Solar Power and Chemical Energy Systems

Overview of central receiver and dish systems

IEA TECHNOLOGY ROADMAPS: SOLAR ELECTRICITY

2014 Updates - 1st Workshop 3-4 February 2014

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SolarPACES




Overview current tower projects

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
PS10	Operation	June 2007	11,0	Spain	Water/Steam	275	Abengoa
PS20	Operation	April 2009	20,0	Spain	Water/Steam	275	Abengoa
Jülich Solar Tower	Operation	December 2008	1,5	Germany	Air	680	KAM / DLR
Sierra SunTower	Operation	July 2009	5,0	USA	Water/Steam	440	eSolar
ACME Solar Tower	Operation	April 2011	2,5	India	Water/Steam	440	ACME/eSolar
Gemasolar	Operation	April 2011	20,0	Spain	Molten Salts	565	Torresol Energy
Lake Cargelligo	Operation	May 2011	3,0	Australia	Water/Steam	500	Graphite Energy
Daegu Solar Tower	Operation	June 2011	0,2	South Korea	Air	680	Daesung Energy
Dahan Tower Plant	Operation	August 2012	1,0	China	Water/Steam	400	IEECAS
Supcon Solar Project	Operation	July 2013	10,0	China	Water/Steam	-	Supcon Solar
Crescent Dunes	Construction	Mid 2014	110,0	USA	Molten Salts	565	Solar Reserve
Ivanpah	Construction	Early 2014	377,0	USA	Water/Steam	565	BrightSource Energy
Khi Solar One	Construction	January 2015	50,0	South Africa	Water/Steam	530	Abengoa
Ashalim 1	Development	2017	121,0	Israel	Water/Steam	565	BrightSource Energy
Palen Solar Complex	Development	??	500,0	USA	Water/Steam	565	BrightSource + Abengoa
Rice Solar Energy Project	Development	??	150,0	USA	Molten Salts	565	Solar Reserve
Planta Solar Cerro Dominador	Development	2017	110,0	Chile	Molten Salts	-	Abengoa

From: SolarPACES Project Database, www.nrel.gov/csp/solarpaces/

PS10, 11 MWe, Spain
PS20, 20 Mwe, Spain

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
PS10	Operation	June 2007	11,0	Spain	Water/Steam	275	Abengoa
PS20	Operation	April 2009	20,0	Spain	Water/Steam	275	Abengoa

Jülich, 1.5 MWe, Germany

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Jülich Solar Tower	Operation	December 2008	1,5	Germany	Air	680	KAM / DLR

Sierra SunTower, 5 MWe, USA

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Sierra SunTower	Operation	July 2009	5,0	USA	Water/Steam	440	eSolar

Gemasolar, 20 MWe, Spain

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Gemasolar	Operation	April 2011	20,0	Spain	Molten Salts	565	Torresol Energy

Lake Cargelligo, 3 MWe, Australia

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Lake Cargelligo	Operation	May 2011	3,0	Australia	Water/Steam	500	Graphite Energy

Daegu Solar Tower, 200 kWe, Korea

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Daegu Solar Tower	Operation	June 2011	0,2	South Korea	Air	680	Daesung Energy

Dahan Tower Plant, 1 MWe, China

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Dahan Tower Plant	Operation	August 2012	1,0	China	Water/Steam	400	IEECAS

Supcon, 10 MWe, China

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Supcon Solar Project	Operation	July 2013	10,0	China	Water/Steam	-	Supcon Solar

Ivanpah, 377 MWe, USA

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Ivanpah	Construction	Early 2014	377,0	USA	Water/Steam	565	BrightSource Energy

Crescent Dunes, 110 MWe, USA

Towers	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Crescent Dunes	Construction	Mid 2014	110,0	USA	Molten Salts	565	Solar Reserve

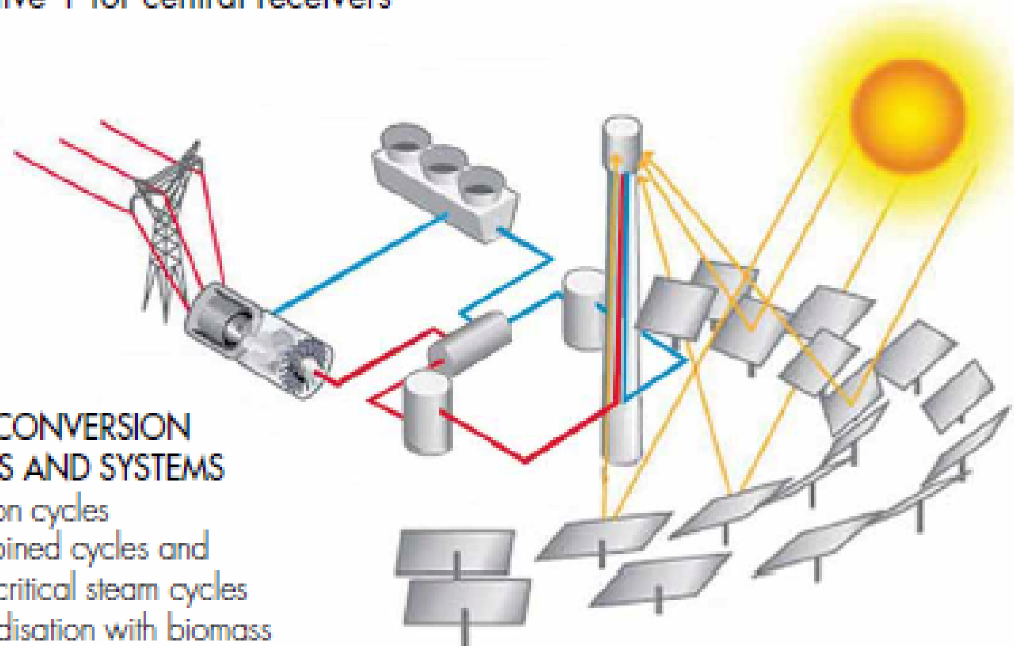
Solar Power and Chemical Energy Systems

R&D Central Receiver Systems

CENTRAL RECEIVERS

Research topics to be investigated to reach objective 1 for central receivers

RECEIVER
- Advanced high temperature receiver (direct absorption)
- New engineered materials (ceramic tubes)



HEAT TRANSFER FLUID
- Molten salt for supercritical steam cycles
- Air and CO_2 as primary fluids
- Direct superheated steam
- Particle receiver systems

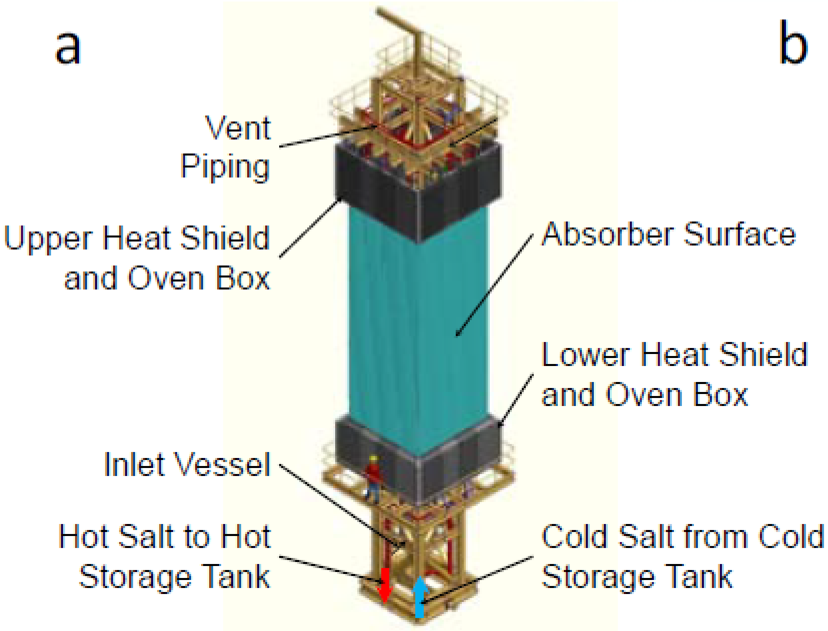
HELIOSTAT FIELD
- Multiple small towers configuration
- Reliable wireless heliostat control systems
- Optimised heliostat field
- Improve drive mechanisms
- Autonomous drive units and local controls (wireless)

NEW CONVERSION CYCLES AND SYSTEMS
- Brayton cycles
- Combined cycles and supercritical steam cycles
- Hybridisation with biomass
- Secondary concentrators

Source: ESTELA, Implementation Plan for CSP 2013 - 2015

Modular Towers (e-solar)

a



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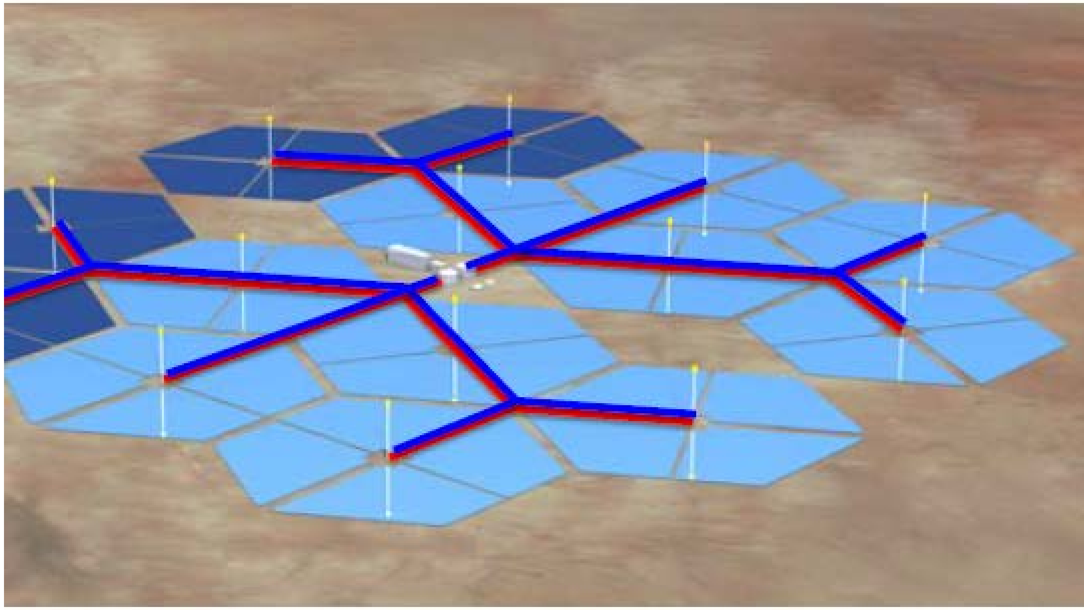


C. Tyner et al, eSolar's Modular, Scalable Molten Salt Power Tower Reference Plant Design, SolarPACES 2013, (to be published in Elsevier Energy Procedia)

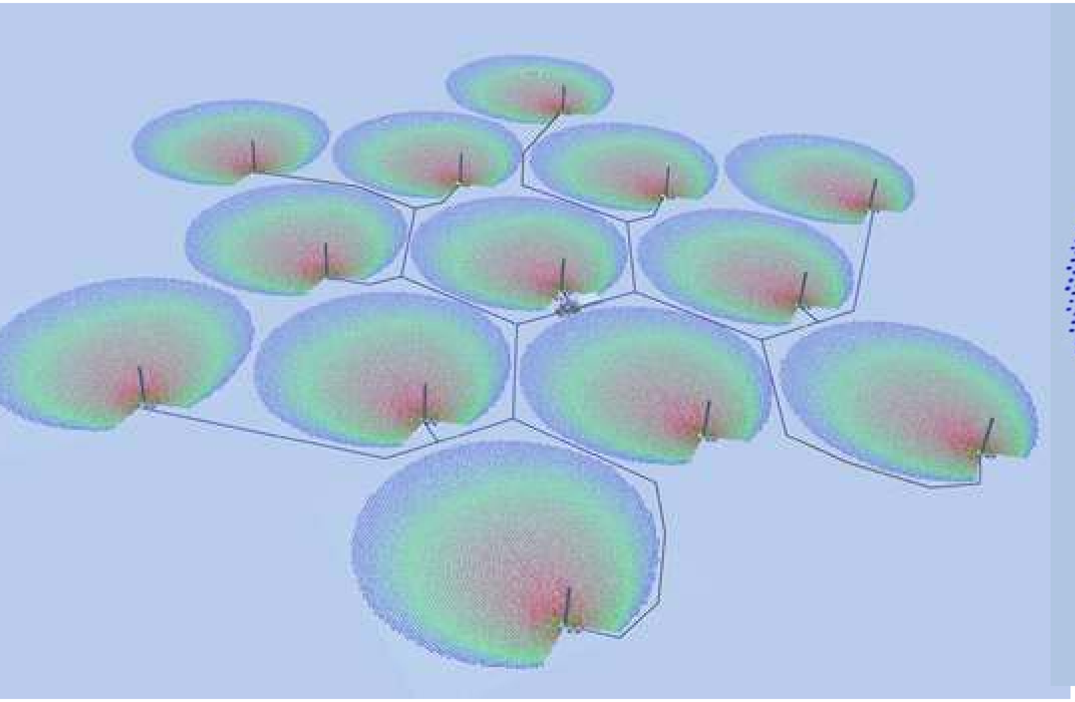
Modular Towers (e-solar)

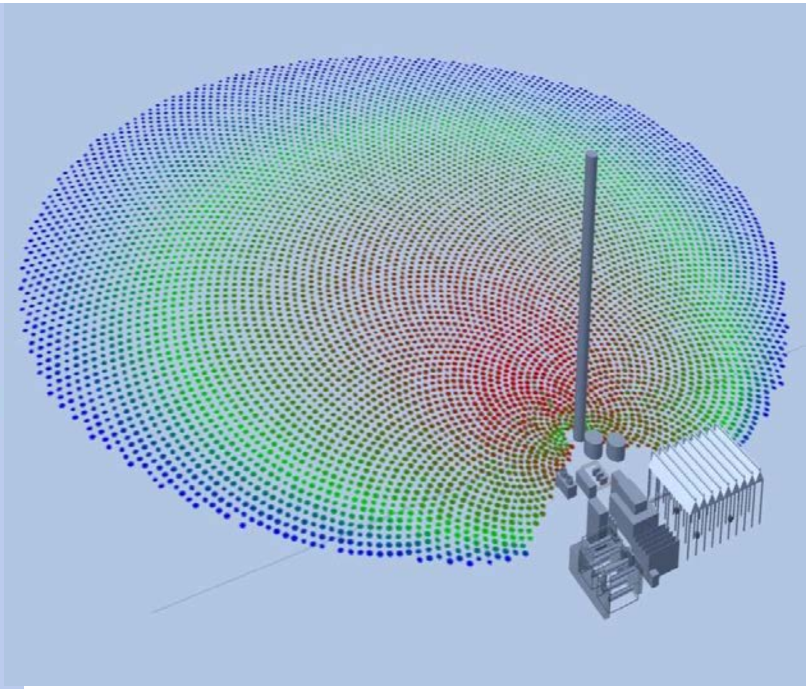
Annual and Design Point Efficiencies for 14-Module, Dry-Cooled, 75% Capacity Factor Plant

System Efficiency	Annual		Design Point	
	Relative	Cumulative	Relative	Cumulative
Outages	95.6%	95.6%	100.0%	100.0%
Design Oversize	94.6%	90.4%	82.2%	82.2%
Solar Collector	56.0%	50.6%	67.1%	55.2%
Receiver	81.8%	41.4%	86.1%	47.5%
Piping	98.9%	41.0%	99.7%	47.4%
Thermal Storage	99.5%	40.8%	100.0%	47.4%
Steam Generator	99.9%	40.7%	99.9%	47.3%
Power Generation	42.1%	17.1%	42.3%	20.0%
Parasitics	91.9%	15.8%	88.7%	17.8%
Operational Efficiency		16.7%		21.6%

Source: C. Tyner et al, eSolar's Modular, Scalable Molten Salt Power Tower Reference Plant Design, SolarPACES 2013 (to be published in Elsevier Energy Procedia)

Modular Towers (Heliotower design)



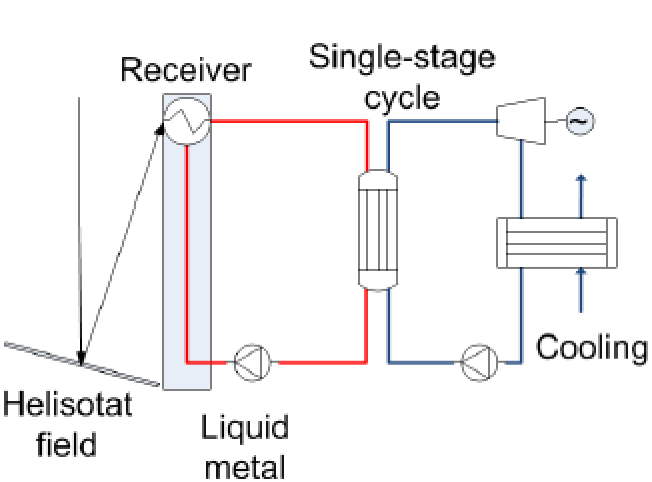


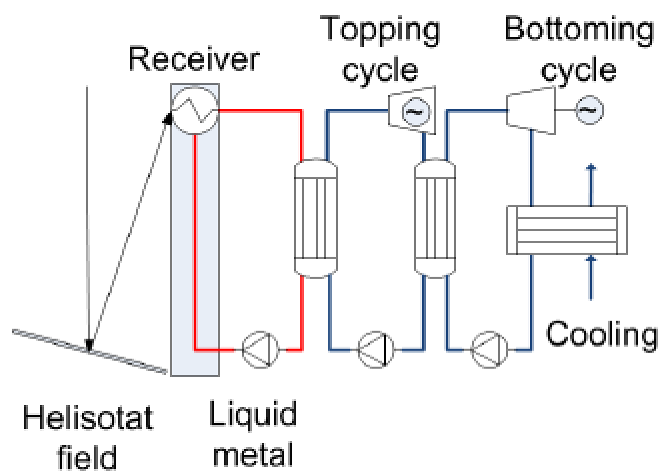
- The Modular Building Block concept offers LCOE below 10 ct€/kWh
- It has special benefits for the Arab World and other regions of the globe with imperfect atmospheric conditions
- LCOE are very sensitive to debt rates. The concept gives the opportunity for improved project financing and project risk reduction
- Further development and validation of the concept will be necessary

Source: Kai Wieghardt et al., Modular Solar Tower Plants for Global Application, SolarPACES 2012

Heat Transfer Fluids

- Liquid Metals, different cycle options



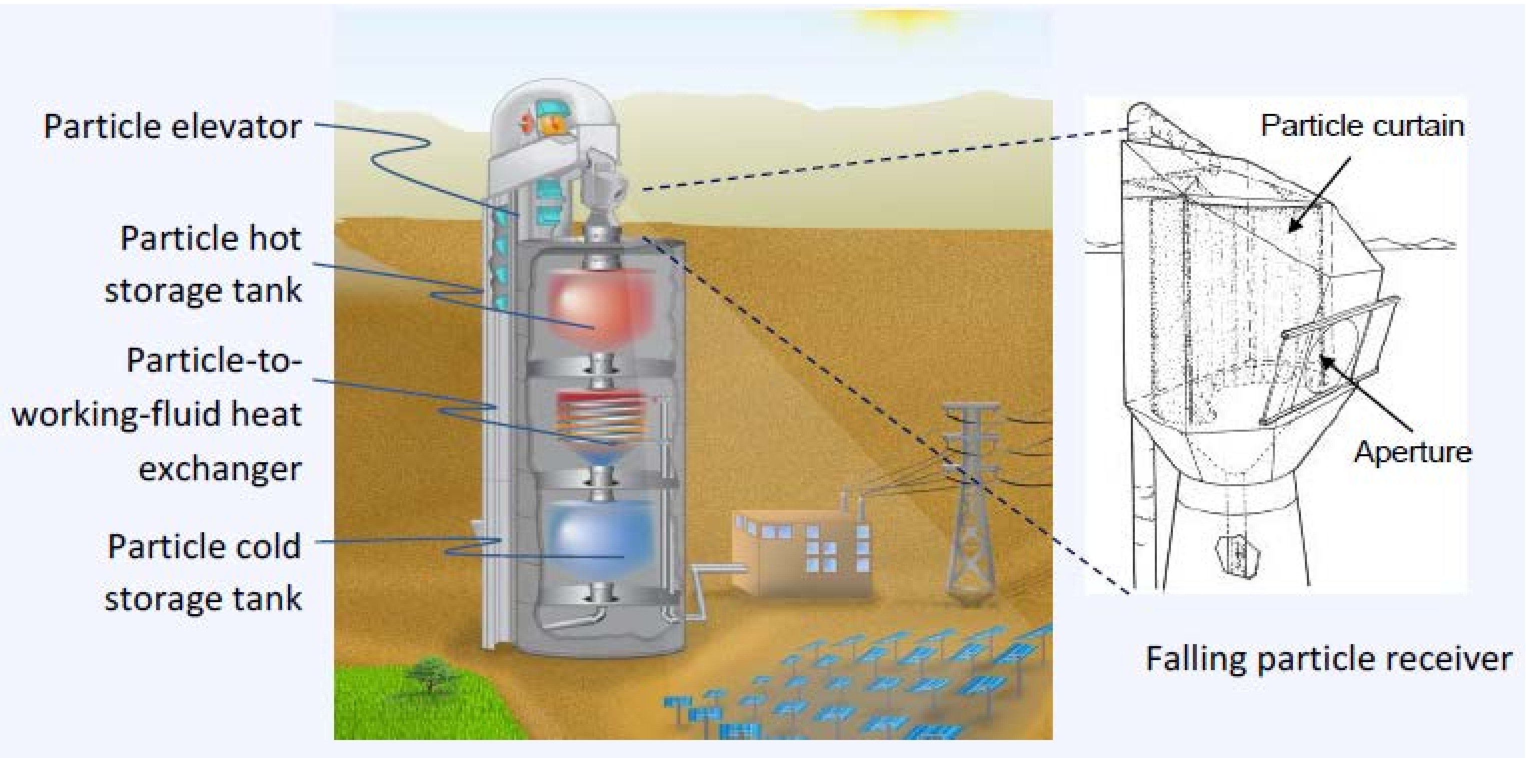


- Single-stage, e.g. USC water
- 700°C, 300 bar, η=52%
- Lower development (CSP side)

- Combined, e.g. Brayton/Rankine
- Top: ~1000°C, bottom: 600°C
- Larger development (CSP side)

Source: J. Pacio et al, , Liquid Metals as efficient coolants for next generation CSP systems, SolarPACES 2013 (to be published in Elsevier Energy Procedia)

Particle Receivers



Falling Particle Receiver Technology

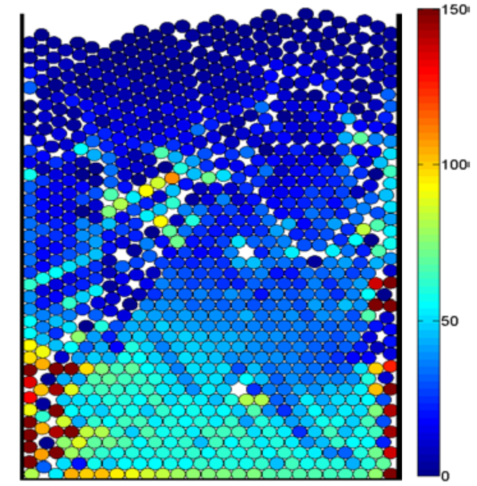
Source: C. Ho et al, Technology Advancements for Next Generation Falling Particle Receivers, SolarPACES 2013 (to be published in Elsevier Energy Procedia)

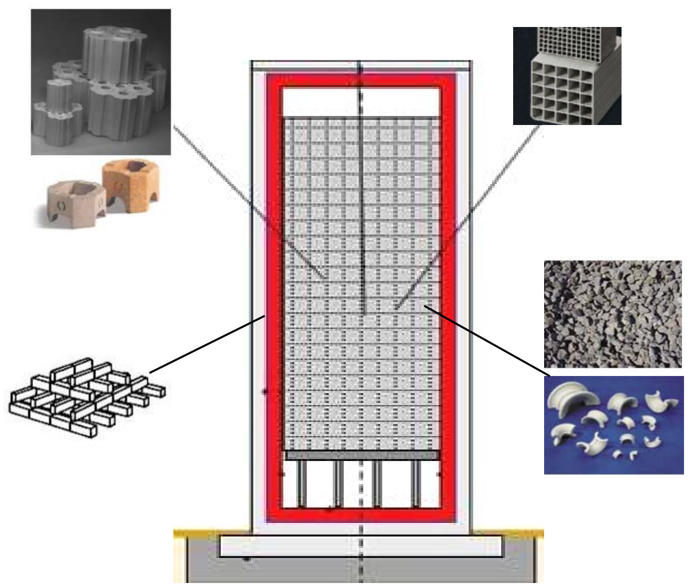
Storage for Solar Tower Plants with Air Receiver

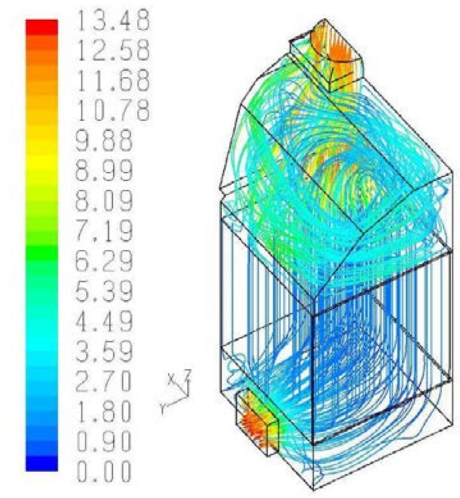
Regenerator Storage

Challenges:

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







Slide Source: D. Laing, DLR TT

Solar Thermochemical Gasification

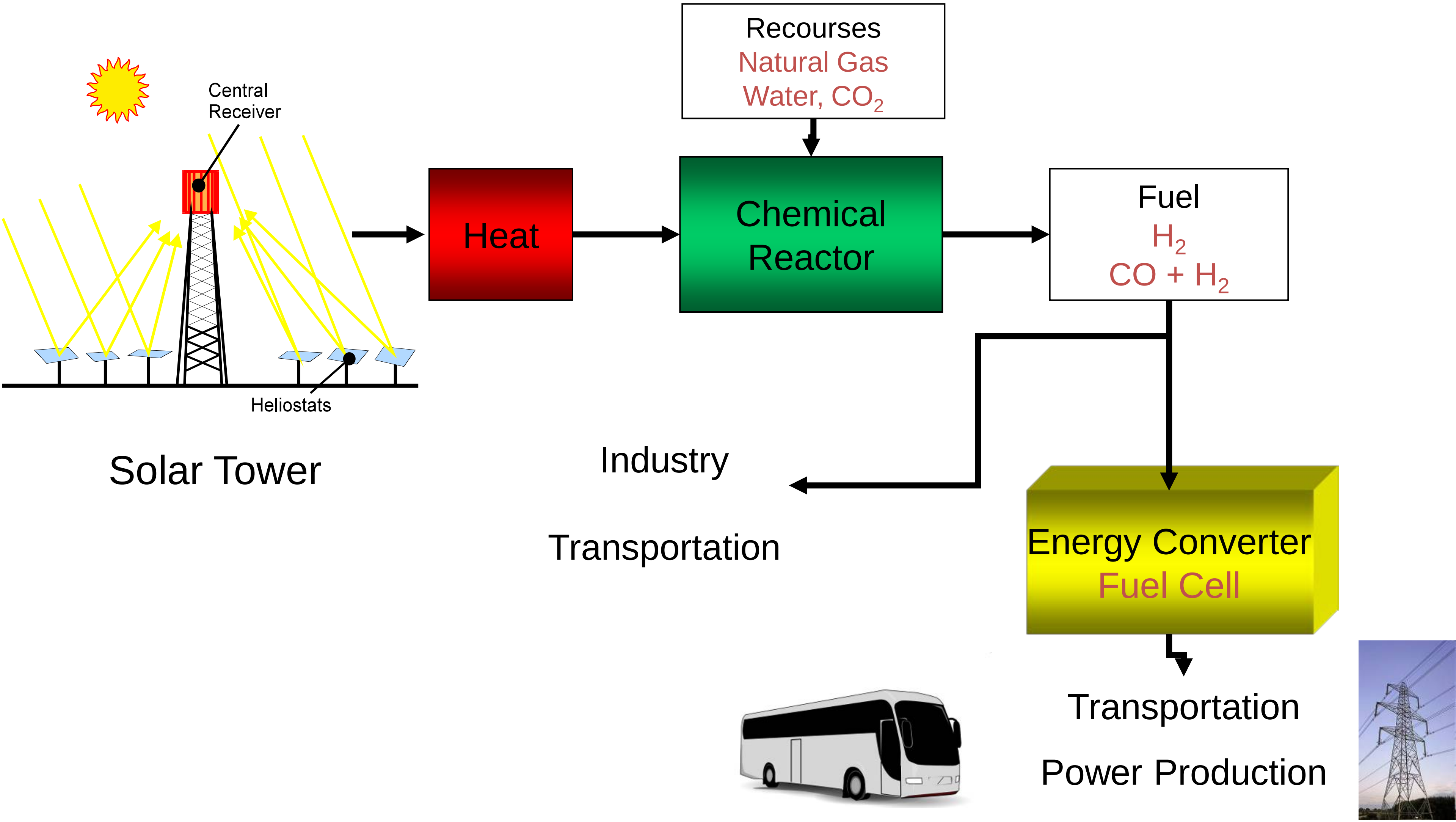
Slide courtesy Anton Meier, PSI, Switzerland

Solar Syngas from Carbonaceous Wastes

- Industrial Project SOLSYN (2007-2012) with Holcim
  http://www.pre.ethz.ch/research/projects/?id=solsyn
- 150 kW_{th} solar pilot plant at PSA, Spain
- Indirect-irradiation two-cavity solar reactor for beam-down application (1000-1200°C)
- Variety of feedstock converted to syngas
- Max. efficiency η_{th} = 35% for low-rank coal
- Max. energetic upgrade 30% for sugar cane bagasse
- Conclusion: Solar reactor concept is scalable to industrial application (MW_{th}) and can accept bulk carbonaceous feedstock of any shape and size without prior processing

- Energy & Fuels, 27, 4770-4776, 2013.

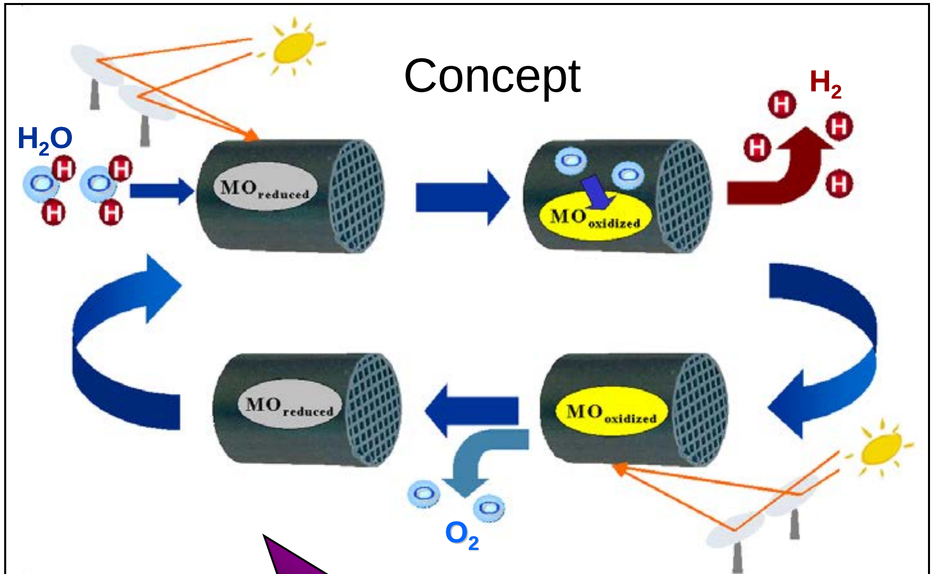
Principle of the solar thermal fuel production

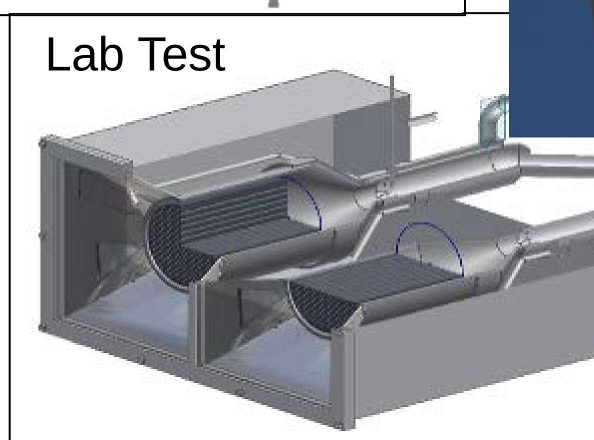


Slide Source: C. Sattler, DLR SF

Future applications: Solar Fuels (e. g. Hydrogen)

Example HYDROSOL Project (EU FP6)





Scale-up 100 kW

Slide Source: C. Sattler, DLR SF

Dish Systems

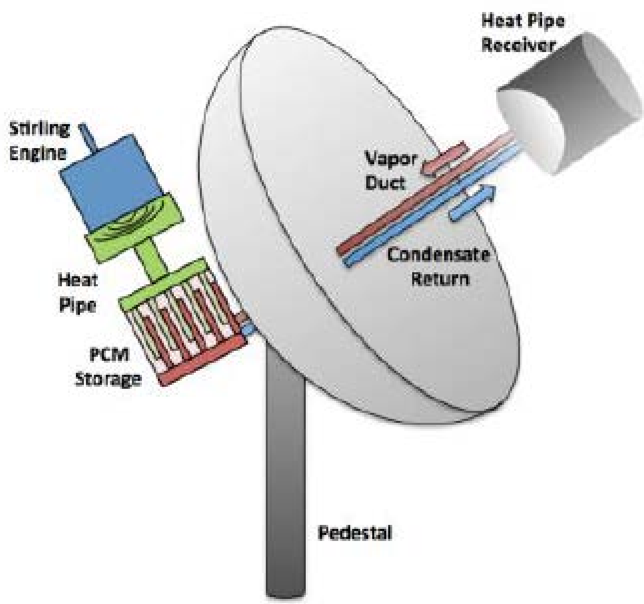
Maricopa, 1.5 MWe, USA
(Decommsioned)

Orion, 1 MWe, China

Several Dish-Stirling systems in test centers in use

Dishes	Status	Operation	Capacity (MW)	Country	HTF	Temp. (ºC)	Developer
Maricopa	Decommissioned	-	1,5	USA			Tessera Solar
Orion	Operational	November 2013	1	China			HelioFocus

Latent Heat Storage for Dish Stirling



Source: C. Andraka, Dish Stirling Advanced Latent Storage Feasibility, SolarPACES 2013
(to be published in Elsevier Energy Procedia)

Scheffler Dishes

Successful for cooking and related process heat applications

Summary

- Solar Towers increase market share
- R&D for subsystem optimization ongoing
- Good perspectives for further cost reduction
- Future potential also in high temperature process heat

- Thank you for your attention
- Follow up in 2014 SolarPACES conference,

16. – 19. September 2014, Bejing, China (www.solarpaces2014.solarpaces.org soon online)