MAN Energy Solutions
Future in the making

Flexible Infrastructure for an Electrified Future

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Aug 4th 2022

Disclaimer

All data provided in this document is non-binding.
This data serves informational purposes only and is especially not guaranteed in any way.
Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.

Decarbonization of heat – energy storage and heat pumps playing increasingly important role

Total Final Energy Consumption, by Final Energy Use, 2017[1]

Power
17 %

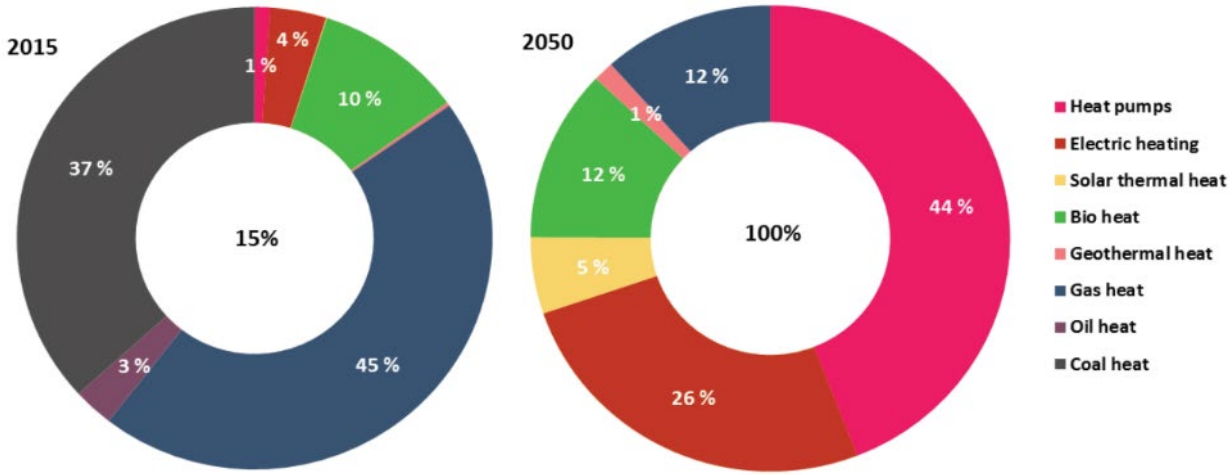
Transport
32 %

Thermal
51%

… of which only ~10% comes today from renewable sources

Decarboni-zation of thermal segment is critical to reduce global CO2 emissions

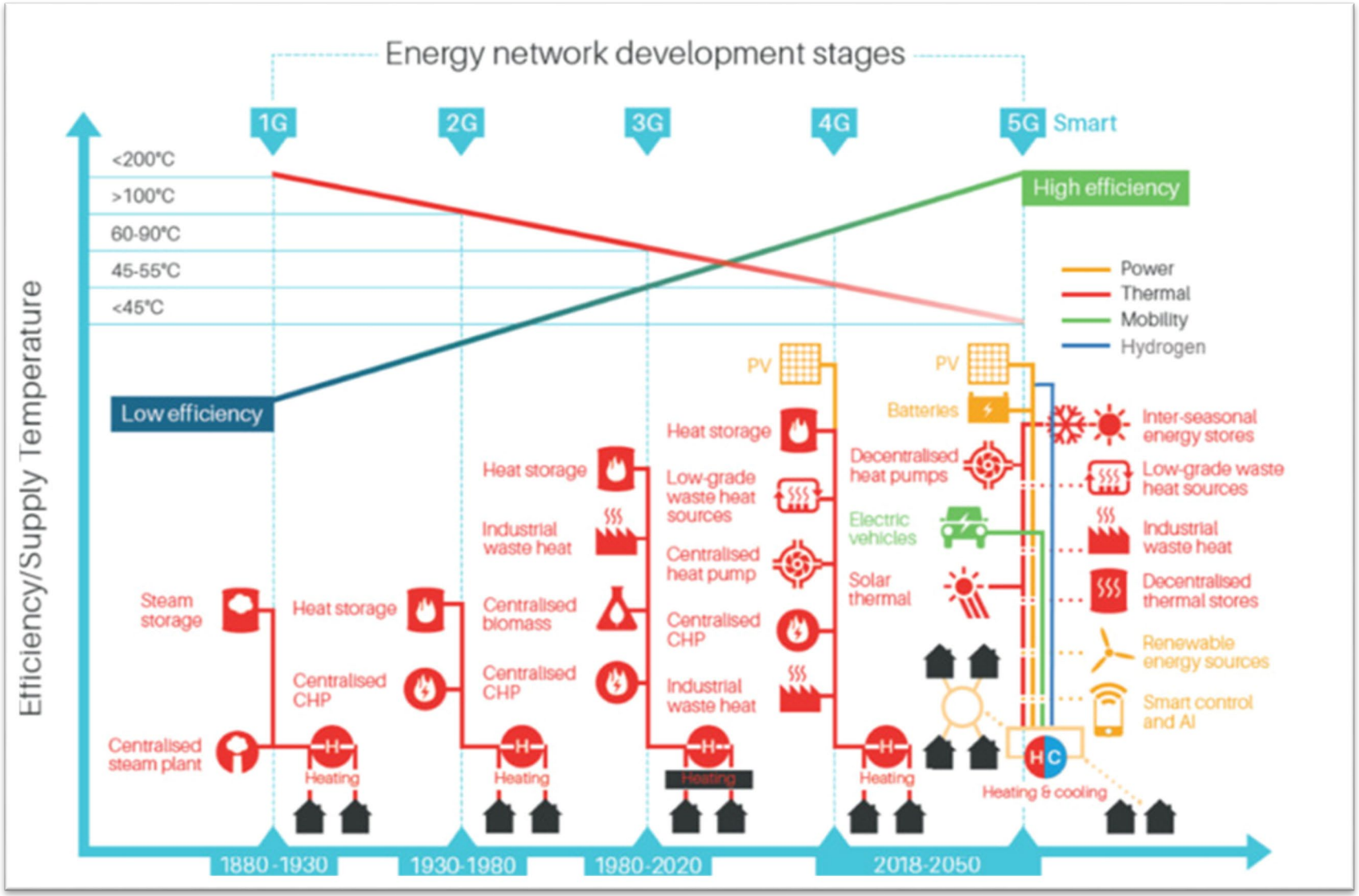
Scenario for a 100% renewable heat supply:[2]



- Heat supply shifts from 85% fossil fuels domination towards 100% renewable energy supply in 2050
- Electrification, esp. with heat pumps, plays a significant role in this transition
- Renewable and synthetic gases as alternative, especially for high temperatures

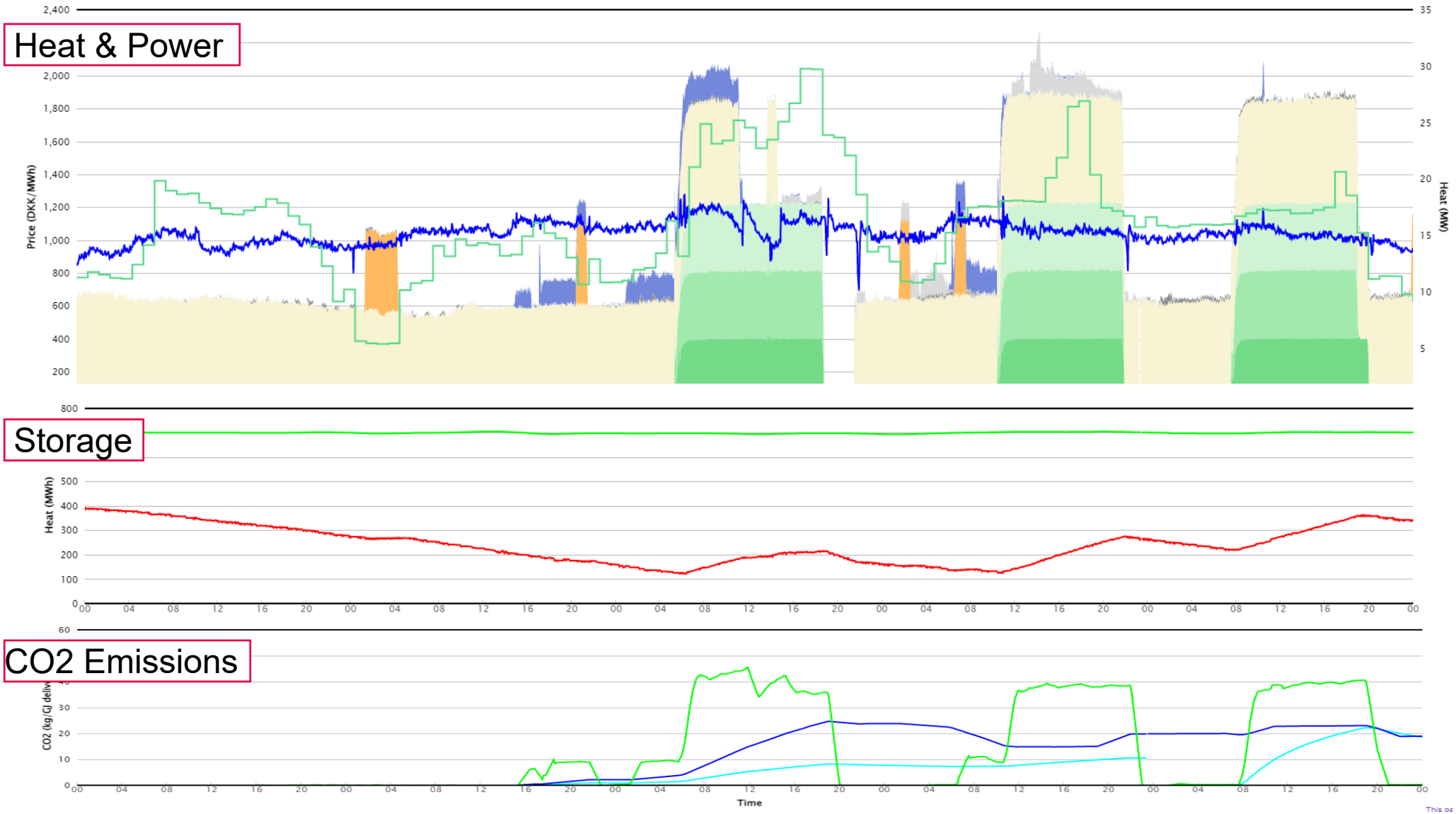
[1]Source: REN21, Renewables 2020, global status report based on OECD/IEA data; [2]LUT University, Energy Watch Group, Scenario of 100% renewable energy system in Europe in 2050

The Flexible “Grid(s)” of the Future



- **1st** – High temps, built around central plant.
- **2nd** – Introduced CHP, and pressurized water loops
- **3rd** – Introduced pre-insulated piping and focus on heat recovery
- **4th** – Introduced large fluctuating energy sources and started to “Recycle heat”
- **5th** – Decentralized Bi-directional exchange, Demand driven.

Skagen Network- Jan 5th-9th 2022



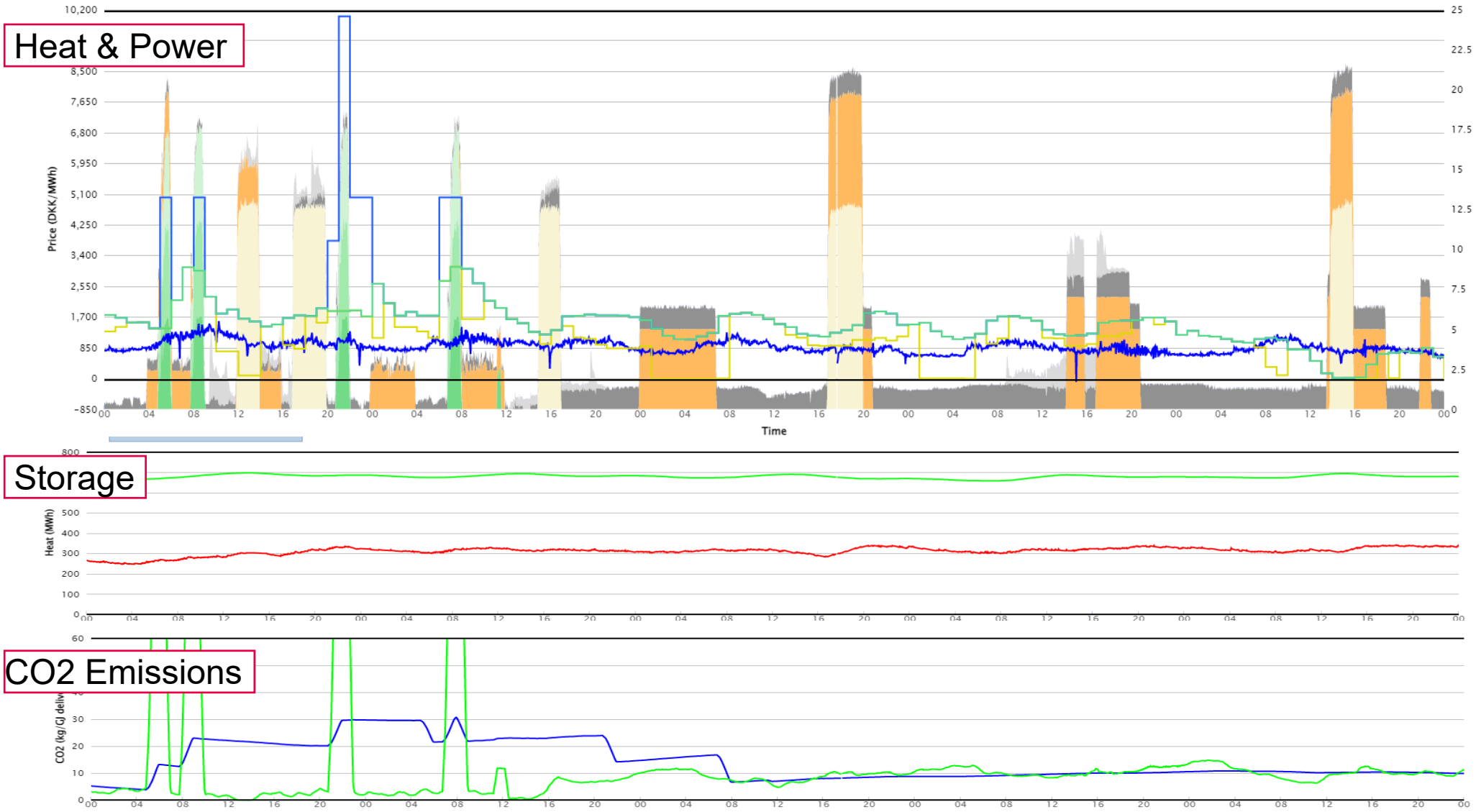
Decarbonization Incentives:

- Renewable Power Source
- Gas Consumption: 353MM -> 70MM Ft^3

Equivalent to:

- 15,588 TPA CO2 Reduction
- 257,750 Trees (10yrs)
- 636,534 Propane Cylinders (5gal)

Skagen Network- July 5th – 9th 2022

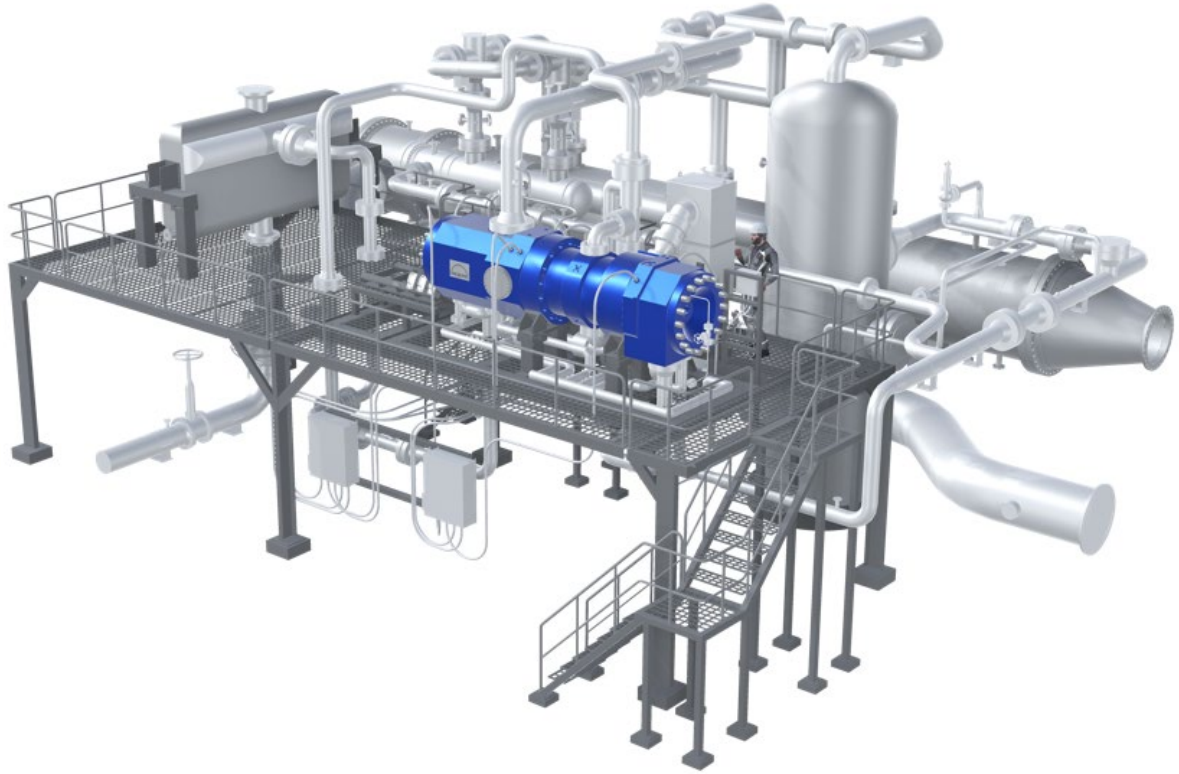


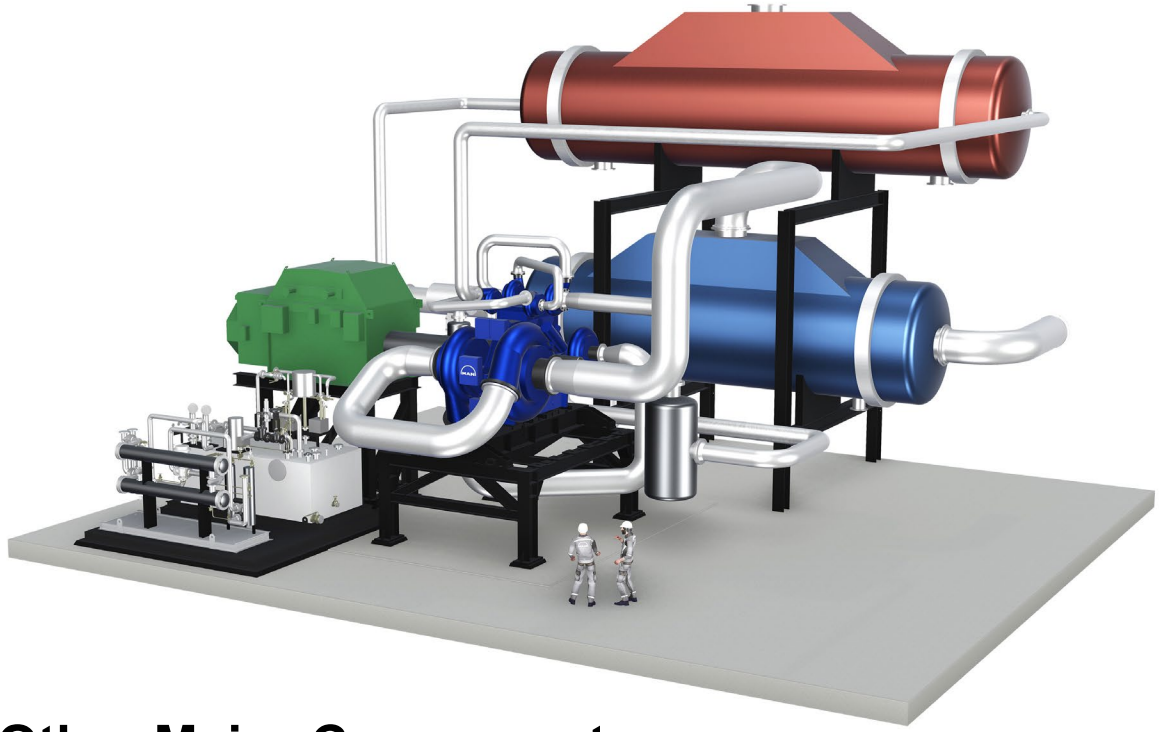
Financial Incentives:

- Spot Price Arbitrage
- Frequency Response
  - Approx. 25 monetization opportunities
- Heat Arbitrage / Reduced gas cost
- CO2 Tax Avoidance
- Premium for Renewable Heat

Centralized Heat Pumps

Components of a Decarbonized Grid

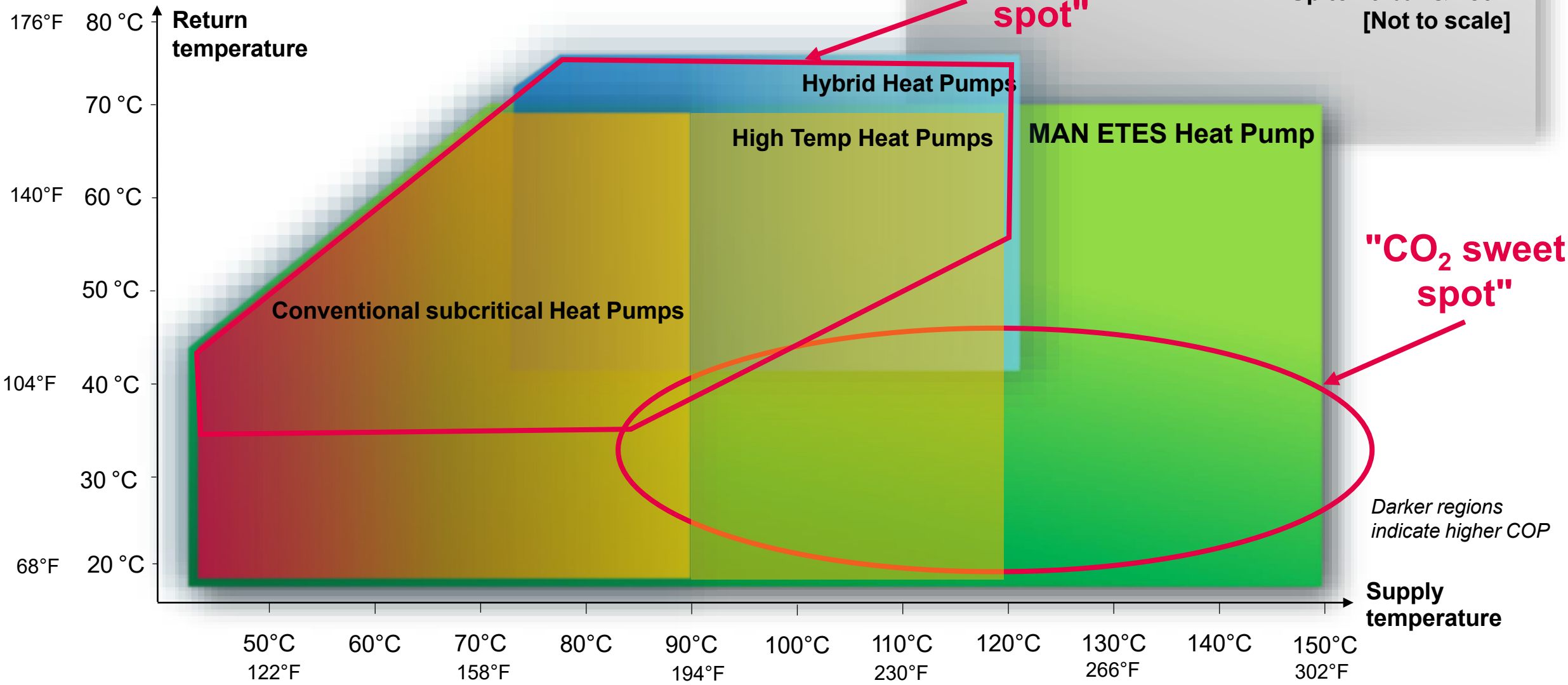




Other Major Components

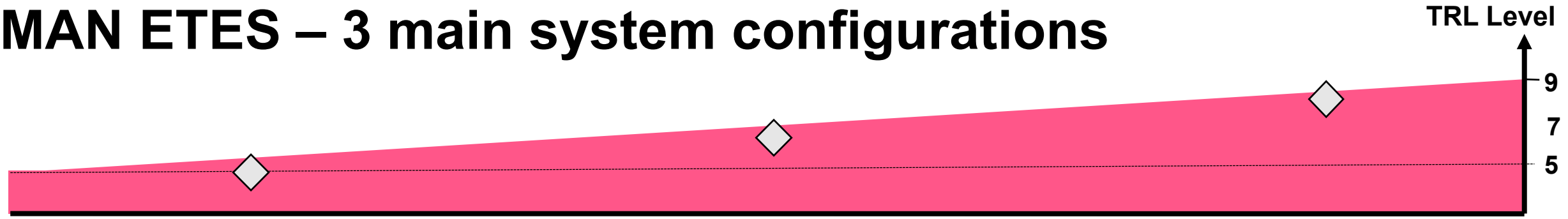
- CHP
- Electric Boilers
- Thermal Storage
- Electric Storage
- Low Grade Heat Sources
- Asset Optimization
- Renewables
- Connections (Electric / Thermal)
- Flexible Loads
- Firm Generation

Heat Pumps cover the entire range of applications:



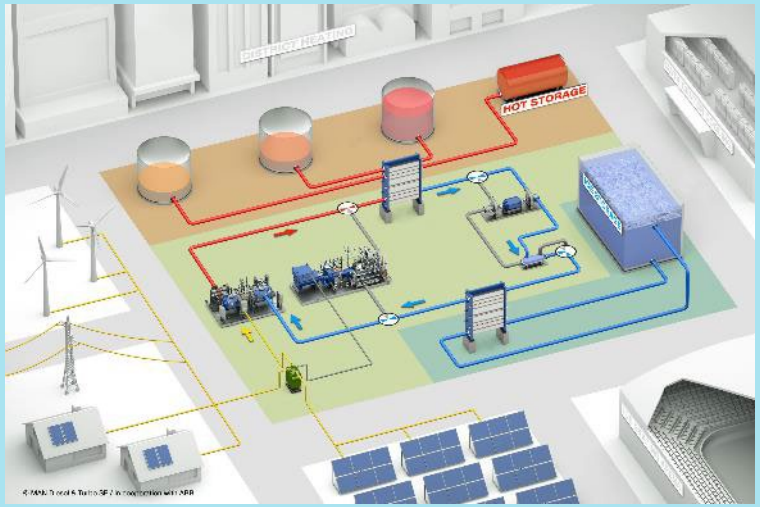
sCO2 Heat Pump Technology & Flexibility

MAN ETES – 3 main system configurations



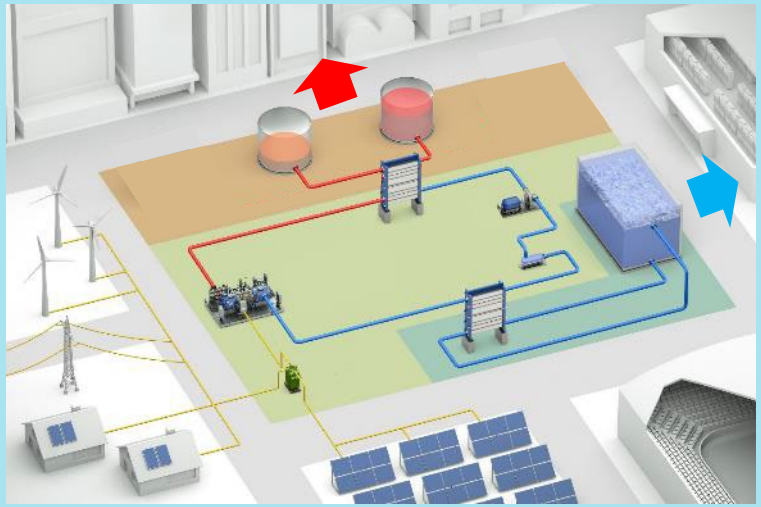
MAN ETES ("Carnot Battery")

- Heat pump
- Storage
- Re-electrification



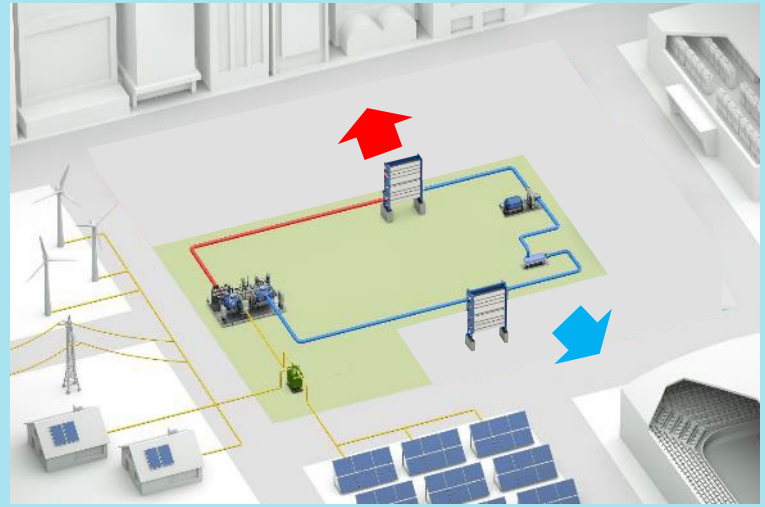
MAN ETES "Light"

- Heat pump
- Storage



MAN ETES Heat Pump Unit (HPU)

- Heat pump

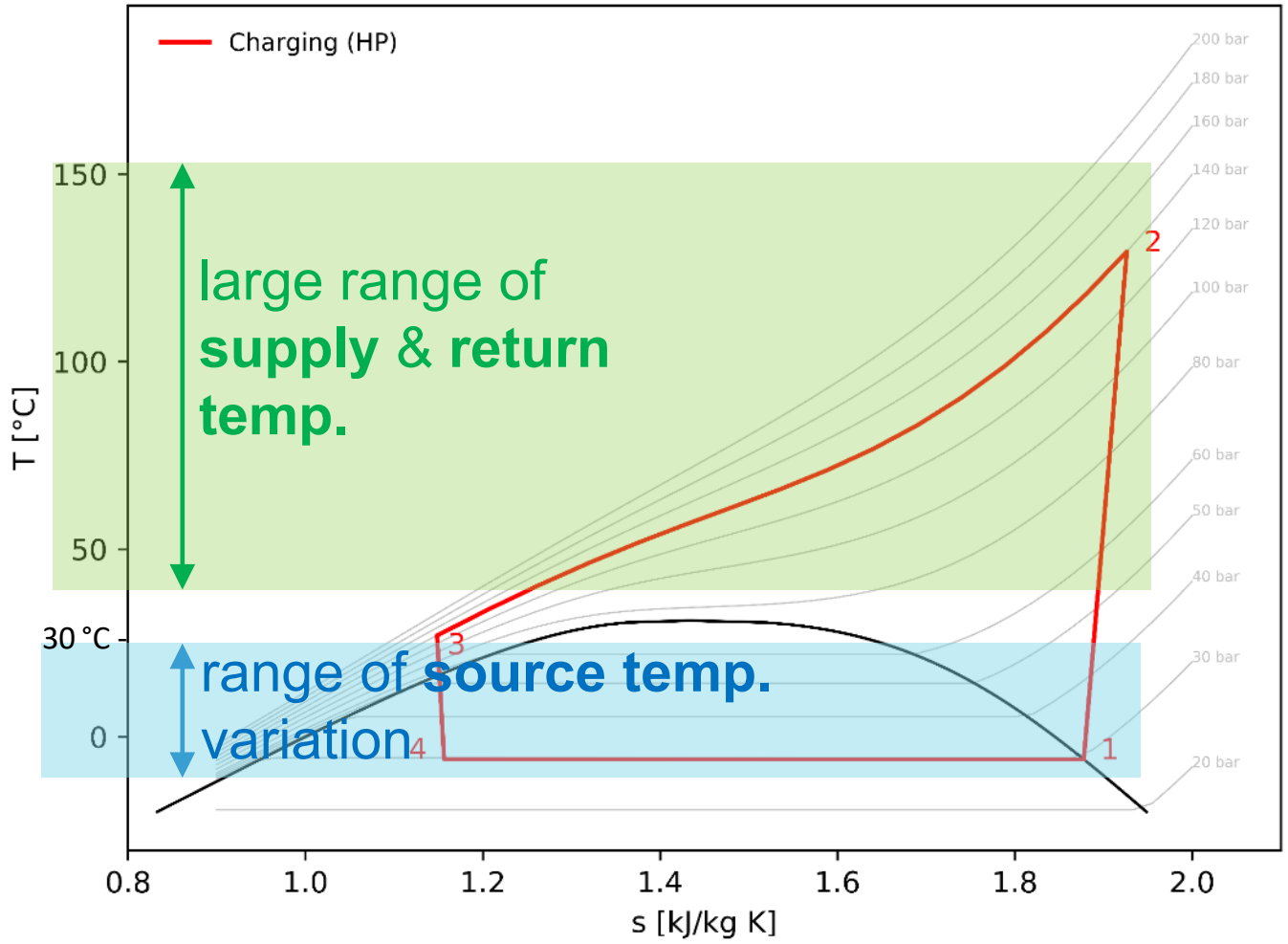


CO_2 is the adequate fluid for HTHP and Energy Storage

Suitable for a medium to high temperature range + flexible design & operating conditions

- Large range of applications
- Low critical point and high power density => favorable heat transfer properties
- Natural refrigerant => suitable for high heating capacities resp. large quantities
- Readily available, non-toxic, non flammable

Refrigerant	GWP	ASHRAE characteristics*		
		Toxicity** (A/B)	Flammability** (#)	Group
CO2 (R744)	1	A	1	A1
Ammonia (R717)	0	B	2L***	B2L
R1234zez	1	A	2L***	A2L
R134a	1430	A	1	A1
R22	1810	A	1	A1
R32	675	A	2	A2



T-s diagram of the cycle with CO_2

Green Heat & cold supply production and storage

Thermal share: 100% (HPU & ETES Light)

E_{ch}

Electricity input

Frame sizes
2-5 MWelectricity
5-9 MWelectricity
9-16 MWelectricity

45% part load operation possible

Heat production

Sensible storage (30-150°C)

Thermal export
6-15 MWthermal
15-27 MWthermal
27-48 MWthermal

Q_{hot}

Q_{hot}^{bal}

Q_{cold}^{bal}

Cold production

Latent storage (0°C)

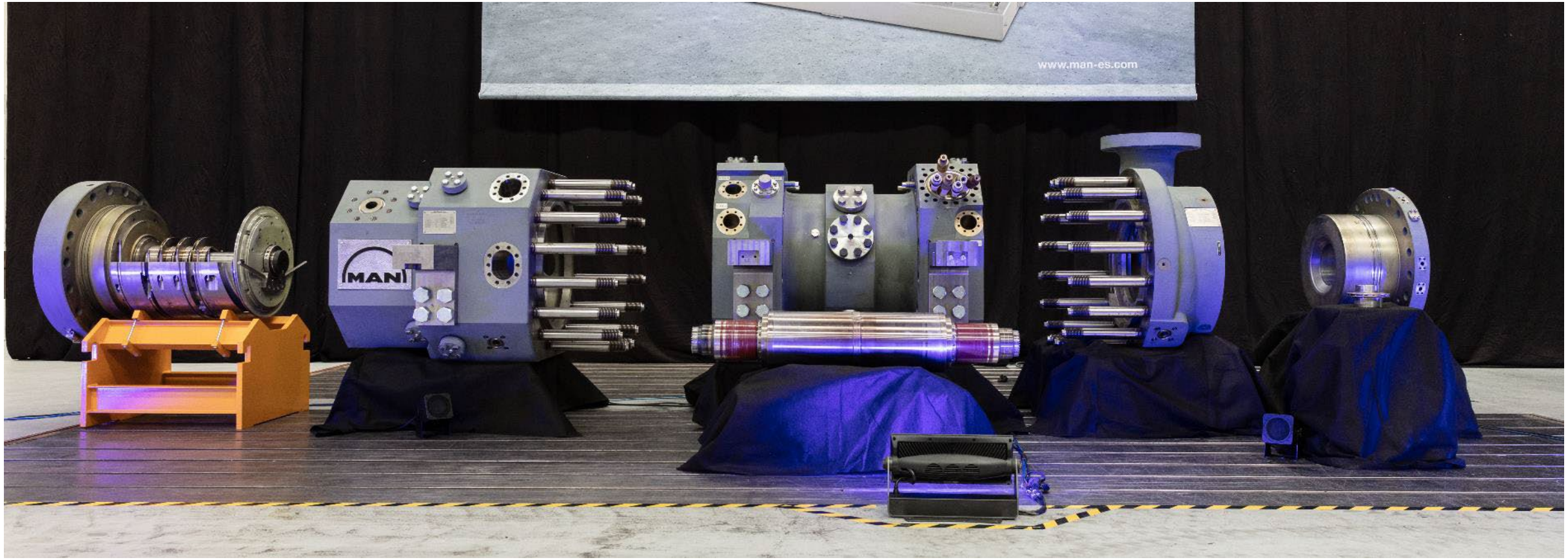
Thermal export
4-10 MWthermal
10-18 MWthermal
18-32 MWthermal

Q_{cold}

4 Testing campaigns

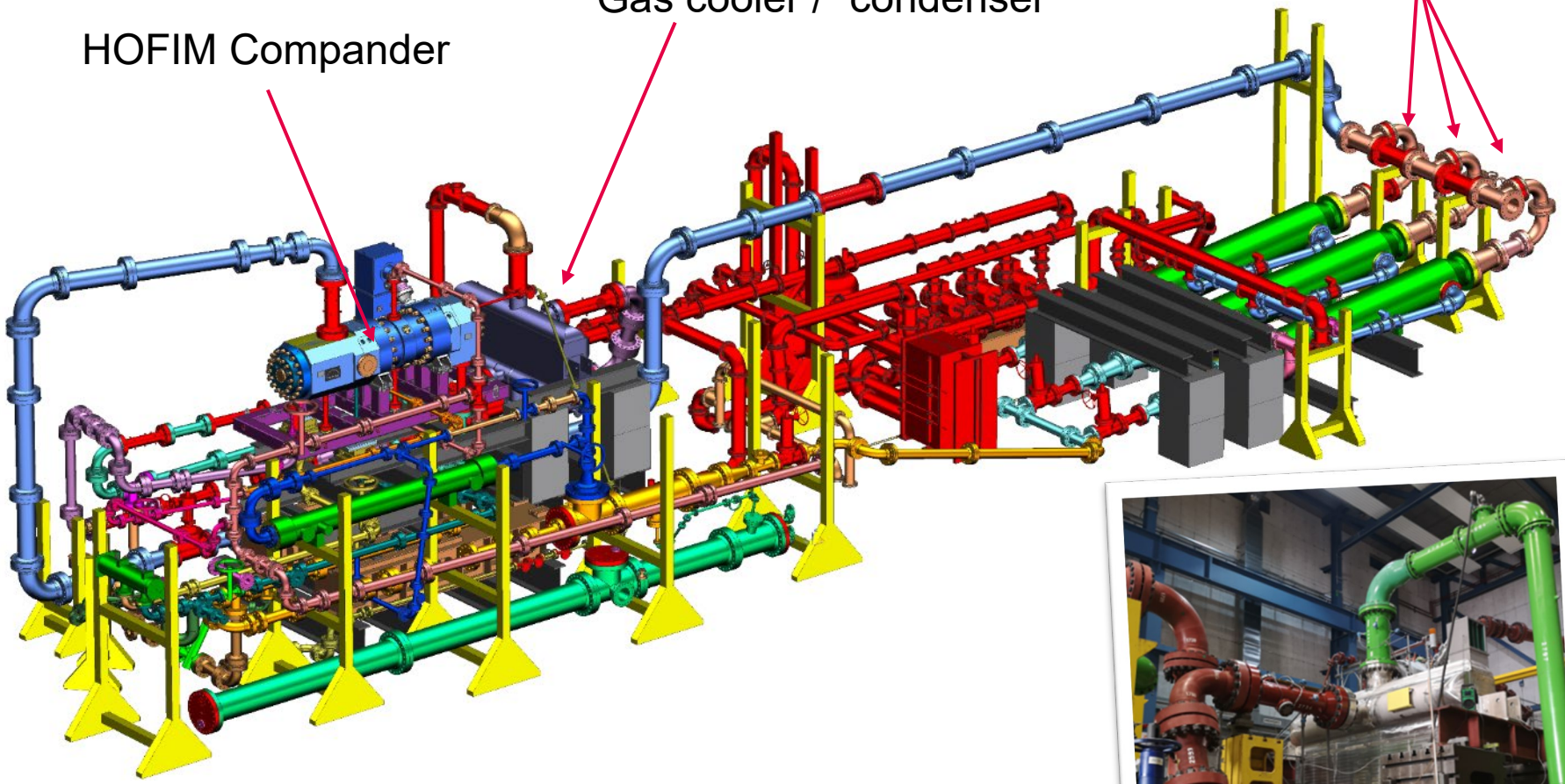
The heart of the system: HOFIM® with integrated expander

HOFIM®: Highspeed oil-free integrated motor compressor



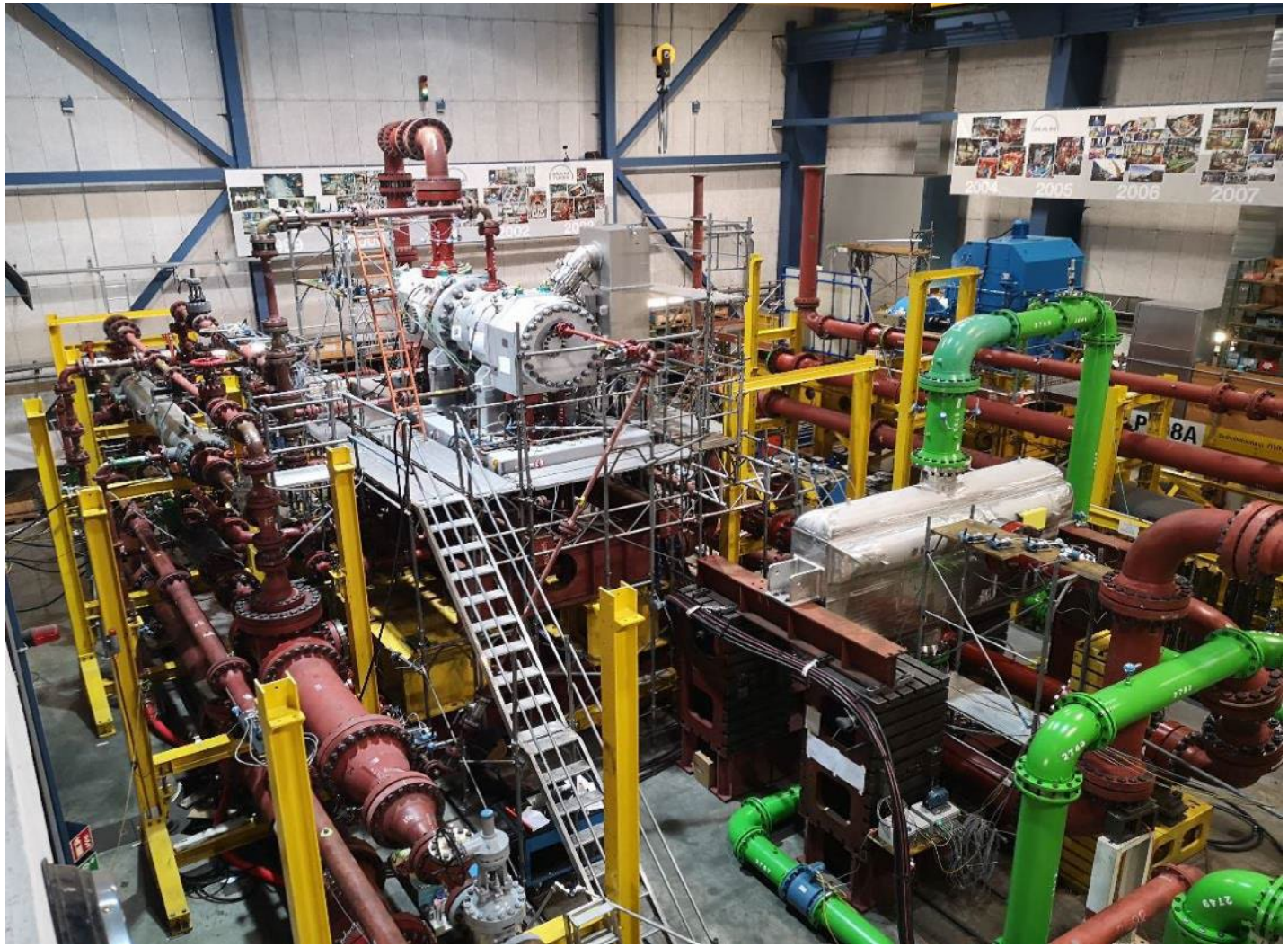
HOFIM® with integrated expander allows >10 % energy savings in heat pump applications. Picture shows the M28 frame size.

Factory Acceptance Test 2022

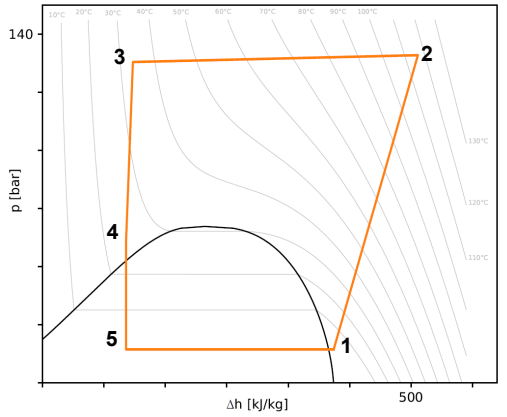


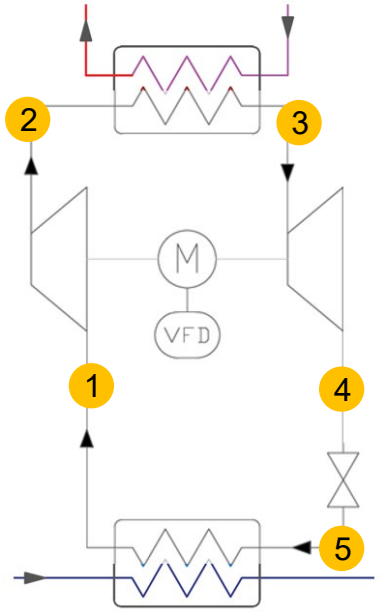
FAT completed

Full load test performed on Zurich test loop



- **Up to 38 MW_{th} Heat Power**
- **Up to 11.5 MWe Electrical Power**
- **Supply temp. 60 – 109 °C**
- **Fast load change > +/- 7 MW_{el} / 30 sec**
- **System main component performance validated:**
  - Motor
  - Expander
  - Compressor
  - DH Hex

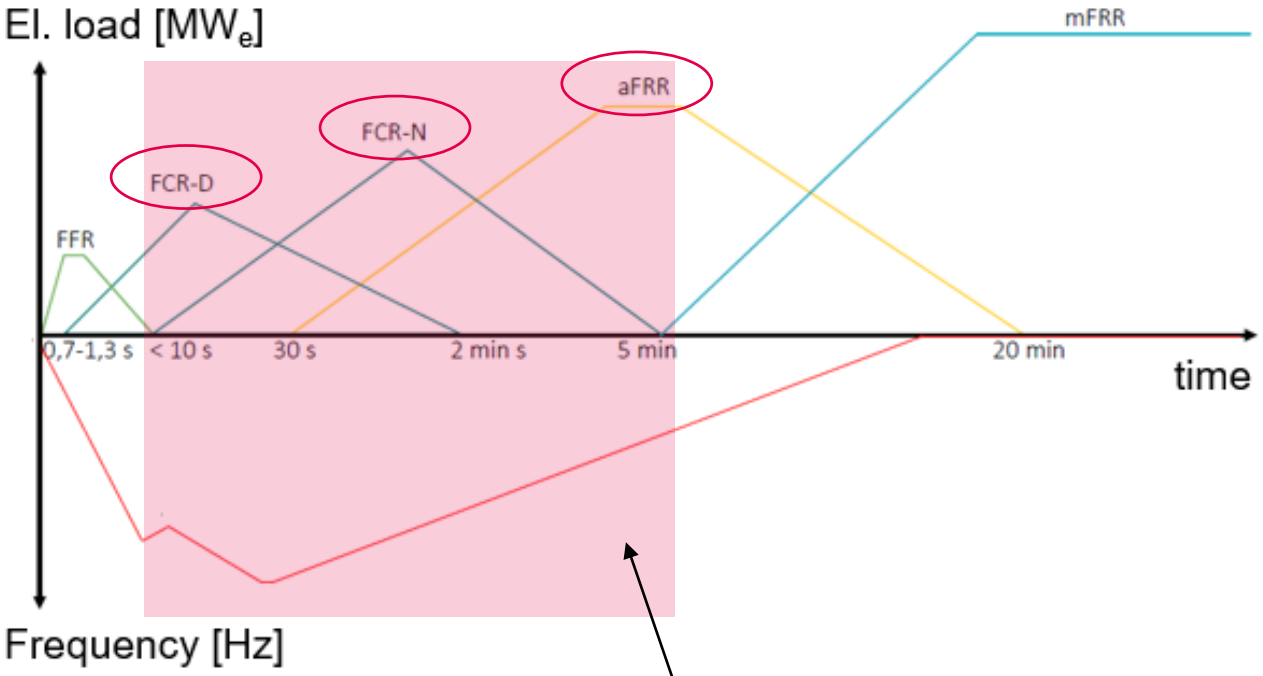




Grid stabilization with HPU Fast Power Balancing

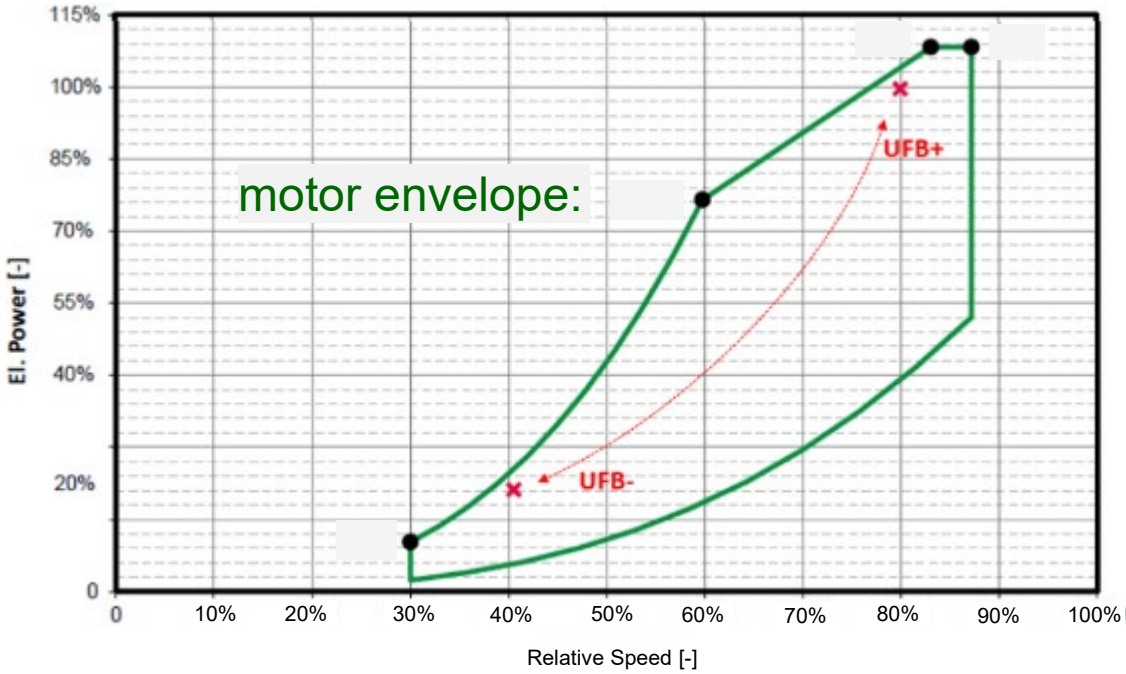
FCR and aFRR can be addressed in heat pump operation

- Grid requirements:



Grid stabilization services addressed with MAN CO2 HPU

- Grid stabilization capabilities :
  → governed by fast motor speed variation

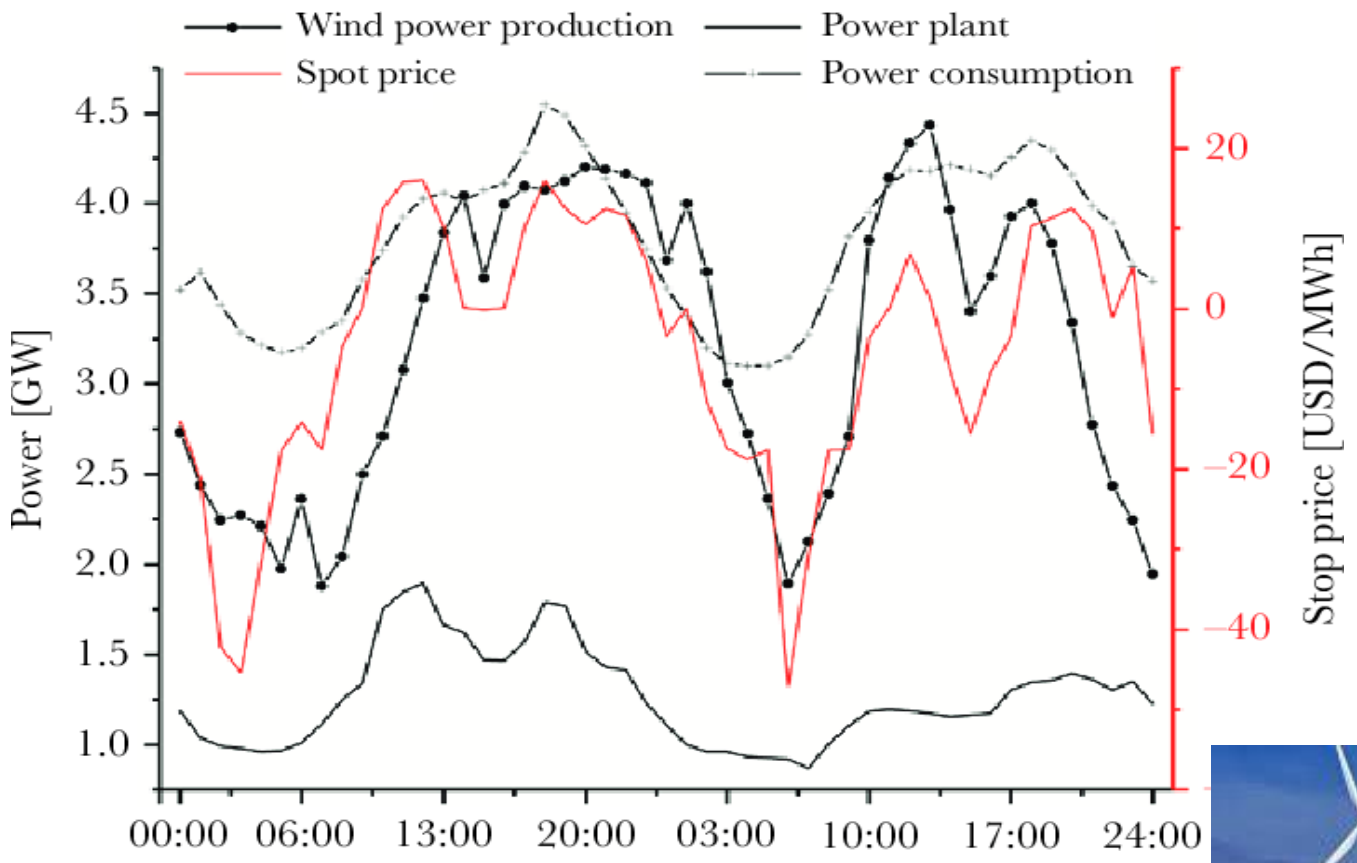


- Achievements (Tests*) : **> +/- 7 MWe / 30s ***

** ref. to testing results, 2022 test bed Zurich*

3 Esbjerg Project Highlights

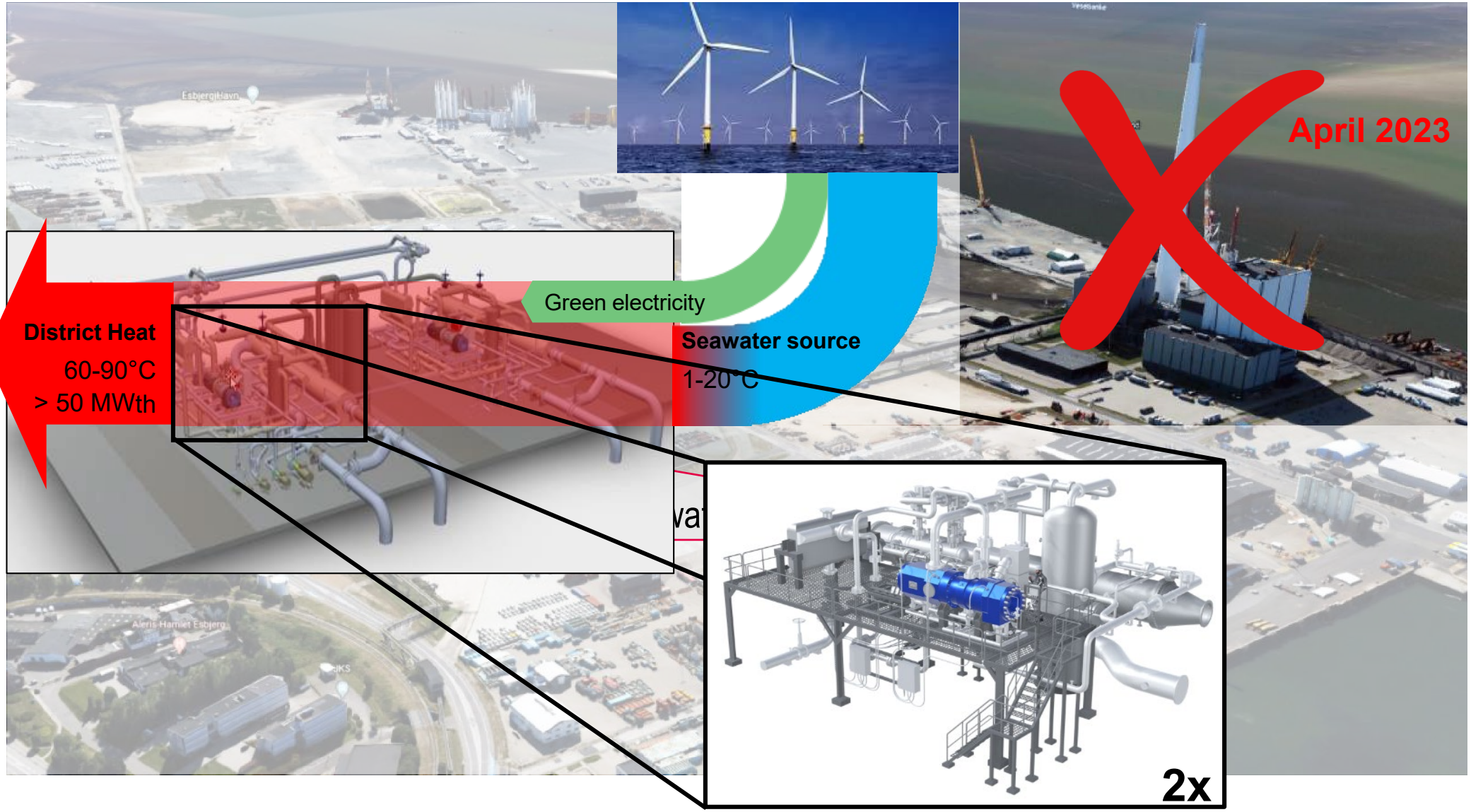
Esbjerg heat pumps to provide power balancing



- **mismatch** between power **consumption** and **production**
- Get **paid to** provide **balancing** (primary and secondary balancing)

Power generation, consumption and spot price in Denmark on two typical days in 2016. Source: https://www.researchgate.net/figure/Power-generation-consumption-and-spot-price-in-Denmark-on-two-typical-days-in-2016-data_fig6_321283427

2x MAN HPU's under delivery to Denmark!



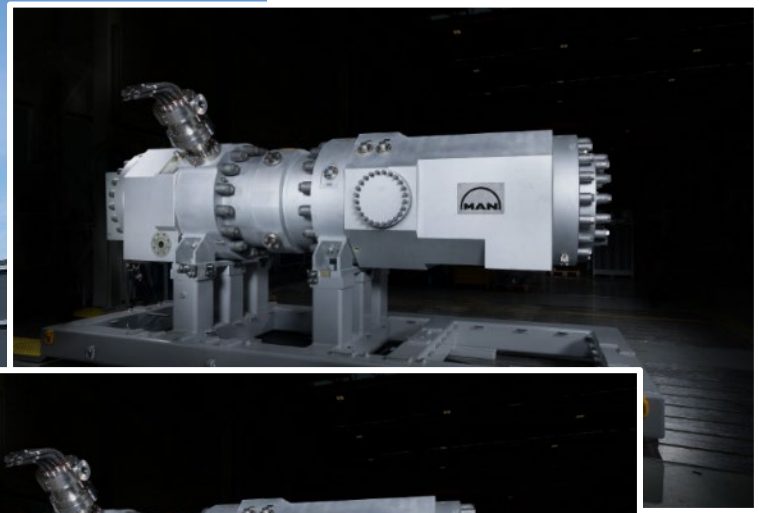
Carbon neutral district heating for over 100’000 inhabitants

- **235’000 MWh** CO_2-neutral district heating per year
  → enough for approx. 25’000 households
- **100’000 t CO_2** savings per year
  → Emission of approx. 20’000 cars
- **50 to 70 MW** heat output
  → Olympic swimming pool brought to boil under 4h
- **63,400 GPM** of seawater into evaporator
  → 99% of DC’s domestic water demand
- Largest sCO_2 heat pump worldwide in the public sector!
- On April 1st 2023 the coal-fired power station will be shut down completely.

Quelle: URL https://fremtidensfjernvarme.dk/da-dk/fremtidens-fjernvarme-i-esbjerg-varde-og-nordby/vores-fjernvarme-i-dag (18.01.21)

Status on-site

2x HPU43 to be delivered in Esbjerg harbor



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Thank you!