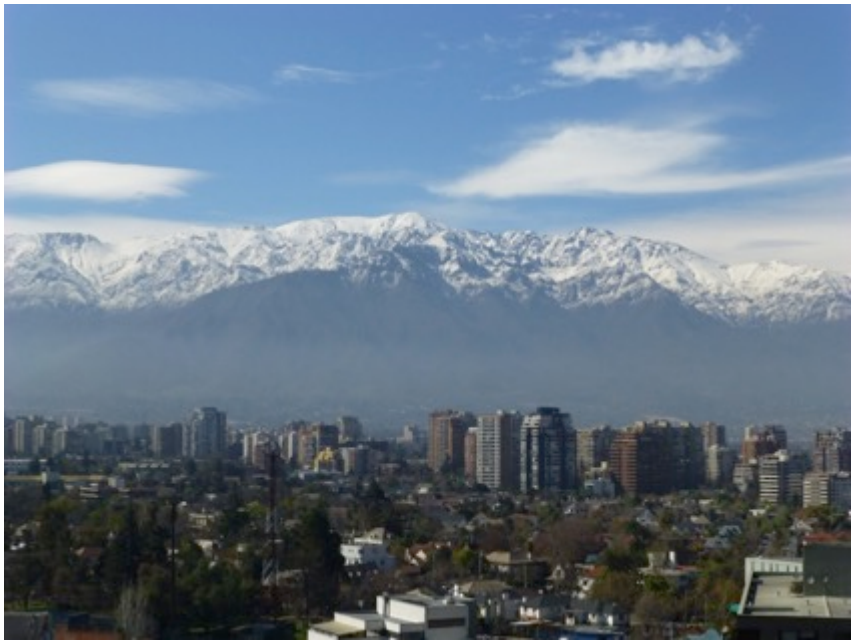
“CSP Market World-wide”

Fraunhofer Center for Solar Energy Technologies „CSET“



Prof. Dr. Frank Dinter

Solar Thermal Seminar

2. April 2018

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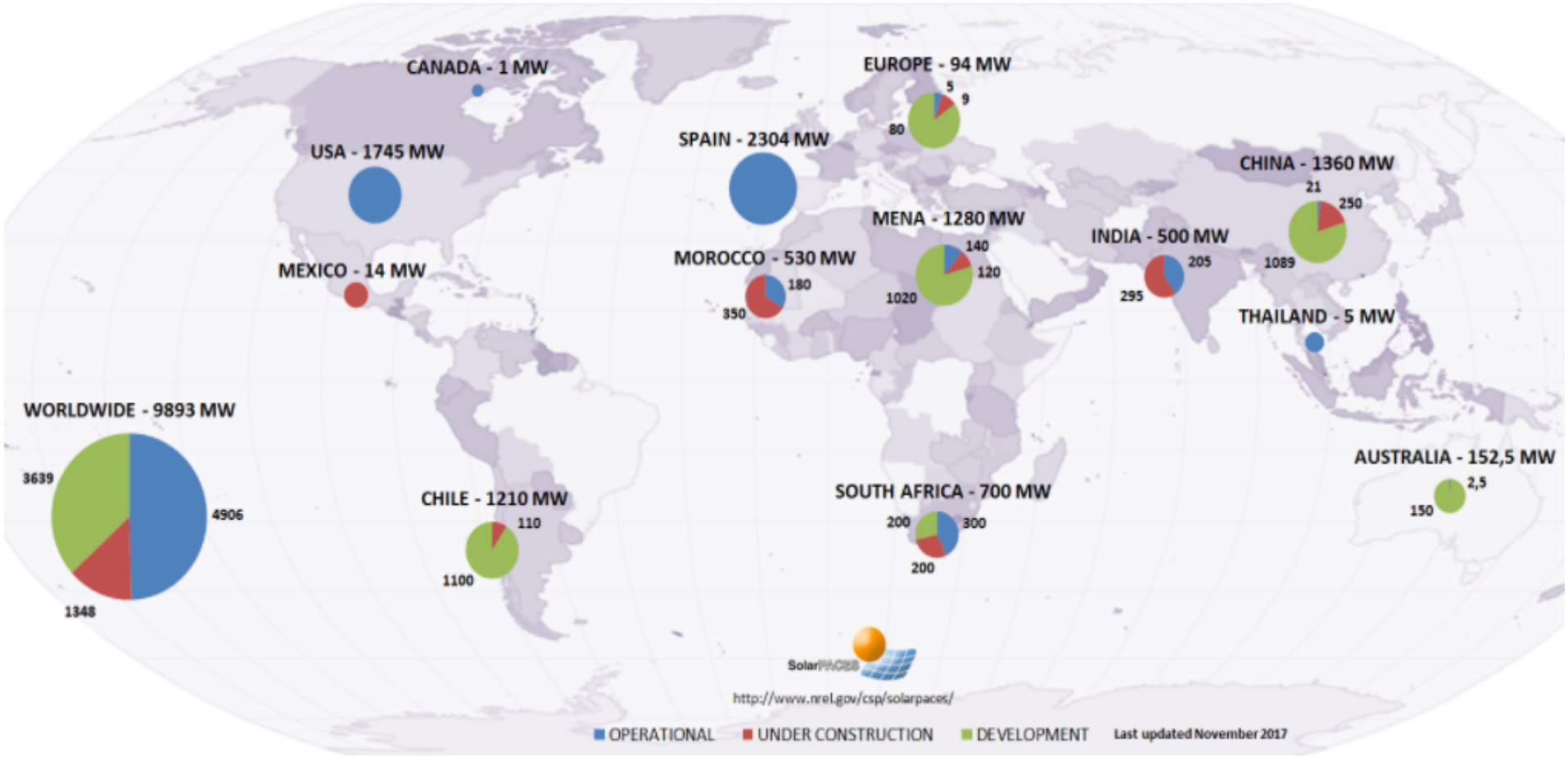
CSP Market World-wide

CSP Projects around the world



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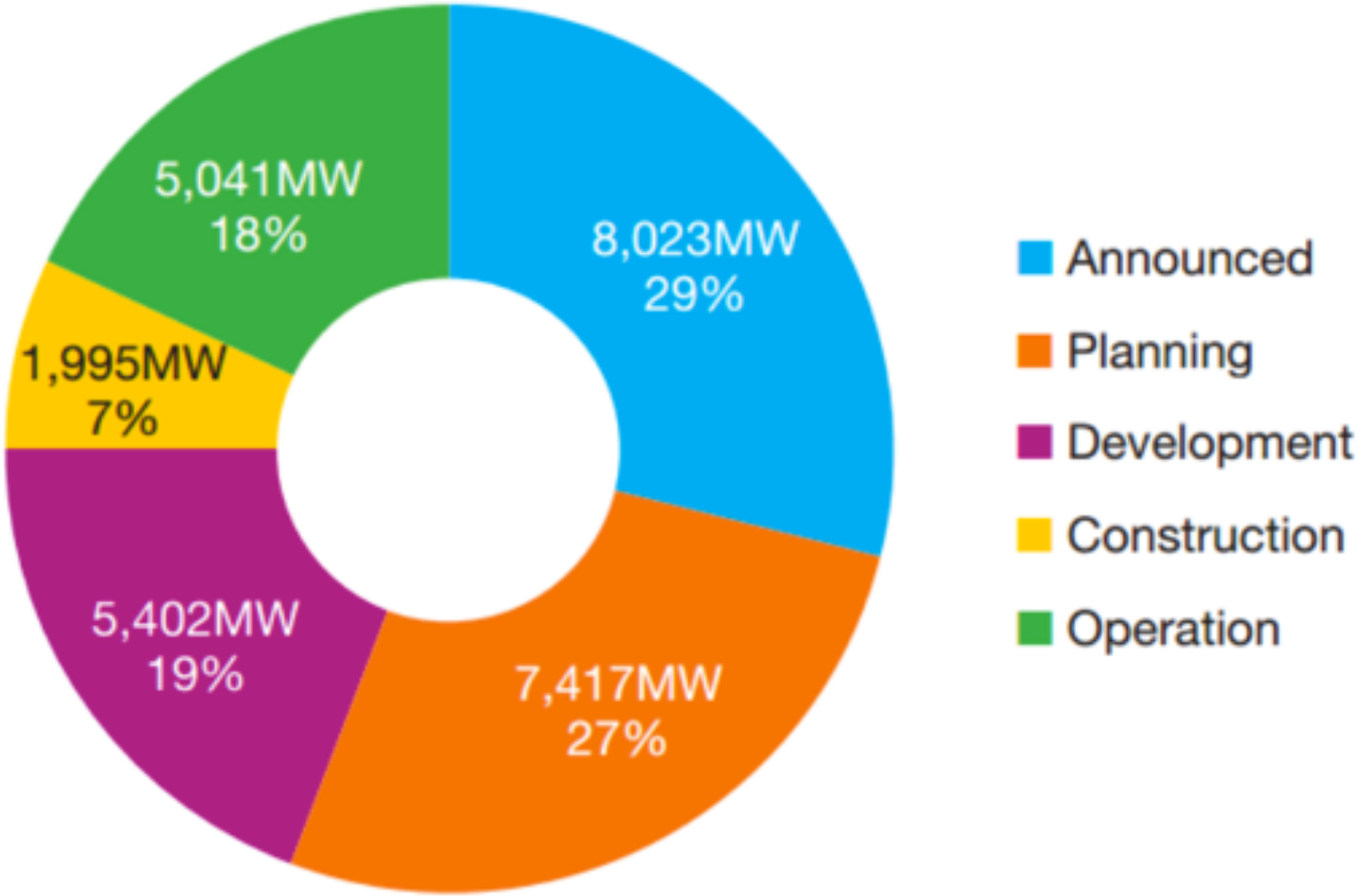
CSP Market World-wide

CSP Market today: „Capacity in MW“



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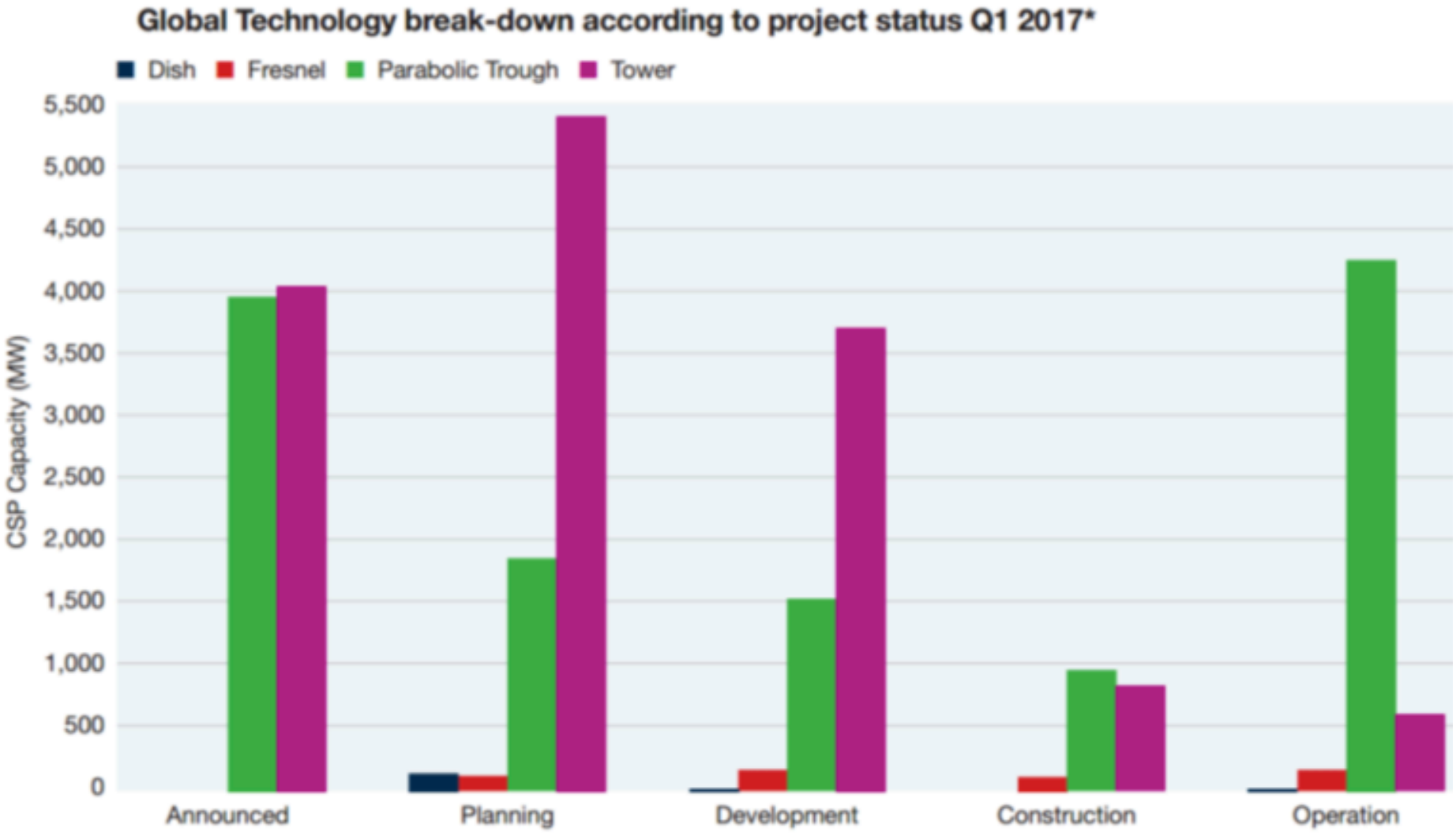
CSP Market World-wide

CSP Market today: „Technology breakdown“



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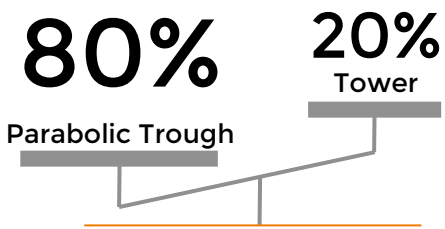
CSP Market World-wide

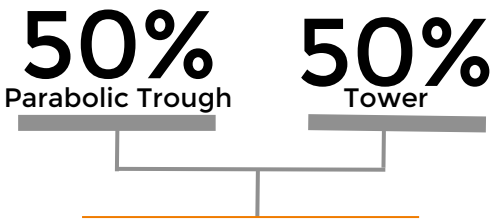
CSP Market today - an overview

6 GWe Installed Capacity



70% with storage

2 GWe Tendered - Under Construction



100% with storage

China 1 GW - Morocco 0.7 GW

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CSP Market World-wide

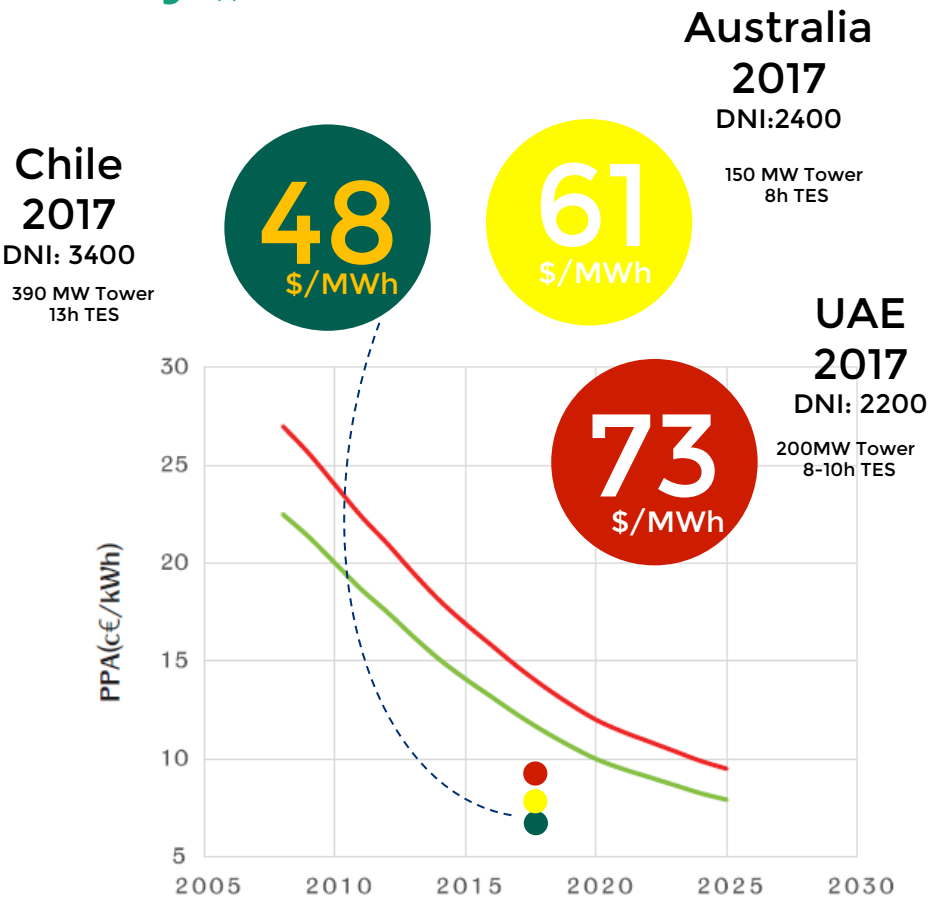
Race of CSP price reached new records

- DEWA call: **73 USD/MWh** for a **700 MW** CSP Plant in Dubai with a parabolic trough+solar tower by ACWA
- Australia: SolarReserve PPA at **61 USD/MWh** for planned **150 MW** Solar Tower Aurora CSP plant at Port Augusta
- Chile: **48 USD/MWh** were offered by SolarReserve for a Solar Tower CSP Project in Likana

Source: Dr.Reiner Buck, clossing session SolarPACES 2017

CSP Market World-wide

today „Prices“



- CSP is generally seen as less competitive on the basis of $/MWh
- Aggresive PPA bids, yet higher than other renewables e.g. PV
- $/MWh proportional to solar resource
- It is now being understood that its value relies on its dispatchable attribute.
- This has led to tech-specific tenders with time-of-use tariffs (hourly)
- This means that the optimum design and operation of each plant is unique to each tender and location

➢ **CSP costs are coming down seriously**

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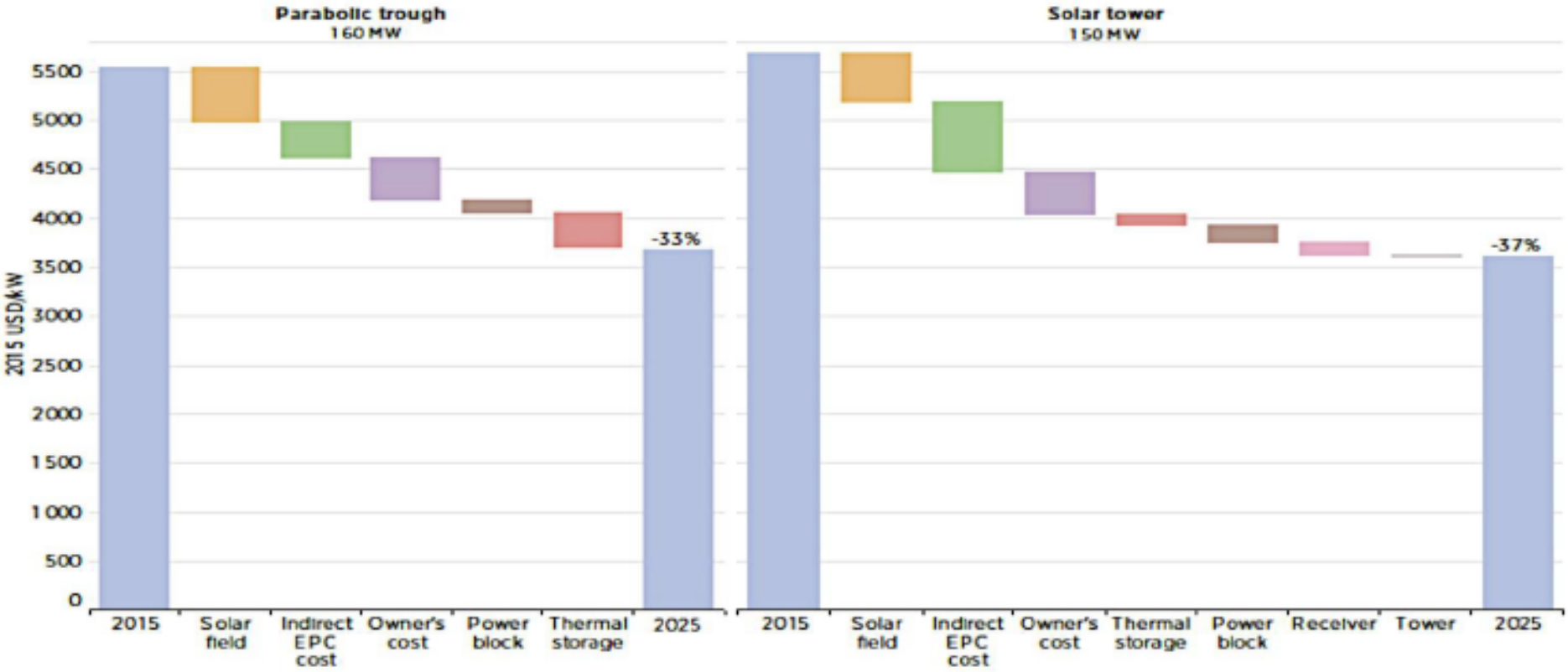
CSP Market World-wide

Future CSP Capital Cost Reductions

PTC and ST total installed cost reduction potential by source, 2015-2025



Source: IRENA and DLR, 2016

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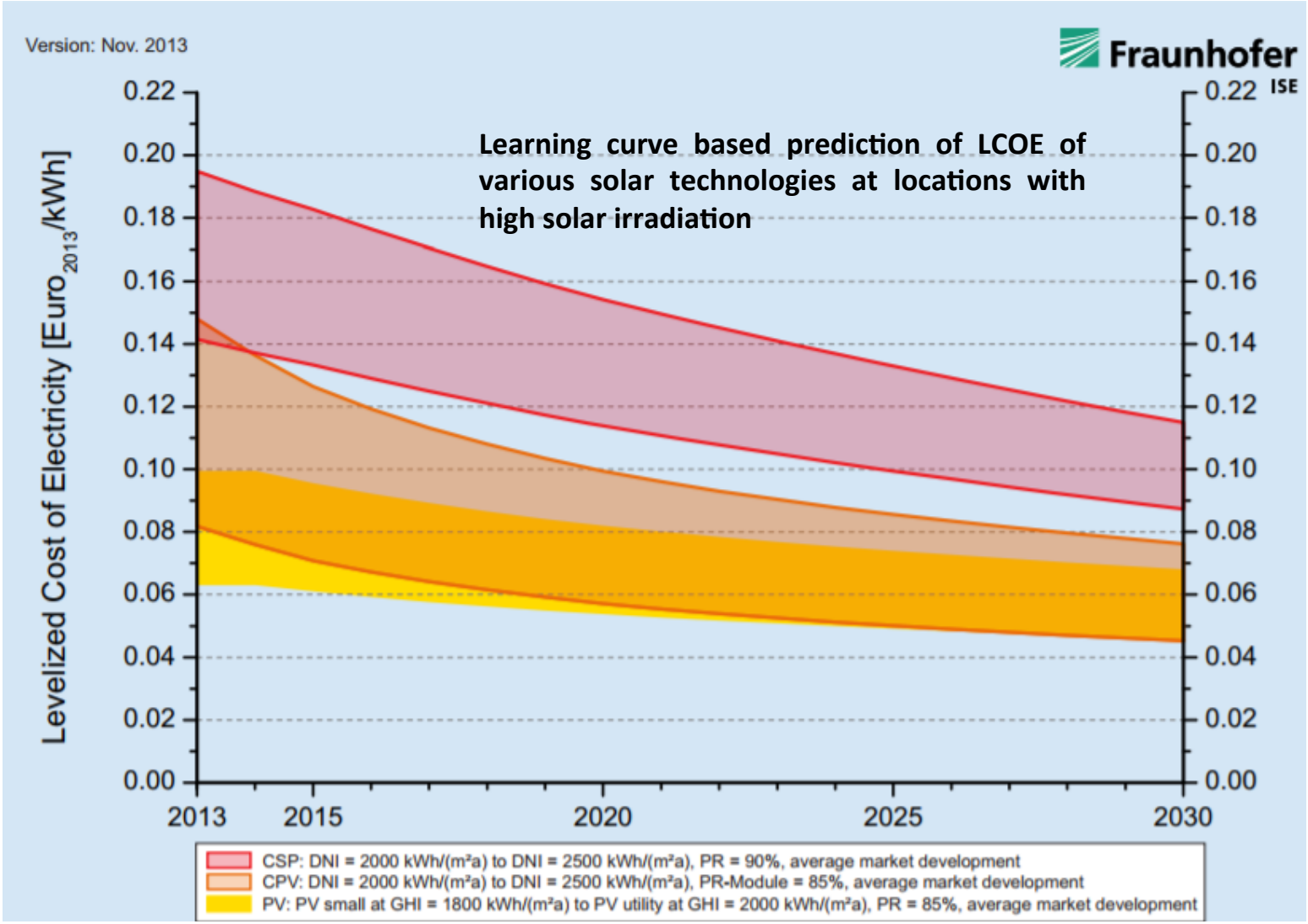
CSP Market World wide

LCOE Comparison of PV and CSP projects



Source: www.newenergyupdate.com

Image source: Fraunhofer ISE

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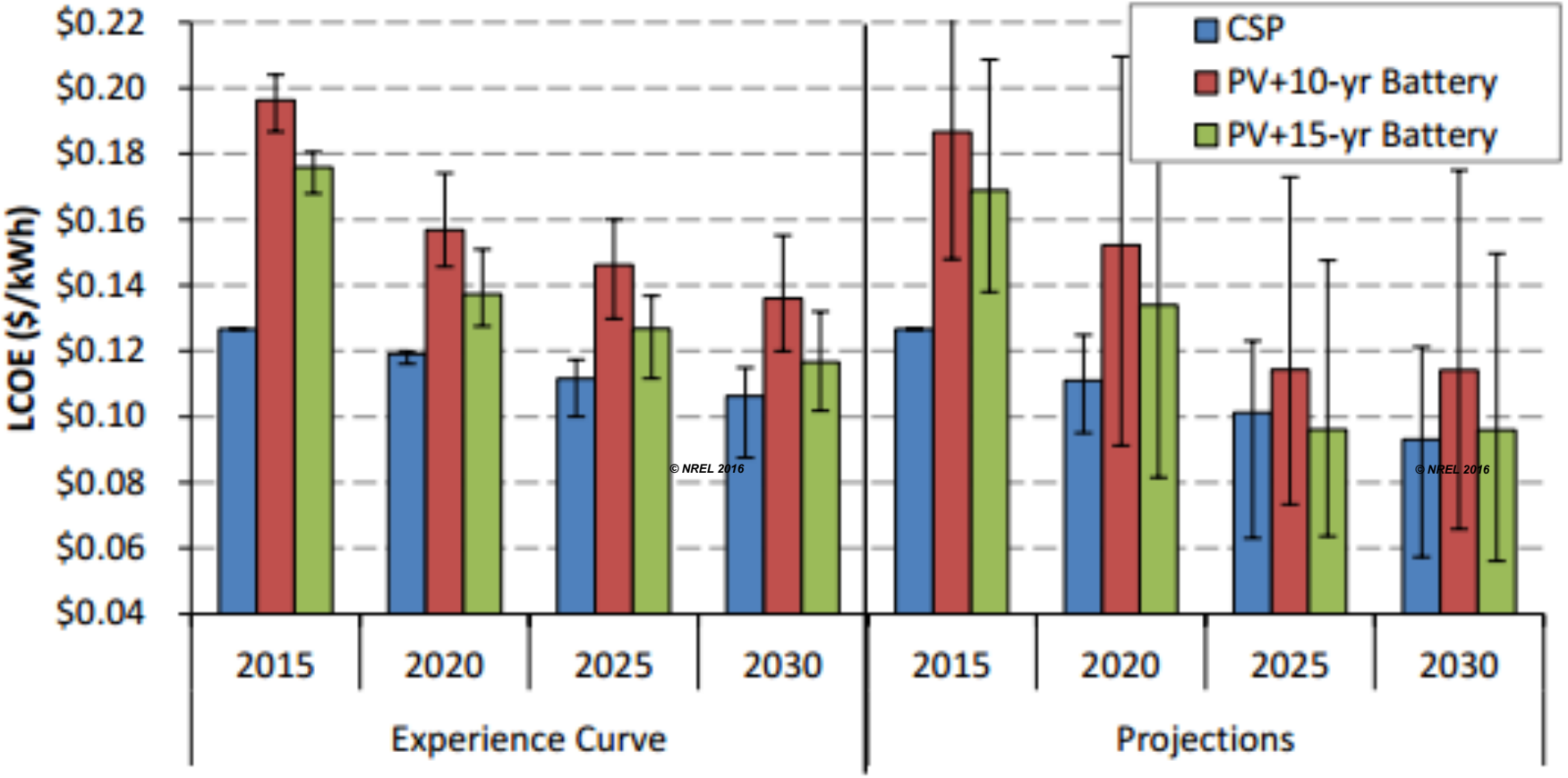
CSP Market World wide

LCOE Comparison of PV vs. CSP projects for 6 h storage

- For a 200 $/kWh combined battery and battery BOS costs and increased lifetime
- For PV systems (module + BOS) of 1 $/W



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CSP Market World-wide

Some Capacity Announced and under Construction

	DNI kWh/m²	Capacity Annouced (MW)	Capacity under Construction (MW)
Australia	2400	20	2
Chile	3300	1445	110
China	2000	4512	575
India	2100	50	25
Israel	2500	-	231
Morocco	2400	-	150

CSP Market World-wide

Some Projects running in the world (without China)

Technology	Project Name	Country	Status	PCOD	Capacity (MW)
Parabolic trough	Noor 1	Morocco	Operational	2016	160
Parabolic trough	Noor 2	Morocco	Operational	late 2017	200
Parabolic trough	Bokpoort	South Africa	Operational	2016	50
Parabolic trough	DEWA	UAE	Under development	2020	2x300
Parabolic trough	Xina Solar One	South Africa	Operational	2016	100
Parabolic trough	Ashalim	Israel	Under Construction	late 2017	110
Tower	Noor 3	Morocco	Under Construction	early 2018	150
Tower	Redstone	South Africa	Under development	2018	100
Tower	DEWA	UAE	Under development	2020	100
Tower	Cerro Dominador	Chile	Under Construction	2019	110
Tower	Aurora	Australia	Under development	2020	150
Tower	Ashalim	Israel	Under construction	early 2018	121
Tower	Aalborg CSP-Brønderslev	Denmark	Operational	2016	16.6

Source: https://www.nrel.gov/csp/solarpaces/by_status.cfm

CSP Market World-wide

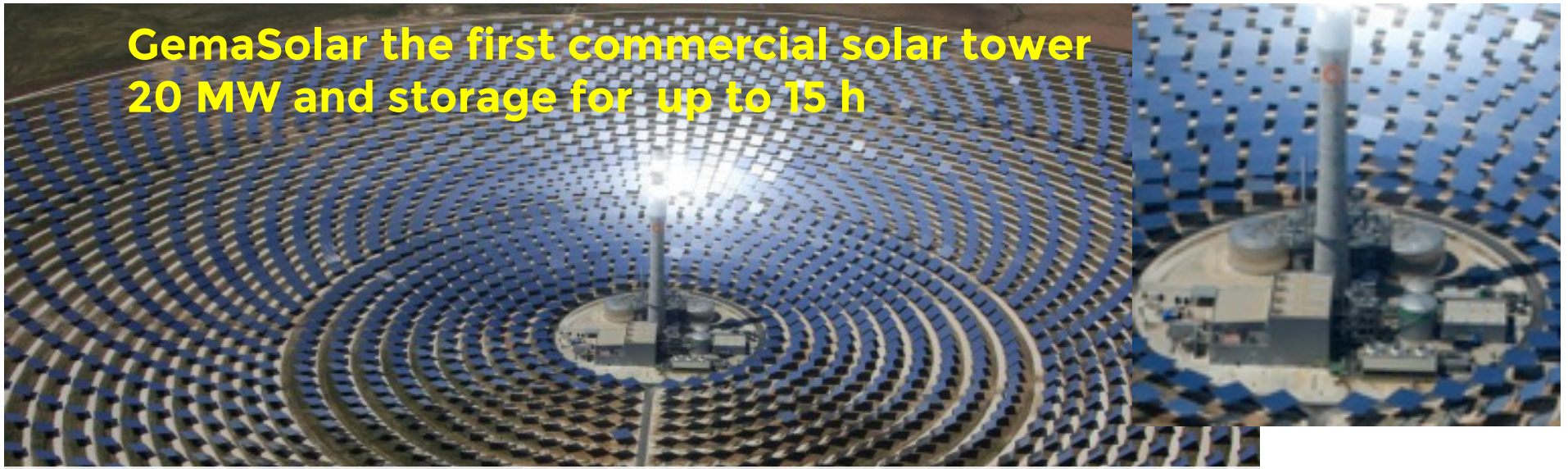
Some Projects in China

Technology	Project Name	Status	PCOD	Capacity (MW)
Parabolic trough	CGN Delingha	Under construction	June 2018	50
Parabolic trough	CNNC Royal Tech	Under construction	End 2018	100
Parabolic trough	Jinfan Akesai	Under development	End 2018	50
Parabolic trough	Rayspower Yumen	Under construction	-	50
Parabolic trough	Royal Tech Yumen	Under development	End 2018	50
Parabolic trough	Shouhang Dunhuang	Under construction	August 2018	100
Tower	CPECC Hami	Under development	June 2019	50
Tower	PowerChina Gonghe	Under construction	End 2018	50
Tower	Supcon Delingha	Under construction	End 2018	50
Tower	Yumen Xinneng	Under construction	End 2018	50

Source: www.helioscsp.com; www.nrel.gov

CSP Market World-wide

SPAIN - Gemasolar CSP Plant



- Location: Spain with an annual DNI of 2 100 kWh/m²a
- Heat transfer fluid (HTF): Molten salt
- Storage: 2-tank system (hot and cold) for molten salt
- World Record in 2013:
  36 consecutive days of continuous 24 h production

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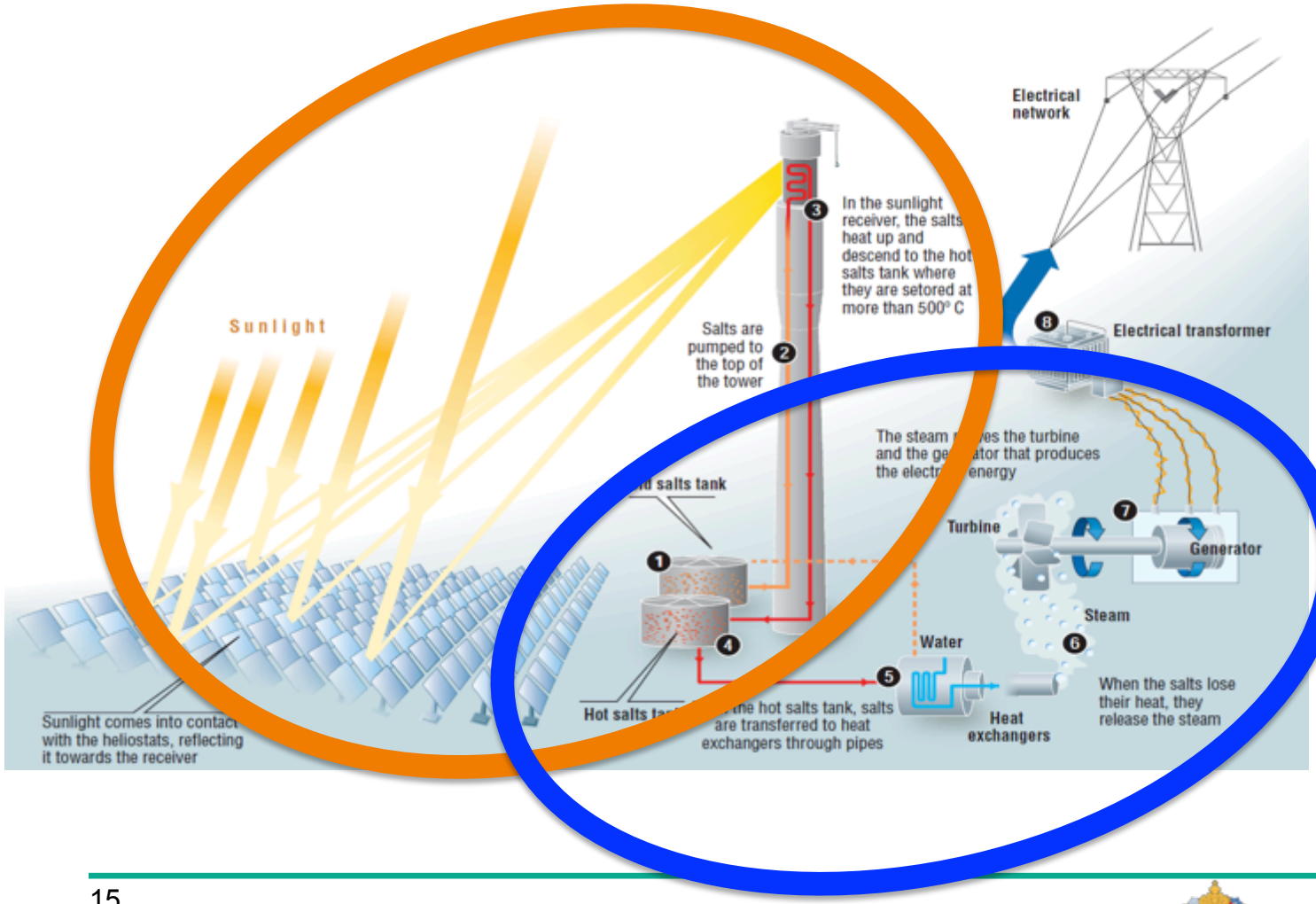
CSP Market World-wide

SPAIN - Gemasolar CSP Plant

Solar tower with molten salt



- **1. loop (solar):** charging the storage system with 565°C HTF
- **2. loop (heat to steam generator):** discharging the storage for steam generation - instead of fossil fired boiler in a conventional power plant

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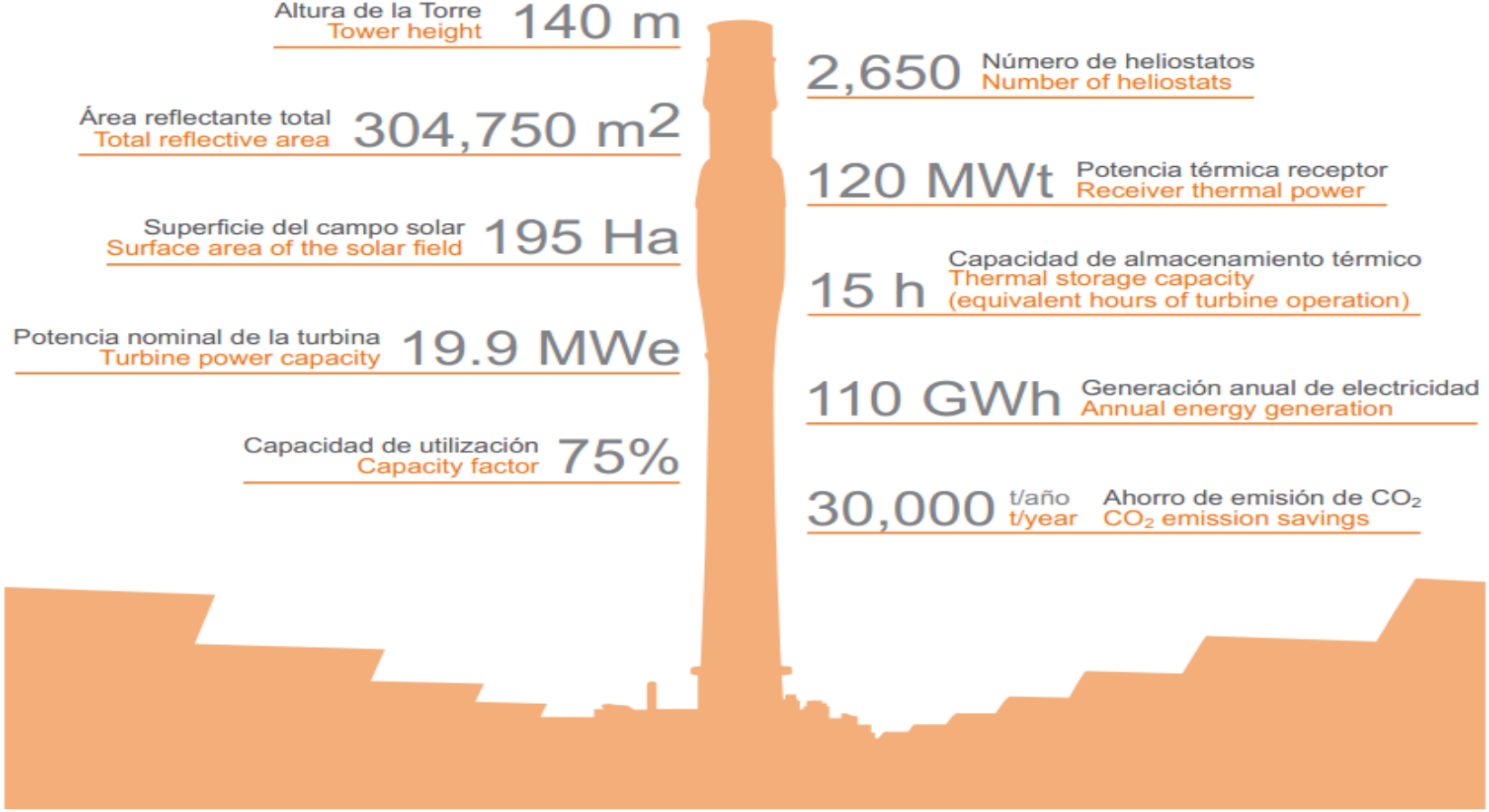
CSP Market World-wide

SPAIN - Gemasolar CSP Plant – additional data



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CSP Market World-wide

CHILE

- **Cerro Dominador plant (Atacama 1)**: A 110 MW CSP tower plant with **17.5 hours of molten salt storage**, together with 100 MW PV Project.
  - **Location: Atacama Dessert**
  - PPA of **$114/MWh**
  - **Status of the plant:** under-construction.
  - Predicted date to be finished: **2019**
  - First Solar Tower in Chile

Image source: cerrodominador.com

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CSP Market World-wide
CHILE

3 Projects of SolarReserve ready to build (under development), waiting for PPA

- Copiapó: **260 MW** CSP tower technology with Molten Salt Thermal Energy Storage of 13h.
  Start year: 2019

- Likana: **World Bid record of USD 48/MWh** for **390 MW** tower CSP project with 13h of molten salts offered by SolarReserve in 2017 for dispatchable 24-hour.
  Start year: 2021

- Tamarugal: **450 MW** tower plant + 13h of molten salt storage.
  Start year: 2021

CSP Market World-wide
MOROCCO

- Aim: 42% installed capacity coming from renewables for 2020
- NOOR I by ACWA:
  - 160 MW Parabolic trough plant + 3h of TES
  - Status: in operation since 2016

Image source:https://www.npr.org

CSP Market World-wide

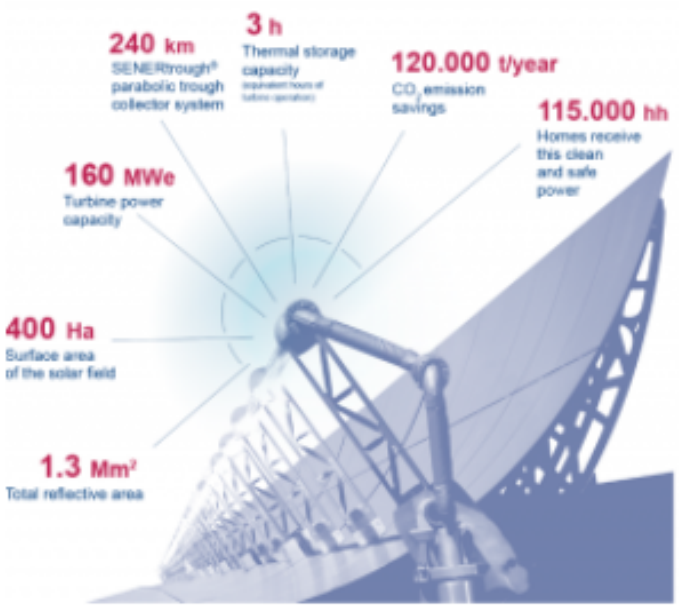
MOROCCO

NOOR II by ACWA:

- 200 MW Parabolic trough plant + 6h of TES
- Status: under construction, expected grid connection: early 2018

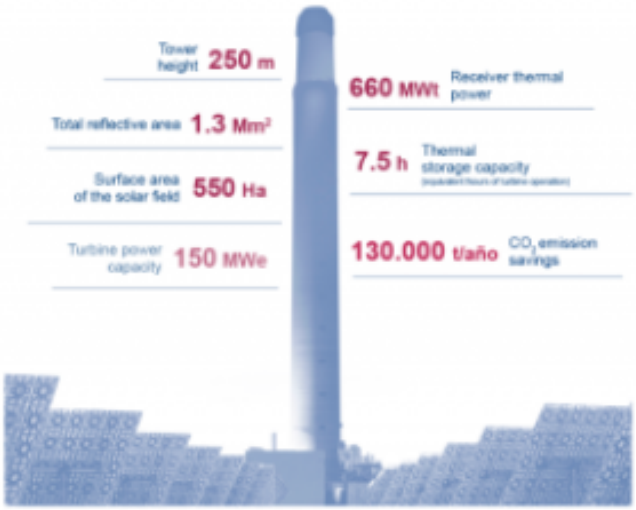
NOOR III by ACWA:

- 150 MW with 250m Tower plant + 7.5h of TES
- Status: under construction, expected grid connection: 2018



Noor 1

Noor 2



Noor 3

Image Source: SENER

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CSP Market World-wide

UAE - United Arabic Emirates

DEWA (Dubai Electricity and Water Authority) CSP plants (700 MW project):

- 1 Project of 100 MW Tower CSP plant + 15h of storage
- 3 Parabolic Trough Projects of 200 MW (600MW) + 10h of storage.
- **Status:** under development
- Bid: **USD 73 /MWh** in September 2017 by ACWA

- **Saudi Arabia** will tender **3.25 GW** of solar power Projects in 2018 (both PV and CSP)

 Source: www.helioscsp.com; www.newenergyupdate.com

CSP Market World-wide

CHINA – Some CSP projects

CGN Delingha 50 MW Parabolic Trough Project

- Expected to be the first comercial Parabolic trough Project in China
- Expected connection to the grid: middle 2018

CNNC Royal Tech Urad 100 MW Parabolic Trough Project

- Under construction, expected connection to the grid: end 2018

CPECC Hami 50 MW Molten Salt Tower Project

- Under construction, expected connection to the grid: 2019

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CSP Market World-wide

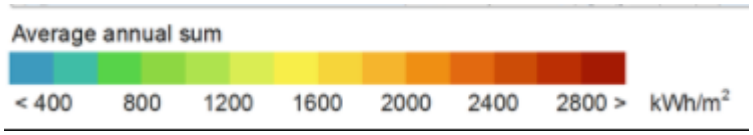
CHINA – Some CSP projects

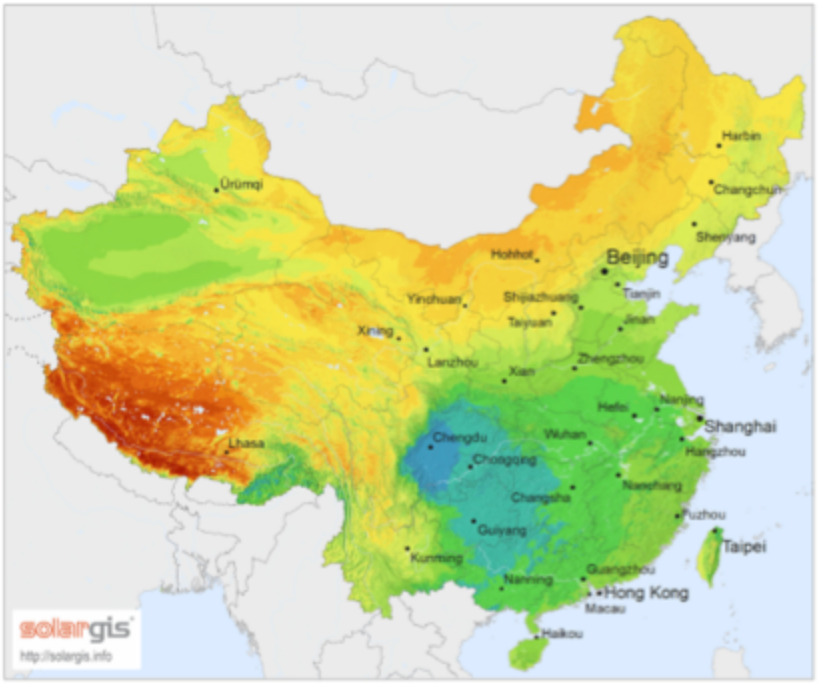
Jinfan Akesai 50 MW Molten Salt Parabolic Trough Project

- Under development, expected grid connection grid: end 2018

PowerChina Gonghe 50 MW Molten Salt Tower Project

- Biddings for construction has been opened, expected grid connection: end 2018





Source:www.helioscsp.com; Image source:SolarGus

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CSP Market World-wide
SOUTH AFRICA

Window 1 (150 MW)

Kaxu – 100 MW trough - Abengoa

Khi – 50 MW tower - Abengoa

Window 2 (50 MW)

Bokpoort – 50 MW trough - ACWA

Window 3 (200 MW)

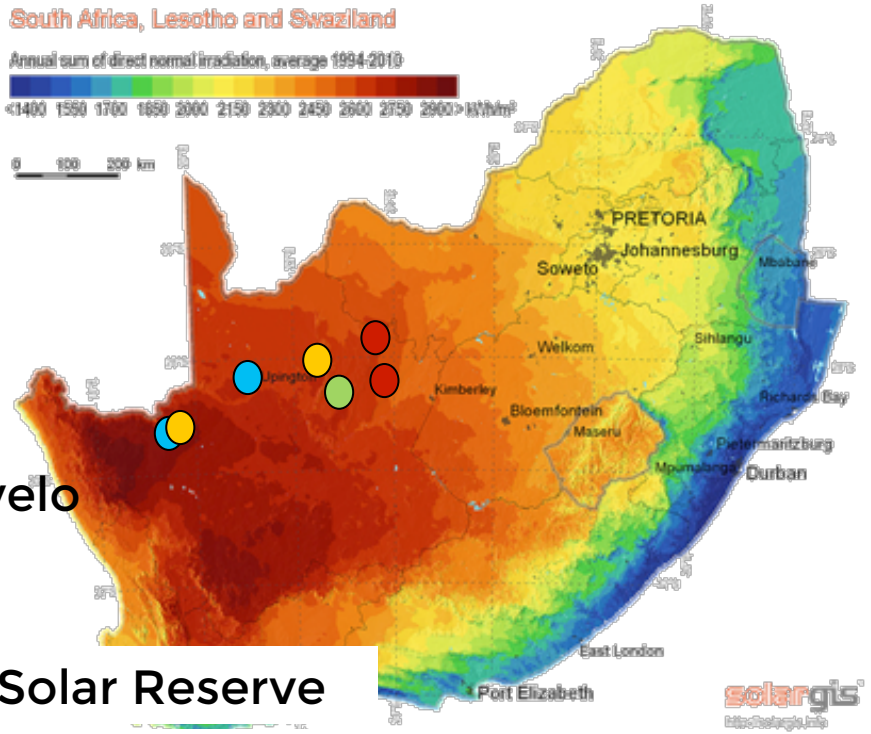
Xina – 100 MW trough - Abengoa

Ilangalethu 1 – 100 MW trough - Emvelo

Window 3.5 (200 MW)

Kathu – 100 MW trough - Engie

Redstone – 100 MW tower – ACWA+Solar Reserve



Window 4.5 (450 MW): All waiting for response from government !

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CSP Market World-wide

SOUTH AFRICA

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CSP Market World-wide

SOUTH AFRICA

Khi operating since beginning of 2016

- **Owners**: Abengoa Solar and IDC
- **Location**: Upington, South Africa
- **Technologie**: Solar power tower
- **Power**: 50 MW_e
- **Commission date: Begin** 2016
- 24h production possible with 2.5 h storage

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CSP Market World-wide

SOUTH AFRICA

Bokpoort

- **Owners: ACWA Power**
- **Location**: Groblershop, South Africa
- **Technologie**: Parabolic trough
- **Power**: 50 MW_e
- **9.3 hour storage system**
- **Commission date:** Begin of 2016
- 14 consecutive days of power production

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CSP Market World-wide

SOUTH AFRICA

Xina Solar One:

100 MW Parabolic Trough Project with 5.5h of storage

- 8.2 m wide trough
- Status: operational since 2017
- Developers: Abengoa Solar

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CSP Market World-wide

AUSTRALIA

Aurora CSP plant near Port Augusta: 150 MW tower CSP project incorporating 8 hours of molten salts storage (1100 MWh of TES capacity).

- **Is a world record low price for CSP:** between USD **$60 and $61** per MWh. **SolarReserve** has broken a solar price record with its 20-year contract (Augusta) to supply the South Australian government with dispatchable solar
- **Project Status**: Generation Project Agreement (GPA) with the State Government of South Australia signed August 14, 2017.
  - Project permitted in October 2017
  - Final approval expected in the first hal of 2018
  - Construction will start after approval
  - Commisioning expected in 2020

Source: www.helioscsp.com

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CSP Market World-wide

DENMARK

Aalborg CSP-Brønderslev with ORC project

- **16.6 MW parabolic trough** plant without TES
- Solar field inlet and out temperatatures: 252/312°C
- Production of both heat and electricity with an **Organic Rankine Cycle**

Source: www.nrel.gov; Image source: www.aalborgcsp.com

CSP Market World-wide
ISRAEL

Ashalim CSP Plant in Negev Desert - 231 MW Project divided in:

- **110 MW Parabolic Trough Project** + 4.5h of MS TES.
  - **Status:** under development
  - Developers: Negev Energy Ltd (Abengoa and Shikun & Binui)
  - Start of commercial operation: 2018

- **121 MW Tower Projects** (without TES) highest tower (250m) until now in the world
  - Status: under construction;
  - Developers: Megalim Solar Power Ltd
  - Start of commercial operation: early 2018

Source: helioscsp.com

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CSP Market World-wide

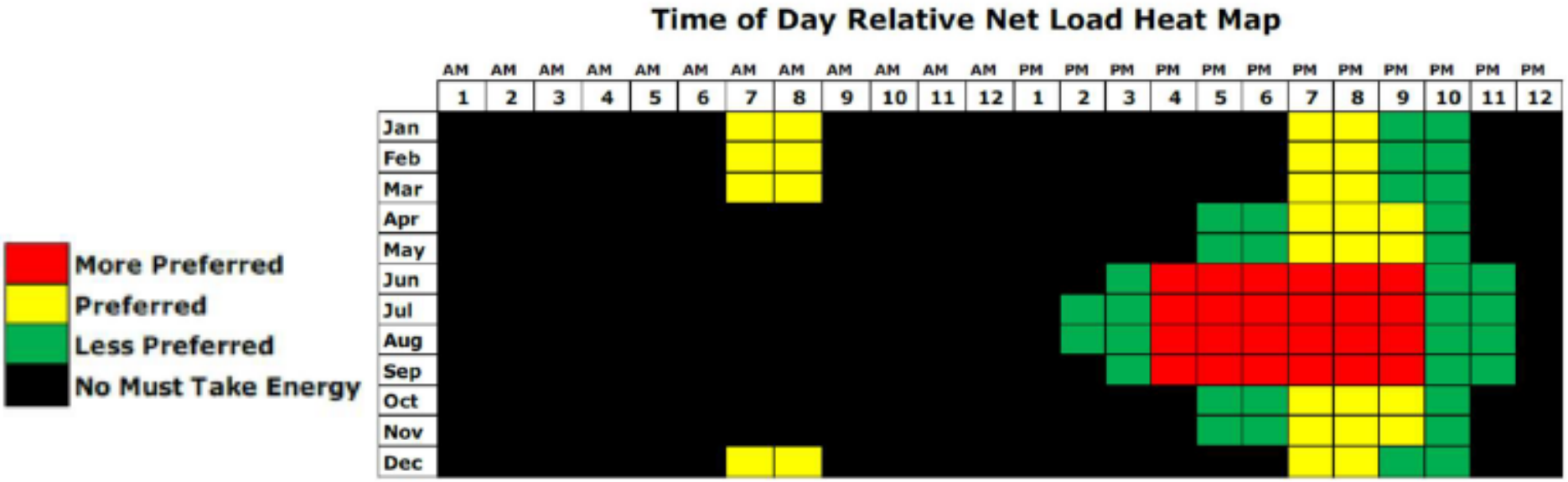
ISRAEL - Images of Ashalim CSP Plant

Source: http://www.brightsourceenergy.com/

CSP Market Word-wide

New concept of CSP operability: Dispachable Solar Power (DSP) plant

- **DSP** plant uses conventional MS Tower Technology
- **DSP** studied for specific cases in USA with sucessful results
- **DSP** plant is a CSP Peaker Plant with flexible operation
- It has only low **solar multiple**



Source: Hank Price – Solar Dynamics LLC

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CSP Market Word-wide

New concept of CSP operability: Dispachable Solar Power (DSP) plant

- **Future Electricity Markets** need flexible renewable peaking capacity
- Molten-salt technology can be used as "**dispatchable solar power**" plants
  - **A reliable source** of capacity
  - **Flexible** operation possible also as a peaker
  - **Competitive** with new fossil power plants
- **Different regions will have different needs:**
  - **Peaker** CSP plants may make sense in some regions
  - **Baseload** CSP plants will continue to make sense in other regions
  - Some regions will need **both**

Source: Hank Price - SolarDynamics

CSP Market Word-wide
Conclusions

- **CSP prices** offered in auctions have decreased considerably **below USD50/MWh in Chile**
- **Solar Tower Technology** is catching up
- **Highlighted countries with ongoing CSP projects:** Chile, Morocco, Australia, UAE, South Africa and China
- **China** seems to become the country with most CSP capacity installed in the world

➢ **CSP is the future of large scale electricity production !**

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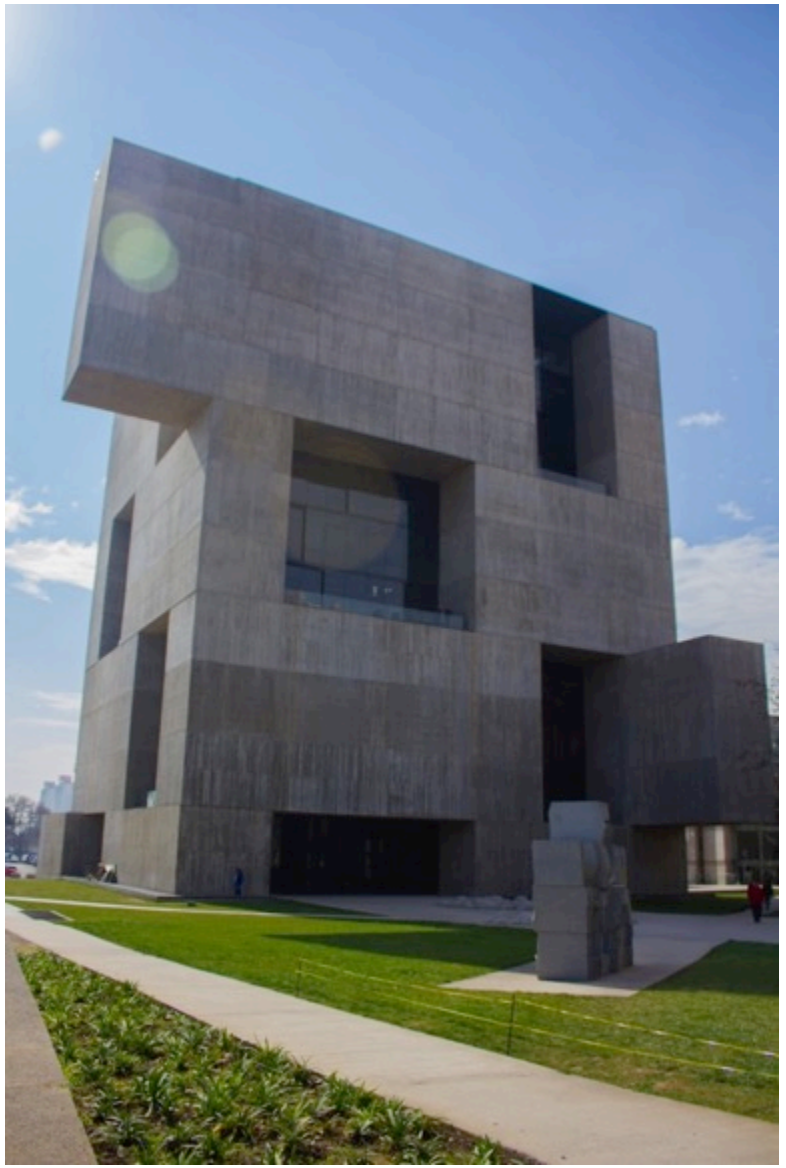
For a Solar Future of Chile



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