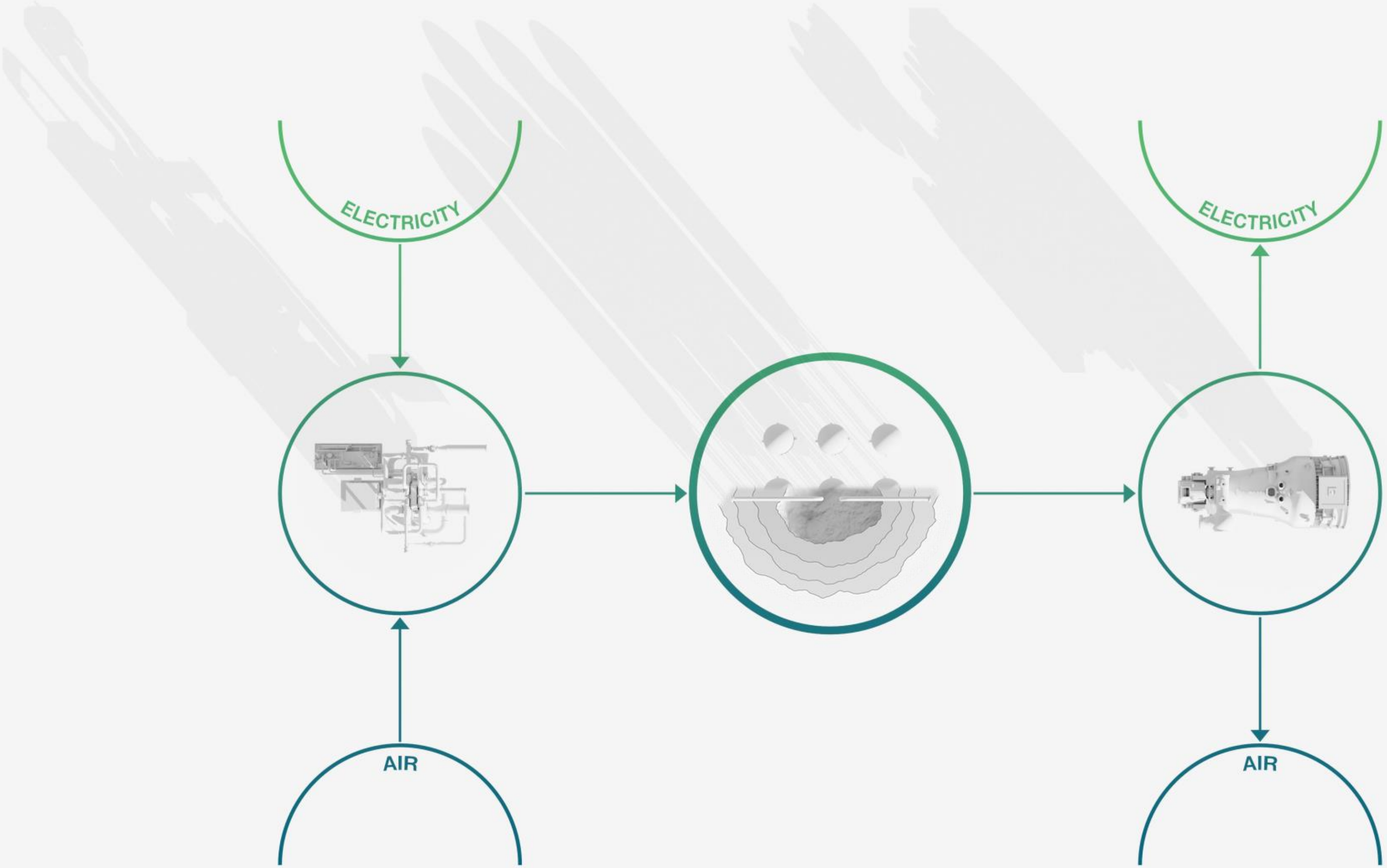
Energy Storage with Turbomachinery



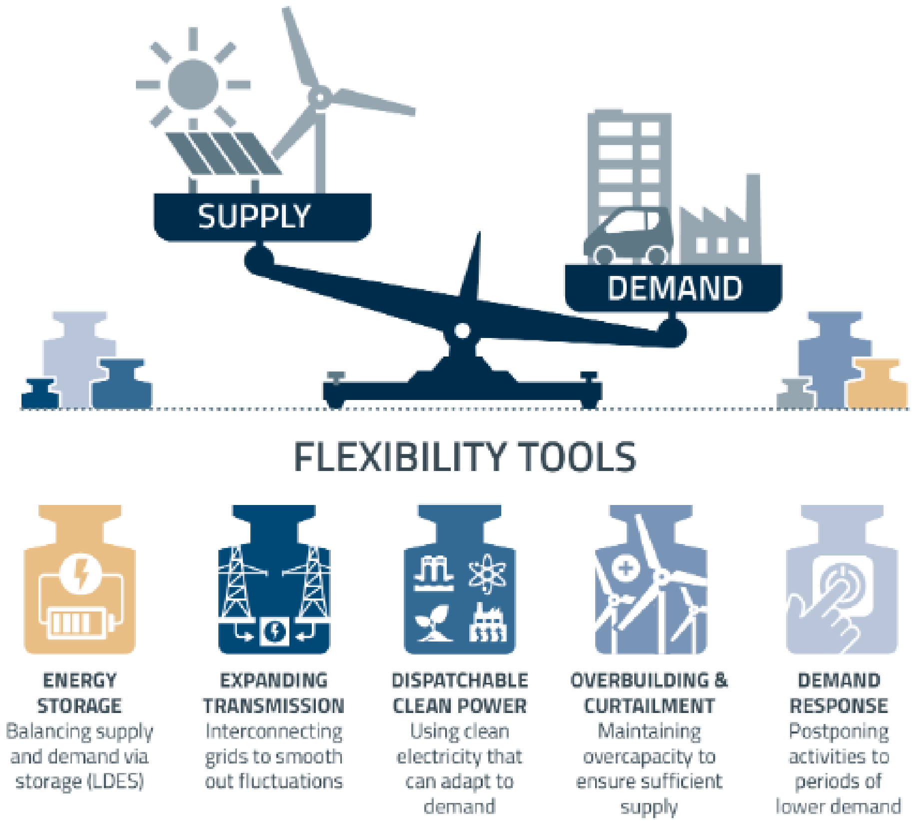
Three answers for long duration storage task CAES, LAES & CO2 Battery

Agenda

1 Long duration energy storages – why & when?
2 Power and duration requirements
3 What are the use cases of energy storage
4 First commercial CAES plant in the world – Huntorf (Germany)
5 Adiabatic energy storage with turbomachinery in a nutshell
6 Compressors & expanders portfolio for CAES / LAES & CO2 Battery
7 Process and project of CAES / LAES & CO2 Battery
8 Use cases and resulting challenges for the turbomachinery

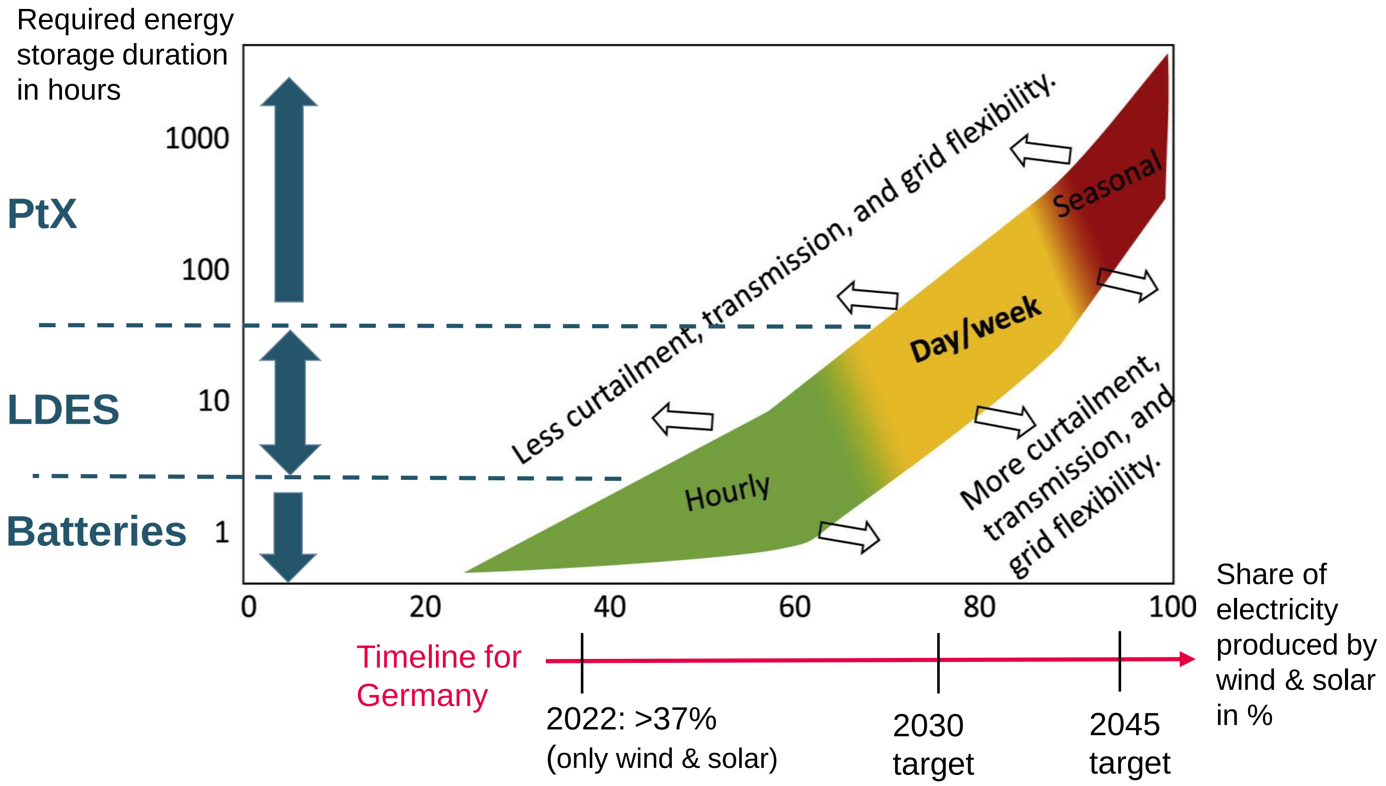
Long duration energy storages – crucial to reach net zero

Why are they so important?



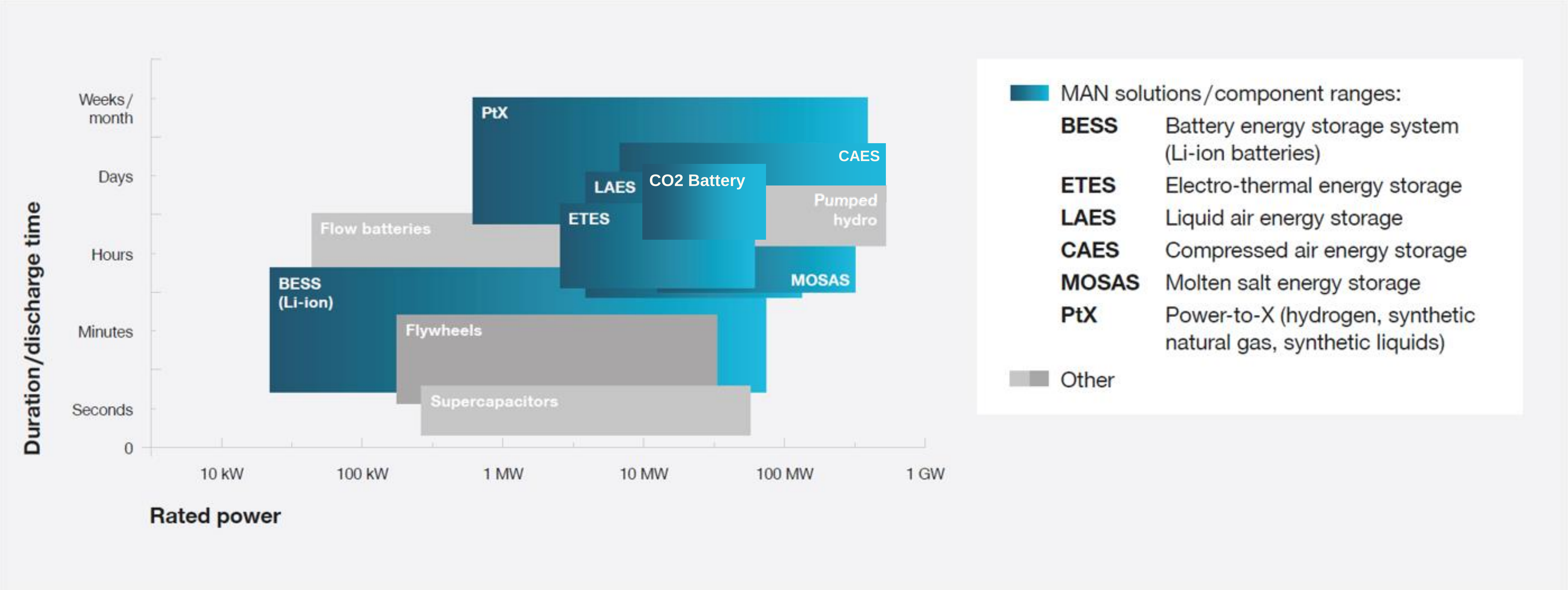
Source: The Basics & The Gaps LDES – Future Cleantech Architects (fcarchitects.org)

When will we need them?



Source: P. Albertus et al, Long-Duration Electricity Storage Applications, Economics, and Technologies, 2020

Power and duration requirements determine most suitable technology for specific purpose



Storage systems can provide multiple services for the energy system

What are the use cases?

Focus	Use case	Description
Power focus: Provide large amount of power in a relatively short period of time	Spinning reserve	▪ Maintain system stability, esp. during emergency conditions and unforeseen load swings
	Frequency & voltage regulation / response	▪ Provide grid services (balance fluctuation, manage frequency and reactive power)
	RES smoothing & integration	▪ Keep the net volatile output of RES within certain level ▪ Balance local excess of deficits
	Black start	▪ Energize a system in the event of generation or grid outage without outside assistance
Energy focus: Provide steady amount of power for an extended amount of time	Transmission and distribution optimization	▪ Defer or avoid upgrades of T&D system ▪ Load leveling close to loads; improve power quality
	Capacity	▪ Provide energy for peak and base load consumption ▪ Avoid output curtailment; shift RES to high demand
Non-electricity applications:	Synthetic fuel production	▪ Conversion of surplus electricity in synthetic fuels ▪ CO2 neutral fuel for transportation or marine
	Thermal energy management	▪ Absorption, storage and generation of thermal energy ▪ Direct use e.g., for cooling purposes or district hearing

First commercial CAES Plant in the World – Huntorf (Germany)

Huntorf Plant – source UNIPER

Huntorf Charging Compressor Train

Compressed Air Energy Storage established technology since 1978

- Salt cavern size 2x 150.000 m³ up to70 bar
- No heat storage (external firing)
- LP & HP Compression (Sulzer/MAN ES)
  Power consumption 60 MW
- Charging duration 6 h
- Gas Turbine (BBC/ALSTOM)
  Power Output(el) 290 MW
- Discharging duration for 2h
- Efficiency 42%

Adiabatic energy storage with turbomachinery in a nutshell

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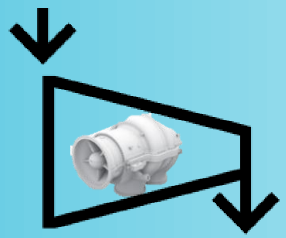

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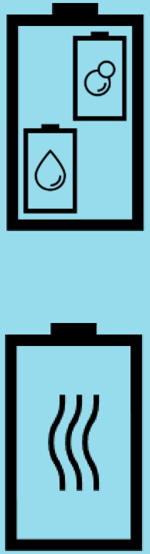

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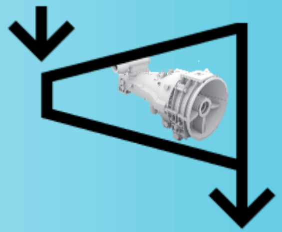

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❶ Off-peak or excess renewable electricity is used to drive a compressor

❷ The compressor compressed a medium (e. g. air or CO2) transport it to a storage.

❷ The heat generated during compression is also transfer to a storage

❸ The medium is storage under pressure and gaseous or liquefied in a cavern, tanks or vessels

❸ The heat is storage in thermal heat system like (e. g. water based or molten salt etc.)

❹ When electricity is needed the medium will be evaporated (if applicable) heated up with the heat from the heat storage and expanded in a turbine which drive a generator

❺ Green electricity is provided to industry, city's or enable a 100 % green hydrogen production

MAN ES Compressors portfolio

First choice for **CAES, LAES & CO_2 battery**

+ outlet pressure

- *Up to 21 bara*

Radial Compressor (single shaft)

- Isothermal compressor
- Compact design
- Reliable and excellent market position
- *Up to 670.000 m³/h*

- *Up to 25 bara*

Axial Compressor

- High efficiency
- Up to 350 °C discharge temperature
- *Up to 1.400.000 m³/h*

- *Up to 50 bara*

Screw compressor

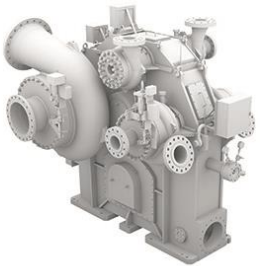
- Oil free
- Suction flow rates up to 100,000 m3/h

- *Up to 80 bara*

Radial Horizontal split Compressor

- *Suction flow rates up to 710,000 m3/h*

- *Up to 250 bara*



Radial Gear Compressor

as MAC/RAC or combined (multi shaft – integrally geared)

- High efficiency, process flexibility & Wide operation range
- Up to 250 bar (3625 psi) or
- *Up to 450 °C (842 °F) discharge temperature*
- Various mediums: E.g. Air, CO_2, Fuel Gas
- *Up to 500.000 m³/h*

- *Up to 300 bara*

HOFIM™ technology

- Gas compression up to 18 MW
- Suction flow rates up to 30,000 m3/h
- Hermetically sealed compact compressors
- with integrated high-speed electrical motor and active magnetic bearings

- *Up to 1.000 bara*

Radial vertical split Compressor (Barrel-type design)

- Suction flow rates up to 330,000 m3/h
- Min. suction flow rates: 100 m3/h

MAN ES Expanders & Turbines portfolio

First choice for **CAES, LAES & CO2 battery**

+ inlet pressure

- **Hot Gas Expander**

Up to 5,5 bara

Hot Gas Expander

- Axial blading
- Up to 5,5 bar (80 psi) inlet pressure
- Up to 760 °C (1400 °F) inlet temperature
- Up to 45 MW / Machine
- Mediums: Fluid Catalytic Cracking,

- **Hot Gas Expander**

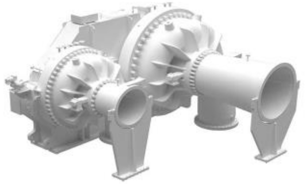
Up to 25 bara

Expander (horizontal)

- Up to 13 bara (psi) inlet pressure
- Up to 540/750 °C (1004°F/1382°F) inlet temperature
- Up to 30 MW / Machine
- Mediums: Fluid Catalytic Cracking,

- **Radial Gear Expander**

Up to 60 bara



Radial Gear Expander

- Impeller
- Up to 60 bara (435 psi) inlet pressure
- Up to 350 °C (662 °F) inlet temperature
- Up to 80 MW / Machine
- Mediums: Terephthalic Acid, Nitric Acid, Offgas, Tail gas

- **Turbines**

Up to 150 bara

Turbines (MST & MXT)

- Axial blading
- High efficiency
- Up to 150 bar (2175 psi) inlet pressure
- Up to 540 °C (1004 °F) inlet temperature
- Up to 180 MW / Machine
- Mediums: Steam, Air, CO2

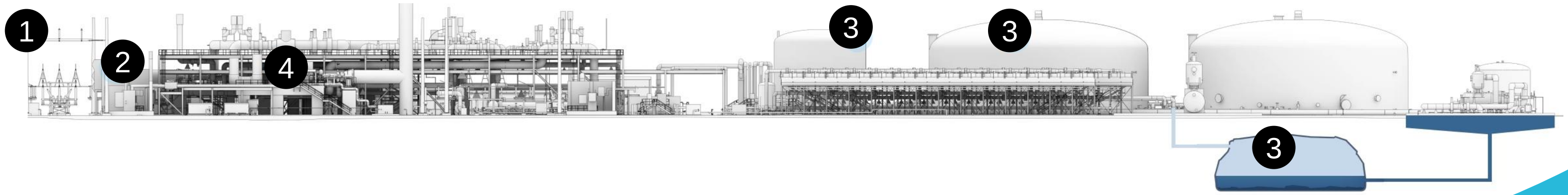
- **Barrel Expander**

Over 250 bara

Barrel Expander (MBT)

- Axial blading
- Dry gas seals
- Based on the in-house barrel compressor and turbine technologies
- Over 250 bar (3625 psi) inlet pressure
- Up to 200 °C (392 °F) inlet temperature
- Mediums: Air, Fuel gas, H2

Advance Adiabatic CAES



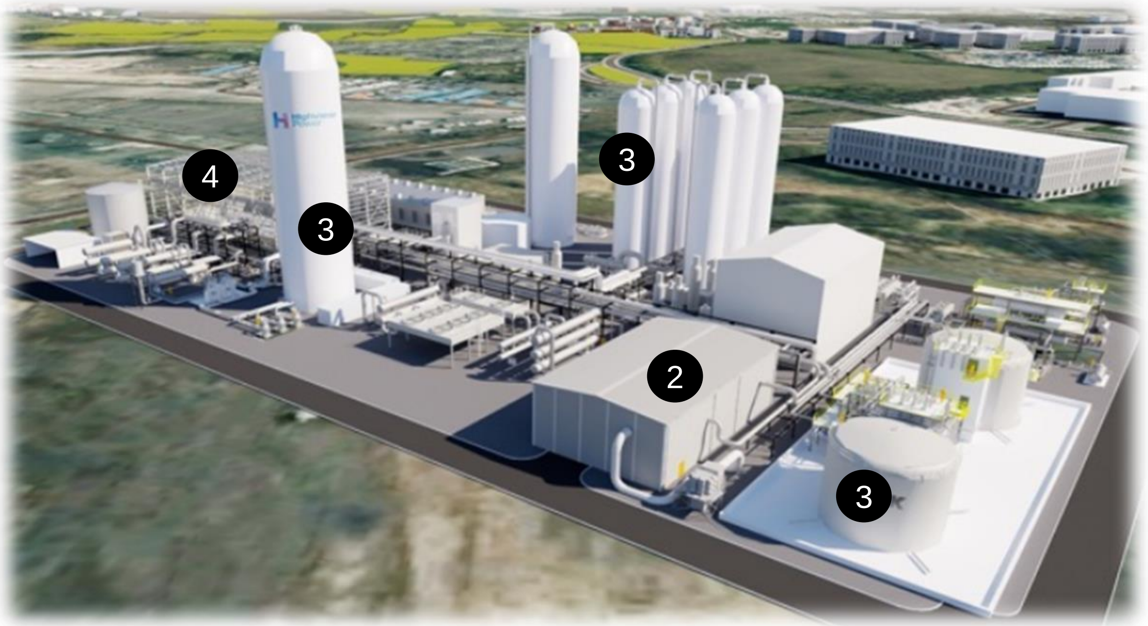
- ❶ Off-peak or excess renewable electricity is used to drive an axial and radial geared compressor
- ❷ Advanced adiabatic compression 
- ❸ Compressed air is stored in a rock cavern
- ❸ The heat is stored (water based thermal heat storage)
- ❹ Compresses air is recombined with the stored heat and expanded 

→ Further details please contact HYDROSTOR
https://hydrostor.ca/

BROKEN HILL, NSW, AUSTRALIA

- Rock cavern from 1600 MWh+
- Water based heat storage
- Power consumption 200 MW (100MW/ train)
- Charging duration 13 h
- Power Output(el) 200 MW (100MW/ train)
- Discharging duration for 8h
- Efficiency approx. 60%
- Zero emission

Liquide Air Energy Storage



❷ High temperatures adiabatic compression 

❷ Air is cooled down to sub-zero temperatures until it liquefies.

❸ Liquid air is stored at low pressure in insulated tanks

❸ Heat (compression) and cold (expansion) is stored

❹ Liquide air is evaporated, heated and then expanded 

→ Further details please contact Highview Power
https://highviewpower.com/

Carrington, UK

Liquid air tanks from 300MWh+

Heat storage based on molten salts

Power consumption 30 MW (min)

Charging duration 16 h

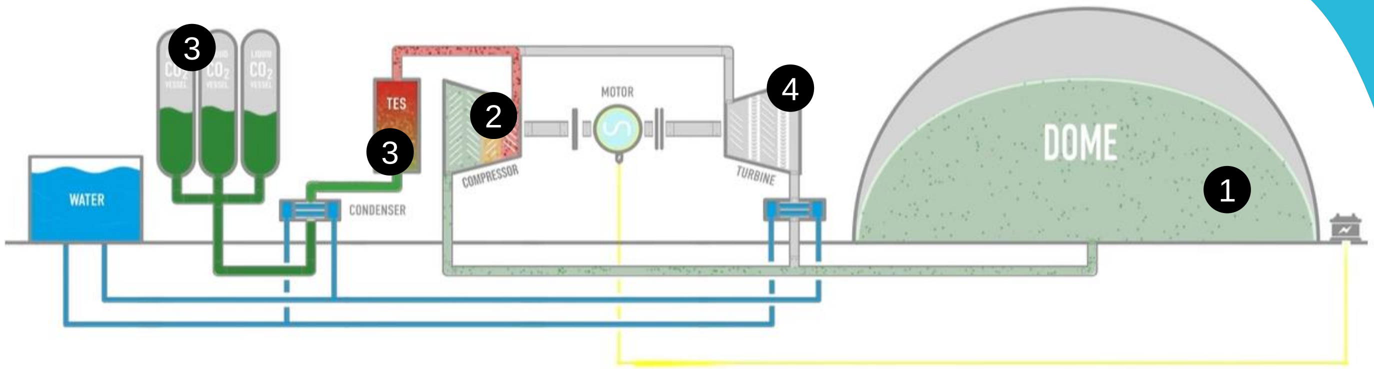
Power Output(el) 50 MW (min)

Discharging duration for 6h

Efficiency approx. 60%

CO_2 Zero emission

CO2 Battery Process



❶ Dome is filled with CO_2 (ambient condition)

❷ Adiabatic high temperature compression 

❸ Compression heat is stored in a thermal energy storage (TES)

❸ Liquefied CO2 is stored in vessels under pressure at ambient temperature

❹ CO2 is heated up, evaporated and expanded in a turbine before it flows back to the Dome. 

→ Further details please contact
https://energydome.com/co2-battery/

Ottana, Sardinia, Italy

Vessel size for 200MWh

Heat storage based on solid filler

Power consumption 25 MW

Charging duration 10 h

Power Output(el) 20 MW

Discharging duration for 10h

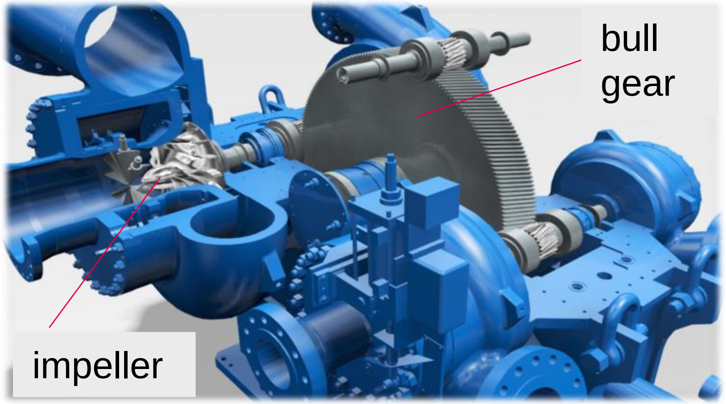
Efficiency approx. 75%

Zero emission

Use cases and resulting challenges for the turbomachinery

Capacity

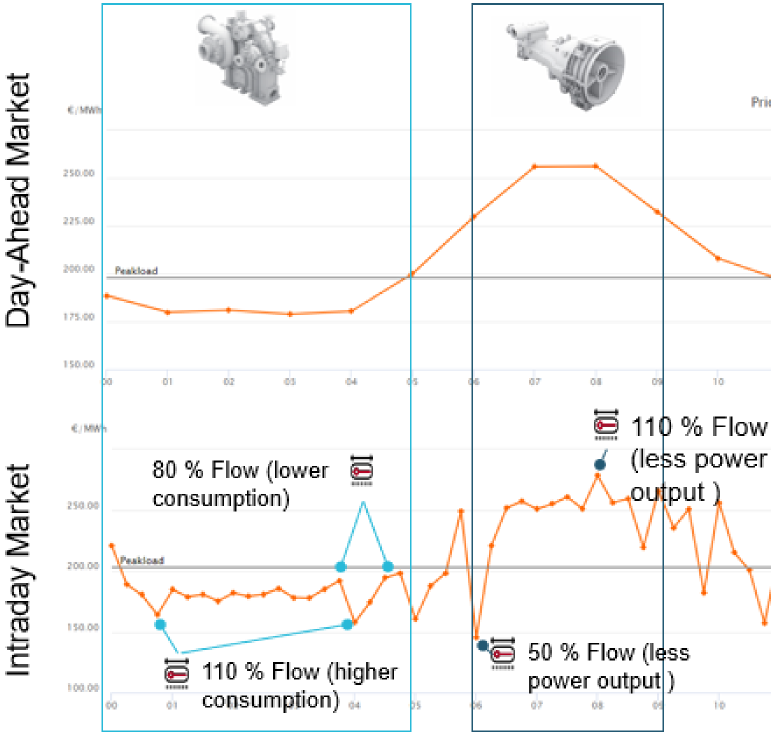
Multiple times starts a day
To charge the system during periods with low electricity prices



Equipment must be designed for multiple cycle e.g. bull gear with bigger tooth or considered centrifugal loads and thermal loads for the impeller design

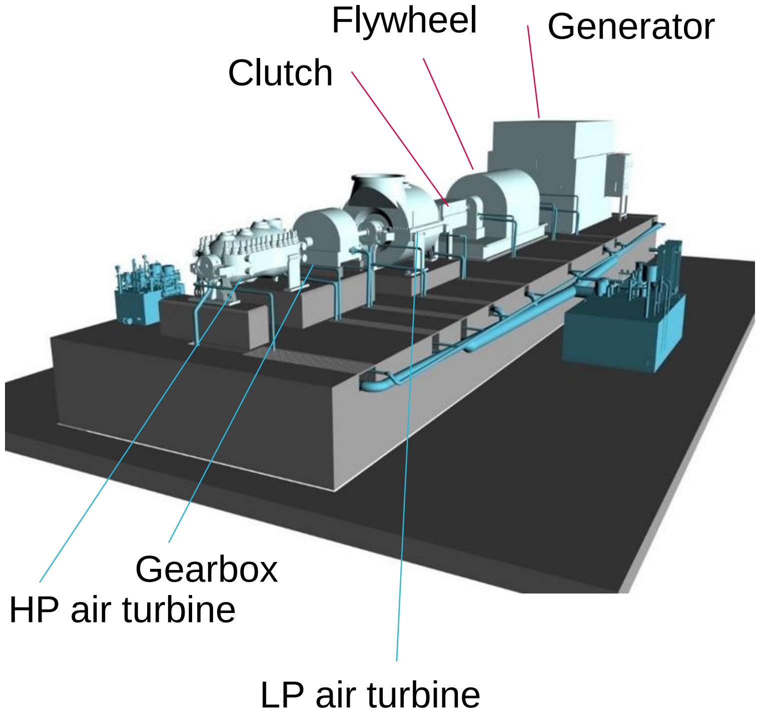
Capacity

Flexibility in capacity: Reducing flow & power output / power consumption in seconds.



Spinning reserve

Increasing inertia with adding more rotating mass to a discharging turbine train.



https://www.epexspot.com/en/market-data?market_area=DE-LU&trading_date=2022-04-20&delivery_date=2022-04-21&underlying_year=&modality=Auction&sub_modality=DayAhead&product=60&data_mode=graph&period=

Energy Storage with turbomachinery

On the example of CAES, LAES and CO2 Battery – key take aways

- Turbomachinery can make a significant contribution for carbon neutral future
- Power outputs from 20 MW up to 200 MW / train possible
- Long discharge duration up to 12 hours under full load is possible
- Efficiency over 55 % and more is possible
- Higher compression temperatures enable further heat storages
- Over 30+ years lifetime
- Over 20.000 load cycles
- Storage systems can provide multiple services for the energy system e.g., Spinning reserve, Black start)
- CO2 Zero Emissions

MAN Energy Solutions
Future in the making

Thank you very much!

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