sector coupling, or tying energy systems together increases efficiency, resiliency, payback and decarbonization
- We can learn a lot and simplify a complicated system by segmenting it and understanding alternative applications
- Increasing data center cooling temperature with new cooling technologies significantly increases the return also for heat reuse
- Hydronic separation of data center cooling from heat recovery system eliminates much of the separate business model complications
- “Heat reuse-ready” data center system design enables ambient-independent free cooling and removes barriers to building new data centers
- Data centers are an optimal source for electrification of not only district energy systems, but any application electrifying their heat source
- The resiliency of the data center and critical facility system from their backup power enables reuse resiliency
- **Critical facility cooling systems, including data centers are the future baseload source for a decarbonized and resilient electrified energy system**

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