MAN Energy Solutions
Future in the making

Electro-Thermal Energy Storage

General Presentation

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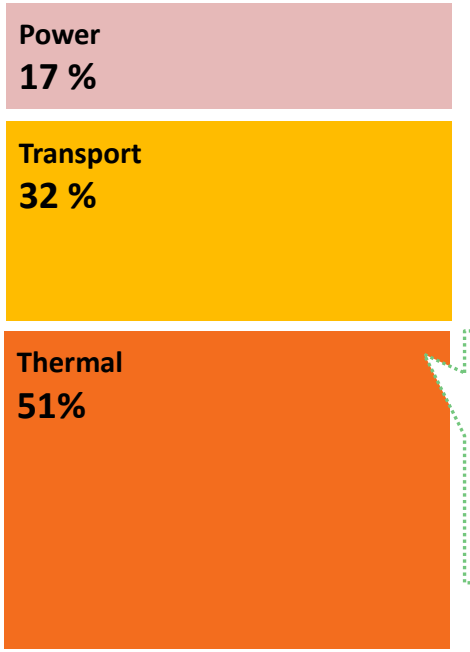
National Sales Manager
August 2021

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

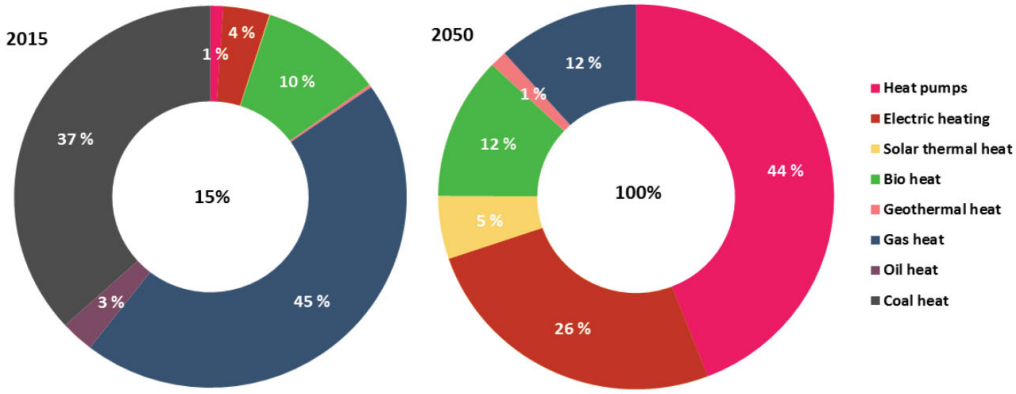
Total Final Energy Consumption, by Final Energy Use, 2017[1]



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

Decarbonization of thermal segment is critical to reduce global CO2 emissions

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

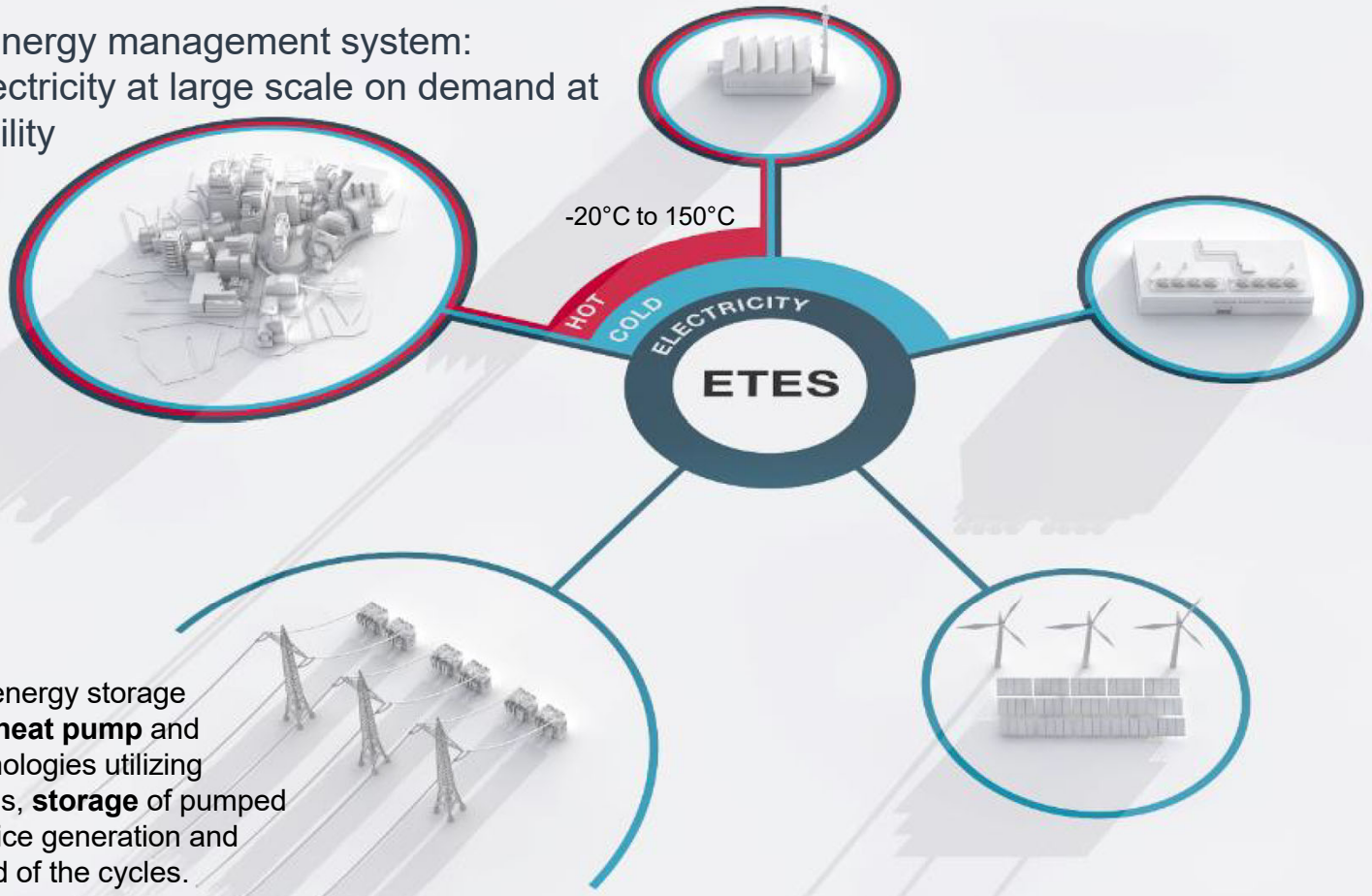


- Heat supply shifts from 85% fossil fuels domination towards 100% renewable energy supply in 2050
- Electrification, esp. with heat pumps, plays a significant role in this transition
- Renewable and synthetic gases as alternative, especially for high temperatures

[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

MAN ETES – Electro Thermal Energy Storage

A tri-generation energy management system:
Heat & cold & electricity at large scale on demand at unmatched flexibility



MAN ETES is a bulk energy storage technology based on **heat pump** and **thermal engine** technologies utilizing transcritical CO_2 cycles, **storage** of pumped heat in hot water and ice generation and melting at the cold end of the cycles.

Developed in cooperation with ABB

MAN ETES – charging cycle

Conversion of electricity in thermal energy – heat pump operation

(1) The HOFIM™ turbo-compressor runs on surplus energy from renewable resources, compressing CO_2 in the cycle, which is heated to 120°C.

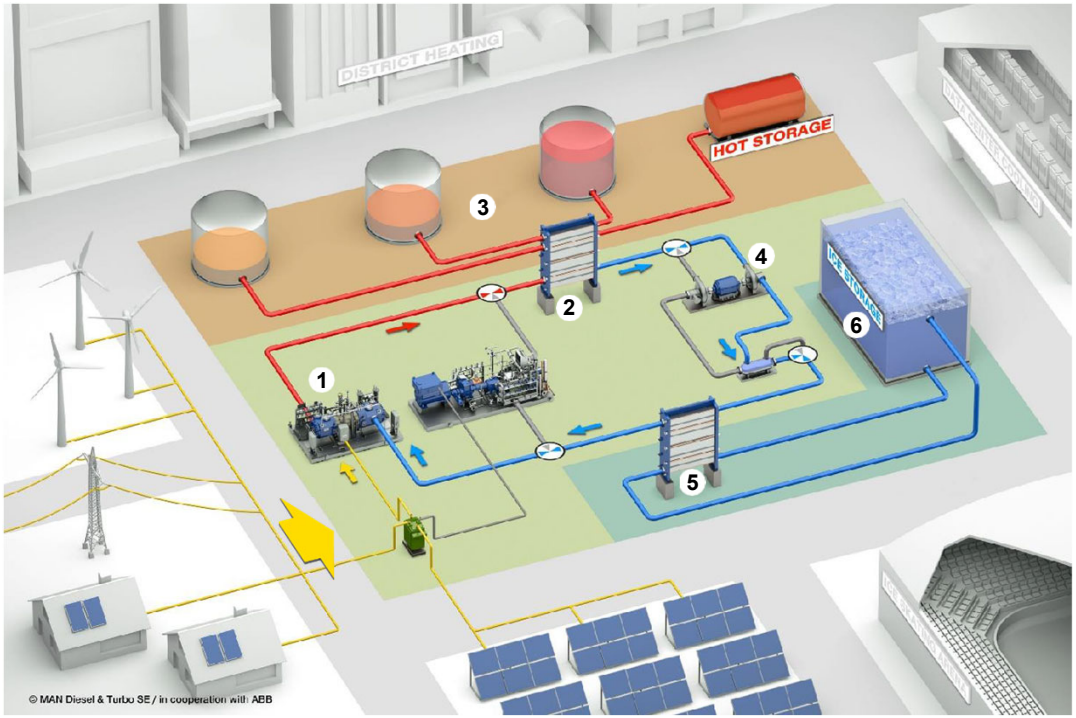
(2) The CO_2 is fed into a heat exchanger and heats the water.

(3) The hot water is stored in isolated tanks, each one at a separately-defined temperature level.

(4) Still under high pressure, the CO_2 is fed into an expander, which reduces the pressure – the CO_2 is liquefied and cooled.

(5/6) The liquefied CO_2 is again pumped through a heat-exchange system, this time on the cold side of the system. Heat is taken from the surrounding water and ice is formed in the ice storage tank.

Schematic is not to scale, only for demonstration purposes



Link to animation

MAN ETES – discharging cycle

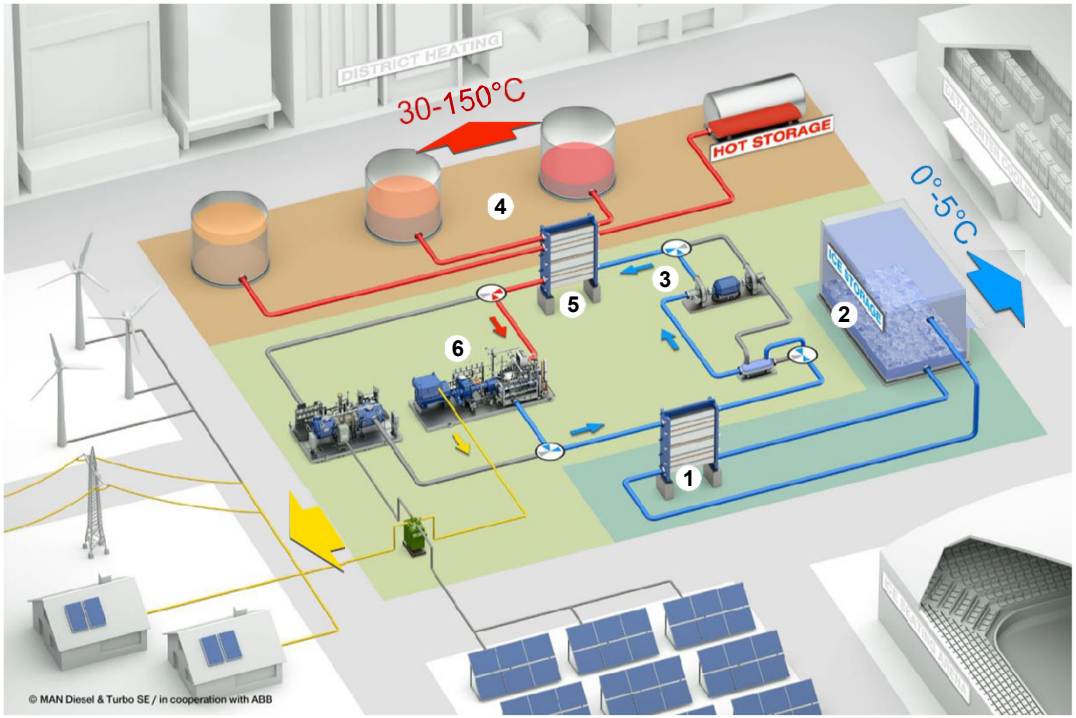
Conversion of thermal energy into electricity – heat engine operation

(1/2) Gaseous CO2 enters the heat exchanger on the cold side of the system where it condenses because of the cold from the ice-storage tank. The ice in the tank melts.

(3) The CO2 pump increases the pressure of the CO2 again.

(4/5) The CO2 passes through the heat exchanger and is heated by the water in the hot-water storage tanks.

(6) The heat from the heated CO2 is fed into the power turbine where the heat is converted back into electrical energy via a coupled generator. The electricity flows into the grid and is distributed to consumers.



Schematic is not to scale, only for demonstration purposes

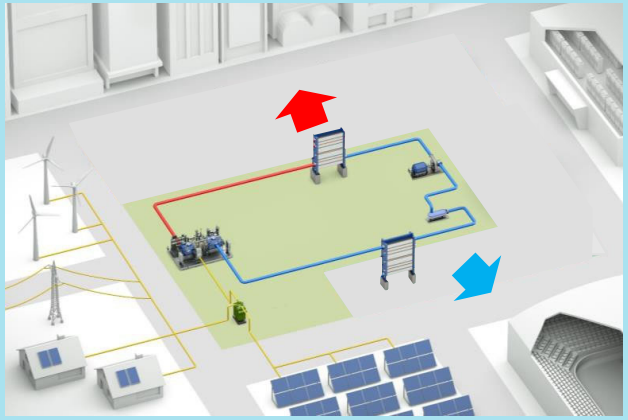
Link to animation

From Heat Pump to Electro Thermal Energy Storage

Focus on heat pump business opportunities

MAN ETES Heat Pump

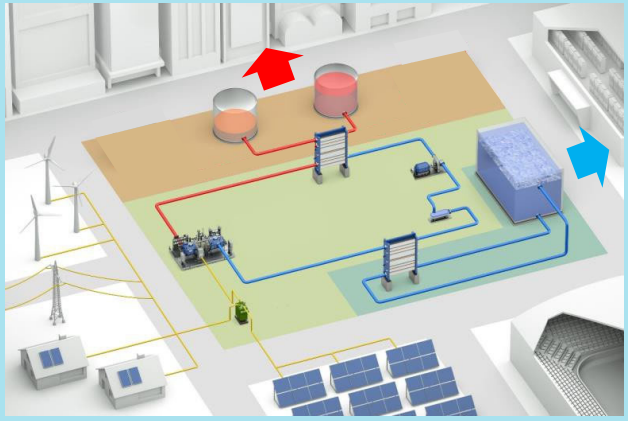
– Heat pump



MAN ETES “light”

– Heat pump

– Storage

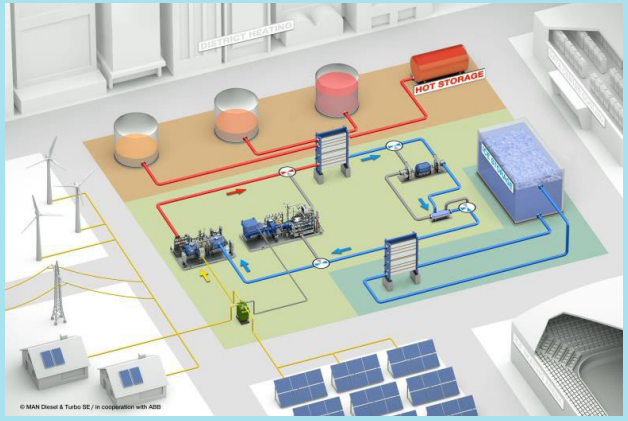


MAN ETES

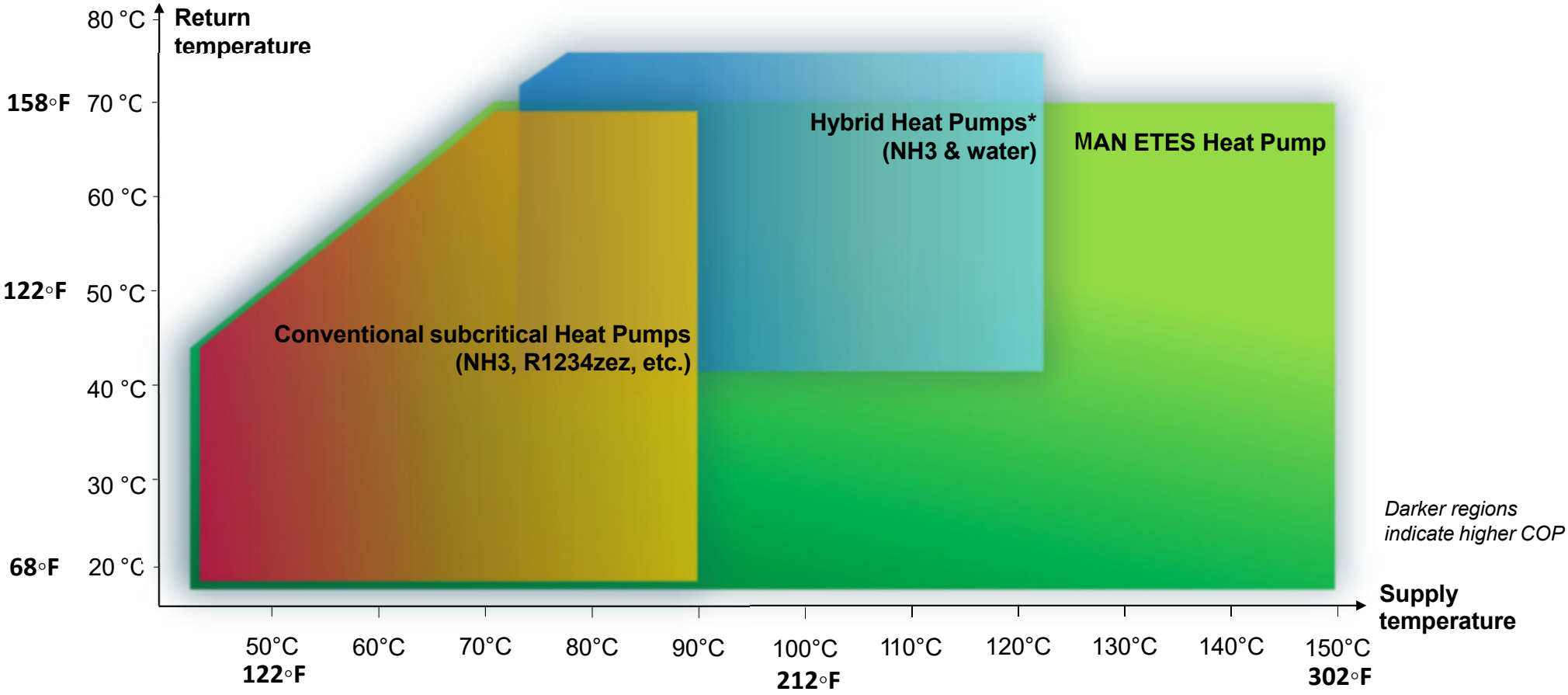
– Heat pump

– Storage

– Re-electrification



Cover the entire range of applications with CO_2:
a safe and natural refrigerant



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Heat Pump Test Runs

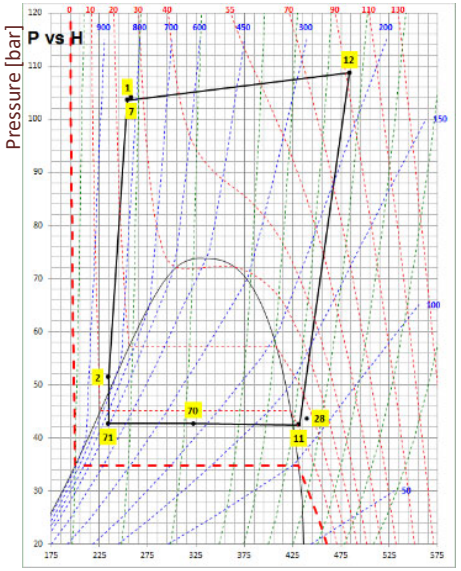
ETES Heat Pump Cycle

Test Loop with HOFIM® Compressor & integrated Expander @ MAN Zurich, Switzerland

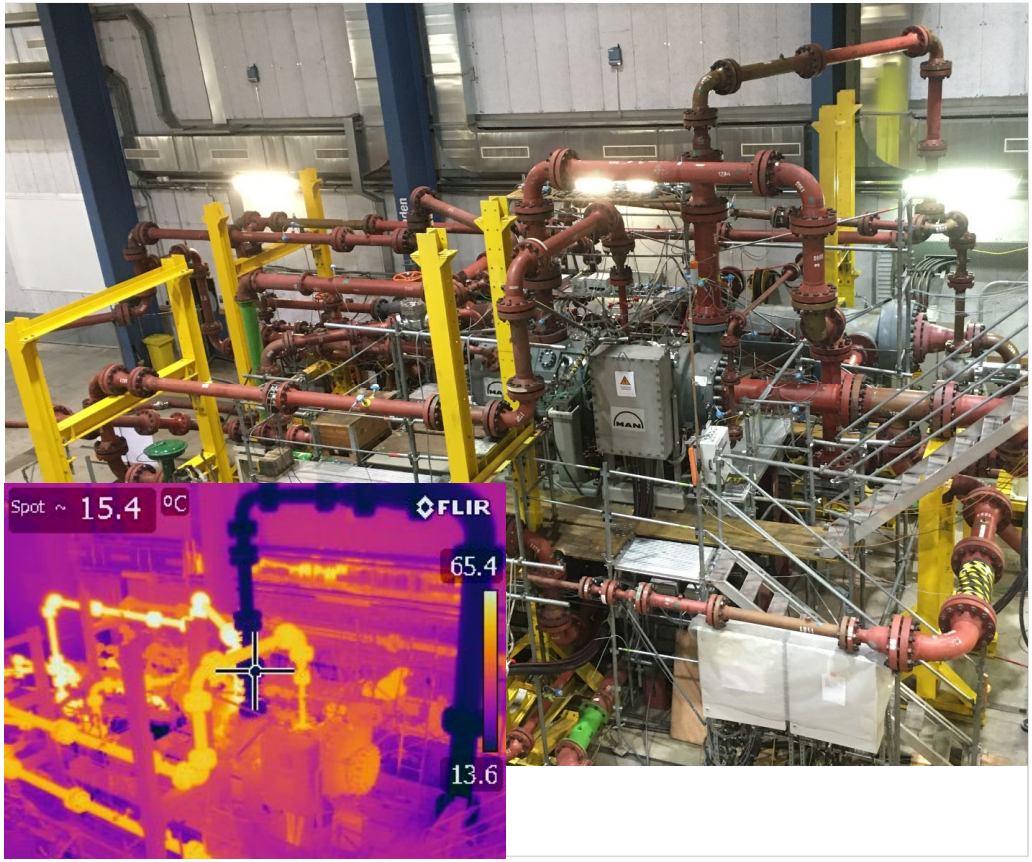
Achievements:

- **Proof of Concept CO2 Transcritical HeatPump cycle** ☑
  - CO_2 Compression (superheated gas & multi-phase suction) ☑
  - Supercritical cooling ("condenser") ☑
  - Expansion from CO_2 supercritical to saturated liquid ☑
  - Power recovery over an Expander stage ☑
  - subcritical evaporation ☑
- **Max. achieved process parameters:**
  - Max Compressor Power 2.5 MW_e
  - Max Heating duty approx. 5 MW_{th}
  - Max Cooling duty approx. 3 MW_{th}
  - COP 2-5
  - Max CO2 pressure 110 bar
  - Max CO2 temp. 120°C
  - Min CO2 evaporation temp. -1.5°C

Test results on 11/13/2020:



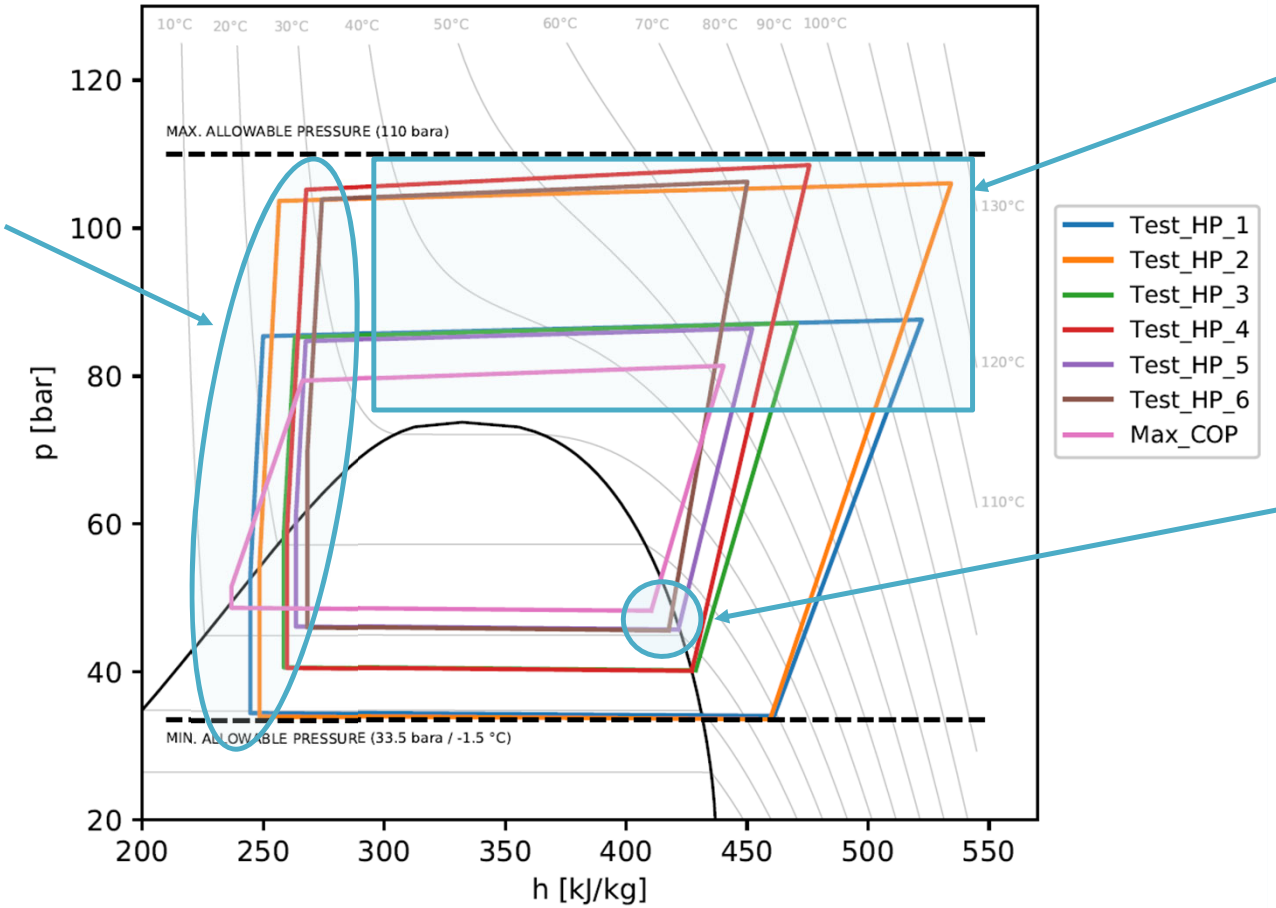
comparable tests conditions with real project applications!



Heat Pump performance tests

Covering broad range of suction and discharge conditions

broad range of expansion validated

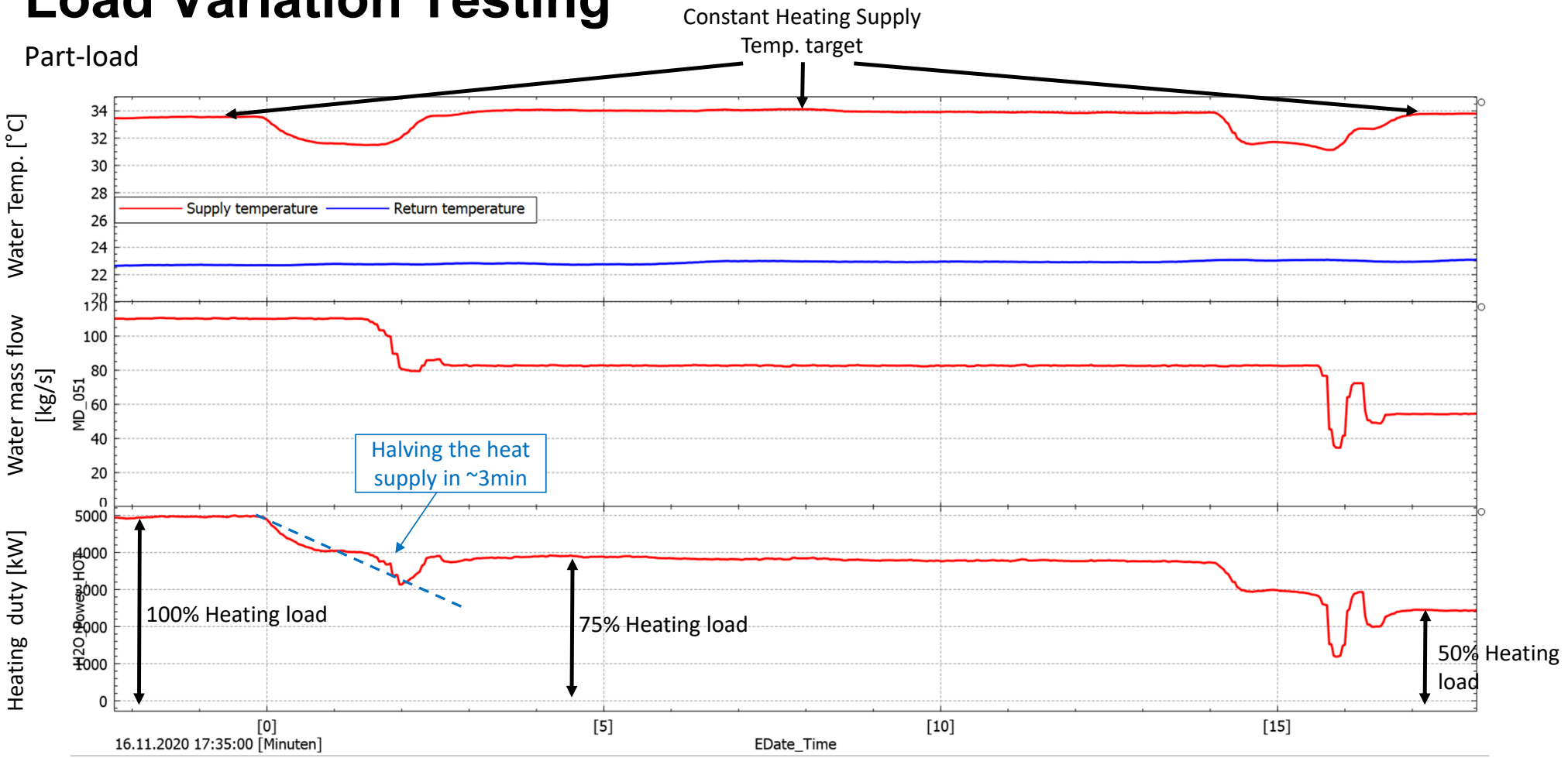


broad range of CO2 supercritical heat exchange conditions validated

Multiphase compression (gas + up to 15%liquid CO2 at compressor suction)

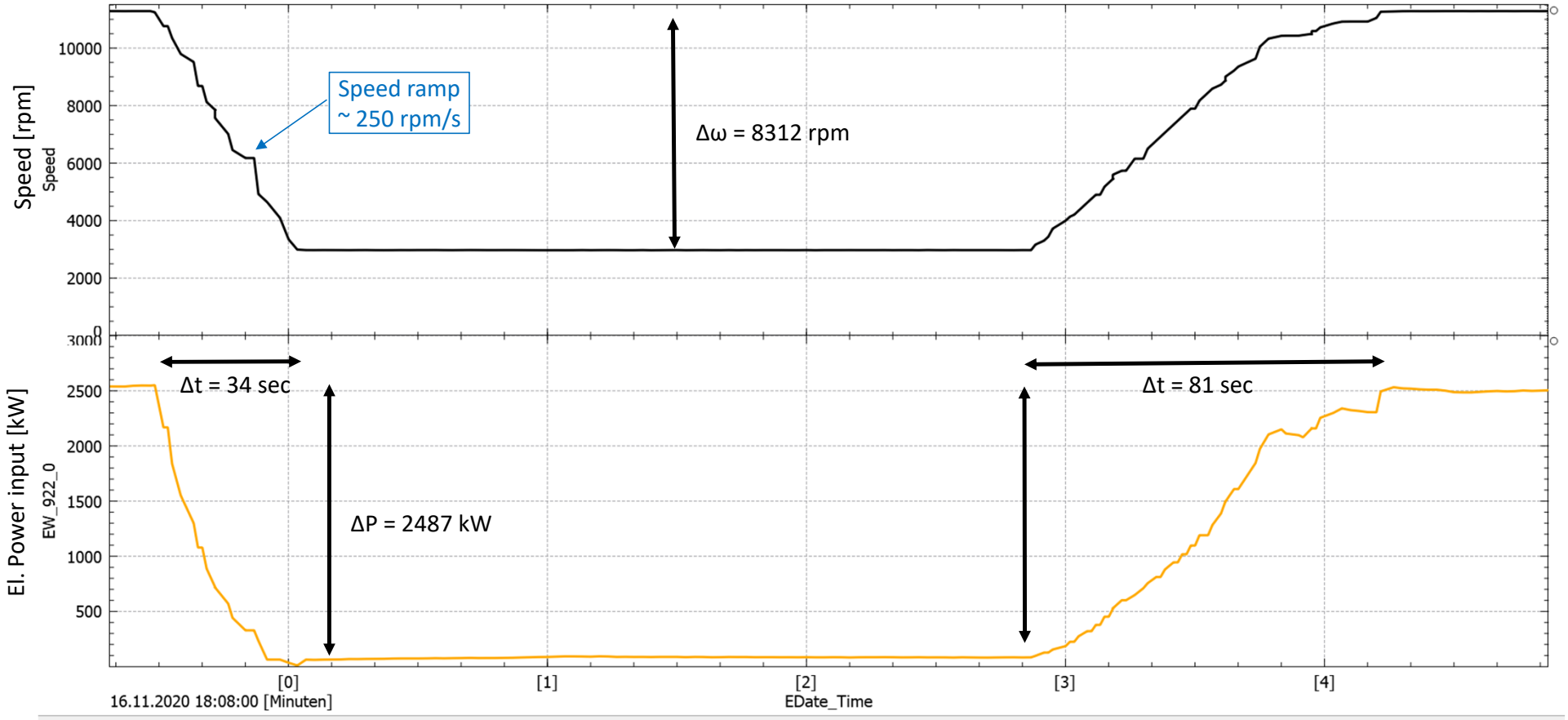
Load Variation Testing

Part-load



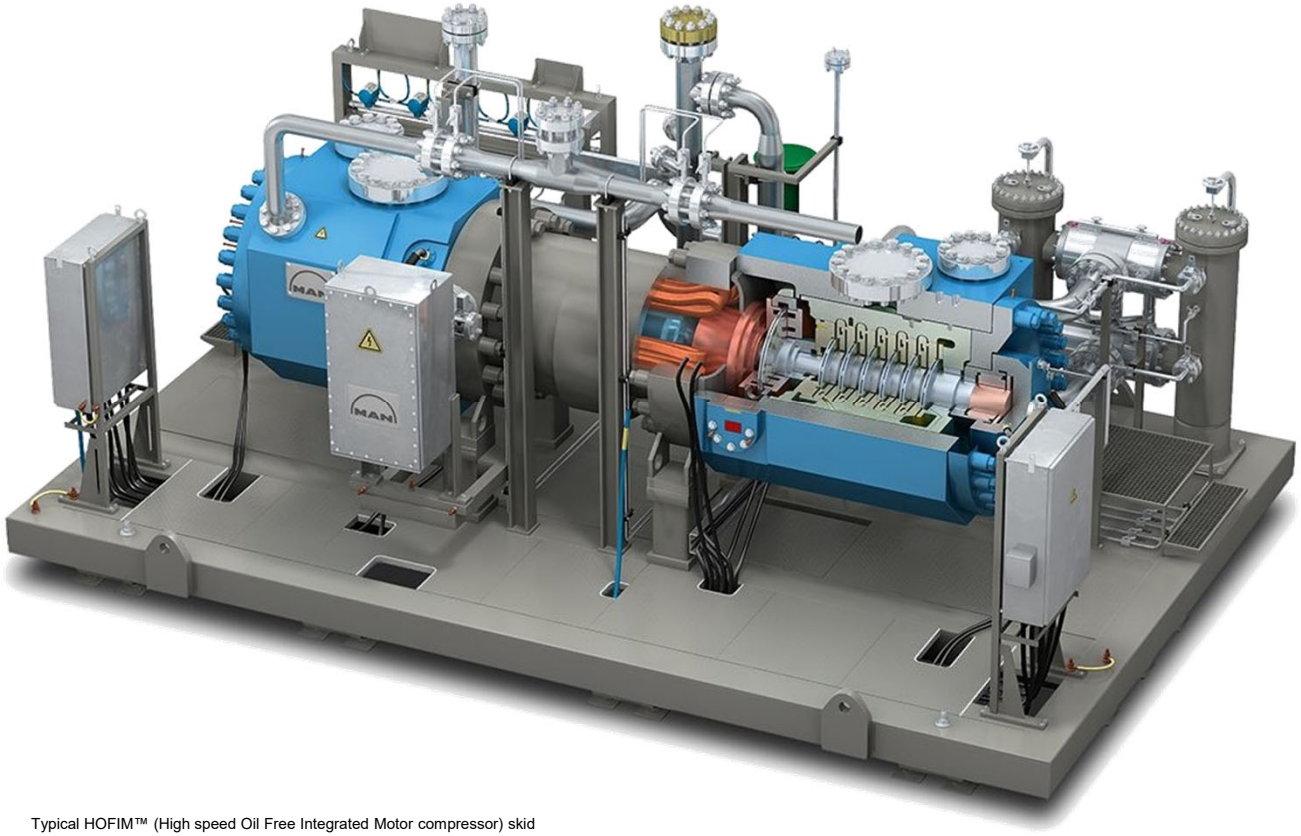
System Response Time Testing

Fast electrical load change ("balancing")



CO_2 Compression & Expansion with HOFIM™

The heart of the ETES heat pump system

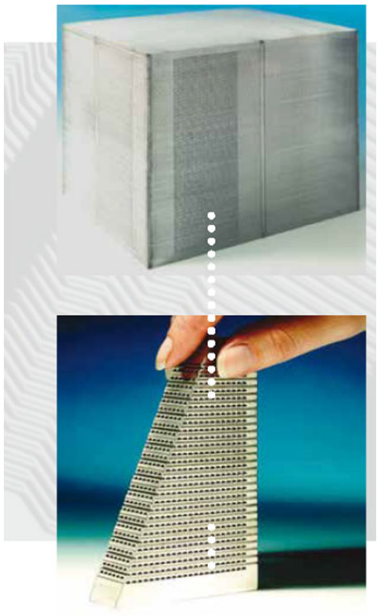


Typical HOFIM™ (High speed Oil Free Integrated Motor compressor) skid

- Barrel compressor – **robust, reliable & compact**
- Integrated expander – **increase process efficiency**
- Highspeed motor – **flexible & dynamic operation**
- Motor cooled by process gas – **heat losses reintroduced into process**
- Running on MECOS magnetic bearings – **no lube oil, no wear**
- Reduced auxiliaries – **increased reliability, reduce OPEX**
- Fully electric – **remote control**
- Hermetically sealed – **no emissions**

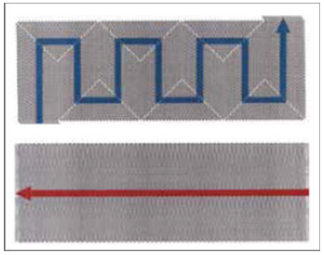
Efficient & Compact Process Equipment

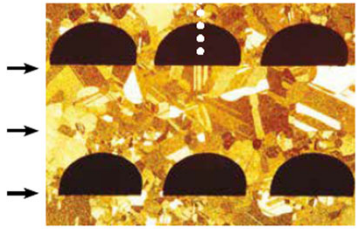
Print Circuit Heat Exchanger as District Heating Heat Exchanger



Heatric

MEGGITT





- High heat transfer coefficient & multipass flow – **efficient, compact fit for high duty**
- Low fouling (incl. filter integrated in the process) – **no performance degradation over time**
- Low pinch and approach temperature – **high performance (COP) and broad operating range**
- Stainless steal & diffusion bonding technology – **corrosion proof, no vibration by flow variation**
- Suitable for CO_2 at high pressure (supercritical) process conditions – **reliable design**

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Esbjerg

Port of Esbjerg, Denmark

Esbjerg: Order received for 50MW Seawater Heat Pump World's largest Heat Pump based on CO_2 as refrigerant

Press releases Project Esbjerg January 2021
DIN Forsyning and MAN ES

Press release DINF
20 article in DK published
Some international articles

Biomass boiler

Transformer house

Seawater heat pump building

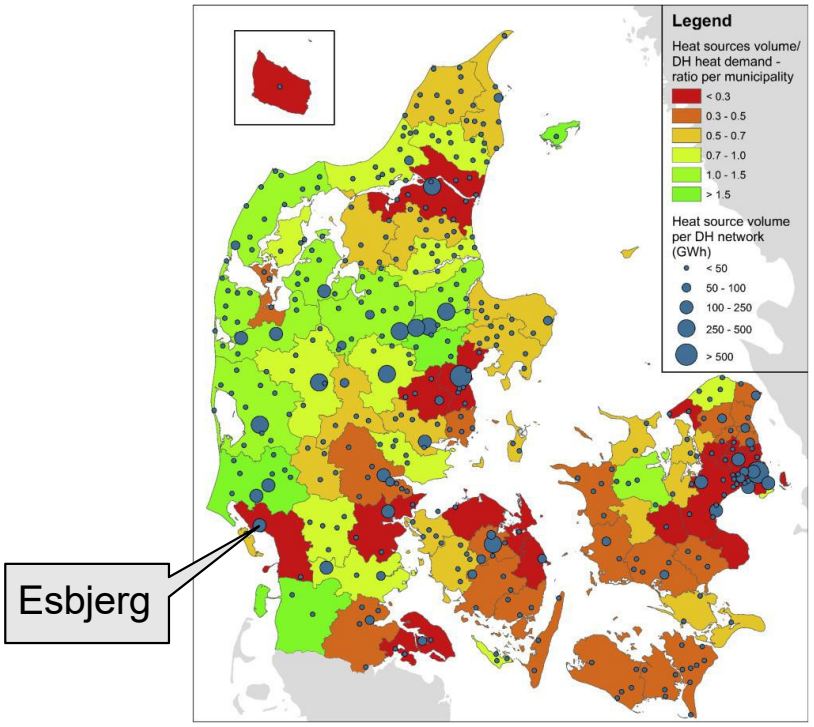
2 x 25 MW CO_2 Heat Pump units located in the machinery building

Press release MAN
– >20 article published and counting

Denmark: Highest renewable power production & largest district heating network

Electrify the heat!

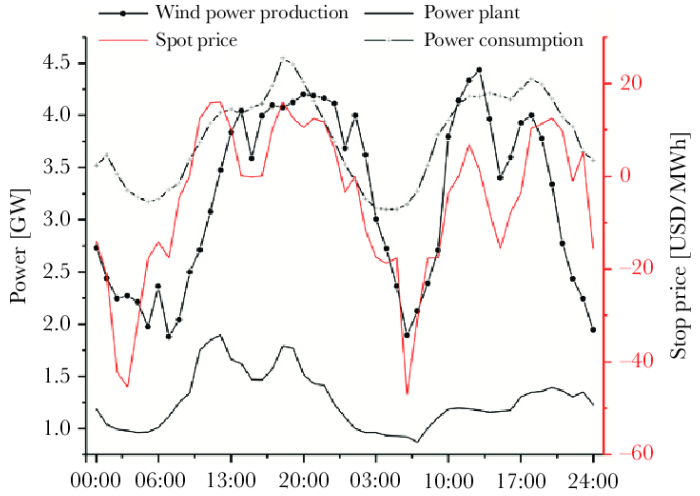
Wind and solar generation met up to 50% of Denmark's electricity demand during 2019



District heating coverage in Denmark

Heat Pumps provide power balancing

- **Mismatch** between power **consumption** and **production**
- Electrical spot **price vary** as wind blows and sun shines!
- **Balance of the grid**: consumption = production + import – export
- 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

Esbjerg at a glance

Seawater Heat Pump replacing coal

Heat Pump Building

District Heat
T_2

Green electricity

T_1

Sea as heat source

MAN ES scope of supply

Coal power plant supplying heat to be shut down in 2023

At a glance:

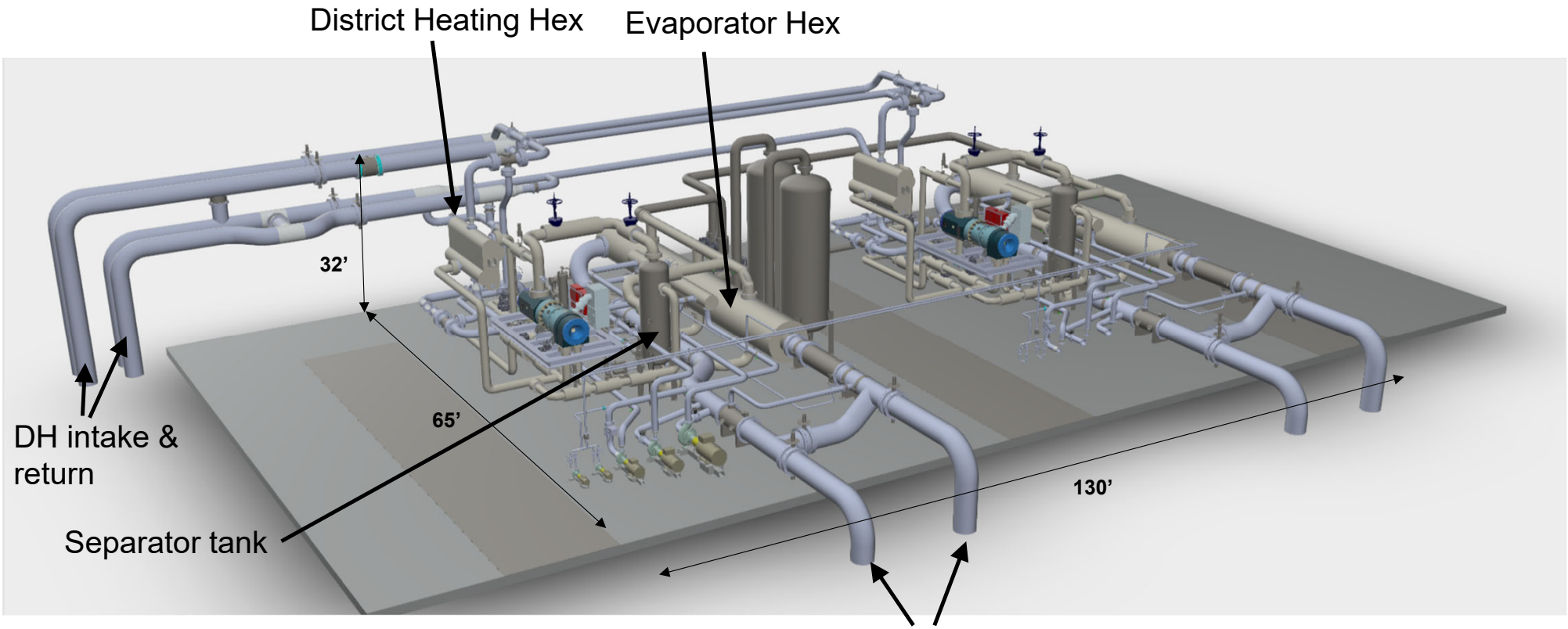
- District Heat for 25‘000 house holds
- CO_2 savings:100‘000 t = ~20‘000 cars
- CO_2 tax savings = ~ 120 Mio € (18 years)

Success factors:

1. Environmental friendly and safe refrigerant CO_2
2. Compact, reliable, future proof technology based on oil&gas industry standards
3. MAN ES and ABB as strong partner

Heat Pump Layout

General Arrangement



Two heat pump lines each with an heat supply power of 2 x 25 MW
Electrical scope not showed

ETES Summary

Future in the Making

- **Emission free - CO_2 neutral** thermal heat source
  - **100% decarbonized** with renewables integration
- **Large scale & high temperature heat-pump**
  - Output: **8-80 MW_{th}**
  - Storage Capacity: **120MW_{el}**
  - Max Supply Temperature: **302F**
- **Unmatched** Scalability and **Flexibility**
- **System ready to implement** – based on proven & reliable technology
- **Proof of Concept tested at scale in real world process conditions - (TRL7, 2020)**
- **First commercial project under execution - (TRL9, ~2023)**

Thank you!