Future Concepts
in Solar Thermal Electricity Technology

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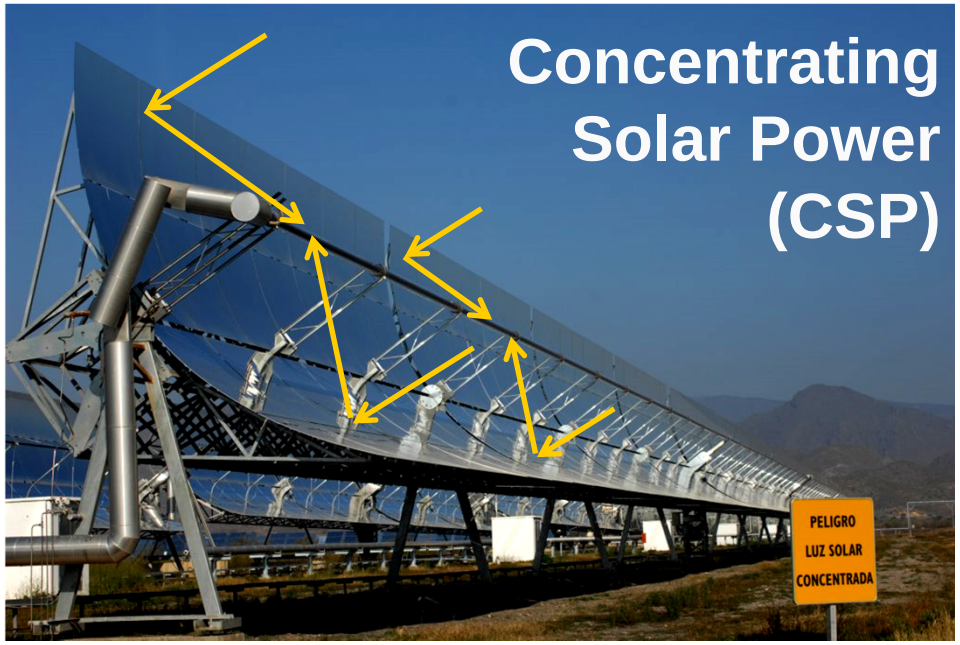
Overview

1. **INTRODUCTION** to Concentrating Solar Power (CSP)
2. **COST STRUCTURE** of CSP Plants
3. **COMMON FEATURES** of Future Concepts
4. **EXAMPLES** of Future Concepts
5. **SUMMARY**

Introduction to Concentrating Solar Power (CSP)



Sunlight

ELECTRICITY

Sunlight

Concentration

HEAT

Thermal Heat

Storage

Turbine

SOLAR FUELS

ELECTRICITY

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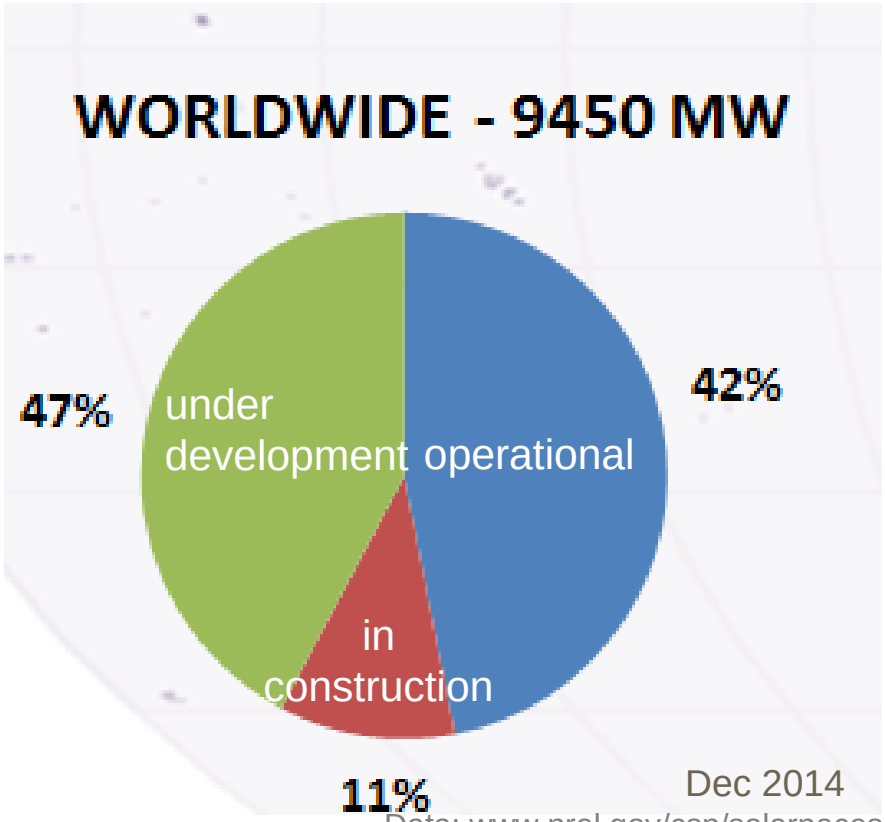
Introduction to Concentrating Solar Power (CSP)

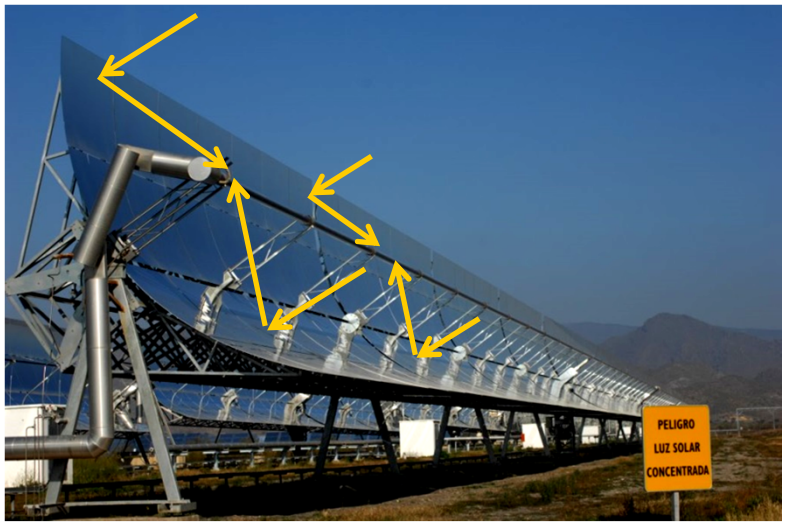
Projects worldwide



Dec 2014

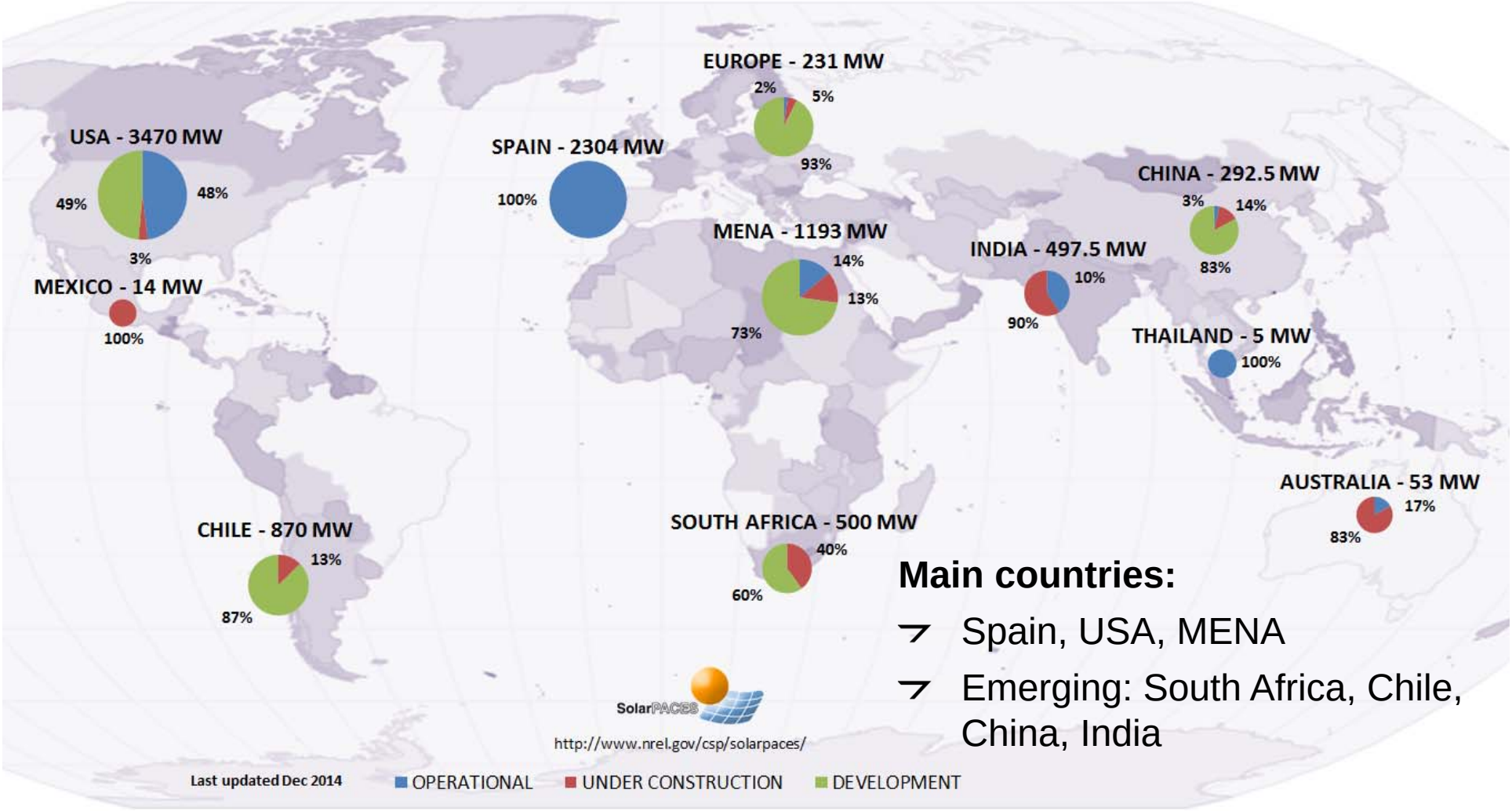
Data: www.nrel.gov/csp/solarpaces

- CSP is a dynamic sector with
  - almost 5 GW in operation and
  - ~5 GW under development or construction



Introduction to Concentrating Solar Power (CSP)

Projects worldwide



Main countries:

- Spain, USA, MENA
- Emerging: South Africa, Chile, China, India

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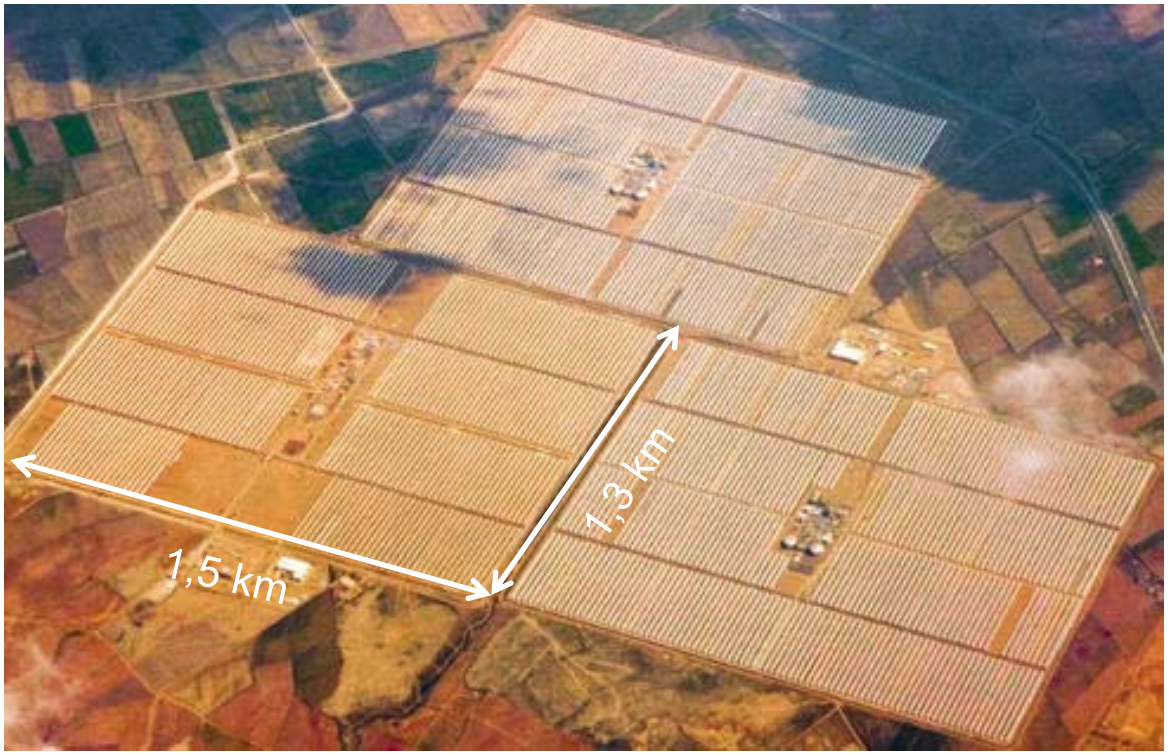
Introduction to Concentrating Solar Power

State-of-the-art Parabolic Trough Plant



Andasol Plants, I, II, III (2010)

ANDASOL-III Plant

- Land: 2’100’000 m^2
  (294 soccer fields)
- Collector: ~500’000 m^2
  (70 soccer fields)
- Receiver Length 90 km
- 50 MW-Turbine
- 7,5h Molten Salt Storage
  (production at night possible)

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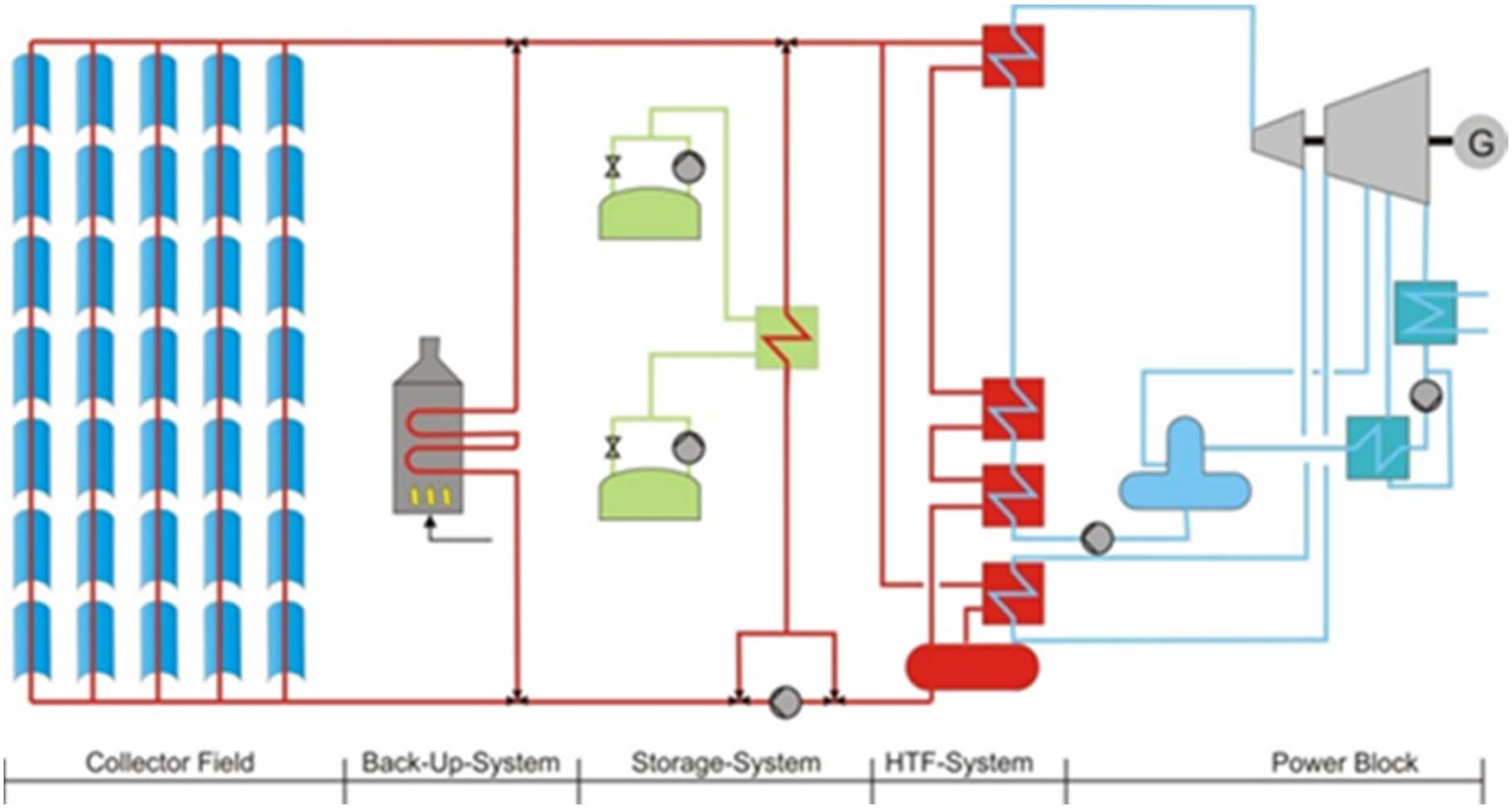
Introduction to Concentrating Solar Power

State-of-the-art Parabolic Trough Plant



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Introduction to Concentrating Solar Power

Central Receiver System

Crescent Dunes Plant

- Land: 6’475’000 m^2
  (906 soccer fields)
- Heliostat Aperture: ~1’071’000 m^2
  (150 soccer fields,
  17’170 Heliostats, each 62.4 m2,
  2 axis tracking)
- Molten Salt Receiver 565° C
- 110 MW-Turbine
- 10h Molten Salt Storage
  (production at night possible)

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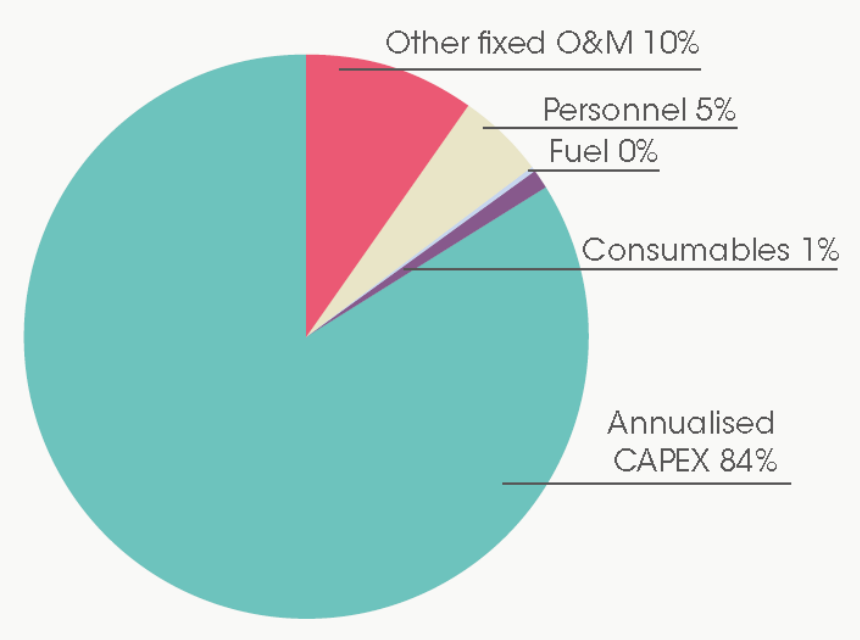
Cost Structure of CSP Plants
Central Receiver System

100MW solar tower with 15h-storage



- The annualized capital cost is the cost driver of a CSP plant (>80%)

IRENA Renewable Energy Technologies, Cost Analysis Series, Volume 1: Power Sector, Issue 2/5, Concentrating Solar Power, June 2012 // Fichtner 2010

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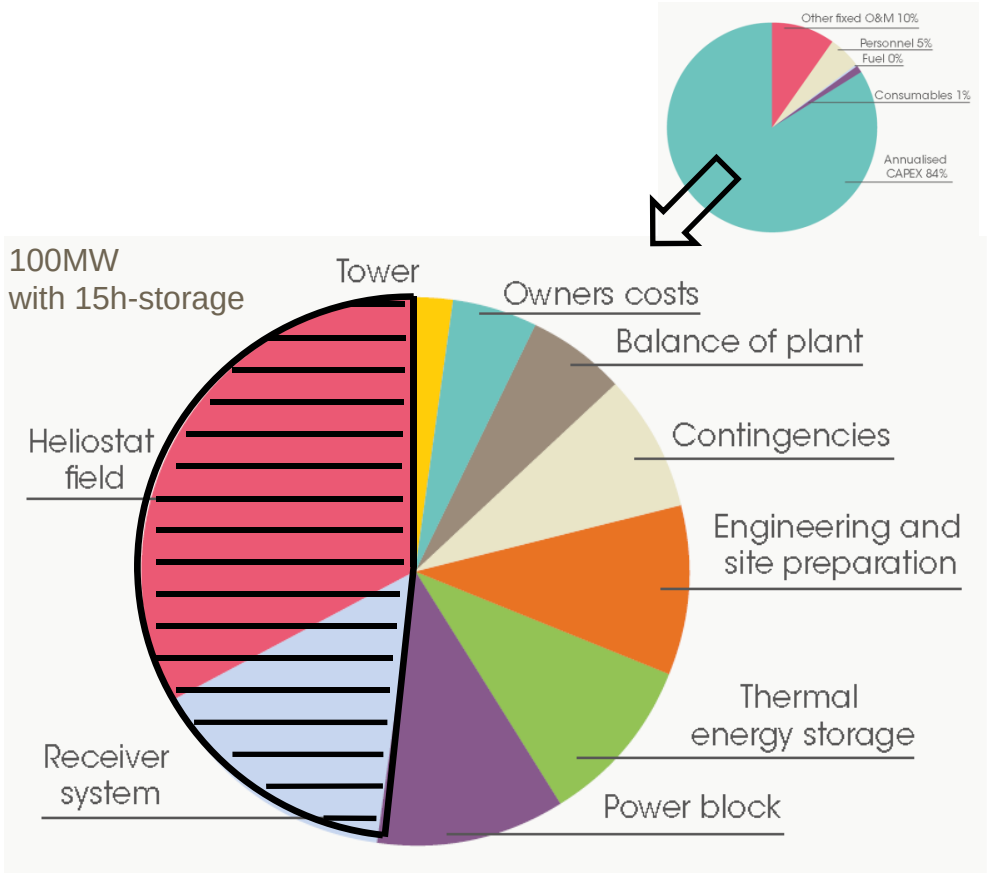
Cost Structure of CSP Plants
Central Receiver System



- The annualized capital cost is the cost driver of a CSP plant (>80%)

CAPEX:

- Heliostat field and receiver constitute about half of capital costs
- Future concepts have to tackle these main cost drivers

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Common Features of Future Concepts

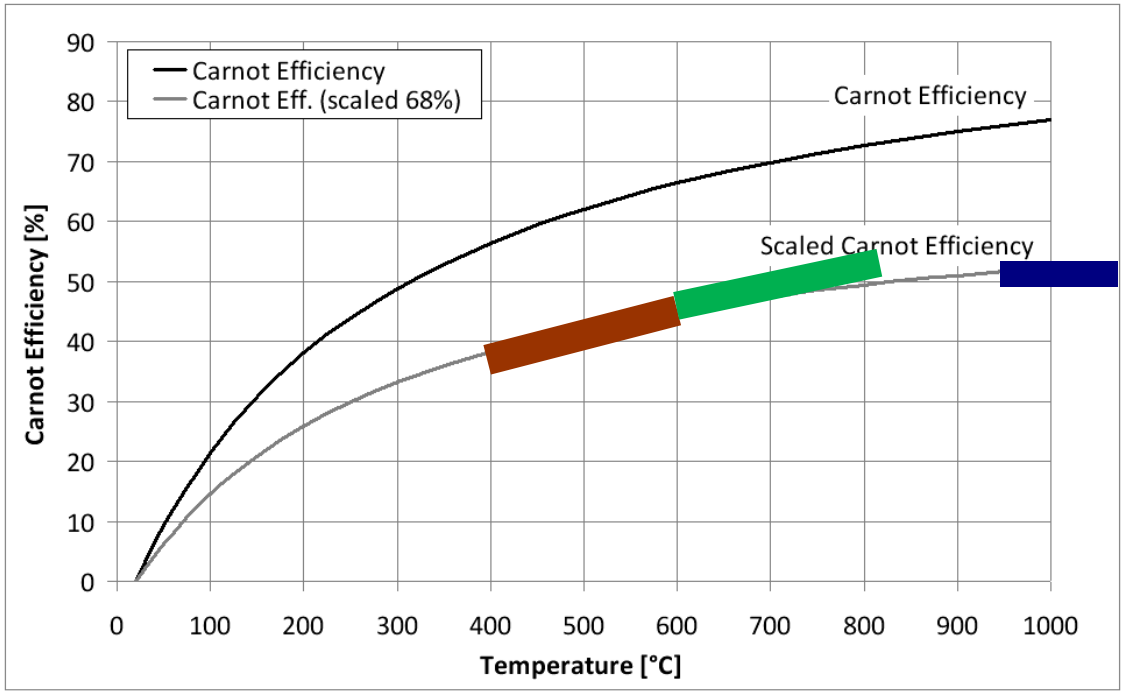
Common Features of Future Concepts should have:

- **Higher concentrations** for higher temperatures/ **Highly efficient cycles**
  → Leads to reduction of solar field and receiver size and hence costs

Common Features of Future Concepts

Higher concentrations, temperatures and system efficiencies

- Future CSP concepts have high concentration ratios (>100 to >1000 suns) which generate high (not very high) temperatures with good collector efficiency
- These high-temperature heat can be transformed to power with highly efficient cycles (Carnot), e.g. high-temperature steam or supercritical steam, supercritical CO_2, closed Brayton, combined cycles



Rankine Cycle

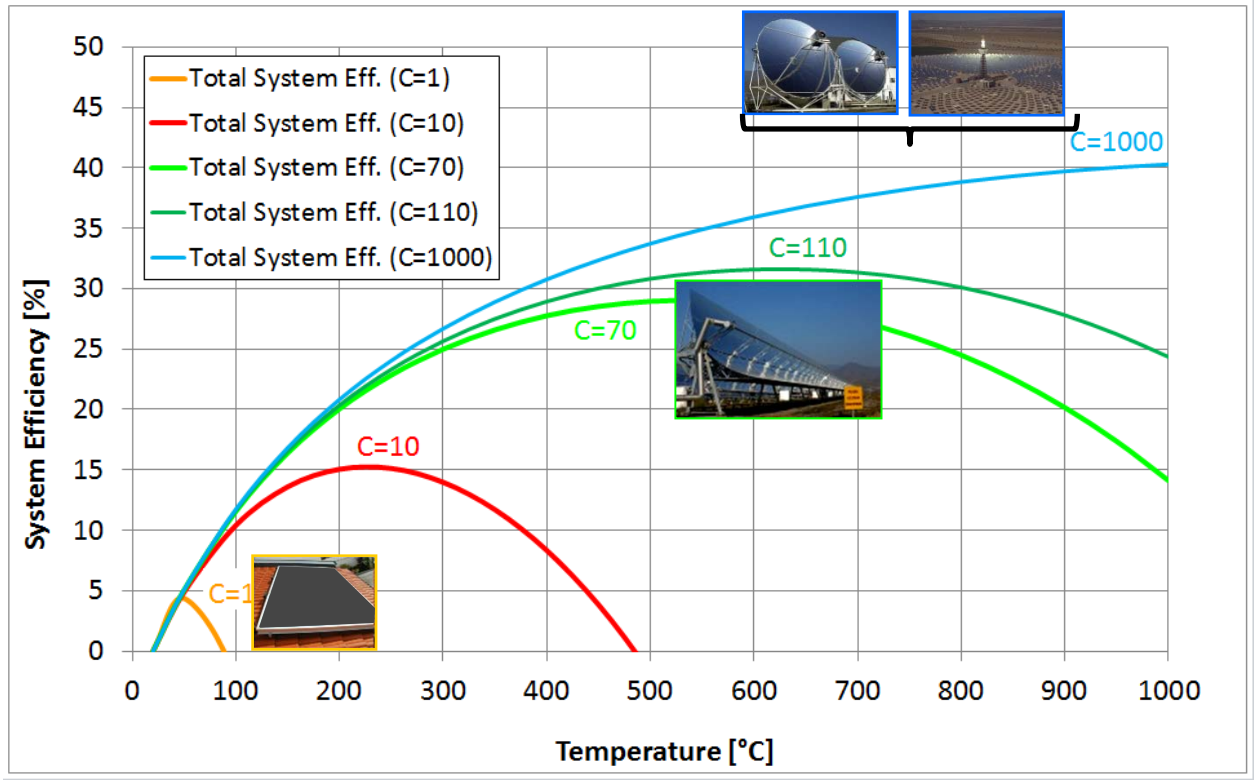
Supercritical steam / s-CO_2

Combined Cycle

Common Features of Future Concepts

High concentrations, temperatures and system efficiencies

- Very high temperatures (>1000/1100° C) seem not be necessary
- Solar Towers and Large-Aperture Parabolic Troughs seem appropriate



Common Features of Future Concepts

Common Features of Future Concepts should have:

- **Higher concentrations** for higher temperatures/ **Highly efficient cycles**
  → Leads to reduction of solar field and receiver size and hence costs
- **Dispatchability**
  → Increases value of CSP electricity by offering dispatchable electricity

Common Features of Future Concepts

Dispatchability by Thermal Energy Storage

- Collected solar heat can be stored in thermal energy storage
- CSP includes this attractive option
- Thermal energy storage is
  - much cheaper (40€/kW_{th})
  - and more efficient (η=95%)

  than storing electricity

Storage Technologies:

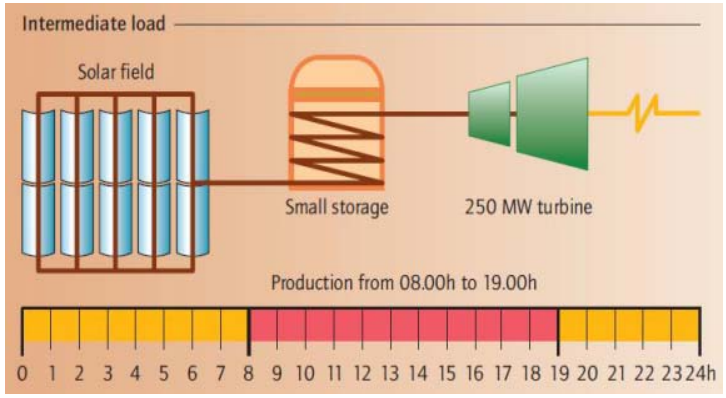
- Sensible heat in liquids (molten salts/metals/steam)
- Sensible heat in solids (e.g. moving particles, rocks, concrete)
- Latent heat in Phase Change Materials
- Chemical storage

Heat transfer: either direct or via heat exchanger

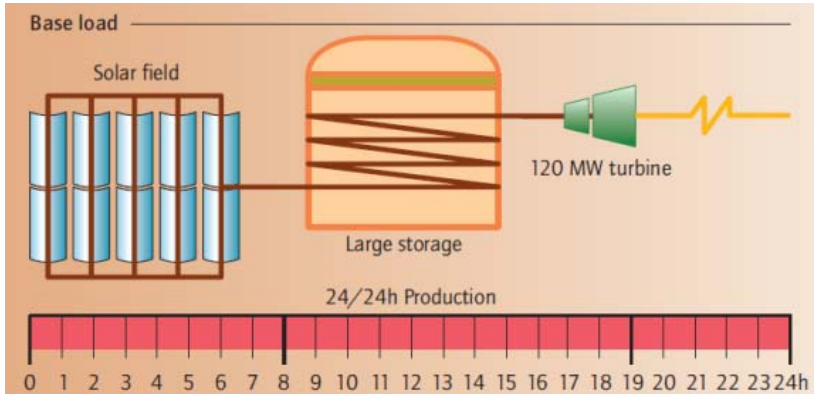
Common Features of Future Concepts

Dispatchability by Thermal Energy Storage

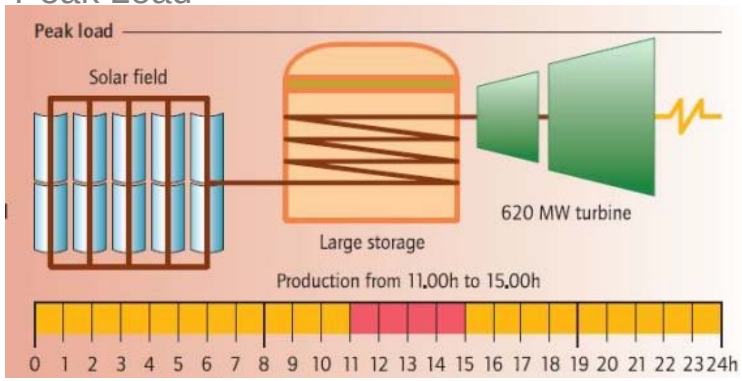
Intermediate Load



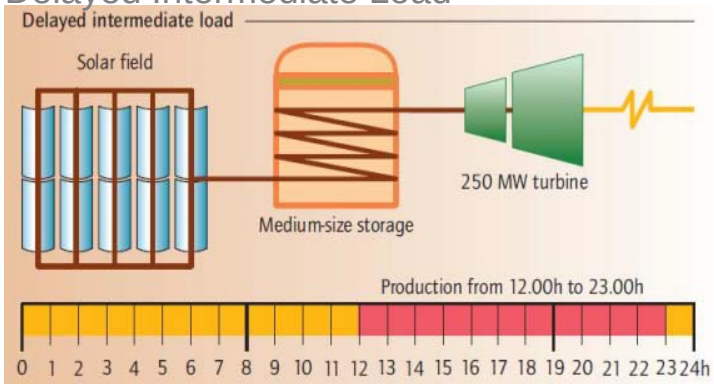
Base Load



Peak Load



Delayed Intermediate Load



- Different combinations of solar field, storage and turbine size permit different services

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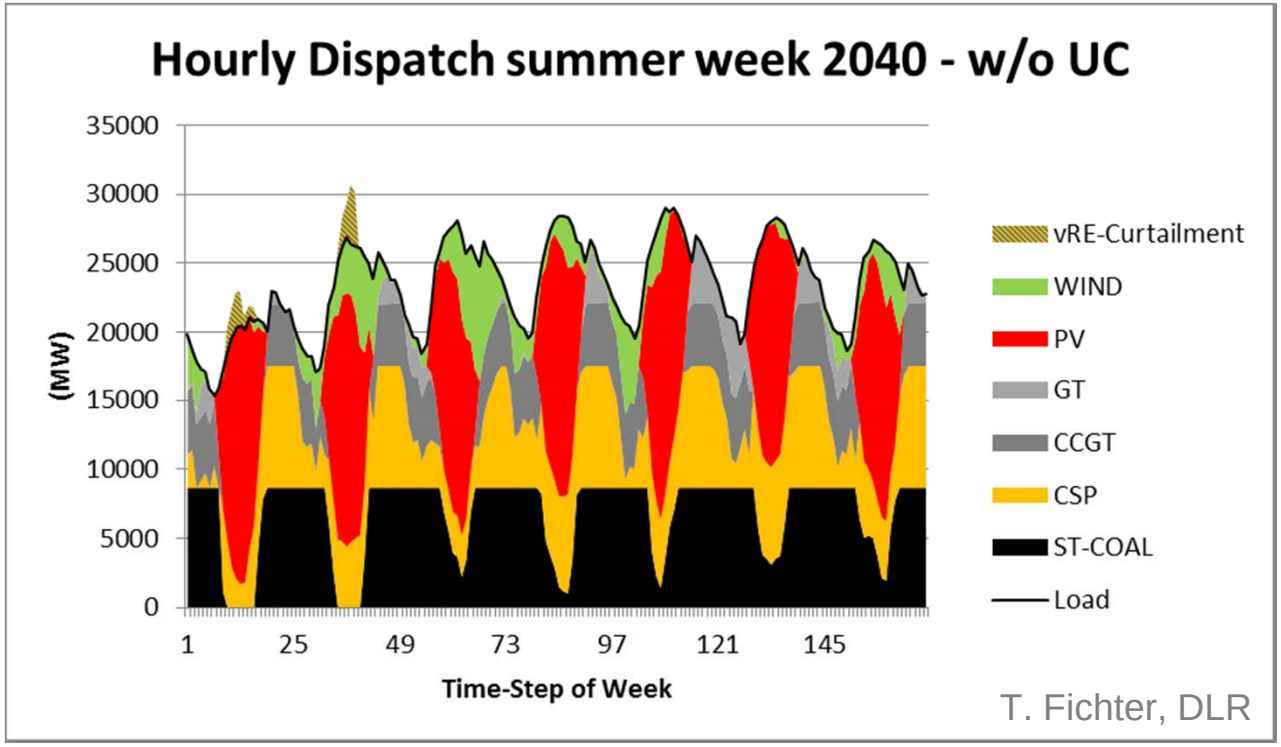
Common Features of Future Concepts

Value of CSP Capacity



- Although levelized electricity generation costs may be higher for CSP than for wind or PV, the **value of CSP is higher** thanks to its possibility to dispatch electricity when needed (firm and flexible renewable capacity)
- CSP can **increase share of intermittent renewables** like PV or wind

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Common Features of Future Concepts

Common Features of Future Concepts should have:

- **Higher concentrations** for higher temperatures/ **Highly efficient cycles**
  → Leads to reduction of solar field and receiver size and hence costs
- **Dispatchability**
  → Increases value of CSP electricity by offering dispatchable electricity
- **Reduced complexity**, e.g. one medium for receiver and storage system
  e.g. simple heliostat and receiver layouts
  e.g. non-pressurized system
  → Leads to system cost reduction

Further non-technological Issues for Cost Reduction

- Scale-up, repetition of plants, component mass production
  → Economies of scale
- Qualification and performance testing, standardization
  → Reduces technological project risk (“bankability”)

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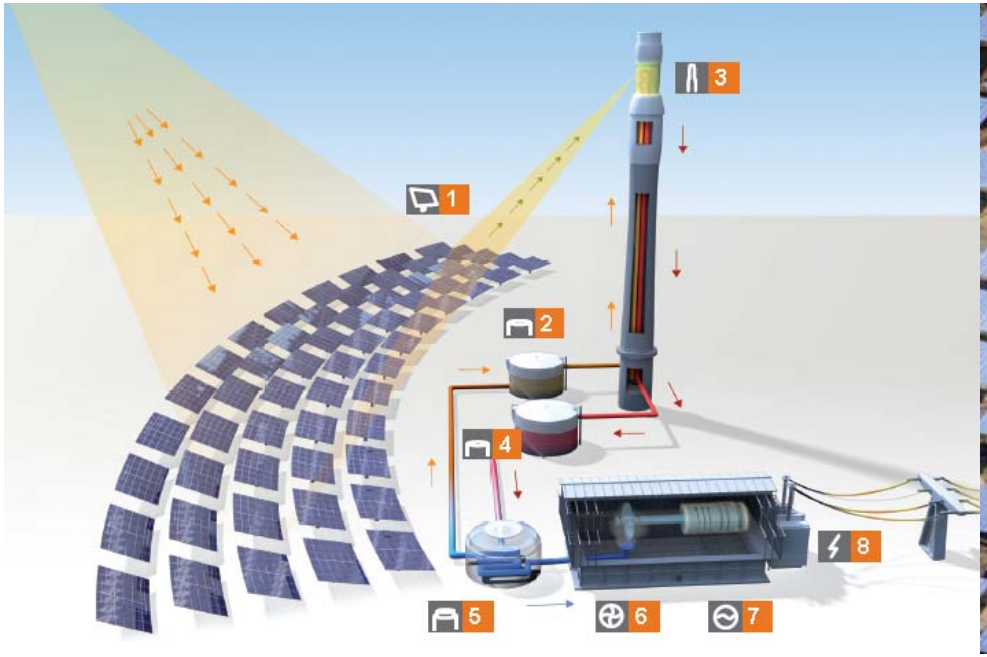
Examples of Future Concepts

A Solar Tower with Liquid HTF and Storage

Meets:

- High Concentration, High Temperature, Efficient Cycles
- Dispatchability
- Reduced complexity: one medium for receiver and storage; non-pressurized



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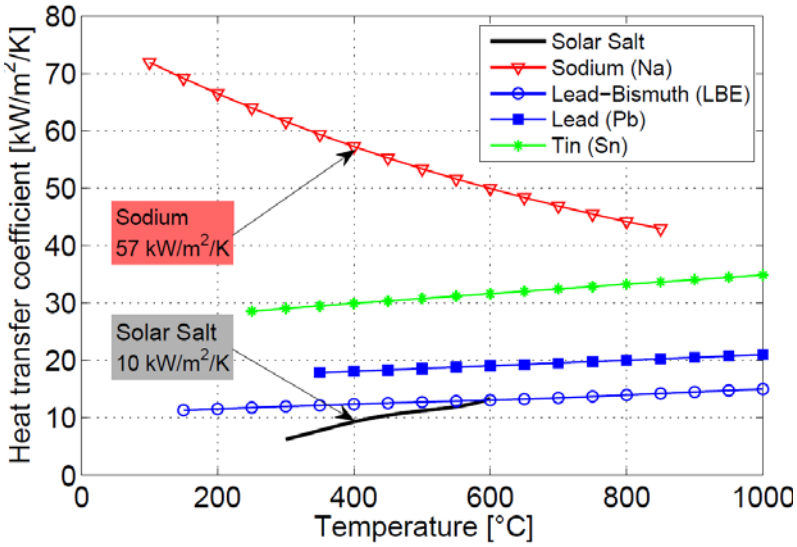
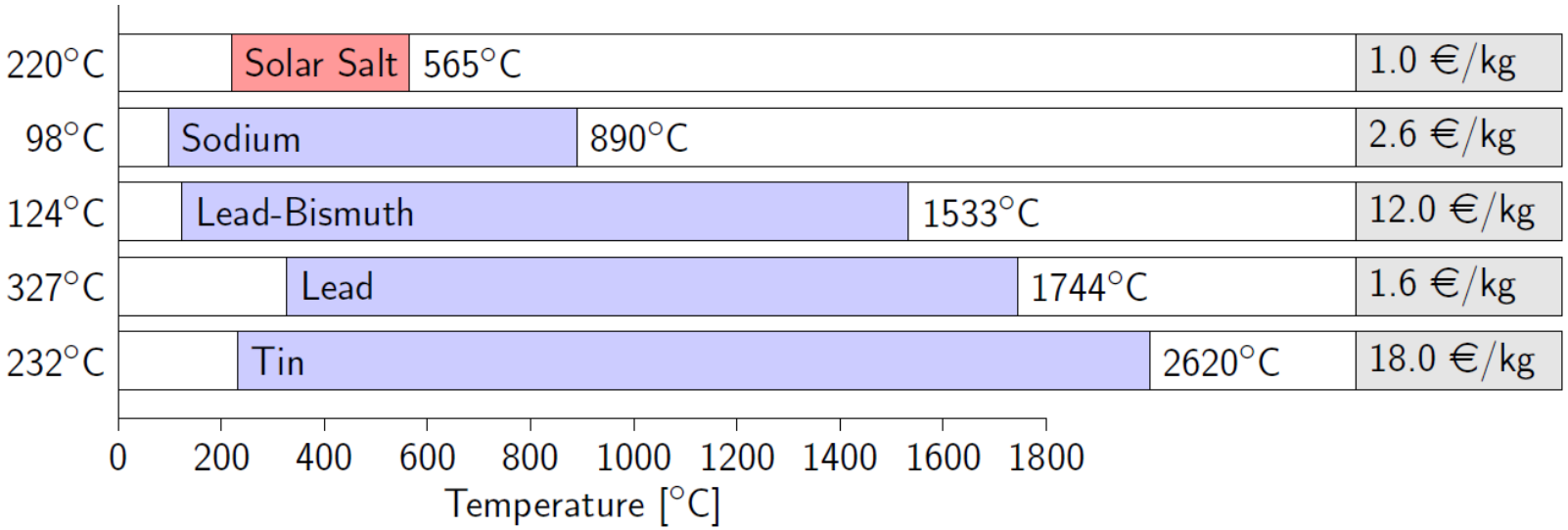
Examples of Future Concepts

A Solar Tower with Liquid HTF

Metals are interesting candidates to increase temperatures

- High temperature range
- High heat transfer coefficients allow high solar fluxes + low surface temperatures = highly efficient receivers
- Low vapour pressure (non-pressurized system)



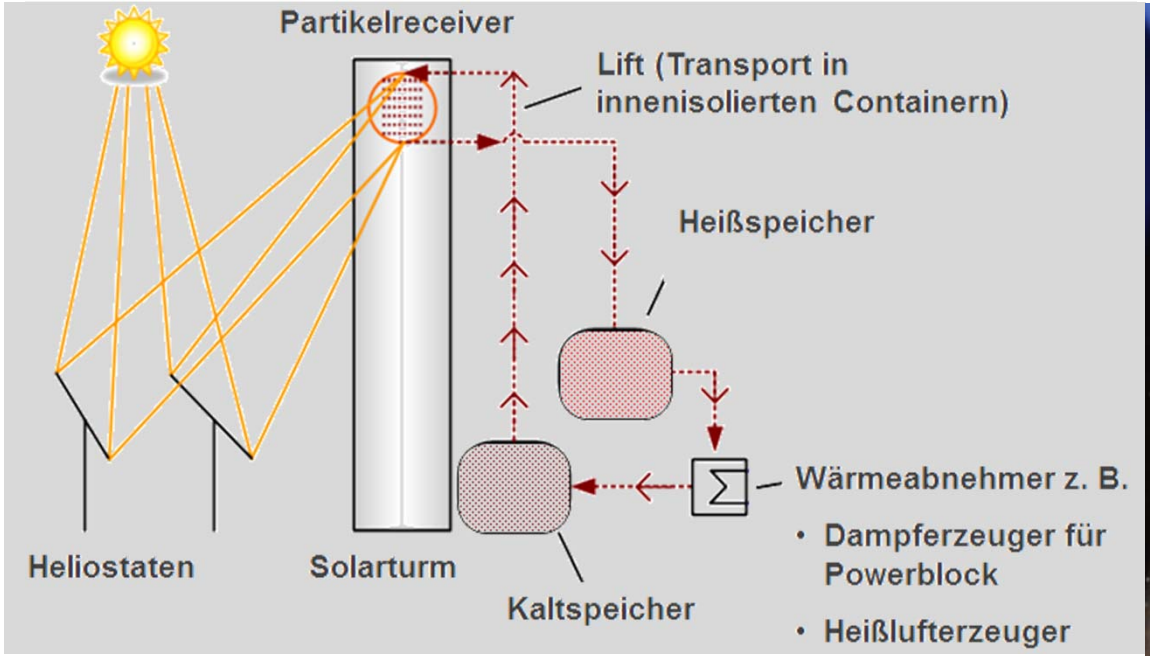


Examples of Future Concepts

B Solar Tower with Particle Receiver and Storage

Meets:

- High Concentration, High Temperature, Efficient Cycles
- Dispatchability
- Reduced complexity: one medium for receiver and storage; non-pressurized

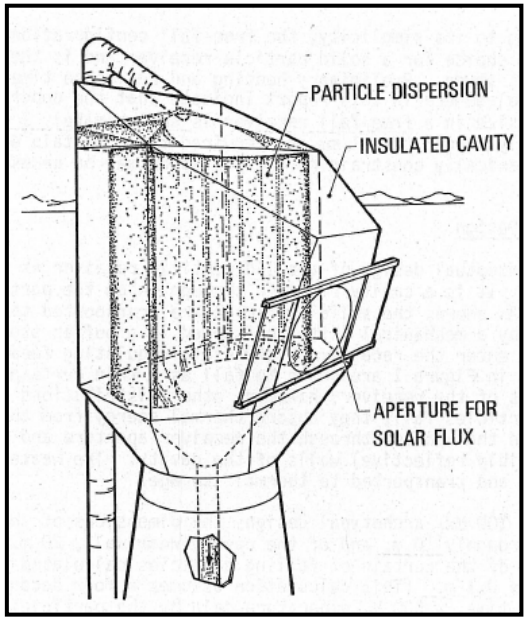


Examples of Future Concepts

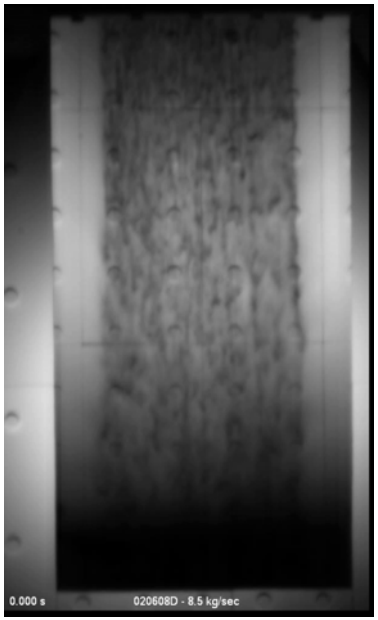
B Solar Tower with Particle Receiver and Storage

Falling Particle Receiver

- Particles in free fall through solar focus
- Particle sizes around ~0.7mm
- Doped (Blackened) Al_2O_3 particles



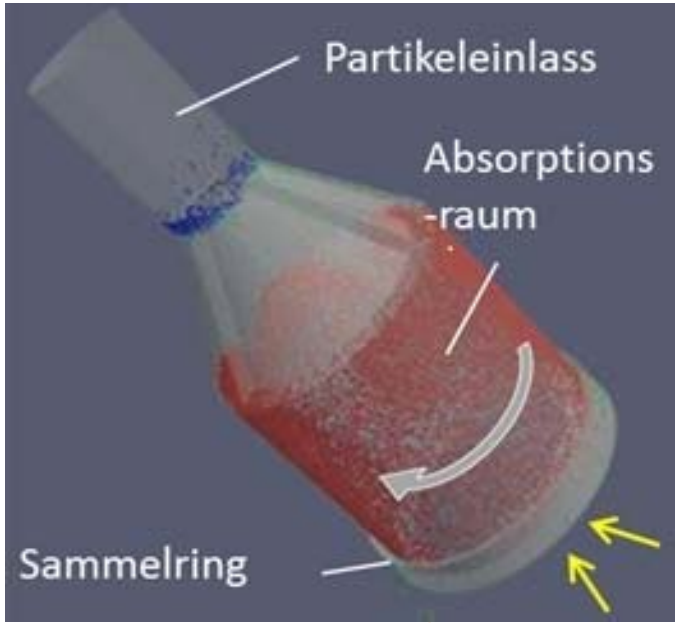
SNL-Report: Sand 85-8208



High Mass Flow Rate
(SNL – Tests 2008)

Centrifugal Receiver

- Retention time = Heating time of particles inside receiver controllable by centrifugal and frictional forces



Examples of Future Concepts

B Solar Tower with Particle Receiver and Storage

Advantages of Direct Absorption Receiver

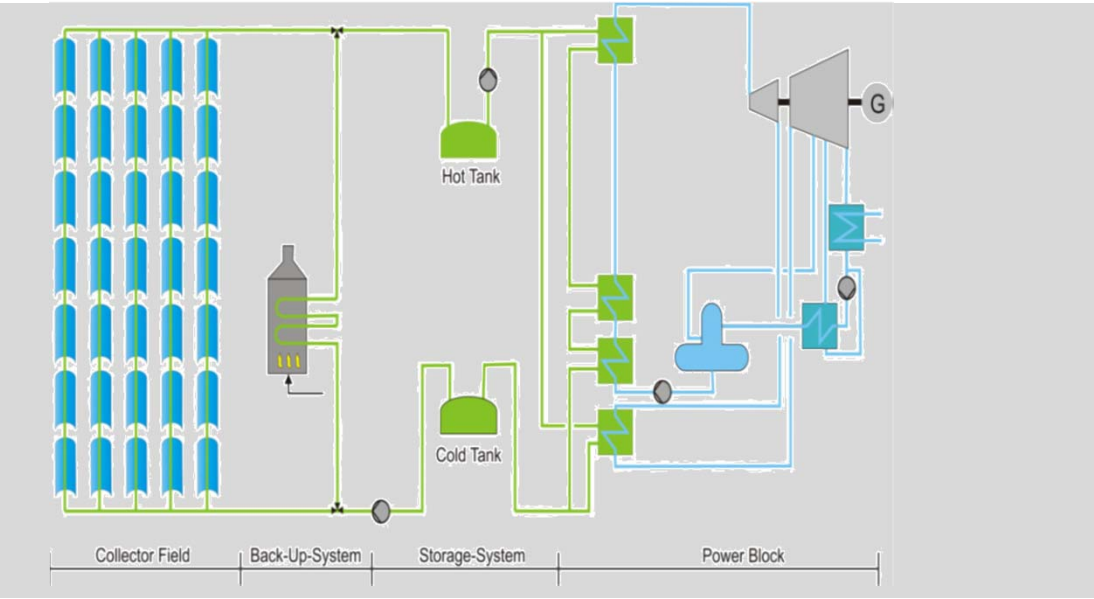
- Direct solar radiation into the storage medium
- High solar flux possible
- Low sensitivity to peaks and transients in solar radiation
- No expensive high-temperature alloys
- Receiver and storage at atmospheric pressure
- Continuous operation of high-temperature processes

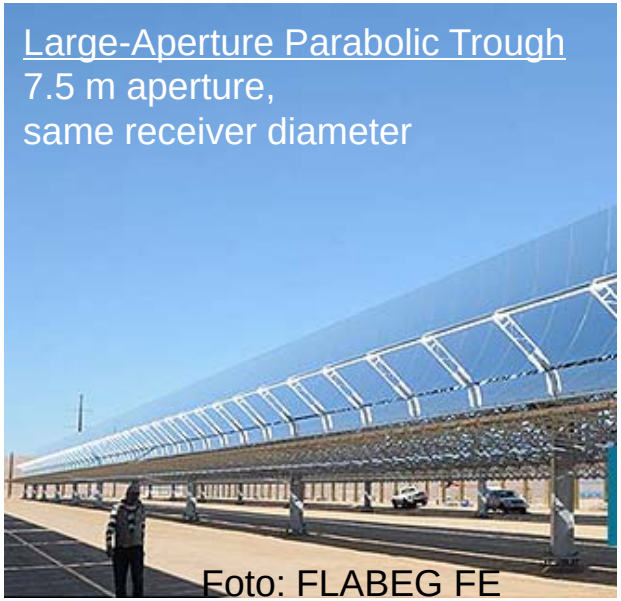
Examples of Future Concepts

C Molten Salt Large-Aperture Parabolic Trough

Meets:

- Higher Concentration, Higher Temperature, Efficient Cycles
  (compared to standard parabolic trough with oil as HTF)
- Dispatchability
- Reduced Complexity: one medium for receiver and storage, non-pressurized





Examples of Future Concepts

C Molten Salt Large-Aperture Parabolic Trough

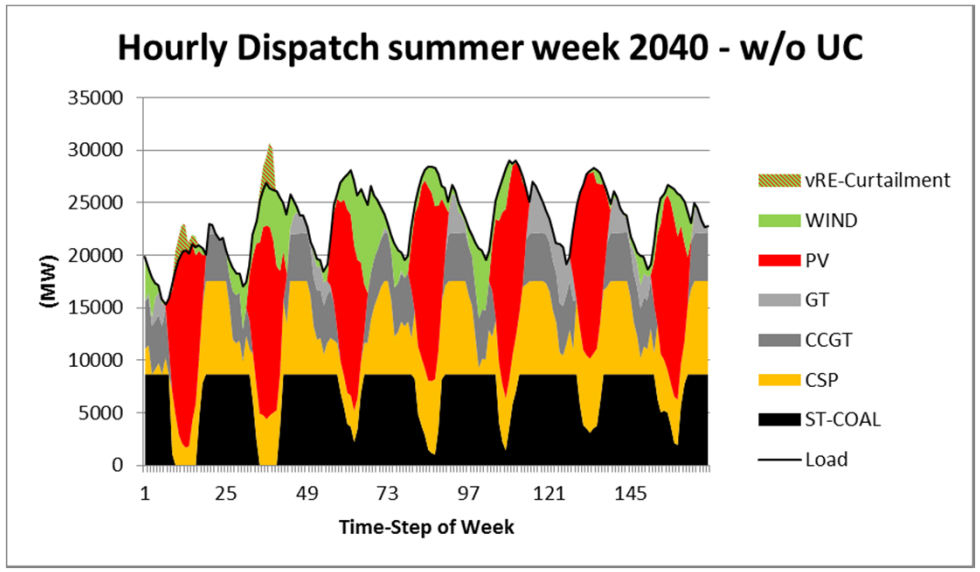
Advantages of molten salt large-aperature parabolic trough
(compared to standard parabolic trough, oil-based HTF)

- Higher efficiencies
  - Increase in concentration ratio from 82 to 107 suns
  - Higher temperatures (up to ~550° C) with high efficiencies
  - Higher power block efficiency
- Dispatchability
  - Smaller storage system due to higher energy density ($\Delta T \uparrow$)
- Reduced Complexity:
  - Salt acts as unique medium for solar field and storage
    (no heat exchanger, no exergy loss)
  - Better environmental footprint (no oil)
  - Less receivers, mirrors, joints, drives, foundations, sensor per m^2 mirror

Examples of Future Concepts

D Combination of PV and CSP Plant

- Solar Power Project Developer may combine low-cost, intermittent PV with higher-value firm and flexible CSP to serve grid services.
- PV and CSP plant could be two separate plants with one control room and transformer station, or in future, combined systems. Synergies are possible.



Red and orange areas could be provided by one solar provider

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Summary

1. **Concentrating Solar Power** (CSP) offers **firm and flexible renewable capacity** using a thermal storage and hence an **additional value** to intermittent wind and CSP

2. **Future Concepts** of CSP will probably have
   - **High solar concentrations** for moderate high temperatures and **highly efficient cycles** using moderate temperatures (superheated or supercritical steam or s-CO_2, closed Brayton)
   - **Thermal storage** to use the full potential of the technology
   - **Reduced complexity**, e.g. one medium for receiver and storage system
     e.g. simple heliostat and receiver layouts, etc.

3. **Examples** for Future Concepts (all include storage)
   - **Solar towers** with **molten salt/molten metal** receiver
   - **Solar towers** with **particle** receiver
   - **Large-aperture parabolic troughs** with **molten salt**
   - **Combined CSP and PV** plants.

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THANK YOU
for your attention.

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