

MAN Energy Solutions
Future in the making



sCO₂ Heat Pumps



Member of the Volkswagen Group

MAN Energy Solutions is part of a brand family



Passenger Car Business Area



VW



Audi



Skoda



Seat



Bentley



Porsche

+ Others

Commercial Vehicle Business Area



VWN

Nutzfahrzeuge



Scania



MAN
Truck
& Bus



Power Engineering Business Area

MAN Energy Solutions 

14,000 Employees worldwide

3.8 bn € Annual revenue



VW GROUP AT A GLANCE

284 bn €

Annual revenue

675,000

Employees worldwide

120

Global manufacturing locations

From Components to Solutions



Components

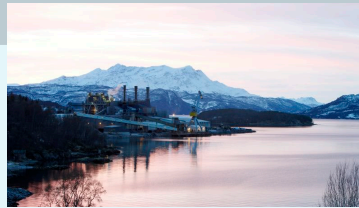
Engines & Marine Systems



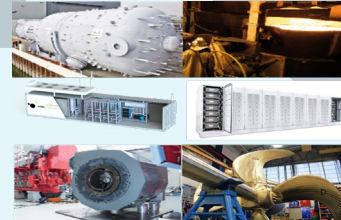
Power Plants



Turbomachinery



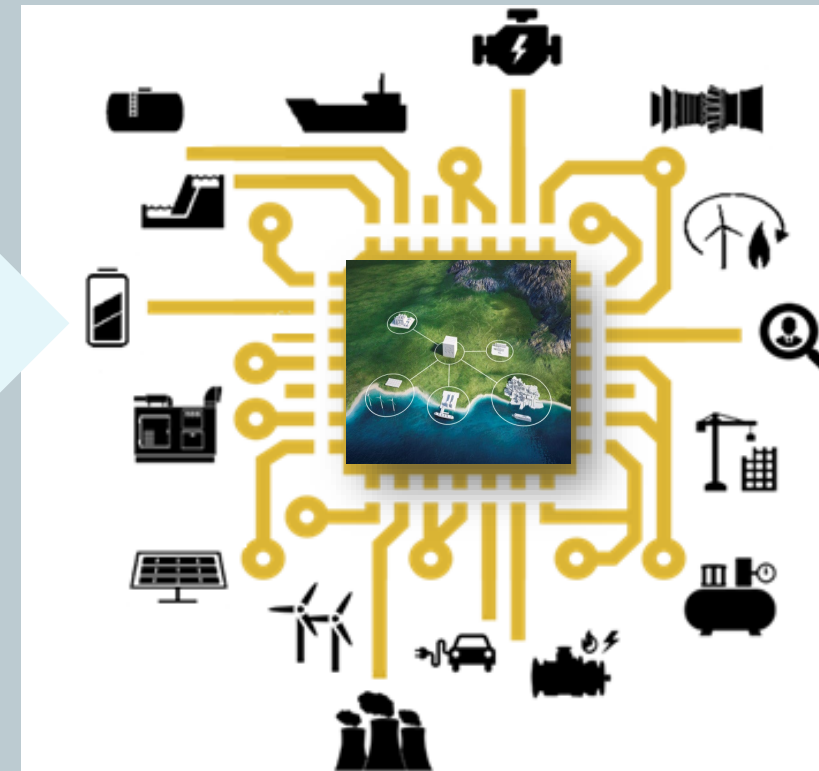
Customized Components



MAN PrimeServ



Solutions



Moving big things to zero

We engineer systems for deep decarbonization in sectors that matter most

Heat Pumps

Decarbonization of heat supply in industry and households



Carbon Capture

Solutions for unavoidable process emissions and carbon cycles



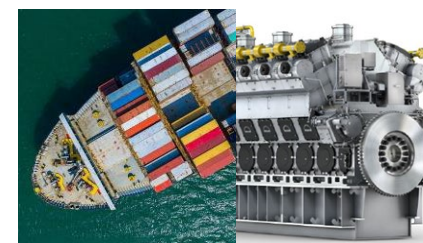
PEM-Elektrolysis

H₂ will play a key role for sectors where direct electrification is not possible.



Green Engines

CO₂-neutral propulsion systems for shipping and power generation



Retrofits

Decarbonization of our customers' existing fleets



These are the technologies we rely on to help our clients achieving the target of 'net zero'.

Why Heat Pumps

Global Energy Demand



Global Energy Consumption: Total 165,319 TWh (2021)

- Heat & Cooling is 50% of global energy consumption
- Heat contributes 40% of global carbon dioxide (CO₂) emissions.



Global Heat Consumption: 82,659 TWh (2021)

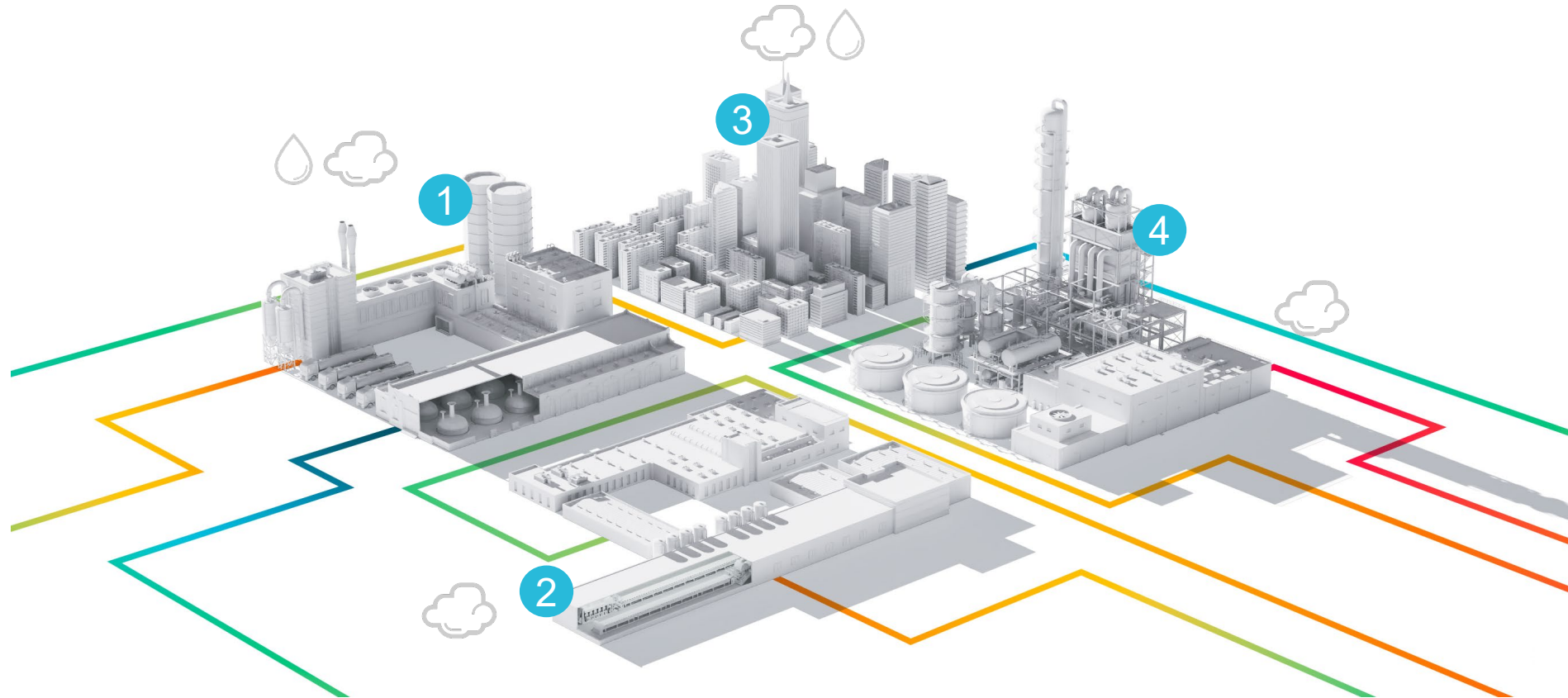
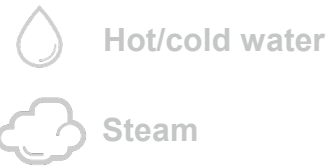
- 50% of total heat produced was used for industrial processes
- 46% was consumed in buildings for space and water heating and, to a lesser extent, for cooking
- Fossil fuels continue to dominate heat supplies
 - Modern renewables (i.e. excluding the traditional use of biomass) met only 10% of global heat demand.

Decarbonisation of thermal energy segment is critical to reduce global CO₂ emissions

Source: IEA – World Energy Outlook (2022) and Statista (2022)

MAN heat-pump solutions for various industrial segments

- 1 Food & Beverages**
4°C – 185°C
- 2 Pulp & Paper**
120°C – 180°C
- 3 District Heating**
20°C – 150°C
- 4 Industrial Processes**
120°C – 280°C



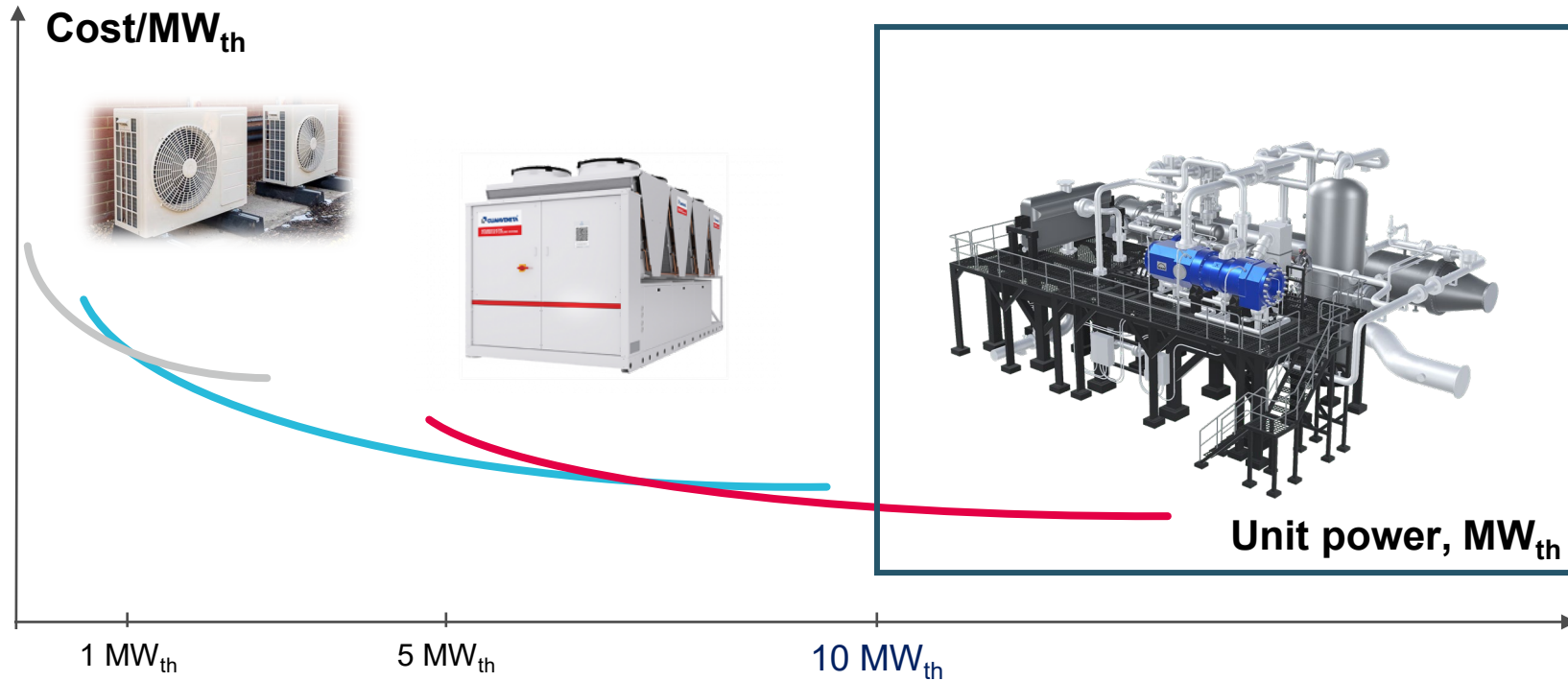
Heat Pump Technology Introduction



Heat Pump Technology Classification

Available large-scale heat-pumps by different compressor technologies

Sweet spot of centrifugal compressors
 — Scroll/Reciprocating
— Screw
— Centrifugal (inline and radially geared)



Use Classification

- < 2 MW_{th}, Residential, small commercial applications
- 5-10 MW_{th}, Commercial applications
- >10MW_{th}, Industrial or very large commercial applications

Usually, oil lubricated screws are used

For large unit power (>10MW) centrifugal compressors are most cost competitive

Source: Heat pump strategy project team

MAN-ES Portfolio Covers all Customer Use Cases

TCC, VCC, SC


Key customer use cases

Thermodynamic cycle

Value Proposition

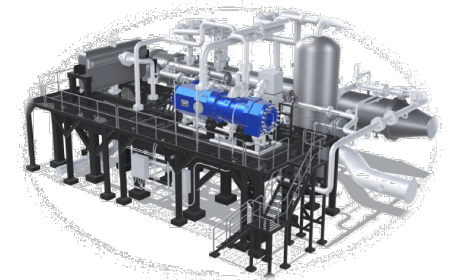
Covered by MAN-ES portfolio

Hot water production



Transcritical cycle (TCC)

- Fast response times and operations
- High COPs (for Water)
- Small Footprint
- Able to couple sectors (heat, electric, cooling)



Steam production



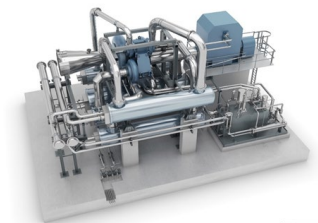
Vapor compression cycle (VCC)

- Direct Steam Generation
- High COPs (for Steam or Water)
- Large Thermal Capacities (up to 100MWth)
- Refrigerant Flexibility (Natural or Synthetic)



Steam compression (SC)

- Increases Steam Temperature
- Increases Steam Pressure
- Most competitive option to meet customers' needs for high pressure/temperature steam



VCC: Vapour compression cycle; TCC: Transcritical cycle; SC Steam Compression cycle

No Perfect Refrigerants

Potential refrigerant portfolio

■ Good
 ■ Medium
 ■ Unfavorable

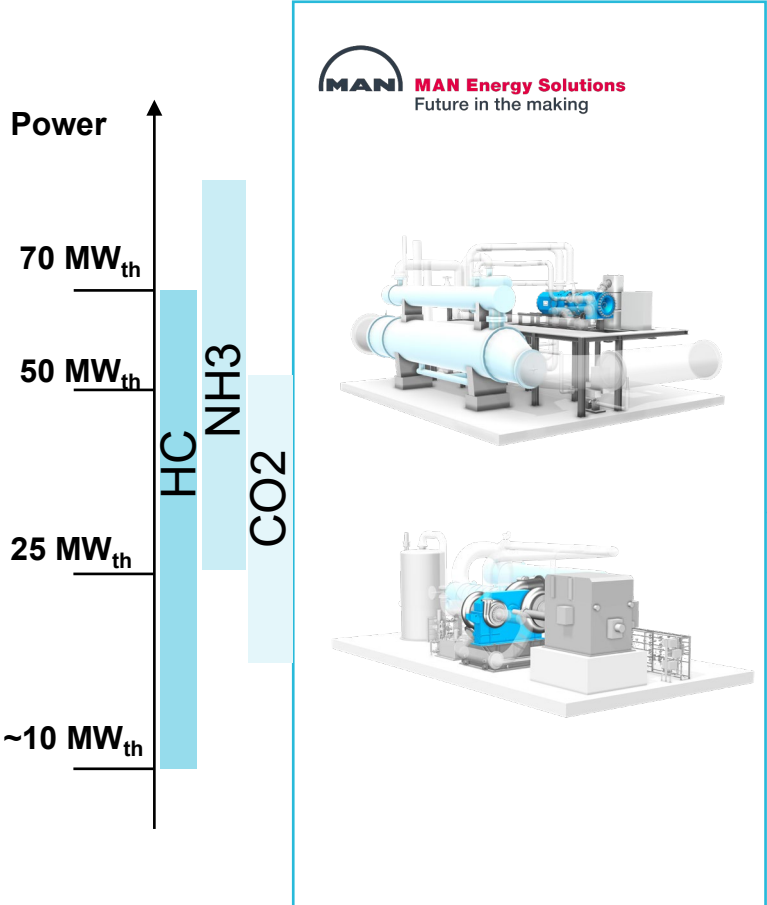
1. Only possible with low performance
2. Global warming potential
3. According to ASHRAE standards

	Sustainability		Safety ³		Technology		Key advantage
	GWP ²	Flourine	Toxicity	Flamm-ability	Max. temp.	Steam prod.	
CO2 (R744)	1	no	A	1	~135	no ¹	Non-toxic, non-flammable, non fluorinated refrigerant
Ammonia (R717)	0	no	B	2L	~115	yes	High performing natural refrigerant
Synth. Refrigerants (e.g., R1234ze)	<1	yes	A	2L	~135	yes	Safe refrigerant
Hydrocarbons (e.g., Butane)	<5	no	A	3	~135	yes	Non-toxic natural refrigerant (no fluorine)

There is no “perfect” refrigerant, a balanced portfolio should cover several ones

MAN Heat Pumps - Technical Solution Matrix

SOURCE / COOLING
<ul style="list-style-type: none"> – Seawater / River / Lake – Geothermal – Ambient Air – Waste Water / Sewage
<ul style="list-style-type: none"> – Waste Heat Recovery – Industrial Cooling
<ul style="list-style-type: none"> – CCS – P2X – Industries

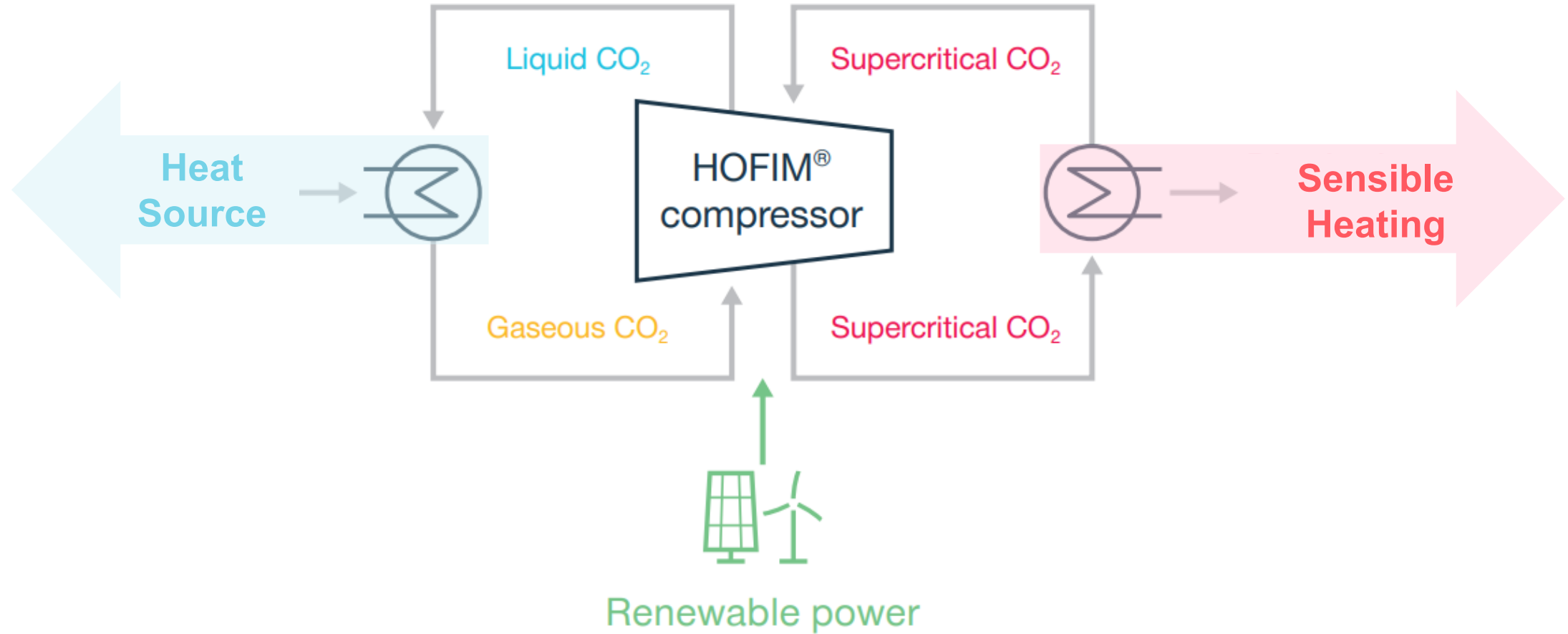


SINK / HOT SIDE
<ul style="list-style-type: none"> – Hot Water 95°C – Hot Water 125°C – Hot Water 150°+C
<ul style="list-style-type: none"> – Steam 1-3bar / 125°C – Steam 7bar / 160°C – Steam 25bar / 285°C

Trans-Critical CO2 Cycles

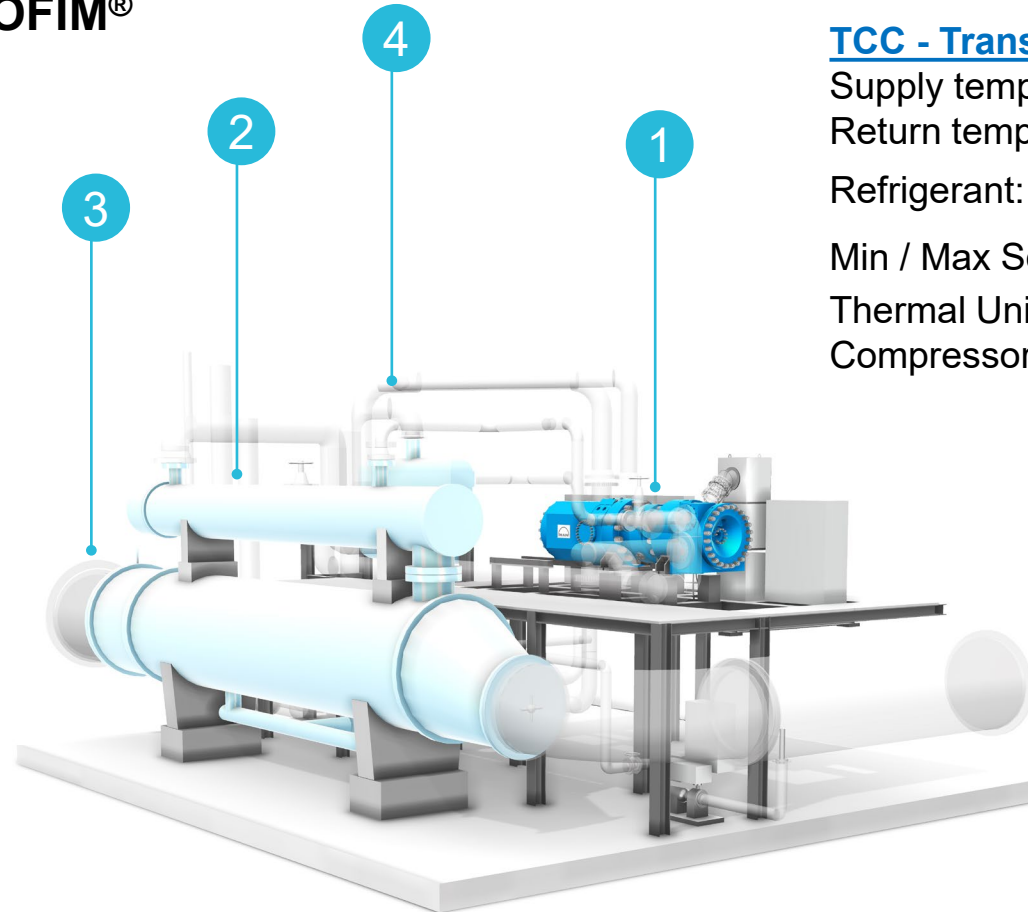


Heating & Cooling with TCC Heat Pumps



Transcritical CO₂ (TCC) heat-pump design

- 1 **Motor-Compressor HOFIM[®]**
w/ integrated expander
- 2 **Condenser**
- 3 **Evaporator**
- 4 **Piping and steel structure**



TCC - Transcritical Compression Cycle

Supply temperature range: up to 150°C
Return temperature range: best if < 50°C
Refrigerant: CO₂ (R744)
Min / Max Source Temperature: ~ -20°C / 40°C
Thermal Unit Power Range: 10MW ~>50+ MW
Compressor Types: HOFIM (RB)

The heart of the system: HOFIM[®] with integrated expander

HOFIM[®]: Highspeed oil-free integrated motor compressor from MAN Energy Solutions

- Highspeed motor, barrel compressor, radial expander
- Cooled by process gas – heat losses reintroduced into process
- Running on active magnetic bearings – **wide operating range**
- No dynamic seals, no lube oil – **increased reliability**
- Fully electric – **remote control**
- Hermetically sealed – **no emissions**
- Overall **cost optimization** through reduced footprint & weight
- **Low noise and vibrations**
- **Low maintenance**
- 30 years of operation with 126 references

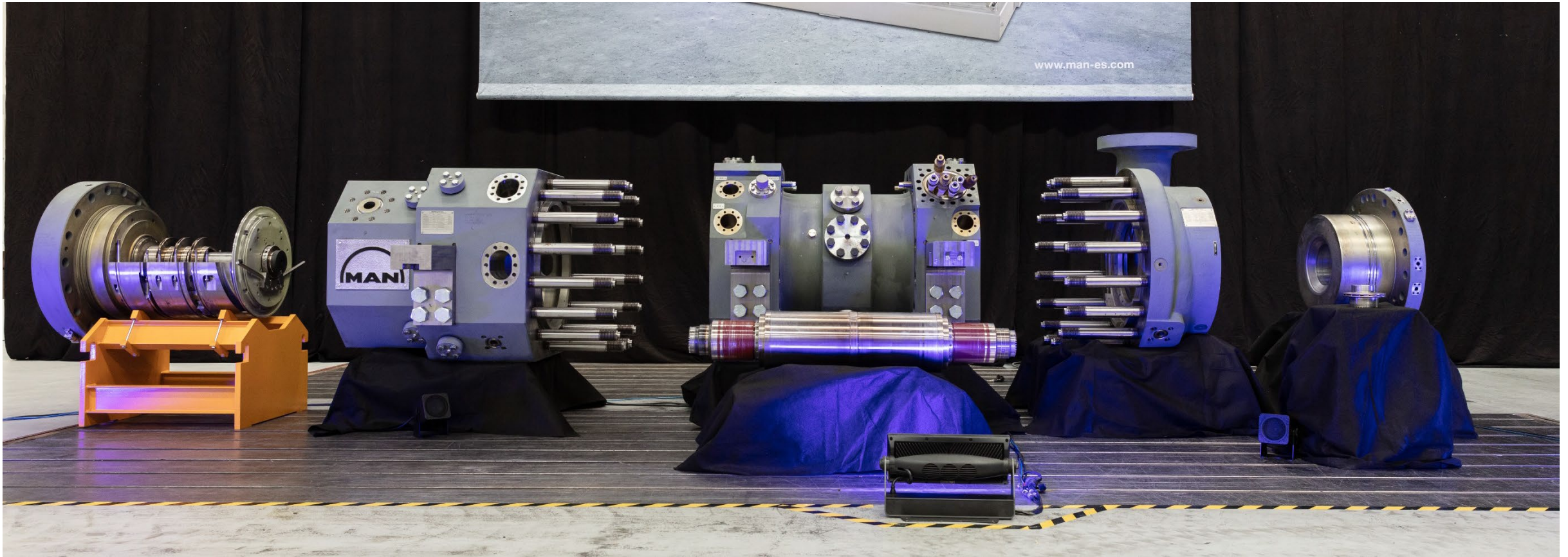


MAN ES HOFIM[®] compressor with electrical power of up to 14MW

	Framesize		
	M28	M33	M43
Elec. Power [MW]	4.9	8.8	14.1
Heat Power [MW]	>12	>25	>40

The heart of the system: HOFIM[®] with integrated expander

HOFIM[®]: Highspeed oil-free integrated motor compressor from MAN Energy Solutions



HOFIM[®] with integrated expander allows for up to 15% energy savings in heat pump applications. Picture shows the M28 frame size.

Beyond Theoretical



ETES Heat Pump Cycle

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

Achievements:

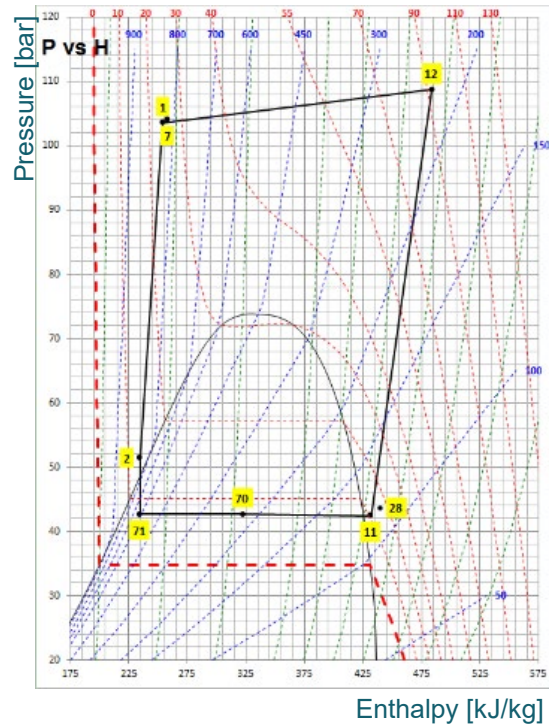
• Proof of Concept Trans-critical CO₂ HeatPump cycle ✓

- CO₂ Compression (superheated gas & multi-phase suction) ✓
- Supercritical cooling ("condenser") ✓
- Expansion from CO₂ supercritical to saturated liquid ✓
- Power recovery over an Expander stage ✓
- subcritical evaporation ✓

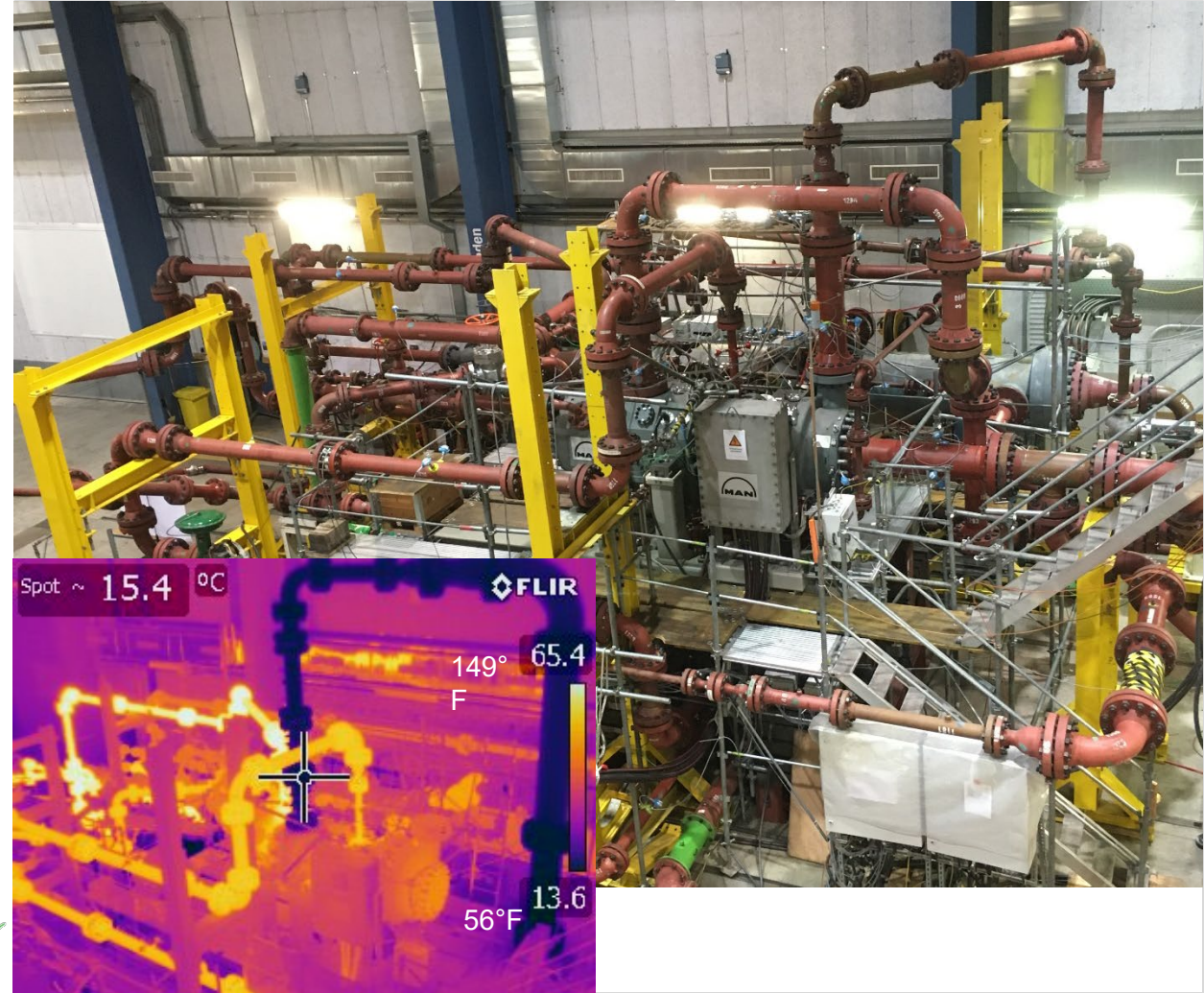
• Max. achieved process parameters:

- 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

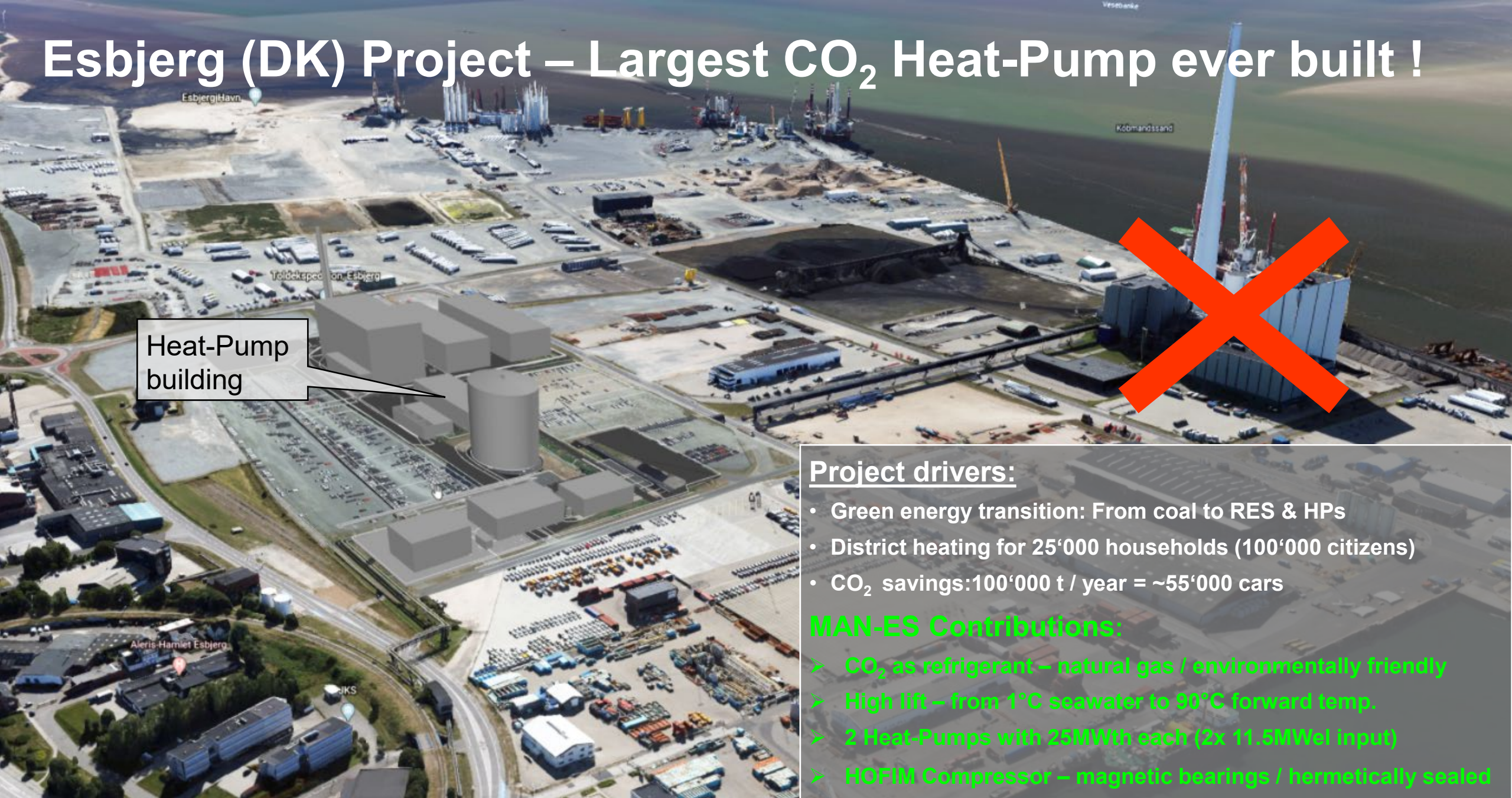
Test results on 11/13/2020:



comparable tests conditions with real project applications!



Esbjerg (DK) Project – Largest CO₂ Heat-Pump ever built !



Heat-Pump building

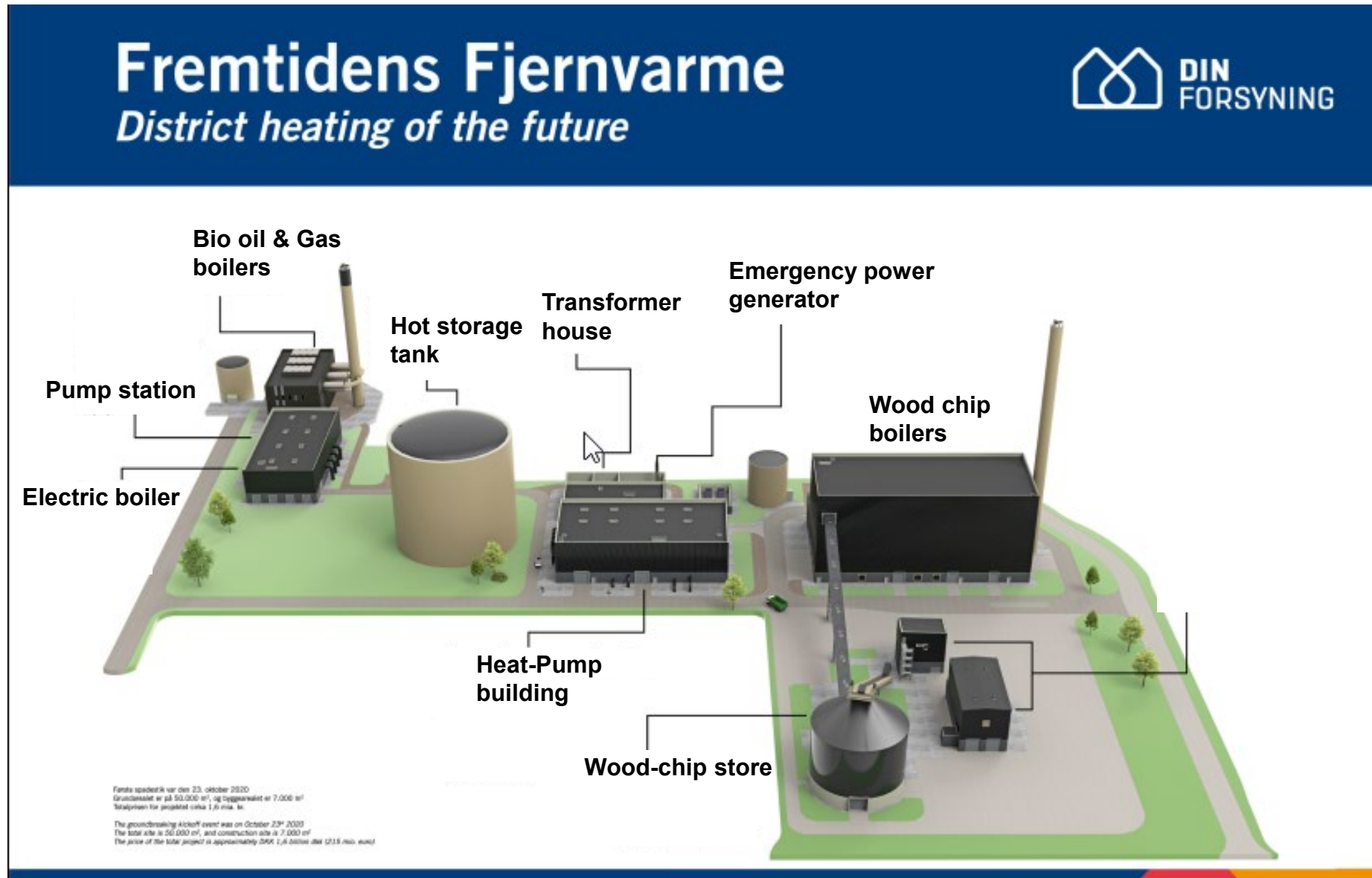
Project drivers:

- Green energy transition: From coal to RES & HPs
- District heating for 25'000 households (100'000 citizens)
- CO₂ savings: 100'000 t / year = ~55'000 cars

MAN-ES Contributions:

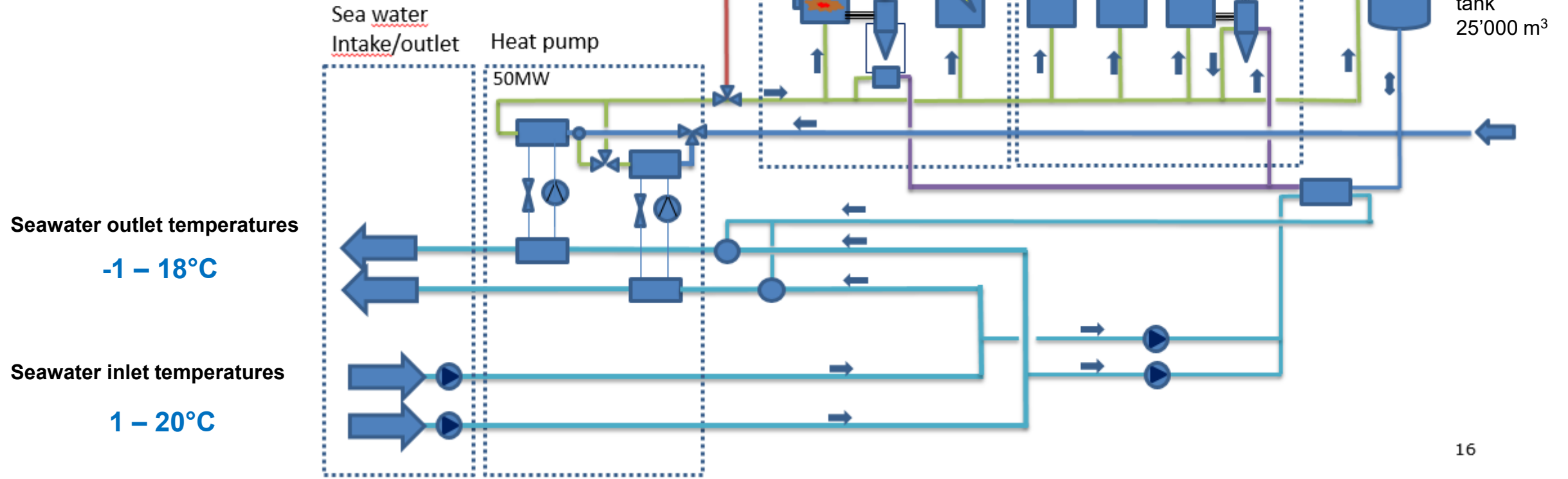
- CO₂ as refrigerant – natural gas / environmentally friendly
- High lift – from 1°C seawater to 90°C forward temp.
- 2 Heat-Pumps with 25MWth each (2x 11.5MWel input)
- HOFIM Compressor – magnetic bearings / hermetically sealed

Esbjerg (DK) project – Heating sources for District heating



Esbjerg (DK) project

- Forward temperatures to network 70-90°C
- Return temperatures 33° – 39°C
- COP 3.3 (winter) – 3.5 - 4 (summer)
- Heat-Pumps: 2x 25MWth / 2x 11.5MWeI input
- From turndown 50% to 100% in <30sec.
- 4000 litre of water per second / 48'' evap pipes



Esbjerg (DK) project



MAN Compressor in Zurich factory



MAN Compressor @ site in Esbjerg



CO₂ storage tank

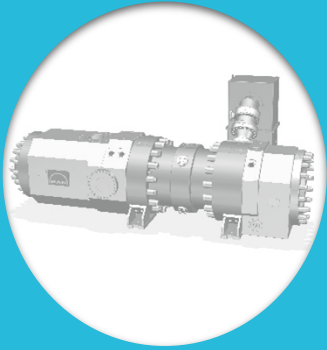


Evaporator - Length: 17m / 60 tons

Esbjerg (DK) project



Esbjerg HOFIM & Testing Program (March 2022)



Core Machine



Motor

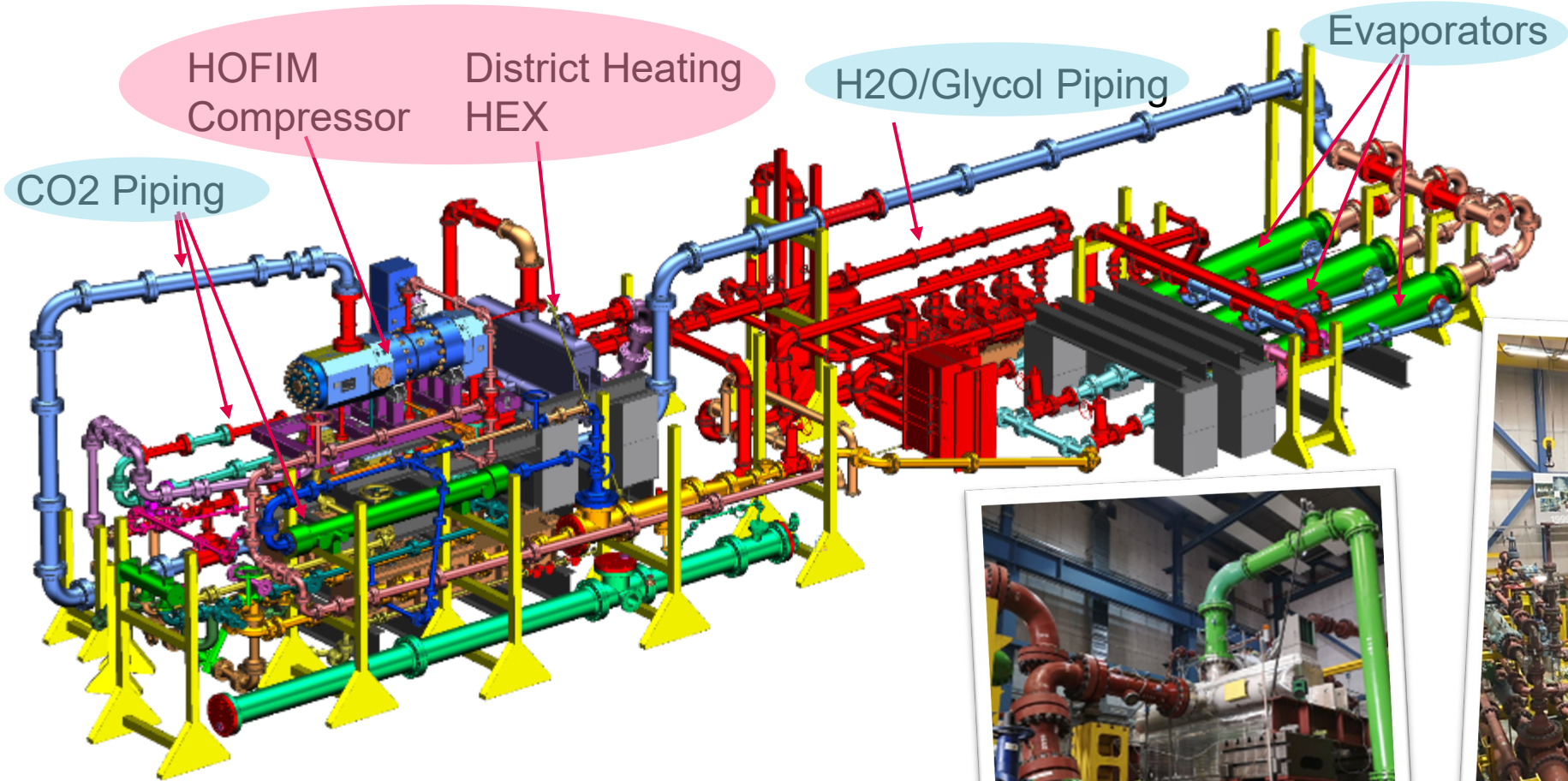
Compressor





Expander

Esbjerg Heat Pump Factory Test

Setup for Technology Validation and Project Derisking

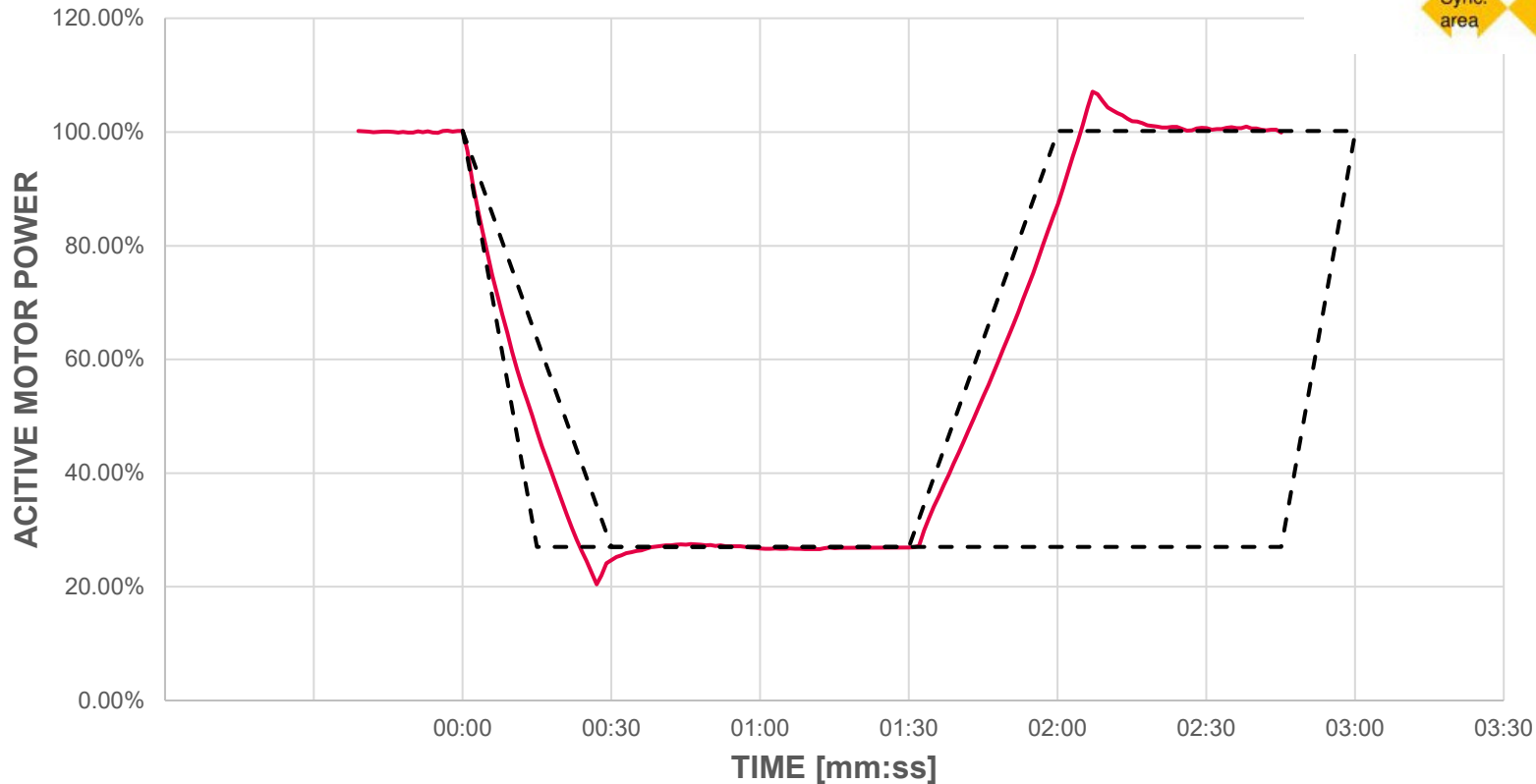
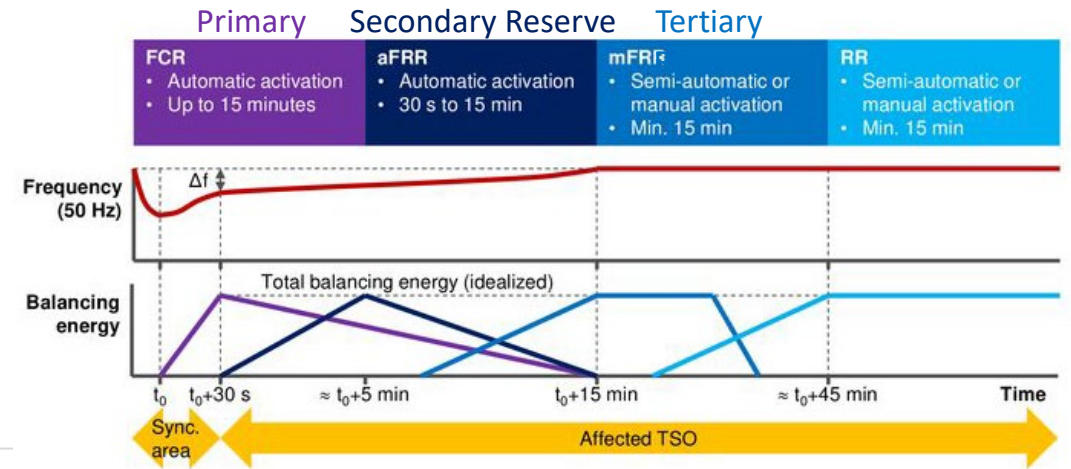


-  = Job Equipment
-  = MAN Testbed Equipment



Flexibility – Grid Response

Primary Reserve Requirements vs Test data



— NI_ChannelName - [kW]

- - - Min Response

- - - Max Response



Typical process start-up and shut-down

From 0rpm to 7400rpm full load and back test.

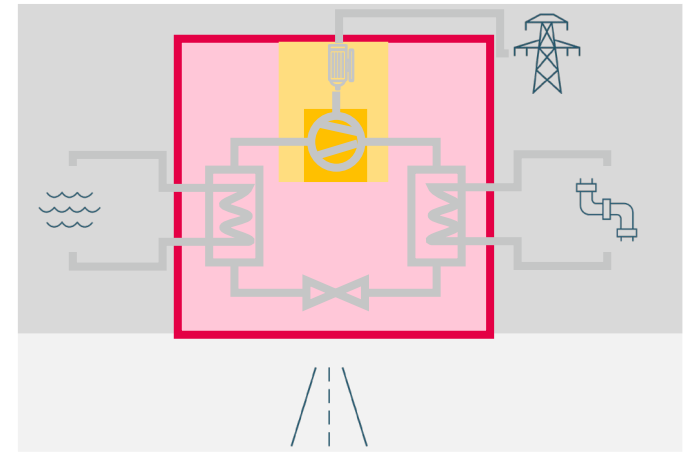


Esbjerg (DK) project



MAN scope of works

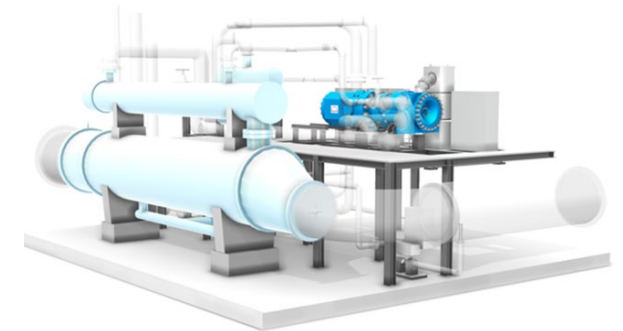
Project scope



Typical scope of delivery

MAN Energy Solutions delivery

- Compressor unit
- Heat Exchangers (Condenser & Evaporator)
- Complete piping and steel structure
- Refrigerant tank
 - Valves, instrumentation, connecting cables, water pumps, seawater pumps
 - Complete electrical scope including drivers/starting equipment
 - Complete control system
 - FAT of main equipment
 - Installation and commissioning
 - On site testing



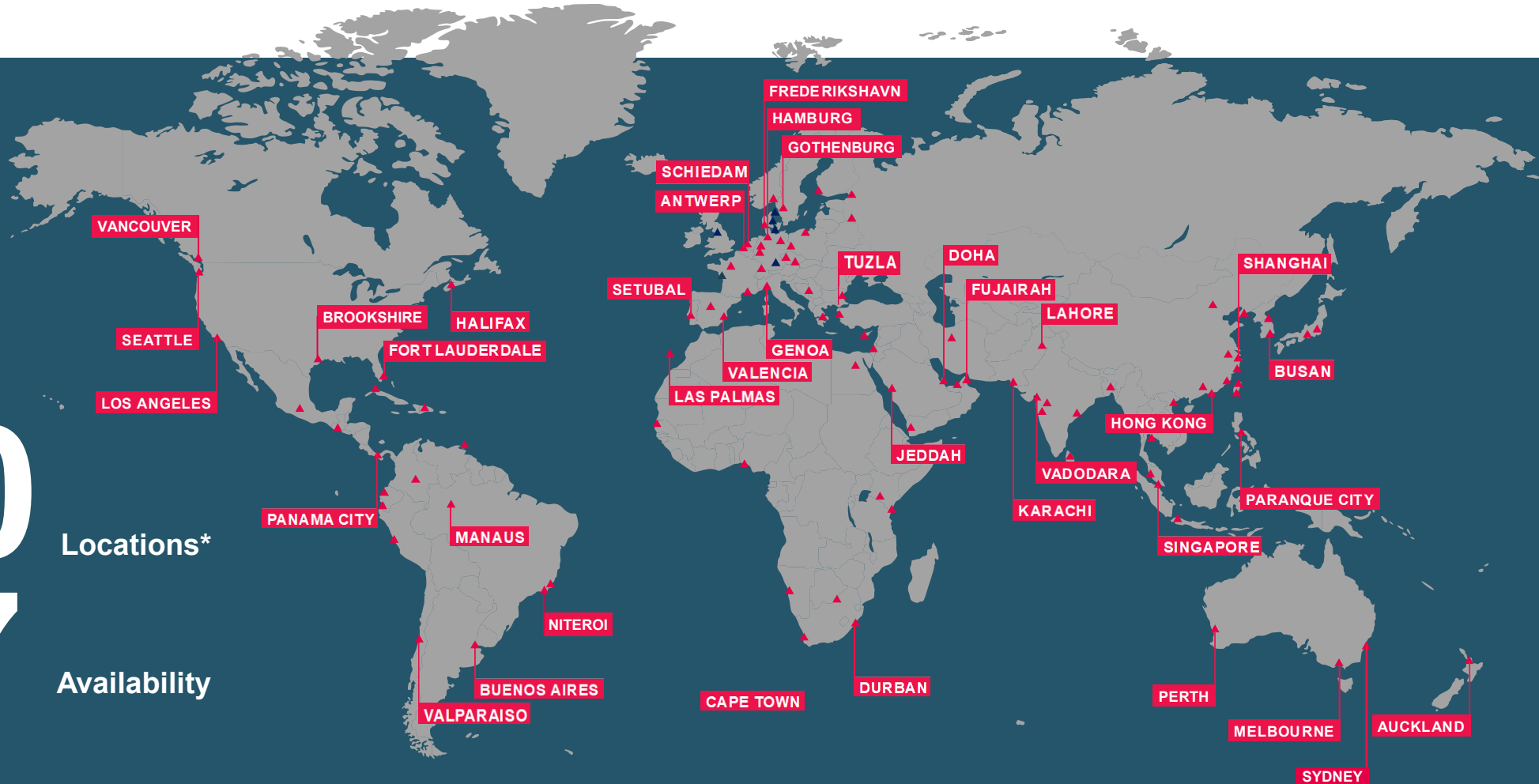
Grid, heat-sink and heat-source connection

Civil work (e.g. roads, buildings)

Our Global Network



>140 Locations*
24/7 Availability



*Number of countries served by headquarters, service locations or responsible sales partners.



Thank you!



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