Thermal Energy Storage Makes Concentrating Solar Power Dispatchable

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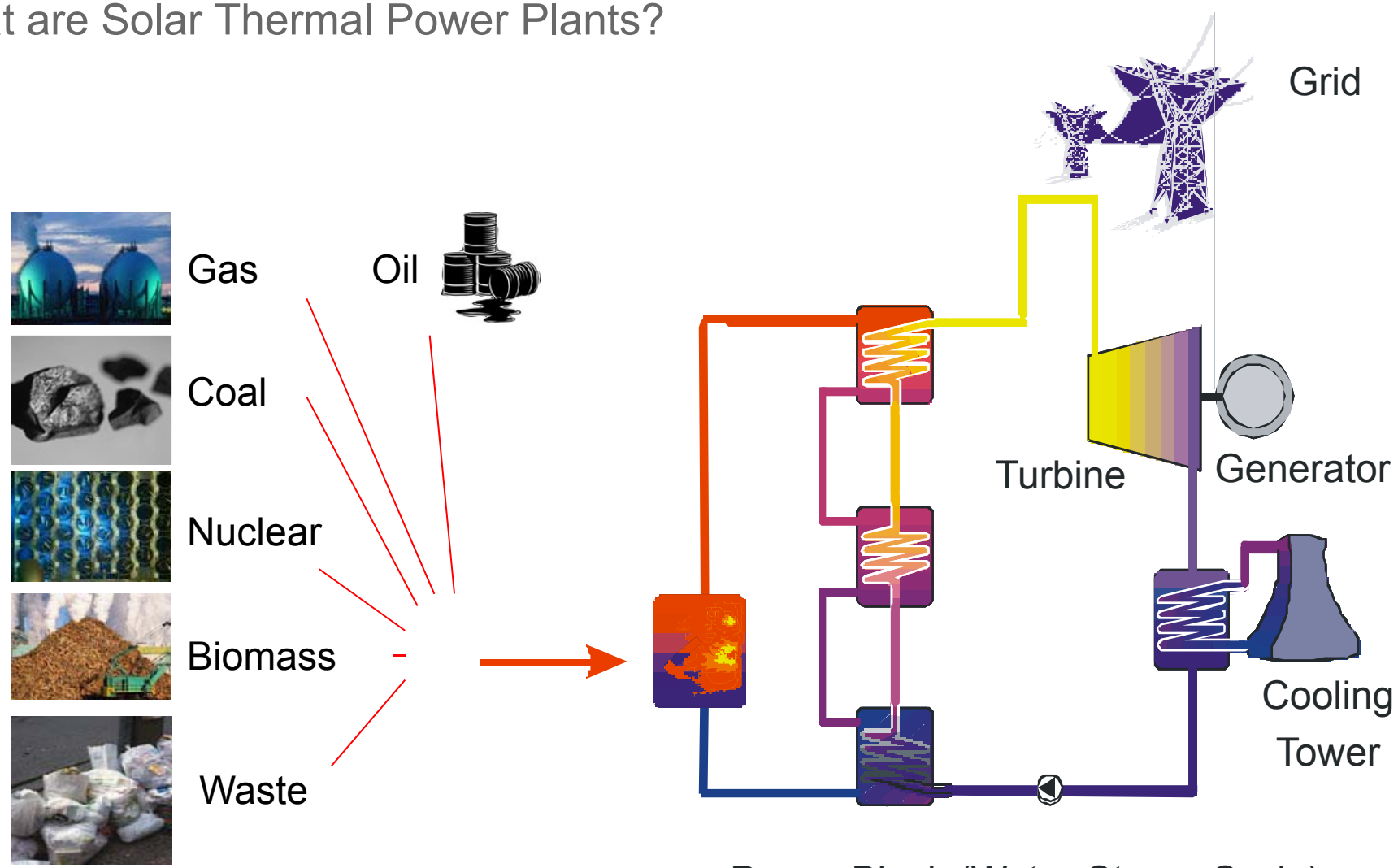
Outline

- Introduction
- Technical Options for Thermal Energy Storage (TES)
- Current Developments
- Conclusions / Questions

Introduction

What are Solar Thermal Power Plants?



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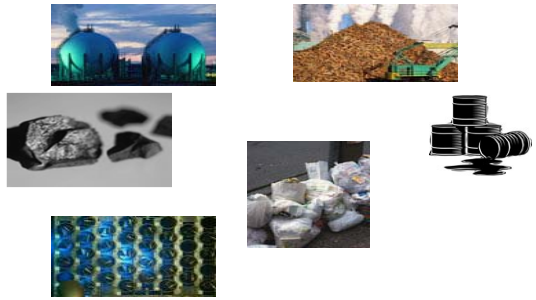
Introduction

What are Solar Thermal Power Plants?



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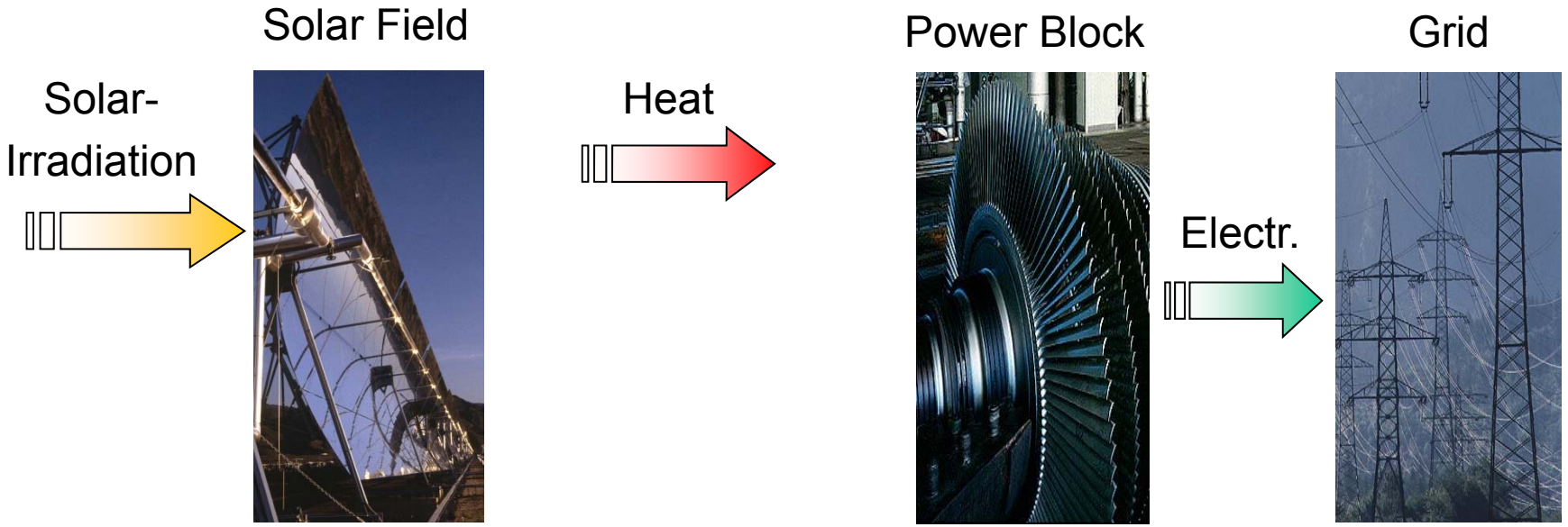

- Pure solar operation
- Additional back-up capacities required in the grid

Introduction

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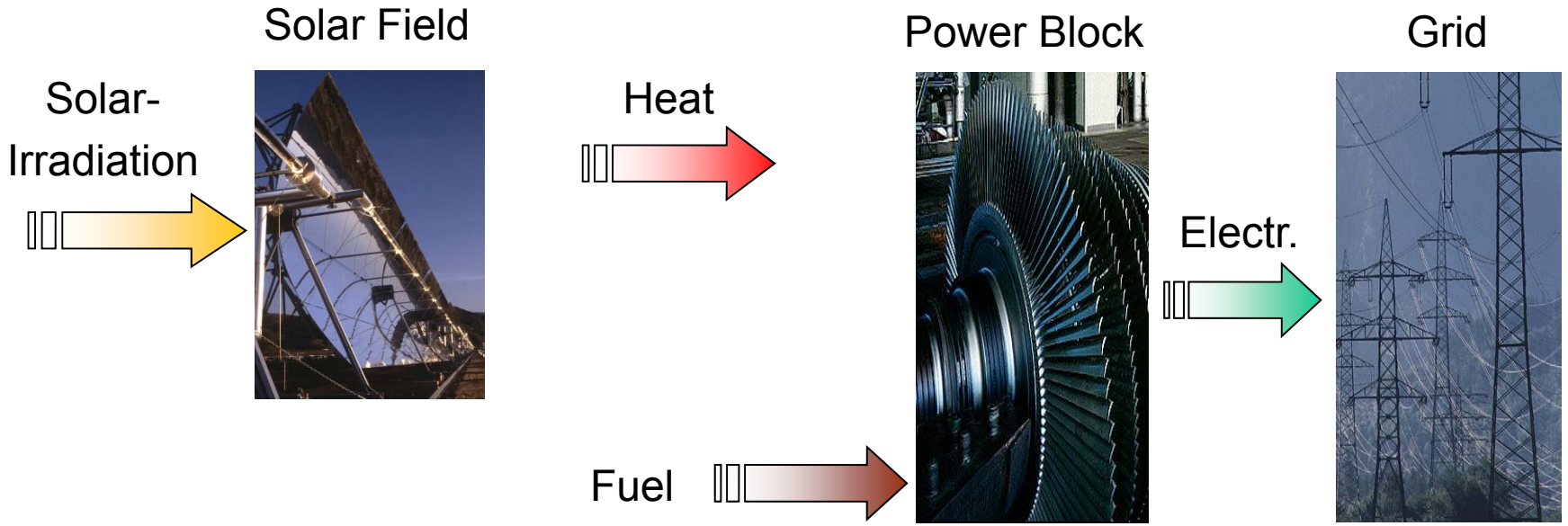

- Solar electricity production
- Integrated fossil back-up capacity for power on demand

Introduction

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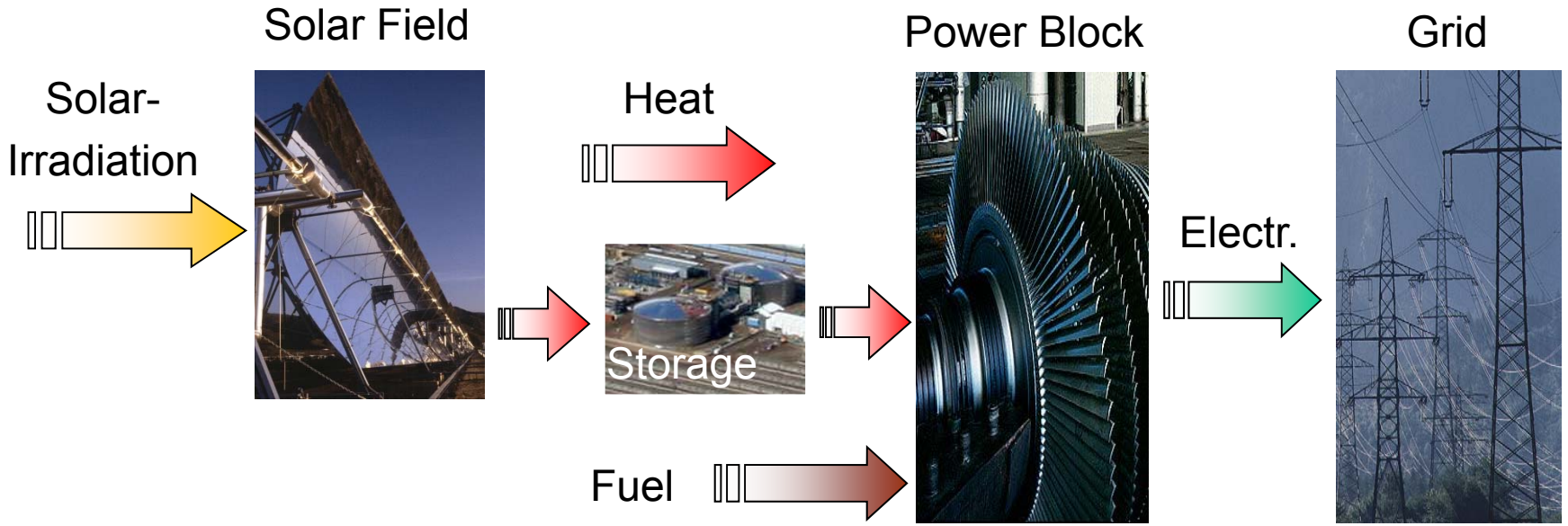
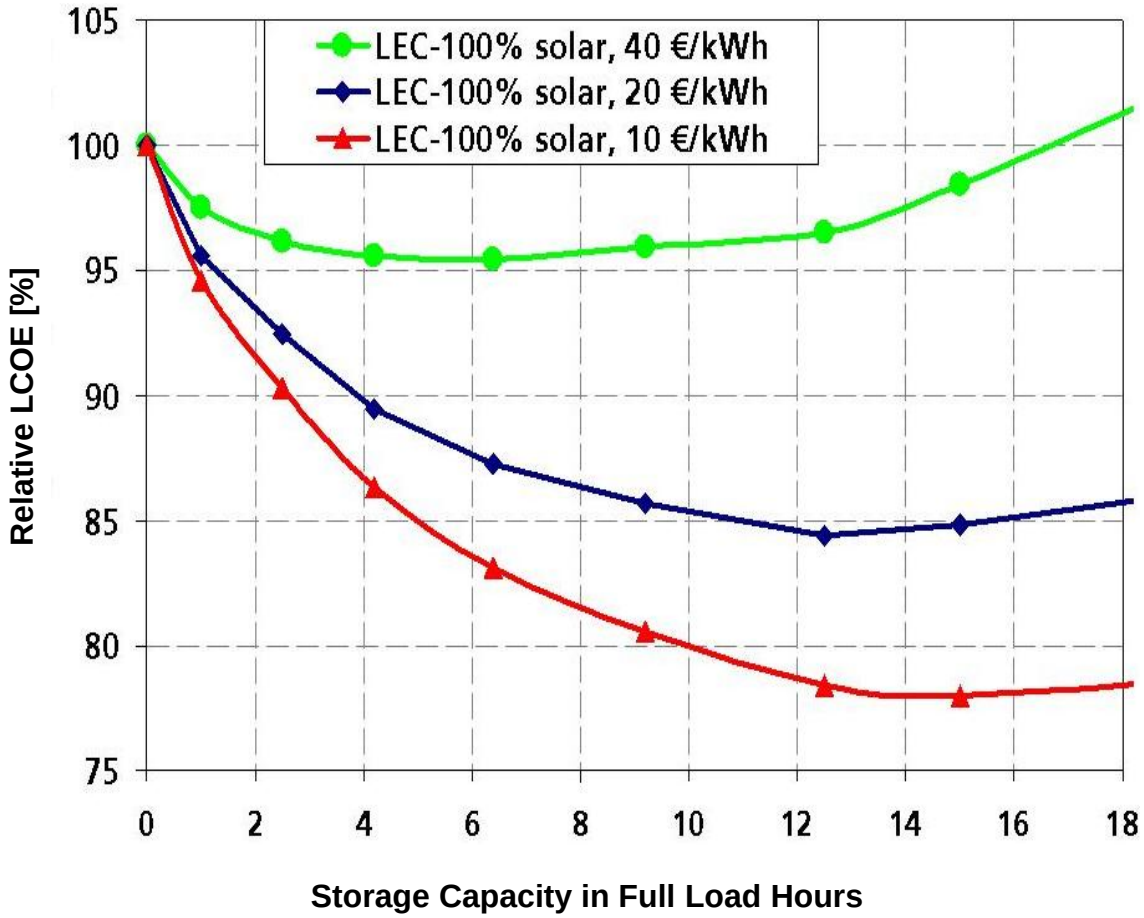


- Solar electricity production
- Integrated storage for increased capacity factor and electricity on demand
- Additional fossil back-up

Introduction

Economic effect of integrated thermal storage capacity?



Technical Options for Thermal Energy Storage

System Requirements

Heat Transfer Fluid	Collector System	Pressure	Temperature
synthetic oil	trough/Fresnel	15 bar	400°C
saturated steam	tower/Fresnel	40 bar	260°C
superhaeted steam	trough/Fresnel	50-120 bar	400-500°C
molten salt	tower/trough	1 bar	500-600°C
air	tower	1 bar	700-1000°C
air	tower	15 bar	800-900°C
new concepts			

storage system

Heat Engine
ORC
steam turbine
gas turbine
Stirling engine
others

ONE single storage technology will not meet
the unique requirements of different solar power plants

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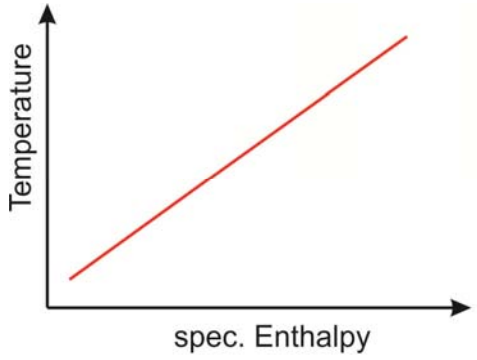
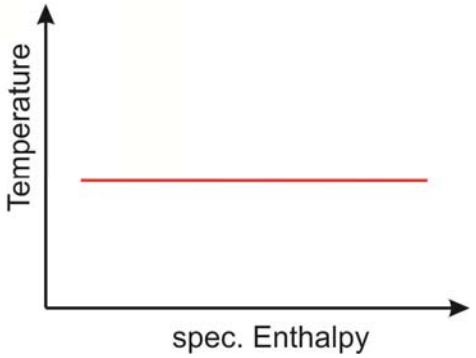
Technical Options for TES

Classification of Storage Systems

	Sensible Heat	Latent Heat
Storage-medium	Liquid	Phase Change Material (PCM)
	Solid	Steam Accumulator





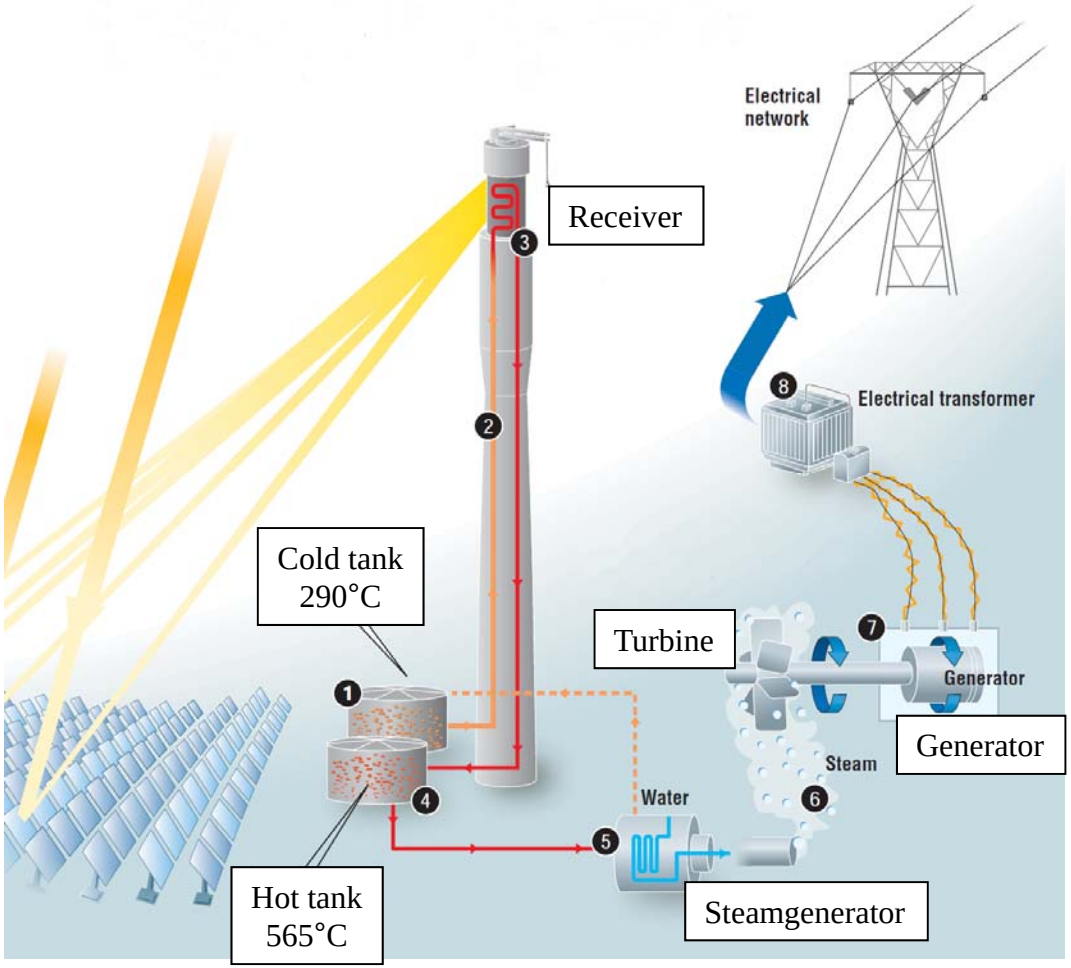
Technical Options for TES

Sensible Heat – Liquid Media (direct)

Storage-medium	Sensible Heat	Latent Heat
	Liquid	Phase Change Material (PCM)
	Solid	Steam Accumulator

- Heat transfer fluid and storage medium are the same
- 1st system: Solar Two Project by Sandia
- 2nd commercial tower system at Gemasolar plant (Spain):

  Solar Tower plant with 15 h storage capacity
- Several indirect systems with parabolic troughs are in operation (Spain)



Source: Homepage Torresol Energy

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Source: Gemasolar

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Source: Solar Millennium

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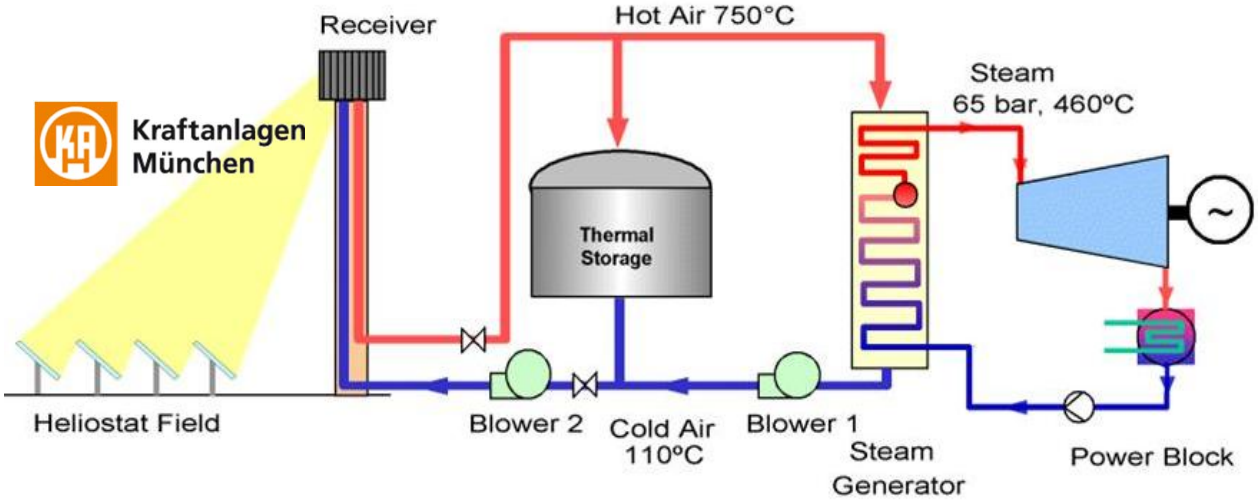
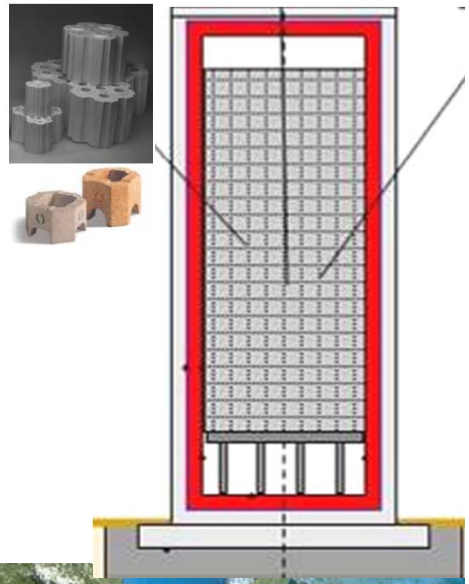
Technical Options for TES

Sensible Heat – Solid Media – Regenerator Storage

Storage-medium	Sensible Heat	Latent Heat
	Liquid	Phase Change Material (PCM)
	Solid	Steam Accumulator





- Regenerator storage as storage option for air
  - Simple setup, allows use of low-cost storage materials
  - Direct contact air / storage material
  - Can be used up to very high temperatures
- 1,5 flh demo storage at 1.5 MWe experimental Solar Tower Plant in Jülich, Germany

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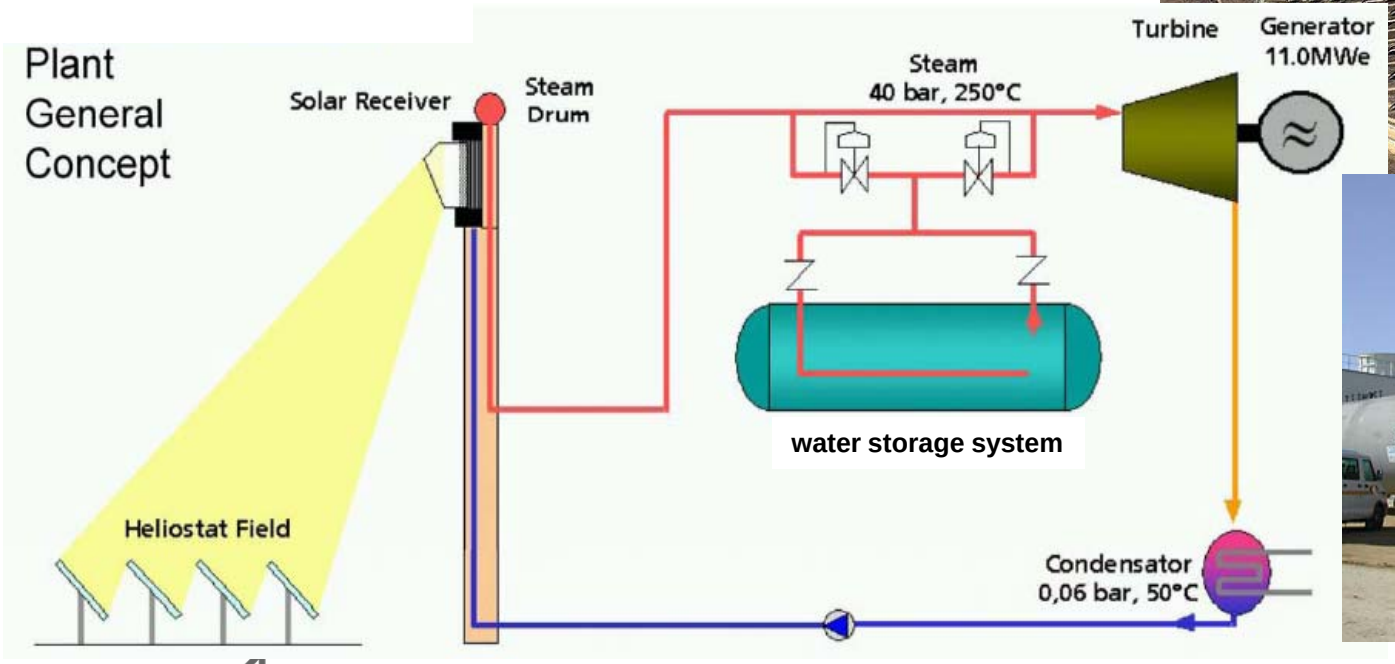
Technical Options for TES

Latent Heat – Steam Accumulator – PS-10

Storage-medium	Sensible Heat	Latent Heat
	Liquid	Phase Change Material (PCM)
	Solid	Steam Accumulator

- Example: PS-10
- Saturated steam at 250°C
- 50 min storage operation at 50% load



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Technical Options for TES

Latent Heat – PCM Storage

Storage-medium	Sensible Heat	Latent Heat
	Liquid	Phase Change Material (PCM)
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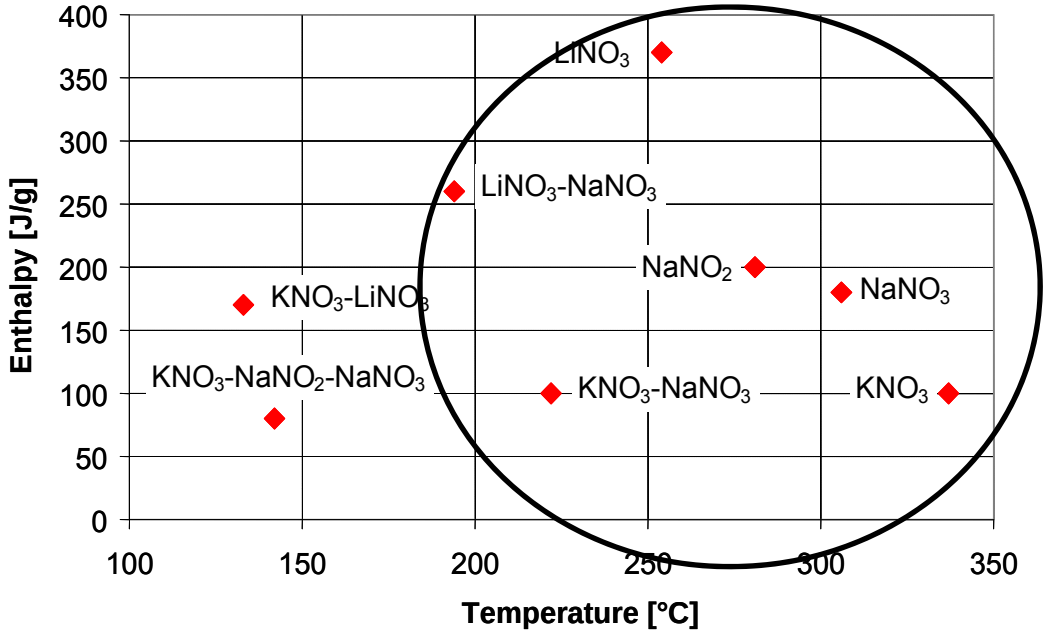
- Nitrate salt represent possible PCMs for applications beyond 100 °C
- Important PCM criteria: thermal conductivity, melting enthalpy, thermal stability, material cost, corrosion, hygroscopy



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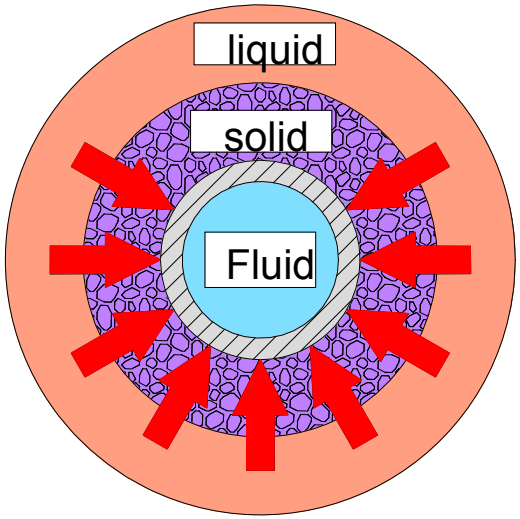
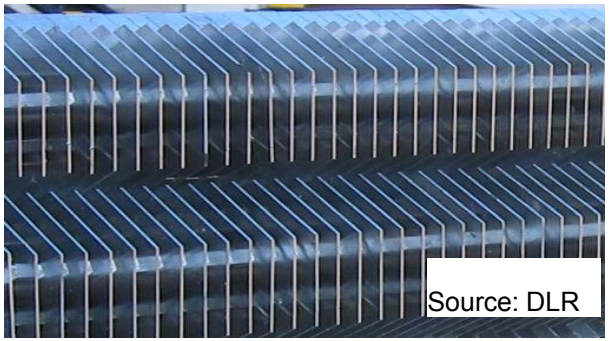
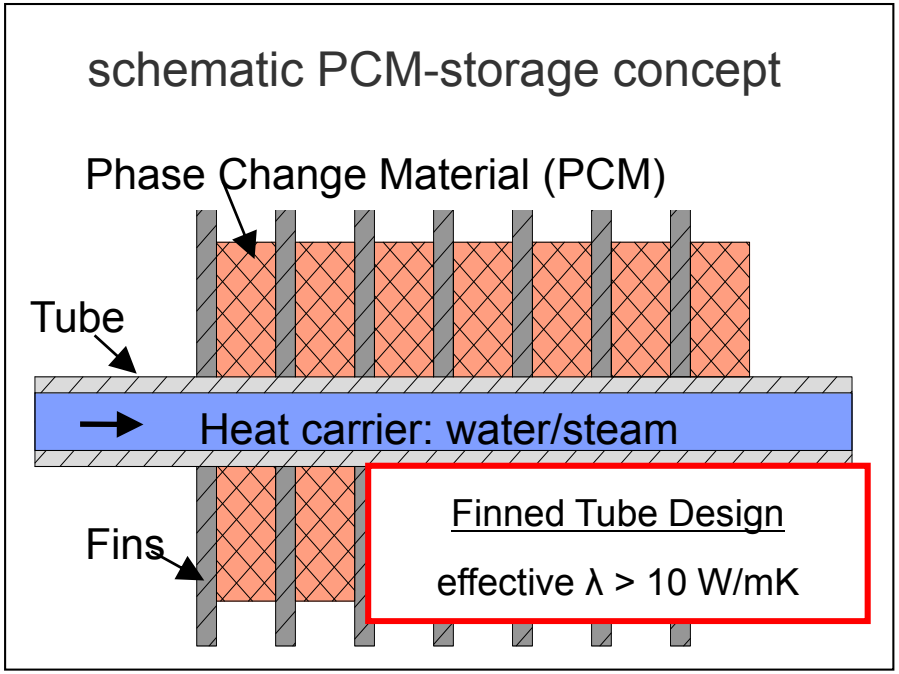




Heat transfer coefficient is dominated by the thermal conductivity of the solid PCM

→ Low thermal conductivity is bottleneck for PCM



Technical Options for TES

Latent Heat – PCM Storage

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Phase change material

Demonstrated at DLR:

- $NaNO_3$ - KNO_3 - $NaNO_2$ 142 °C
- $LiNO_3$ - $NaNO_3$ 194 °C
- $NaNO_3$ - KNO_3 222 °C
- $NaNO_3$ 306 °C

Source: DLR

Experimental validation

- 5 test modules with 140 – 2000 kg PCM
- Worlds largest high temperature latent heat storage with 14 tons of $NaNO_3$ (700 kWh) operating since 2010

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Current Developments

Sensible Heat – Identification of Improved materials

Storage-medium	Sensible Heat	Latent Heat
	Liquid	Phase Change Material (PCM)
	Solid	Steam Accumulator

Demand for…

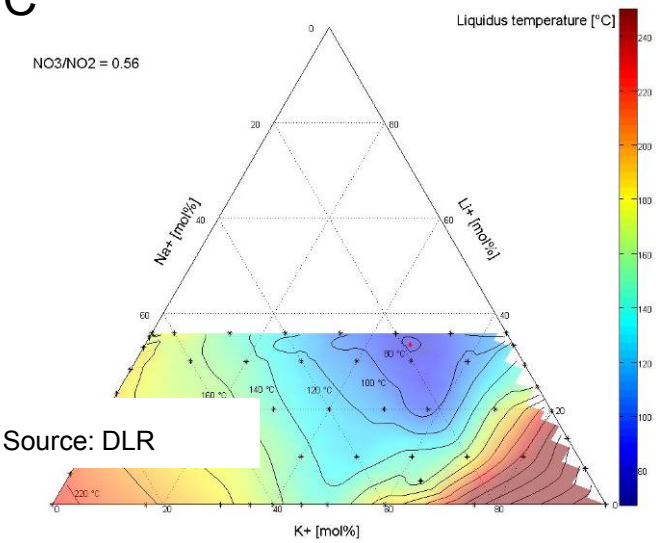
…higher thermal stabilities of molten salts → 700 °C

…Lower melting points → < 140 °C

…improved thermo-physical properties

Research on new salt mixtures:

Ternary system	$Ca(NO_3)_2$-KNO_3-$NaNO_3$
Quaternary system	Li, Na, K // NO_2,NO_3



- Source: DLR

Current Developments

Sensible Heat – Solid Media

- Durability of inexpensive storage materials
- Containment technology and HT-insulation
- Thermo-mechanical issues
- Even flow distribution through storage material

	Sensible Heat	Latent Heat
Storage-medium	Liquid	Phase Change Material (PCM)
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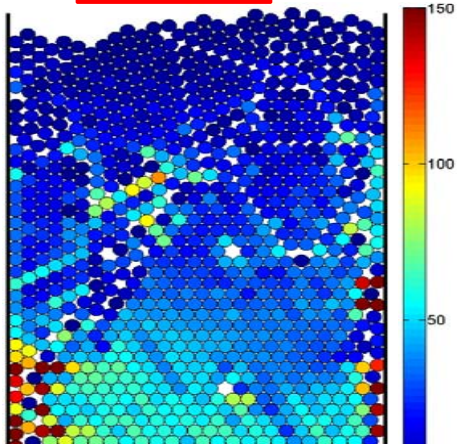

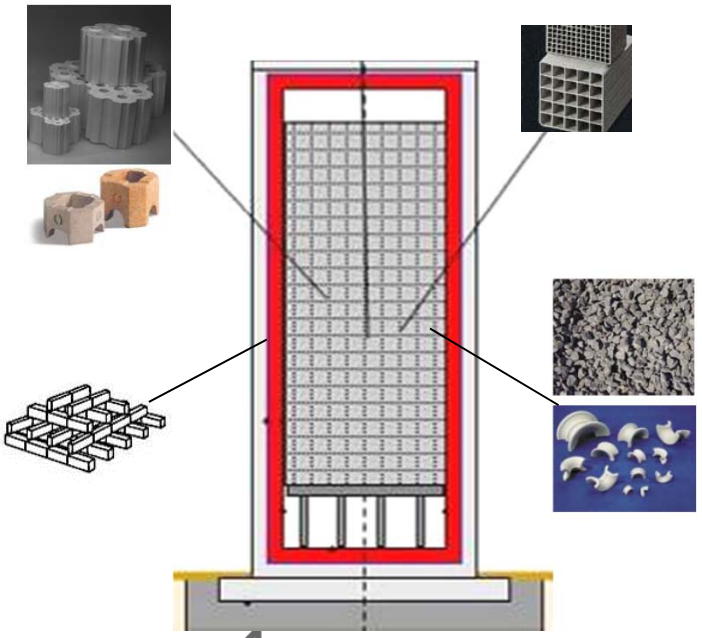

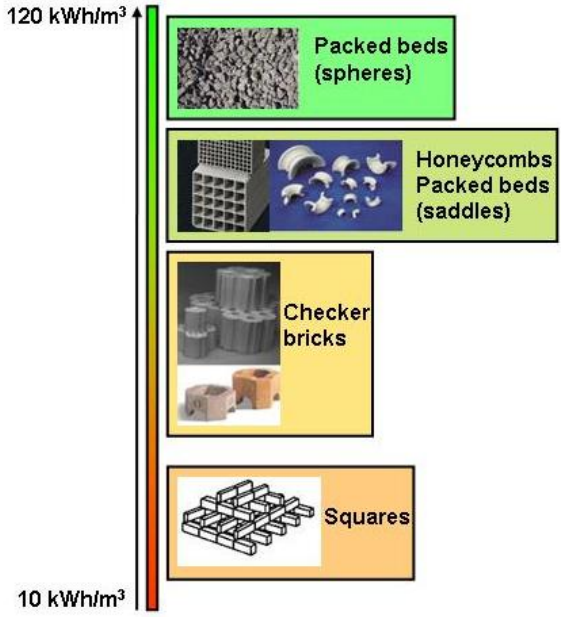

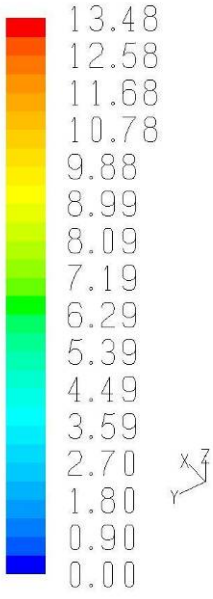

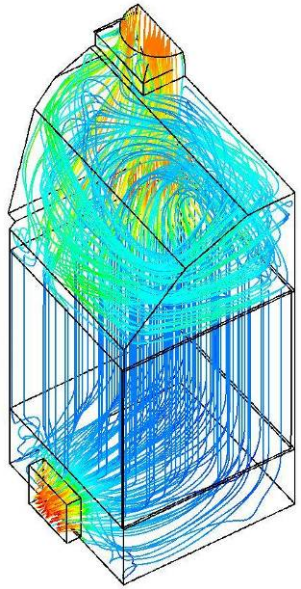

Current Developments

Latent Heat – PCM

Storage-medium	Sensible Heat	Latent Heat
	Liquid	Phase Change Material (PCM)
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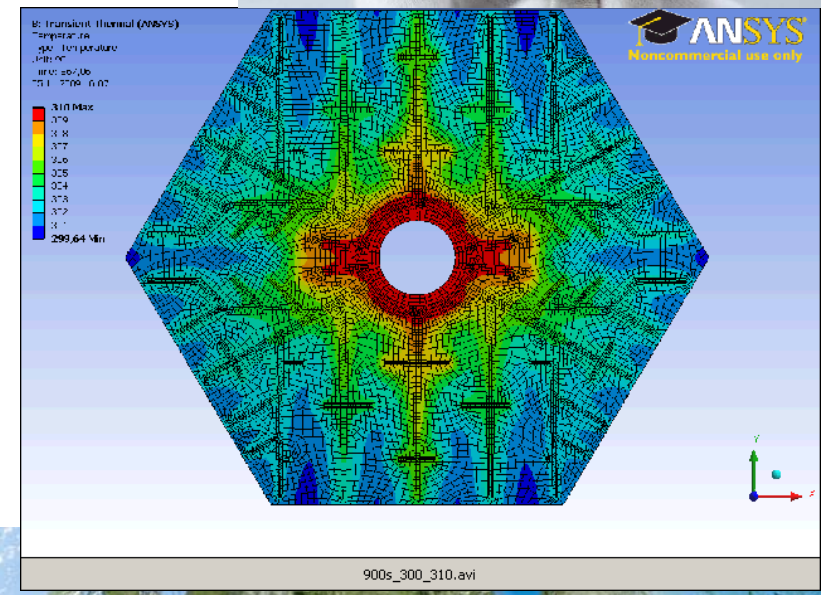
Enhanced heat transfer by extruded longitudinal fins

- Cost-effective production and assembly
- Free flow path in vertical direction
  => no risk with volume change during phase change
- Controlled distribution of heat in the storage
- Concept optimized by FEM analysis
- Successful demonstration in lab-scale
- Major cost reduction expected



Conclusions

- Different technical approaches for different process requirements available
- Proven options:
  - Two-Tank molten salt storage up to 560°C and 1010 MWh_{th}
- Demonstrated options:
  - PCM storage up to 100 bar and 700 kWh_{th}
  - Pecked bed storage up to 700°C and 1,5 Mwh_{e}

Questions

- …
- What are promising storage media?
  - High heat capacity
  - Low melting point
  - High thermal stability
  - Abundant
  - Cheap