Integration of Pumped-Heat-Electricity-Storage into Water / Steam Cycles of Thermal Power Plants

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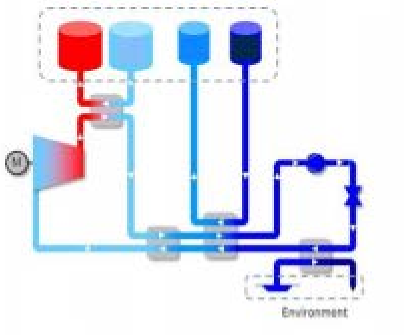
Imagination at work

BACKGROUND

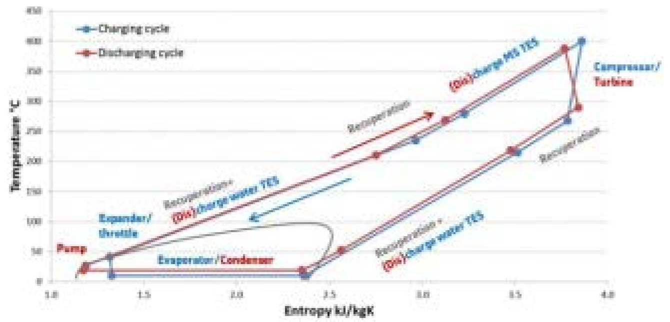
- Pumped Heat Electricity Storage (PHES)
- PHES versus batteries
- Which storage ?

Background – Alstom Concept
Pumped Heat Electricity Storage

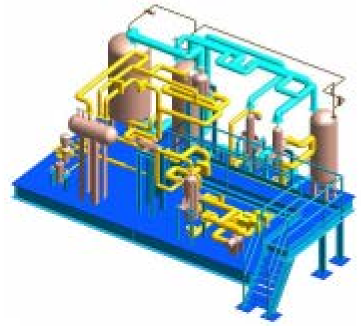
Distributed electricity storage



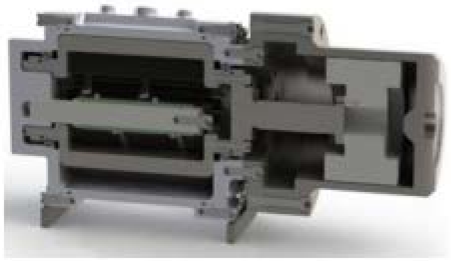
Propane working fluid



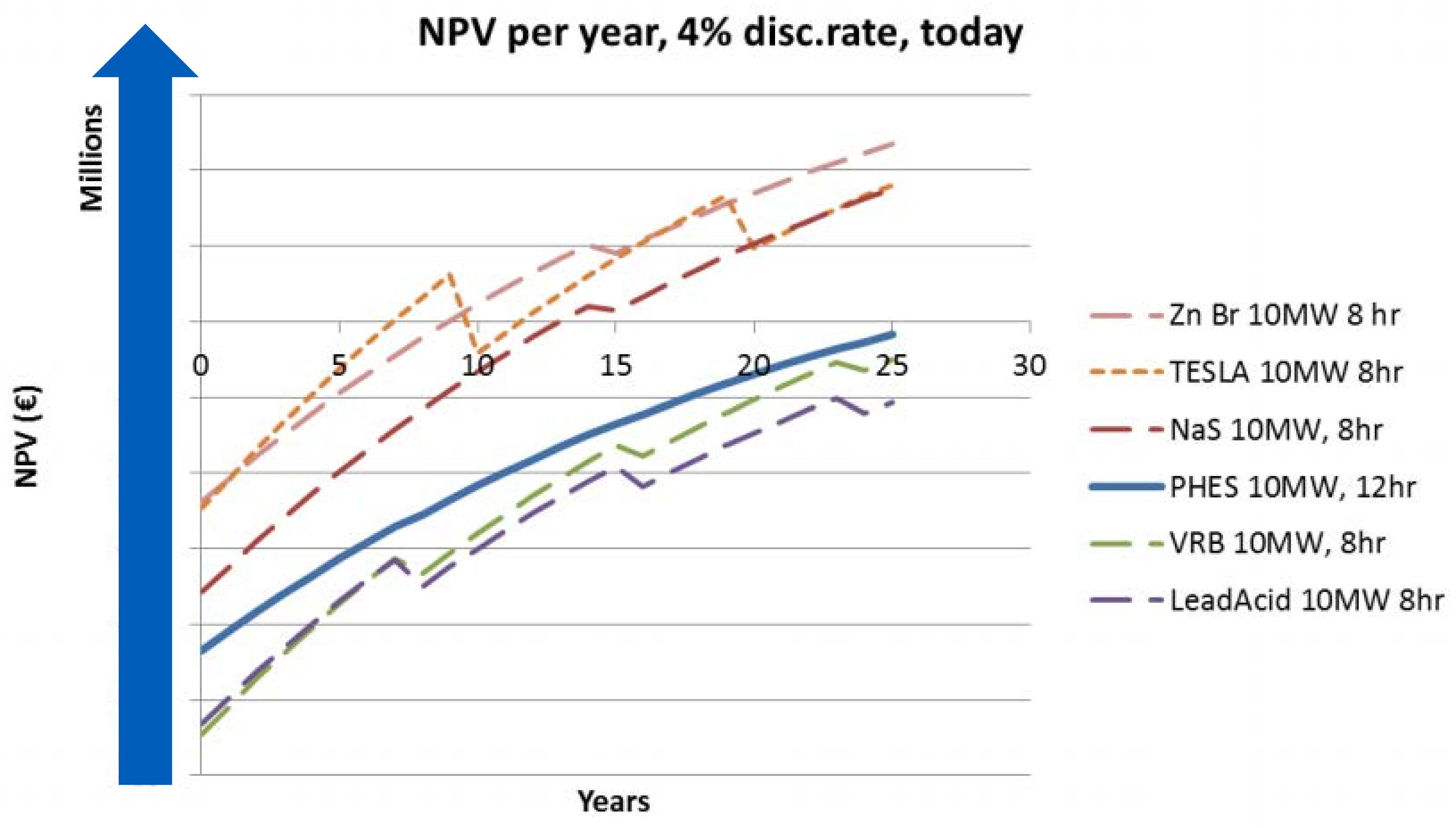
Liquid medium thermal storage



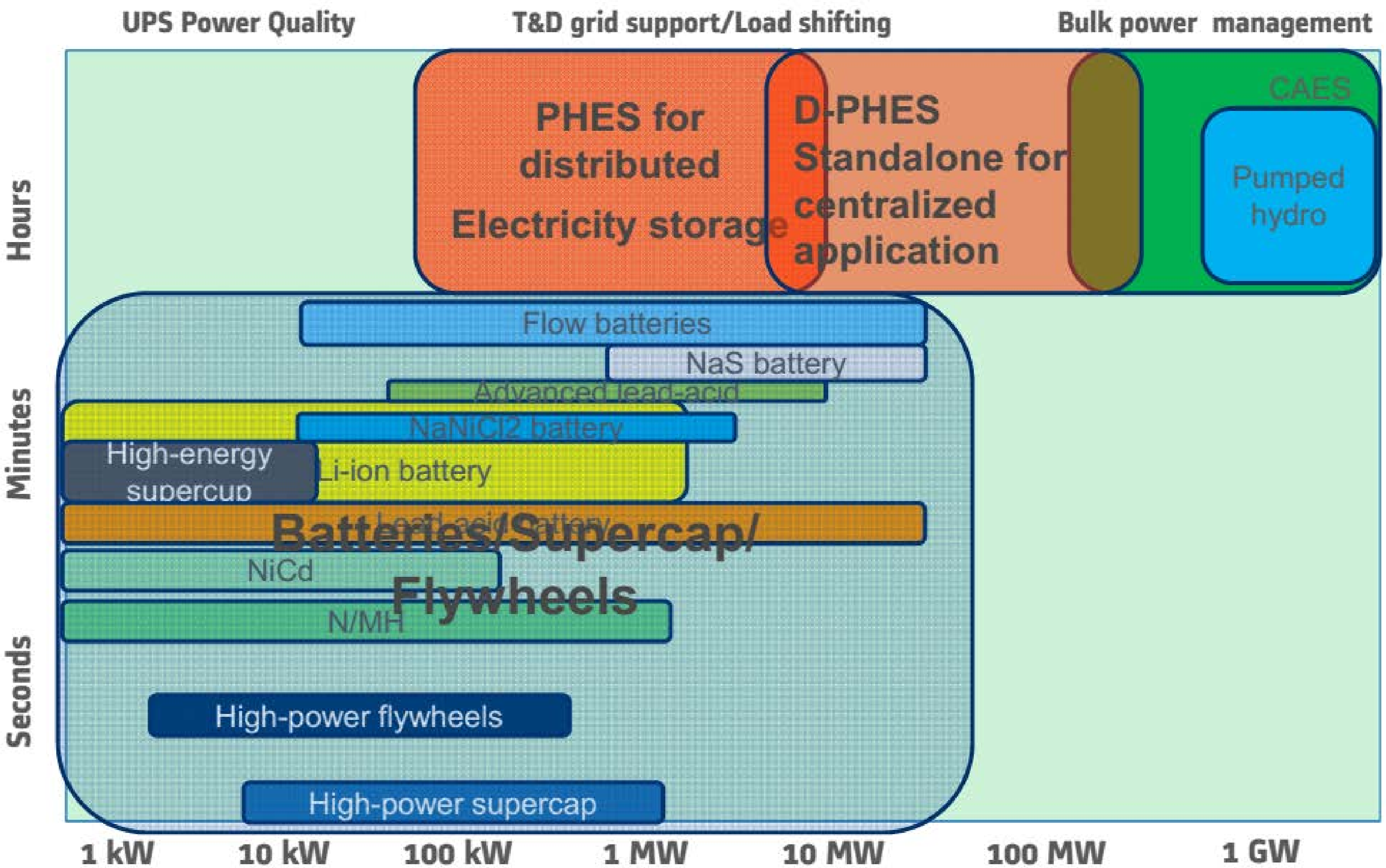
Reversible cycle and components



Rapid changes in battery technology and cost reduced the attractiveness of original concept



Which storage ?



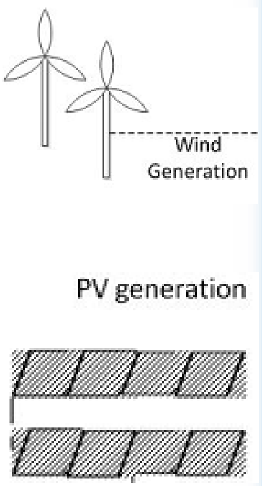
I-PHES
Integrated Pumped Heat Electricity Storage

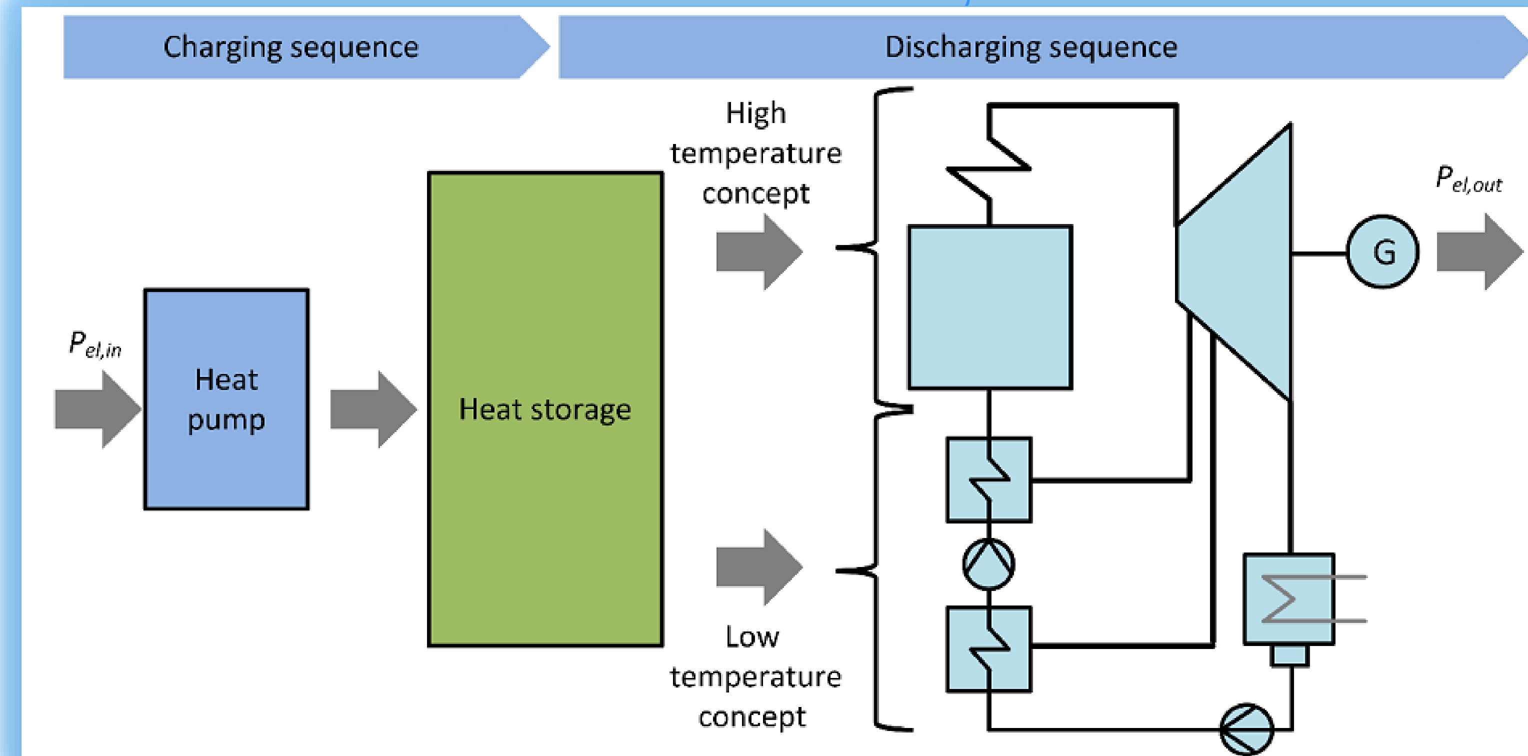
- Principle
- Motivation
- Concepts

I-PHES Principles

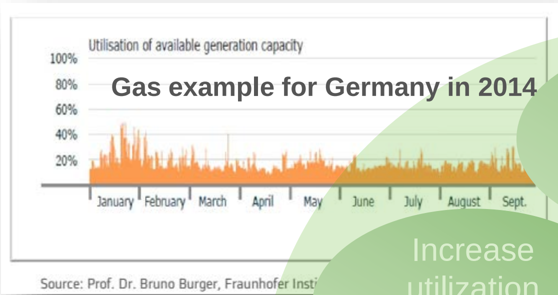
HP making use of excess of electricity

Existing / New power plant
SPP, CCPP





Motivation to improve utilization of power plant



Power Plant Operation Optimization

Utilization of existing fleet

Increase utilization factor of fossil plants

Frequency support

Energy Storage with reduced CAPEX and OPEX

Differentiation to energy storage market

Large scale storage

Easy systems integration

High flexibility

Lean and fast

Renewable back-up capacity

Easy product development

Performances Optimization

Fuel savings

Emissions reduction

Realistic Net Round Trip Efficiency > 60%

Capacity > 20MWe

Price < 0.024 EUR/kWh produced

Daily cycle

Start time (cold) ~ 10 min

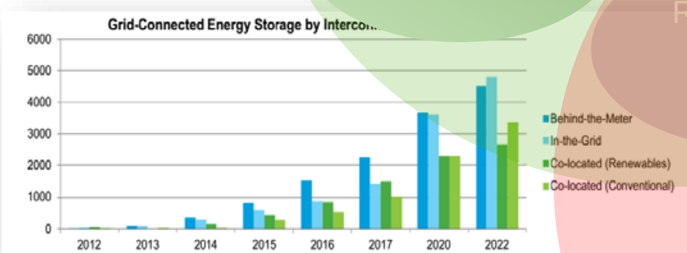
Turn down capability 0-100%

Net LHV efficiency +0.2 to 0.5% pts

Additional net power ~+5%

Emissions -4 to 6%

Fuel savings ~0.5%



CERA-IHS market predictions

Why HP integrated in power plants?

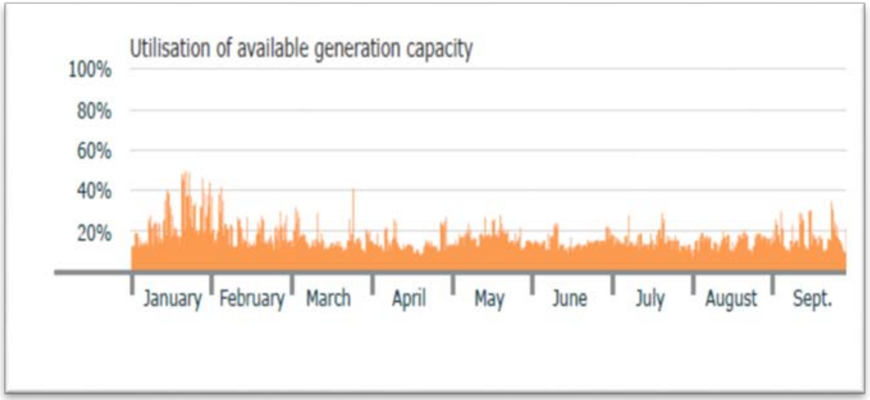
There are at least two main power generation issues that HP in PP can address:

- Installed over-capacity, due to intermittent nature of wind and solar
  - Example for Germany in 2014

	Installed capacity (GW)	Peak production (GW)
Wind+Solar	73.8	-
Thermal	103	-
TOTAL	**176.8**	**~85**

+100%

- Reduced thermal plants utilization
  - Gas example for Germany in 2014



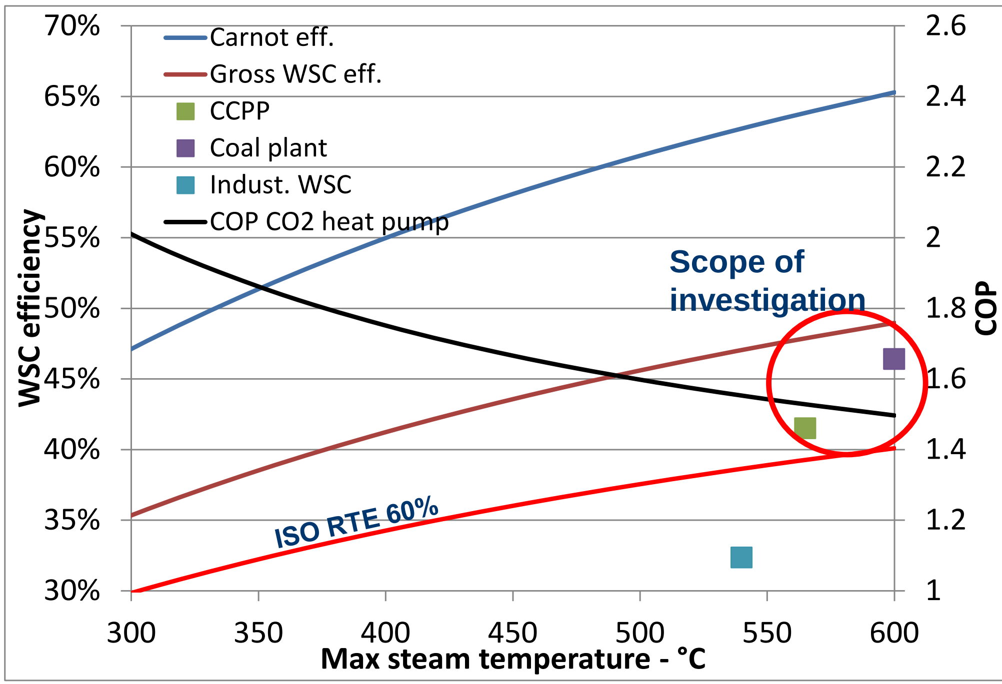
Source: Prof. Dr. Bruno Burger, Fraunhofer Institute for Solar Energy Systems ISE

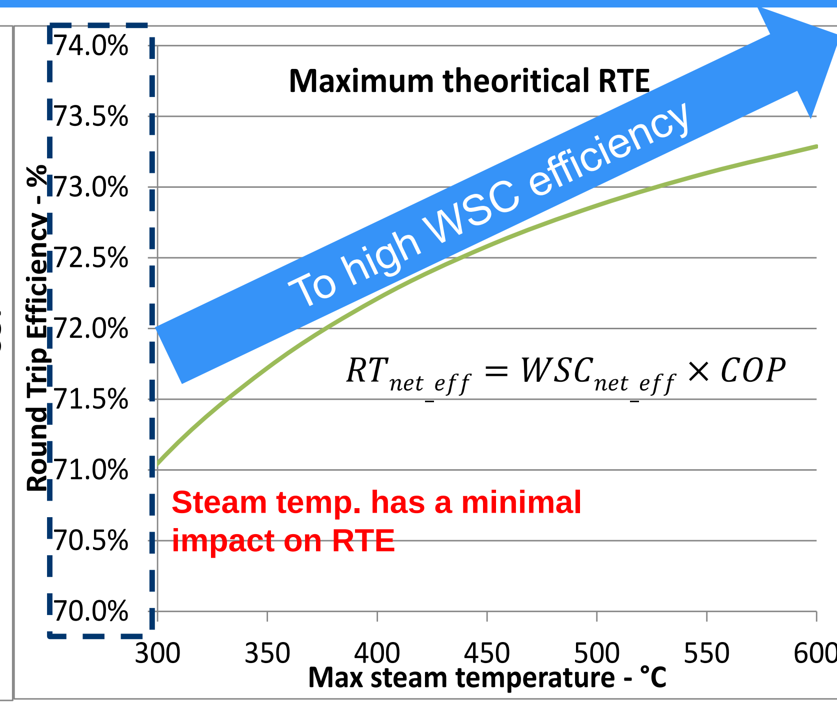
No additional generation capacity

Existing plants to be used more

Maximum RT efficiency achievable

Target for Round-Trip efficiency > 60% reduces the scope of investigation into high-efficiency WSC



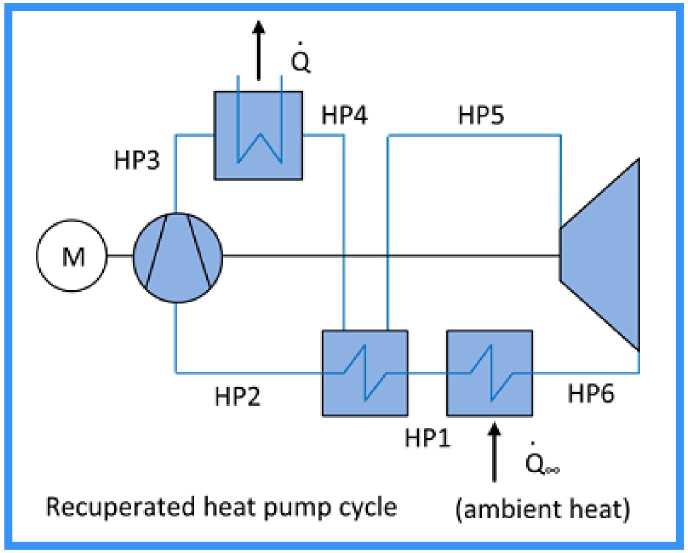


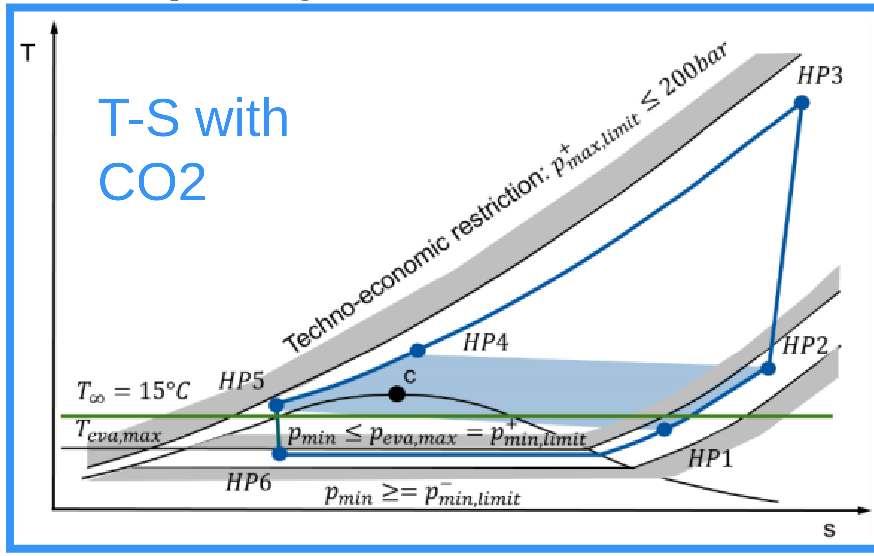
CCPP		KA26-1
Cycle	-	Subcritical
HP Temp.	°C	565
Rating power	MW_{gross}	172
Net efficiency	%	41.5%

Coal plant		RP800
Cycle	-	Ultra-Supercritical
HP Temp.	°C	600
Rating power	MW_{gross}	888
Net efficiency	%	46.4%

Ind. WSC		Altamira
Cycle	-	Subcritical
HP Temp.	°C	540
Rating power	MW_{gross}	102
Net efficiency	%	32.4%

Charging cycle configuration:
Recuperated Heat Pump Cycle



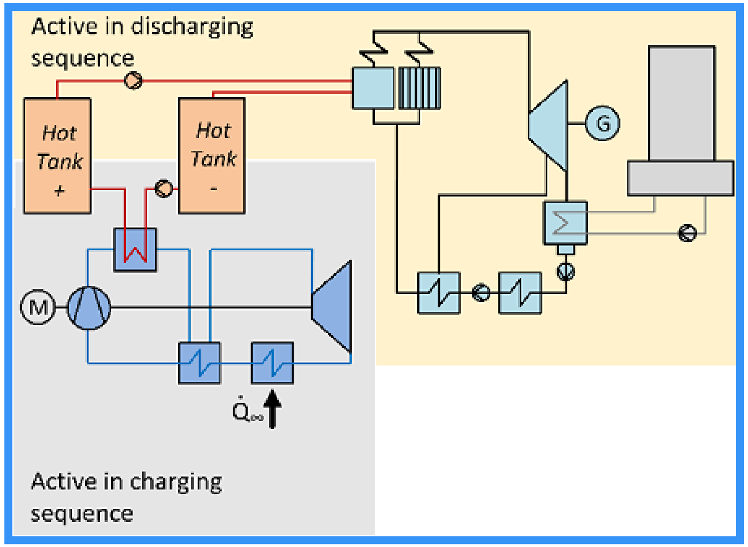


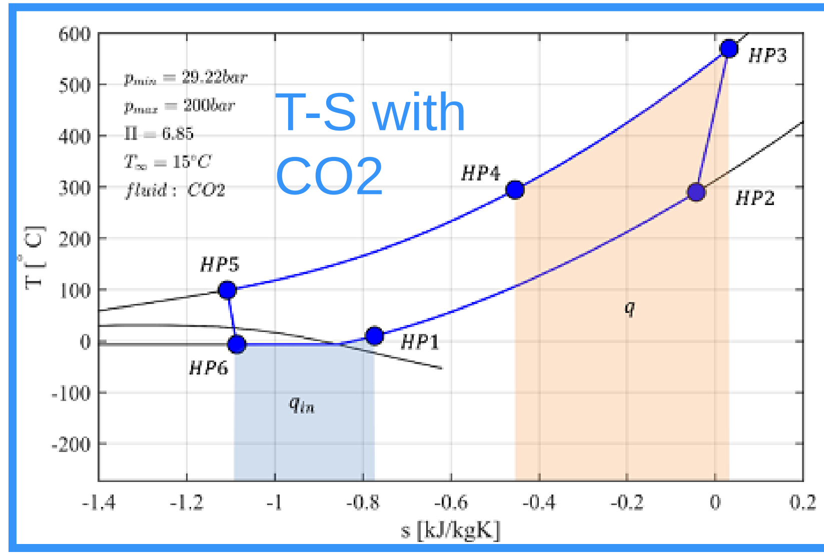
- Fluids: CO_2, air, argon
- CO_2 compressor investigated by Industria de Turbo Propulsores
- Thermal Energy Storage: molten salt, thermal oil, pressurized water

Parameter	Variable	Value	Note
Ambient temperature	T_∞	15°C	T_{ISO}
Temperature range of the provided heat	$T_{HP3} \leftrightarrow T_{HP4}$	predefined	boundary condition dependent on I-PHES concept and reference WSC parameters
Terminal temperature difference of heat exchangers	ΔT_{HEx}	5K	
Evaporator temperature difference	ΔT_{Eva}	15K	CO_2 heat pump only
Upper HP pressure level	$p_{max} = p_{HP3} = p_{HP4} = p_{HP5}$	variable / subject to optimization	$\leq p^+_{max,limit} = 200bar$
Lower HP pressure level	$p_{min} = p_{HP1} = p_{HP2} = p_{HP6}$	variable / subject to optimization	$\leq p^+_{min,limit} = p_{s,CO2}(T_\infty - \Delta T_{Eva}) =$ $34.85bar$ (CO_2 heat pump only) $\geq p^-_{min,limit} = 1bar$
Isentropic compressor efficiency	η_C	0.8	conservative estimate (mainly responsible for irreversibilities within the HP cycle)
Isentropic turbine efficiency	η_T	0.9	

High-temperature I-PHES concept

Simple configuration

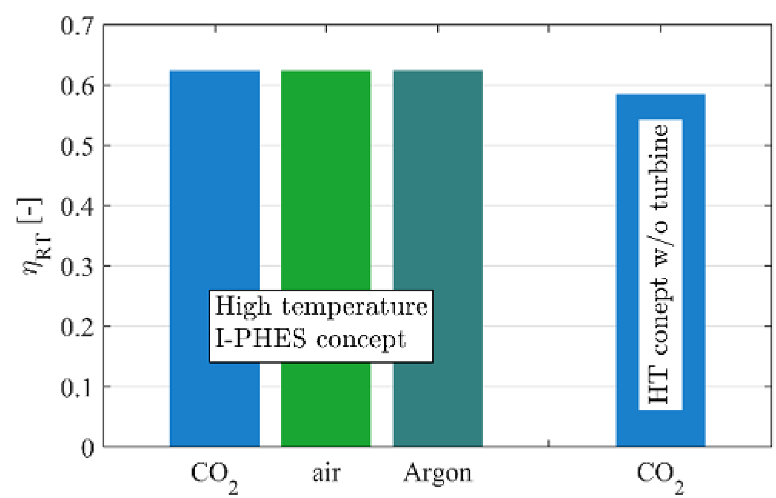




- Similar RT efficiencies for all fluids ~63%

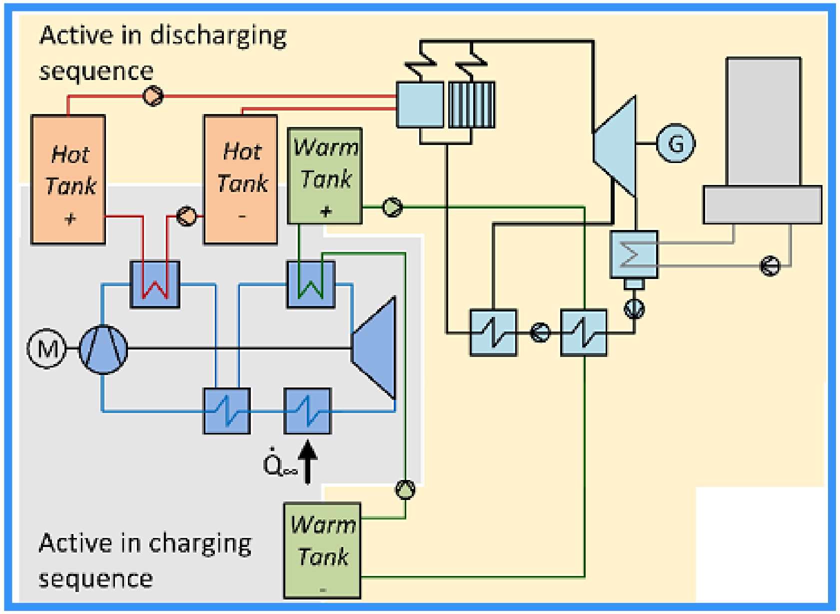
→ Expansion in wet region for CO2 cycle

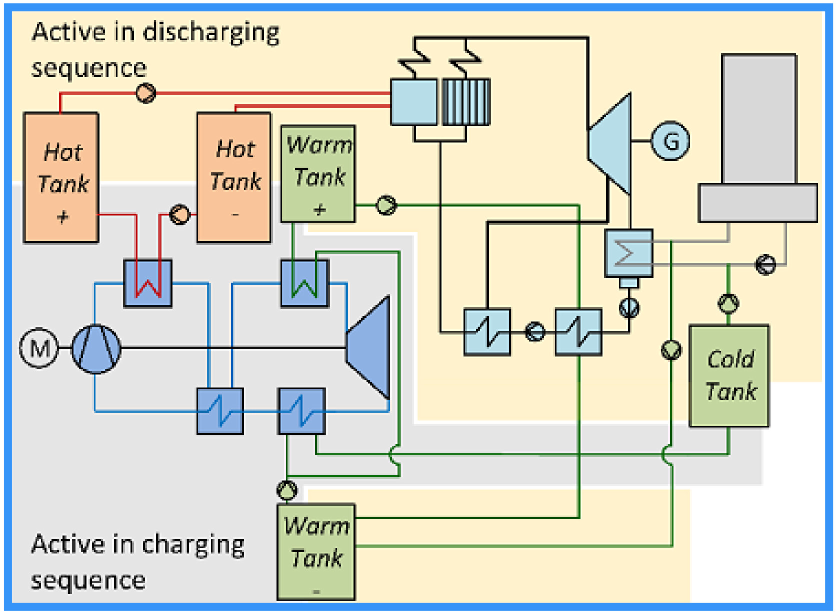
- W/O Expander RTE ~60%
- High risk for CO2 compressor



No benefit with CO2

High-temperature I-PHES concept
More complex configurations

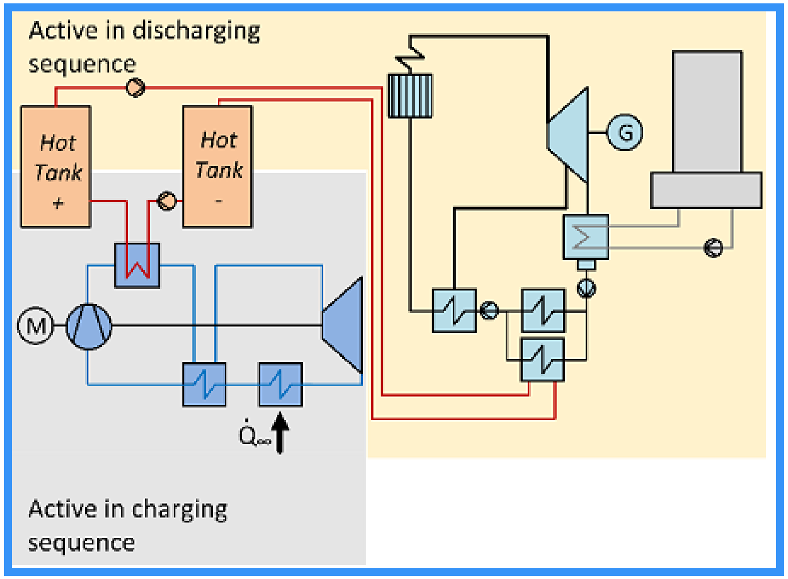


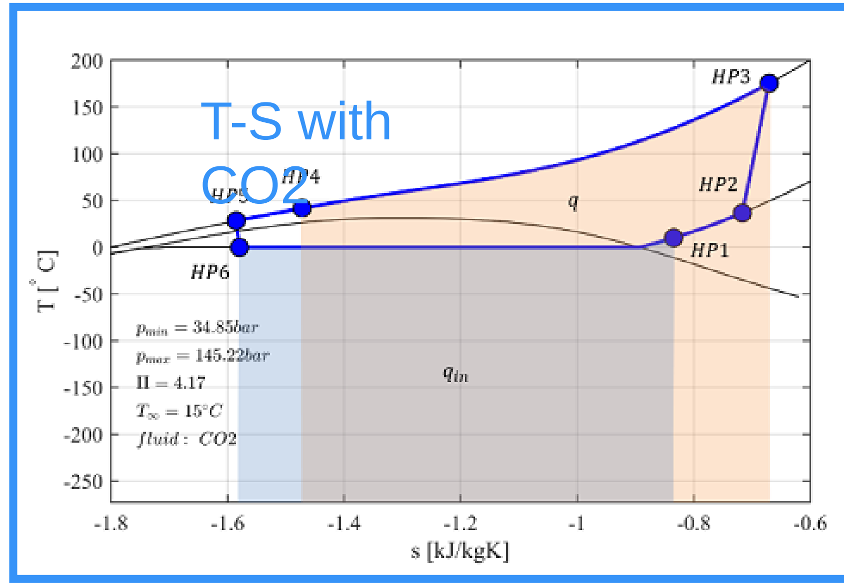


- Extract additional low-temperature heat from the HP cycle
- Exploit (right picture) the lower thermal potential created by the HP process
- Only feasible with CO2 due to strong dependency of the specific heat capacity of CO2 on temperature
- Benefit negligible (<+1% pts) for a complex realization

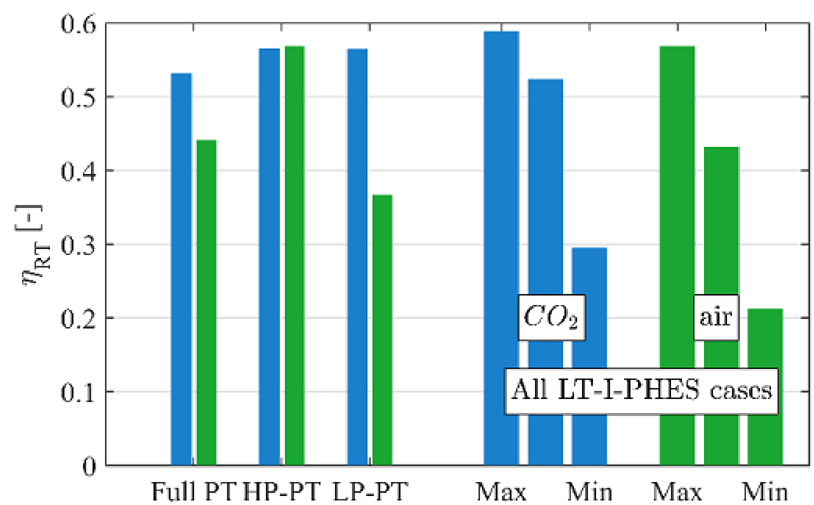
Low-temperature I-PHES concept

Integration into the preheating train





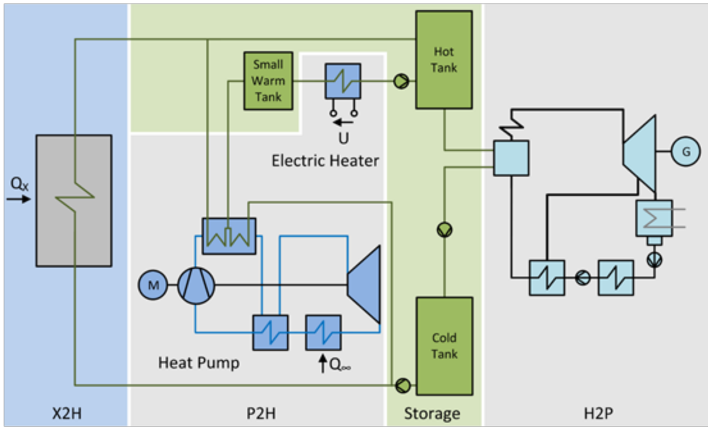
- When integration temperature decreases, CO2 HP is more efficient then air/argon HP
- Low temperature integration allows to achieve relatively high RTE ~56-58% (<200°C)

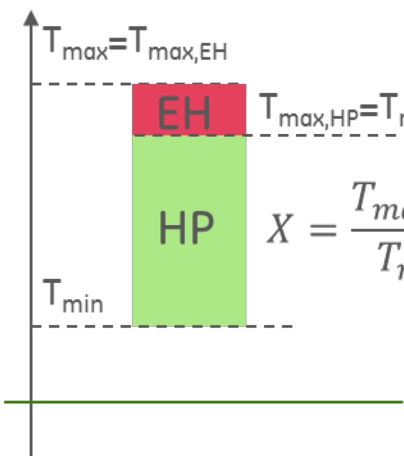


Alternative concepts studied

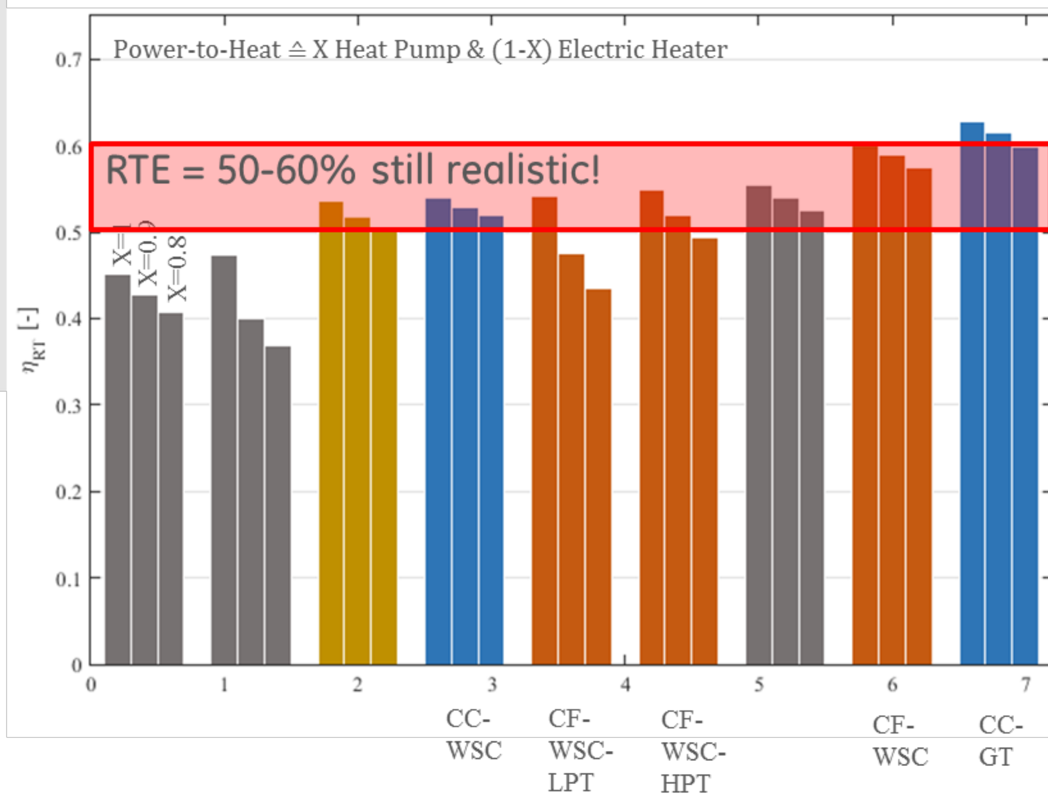
Series connection of heat pump & electric heater

System flexibility much higher (grid service and start-up)





$$X = \frac{T_{max,HP} - T_{min}}{T_{max} - T_{min}}$$



I-PHES
INITIAL VALUE PROPOSITION

- Potential applications
- Increase capacity factor
- Reduce plant cycling

Potential applications

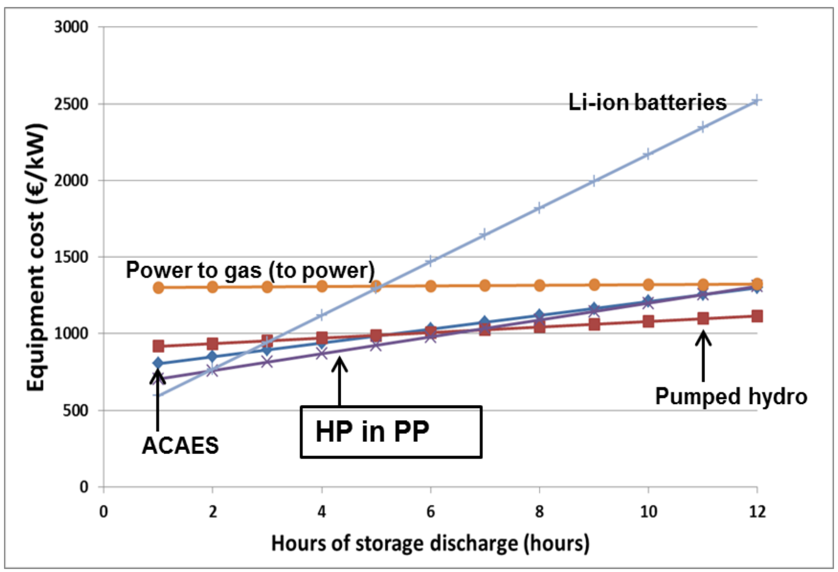
	Plant Type	Applications			
		Electricity to electricity storage	Increase flexibility	Power boost	Renewable back-up capacity
Centralised	Coal	✓✓	✓✓	✓✓	✓✓
	CCPP	✓✓	✓✓	✓✓	✓✓
	Nuclear	✓	✓	✓	
	Solar	✓✓	✓	✓	
	Stand-alone storage new build	✓✓			
Decentr.	Industrial Steam turbine	✓✓	✓✓	✓✓	
	Stand-alone co-located with wind/PV	✓✓	✓✓	✓✓	

Back-up capacity: Capacity credit is the amount of power that can reliably be expected to produce at the times when demand for electricity is highest (International Energy Agency definition).
Power boost: additional power produced with heat from storage (>100% load), WSC running overloaded
Flexibility: Supporting power plant start-up, WSC warming up while compensating renewables fluctuations

Initial value proposition

Value for a storage business

Lowest costs for daily cycles (2<hours of storage<6), together with ACAES



ACAES: Adiabatic Compressed Air Energy Storage
HP in PP: Heat pump integrated in a Power Plant

Value for existing power plants

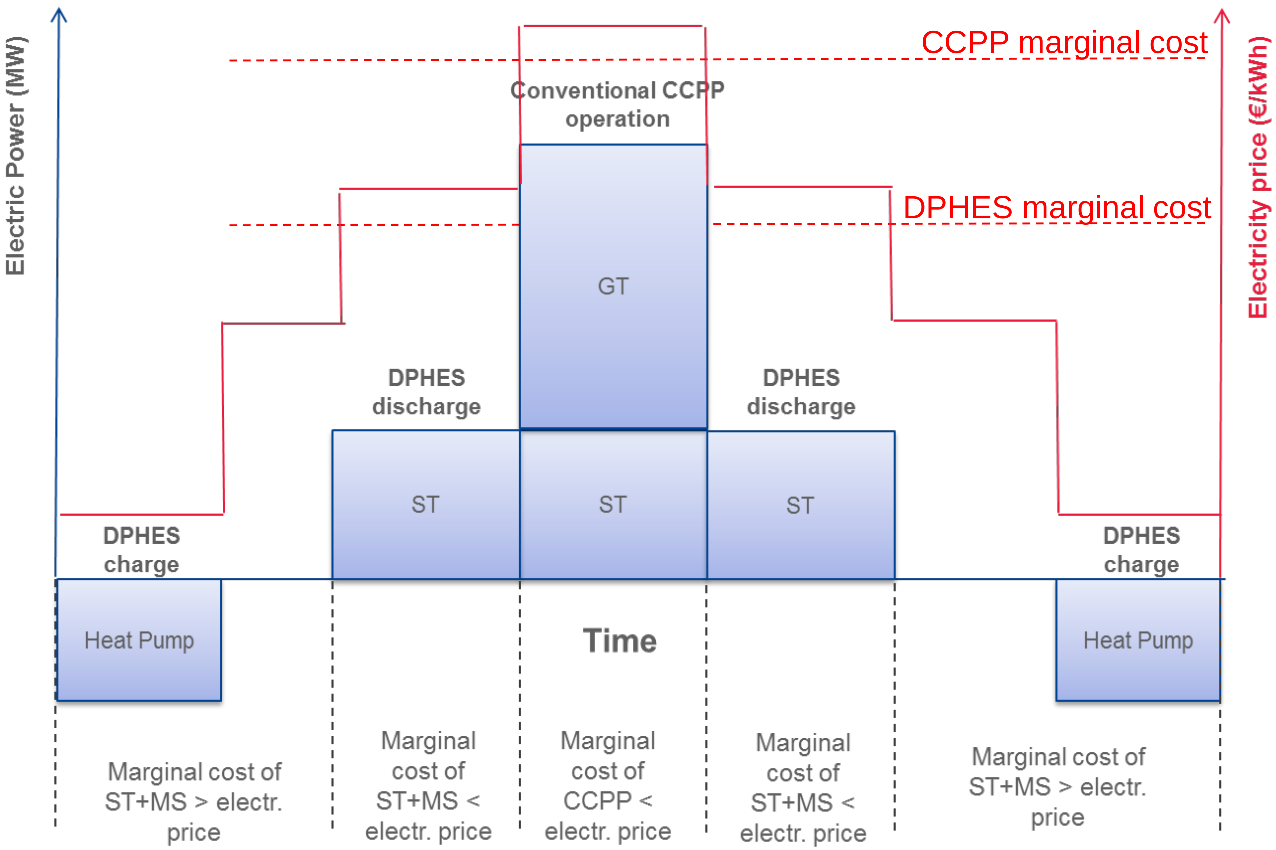
Increased capacity factor of existing power plants (CCPP specific)

- Extend service business for under-utilized power plants

Reduce power plant cycling and related material fatigue

Initial value proposition

Increasing capacity factor of existing Power Plants



ST= steam turbine; MS= molten salt heat storage

Example of calculation: German spot market 2013

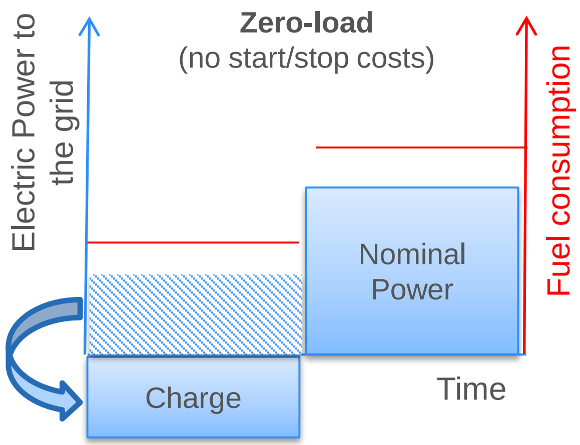
Assumptions:
- Electricity spot price in charging: 20 €/MWh
- Natural gas price cost: 9 €/mmBTU (~30 €/MWh_th)
- CO2 costs: 10 €/Ton
- I-PHES O&M costs: 0.2 cent€/kWh
- CCPP O&M costs: 0.2 cent€/kWh
- I-PHES efficiency: 60%
- CCPP efficiency: 55%

Results:
- Initial CCPP cf*: 8%
- Final capacity factor*: 40%
- Capacity factor* gain: **+32% pt**

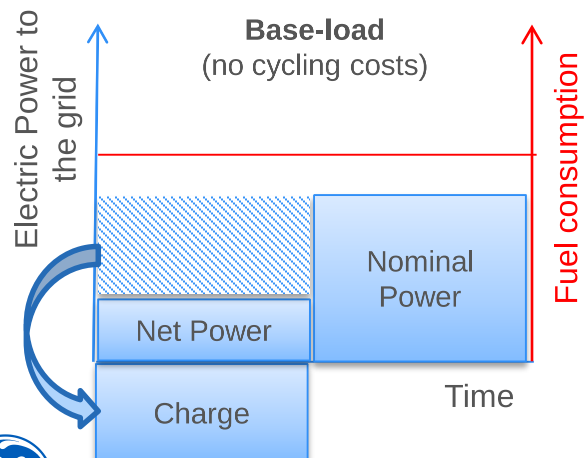
*time-based capacity factor

Initial value proposition

Reduced plant cycling



- No start/stop cost
- Net-zero electricity exported to the grid in charging mode
- Ability to provide frequency support provision in both charging and discharging mode



- No cycling/part-load cost

SUMMARY

Summary

- HP with CO_2 at low temperature represents a low cost/risk solution for preheating train integration, still achieving high RTE
- High temperature will make air HP more attractive: equivalent RTE as CO_2 HP, low risk, cheaper
- CCPP application requires matching high temperature HP: an alternative concept with a serie connection of HP & electric heater
- Further work on system design and integration
  - CO_2 compressor below 200°C, >20MWe
  - Control, dynamic and operation with WSC
  - Sizing in regard with power plant integration