MAN Energy Solutions
Future in the making

MAN Energy Solutions

Energy Storage Solutions

MAN PrimeServ

Company profile

MAN Energy Solutions enables its customers to achieve sustainable value creation in the transition towards a carbon neutral future.

Addressing tomorrow’s challenges within the marine, energy and industrial sectors, we improve efficiency and performance at a systemic level.

Leading the way in advanced engineering for more than 250 years, we provide a unique portfolio of technologies.

Headquartered in Germany, MAN Energy Solutions employs some 14,000 people at over 120 sites globally. Our after-sales brand, MAN PrimeServ, offers a vast network of service centers to our customers all over the world.

Our Mission

We convert energy into sustainable progress and prosperity.

We drive the transition towards a carbon-neutral world together with our partners.

Our strategic business areas

Engines & Marine Systems

Power Plants

Turbomachinery

Aftersales MAN PrimeServ

Home of the diesel engine

Rudolf Diesel 1858 – 1913

Drivers of our company strategy

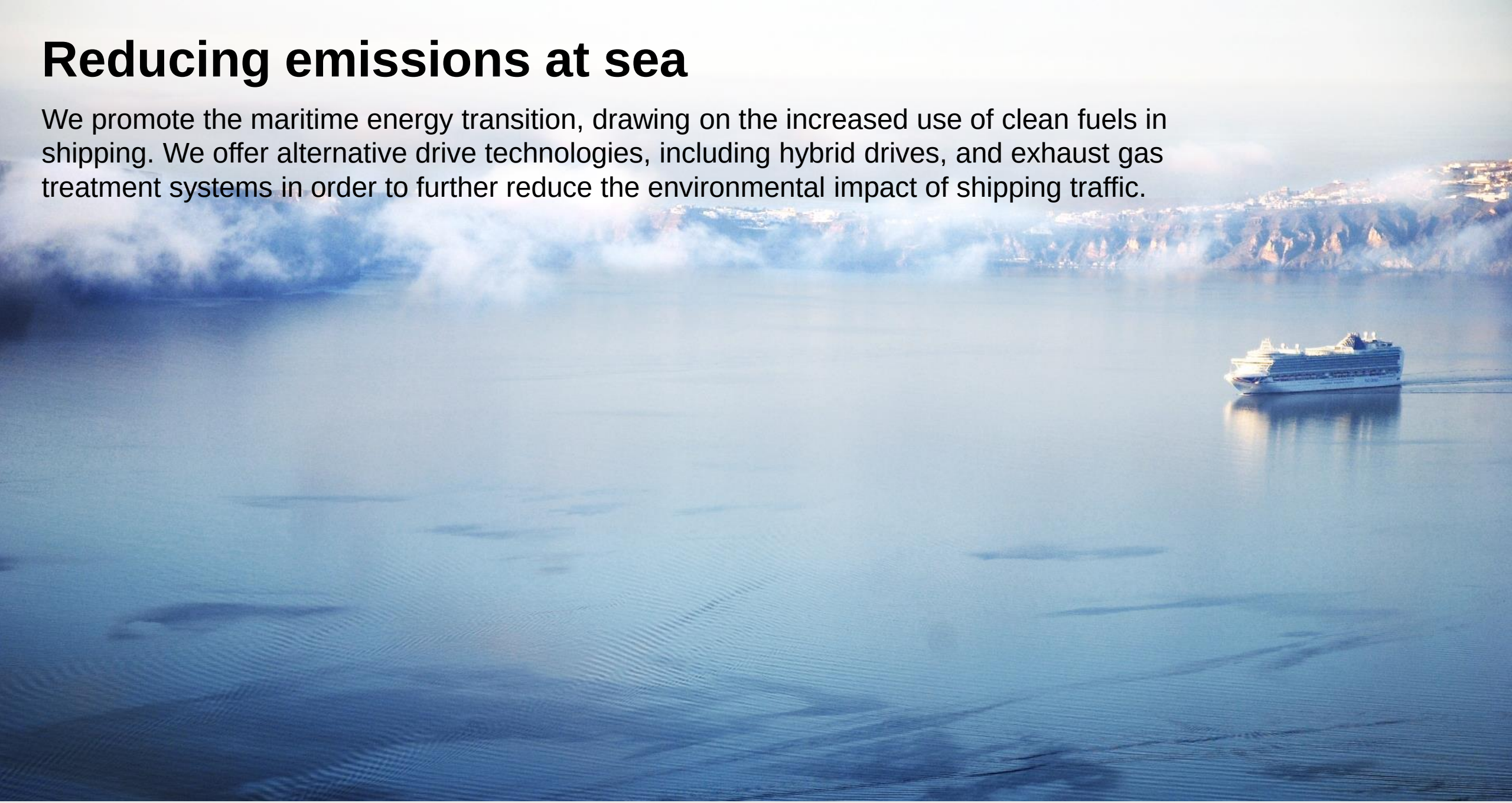
Decarbonization

calls for new technologies

- Limit global warming to below 2° Celsius
- Carbon neutrality until 2050

Reducing emissions at sea

We promote the maritime energy transition, drawing on the increased use of clean fuels in shipping. We offer alternative drive technologies, including hybrid drives, and exhaust gas treatment systems in order to further reduce the environmental impact of shipping traffic.



MAN Energy Solutions
Future in the making

Energy Storage Solutions

MAN’s Solution Offering for Energy Storage

April 26, 2019

Agenda

1 The Relevance of Energy Storage

2 MAN’s Energy Storage Offering

1 The Relevance of Energy Storage

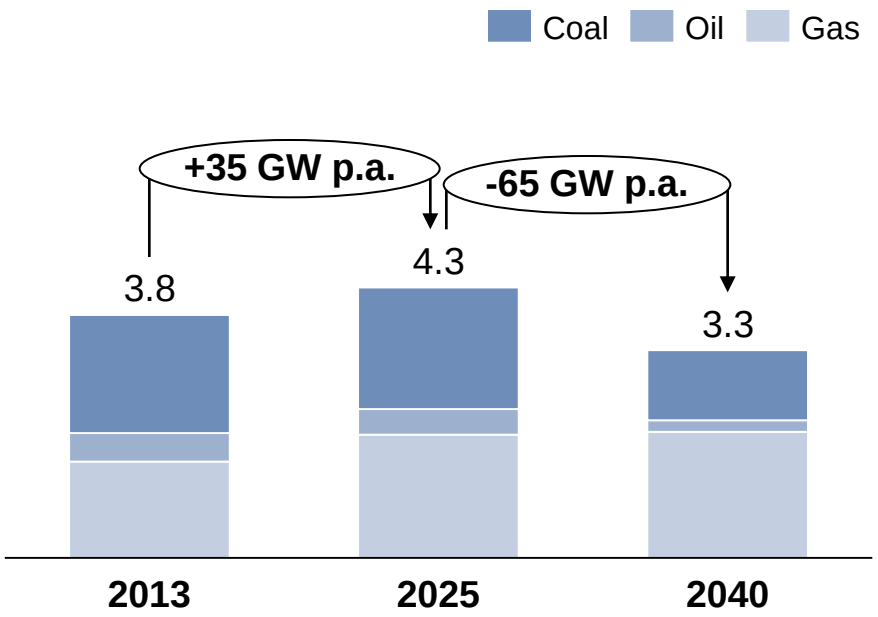
Increase of variable renewable energy sources (RES) disrupting the power market

2° Target

- Limit global warming to 2°C above pre-industrialization situation
- Global CO_2 emissions to be reduced by 50% in relation to 1990 (450 ppm CO_2)

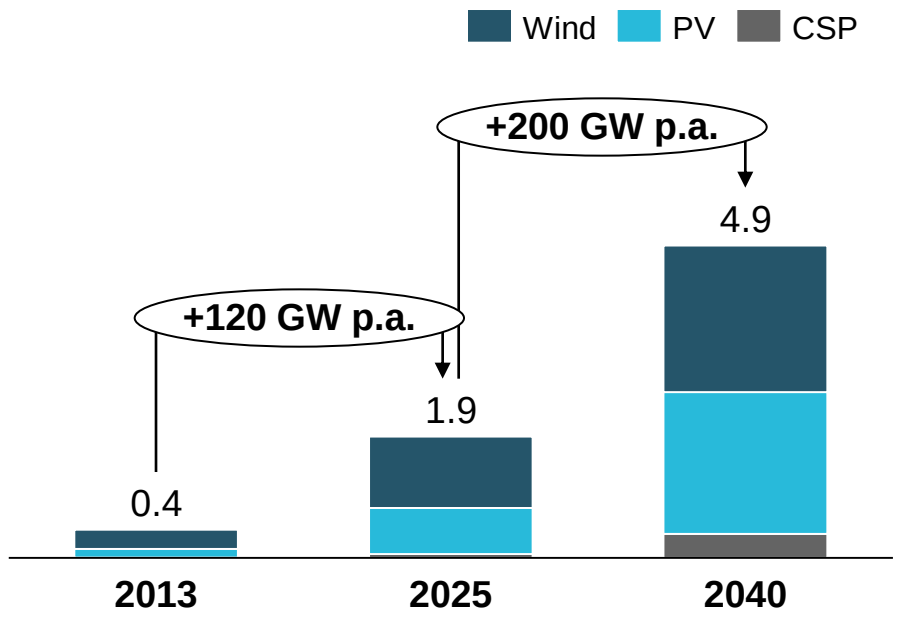
Development fossil plants (world, 2DS)

Capacity (TW)



Development variable renewables (world, 2DS)

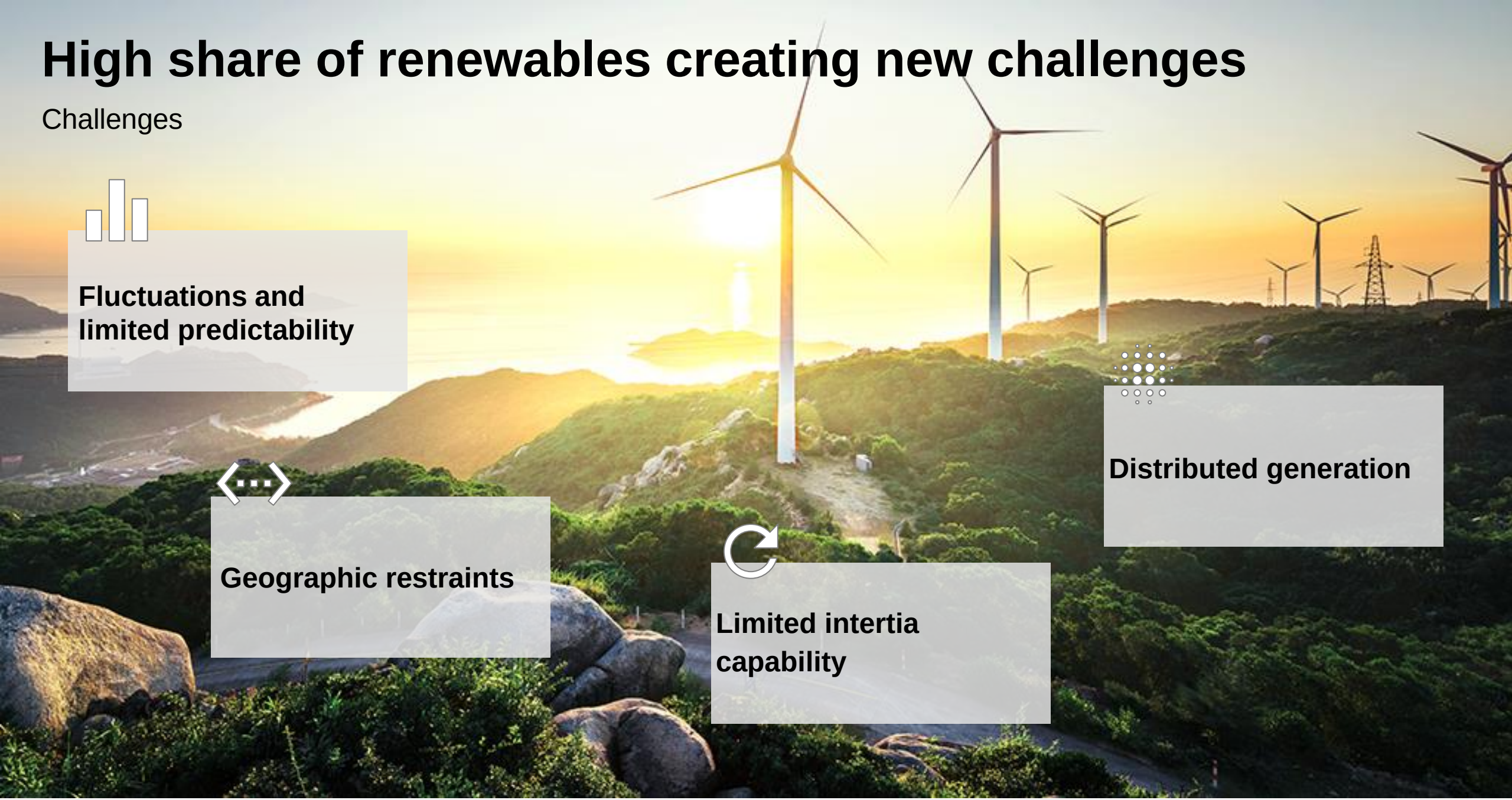
Capacity (TW)



Source: IEA (Energy Technology Perspectives 2016, 2 degree scenario)

High share of renewables creating new challenges

Challenges



Fluctuations and limited predictability

Geographic restraints

Limited intertia capability

Distributed generation

Multiple measures to integrate renewables – energy storage most flexible option

Demand-side response

Transmission & Distribution (T&D)

Flexible power plants / backup plants

Energy storage

Combination of various measures expected, mix depending on specific local situation

Storage systems can provide multiple services for the energy system

Power focus: Provide large amount of power in a relatively short period of time

Energy focus: Provide steady amount of power for an extended amount of time

Non-electricity applications:

 **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
 **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
 **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

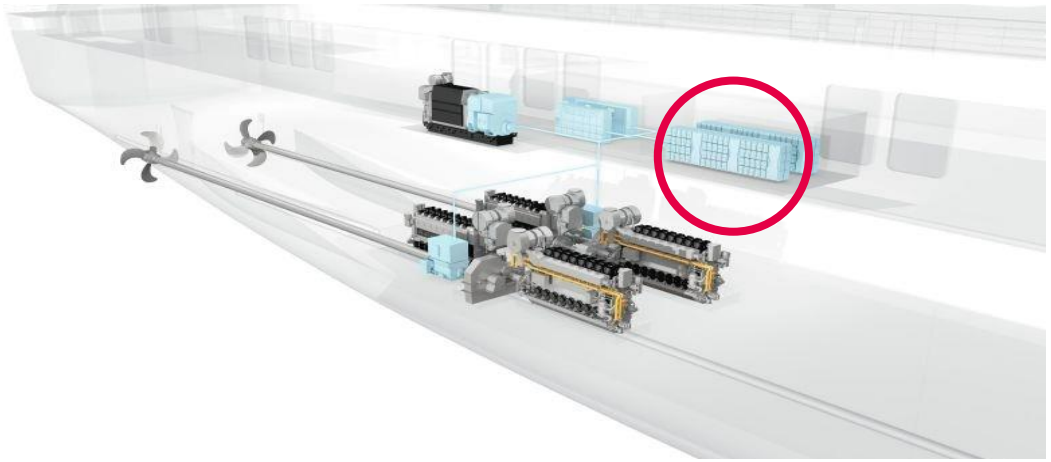
2 MAN’s Energy Storage Offering

MAN experience in land based as well as marine energy storage systems

Land-based

- Energy storage systems are a **key component of hybrid systems and microgrids** by integrating various sources
- **Stand alone storage solutions** in power systems to provide grid services or commercial and industrial applications

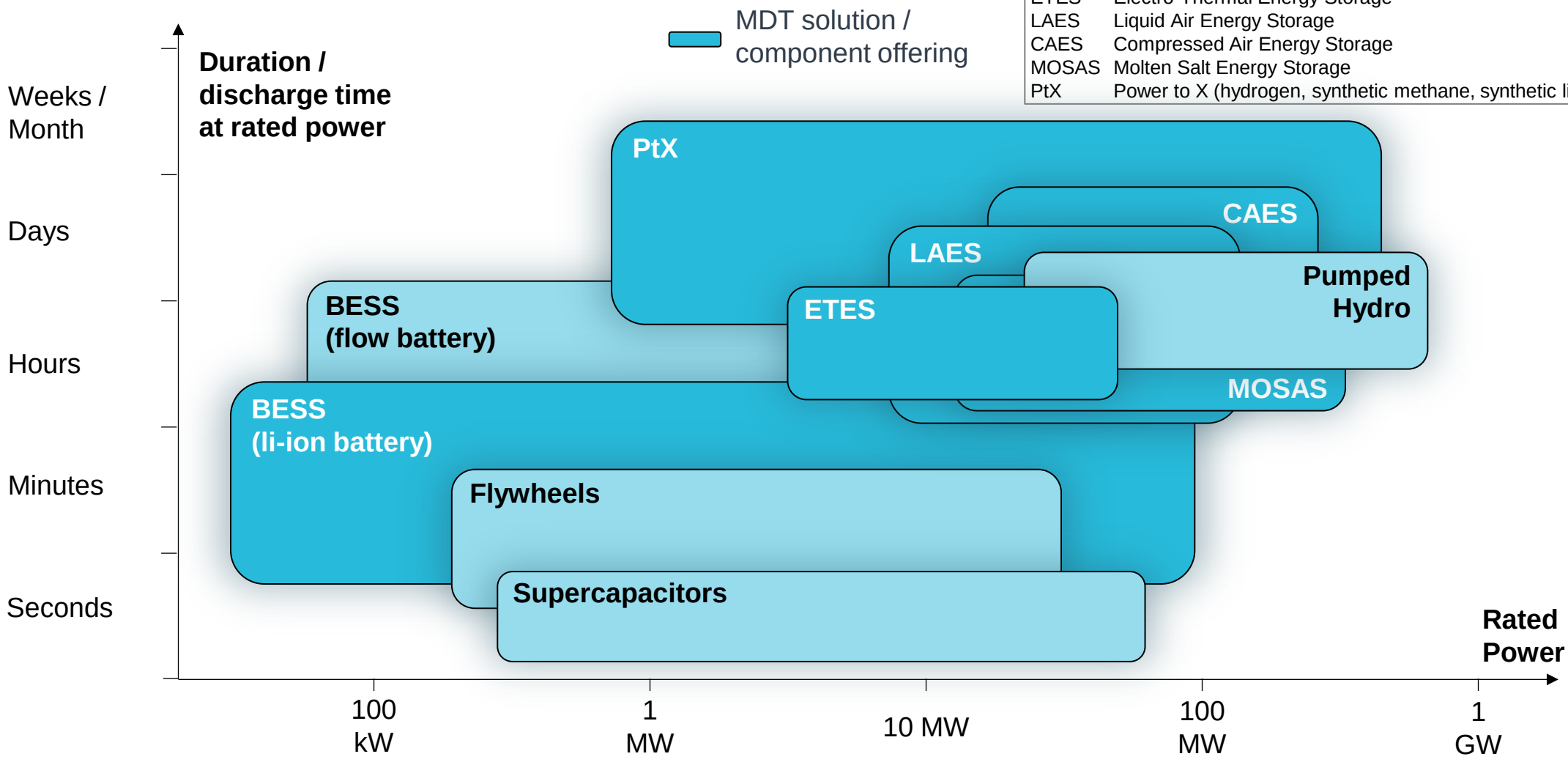
Marine



- Battery storage systems are a **part of battery-hybrid propulsion systems**, balancing the system and increasing efficiency
- Further potential in **full electric vessels** and battery-buffer in on-shore **charging stations**

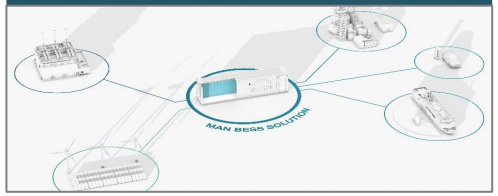
Power and duration requirements determine most suitable technology for specific purpose

BESS	Battery Energy Storage System
ETES	Electro-Thermal Energy Storage
LAES	Liquid Air Energy Storage
CAES	Compressed Air Energy Storage
MOSAS	Molten Salt Energy Storage
PtX	Power to X (hydrogen, synthetic methane, synthetic liquids)



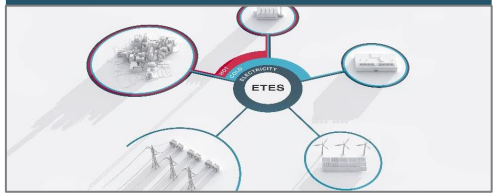
MAN ES supporting it’s customers with multiple storage technologies for different requirements

Battery Energy Storage System (BESS)



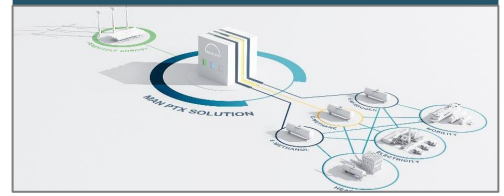
- Lit-ion battery
- High power requirements
- Power to power / re-electrification

Electro-Thermal Energy Storage (ETES)



- Thermal storage and energy mgnt
- Sector integration
- Direct use of thermal energy or re-electrification

Power to X (PtX)



- Conversion of electricity into synthetic fuels
- Direct use or re-electrification

Liquid Air Energy Storage (LAES)

- Cryogenic storage
- Large scale and long duration
- Power to power / re-electrification

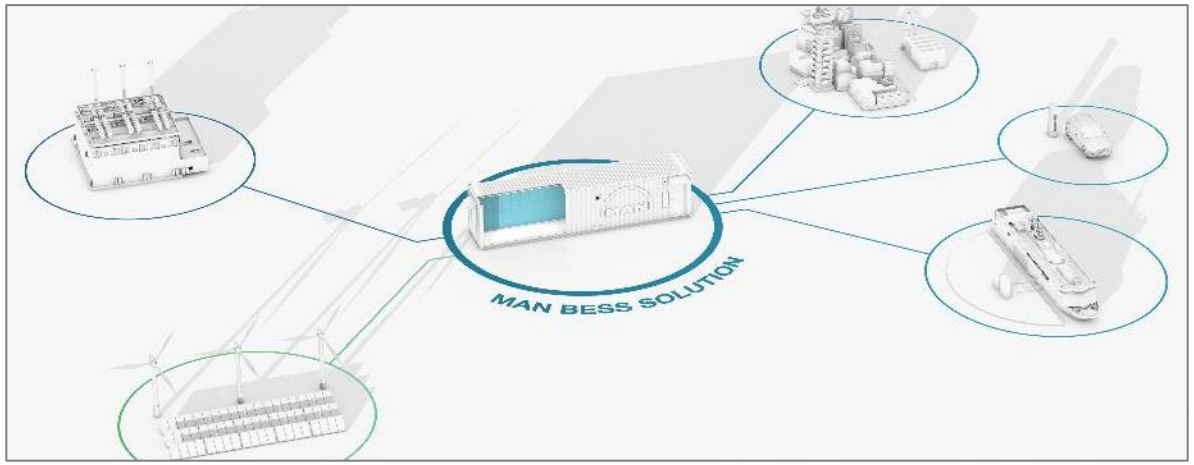
Compressed Air Energy Storage (CAES)

- Mechanical storage
- Large scale and long duration
- Power to power / re-electrification

Molten Salt Energy Storage (MOSAS)

- Thermal storage
- Large scale and long duration
- Storage for CSP or thermal plants

MAN Battery Energy Storage System (BESS)



- **Technology:** Electro-chemical storage system based on Li-ion batteries; solution comprises battery container including power electronics and grid connection / system integration
- **Power & capacity:**
  - Combined 40 ft battery and power electronics containers: ~ 4 MW / 3 MWh (individual configuration possible)
  - Battery only: up to 4.6 MWh per container
  - MAN offering from 1 MW / MWh to 100+ MW / MWh

Applications

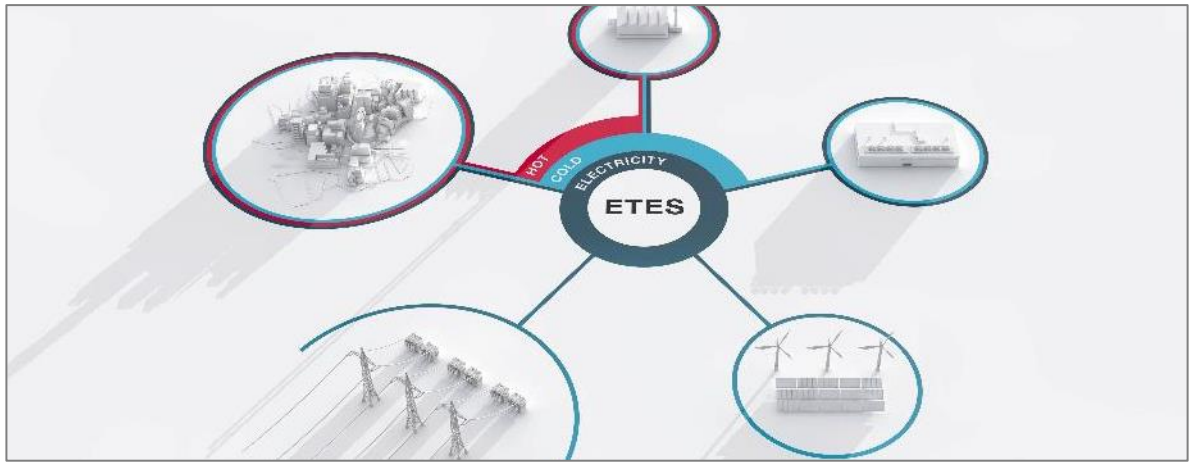
High power, short / medium duration applications:

- Grid services (fast frequency response, voltage control)
- Peak shaving, renewables smoothing
- Demand charge reduction, improve security of power supply

Key benefits

- Battery Energy Storage Systems help improving energy **reliability, availability and efficiency** of the power supply
- BESS can be deployed in **stand alone systems** as well as in **hybrid applications** with engines, and/or renewables
- Key element in **hybrid power solutions** reducing cost, enabling high shares of renewables, increasing efficiency of engine, reducing fuels cost and CO_2 emissions
- MAN provides BESS on a **turnkey basis** including power electronics, battery management, and grid connection

MAN Electro-Thermal Energy Storage (ETES)



- **Technology**: electricity is converted via a thermodynamic process in thermal energy and stored in heat and cold; in discharging mode the thermal energy can directly be used or reconverted in electricity
- **Power & capacity**:
  - Output power starting from ~5 MW, scalable up to 50+ MW
  - Storage capacity: application dependent, ranging from 50 MWh to 1 GWh+ thermal capacity (~1/3 electrical cap.)
  - Individual sizing for specific use case

Applications

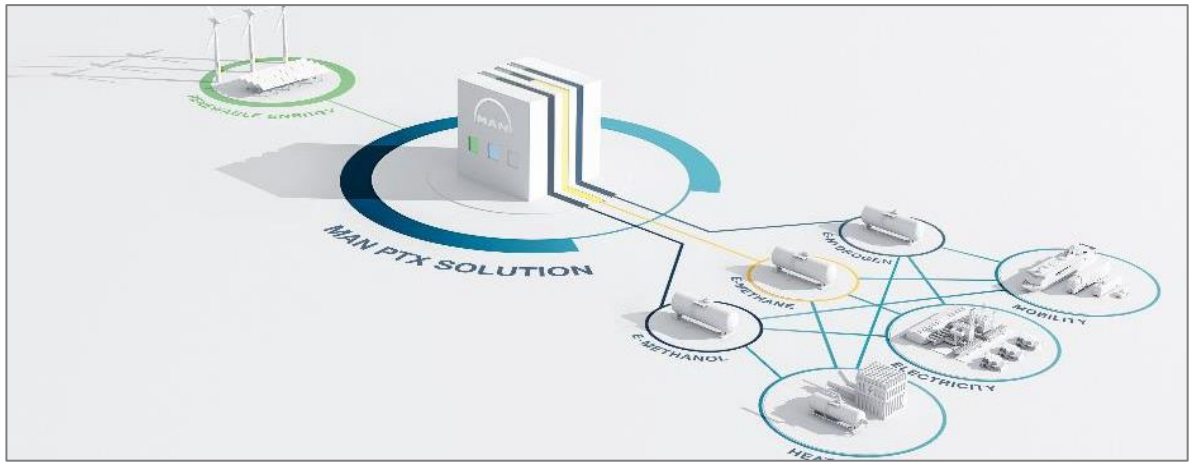
Electro and thermal energy management:

- Heating (district heating, process heat, etc.)
- Cooling (date center, air conditioning, industry, etc.)
- RES smoothing, generation capacity, backup / black start

Key benefits

- Pioneering solution that facilitates the **sector coupling of heating, cooling and electricity**
- ETES provides the flexibility both for **direct use** of the thermal energy as well as for **re-electrification**
- The energy storage system can be deployed as **stand alone solution as well as an integrated system, e.g., as energy management system of a datacenter or for municipals**
- MAN provides the complete ETES system as a **single solution**, with ABB's support as system partner

MAN Power-to-X (PtX)



- **Technology:** Related technologies regarding conversion of electricity in synthetic fuels like hydrogen, synthetic natural gas (SNG), or synthetic liquids for direct use or later reconversion.
- **Power & capacity**
  - Industrial installations starting from ~10 MW, reaching 50MW+ for large scale plants
  - Very large capacities, especially if existing infrastructure is used

Applications

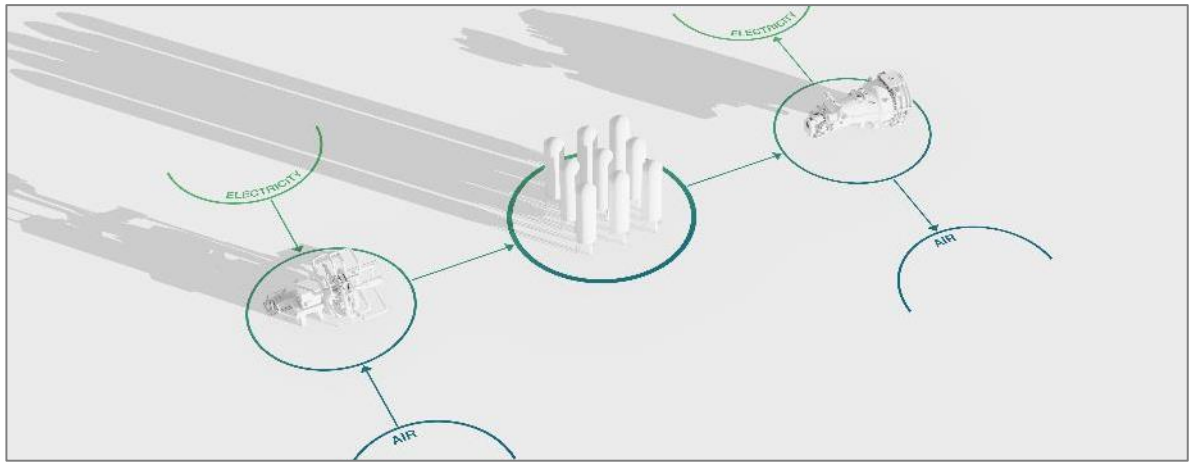
Synfuel production & seasonal / long term storage:

- Direct use as fuel in the transportations or marine sector to improve the carbon footprint
- Storage and later re-electrification to generate CO2 neutral electricity and store electricity over long periods of time

Key benefits

- MAN Power-to-X (PtX) solutions allows large scale, industrial production of **CO2 neutral synthetic fuels** with multiple use cases
- Storage of very **large** amounts of energy over a **long time** with the potential for large scale substitution of fossil fuels
- By **coupling the major energy sectors**, PtX will make a significant contribution to decarbonizing the energy system
- MAN provides **turnkey, large scale PtX plants** out of one hand

Liquid Air Energy Storage (LAES) – MAN equipment



- **Technology**: Electricity is used to generate via compression and cooling liquid air which is stored under high pressure in tanks. To generate electricity again, liquid air is drawn from the tank, evaporated and expanded through a power turbine.
- **Power & capacity**:
  - Power from ~25 MW, scalable to 50-100 MW+
  - Storage capacity: starting from ~50 MWh, scalable to >1 GWh
  - Sizing for specific use case; input and output power independent

Applications

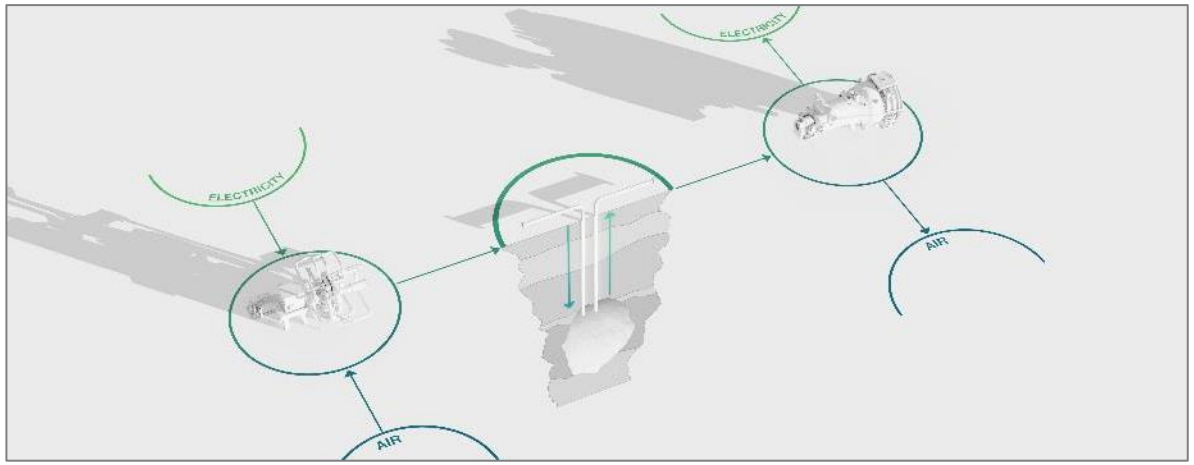
High power and medium to long duration applications

- Generation capacity; renewables integration / smoothing
- Transmission & distribution asset optimization
- Black start

Key benefits

- LAES has **low capacity costs,** is **scalable** to large sizes (power and capacity), has **no geographical limitations**, and is based on **simple and known processes**
- LAES can be deployed as **stand alone system** as well as **integrated solution** with existing thermal power plants (e.g., usage of waste heat for efficiency increase)
- MAN provides the **key components** for LAES (compressors, air turbine, cryogenic equipment) and is supporting customers with process engineering know how

Compressed Air Energy Storage (CAES) – MAN equipment



- **Technology**: Electricity is used to drive a compressor to compress ambient air which is stored at high pressure in subterranean reservoirs. If electricity is required, compressed air is drawn from the reservoir and expanded through an air expander which drives a generator.
- **Power & capacity**:
  - Power from ~50 MW to ~300 MW+
  - Storage capacity: starting from ~200 MWh, scalable to >3 GWh
  - Sizing for specific use case; input and output power independent

Applications

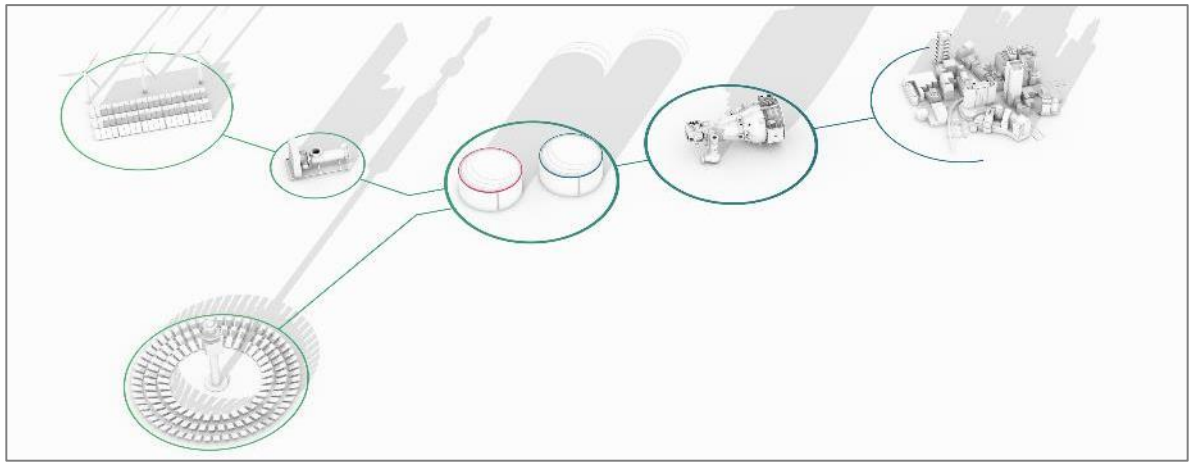
High power and medium to long duration applications

- Generation capacity; renewables integration
- Black start; backup
- Transmission & distribution asset optimization

Key benefits

- Very **low capacity costs** and is **scalable** to large sizes
- **High efficiency** (50-70%) and **proven technology**
- **Stand alone system** as well as **combined solution** with thermal power plant (e.g., usage of waste heat for efficiency increase)
- MAN is a leading provider of the **key components** for CAES (compressors, air turbine)
- MAN provided compressors for the **world's first large-scale CAES** facility (300 MW / 1 GWh) located in Huntorf, Germany

MAN Molten Salt Energy Storage (MOSAS)



- **Technology:** Renewables are used to generate heat directly or via a electrical heat exchanger. The thermal energy is stored in molten salt and later used to produce steam for power generation when needed.
- **Power & capacity**
  - Industrial installations starting from ~25 MW, reaching multiple 100 MW for large scale installations
  - Very large capacities (1 GWh+) possible

Applications

High power and medium to long duration applications

- Retrofit of conventional plants, e.g., coal-fired power plants
- Concentrated solar power: dispatchable reneable generation
- Energy recovery in industrial processes

Key benefits

- **Usable in several power generation applications** (CSP, retrofitting of fossil or nuclear power plants, etc.)
- **Peak shaving** of volatile renewables through conversion into heat and reconversion on demand into electricity
- MAN with **long-term experience of using molten salt** as a heat transfer medium in the chemical industry
- MAN provides the **molten salt system as a complete solution** including EPC for CSP

Multiple storage technologies are needed – not a single technology is suitable for all applications

Fast reacting, high power storage systems to release stress from the grid:

- Peak shaving of supply and demand, improve power quality
- Allow thermal power plants to operate at optimal conditions

Long-duration storage systems enable high renewable penetration:

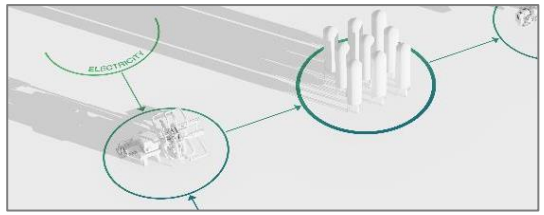
- Shift large amounts of energy across the day to times of demand; avoid the “duck curve”
- Overcome transmission and distribution constraints; replace peaker plants

MAN BESS

Battery Energy Storage System

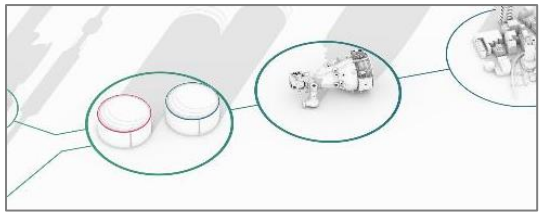
MAN Hybrid Power

MAN LAES & CAES



Liquid Air Energy Storage
Compressed Air Energy Storage

MAN MOSAS



Molten Salt Energy Storage

The non-electricity sectors are at least as important as the power sector for decarbonization

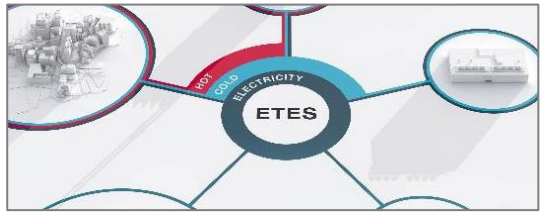
Utilize renewable energy for heating and cooling purposes:

- Heating & cooling account for 48% of global energy use and 39% of all CO_2 emissions
- Currently only 10% of the energy is coming from renewable sources

Substitute fossil fuels with CO_2 neutral synthetic fuels:

- Not all sectors can be electrified: marine, long distance transportation, aviation
- Synthetic fuels utilize existing infra-structure and have a high energy density

MAN ETES



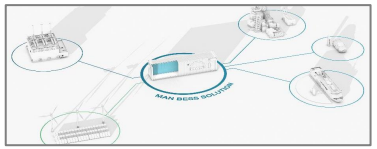
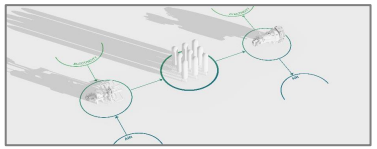
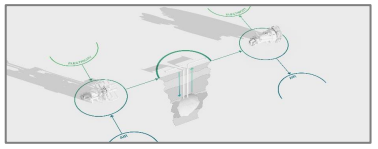
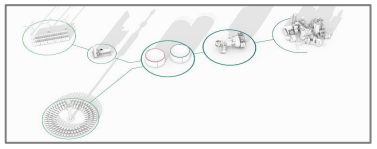
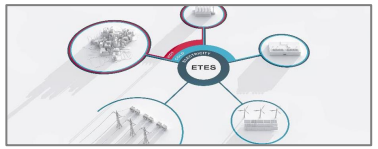
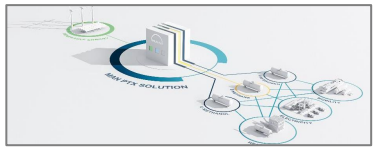
Electro-Thermal Energy Storage

MAN PtX

Power-to-X

Comparison of storage technologies

Indicative figures, individual project based assessment necessary

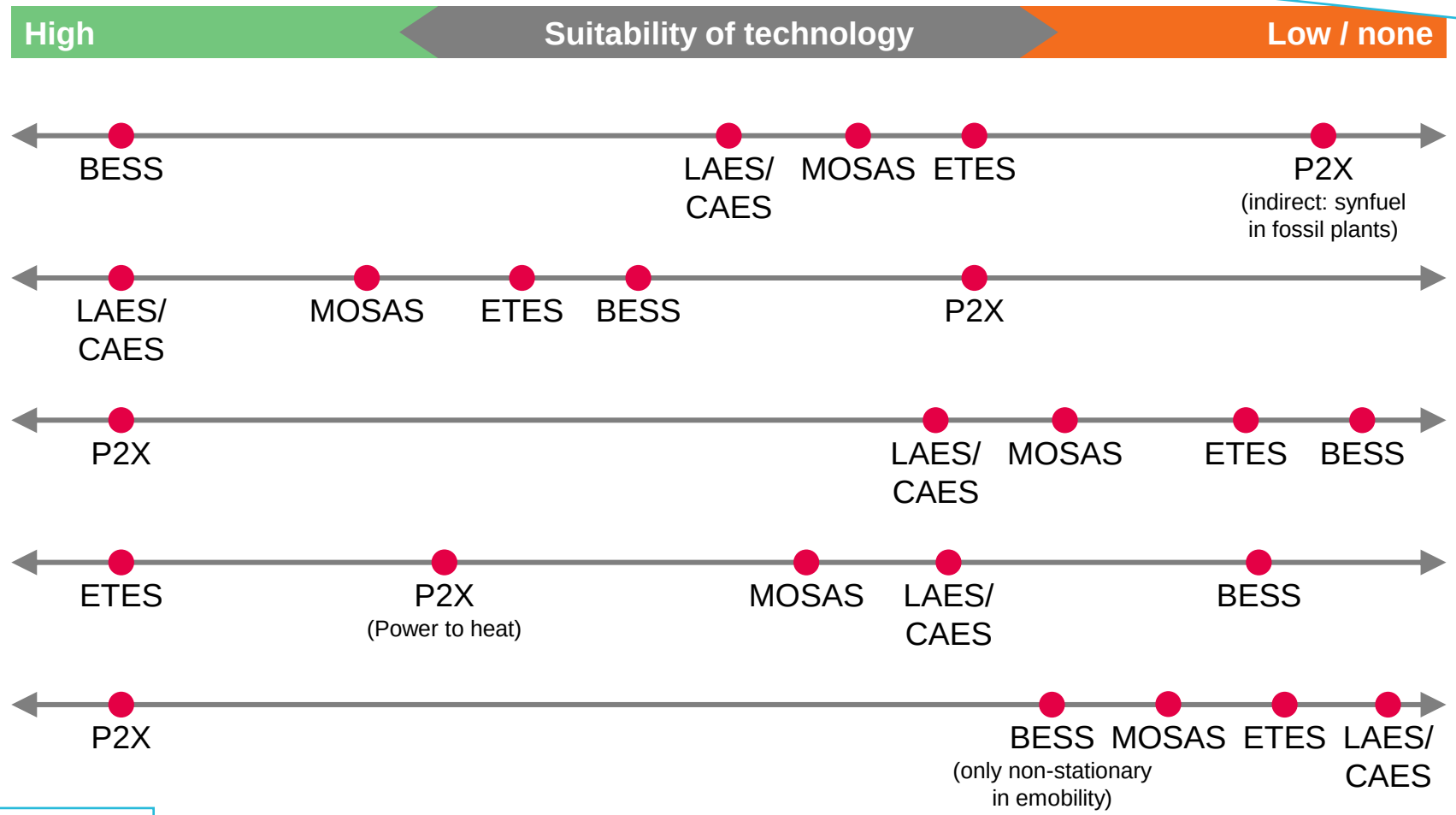
						
Typ	**BESS**	**LAES**	**CAES**	**MOSAS**	**ETES**	**PtX (P-to-SNG-to-P)**
Efficiency	~85-90%	~50-60%[2]	~40-70%[2]	~40%[2]	~45-50%, COP: ~6	~27% (~59% synfuel)
Power	~1-100+ MW	~25-100+ MW	~50-100+ MW	~25-100+ MW	~3-50+ MW	~10-100+ MW
Duration	0.5 – ~4 h	~4-16+ h	~4-16+ h	~4-16+ h	~1-12+ h	Minutes to month
Response[1]	20-100 ms	~10-15 min	5-10 min	5-10 min	~10 min	Seconds
Sector coupling	n/a	✔ (waste) heat and cold usage	✔ (waste) heat usage	✔ (waste) heat usage	✔ heating & cooling	✔ synthetic fuels, CHP, heating
MAN scope	▪ Integrated solution ▪ Stand alone and hybrid	▪ Compressor ▪ Air Expander ▪ Cryogenic equipment	▪ Compressor ▪ Air Expander	▪ Integrated solution, CSP plant ▪ Molten salt system	▪ Integrated solution	▪ Integrated solution ▪ Methanation reactor ▪ Electrolyser (H-TEC)
Key strength	Fast reaction time, multiple applications	Low capacity cost; geographic independent	Very low capacity cost for large scale	Retrofit existing power plants; CSP integration	Integration of heating, cooling and electricity	Production of synthetic fuels; long term storage

[1]Response time for charging mode (input); Hybridization possible for all technologies to increase response time
[2]Significant efficiency increase with external heat/cold source

Stationary storage technologies have different use cases – one technology not suitable for all

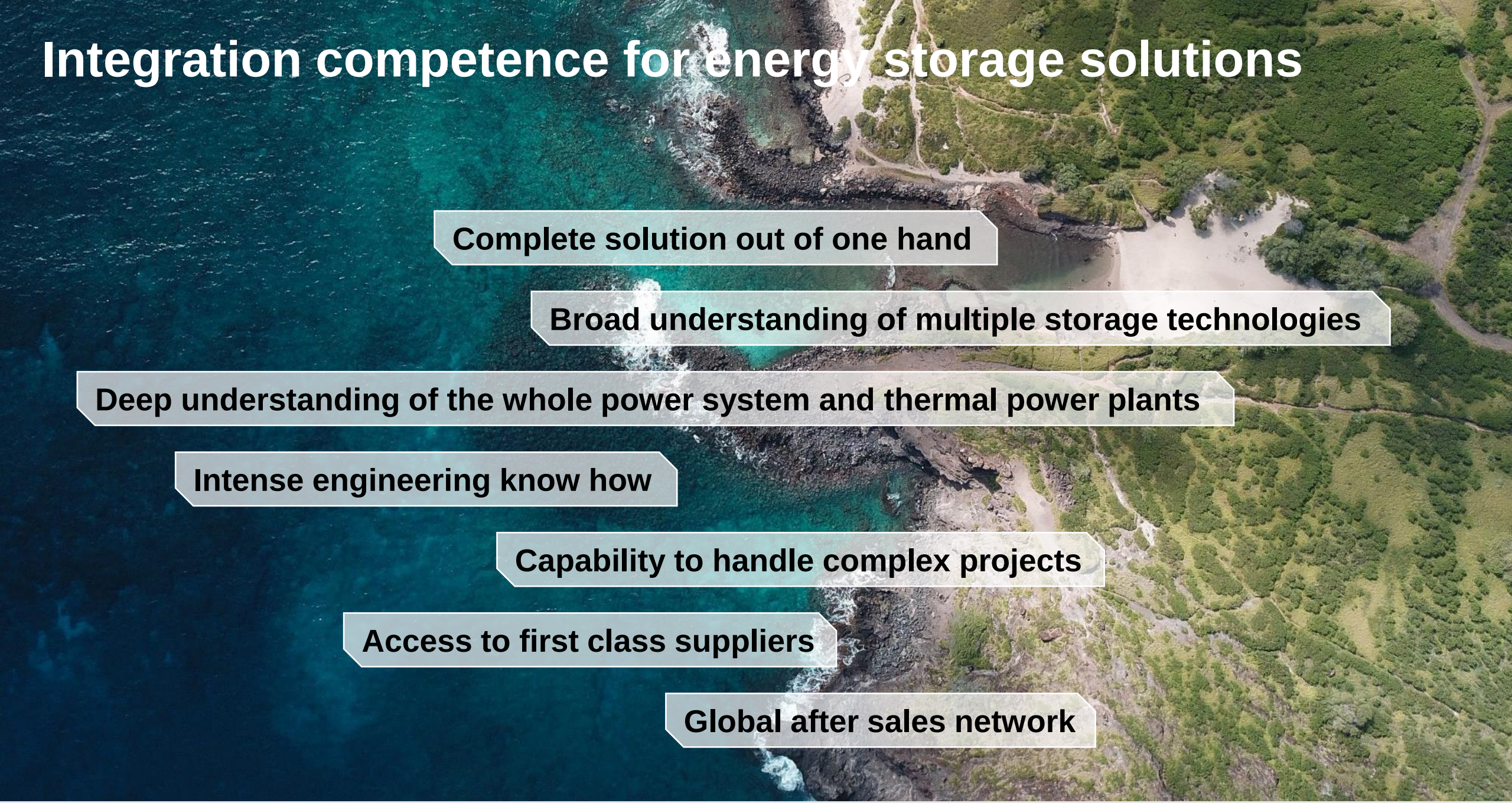
ILLUSTRATIVE

Stationary, large scale, stand alone storage systems – exemplary use cases:



Combination / hybridization of systems possible broaden range of use of specific technologies

Integration competence for energy storage solutions



- Complete solution out of one hand
- Broad understanding of multiple storage technologies
- Deep understanding of the whole power system and thermal power plants
- Intense engineering know how
- Capability to handle complex projects
- Access to first class suppliers
- Global after sales network

MAN Energy Solutions
Future in the making

Thank you very much!

Author
Department
Phone
E-Mail
Day, Month, Year

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.