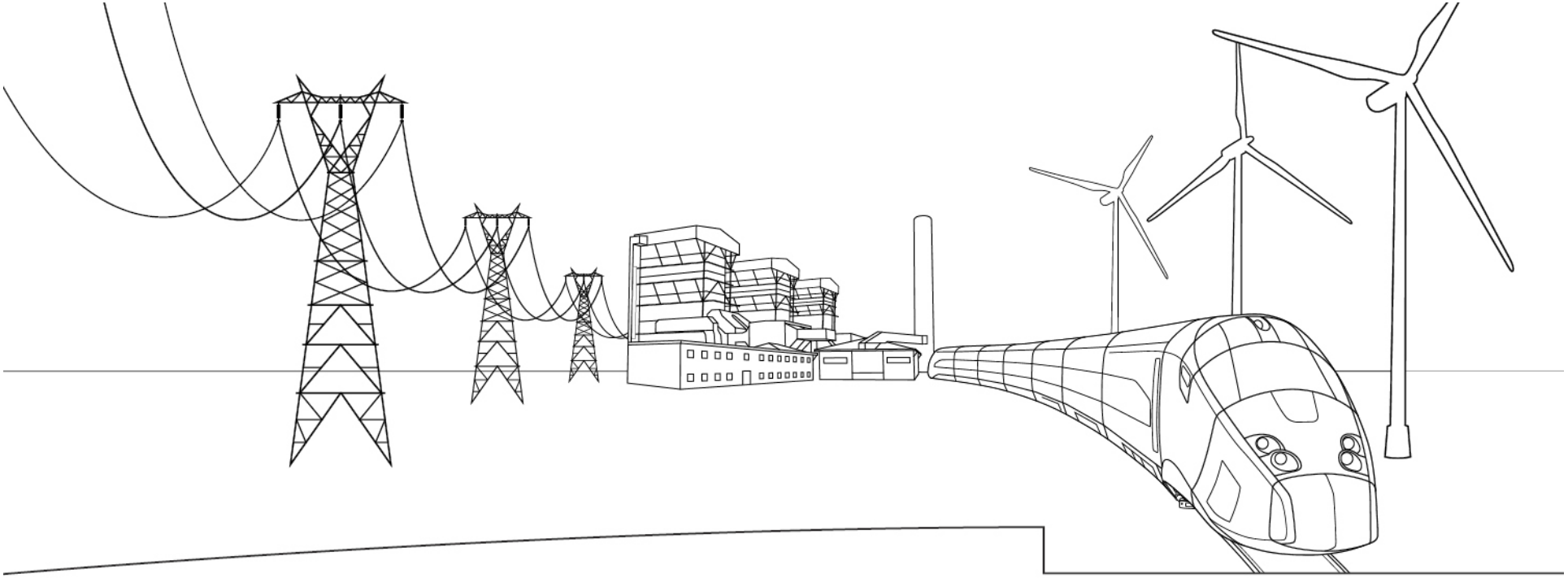

Energy Storage Solutions

Alstom Approach

G.L. Agostinelli, D. Pezzella

Milano

July 2nd, 2015

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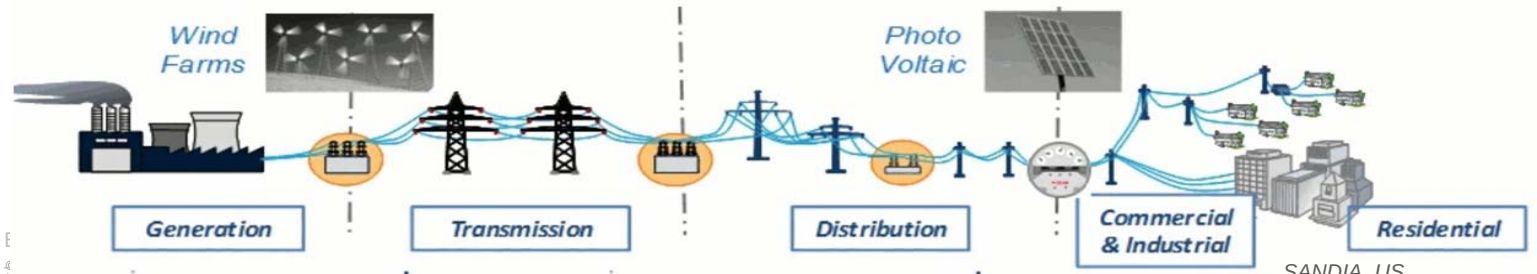
Shaping the future

Agenda

- **Alstom approach**
- **Definition and role of Energy Storage**
- **Alstom solutions**
- **Conclusion**

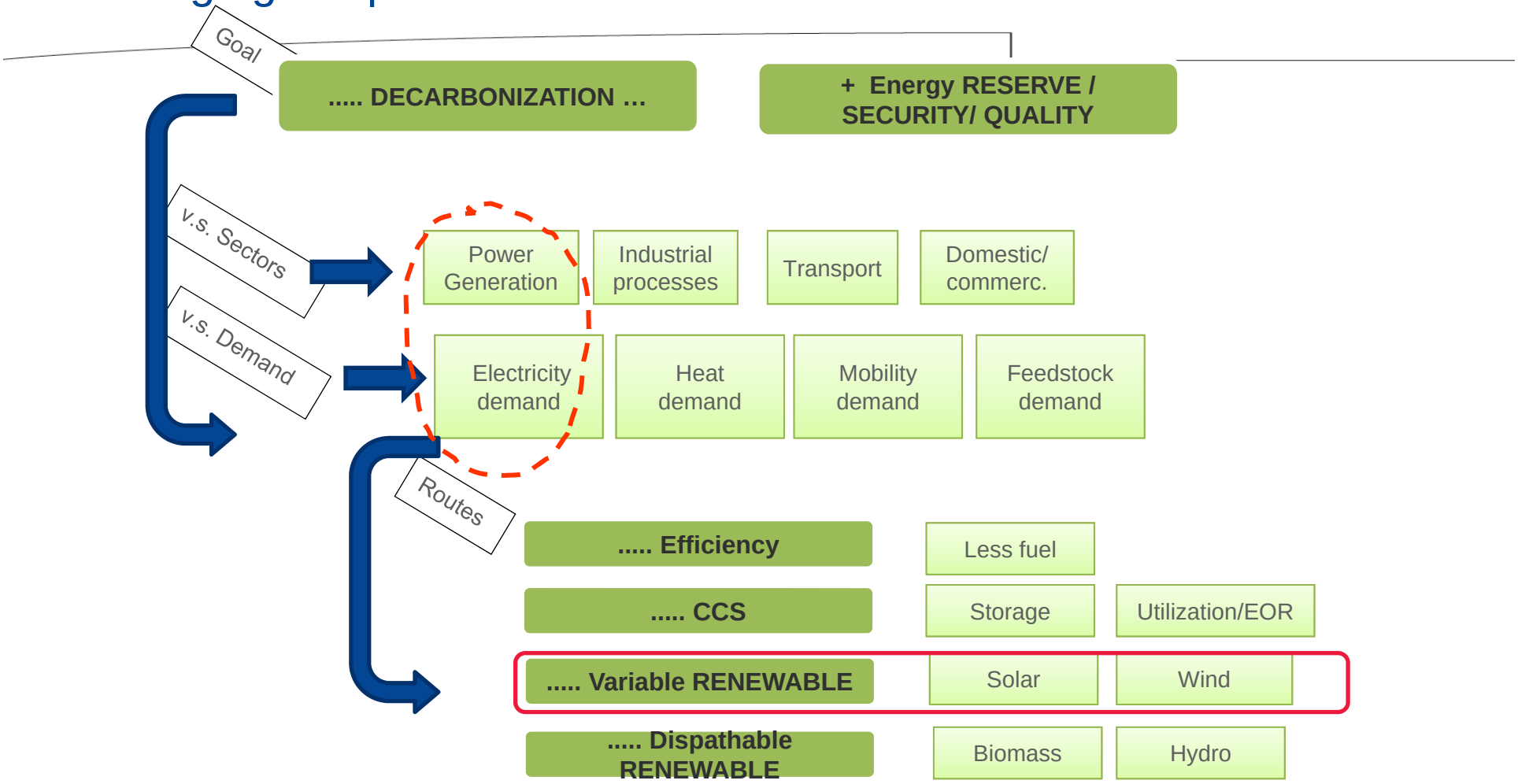
Opportunity of Energy Storage Today and Tomorrow

- **What are the current market conditions ?**
  - Arbitrage
  - Ancillary service (voltage, PCR, SCR)
  - Renewable Plant load shifting (e.g. Feed in tarif day / night)
  - Transmission investment deferral, smart grids
- **What could/should be the future opportunities?**
  - Many studies, two main perspectives to assess value of Energy Storage:
    - Total system cost (ideal mix or evolution)
    - Market perspectives (merit order, arbitrage, ETS, capacity mechanism, ancillary services … at central or distribution level)
  - Policy role in the middle: guiding the energy system assuring a non distorted market
  - We have a Holistic and Technology Neutral approach



SANDIA, US

Target: sustainable, reliable, affordable ENERGY system
Enlarging the picture



Decarbonization relates to all sectors
Different routes within Power Generation

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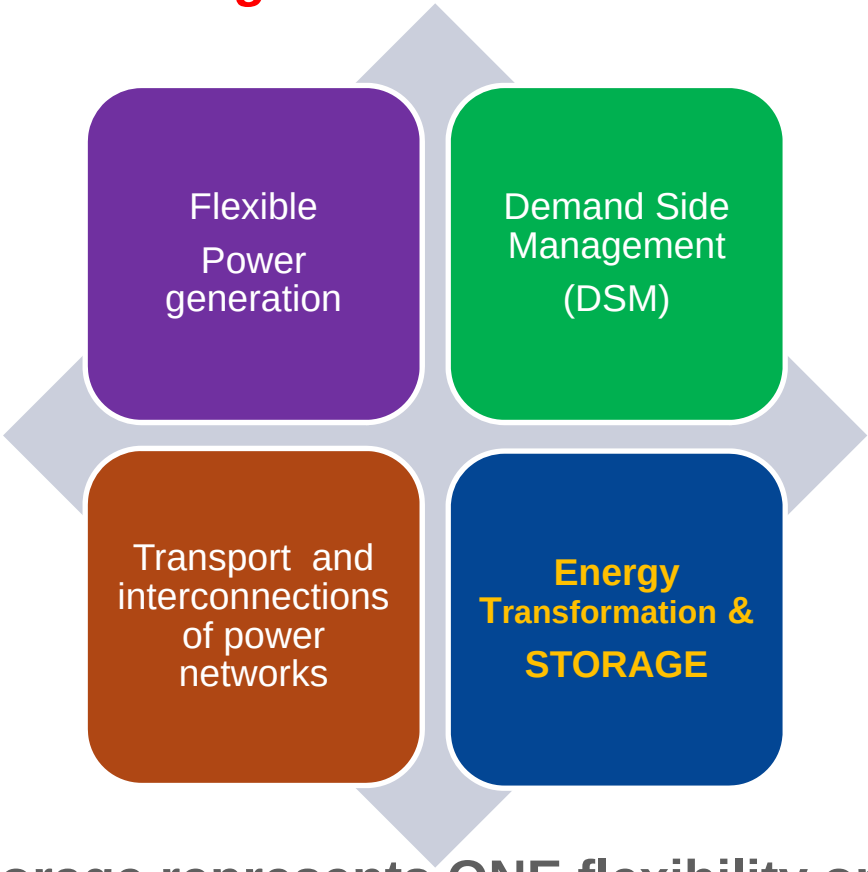
How to integrate variable generation

- Grid operators must offset power generation from wind and sun in a way that leads to the following, 4 pillars to integrate variable renewables

*Power **generation** = Power **consumption***



Storage represents ONE flexibility option

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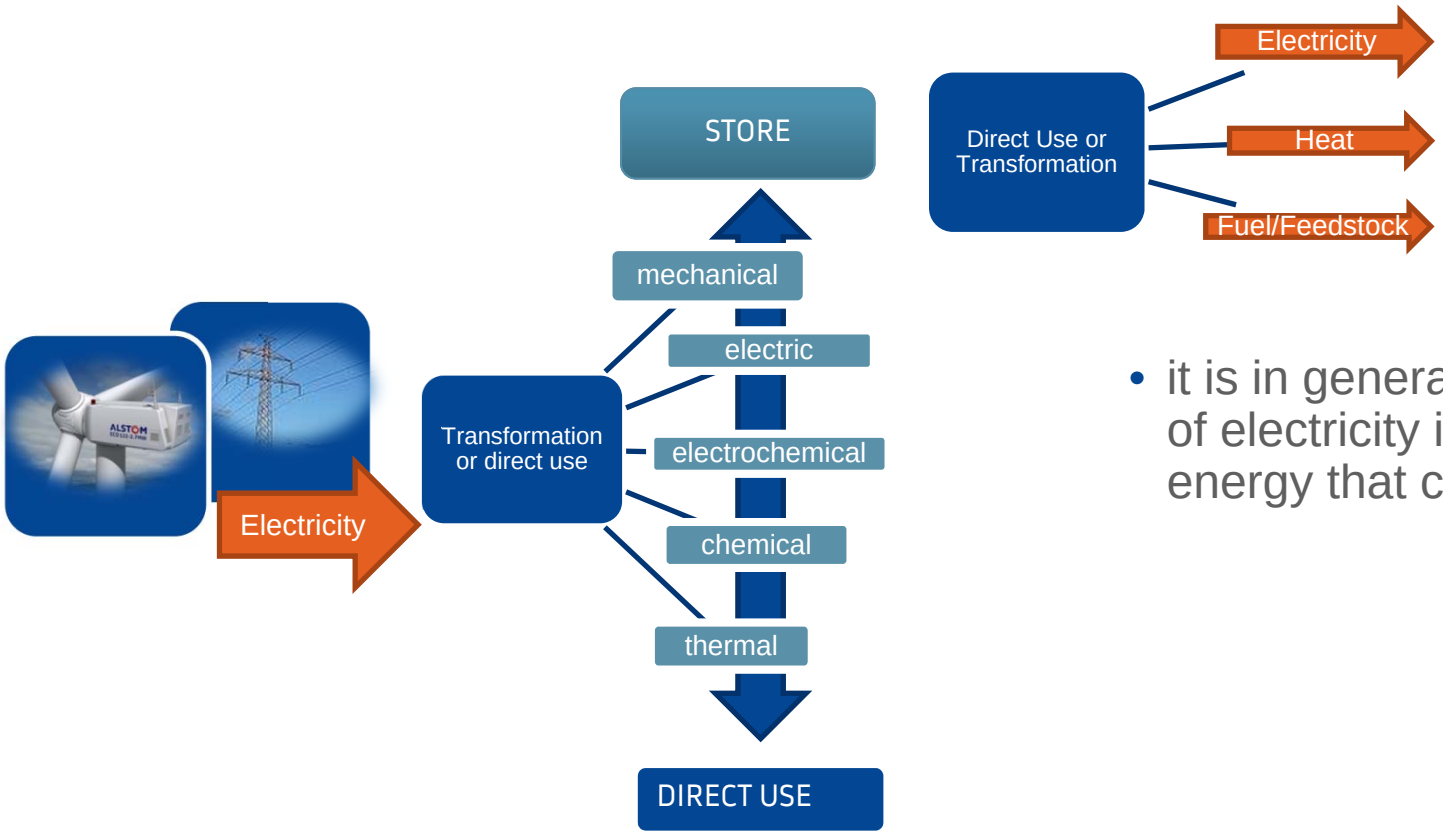
Definition of energy storage

- Energy Storage is a temporary relocation of energy to help aligning generation and consumption, offer and demand.

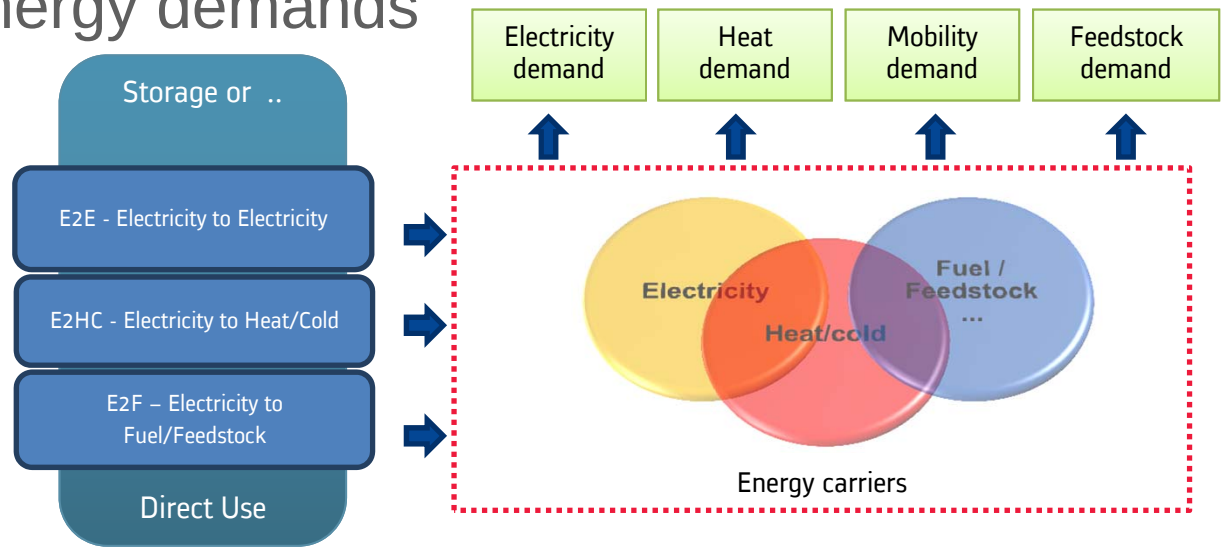


- it is in general a transformation of electricity into a form of energy that can be stored

- the new form of energy can be afterwards re transformed in electricity or in another useful energy form or directly used as it is.

Energy Transformation and energy carriers

- Energy carriers and interconnetions of energy grids to feed energy demands



- **Which one is the "right" technology?**
- Technology neutral approach, everything should be judged according to final application in terms of ability to decarbonize in a reliable and affordable way,
- Therefore considering all aspects (e.g. four pillars)

Variable RE integration into multi energy systems a simple metrics for a first indication

how much does it cost to displace a CO2 via Variable renewable? How much does it cost to integrate Variable RE into multi energy systems?

A simple metrics for a first indication:

- Decarbonization Efficiency

→shall be high!!

$$\frac{kgCO2_{\text{displaced}}}{MWh_{\text{RE in}}}$$

- Decarbonization cost
- → shall be low!!

$$\frac{€}{t\ CO2_{\text{displaced}}}$$

What is the ideal KPI for an ES application?

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Metrics applied to few examples

- **three technologies** of Energy transformation/Storages and three energy carriers:
  - Hydrogen via electrolysis (Electricity to fuel) with storage,
  - Heat pump, Ohmic with Thermal Energy Storage TES (Electricity to Heat)
  - “battery”: representative of any Electricity-to-Electricity to electricity storage
- **utilized in different applications** for different energy demands: **electricity, mobility** and **heat**.
- Two form of direct utilization (e.g. without Storage) : flexibility and Direct use of Electricity into heat demand ,

field of application	Transformation technology (storage or direct use or other mean of RE integration)	
CCPP	H2	H2-GT
	Battery	Bat-GT
	Heat Pump + Thermal Storage	HP-GT
	Direct use – “Flexibility”	Direct-GT
Coal	H2 storage	H2-Coal
	Battery	Bat-Coal
	Heat Pump + Thermal Storage	HP-Coal
	Direct use –“Flexibility”	Direct-Coal
Electric vehicle	H2 storage	H2-Mob
	Battery	Bat-Mob
HEAT	Heat Pump & LT TES Storage	HP-Heat Resid.
	H2 storage	H2 pipe-Heat Resid
	Ohmic Heat + TES	Ohmic Heat + TES
	Direct use - Ohmic Heat Without no TES	Ohmic Heat no TES
	Direct use - Heat Pump no TES	HeatP no TES

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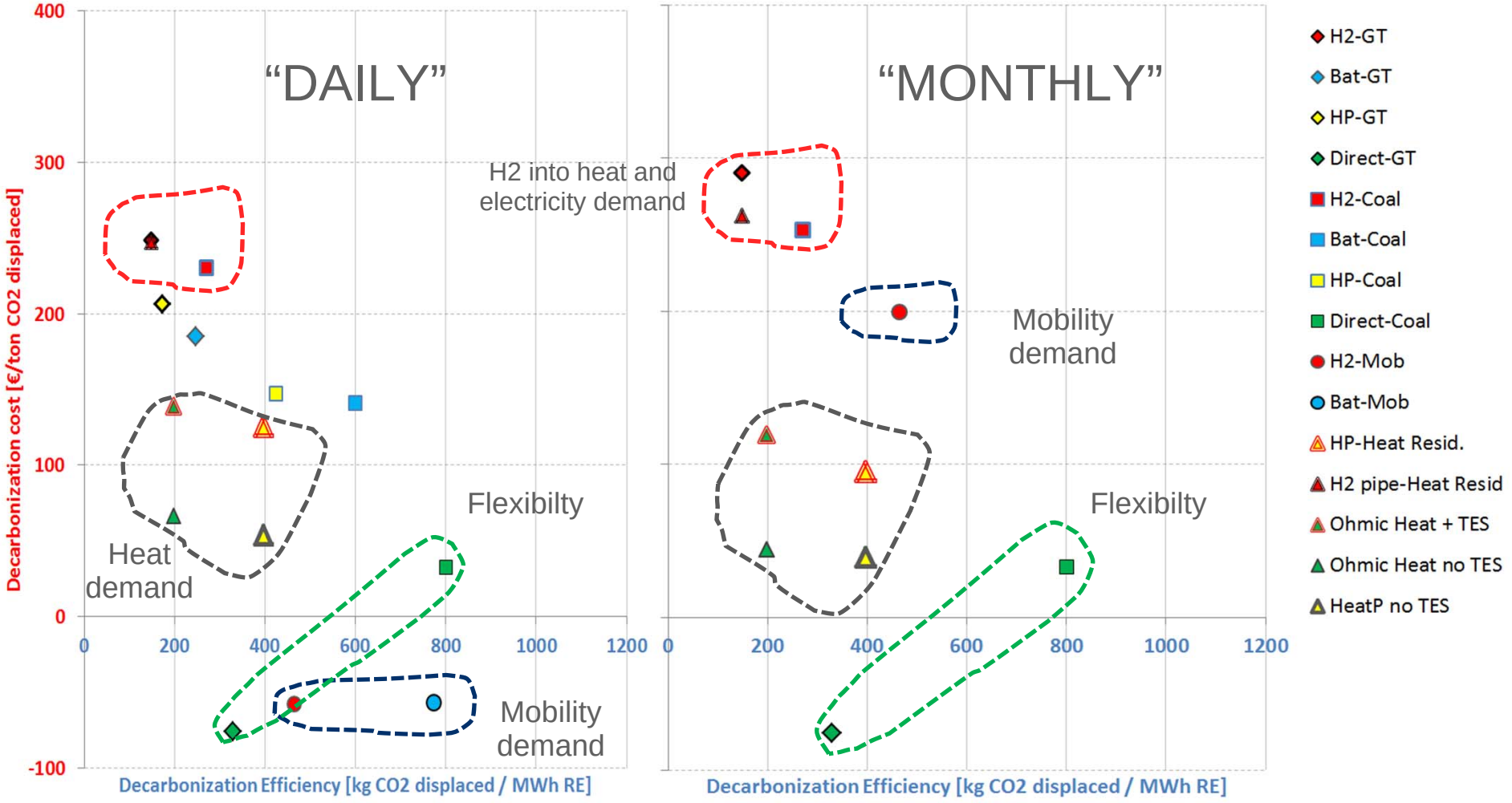
Levelized Cost of Energy (electrical, thermal, mechanical) vs operating profile

Real profiles optimization show two representative operating profiles



Note: Fuel saving is considered → cost can be negative

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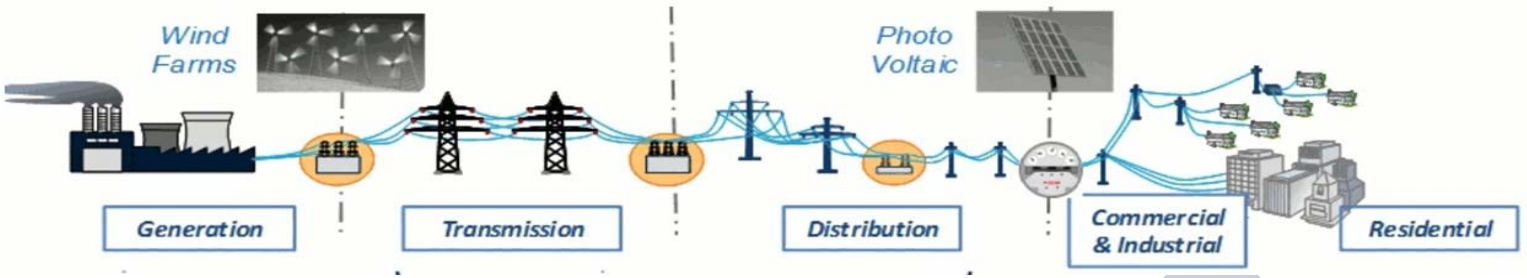
Agenda

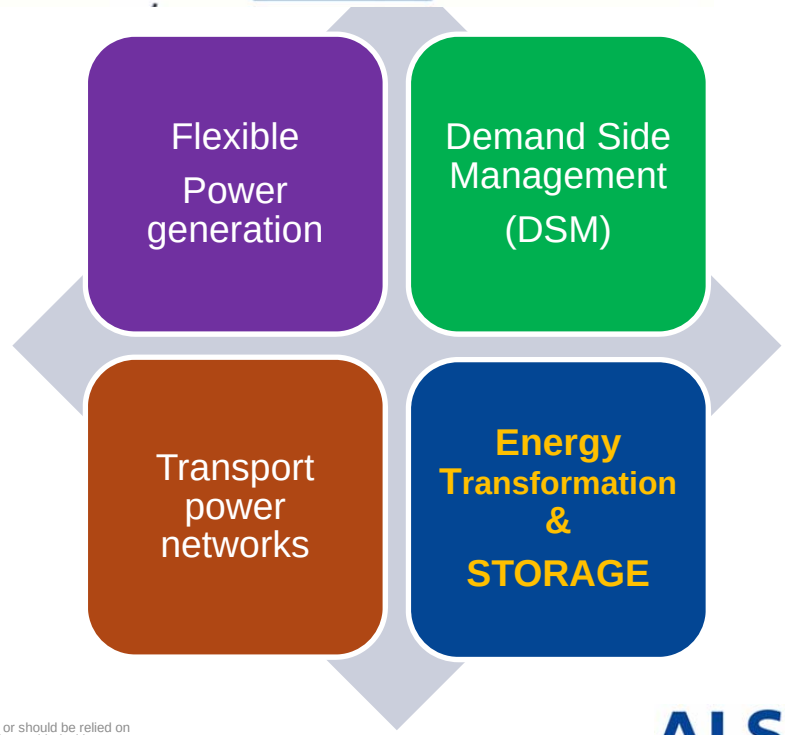
- Alstom approach
- Definition and role of Energy Storage
- **Alstom solutions**
- Conclusion

Where is the focus →wide portfolio of products commercially available or in development

- State of the art commercial products along complete electricity value chain



- But also new solutions based on global perspective of interconnected energy systems and decarbonization routes



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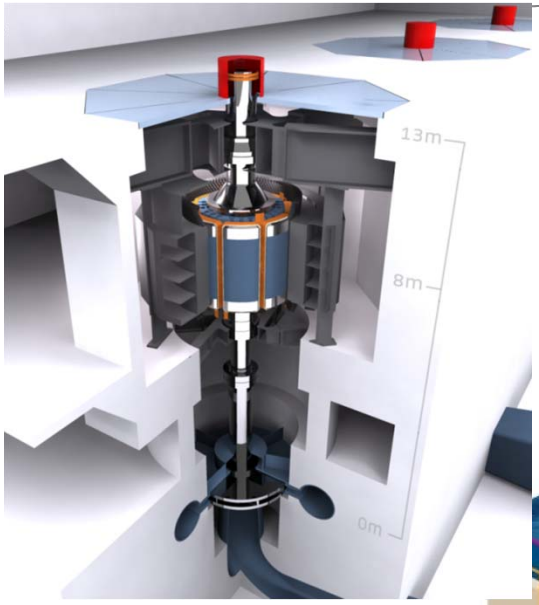
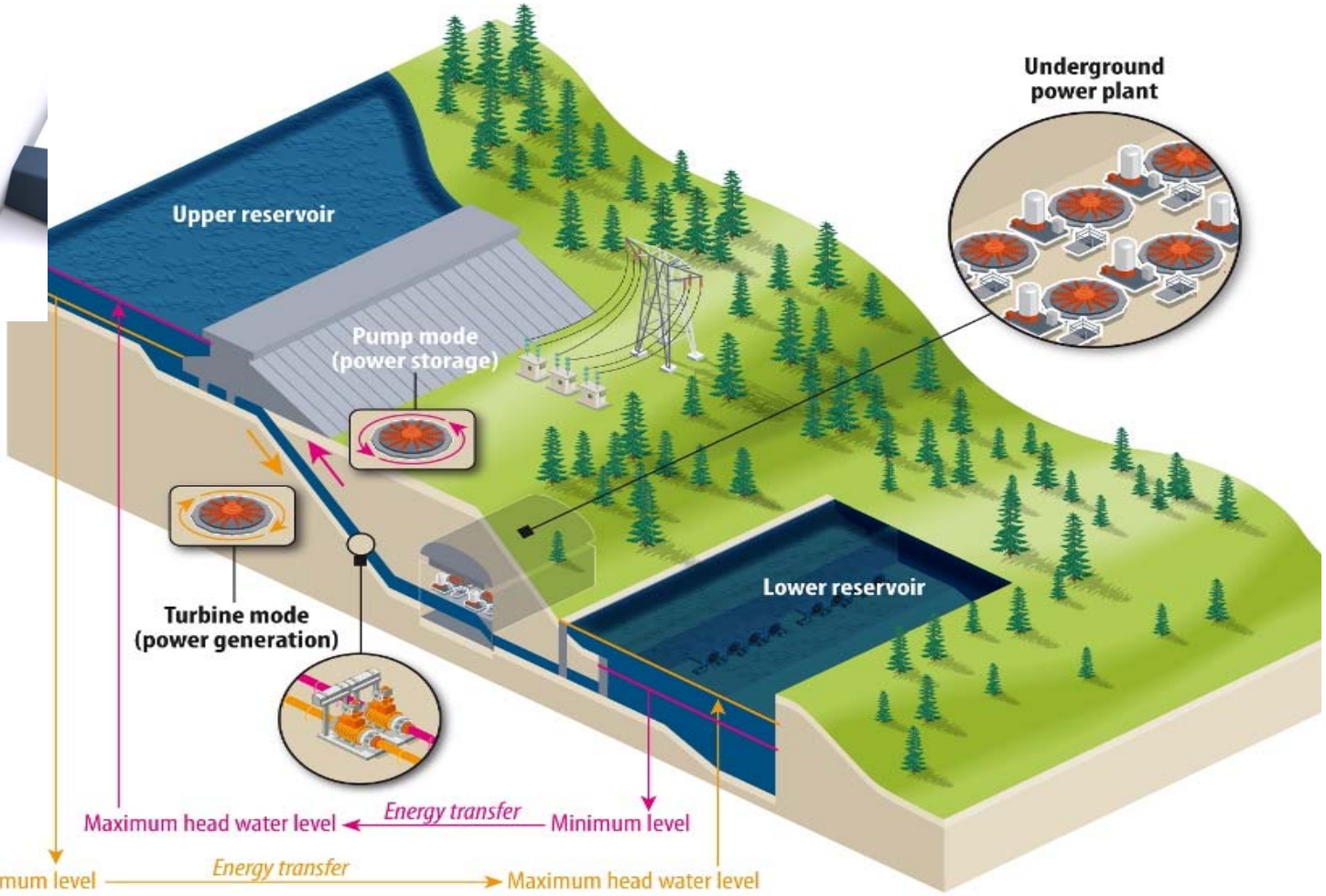
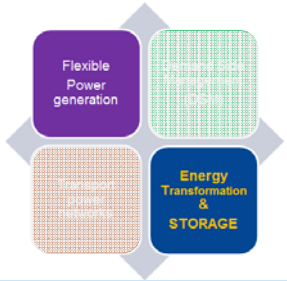
What Alstom offers
Pump Hydro Storage Plant





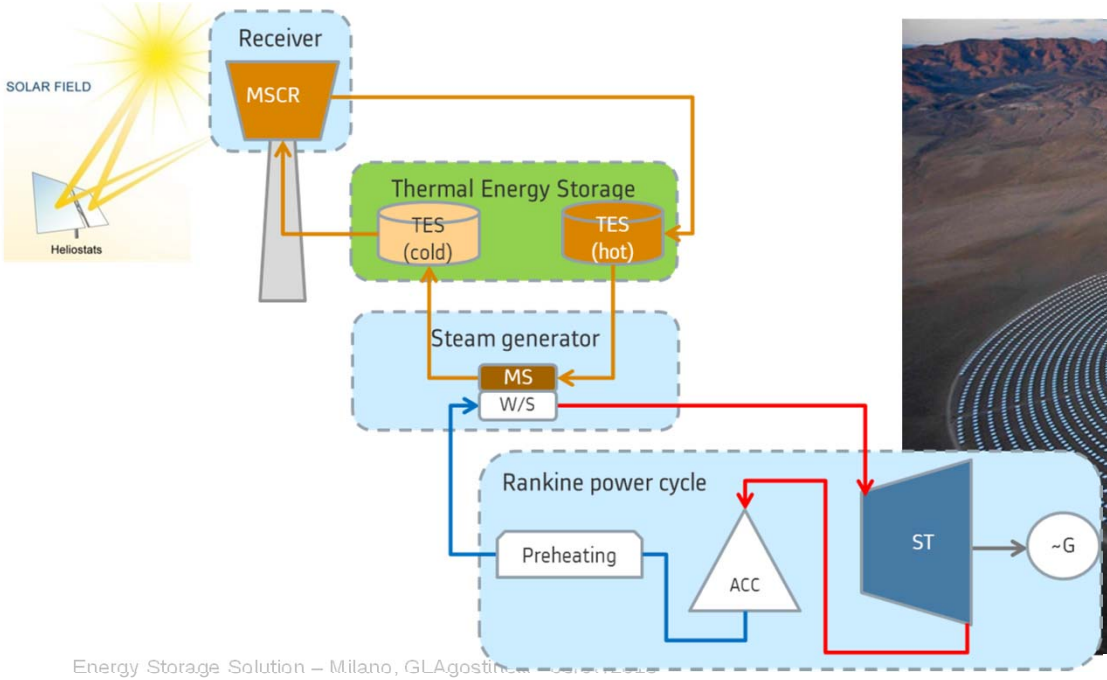
What Alstom offers
CSP with storage; State-of-the-art



- Energy collection and electricity production are decoupled and separated by a buffer, the thermal energy storage system (TESS)
- To extend production hours; to produce when needed

- Suitable medium for energy collection and storage is Molten Salt (60%/40% Na-/K-NO3)
- Proof of concept in the '90s by Sandia (Solar Two)

- Base-load operation
  - No ancillary services
  - No load changes required
- Simple dispatch
  - Collect and produce – as long as it lasts
- Subsidized tariffs
  - Compensates for cost still too high
  - Compensates for baseload operation where net margins are thinnest



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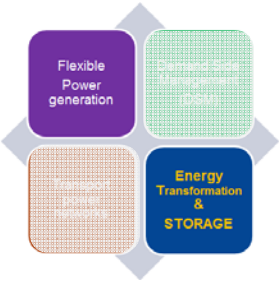
Next generation CSP: Horizon 2020 – PreFlexMS



Aim of H2020 for CSP: Achieve Flexible and Predictable CSP generation – How do we get there?

1. Flexibility

→ Molten Salts Once-Through Steam Generator (MS-OTSG)

2. Predictability

→ Integrated Weather forecasting & Dispatch optimization

3. Demonstration

→ 5 MWth demo at Evora MS Platform

PreFlexMS consortium

Alstom coordination – 13 partners from 8 countries – 18 M€ budget – 7 M€ demo – 3 years

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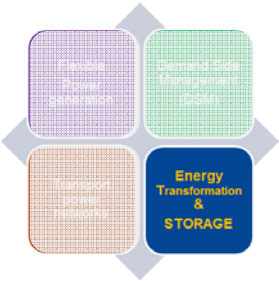
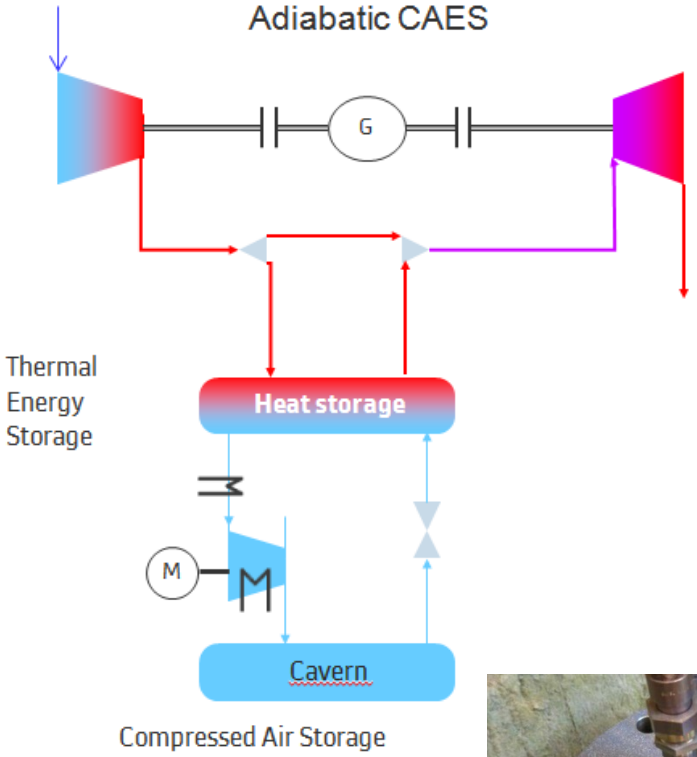
What Alstom offers
Adiabatic CAES, industrial Heat





Concept of 100 MW Adiabatic CAES with Thermal Energy Storage

- >70% round trip efficiency
- Validation at small scale **low cost option for sand based Thermal Energy storage system for high temp range**

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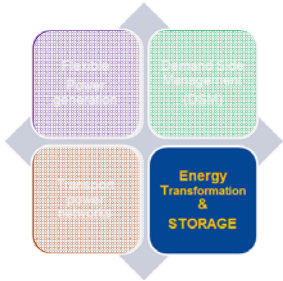
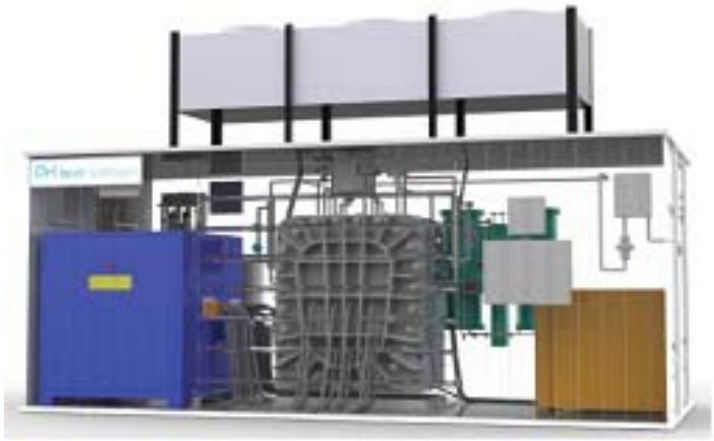
Hydrogen Generation System
Largest Single Stack as Turned Key System



Range of electrolyser systems based on NEXTH2 technology	
Hydrogen peak output	15-500 Nm^3/h
Stack efficiency	70%
Hydrogen pressure	8-10 barg
Oxygen peak output	30 Nm^3/h
Oxygen pressure	8-10 barg
Hydrogen Gas Purity	< 5ppm O_2
Ramp Rate	50% /s (as % of max. capacity)

Alstom can provide and integrated solution for standalone hydrogen production as well as for power to methane and power to chemicals.

Outside of Unit



View of the integrated system

What Alstom offers
Example: Power-to-Gas

Power

CO_2 Separation

CO_2

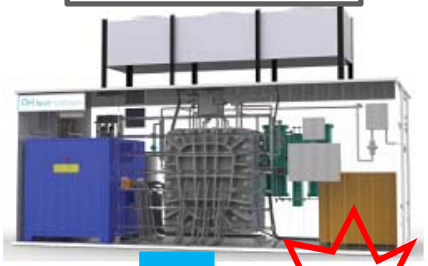
CO_2 sources e.g. Chemical industry, biogas, flue gas, cement and steel industry, waste heat

Methanization

Haldor Topsoe; From solid fuels to SNG using TREMP

Electrolysis

H_2



H_2O

O_2

Heat

Heat

Water removal

H_2O

Natural gas grid

CH_4

…renewable power is **independently temporarily and locally** available through substantial energy storage methane

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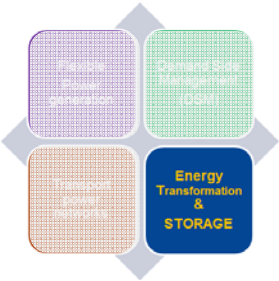
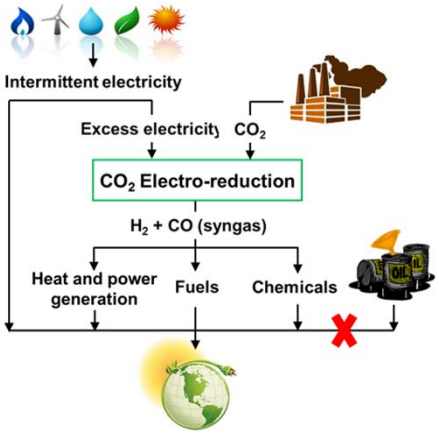
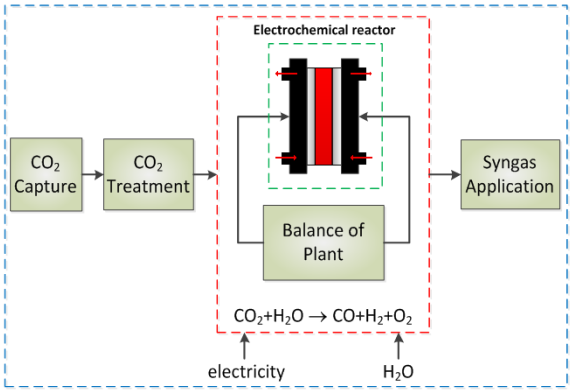
Electrochemical Production of Syngas from CO_2 and Water





"From Waste to Value" – valorisation of CO_2 using excess or cheap electricity

- Similar to power to synthetic methane or hydrogen but resulting in a large volume chemical feedstock
- Use of syngas to produce green plastics, eco friendly materials, renewable alcohols.



Schematic of a system converting CO_2 and water into syngas with electricity.

A 3D model of the "100 kg CO_2 to syngas" unit.

Alstom owns the know-how to the integrated system and together with a technology development partner is able to deliver a full system.

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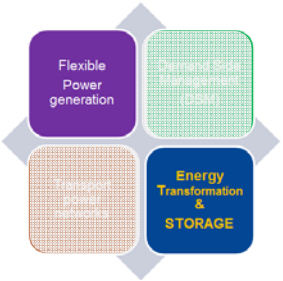
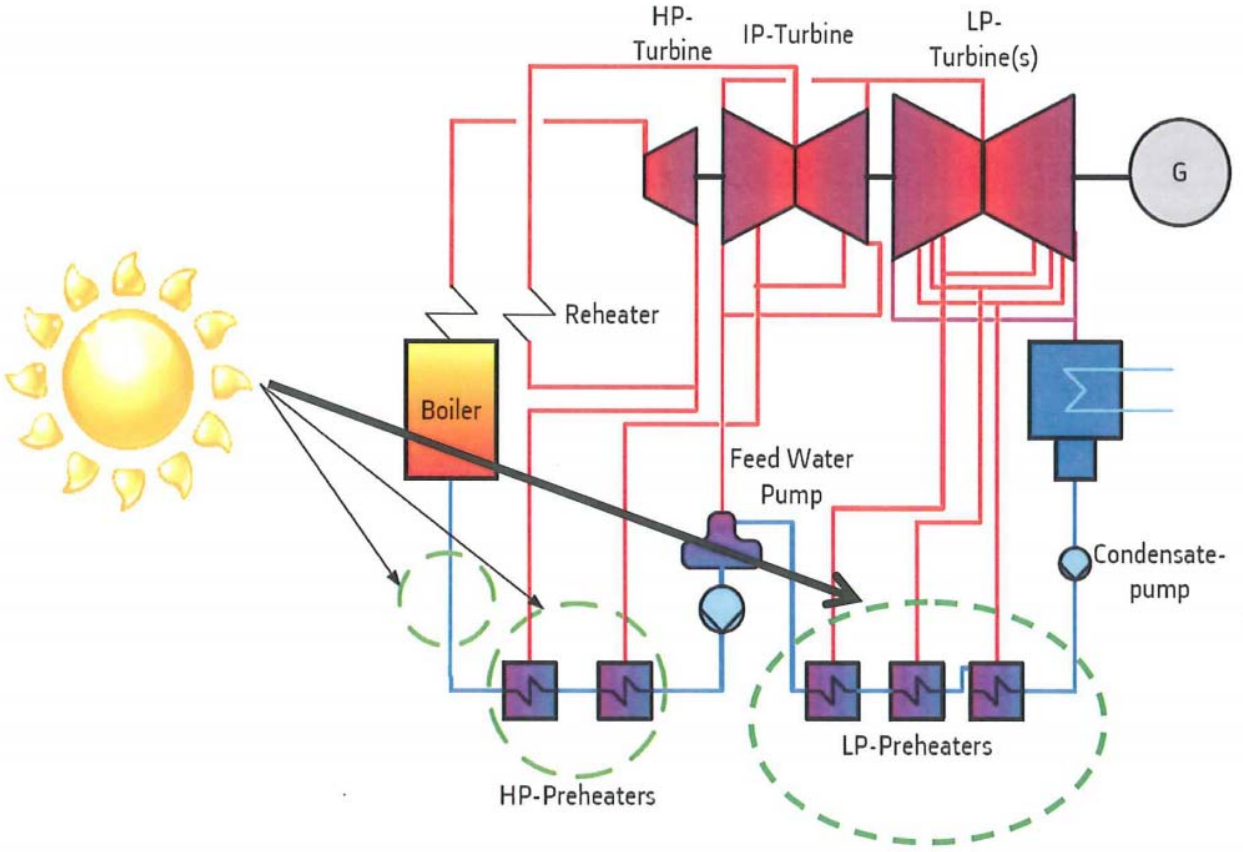
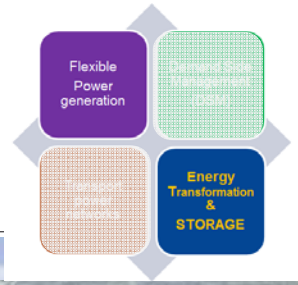
What Alstom offers
Solutions for Plants flexibility and RE integration



- Increased Flexibility of Plants , min load , fast start up , grid support
- but also integration of Thermal Energy Storage and Variable renewable energy. Example preheating of steam cycles in coal power plants

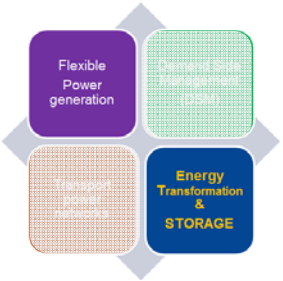


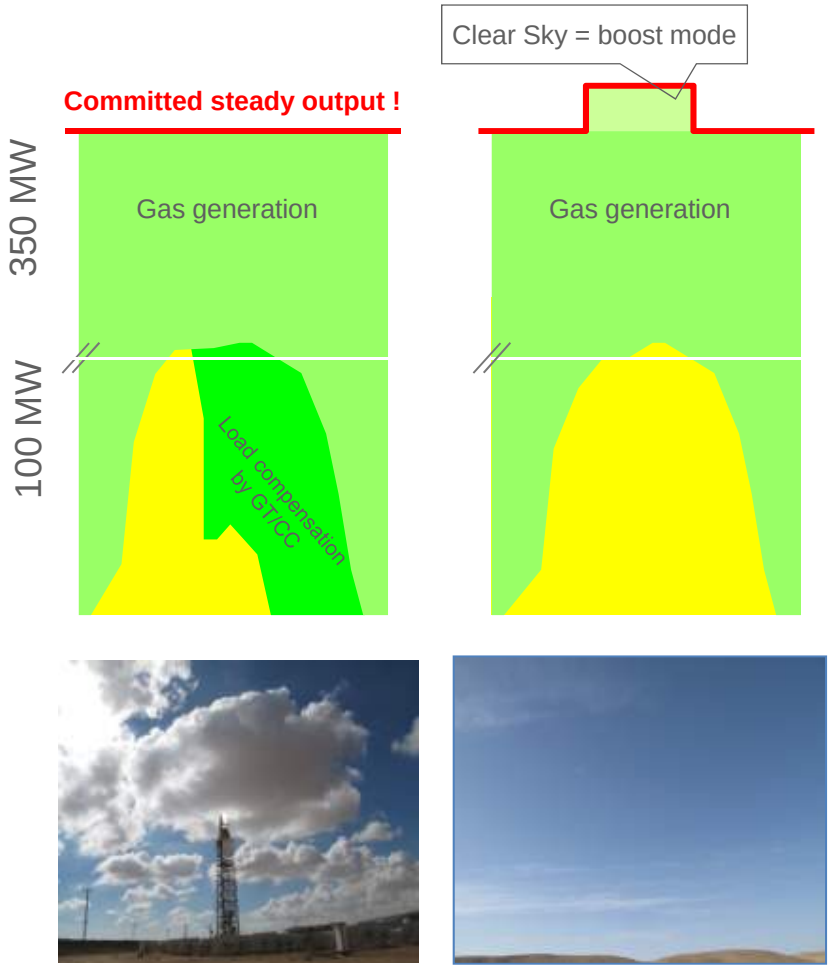
What Alstom offers
Integrated Solar Combined-Cycle solution



An economic solution for cleaner fossil power

Key benefits of KA26-1 ISCC
Dispatchable = Predictable Power





Operation mode – Maximized solar output

- Fully **predictable & dispatchable** power
  - ~500 MW with KA26-1
- ISCC **efficiencies**
  - >75% possible at CC Baseload
  - >80% at CC part-load
- **CO_2 emission reduction** of 80'000 t/yr

Operation mode – Flexible peak output

- On Grid request during clear sky days, **power boost mode** with additional peak power (up to 90 MWel)
- **Wide range of operational flexibility** with best efficiency
- Full range of **ancillary services**

Maximizing plant performance

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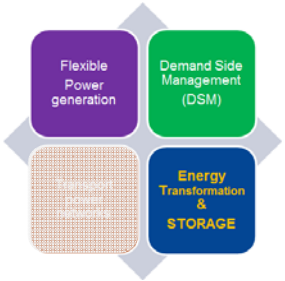
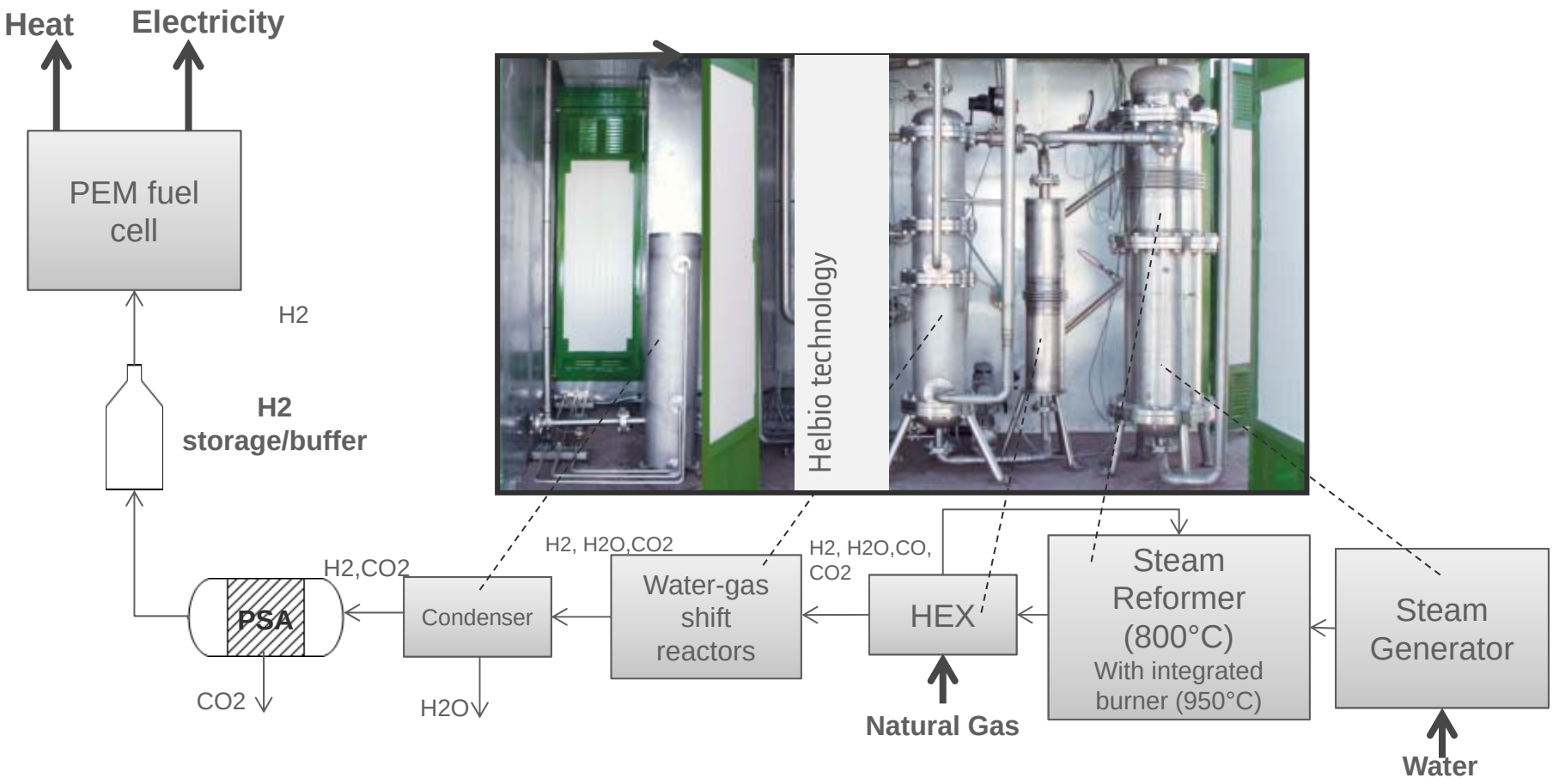
Flexible generation for distributed CHP
Fuel cell and NG reformer, H2 ready





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Conclusions

- ALSTOM has many solutions for the complete electricity value chain that are **covering all decarbonizations routes**, and that can be used to interconnect the multi energy systems of the future.

- **Four pillars** are required to integrate Variable Renewables (VRE): Plant flexibility and back up, grid interconnection and stability, Demand side management and Energy Storage and transformation → Holistic and technology neutral approach to understand each perspective
  - everything should be judged according to final application ability to decarbonize in a reliable and affordable way

- Energy Storage is linked to the concept of Energy transformation → possibility of direct utilization of main energy carriers into **multiple energy demands**. -→ it allows to reduce CO2 emissions in all sectors.
  - Flexibility of dispatchable plants that allows also grid stability is always the cheapest solution and shall be addressed first
  - Heat demand is a promising way to integrate VRE
  - easier VRE integration allowing integration of fuel and feedstock (e.g. Hydrogen) for main appilication outside Electricity demand: industrial and mobility primarily
  - Synergies with other decarbonization routes (Carbon utilization) that helps also to reach non addressable CO2 emissions sectors

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