"Entwicklungsstand und Perspektiven der solarthermischer Kraftwerke

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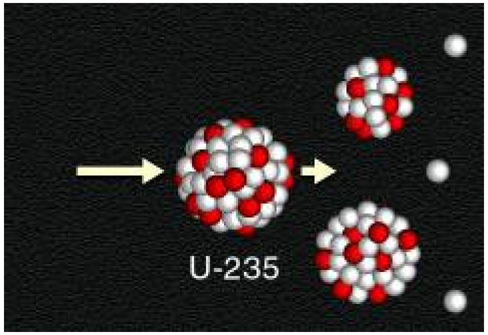
Inhalt

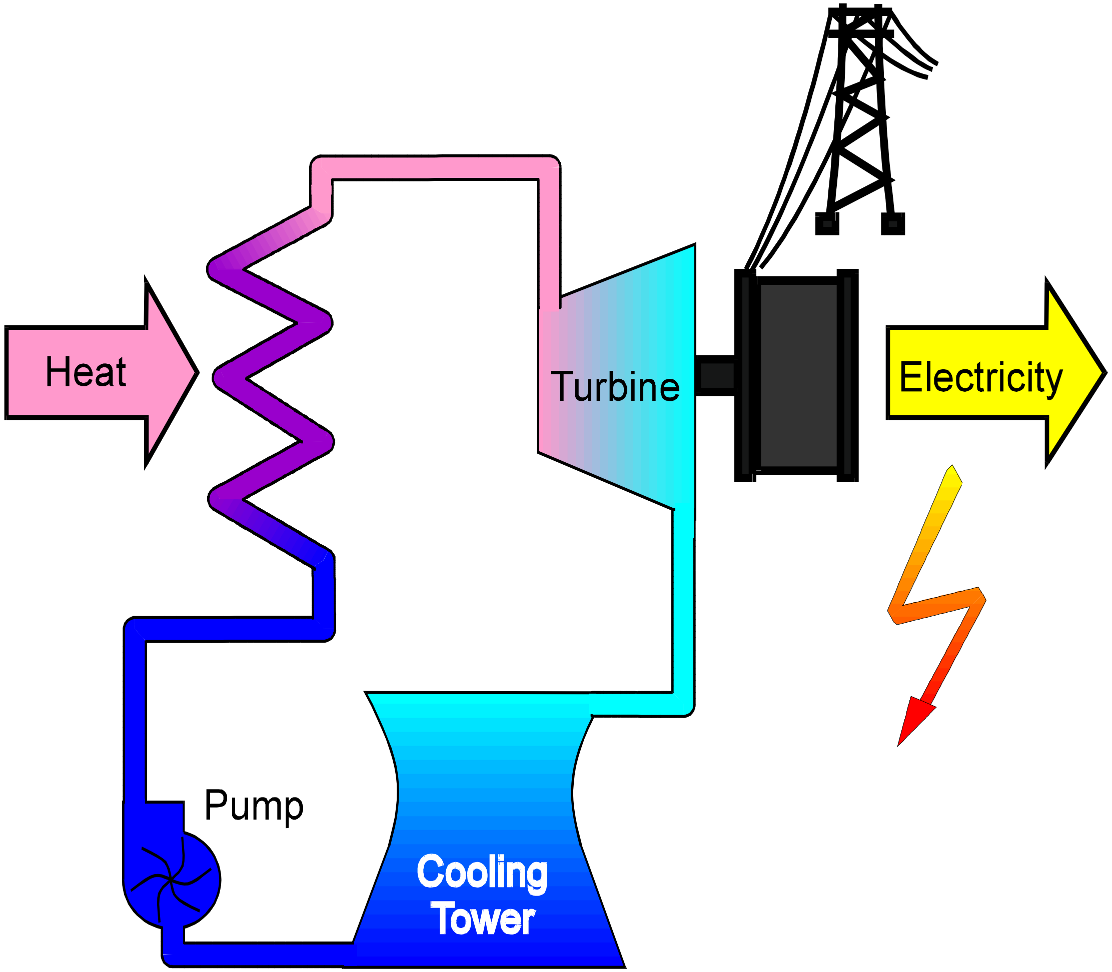
Märkte
- *Spanien*
- *USA*
- *RoW*

Kosten
Kostensenkung
Wert von Strom

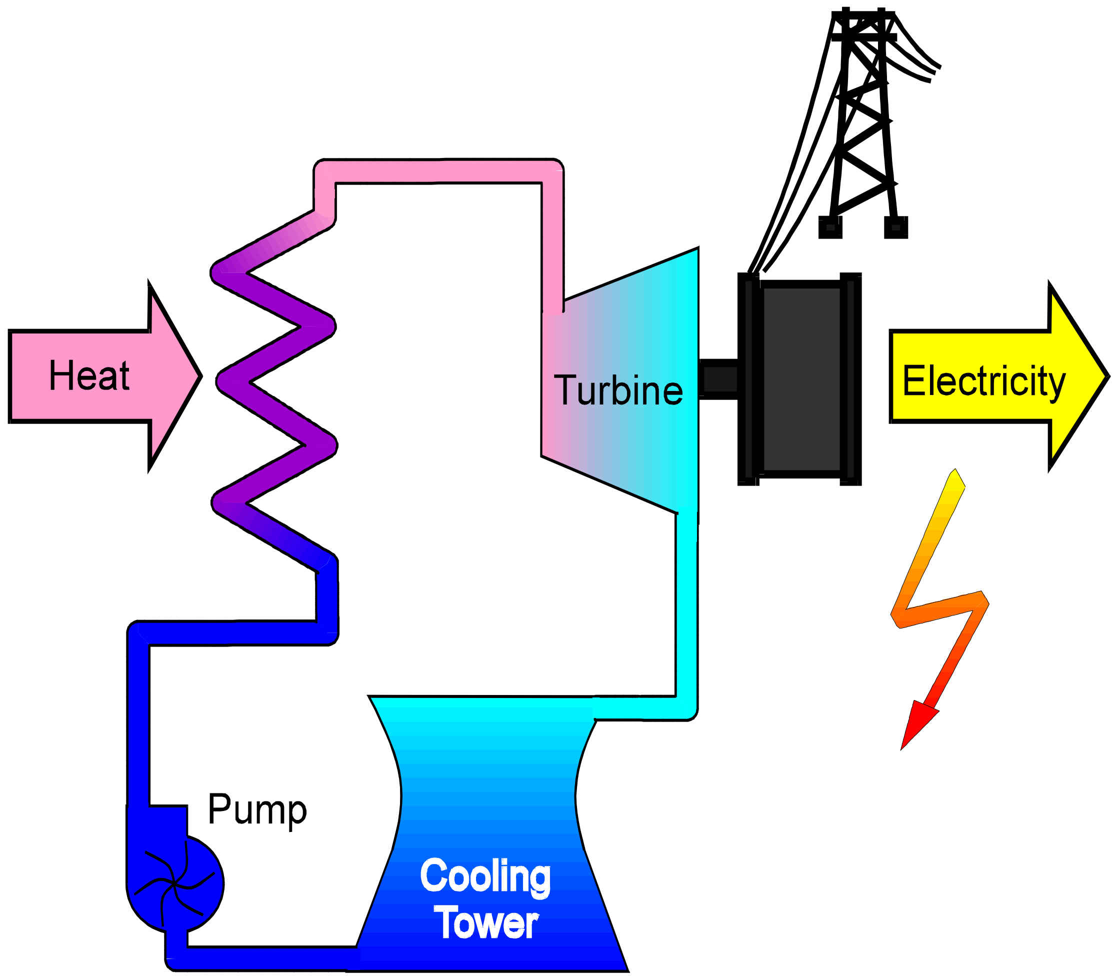
Was ist CSP?



Konventionelle Kraftwerke

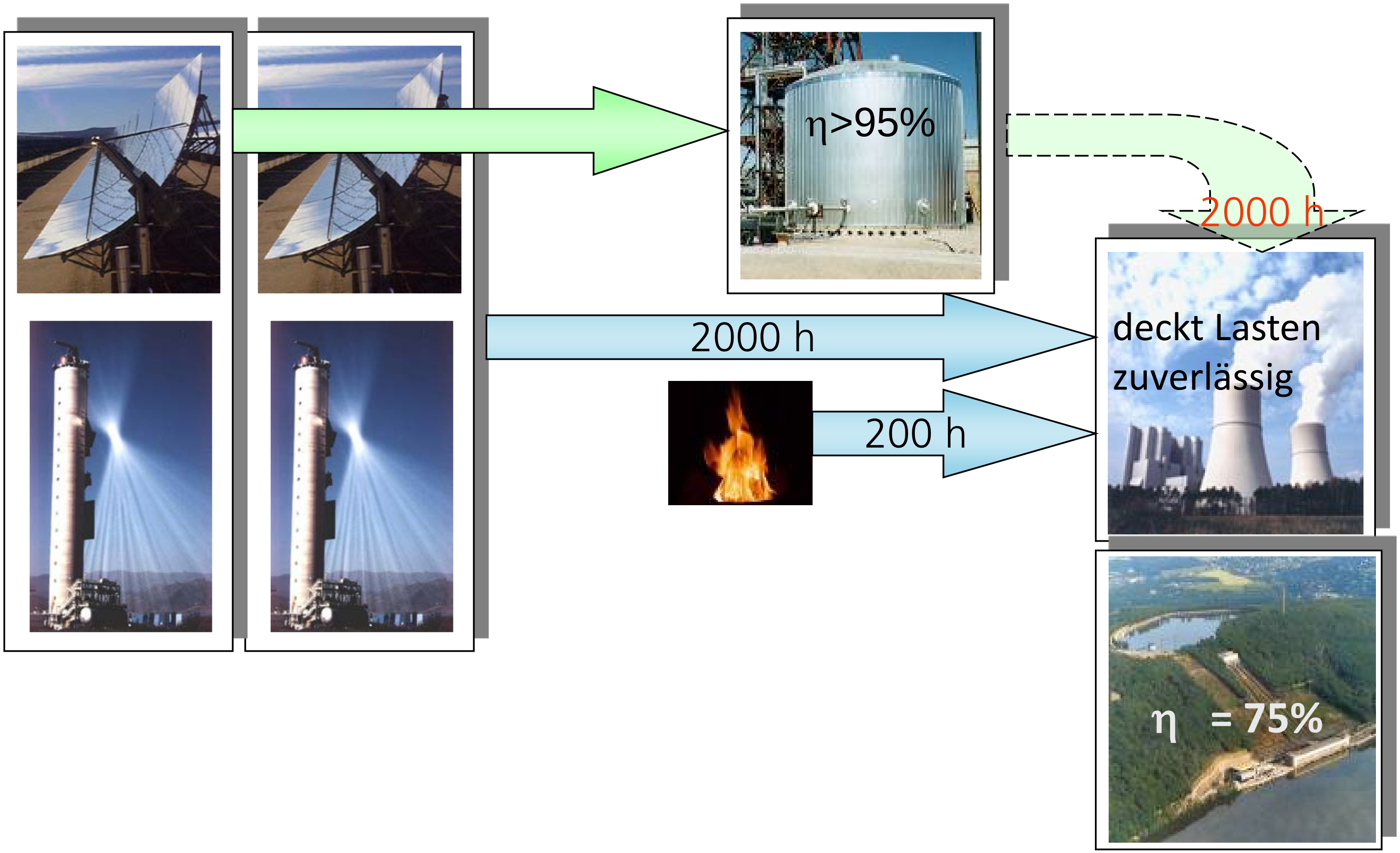


Was ist CSP?



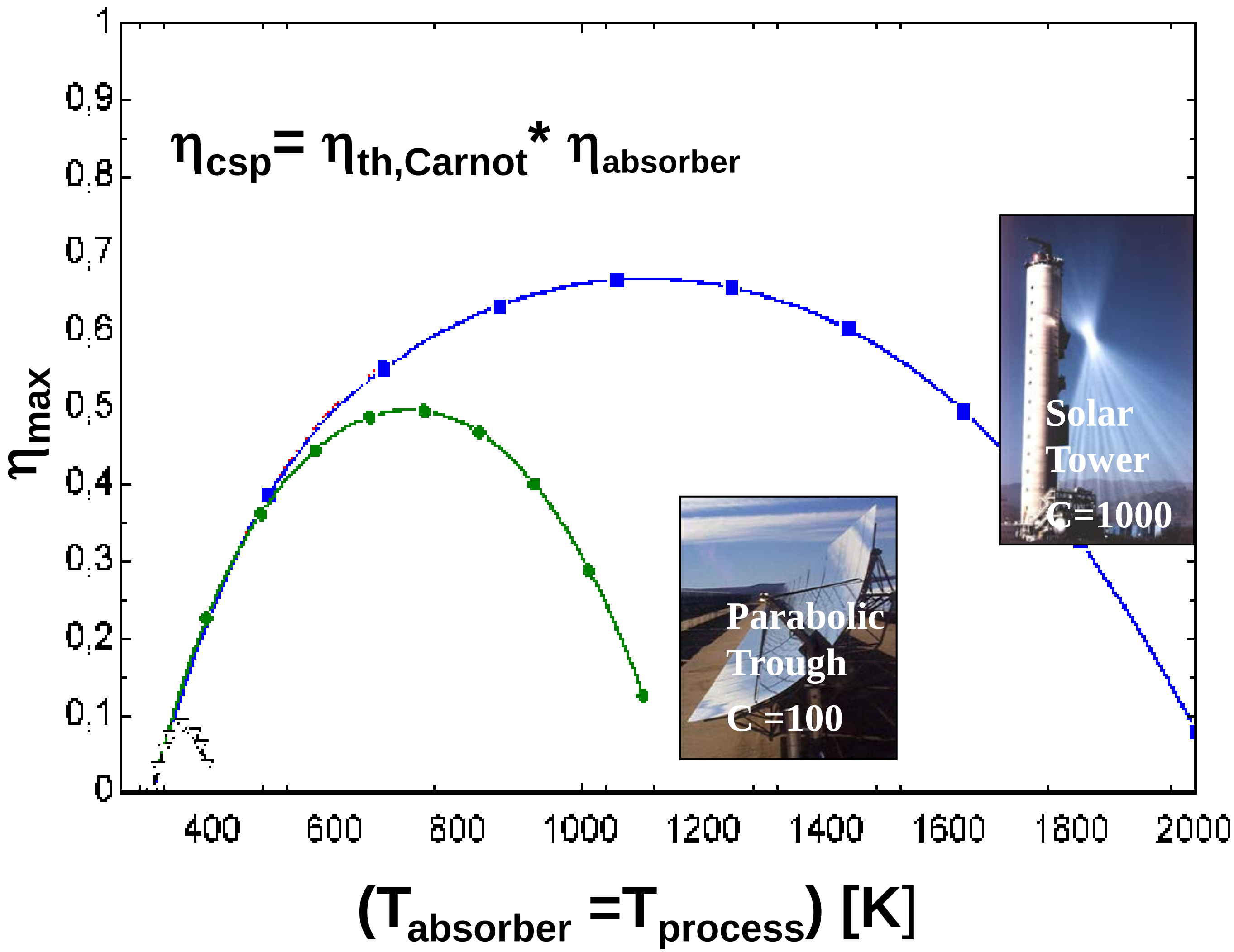
Solarthermische Kraftwerke

Warum Wärmespeicher?



CSP F&E Strategie:

hohe Konzentration + hohe Temperatur = hohe Effizienz => geringe Kosten



Der Markt in Spanien
Aufbruch….und Niedergang

Update on the situation of STE in Spain

- 50 STE plants (2302,9 MWe) are finally in operation. No STE plant is currently under construction or promotion

PROTERMO SOLAR

- Parabolic trough technology:

  45 PT plants (2222,5 MWe):

  - ✓ Twenty six 50MWe-plants without TES
  - ✓ Eighteen 50MWe-plants with 1GWht TES
  - ✓ One 22.5MWe-plant hybridized with biomass

- Central receiver technology:

  3 CR plants (49,9 MWe)

  - ✓ Two saturated steam receiver plants (10MWe and 20MWe)
  - ✓ One molten salt receiver plant (19MWe

- Compact Linear Fresnel technology:

  2 LF plants (31,4 MWe), with saturated steam and no TES

Update on the situation of STE in Spain

- 50 STE plants (2302,9 MWe) are finally in operation. No STE plant is currently under construction or promotion

- In the period January 2012 – February 2013 the legal framework for STE plants in Spain was drastically modified by the Government, thus reducing the incomes of the plants by 37%

- In June 2013, a new law issued by the Spanish Government removed the feed-in tariff and all RE power plants must go to the Pool and they will be paid according to the pool price, plus a *Complementary Payment* to assure a "*reasonable profitability*" for investors (7.5%). The procedure to determine the amount of the complementary payment is not yet legally implemented

- Two weeks ago the Spanish Government has issued for comments the calculation procedure to determine the committed Complementary Payment . The Spanish STE sector does not accept this proposal because the profitability would not be 7,5% but 4% only.

Projects in Spain – Parabolic Troughs

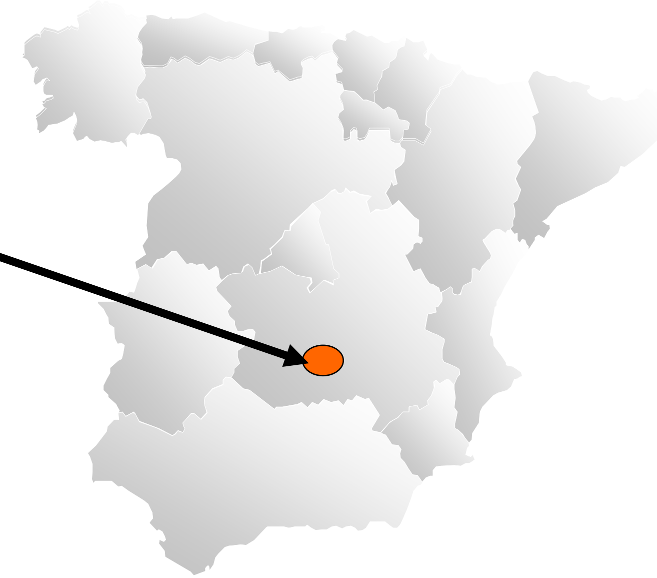
Slide Source: C. Montoya, IDAE

IBERSOL PUERTOLLANO

Town	Puertollano
Province	Ciudad Real
Capacity (MW)	50

Technology	Parabolic Trough
Storage	No
Plant Surface	175 Ha
Components	Mirrors FLABEG & RIOGLASS Structure EUROTHROUGH Pipes SOLEL y SCHOTT Turbine SIEMENS

Startup	2009
PROMOTER	**IBERDROLA (90%), IDAE (10%)**



DLR

Gemasolar Tower plant, 15 h storage
19.9 MW (Torresol Energy)

Macroeconomic Impact of the Solar Thermal Electric Sector in Spain

Download: www.estelasolar.eu
www.protermosolar.com

Available in English and Spanish

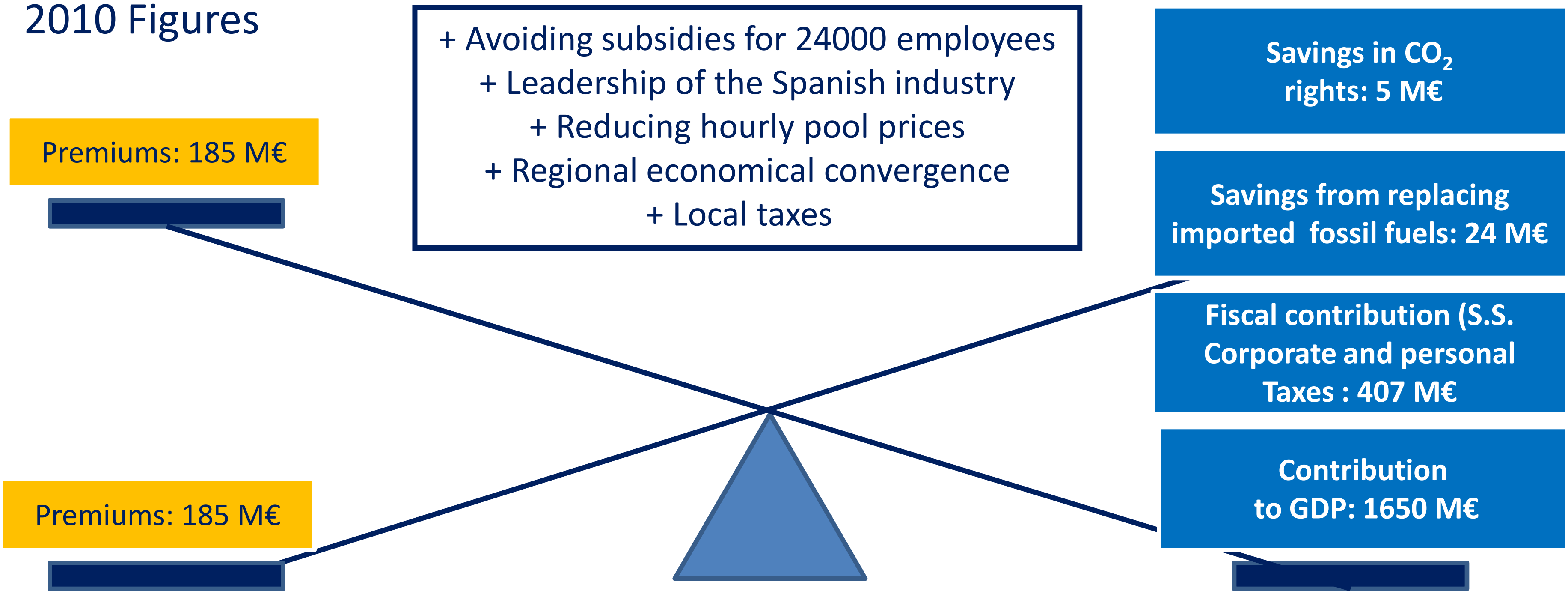
DLR

Slide courtesy of: Luis Crespo, Estela, Spain

Support policy for STE …

… an efficient economic and technological decision for Spain

2010 Figures

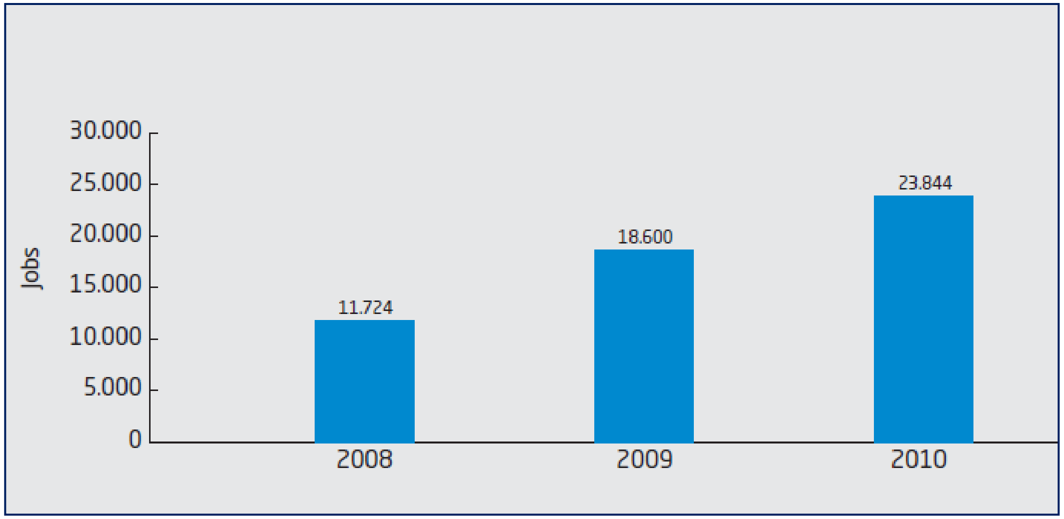


Note:

At the end of 2010 500 MW were in operation. Most of them were connected during the second half of the year. That is why savings in fuel and CO2 were so low. In 2012 these savings will be greater than 300 M€ and 50 M€ respectively.

Slide courtesy of: Luis Crespo, Estela, Spain

STE jobs in Spain

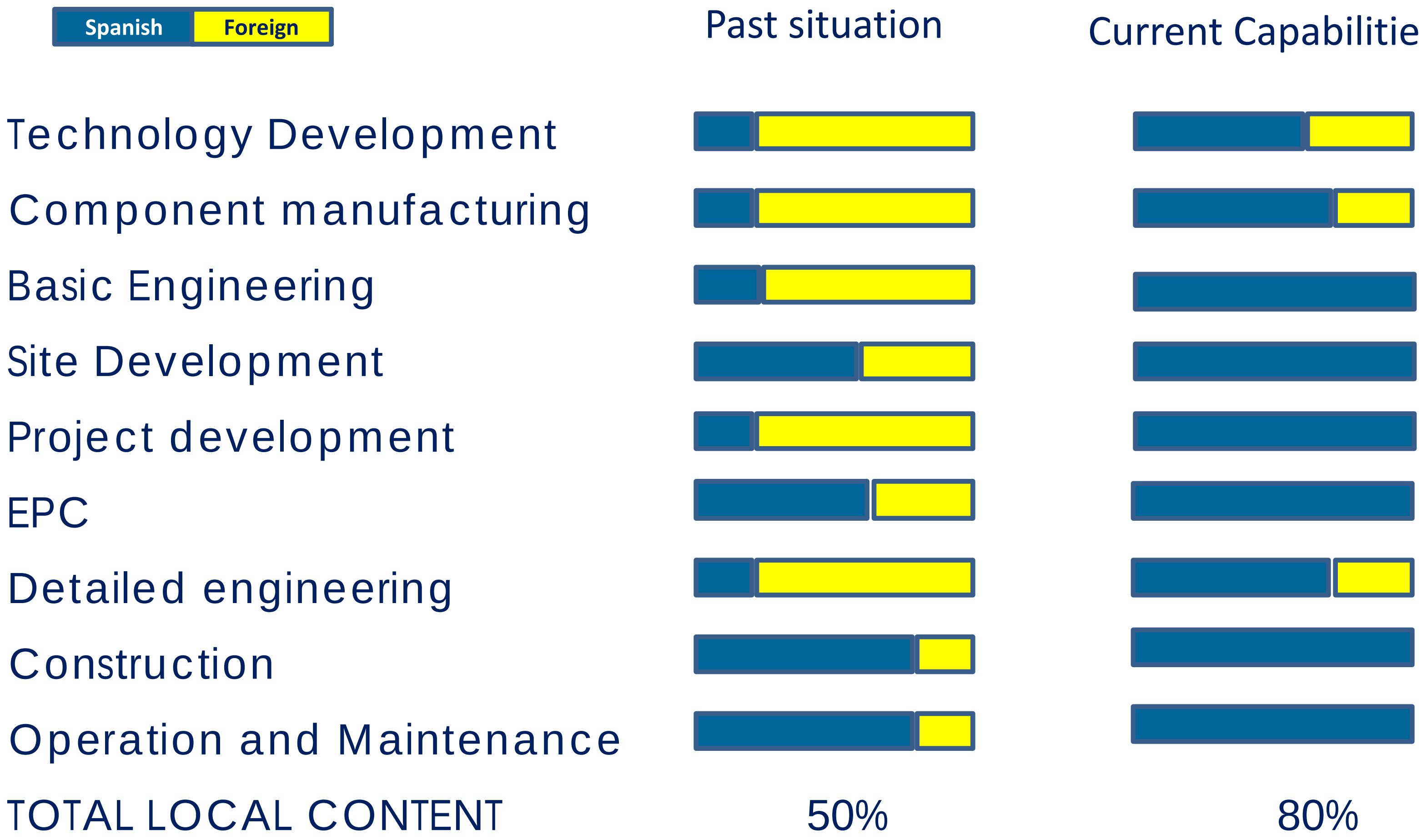


Jobs	2008	2009	2010
Construction	**11.713**	**18.492**	**23.398**
- Plan contracting, construction and assembly	4.399	6.447	8.049
- Components and equipment	4.515	7.442	9.542
- Jobs in the rest of the economy	2.799	4.603	5.807
Power production - O&M	**13**	**123**	**446**
- Plant operation and maintenance	11	108	344
- Jobs in the rest of the economy	2	15	102
TOTAL JOBS	**11.724**	**18.600**	**23.844**

Slide courtesy of: Luis Crespo, Estela, Spain

Localization: A very fruitful period in Spain

From the first large plants connected in 2008 till the new ones



Slide courtesy of: Luis Crespo, Estela, Spain

US Market: Bigger is better…..

USA CSP Market Status

- **Currently Operating**

1. SEGS 1-2 (Cogentrix)	44 MW		
2. SEGS 3-9 (FPL/NextEra)	310 MW		
3. Nevada Solar One (Acciona)	64 MW		
4. Martin (FPL/NextEra)	75 MW		
5. Coalinga (BrightSource)	10 MW		
6. Sierra (eSolar)	5 MW		
7. Kimberlina (Areva)	5 MW		
8. Holaniku (Sopogy)	2 MW		
9. Maricopa (SES)	2 MW		
10. Saguaro (APS)	1 MW		
11. Cameo (Abengoa)	1 MW		
12. Ivanpah (BrightSource)	392 MW	$1.6B LG	(Tower)
13. Solana (Abengoa)	280 MW w/ storage	$1.4B LG	(Trough)

- **Under construction**

14. Crescent Dunes (SolarReserve)	110 MW w/ storage	$0.7B LG	(Tower)
15. Genesis (FPL/NextEra)	250 MW	$0.8B LG	(Trough)
16. Mojave (Abengoa)	250 MW	$1.2B LG	(Trough)
TOTAL	**1,801 MW**	**$5.7B LG (Loan Gurantee)**	

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280 MW plant Solana (Abengoa) now in operation (10. Oct 2013)

280 MW, 6 hours storage (molten salt), Solar field 2.2 M m2, Area 1200 ha, 980 GWh annual energy production.

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Ivanpah (Brightsource) solar tower 130 MW

connected to grid, September 24

Technology:	Power tower
Status:	Operational
Country:	United States
City:	Primm, NV
State:	California
County:	San Bernardino
Lat/Long Location:	35°33′ 8.5″ North, 115°27′ 30.97″ West
Land Area:	3,500 acres
Solar Resource:	2,717 kWh/m²/yr
Source of Solar Resource:	NREL Solar Power Prospector
Electricity Generation:	1,079,232 MWh/yr (Expected/Planned)
Contact(s):	Andy Taylor
Company:	BrightSource Energy
Key References:	Web site
Break Ground:	October 2010
Start Production:	February 13, 2013
Cost (approx):	2,200 USD million
Construction Job-Years:	1896
Annual O&M Jobs:	90
PPA/Tariff Date:	January 2010
PPA/Tariff Period:	25 years
Project Type:	Commercial
Incentives:	$1.6 billion in federal loan guarantees

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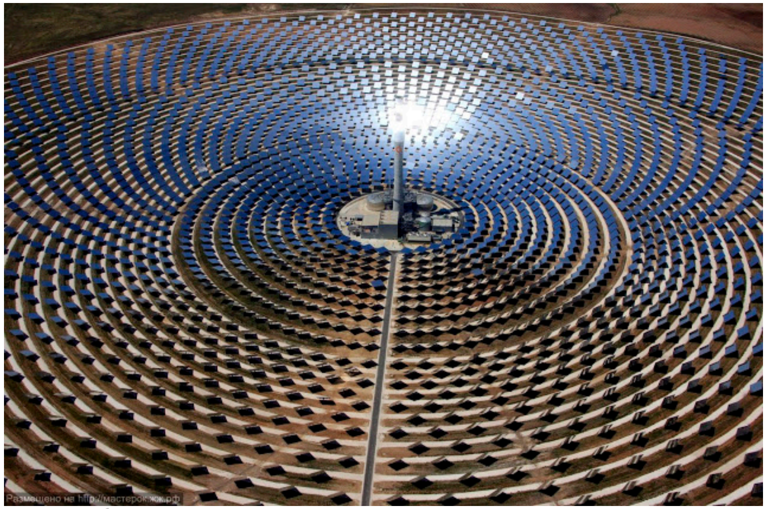
Cresent Dunes (100 MW Molten Salt, 6 h Storage)



Crescent Dunes Solar Energy Project

This page provides information on Crescent Dunes Solar Energy Project, a concentrating solar power (CSP) project, with data organized by backgrounc participants, and power plant configuration.

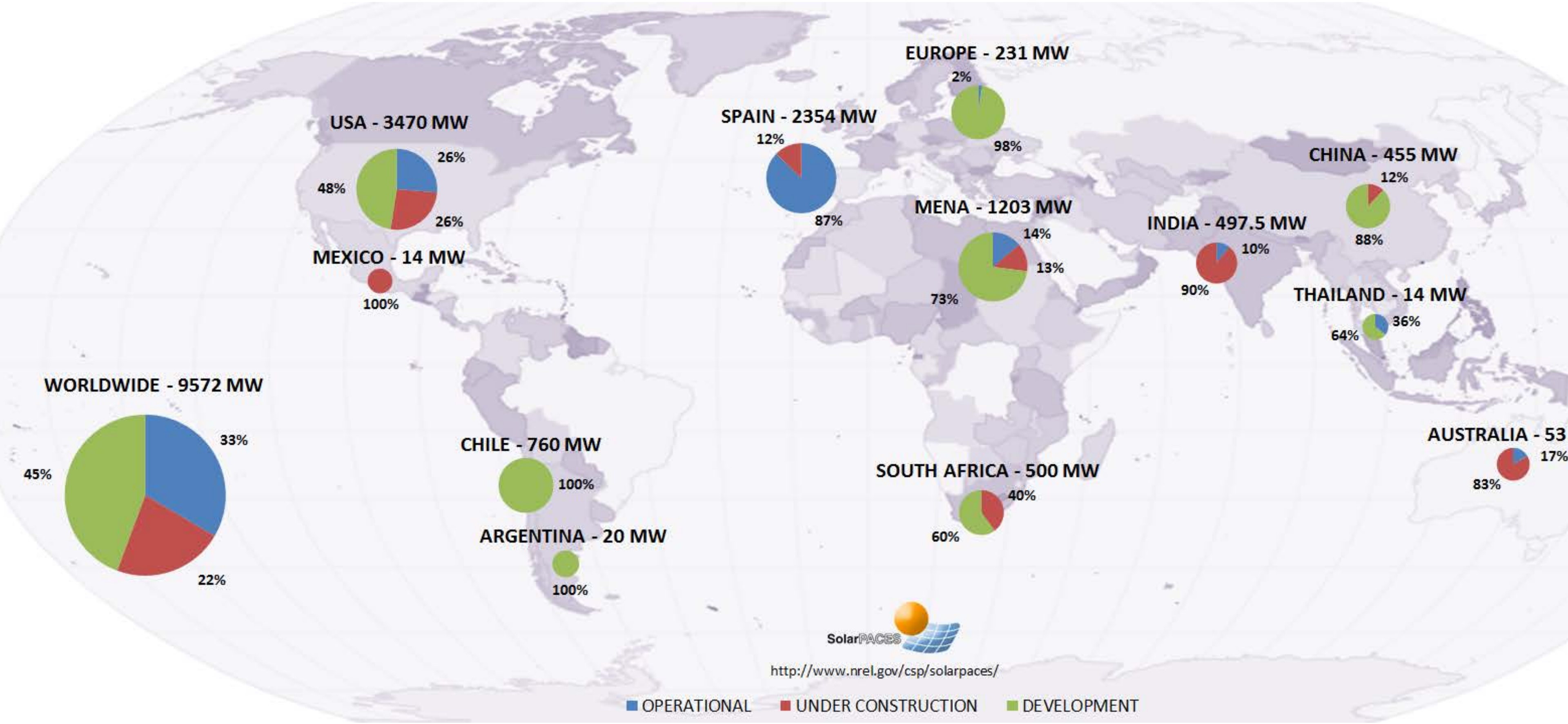
Status Date:	February 26, 2013

Background

Technology:	Power tower
Status:	Under construction
Country:	United States
City:	Tonopah
State:	Nevada
County:	Nye
Region:	Northern Nevada, northwest of Tonopah
Lat/Long Location:	38°14′ North, 117°22′ West
Land Area:	1,600 acres
Solar Resource:	2,685 kWh/m^2/yr
Source of Solar Resource:	NREL Solar Power Prospector
Electricity Generation:	485,000 MWh/yr (Expected)
Contact(s):	Tom Georgis; Rob Howe
Company:	SolarReserve
Key References:	Press release Press release
Break Ground:	April 2011
Start Production:	October 2013
Construction Job-Years:	1500
Annual O&M Jobs:	200
PPA/Tariff Date:	December 22, 2009
PPA/Tariff Rate:	0.135 US$ per kWh
PPA/Tariff Period:	25 years
Project Type:	Commercial

DLR

Project Status October 2013



http://www.nrel.gov/csp/solarpaces/

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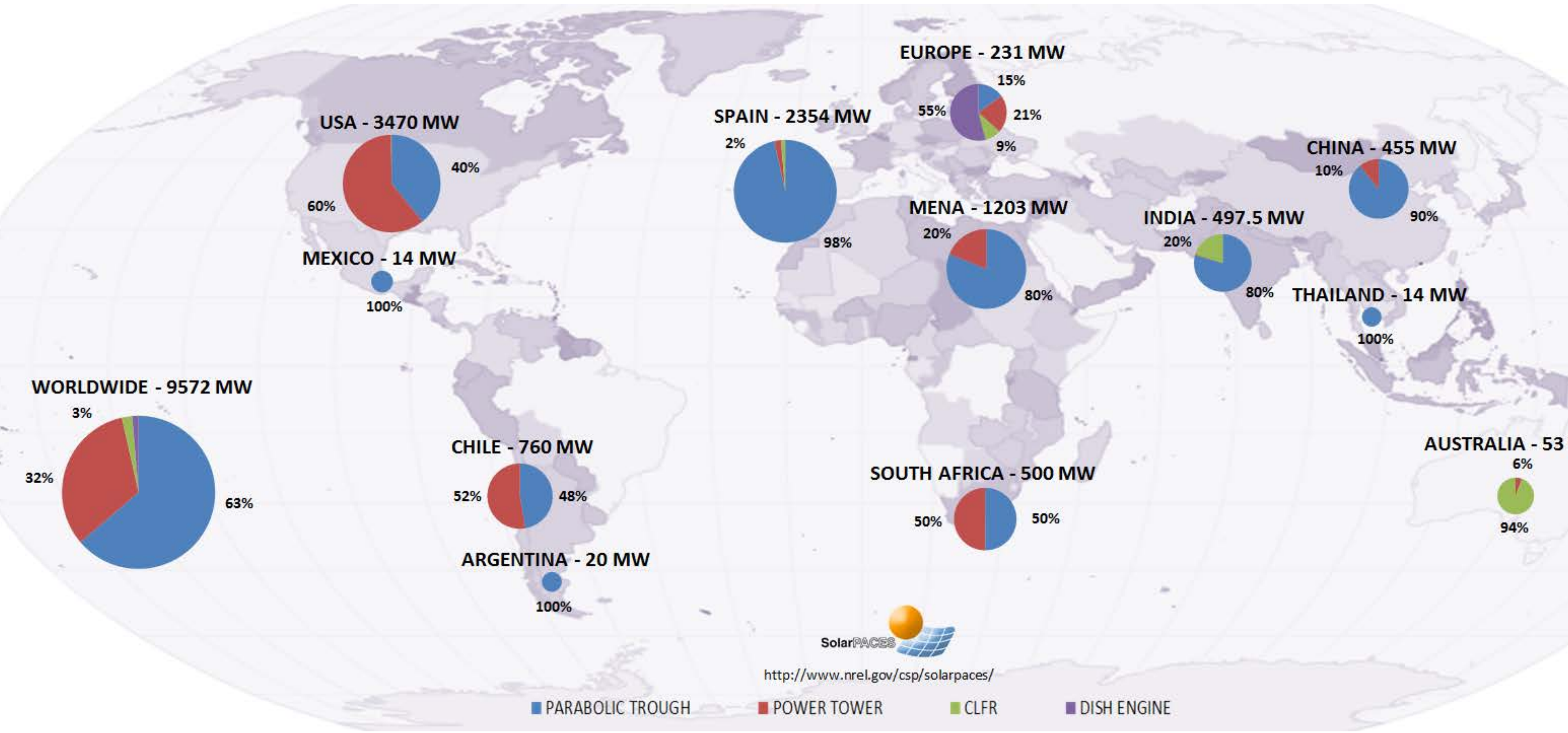
Technology Status October 2013



http://www.nrel.gov/csp/solarpaces/

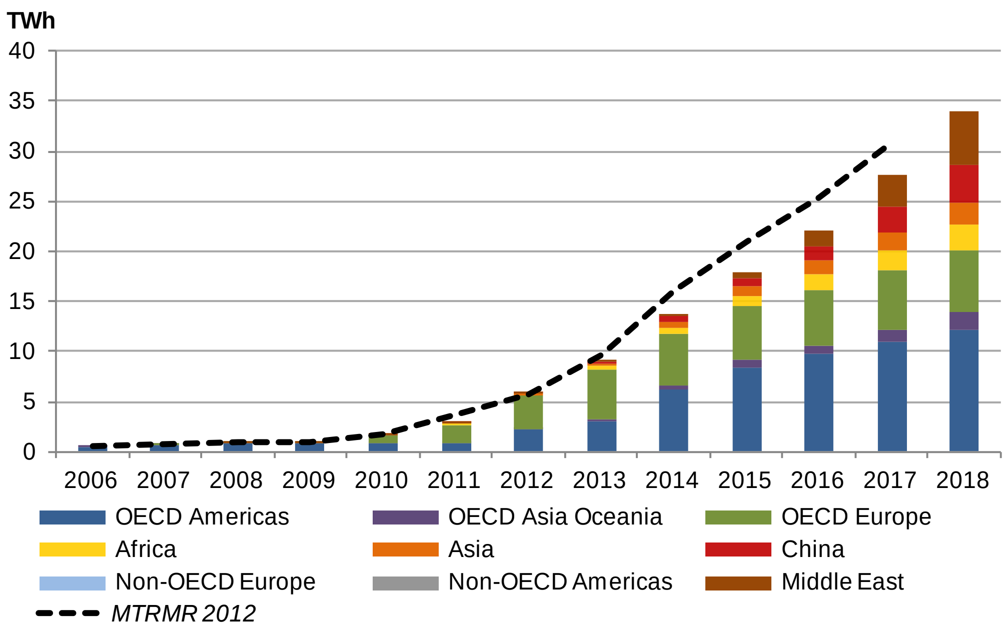
DLR

CSP Marktwachstum

Das projizierte Wachstum der CSP Stromerzeugung ist weiterhin sehr stark, mit einer gewissen Verlangsamung in 2014-2016 gegenüber früheren Vorhersagen

DCSP
Deutscher Industrieverband Concentrated Solar Power

Projektion der CSP Stromerzeugung (TWh)



Quelle: IEA, MTRMR 2013

Top 10 Länder für kumulierte installierte CSP Kapazität in 2020 (MW)

Spain	2206
United States	1973
South Africa	700
Morocco	480
China	318
India	378
Chile	340
Israel	231
United Arab Emirates	101
Saudi Arabia	100
Others	310
Total	**7138**

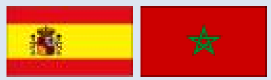
Quelle: Bloomberg New Energy Finance

Regionale Treiber und Befähiger

DCSP
Deutscher Industrieverband
Concentrated Solar Power

Die Treiber und Befähiger für CSP Technologie sind unterschiedlich für jede Region

Treiber

Environmental awareness / climate change 

Export of REN 

Opportunity costs from subsidized Oil/Gas 

Portfolio standards, Directives (EU) 

Demand match in Grids with high REN share 

Independence from Energy Import / growth with REN 

Befähiger

FIT (Feed in Tariff) 

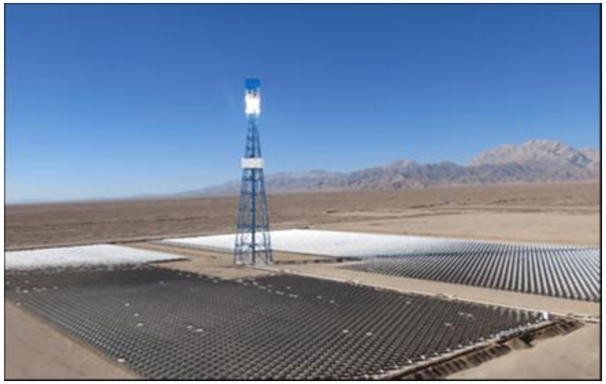
Governmental Loan Guaranties 

ODA (Official Development Assistance) 

Individually guaranteed PPAs 

CSP in China

- China has 5 solar thermal power systems in operation
- China has about 25 sets of solar thermal collecting experiment facilities,
- 14 companies that can produce parabolic trough receiver tube
- 4 companies that can mass produce trough glass reflector mirror,
- 2 companies can provide the EPC for tower type collector systems,
- 2 companies can produce turbine for CSP.



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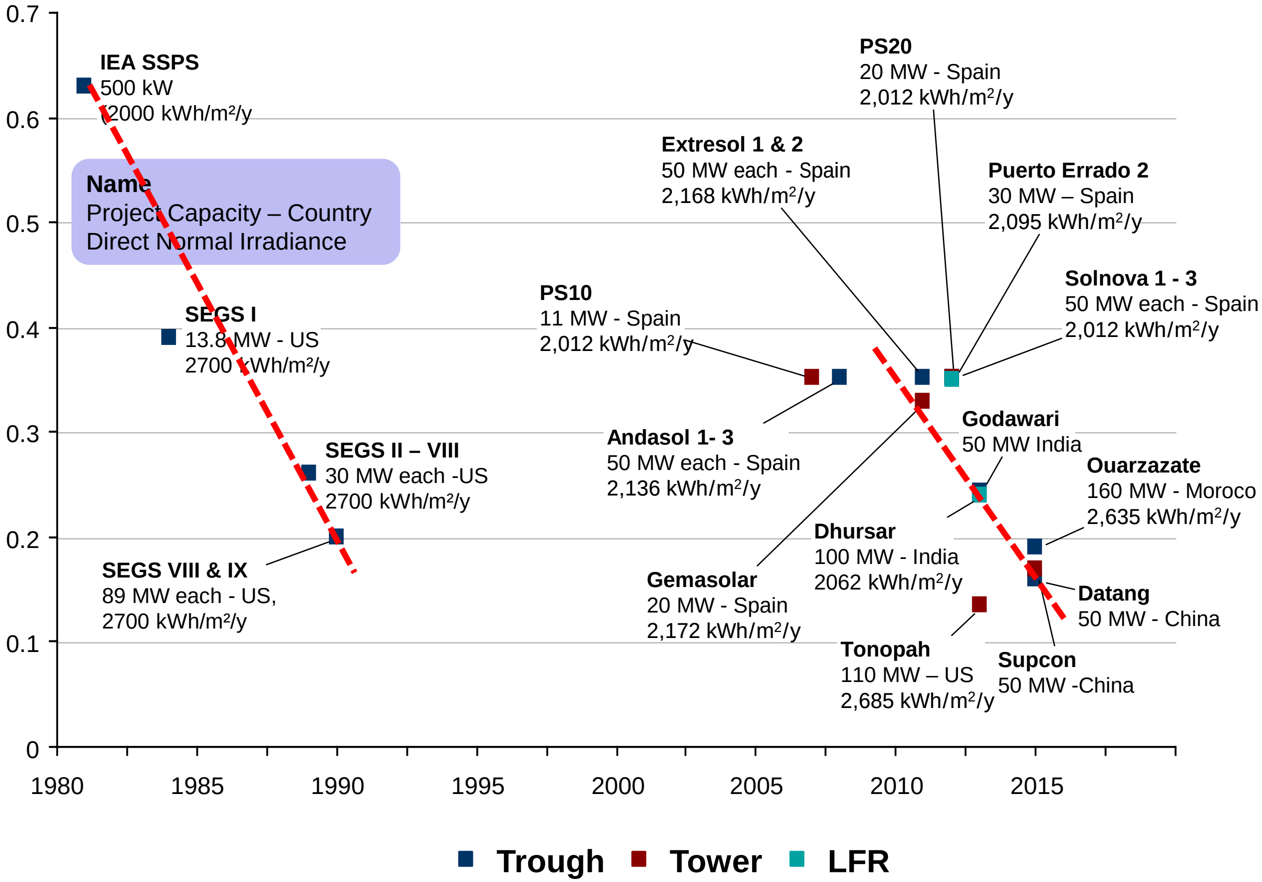
Stromgestehungskosten

Current levelised cost of electricity from CSP ranges from $140/MWh to $360/MWh, depending on location, technology, thermal storage size & competition

ESTIMATED LCOE FOR EXISTING AND PROPOSED CSP PLANTS

USD$_{2010}$ / kWh



- Current levelised cost of electricity from CSP varies widely depending on project, concentrator technology and solar resource:
  - Solar tower LCOE is estimated to range from 140 $/MWh and 270 $/MWh
  - Parabolic trough LCOE is estimated to range from 150 $/MWh and 300 $/MWh
- The cost is highly dependent on the available sunlight and on storage, which dictate the capacity factor

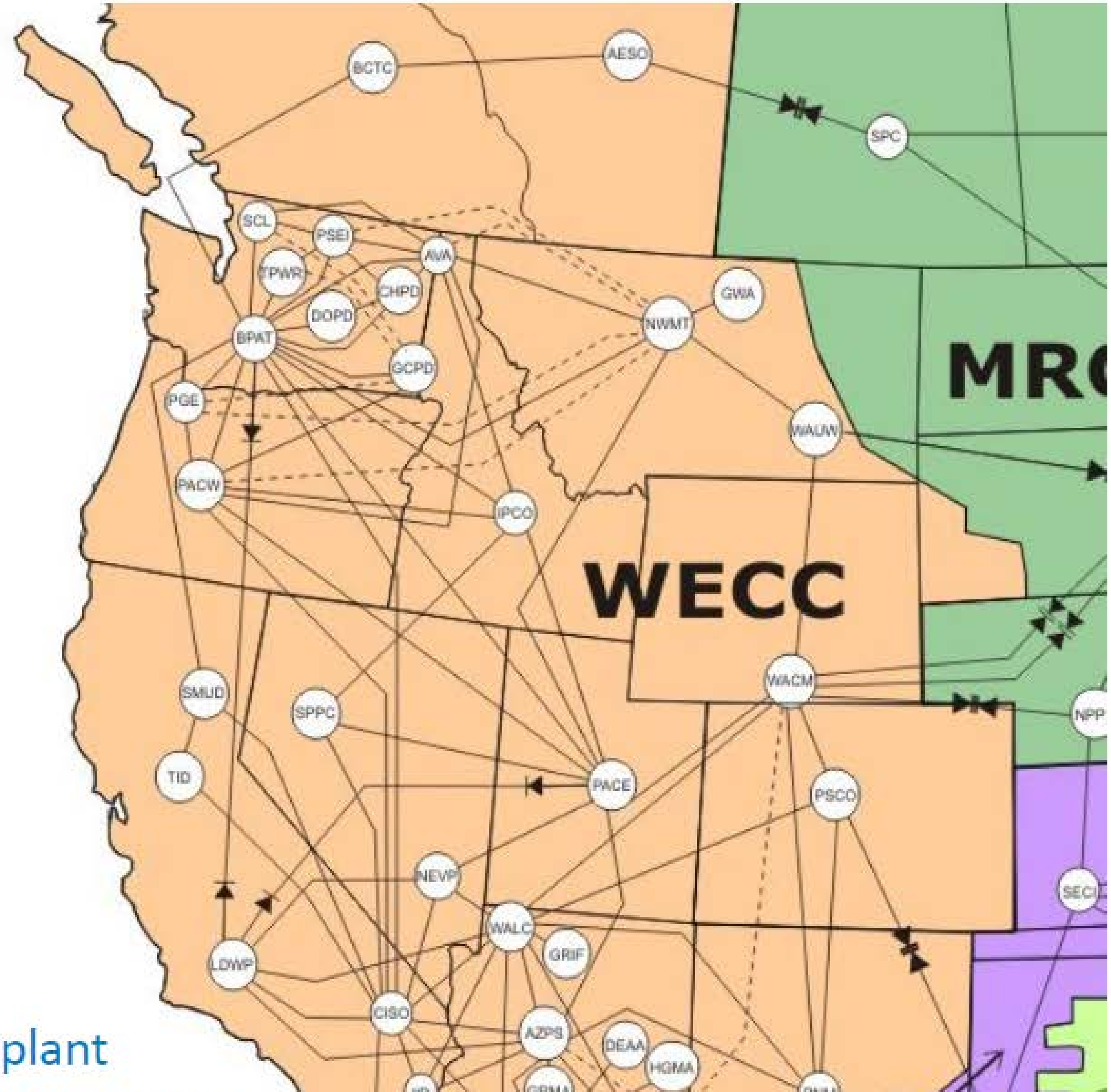
Note LCOE for Levelised Cost of Electrlicity

Source: SBC Energy Institute Analysis based on IRENA (2012), "Renewable Energy Technologies: cost analysis series. Concentrating Solar Power", NREL SolarPaces database (http://www.nrel.gov/csp/solarpaces/by_project.cfm) and BNEF

Der Wert von Elektrizität….

Beispiel Kalifornien 32% Renewable Portfolio Standard

Analyzed System



P. Denholm,
The Value of C
Thermal Energ
SolarPACES 2

Rest of Wes
Electricity C
Council (WE

- Simple pla
  performa
- Linear ope

California:

- Detailed plant

Operational Value Results

PLEXOS generates hour sources of costs for system ope

1. Operational fuel 5,6-6,3 $/MBtU
2. Variable operations and maintenance (O&M)
3. Startup (fuel + start O&M)
4. Emissions 36 $/t

Examining dispatch can explain the origin and differenc

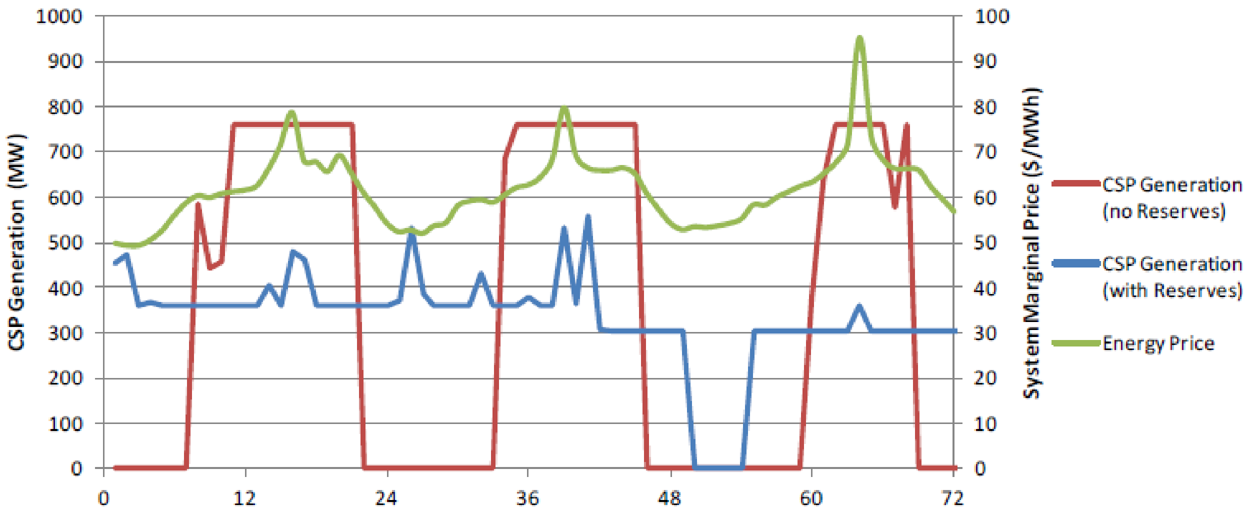
these costs.

Four scenarios, each with an added plant producing approximately equivalent annual energy:

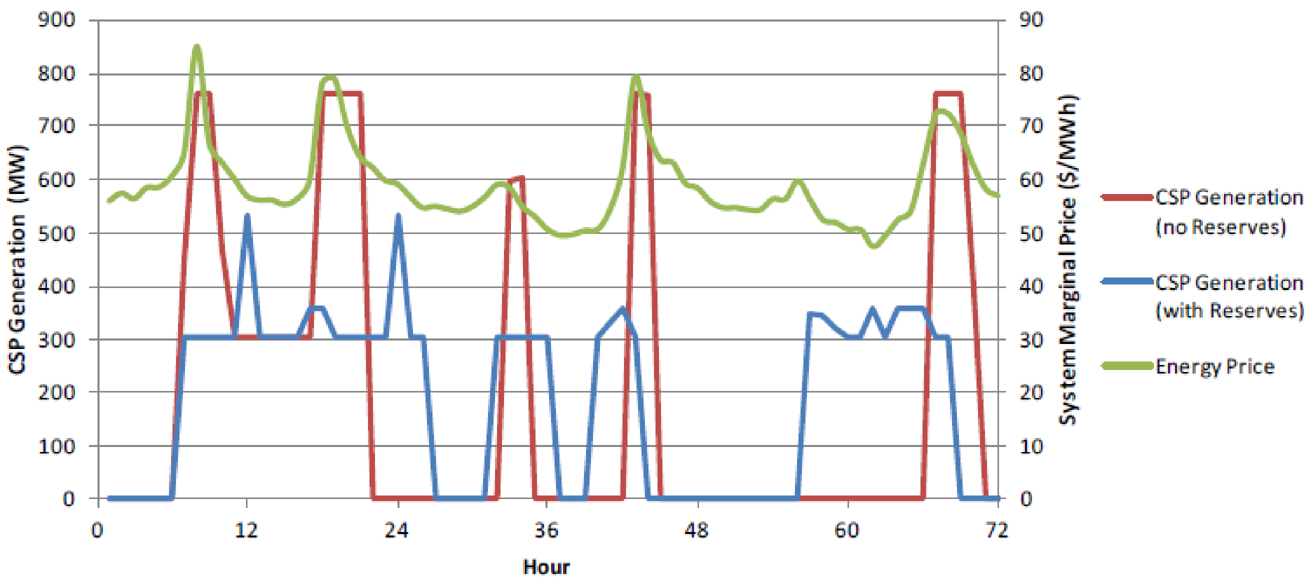
1. CSP plant with 6 hours of storage
   - 762 MW, SM = 2.0
   - Generates about 3,050 GWh, or enough to provide about 1.
     California demand
   - No change in reserve requirements
2. CSP with reserves
   - Same as before, but can provide regulation, load-following, a
3. Solar PV
   - 1548 MW
   - This plant also required additional reserves due to uncertain
     variability
4. Flat block (baseload) resource
   - 359 MW of constant output with zero fuel costs

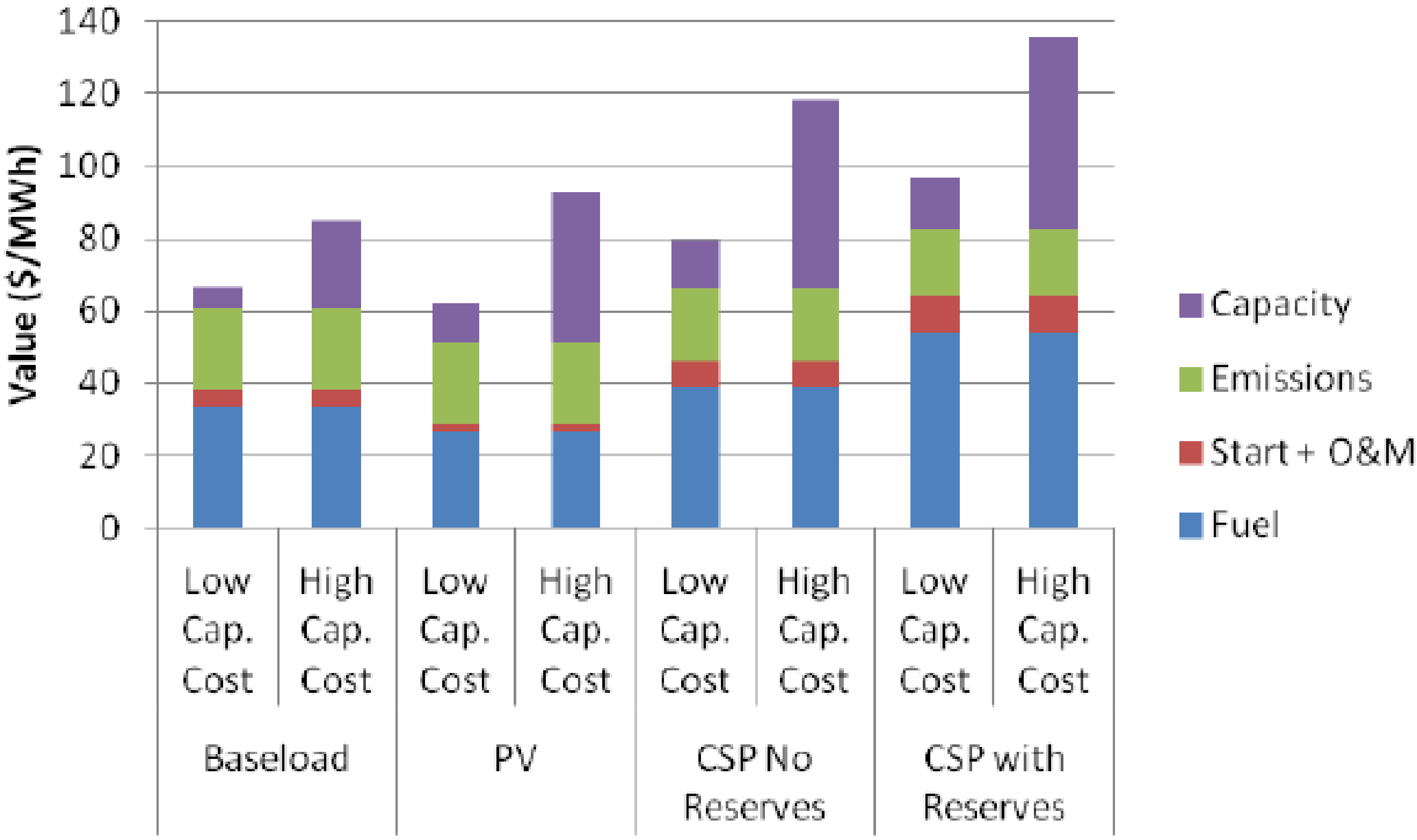
Dispatch Strategien

Sommer



Winter





Value ($/MWh)
140
120
100
80
60
40
20
0
Low Cap. Cost
High Cap. Cost
Baseload
PV
CSP No Reserves
CSP with Reserves
Capacity
Emissions
Start + O&M
Fuel

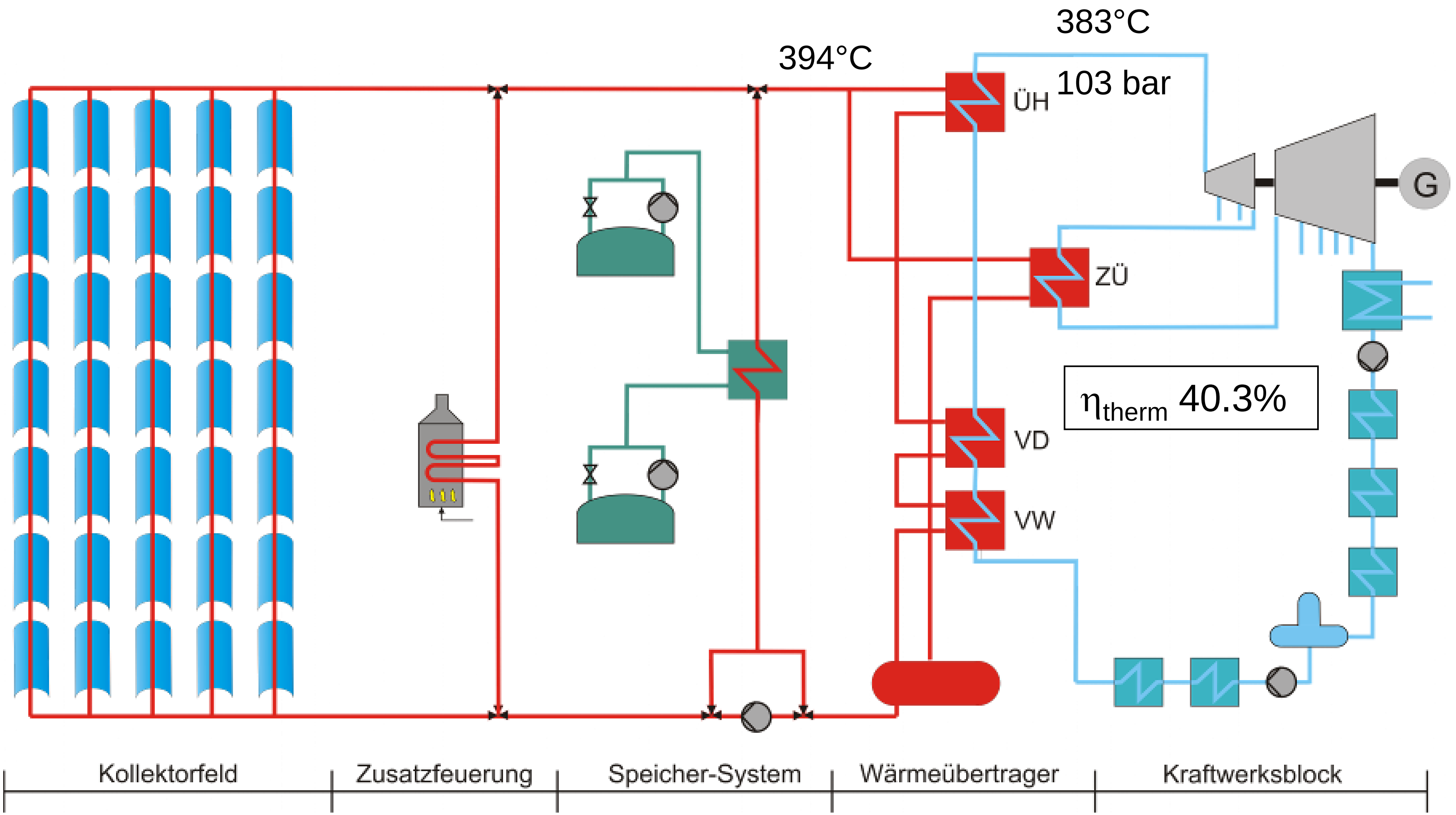
	Difference in Value per Unit of Delivered Energy for a CSP Plant Providing Reserves ($/MWh)		
	Baseload	**PV**	**CSP (no Reserves)**
Fuel	20.1	24.9	15.1
Variable O&M	1.3	1.6	0.8
Start	4.6	7.0	2.7
Emissions	-3.6	-4.4	-1.8
Capacity (Low / High)	7.3 / 20.8	2.8 / 8.1	0 / 0
Total (Low / High)	29.8 / 50.6	32.0 / 40.1	16.8 / 16.8

3-4 cents higher value compared to PV

P. Denholm,
The Value of CSP with Thermal Energy Storage
SolarPACES 2013

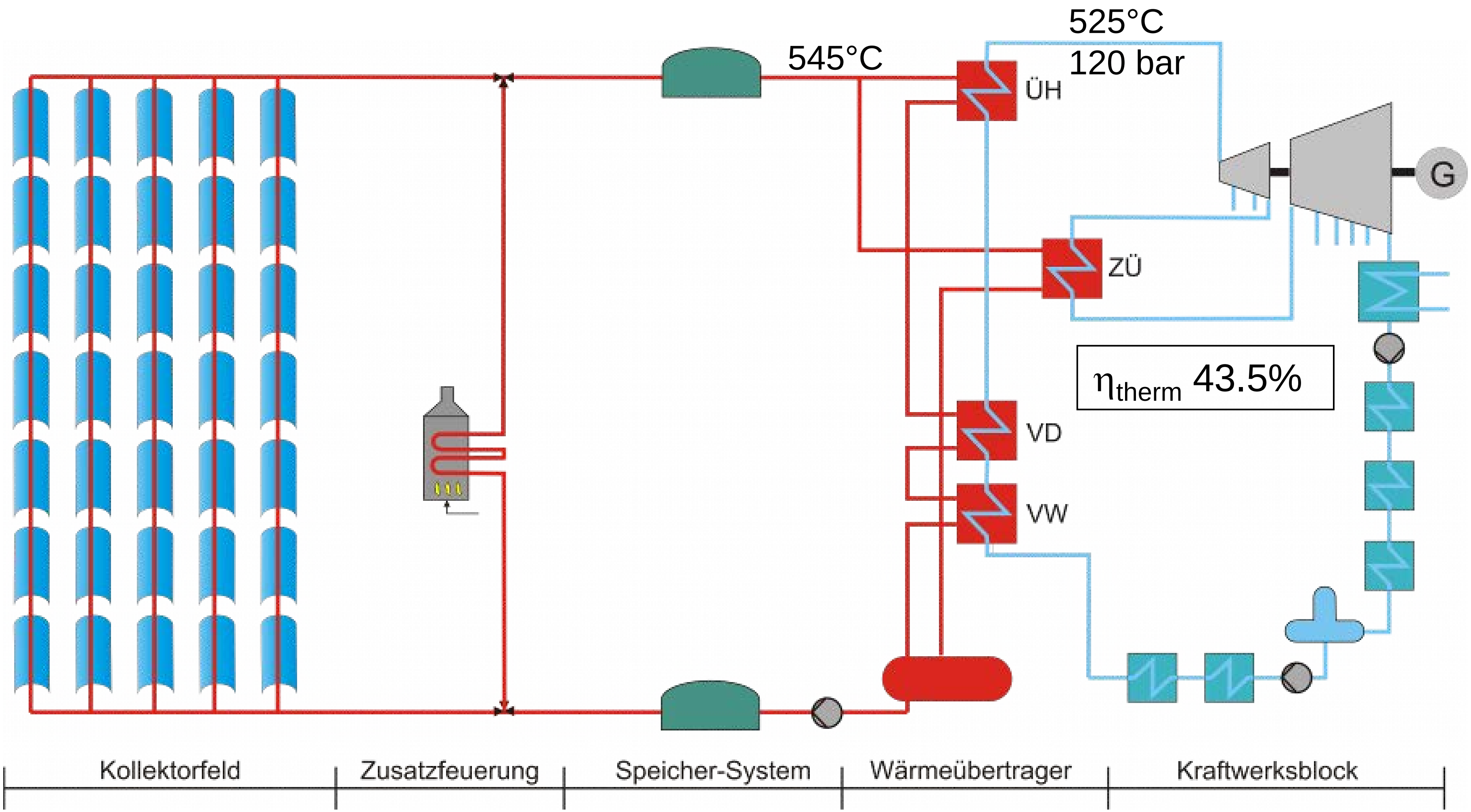
Ansätze zur Kostensenkung

Einfluss der oberen Prozesstemperatur
Beispiel Parabolrinnenkraftwerk: Thermoöl 394°C



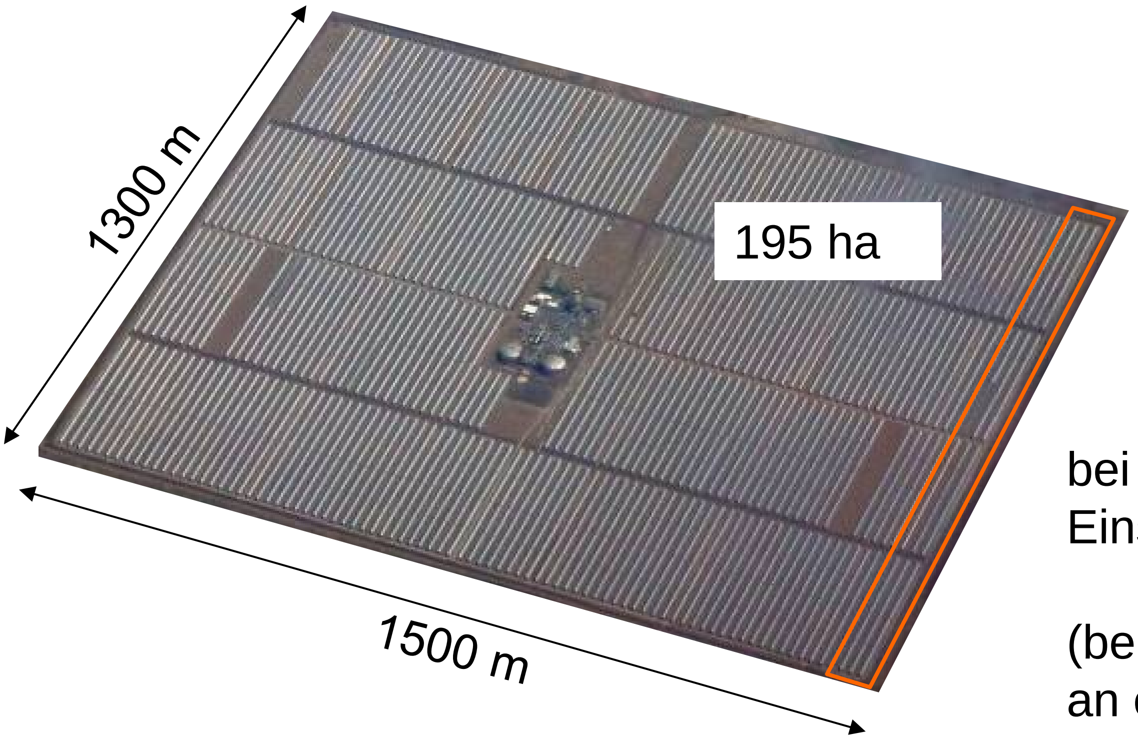
Einfluss der oberen Prozesstemperatur

Beispiel Parabolrinnenkraftwerk: Salzschmelze 545°C



Einfluss der oberen Prozesstemperatur

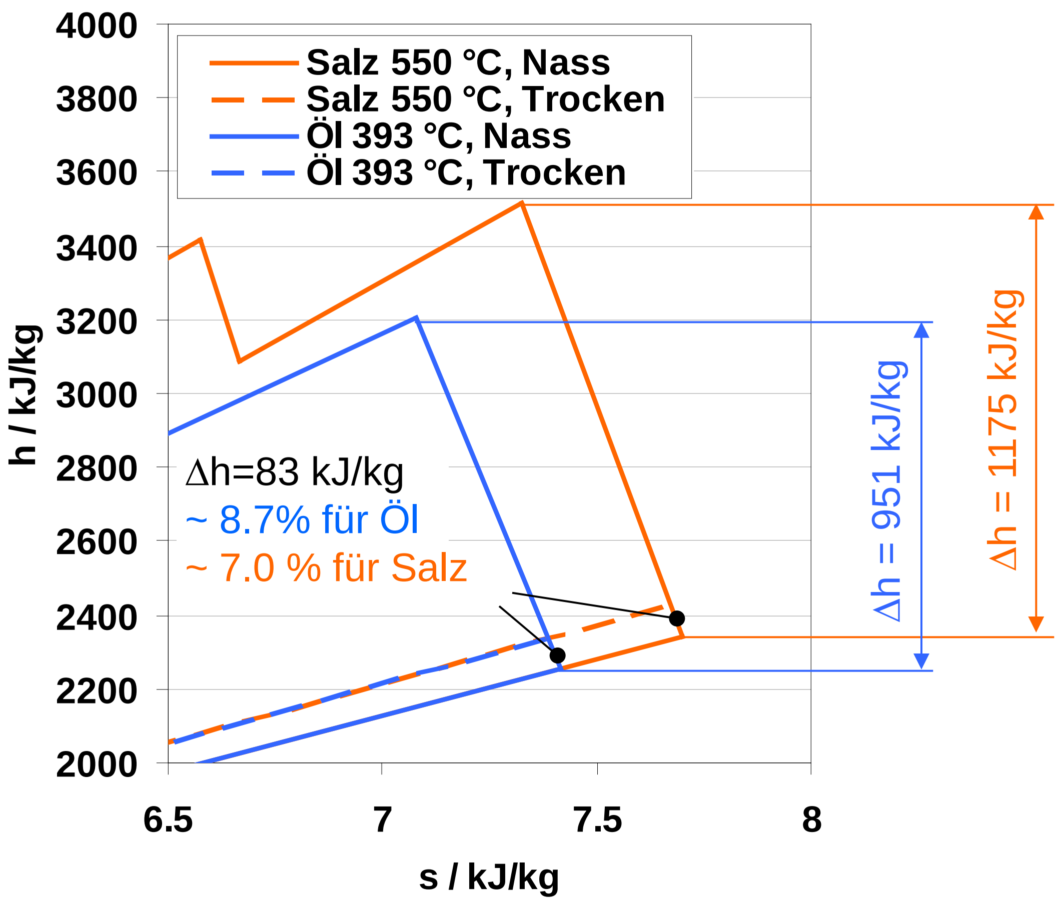
Größenvergleich Solarfeld



bei Salz- statt Ölsystem
Einsparung an Kollektorfläche
~ 7-10%
(bei gleichem Jahresertrag
an einem guten Standort)

Einfluss der oberen Prozesstemperatur

Einbußen an der Niederdruckentspannung durch Trockenkühlung



Einfluß der Trockenkühlung auf thermischen Wirkungsgrad des Gesamtsystems:

- Öl: - 5.3%
- Salz: - 4.4 %

Nasskühlung p_{kond}=47 mbar

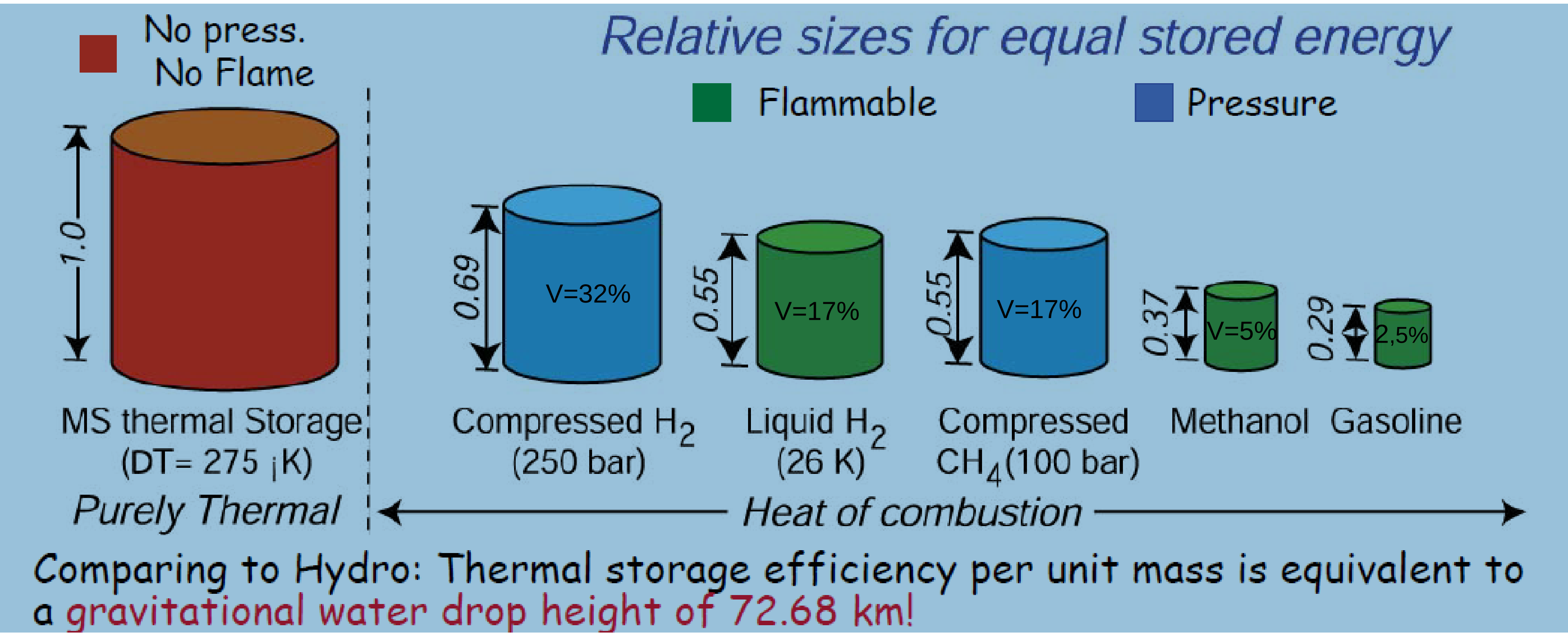
Trockenkühlung p_{kond}=100 mbar

Einfluss der oberen Prozesstemperatur

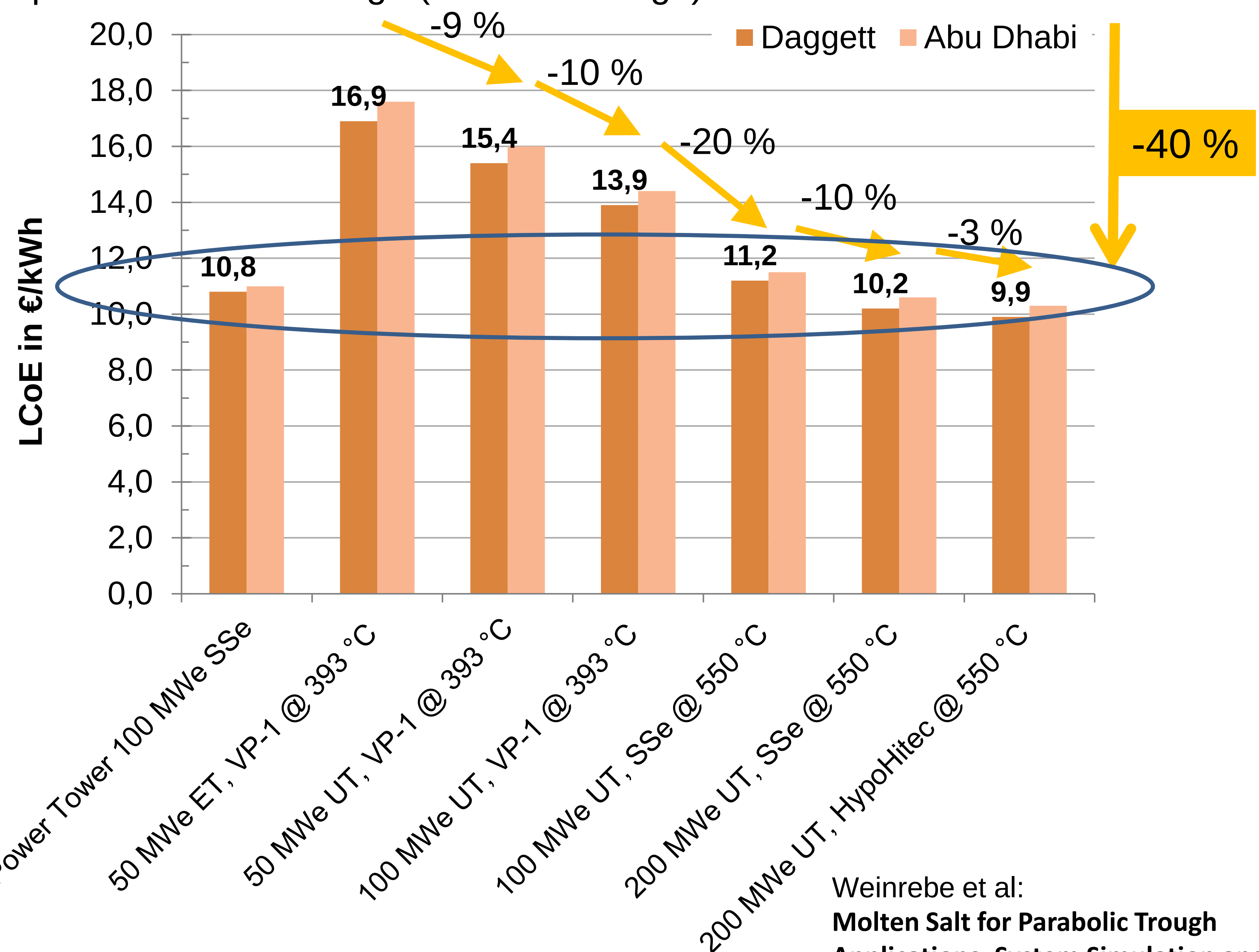
Größenvergleich Speichersystem

Ölsystem

Salzsystem

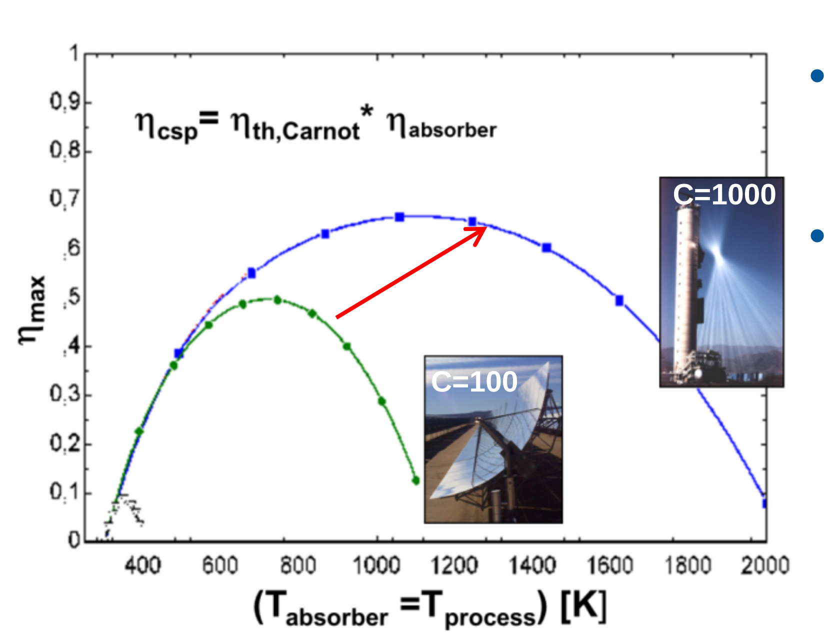


Cost comparison Tower / Trough (Ultimate Trough) w/ Salt as HTF



Weinrebe et al:
Molten Salt for Parabolic Trough Applications: System Simulation and Comparison with a Power Tower SolarPACES 2013

Strategy and Approach



- **High Concentration + High Temperature = High Efficiency = Low Cost**
- **Advanced heat transfer media** needed for:
  - high temperature operation
  - efficient storage integration

to break todays **temperature limit of 550°C**

Helmholtz funding for high risk / high reward approach:

- Tower systems using advanced **salt mixtures**, **liquid metals** or **solid particles** at **T > 650°C** with **η_{sys} > 20%**
- Reduce uncertainty by gaining **scientific understanding of full system** to convince industry to engage in scale-up

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Key Scientific Questions and Topic Structure

Subtopic 1 **Advanced Heat Transfer Media**	**Subtopic 2** **Impact of Desert Environment**
Can molten salt mixtures, liquid metals or ceramic particles be used as efficient heat transfer media at T>650° to achieve η_{sys} > 20% ?	Is the concept fit to be operated for > 20 years in a desert environment?

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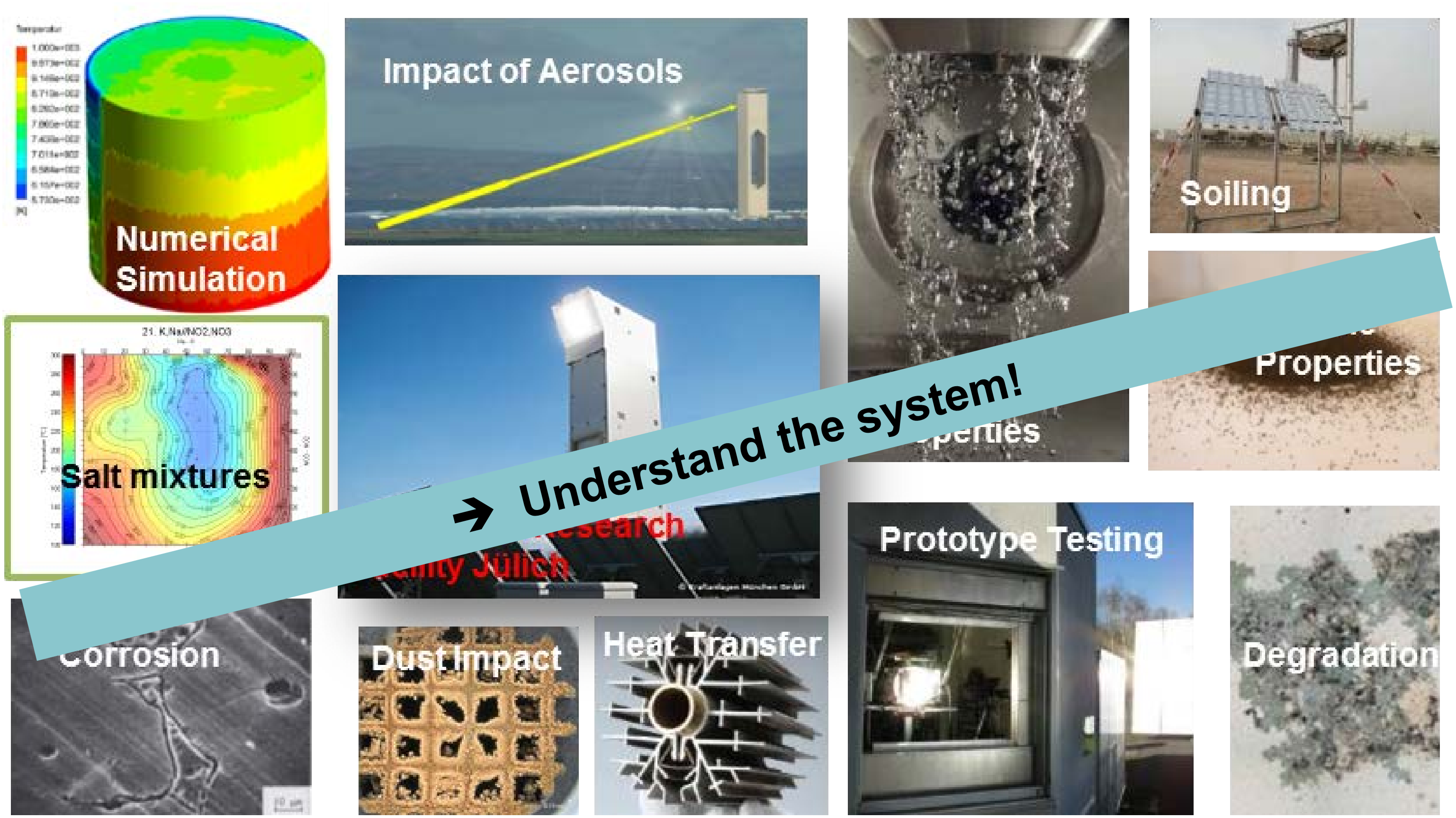
Key Scientific Questions and Topic Structure



Target 2019:
Proof of concept in 100 - 500 kW scale as a basis for tech-transfer

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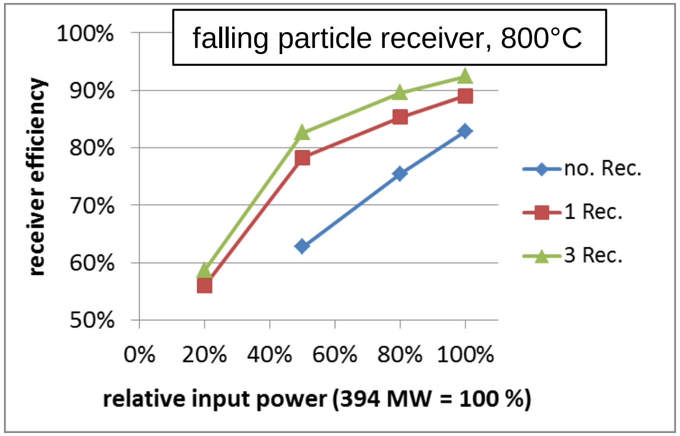
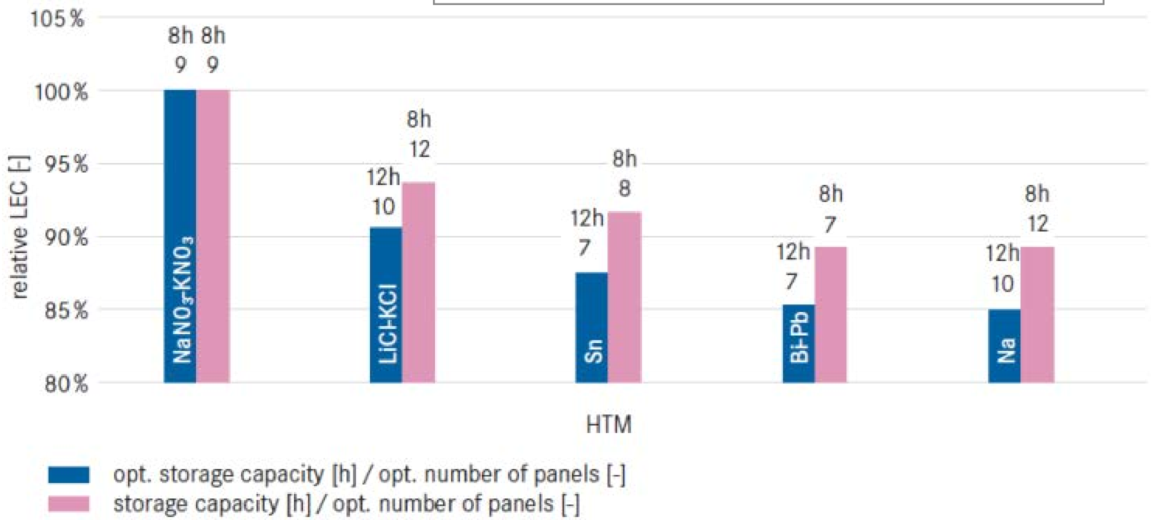
Subtopic 1 - Advanced Heat Transfer Media

Can molten salt mixtures, liquid metals or ceramic particles be used as efficient heat transfer media at T > 650° to achieve η_{sys} > 20% ?

Achievements in POF II

- System models show high efficiency potential
- results in lower LCOE





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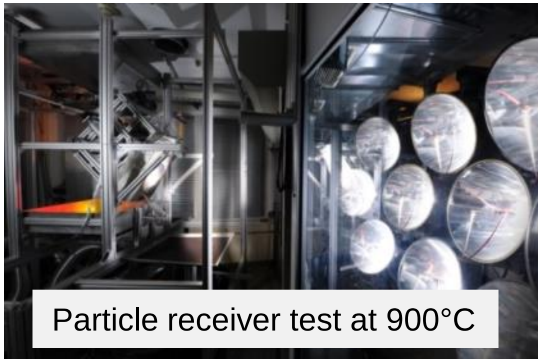
Subtopic 1 - Advanced Heat Transfer Media

Can molten salt mixtures, liquid metals or ceramic particles be used as efficient heat transfer media at T > 650° to achieve η_{sys} > 20% ?

Achievements in POF II

- System models show high efficiency potential
- Prototype of particle receiver prove feasibility in 10 kW scale up to 900°C



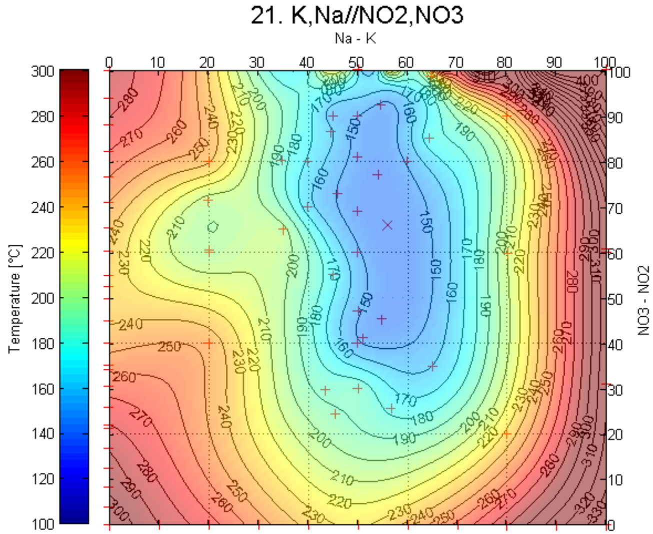
Particle receiver test at 900°C

Subtopic 1 - Advanced Heat Transfer Media

Can molten salt mixtures, liquid metals or ceramic particles be used as efficient heat transfer media at T > 650° to achieve η_{sys} > 20% ?

Achievements in POF II

- System models show high efficiency potential
- Prototype of particle receiver prove feasibility in 10 kW scale up to 900°C
- Suitable salt mixtures identified

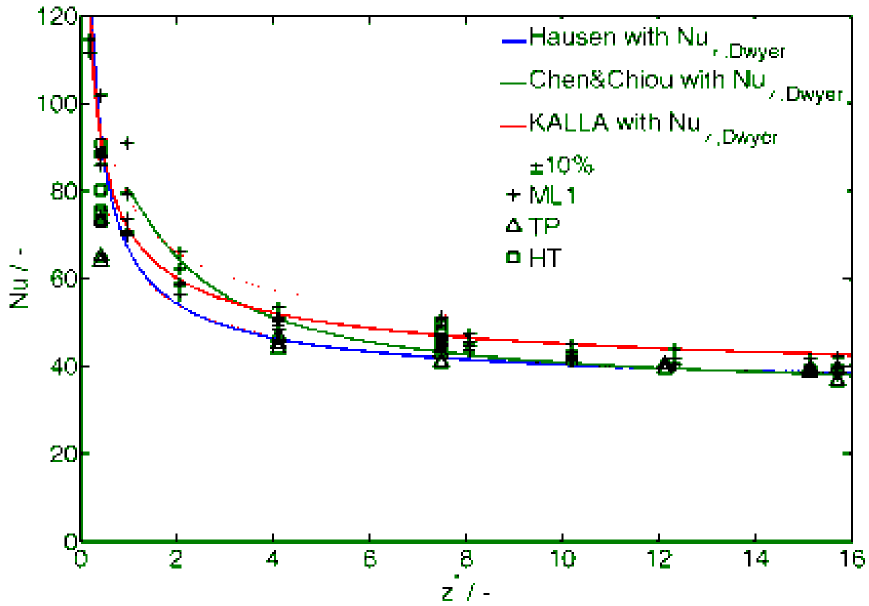


Subtopic 1 - Advanced Heat Transfer Media

Can molten salt mixtures, liquid metals or ceramic particles be used as efficient heat transfer media at T > 650° to achieve η_{sys} > 20% ?

Achievements in POF II

- System models show high efficiency potential
- Prototype of particle receiver prove feasibility in 10 kW scale up to 900°C
- Suitable salt mixtures identified
- Heat transfer correlations for channel/bundle flows with up to 500 kW in PbBi established



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Subtopic 1 - Advanced Heat Transfer Media

Can molten salt mixtures, liquid metals or ceramic particles be used as efficient heat transfer media at T > 650° to achieve η_{sys} > 20% ?

Goals and milestones

- 10 kW Receiver and auxiliaries design, built and tested for all fluids

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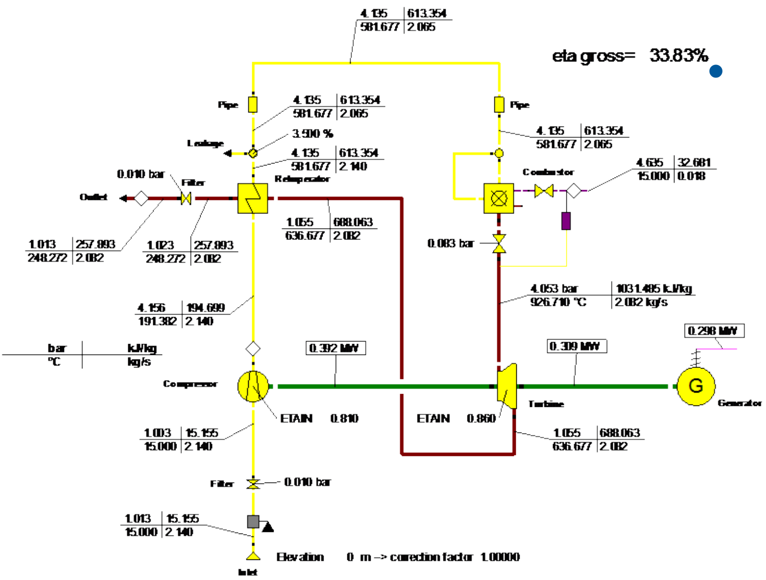

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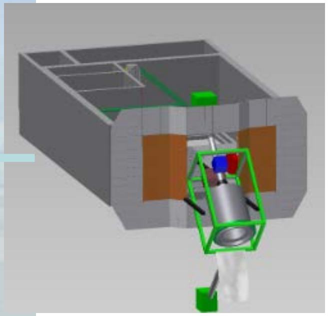

- 10 kW Receiver and auxiliaries design, built and tested for all fluids
- Evaluation of degradation effects on structural materials on all HTM
- System modelling to understand performance and operation constraints and select most promising options
- Design and Test of 100- 500 kW pilot scale installation

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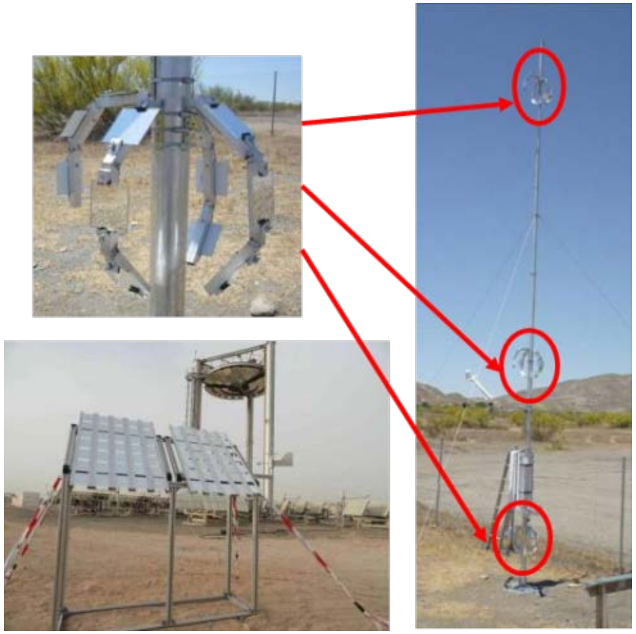
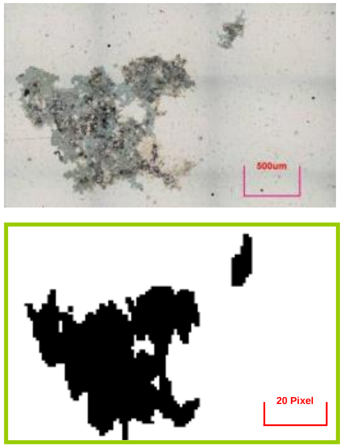
Subtopic 2 - Impact of Desert Environment

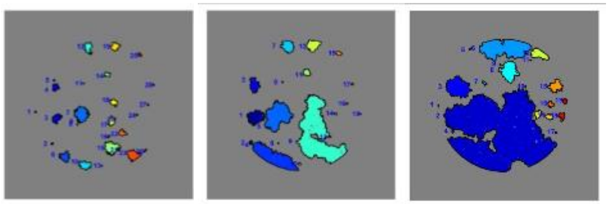
Is the concept fit to be operated for > 20 years in a desert environment?

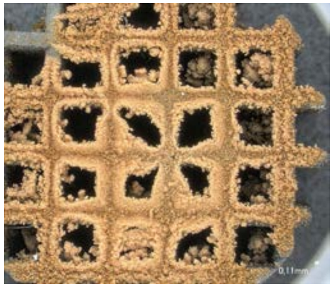
Achievements in POF II

- Soiling and degradation characterization methods developed and installed at 10 different desert sites
- Accelerated aging procedures developed for aluminum reflectors
- Sunshape evaluation reference system developed
- Impact of dust on high temperature ceramics characterized









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Is the concept fit to be operated for > 20 years in a desert environment?

Goals and milestones

- Influence of aerosols on optical plant performance with site specific sunshape and extinction data

Subtopic 2 - Impact of Desert Environment

Is the concept fit to be operated for > 20 years in a desert environment?

Goals and milestones

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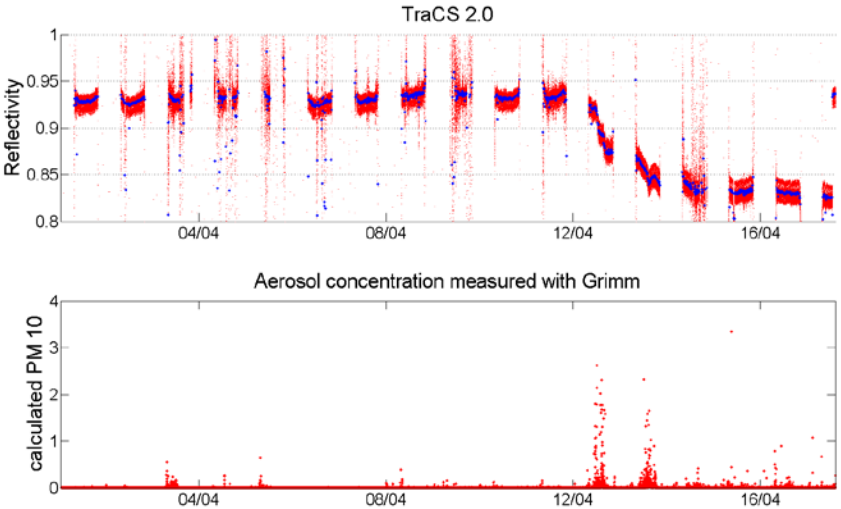
- Quantification of soiling effects



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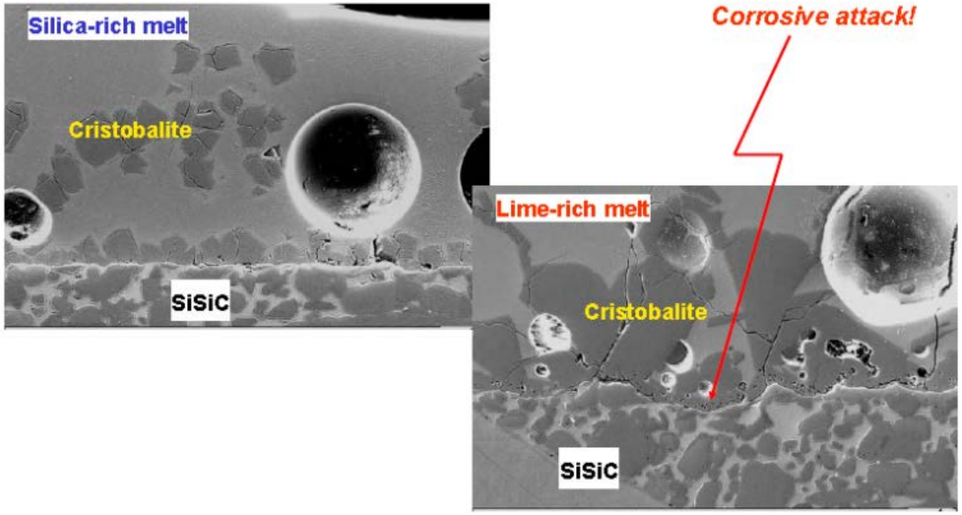

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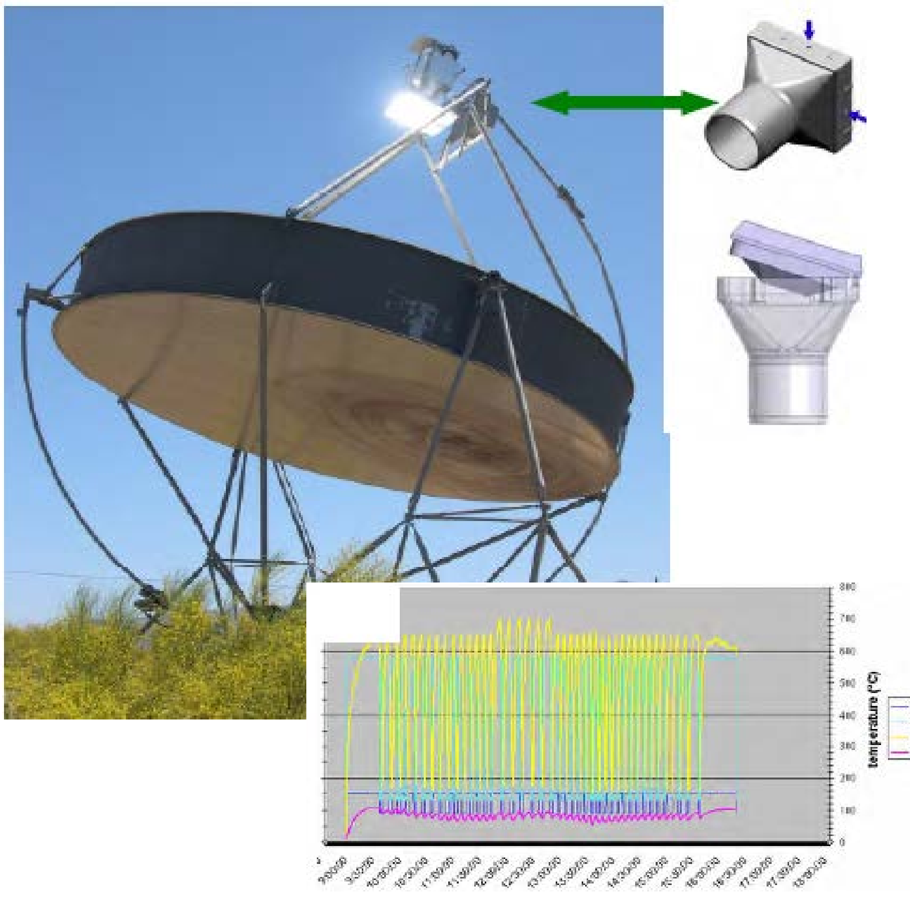

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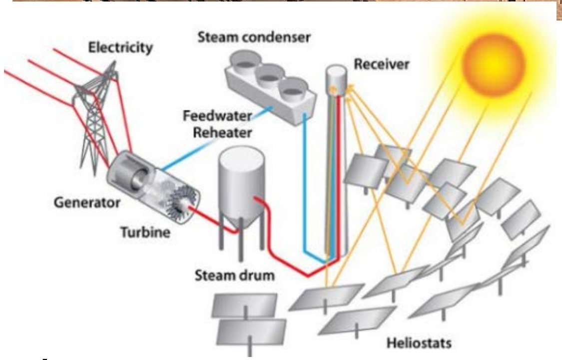
- Simulation model for life time plant performance including soiling and degradation



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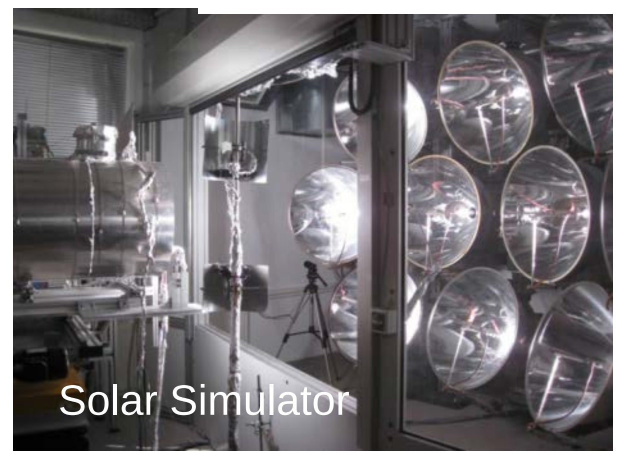
Large scale facilities

<u>Investment Proposal</u>

High Efficiency High Temperature Receiver System (HEHTRES)

≈ 500 kW_{th} Pilot



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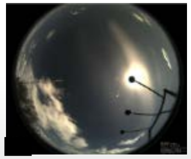
Cooperation

Topic: Thermal Storage (SCI)
(Allied Partner, 16 FTE)

- Molten salt composition and degradation
- Liquid Metal storage integration
- Particle Heat Exchanger

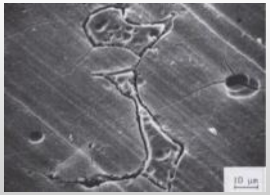
CIEMAT

- Meteorological analysis
- Durability of key components



Topic: Methods for Material Development (EMR)

- Corrosion and degradation of structural materials at high temperature



NREL

- Atmospheric attenuation
- Soiling on components
- Modelling of mirror corrosion

Programme TIS

- Value of thermal storage to the grid system in different scenarios

Sandia

- Particle receiver development
- Receiver simulation tools
- Analysis of particle attrition

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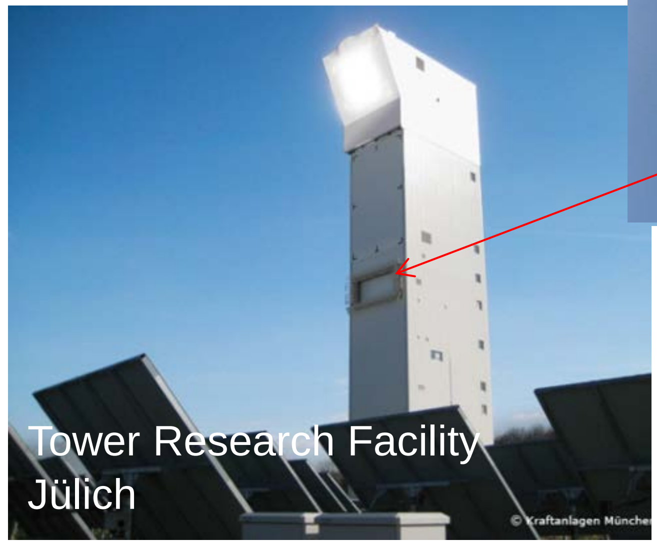
Large scale facilities



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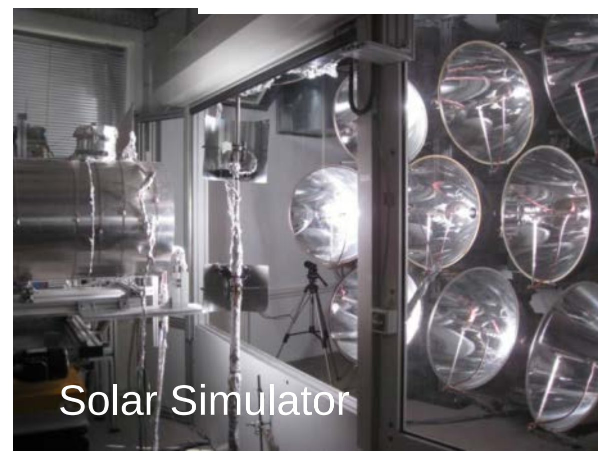

Conclusions

- High **risk/high reward** research proposal to **enable breakthrough technology** that can achieve **>20% annual system ef**ficiency and efficient storage integration
- **Liquid metal competences** and budget from **Nuclear Safety Programme** integrated
- Synergies through **allied partners** from SCI Programme Topic "**Thermal Storage"**
- **Materials competences** integrated from EMR Topic **"Methods and Concepts for Material Development"**
- Leverage through **international co-operation** (CIEMAT, NREL, Sandia)
- Use of existing **large scale facilities**
- **Proof of concept** planned in ≈500 kW scale as a basis for **Tech-Transfer** (HEHTRES - Investment Proposal)

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Vielen Dank für die Aufmerksamkeit

Und hier noch ein Hinweis…..

Mitglieder

Der Verband der Deutschen CSP umfasst aktuell
30 Mitgliedsunternehmen

DCSP
Deutscher Industrieverband
Concentrated Solar Power

ABENGOA SOLAR
CSP Services
CONCENTRATING SOLAR POWER SERVICES
DLR
erfis
glass · thin and tough
enolcon
FICHTNERSOLAR
Excellence in Solar Engineering
Fraunhofer
ISE
GRENZEBACH
HAWE
HYDRAULIK
hogrefe Consult
iA TECH
iLF
CONSULTING
ENGINEERS
KAEFER
Kraftanlagen
München
KSB
LAHMEYER
INTERNATIONAL
LEONI
M+W GROUP
NOVATEC
SOLAR
protarget
SOLAR POWER SYSTEMS
SolEngCo
The Solar Engineering Company
schlaich bergermann
und partner
SCHOTT
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TOWER TECHNOLOGIES
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