MAN Energy Solutions
Future in the making

MAN ETES Electro Thermal Energy Storage

With sector coupling, Heat-Pumps & Energy Storage to Decarbonization

Pioneers think differently !

Raymond.Decorvet@man-es.com
Business Development ETES

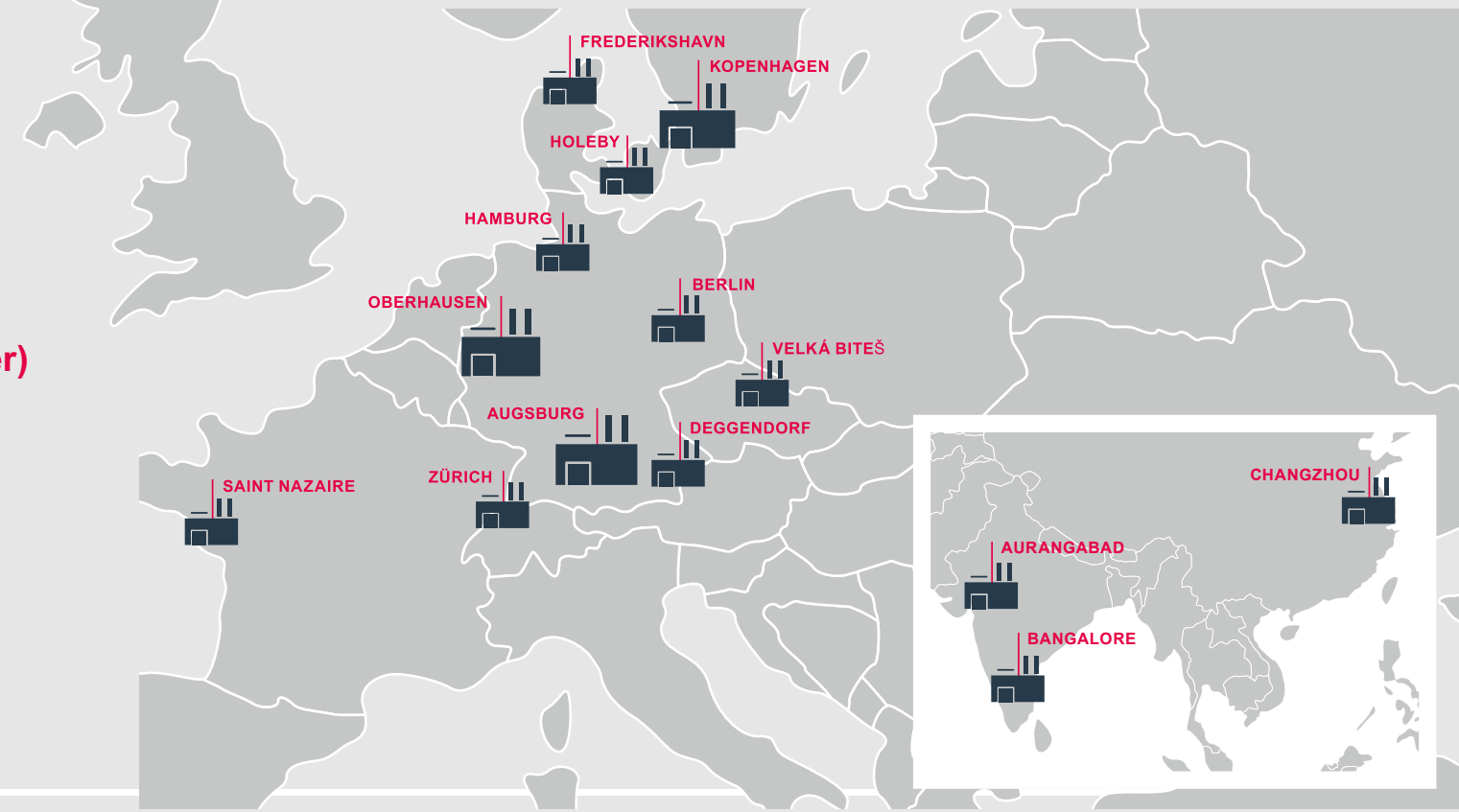
MAN Energy Solutions @ a Glance

Vision:

Building on our unique range of capabilities, we create pioneering solutions to master the business, technical, and operational challenges of decarbonization.

We enable customers to achieve sustainable value creation in the transition towards a carbon neutral future.

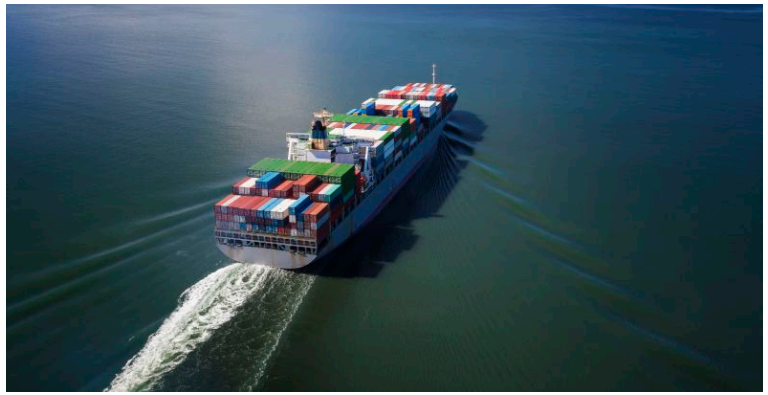
11	Production sites in Europe
3	Production sites in Asia
30	Licensees in 7 countries (two- and 4-stroke, turbocharger)
+14’000	Employees worldwide
3.4bn €	Revenue 2019
HQ	Augsburg / Germany



MAN Energy Solutions Industry segments

Our other contributions to Sustainability & Decarbonization

Engines & Marine Systems



- Clean Fuels
- Hybrid Drives
- Exhaust gas treatment
- Gas Engines (LNG)
- Turbochargers
- Efficiency Management

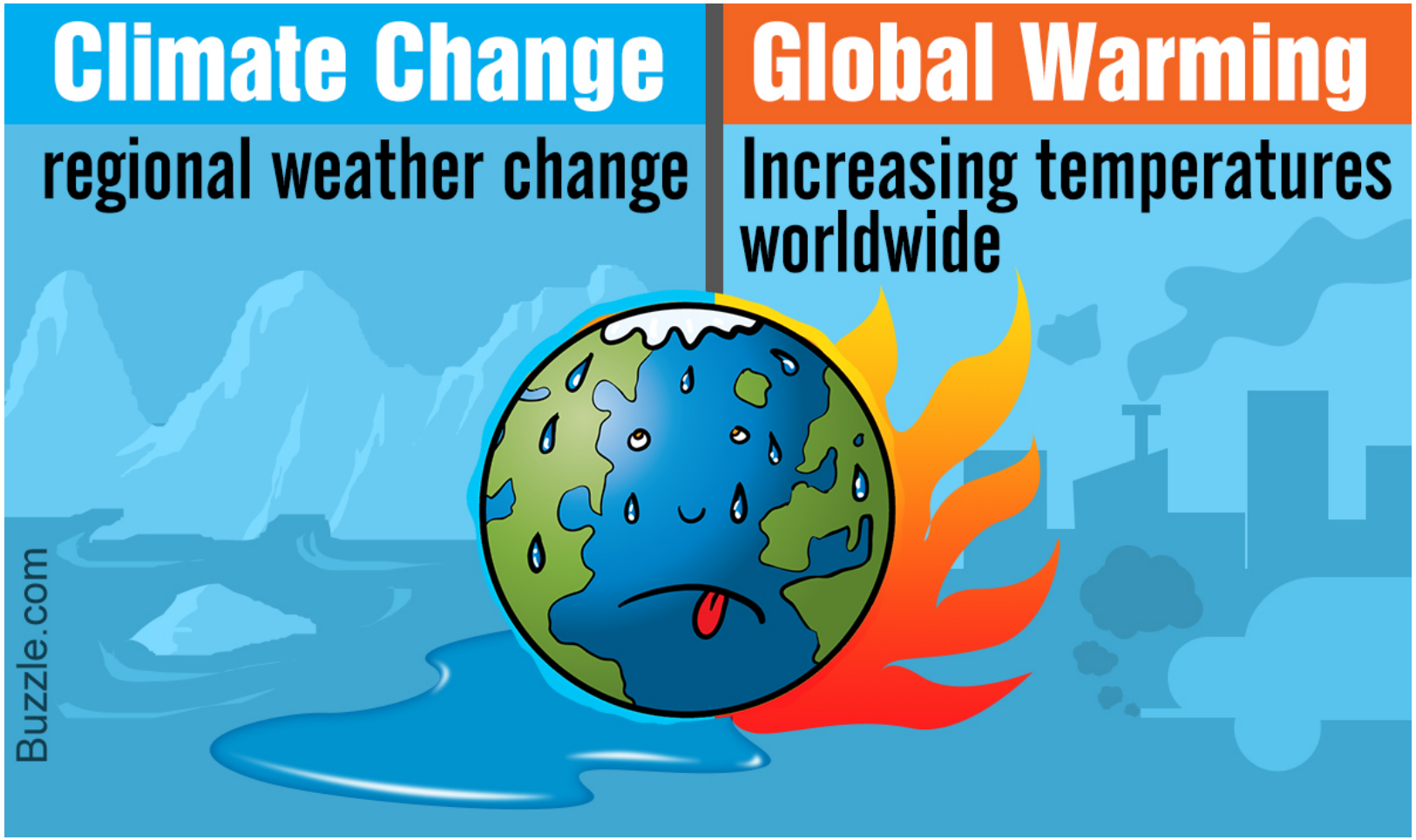
Power Plants

- Hybrid Power Plants
- Microgrids
- RES & MAN Turbines
- Renewable Energy Storage

Turbomachinery

- Oil & Gas Industry
- Process Industry
- Energy Efficiency
- Vacuum Systems
- Flare Gas reduction

Climate Change & Global Warming is real!

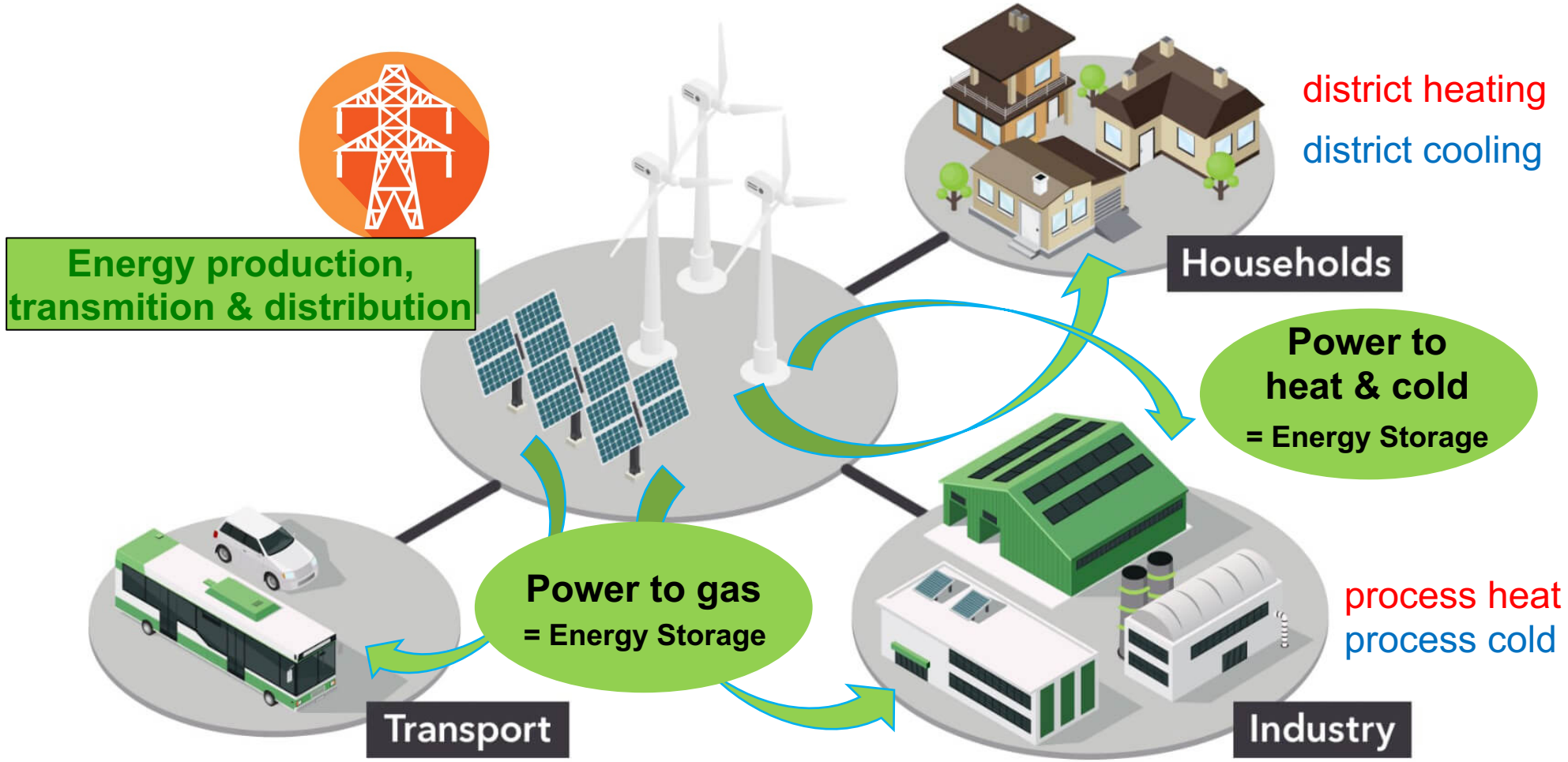


Decarbonisation & CO_2 reduction is <u>THE</u> option !

Ways forward towards decarbonisation heat & cold production

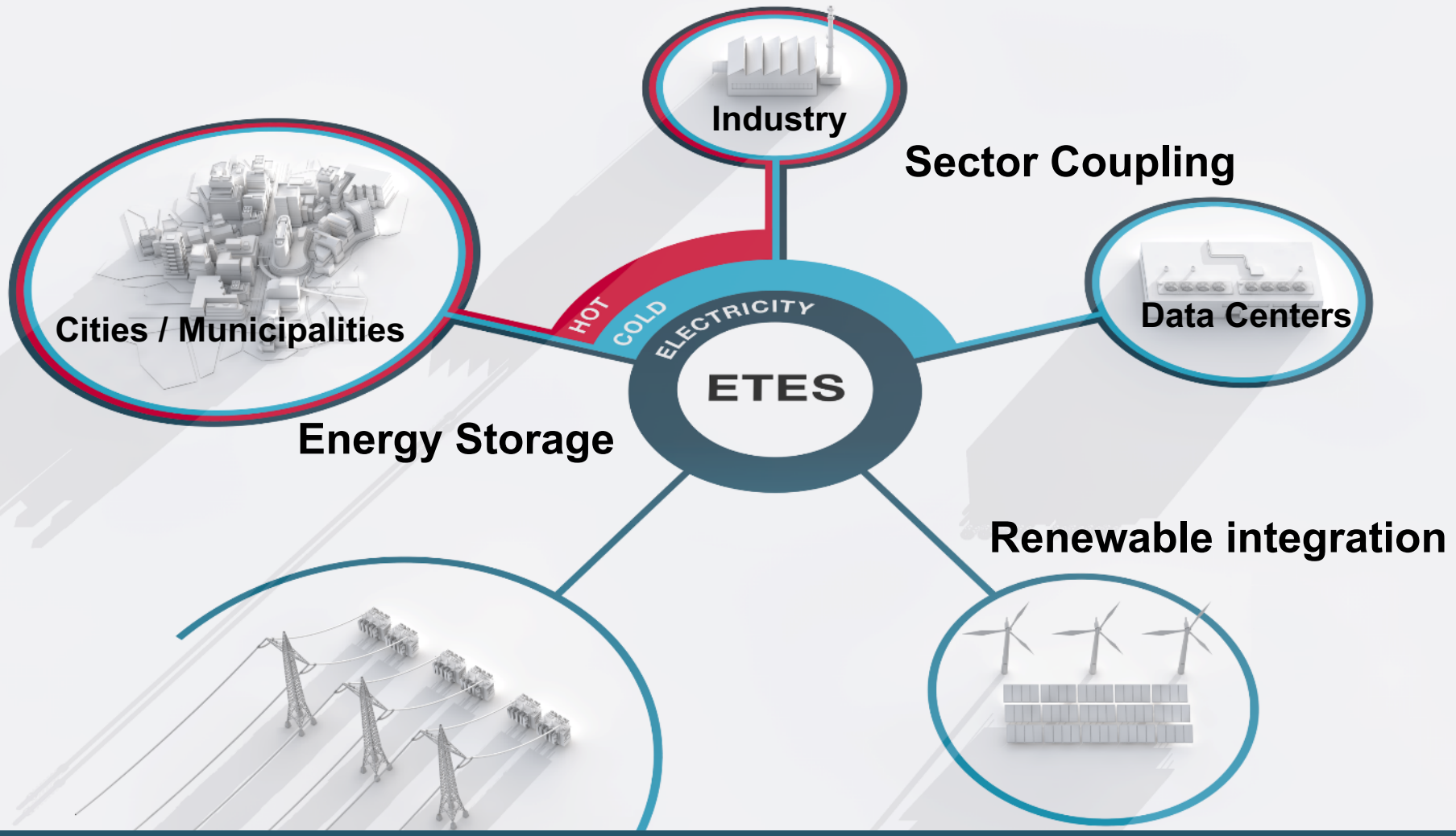
- Reduce energy consumption
- Increase energy efficiency
- Sector coupling
- Invest in technologies that support climate goals
  - ➢ renewables
  - ➢ heat-pumps
  - ➢ energy storage

Sector Coupling – The players and stakeholders



Source: NPROXX

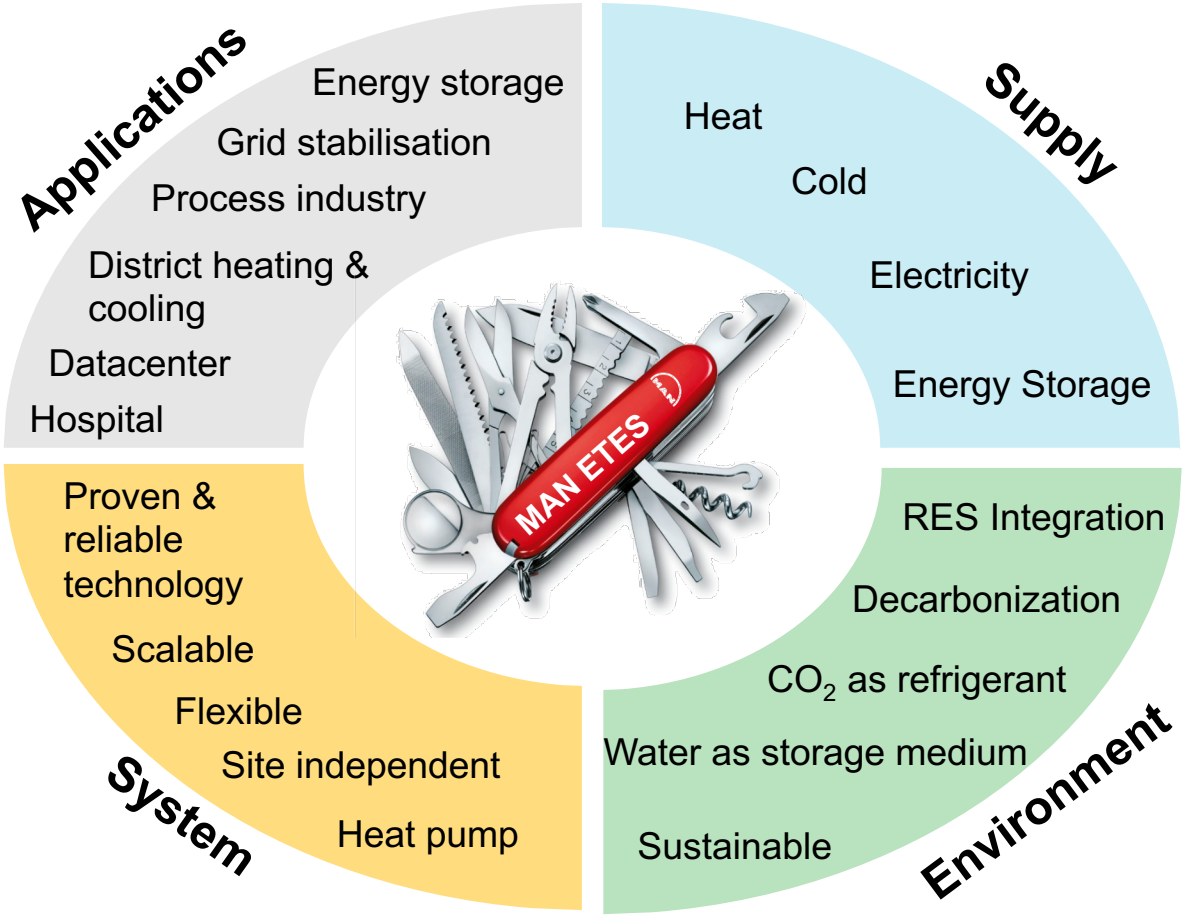
MAN’s contribution to Sector Coupling



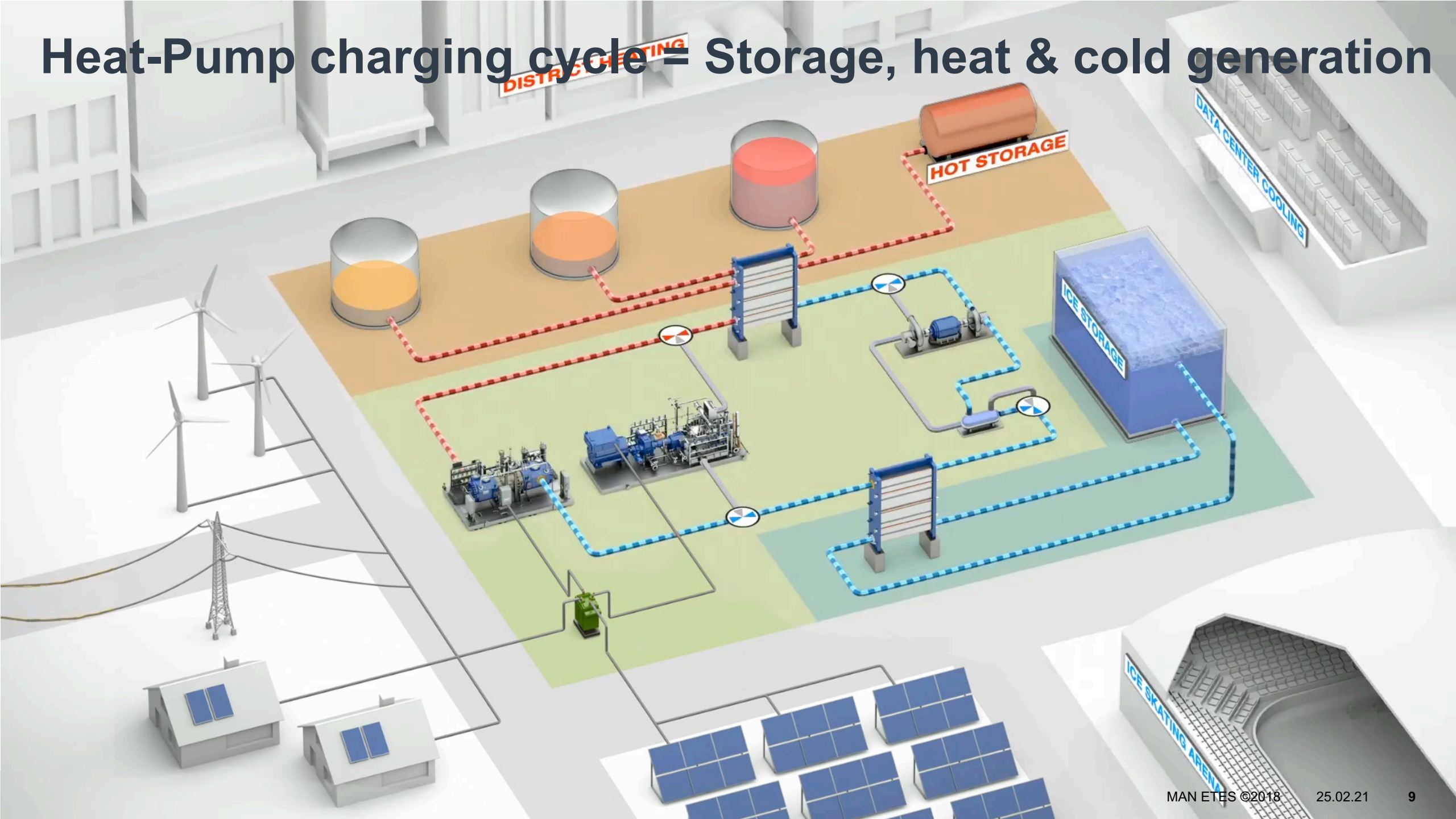
MAN ETES is a tri-generation energy management system

MAN ETES at a glance

- Large scale **trigeneration** multifunctional **energy storage** solution for **heat, cold & electricity**
- **Volumes: 80** MW_{th} and **128** MWh_{el} day/ETES
- **Charging / Discharging** optimisation (arbitrage)
- Temperature levels **(0° - 150° C)** ideal for **sector coupling** (e.g. district heating & process industry)
- **Lifetime:** +35 years
- **NO** efficiency degradation during lifetime



Heat-Pump charging cycle = Storage, heat & cold generation



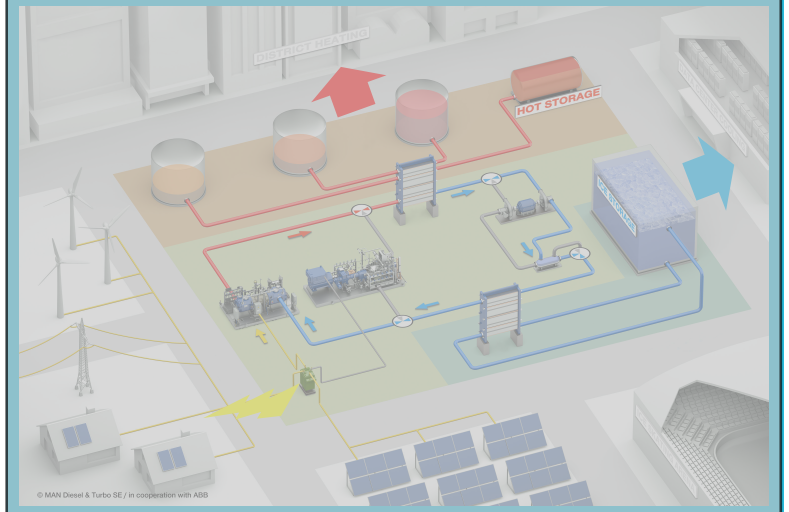
System Flexibility & Scalability – Hot & cold production

Base System Configuration Options

(Compressor ranges: 2 – 18MW electrical input)

MAN ETES

- Heat pump
- Storage
- Re-electrification

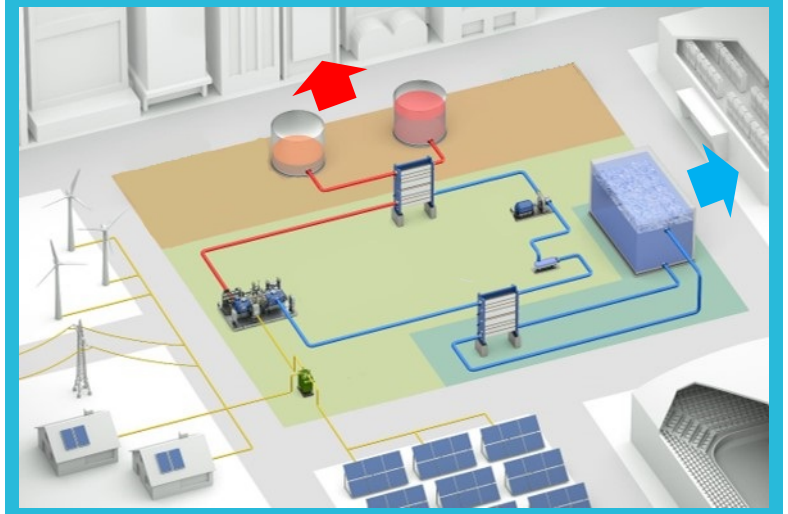


Supply:

- Electricity (primary)
- Heat & cold (0° - 150°C)
- Heat & cold storage (0° - 150°C)

MAN ETES "light"

- Heat pump
- Storage



Supply:

- Heat & cold (0° - 150°C)
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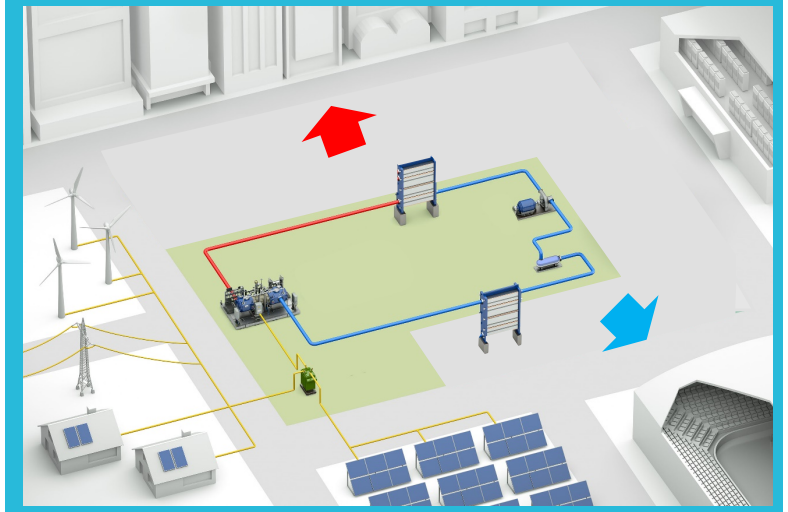
MAN Heat Pump

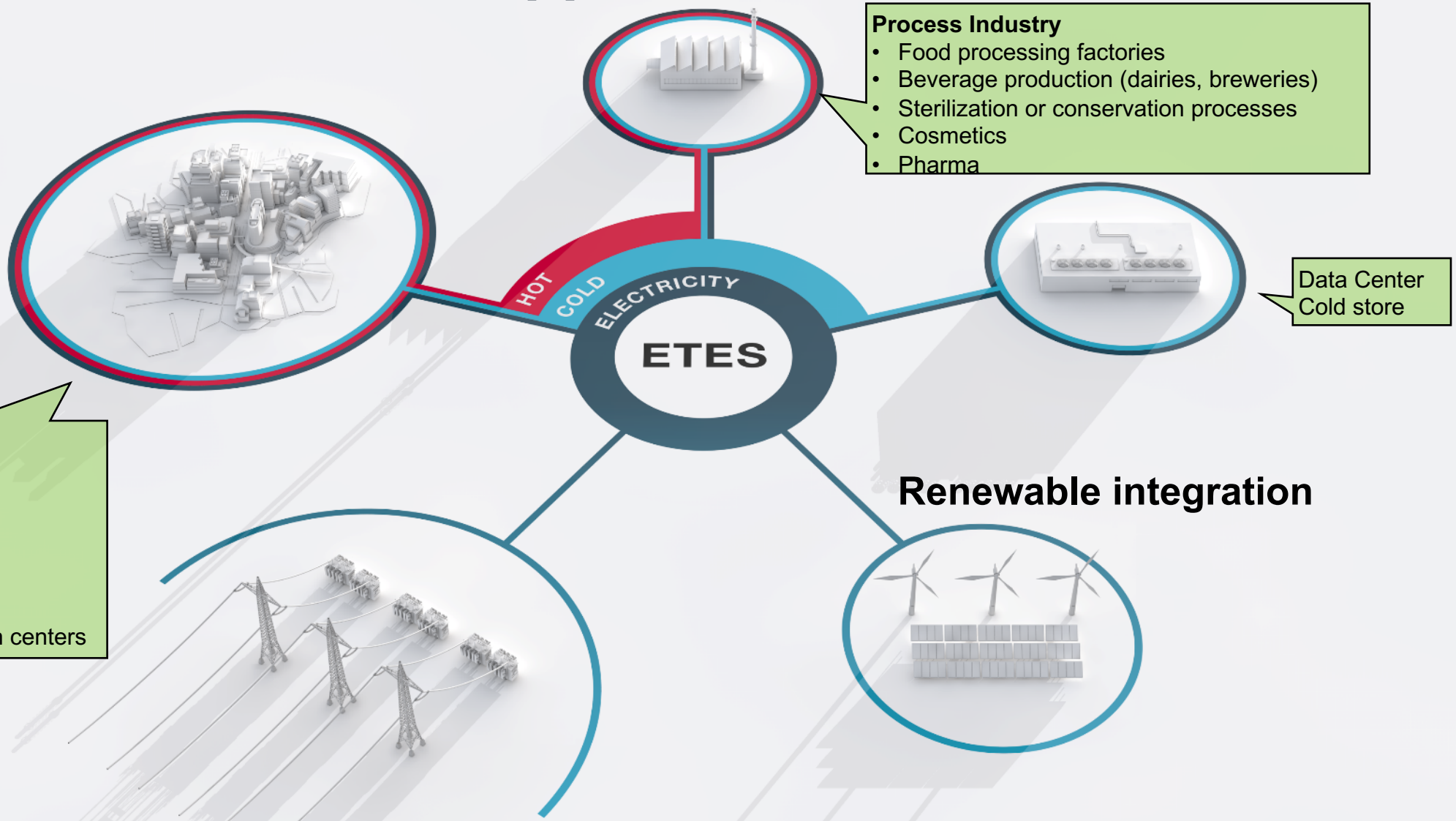
- Heat pump



Supply: (7x24)

- Heat & cold (0° - 150°C)

MAN ETES – Heat & cold applications



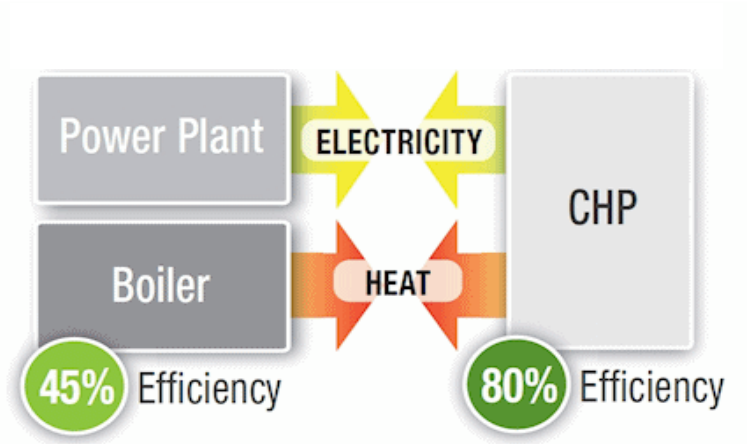
Process Industry
- Food processing factories
- Beverage production (dairies, breweries)
- Sterilization or conservation processes
- Cosmetics
- Pharma

Data Center
Cold store

- District heating
- District cooling
- Industry parks
- Hospitals
- Airports
- University campus
- Shopping malls
- Hotels & convention centers

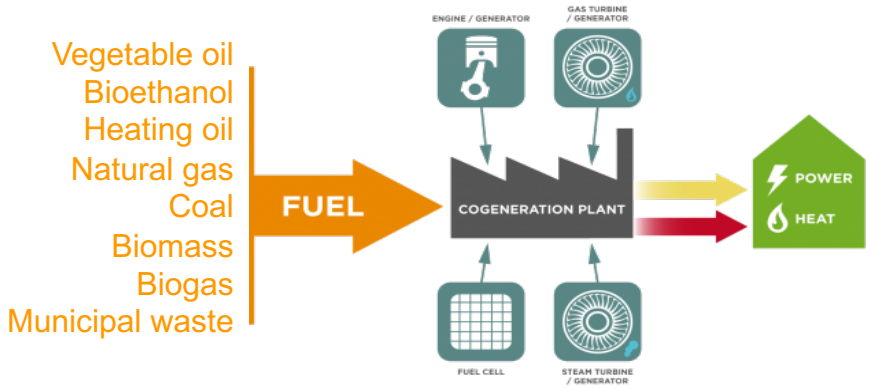
Renewable integration

Replacing CHP systems for District Heating

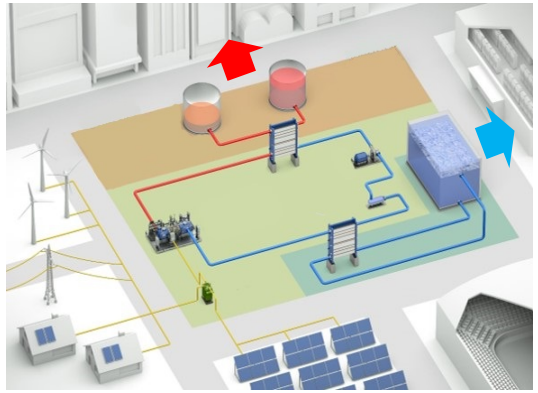


Source: Missouri Division of Energy

CO_2 emission – polution - waste of environment resources !



Source: Association for Decentralised Energy



One MAN HP-unit provides up to:

- 48 $MW_{thermal}$ heat and
- 32 $MW_{thermal}$ cold
- Temperatures up to 150°C
- Short-term and/or Seasonal storage
- Electricity (Power Storage)

Zero CO_2 emission & polution, environmentally friendly

Boiling the water of an Olympic size swimming pool

- Length: 50m
- Width: 25m
- Depth: 2m
- Water: 2.5 million litres
- 20°C

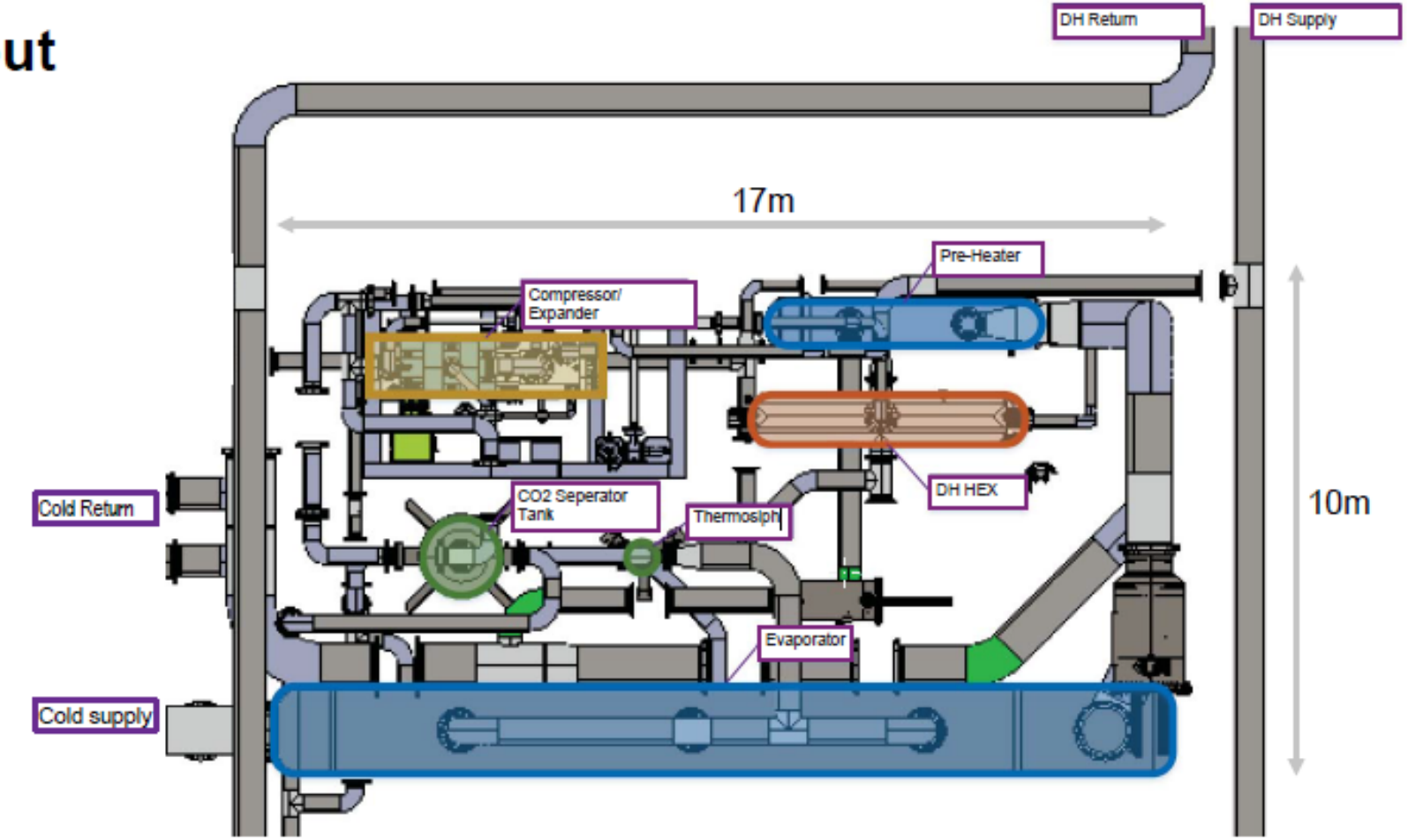
in

< 4 hours

ETES Heat-Pump unit without storage

Layout

Typical



District cooling / heating networks

Centralised heat & cold production

Decentralised heat & cold production

Heat sources for ETES light & MAN heat-pump

Source: lghvacstory.com

Water / liquid

Source: Rogers & Sons

Geothermal

Air

Hot & cold storage systems

Underground caverns

Hot water tanks

1’000 – 50’000 m^3

Pit heat storage
up to 1.5 – 2.0 mio m^3

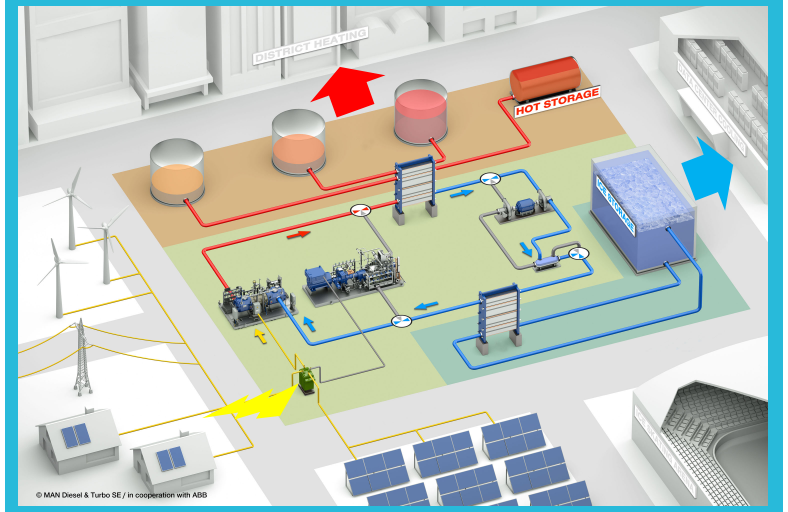
System Flexibility & Scalability

Base System Configuration Options

(Compressor ranges: 2 – 18MW electrical input)

MAN ETES

- Heat pump
- Storage
- Re-electrification



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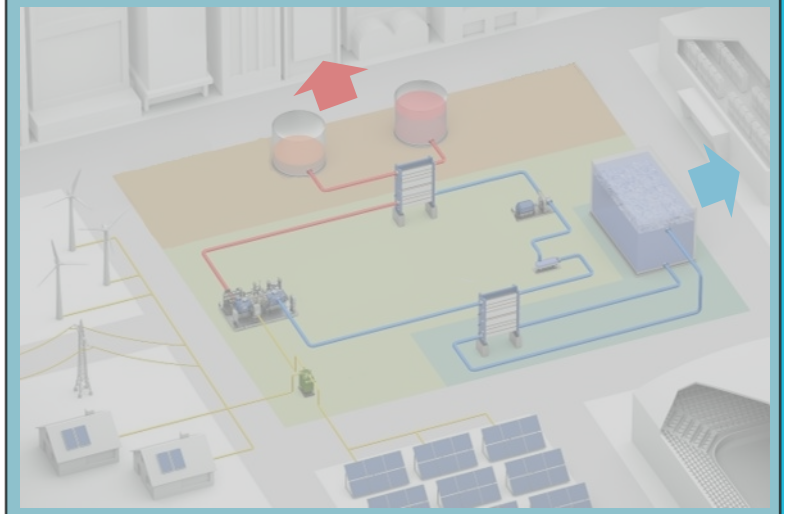
MAN ETES "light"

- Heat pump
- Storage

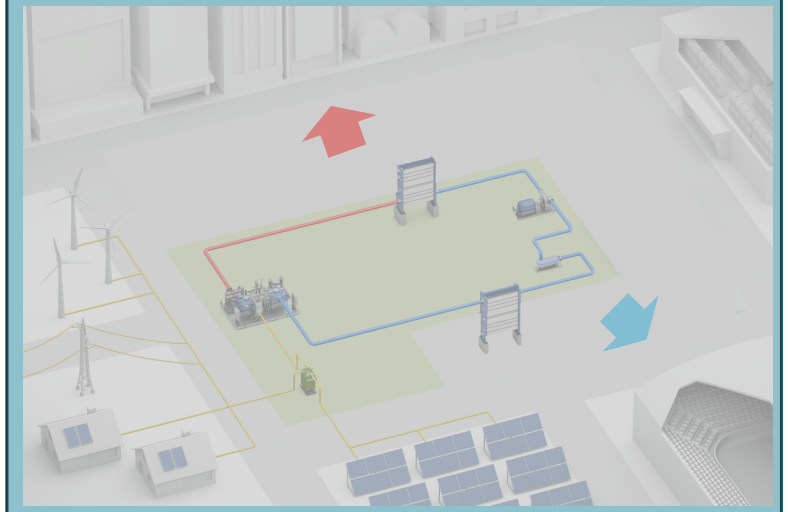


Supply:

- Heat & cold **(0° - 150°C)**
- Heat & cold storage **(0° - 150°C)**

MAN Heat Pump

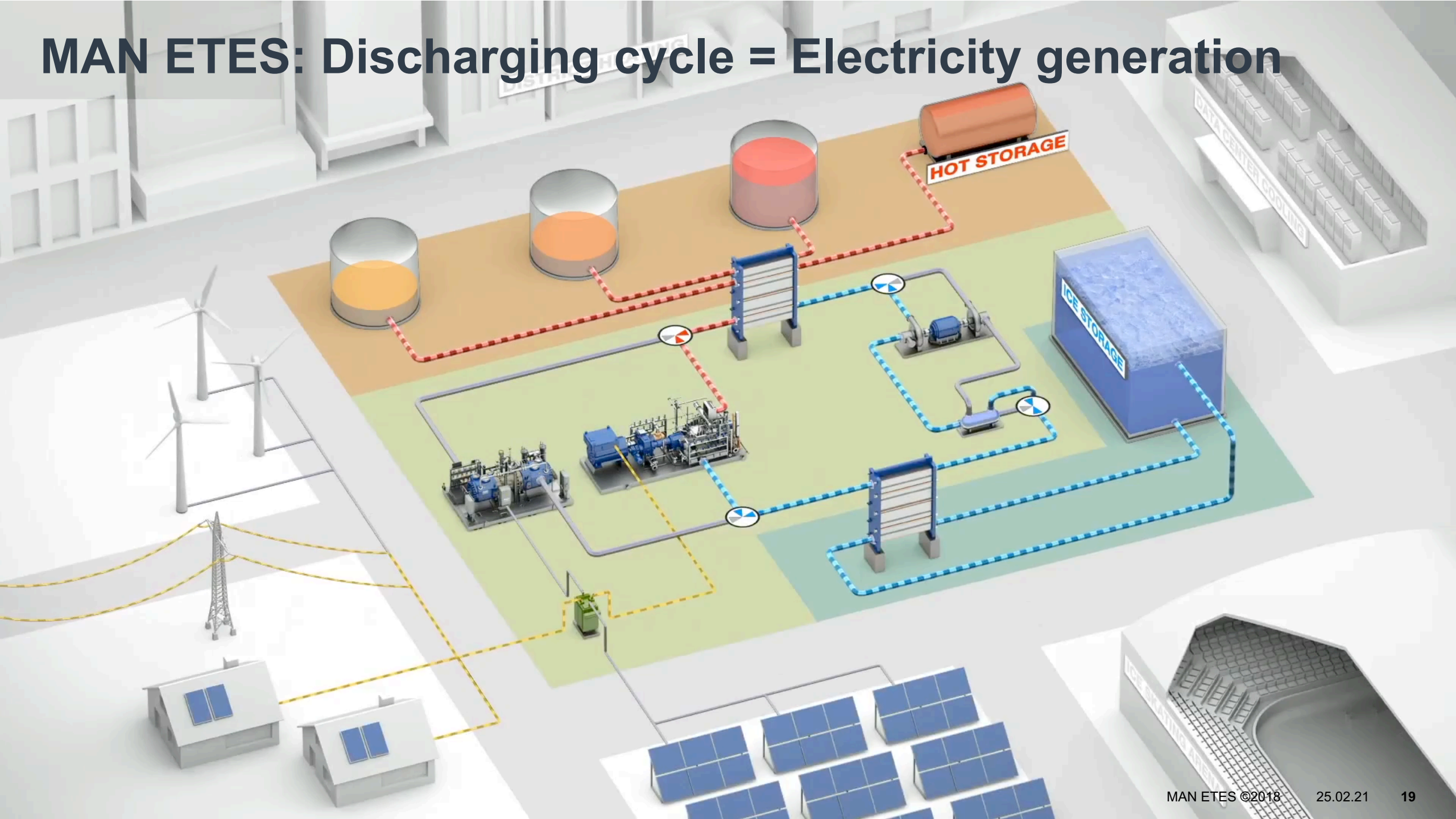
- Heat pump



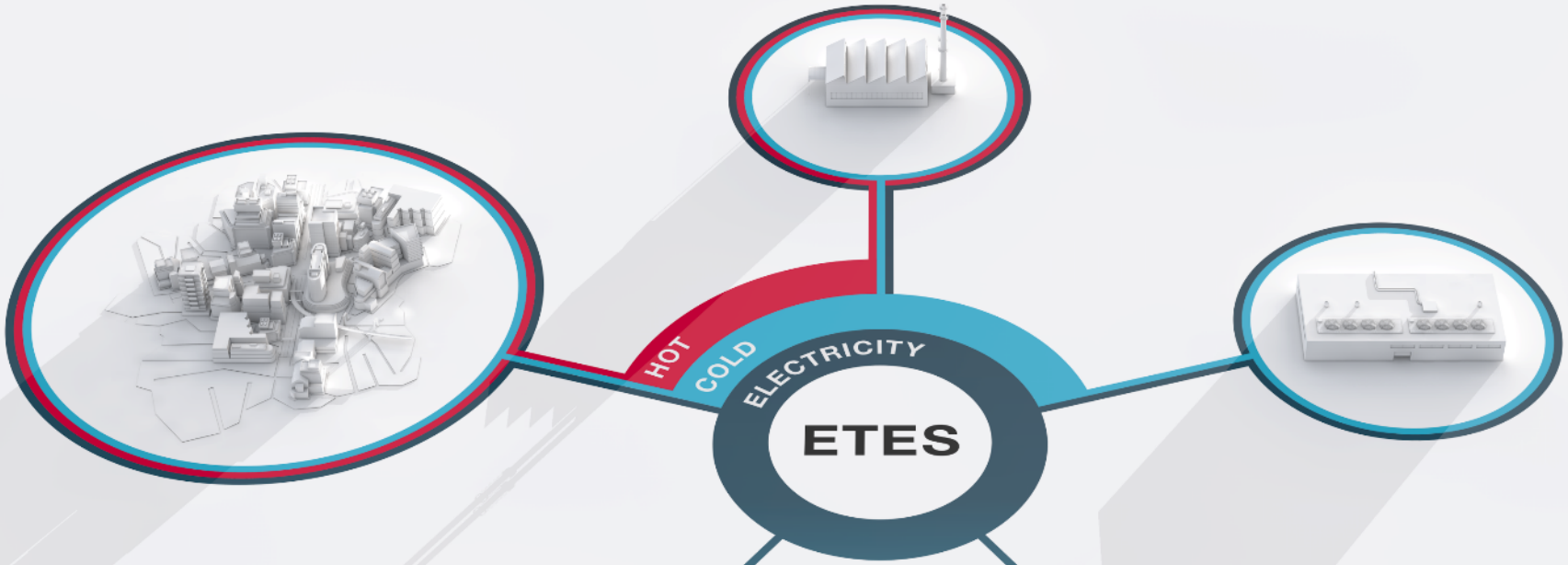
Supply: **(7x24)**

- Heat & cold **(0° - 150°C)**

MAN ETES: Discharging cycle = Electricity generation



MAN ETES – Re-Electrification

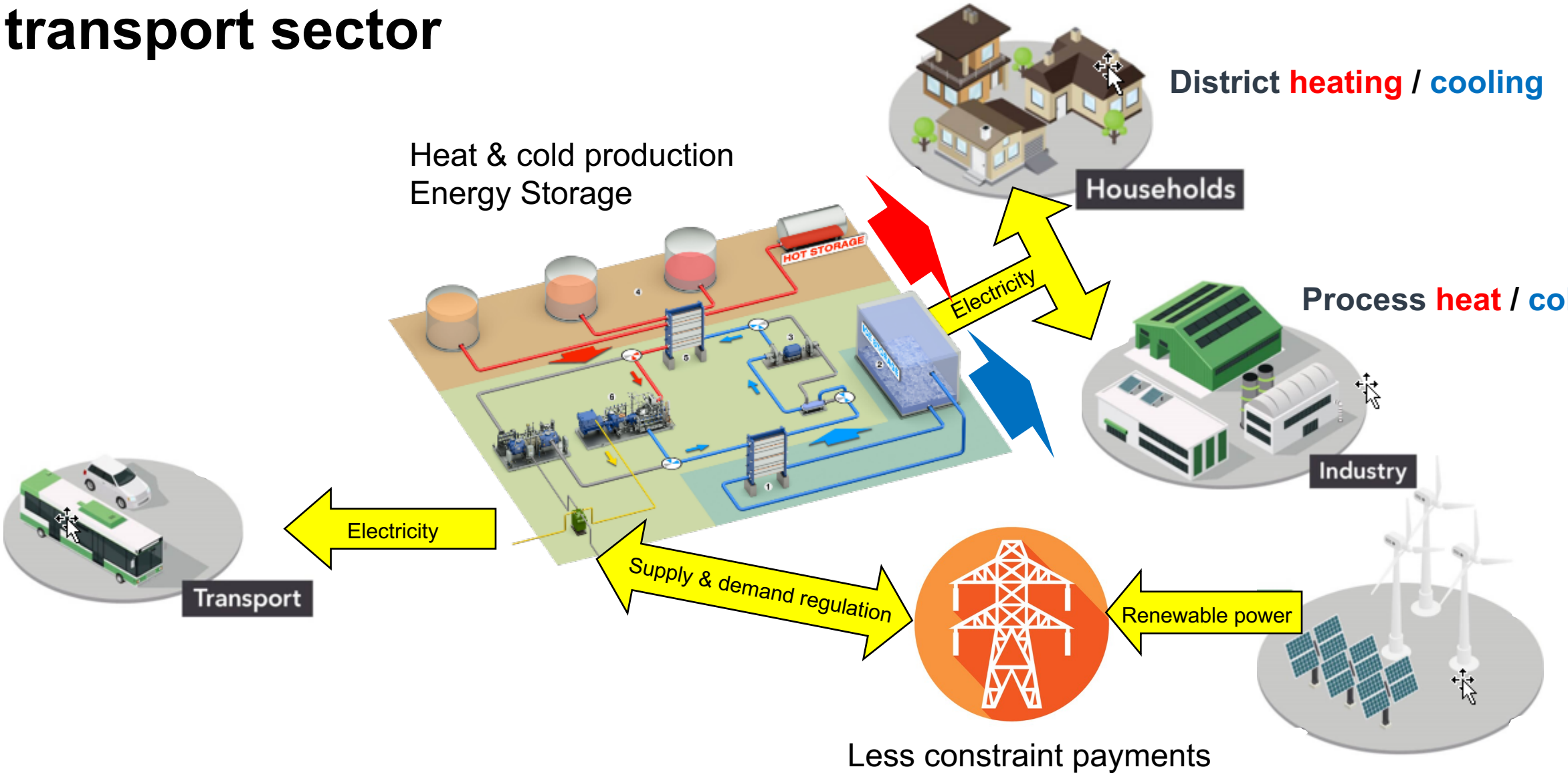


Renewable integration

Long Duration Power Storage (green & sustainable

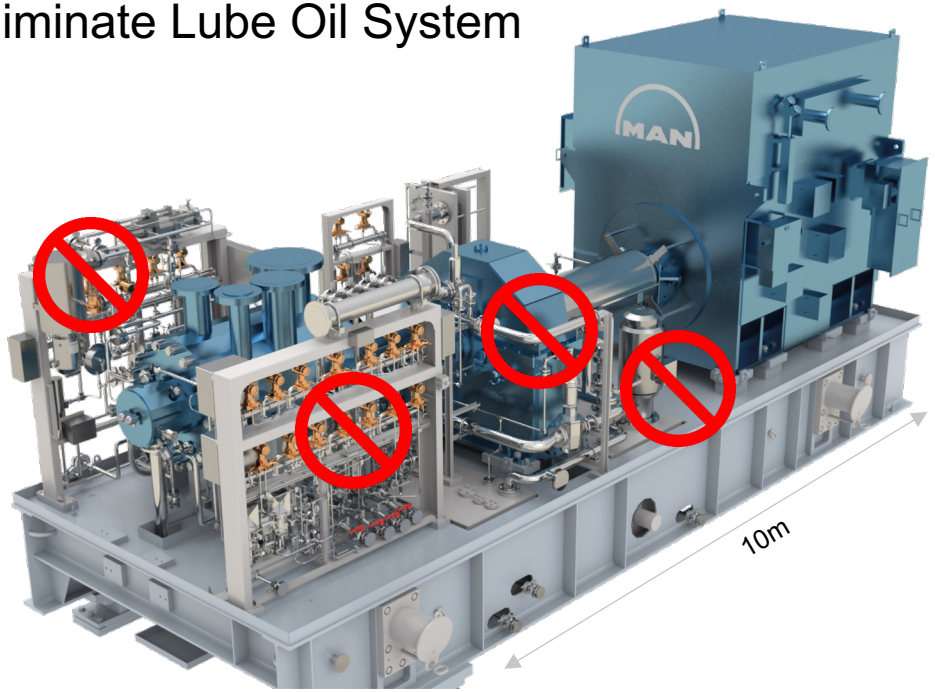
- Grid stability
- Supply and demand balancing
- Reduce constraint payments
- Flexibility

Sector coupling - Serving the industry, energy, buildings & transport sector



Eliminate what is not essential to compression

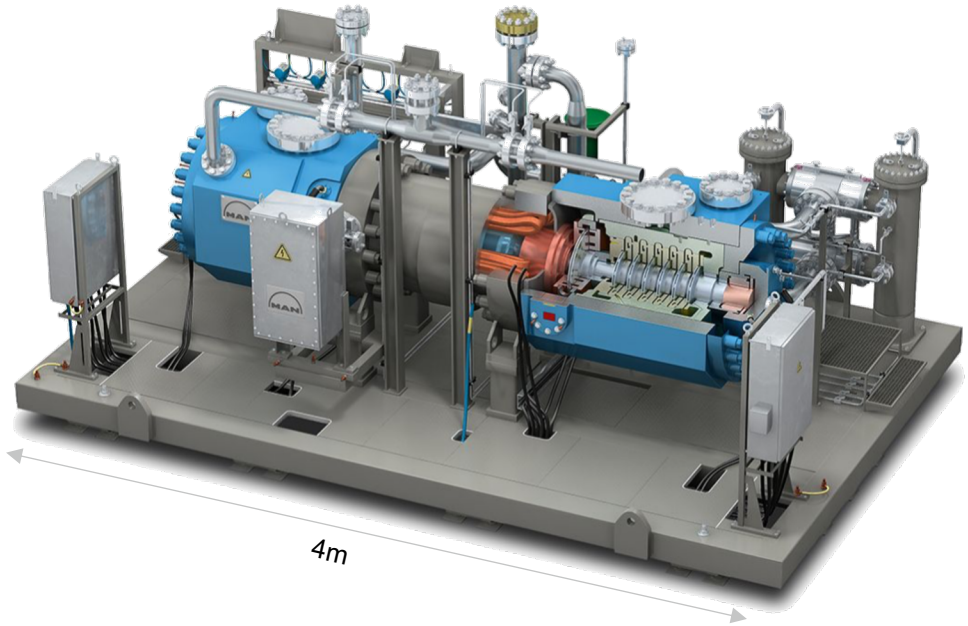
- Eliminate Gearbox
- Eliminate Dry Gas Seals and the seal system
- Eliminate Lube Oil System



Typical motor driven compressor train for upstream application

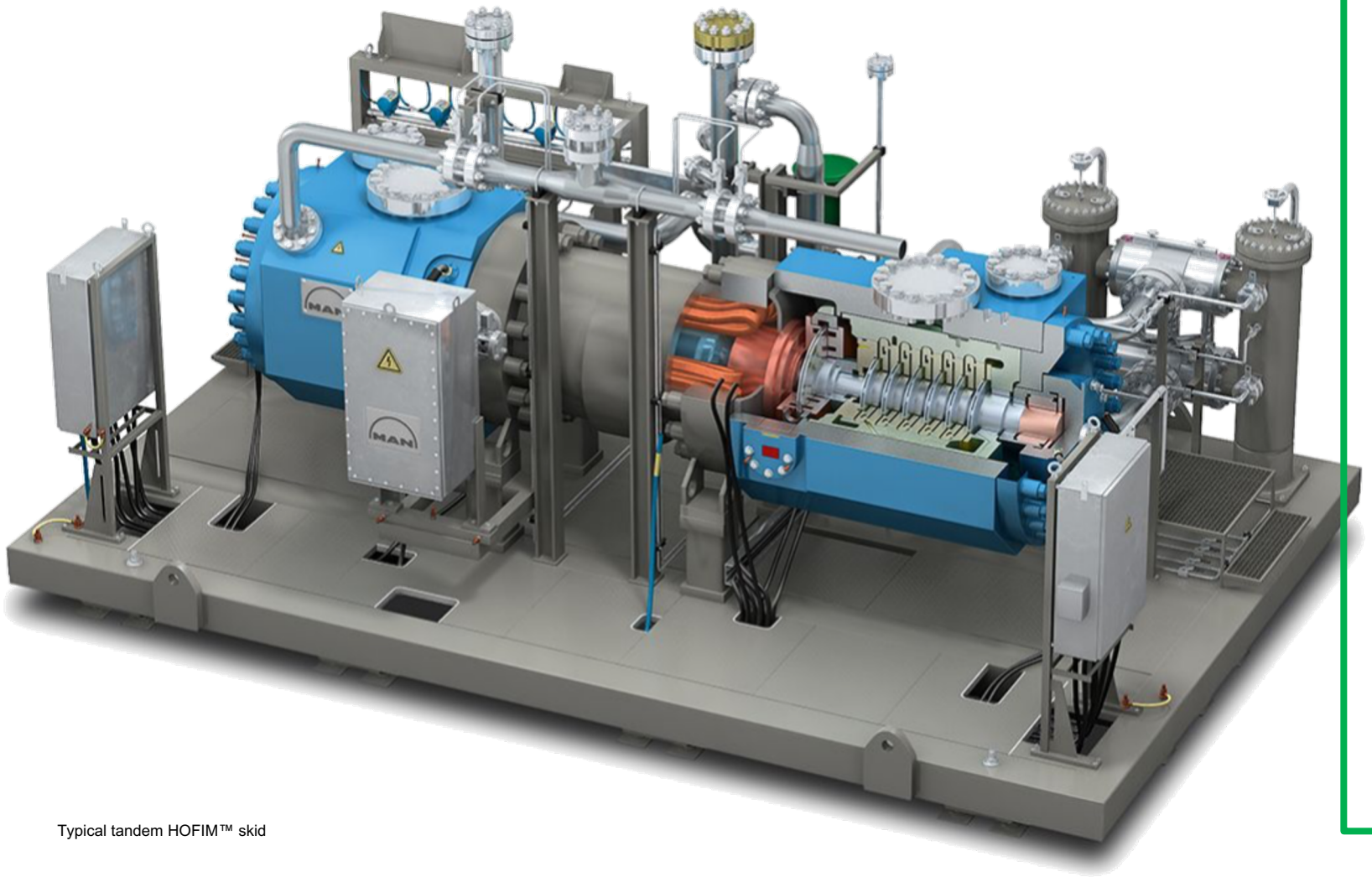
Solution: **HOFIM®**

Highspeed Oil-Free Integrated Motor compressor



Compression with HOFIM™

High speed Oil Free Integrated Motor compressor

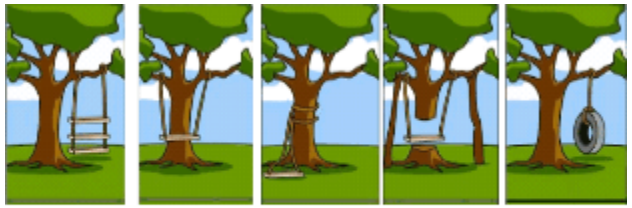


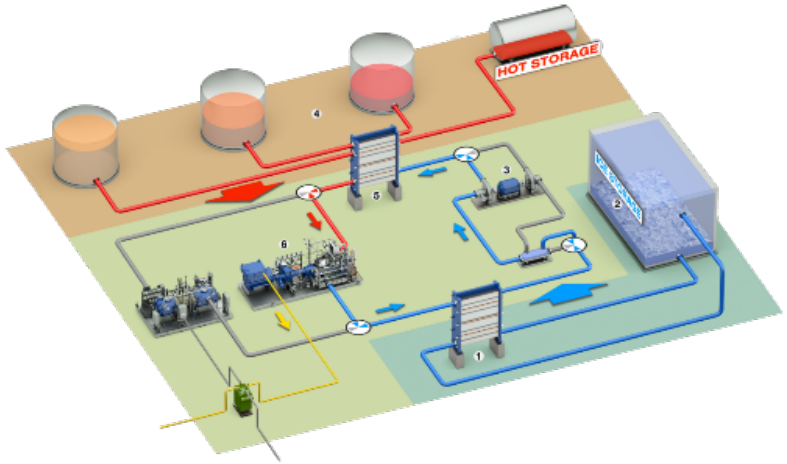
Typical tandem HOFIM™ skid

- Barrel compressor
- Highspeed motor
- Cooled by process gas – heat losses reintroduced into process
- Running on active magnetic bearings
- Reduced auxiliaries – **increased reliability**
- Fully electric – **remote control**
- Hermetically sealed – **no emissions**
- Overall **cost optimization** through reduced footprint & weight
- Sizes: 2 – 18 MW electrical input

Payback: A matter of customising & optimising

The composition of the various parameters determines **YOUR** payback period – 5-7 years is feasible !





Customer requirements

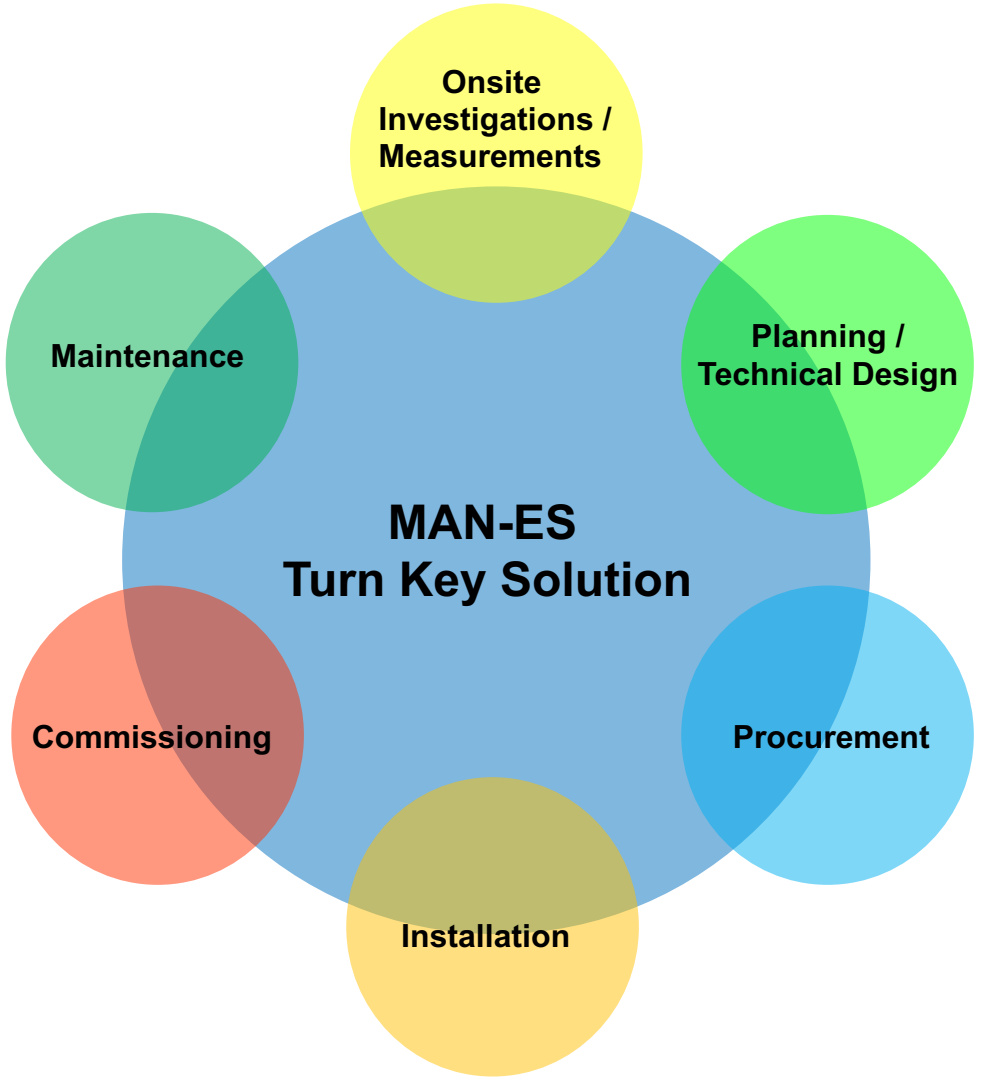
- Heat – cold – electricity
- Temperatures & volumes
- Production cycles & peaks
- System resilience
- Location & available footprint

ETES configuration & design

- Size of infrastructure
- Charging / Discharging cycles
- Redundancies
- Including electricity generation
- Energy supply: own usage or trade

- **Infrastructures & tariffs**
- Energy prices (electricity, cold, heat)
- Availability of renewables
- Upfront infrastructure investments
- Demand for supplies
- Tariffs for grid balancing & peak shaving

MAN Energy Solutions



Alternative forms of collaborations

- MAN-ES Technology Provider
- Local EPC in lead

- MAN-ES Technology Provider
- Consortium of local Stakeholders

- .....

ETES summary

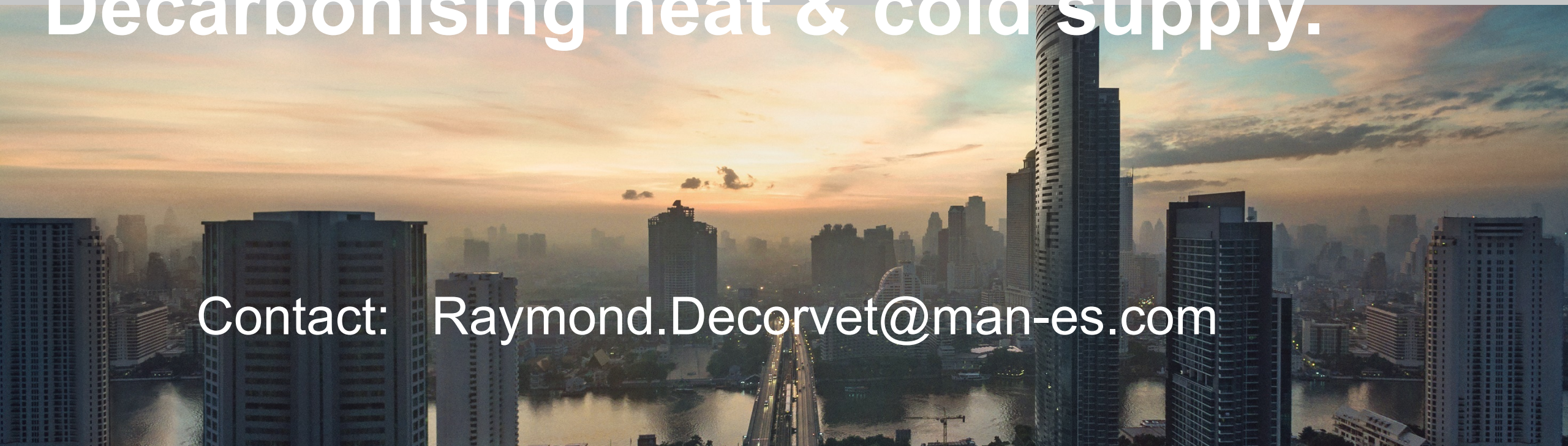
- **CO_2 neutral – 100% decarbonizing** with renewables integration.
- **Fully sustainable**, **environmentally friendly**
- **Large scale - high temperature heat-pump**
- **Energy supply & storage** for heat & cold and electricity
- Temperature levels **(0° - 150° C)** ideal for **sector coupling** and **many applications**
- **Unmatched Scalability and flexibility**
- **TRL7** – based on proven & reliable technology and physical processes.
- **Short to medium payback periods – long lifetime**
- **NO degredation**
- **No limits of charging/discharging cycles**

Contact: raymond.decorvet@man-es.com

MAN Energy Solutions
Future in the making

MAN ETES Heat-Pump technology

Decarbonising heat & cold supply.



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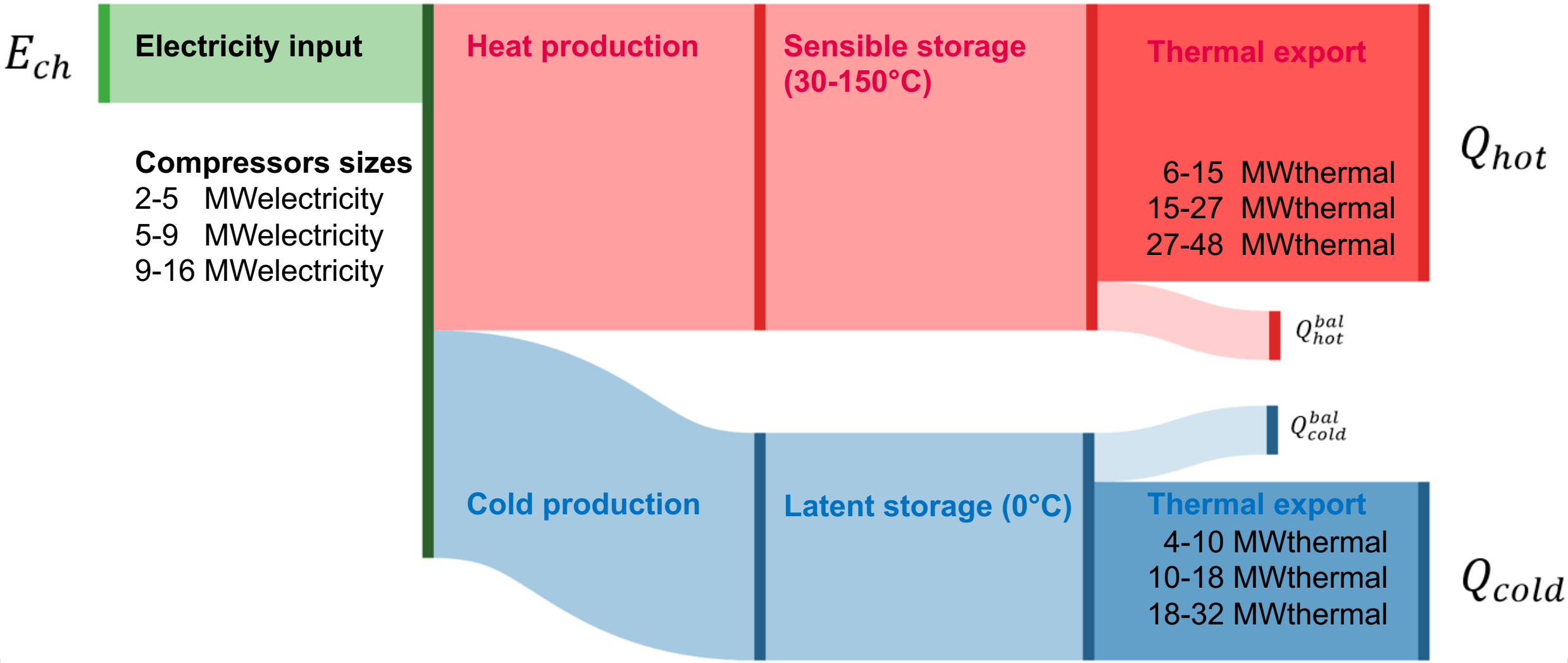
Green Heat & cold supply production and storage

Thermal share: 100% (ETES Light)



CO2 as a refrigerant is the safest choice

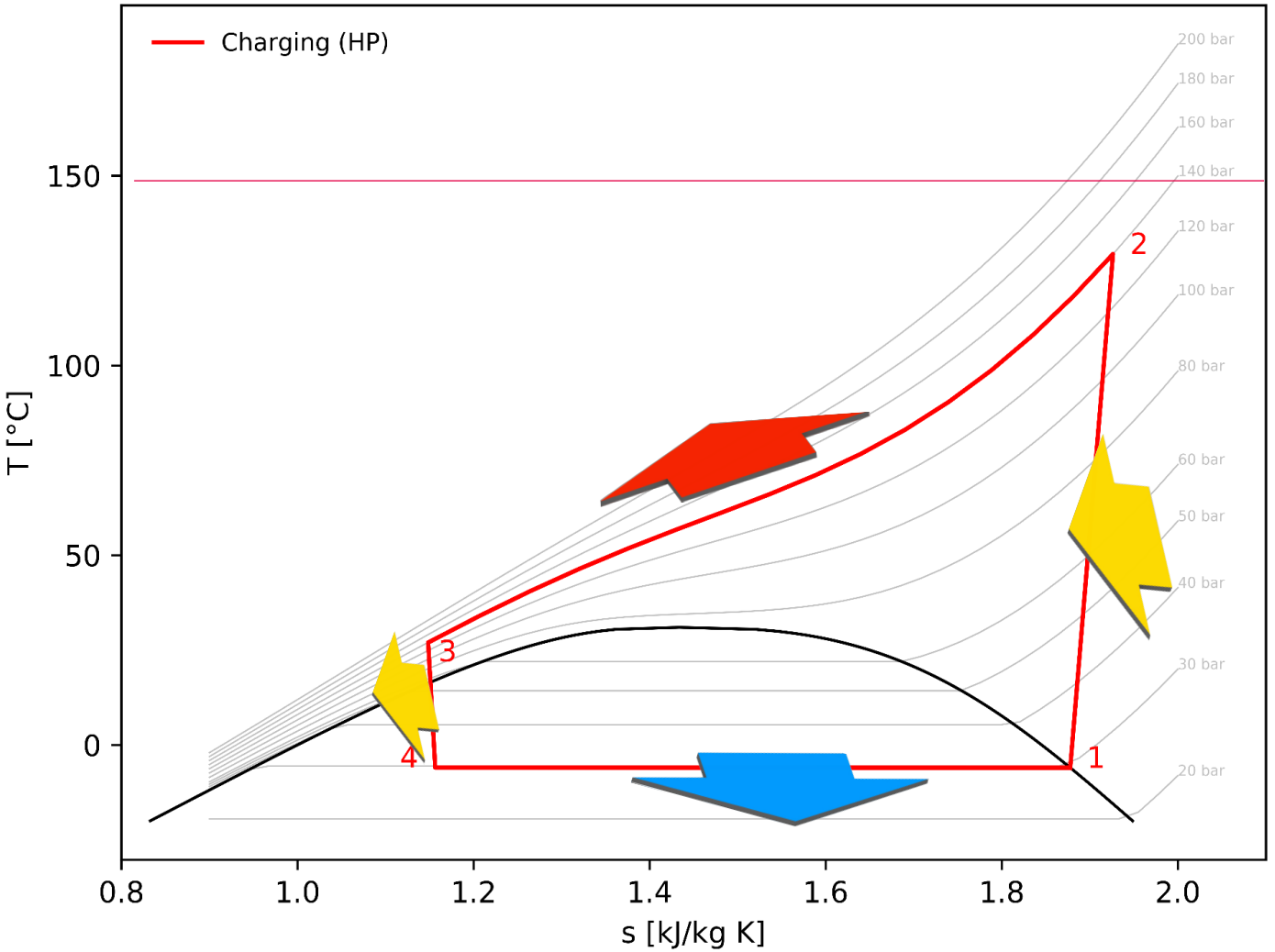
Refrigerant	GWP	ASHRAE characteristics*		
		Toxicity** (A/B)	Flammability** (#)	Group
CO2 (R744)	1	A	1	A1
Ammonia (R717)	0	B	2L***	B2L
R1234zez	1	A	2L***	A2L
R134a	1430	A	1	A1
R22	1810	A	1	A1
R32	675	A	2	A2

*) ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
**) https://www.linde-gas.com/
***) L represents lower flammability refrigerants with a maximum burning velocity of 10 m/s

CO_2 is the adequate refrigerant for large volume HTHP

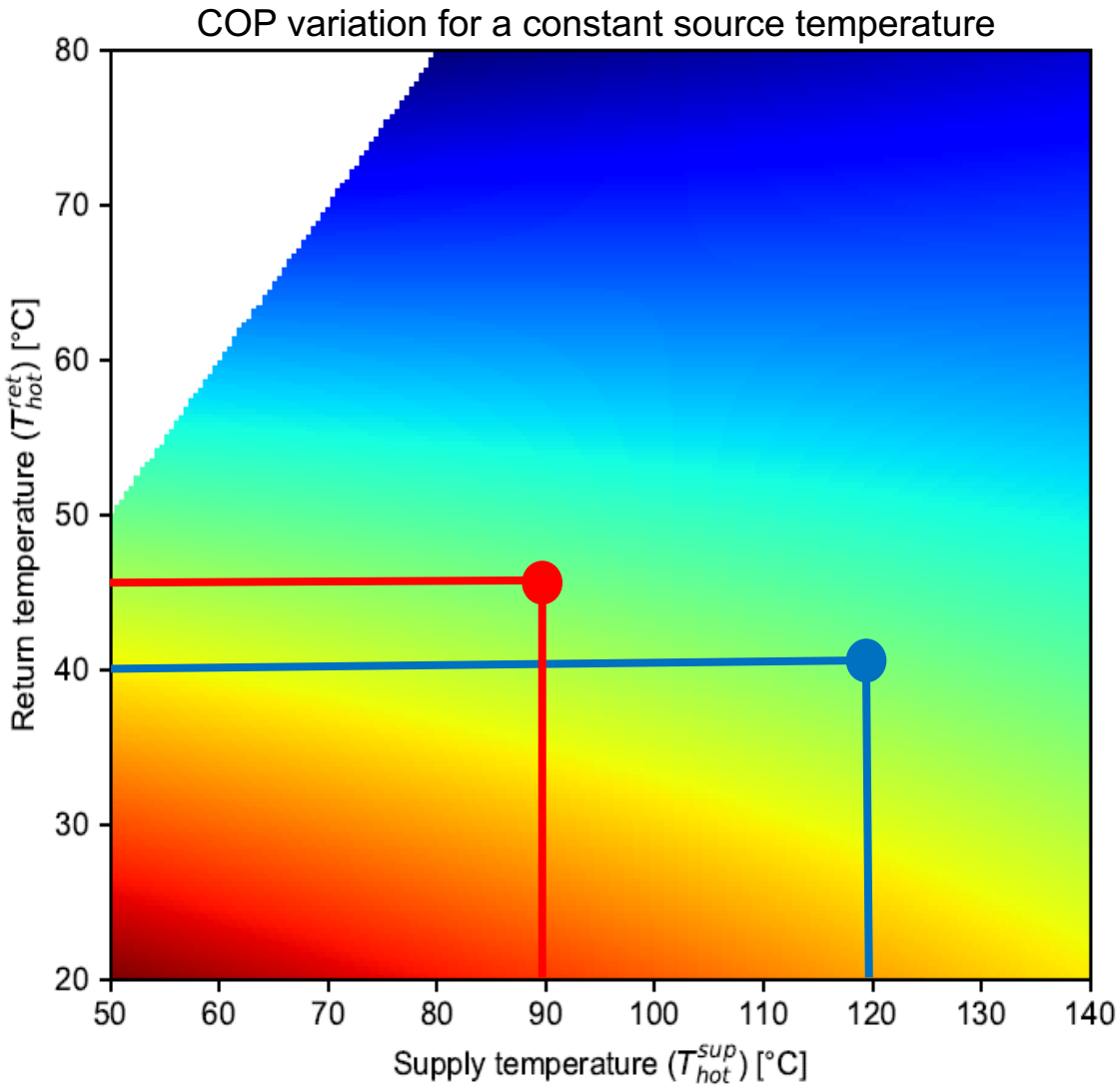
middle to high temperature (150+°C) range

- **Natural refrigerant**
- **Non-flammable and non-toxic**
- **Availability of CO_2**



Why CO_2 as refrigerant for ETES?

A good COP and high supply temperatures are not contradictory.



District heating

- Summer operation
- Winter operation

- The lower the return temperature the better the COP
- Small reduction of COP by increasing supply temperature

Why still waiting ?

State of the art research

Where is there a need for research

NTB Interstaatliche Hochschule für Technik Buchs
FHO Fachhochschule Ostschweiz

1) Development and testing of new synthetic refrigerants with low greenhouse warming potential (GWP) such as hydrocarbons (R600, R601), CO_2 or water
2) Increasing the efficiency (COP) of heat pumps (e.g. through multi-stage circuits, with oil-free compressors)
3) Extension of the limits of the source and flow temperatures (Tsink) to higher values
4) Optimization and development of heat pump systems with new control strategies for higher temperatures
5) Development of temperature-resistant components (e.g. valves, compressors)
6) Scale-up from functional models to industrial scale

MAN ETES

- ✓ ➢ CO_2 (R744)
- ✓ ➢ HOFIM Kompressor
- ✓ ➢ Temperatures 0° - 150°C +
- ✓ ➢ Supply temp. 150°+ C
- ✓ ➢ HOFIM Kompressor
- ✓ ➢ Up to 48 MW_{th} heat and 32 MW_{th} cold

Arpagaus, C.: Hochtemperatur-Wärmepumpen für industrielle Anwendungen, 4. Internationaler Grosswärmepumpen Kongress, 8. Mai 2019, Zürich.

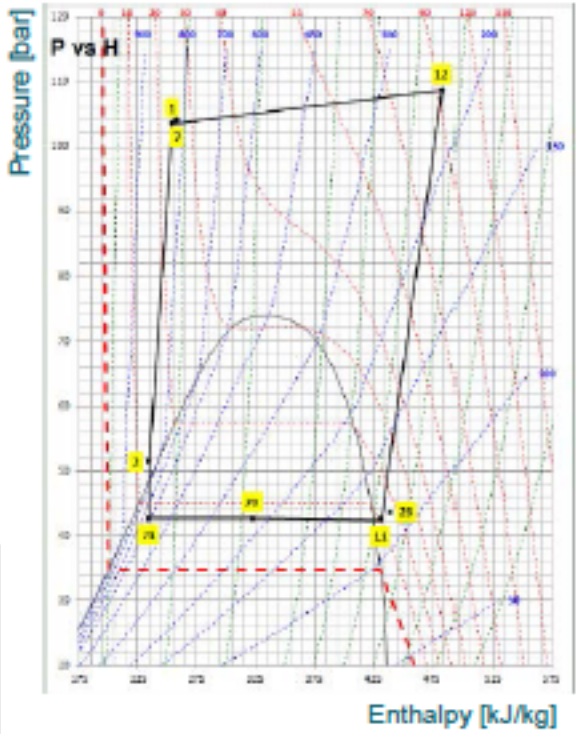
ETES Heat Pump Cycle (TRL 7)

Zurich Test Loop with HOFIM Compressor and integrated Expander

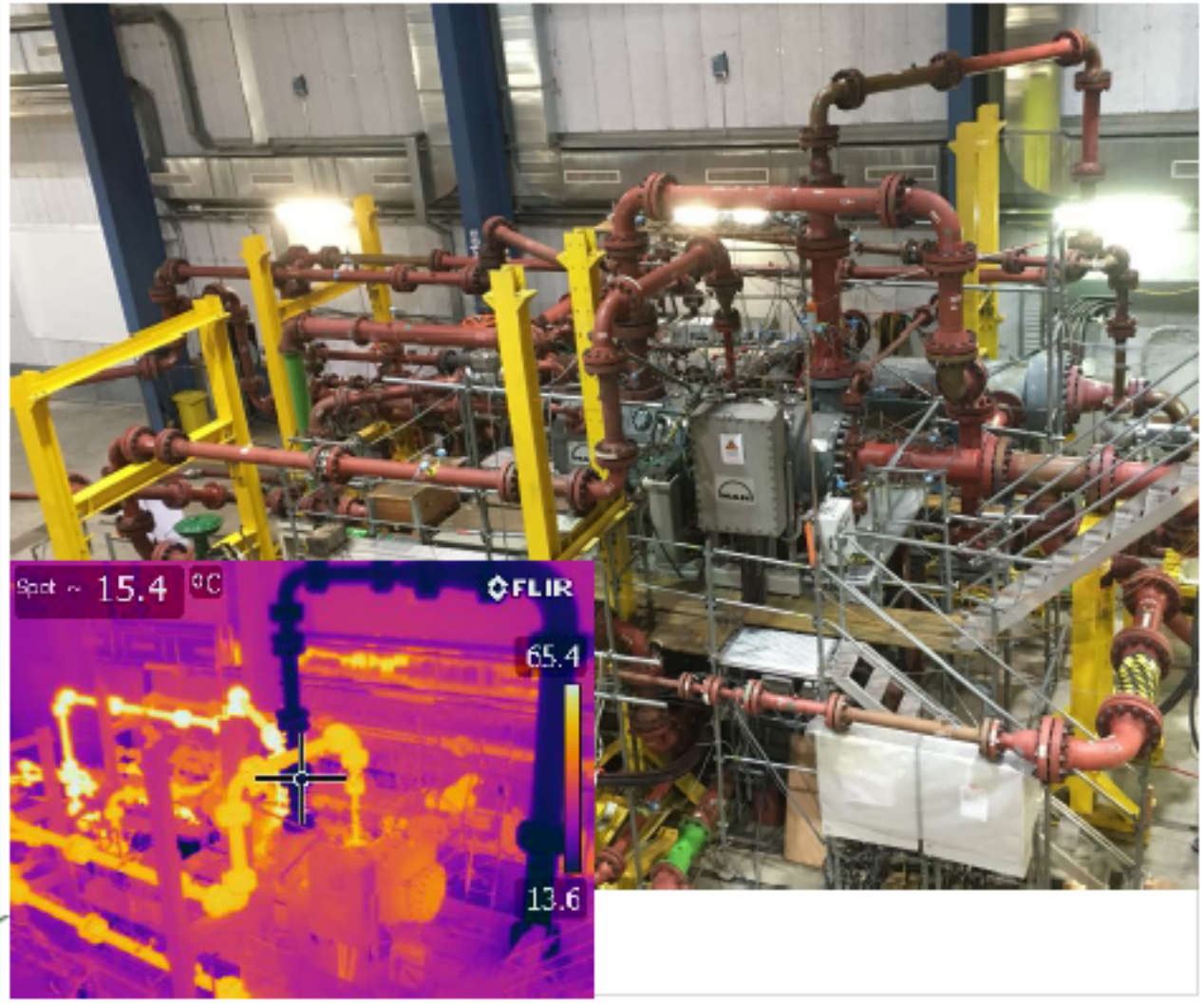
Status & Achievements

- **Proof of Concept CO2 Transcritical HeatPump cycle** ☑
  - CO2 Compression (gas and multi-phase inlet) ☑
  - Expansion from CO2 supercritical to sat. liquid conditions ☑
  - Power recovery over Expander stage ☑
  - Supercritical cooling & 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 13.11.2020:



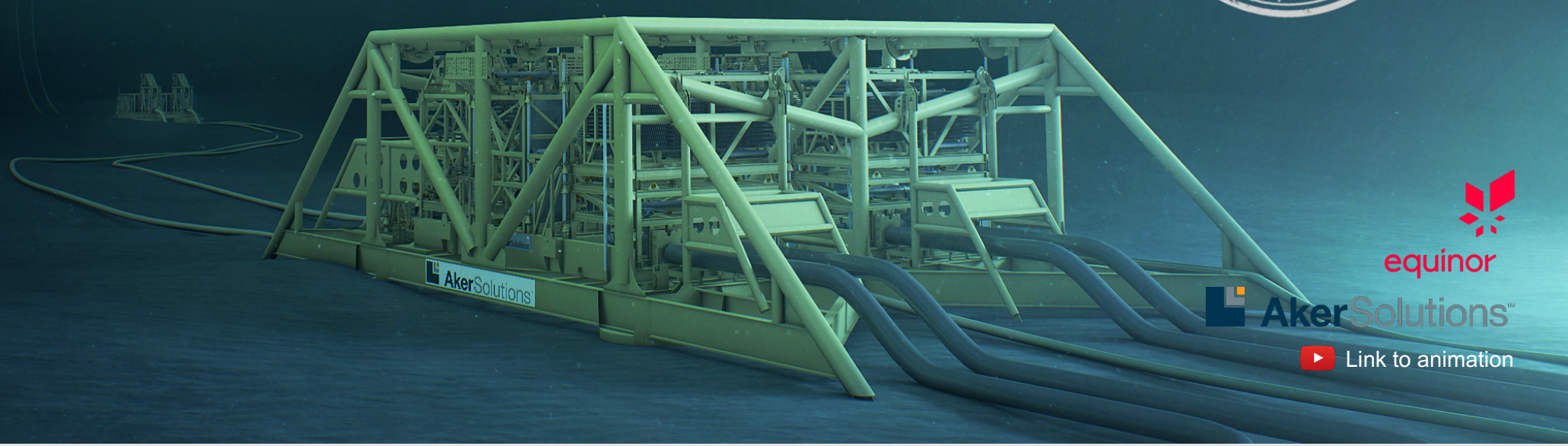
comparable tests conditions with real project applications! ☑



World’s first of its kind

MAN’s Subsea HOFIM™ in operation since September 2015 with 100% reliability

More than 80’000 operating hours



Proven Technology
TRL 7
APPROVED
In operation since September 2015

Åsgard Subsea Compression

- Water depth 300 m
- Gas pressure 220 bar
- Power rating 2 x 11.5 MW

equinor

AkerSolutions

Link to animation

MAN ETES: Charging cycle = Storage, heat & cold generation

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.

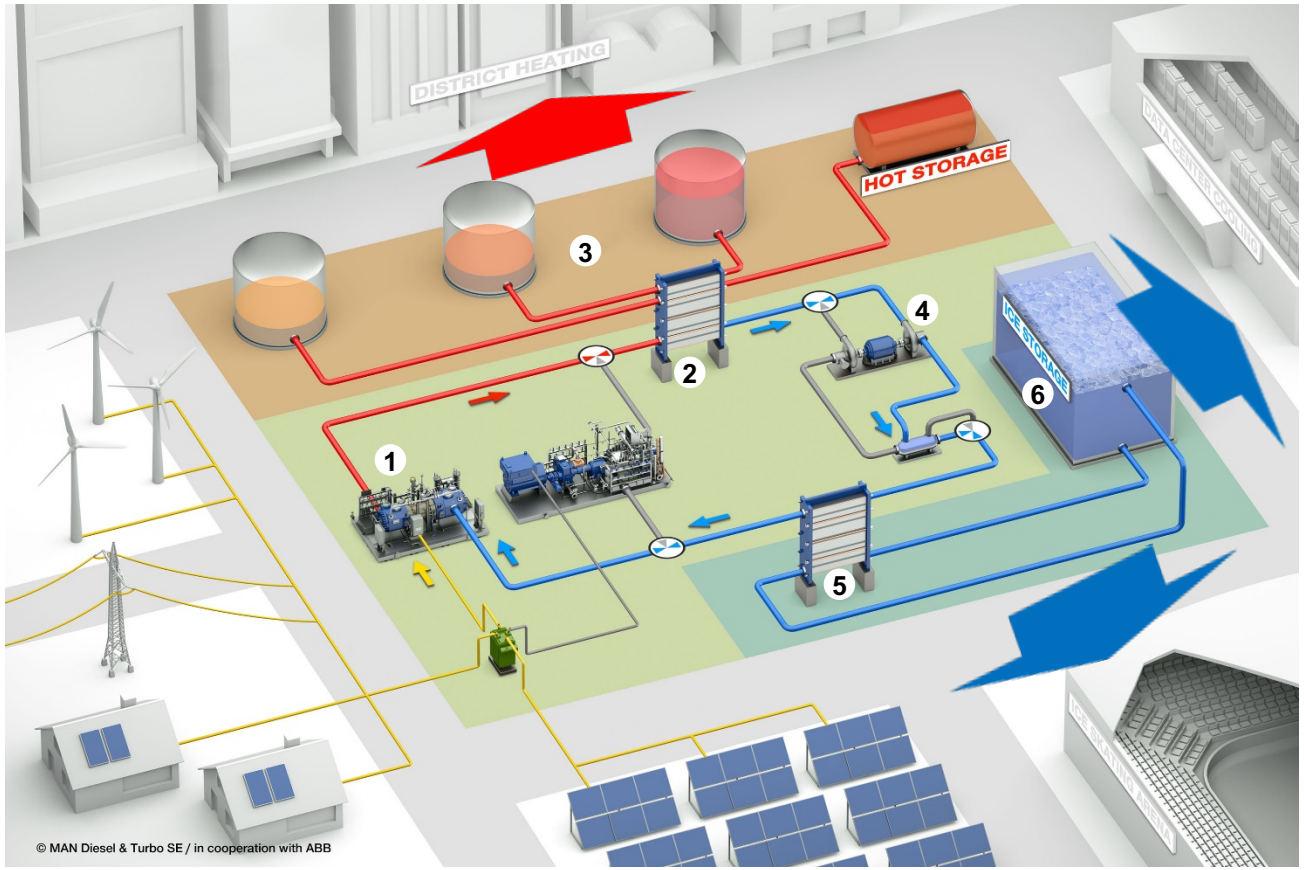
(2) The CO_2 is fed into a heat exchanger and heats the water.

(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 = Electricity generation

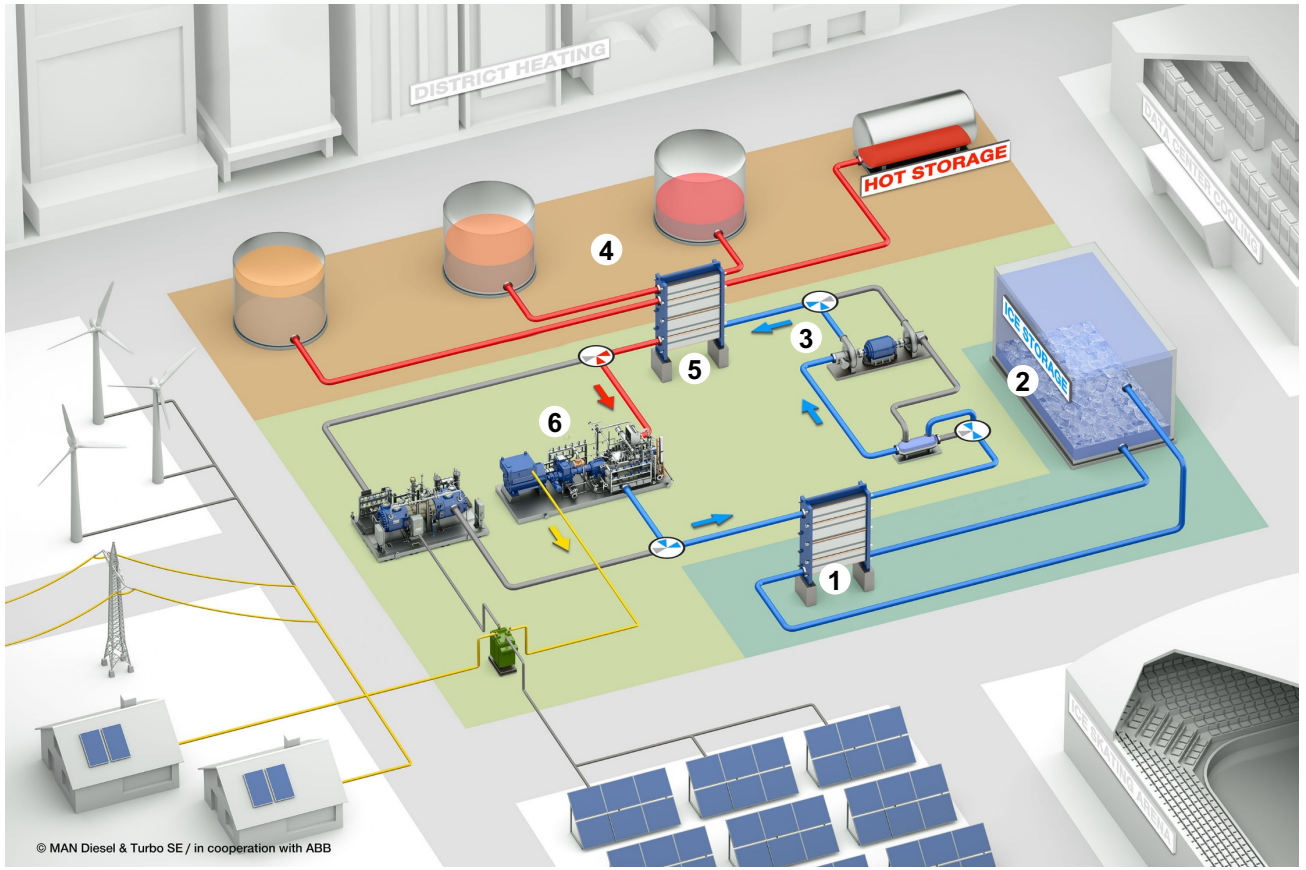
Conversion of thermal energy into electricity – heat engine operation

(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