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Zusammenarbeit (GIZ) GmbH



***Concentrating Solar Power, a key option for energy transition in Chile  
Launching of CSP Association (ACSP)***

# **CSP and Thermal Energy Storage**

## **- the missing link for Energy Transition from fossil to dispatchable Renewable Power**

Dr. Michael Geyer, Senior Advisor

Seminario “Concentración Solar de Potencia, una  
Opción Clave para la Transición Energética”  
Santiago de Chile, April 25, 2019

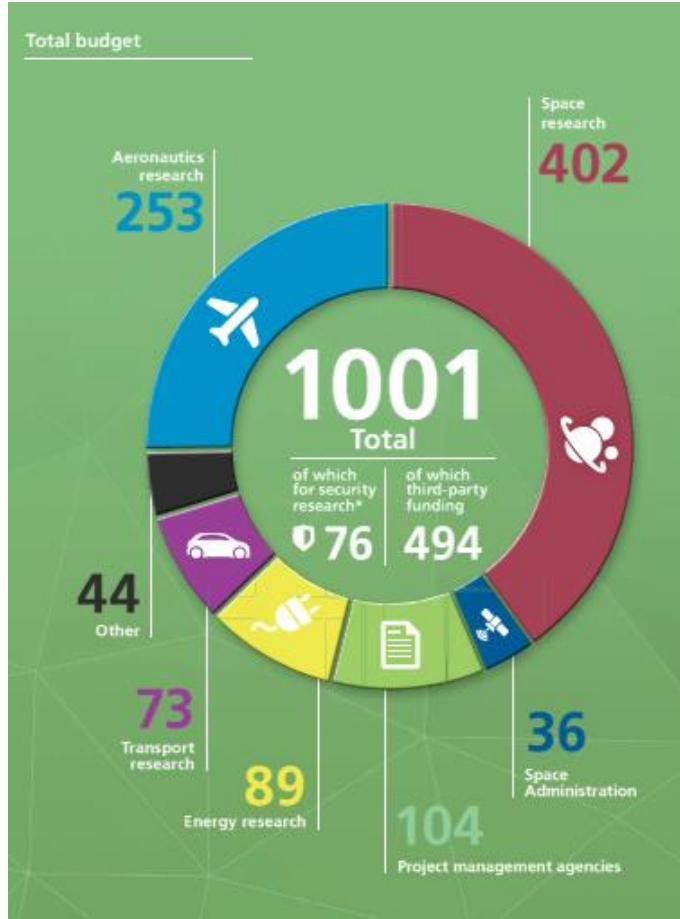


Wissen für Morgen



# DLR in facts and figures

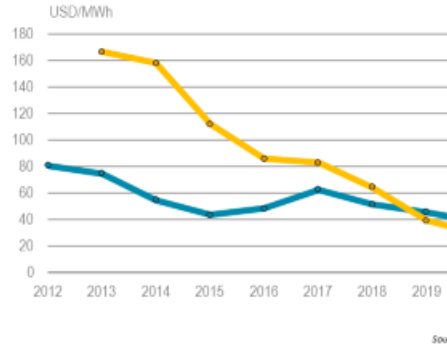
20 sites, 40 institutes and facilities, the Space Administration and Project Management Agencies



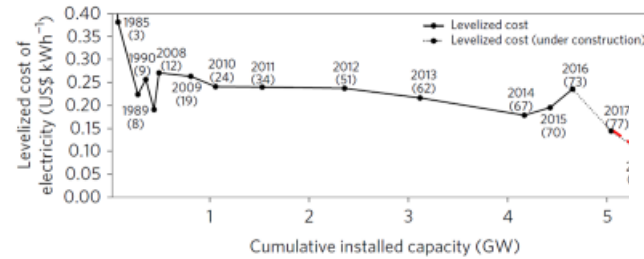
# Mark showed us experience, cost decrease and global expansion of CSP

## Competition driving down costs of PV and wind

Announced wind and solar PV average auction prices by commissioning date

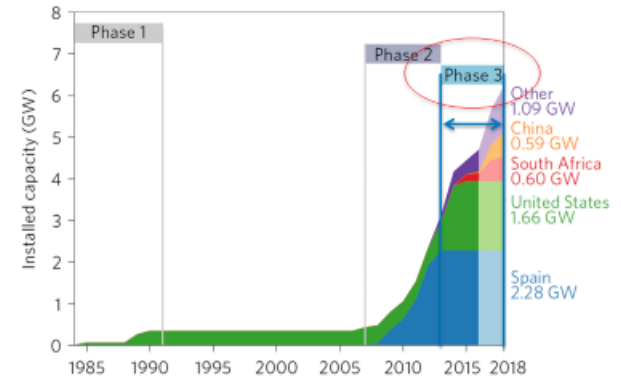


## Cost Reduction Impact of Policy and Learning



Source: Lilliestam et al., Empirically observed learning rates for concentrating solar power and their responses to regime change\*, Nature Energy, 2017

## Global Expansion of CSP

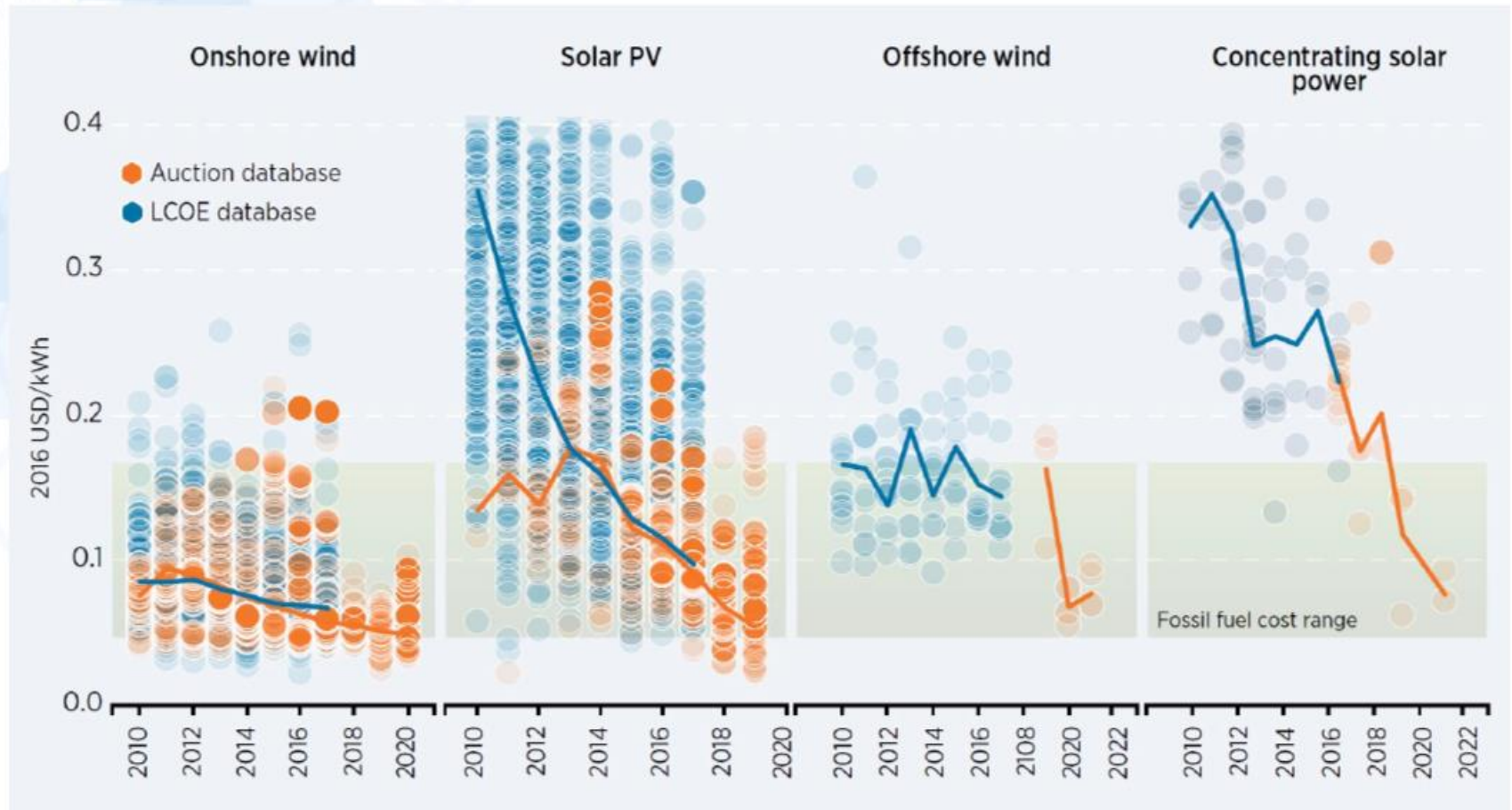


Source: Lilliestam et al., Empirically observed learning rates for concentrating solar power and their responses to regime change\*, Nature Energy, 2017

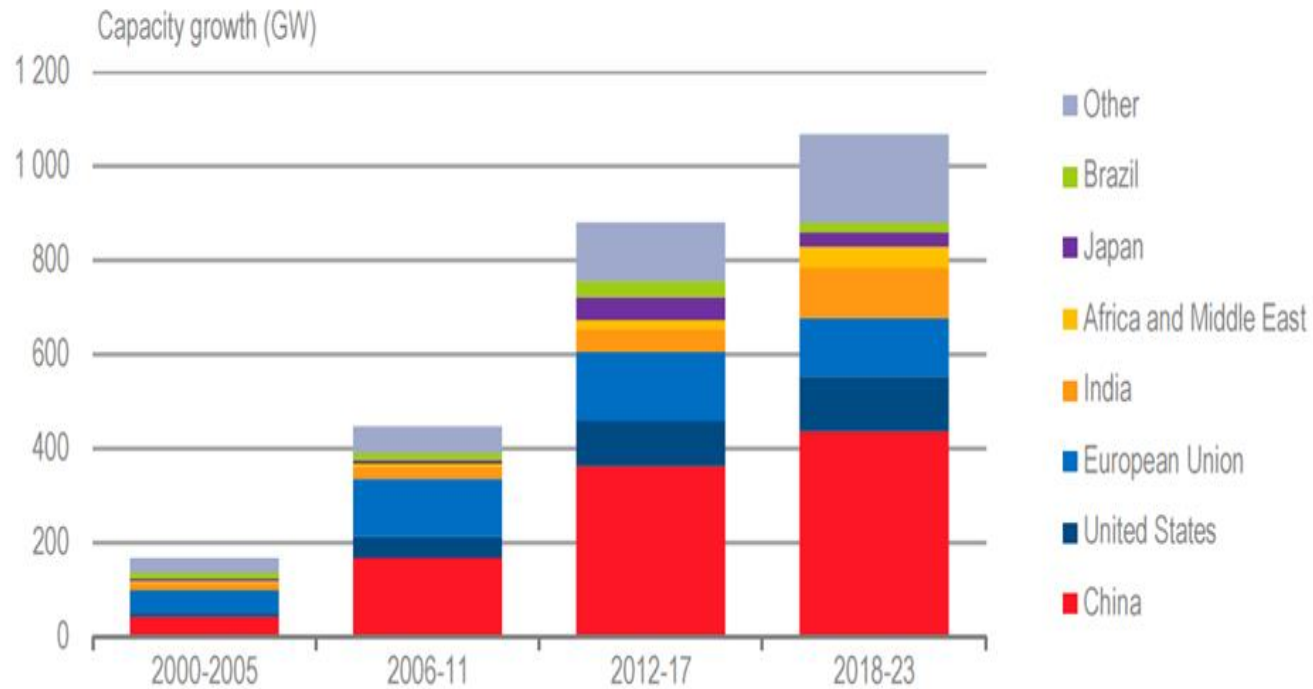


# Worldwide lesson is: Solar and wind power have become competitive with fossil power worldwide

## Solar & Wind: LCOE/Auction Price Evolution Overview IRENA International Renewable Energy Agency



# Renewables have become least cost electricity generation option for many countries – they will have fastest growth from now on



Source: Historical capacity data for OECD countries based on IEA (2017), *Renewables Information 2017*, [www.iea.org/statistics/](http://www.iea.org/statistics/).

- Renewables will have the fastest growth in the electricity sector, providing almost 30% of power demand in 2023, up from 24% in 2017.
- During this period, renewables are forecast to meet more than 70% of global electricity generation growth, led by solar PV and followed by wind, hydropower, and bioenergy.
- To make such variable power generation dispatchable, the need for storage grows simultaneously



# Energy transition from fossil to renewable has started – for economic and environmental reasons

## GLOBAL ENERGY TRANSFORMATION

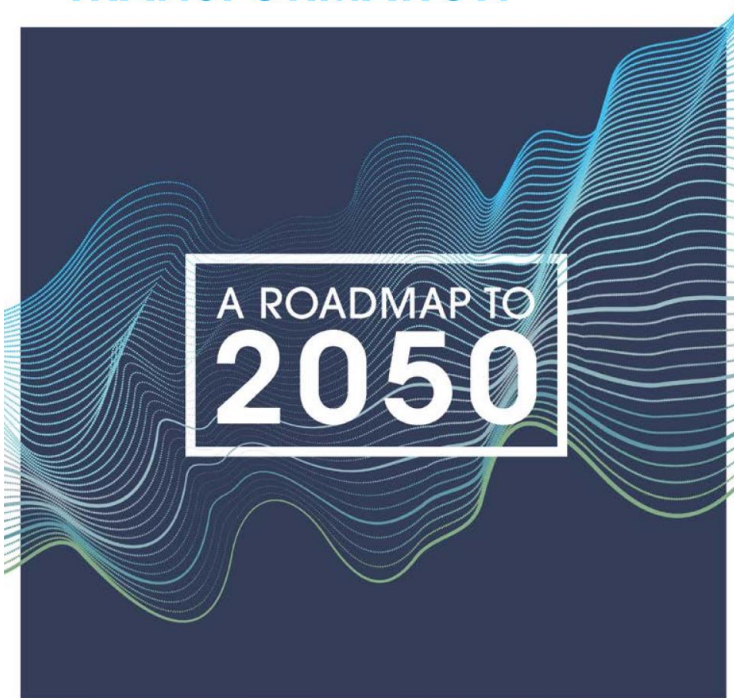
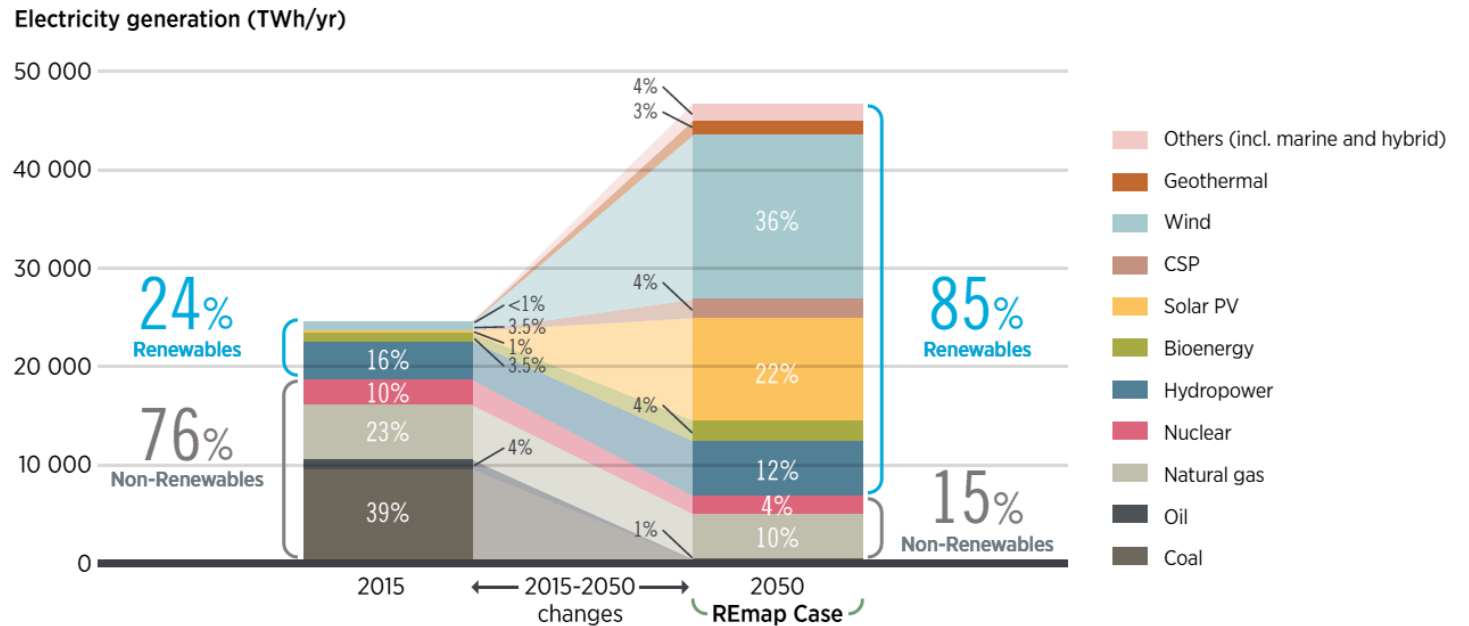


Figure 15. The rising importance of solar and wind energy in the power sector  
*Breakdown of electricity generation, by source (TWh/yr)*

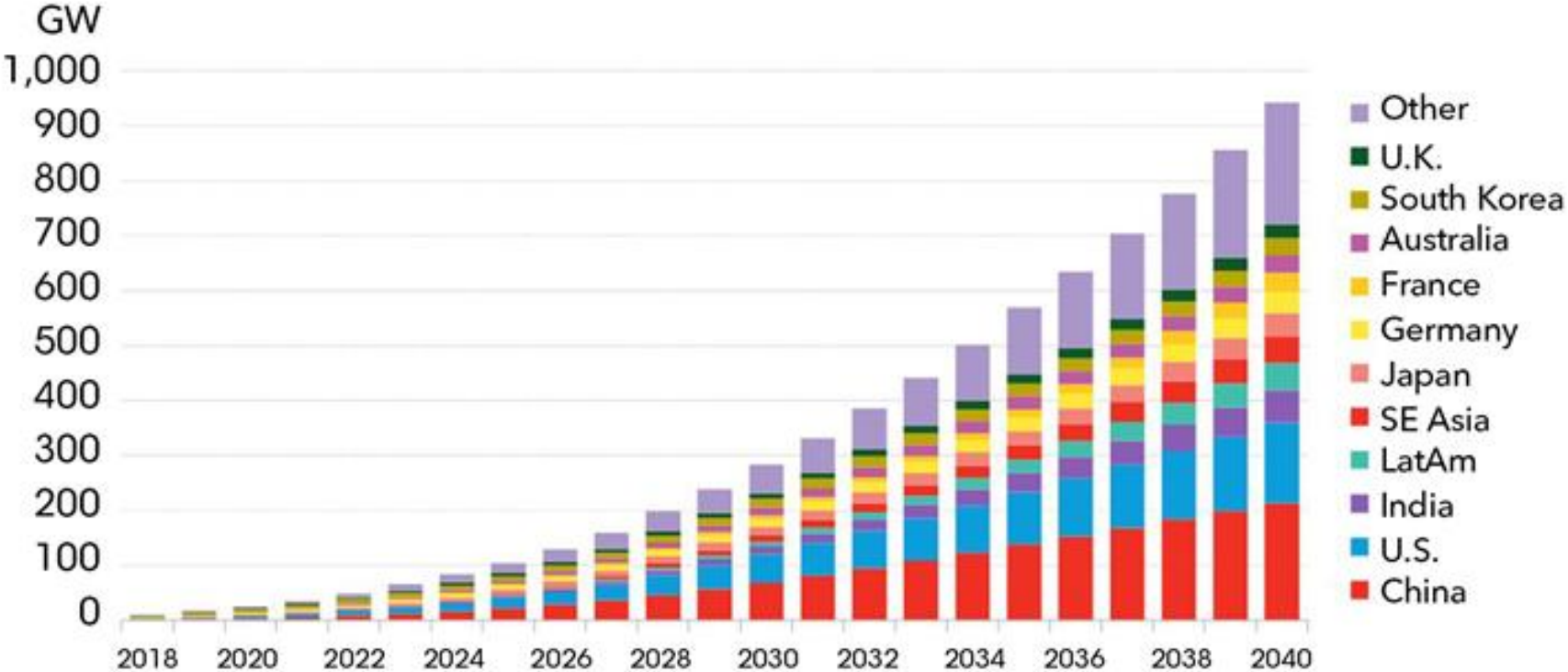


**Gross power generation will almost double with renewable energy providing 85% of electricity.**



# Techno-economic challenge is now to make variable renewable fully dispatchable – this requires cheap and reliable electricity storage

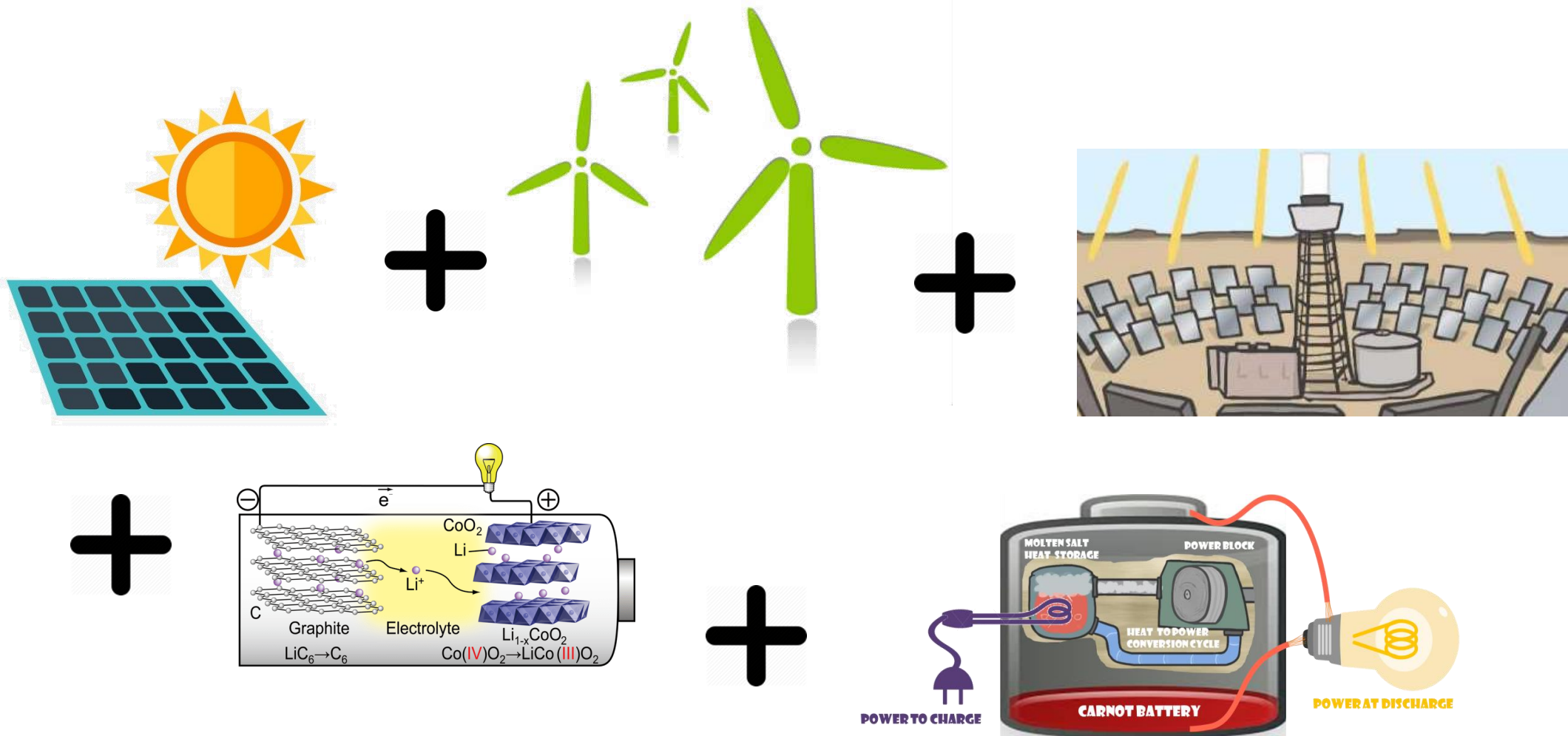
## Global cumulative storage deployments



Source: BloombergNEF



Developers have become experienced and very creative  
- to find least cost “hybrid” renewable generation system mixes with storage





# A 12.5h x 600MW molten salt storage with PTCs has been awarded in Dubai - to complement PV day production between 16:00pm and 10:00am

**600MW = 3x200 MW Dubai PTC**  
**Sponsor ACWA; Technologist Abengoa;**  
**EPC Shanghai Electric + Abengoa**  
**3x2.900.000m<sup>2</sup> parabolic trough**  
**11 hours storage; >500.000tm molten salts**  
**35 year PPA**  
**0.073USD/kWh**  
**Break ground 2018**  
**COD 2021**



**Location: Dubai, UAE (DNI app. 2.000kWh/m<sup>2</sup>yr)**

The Mohammed bin Rashid Al Maktoum Solar Park is the largest single-site solar park in the world, with a planned capacity of 1,000MW by 2020, and 5,000MW by 2030, with a total investment of USD 13.7 billion.

The solar park will be implemented in several phases and use a range of photovoltaic and concentrated solar power technologies.

Project	Capacity	Status
Phase I EPC	13 MW PV	Operational
Phase II IPP	200MW PV	Operational
Phase III IPP	800MW PV	Operational/Under Construction
Phase IV	700MW CSP	Under Construction
Phase V	300MW	2019 Development
Future Projects	3,000MW	Planning Phase



**Dubai set for world's cheapest night-time solar power of 7.3UScent/kWh for 700MW solar CSP Project**



**Dubai gets record-low bid of 2.99UScent/kWh for 800MW solar PV Project**

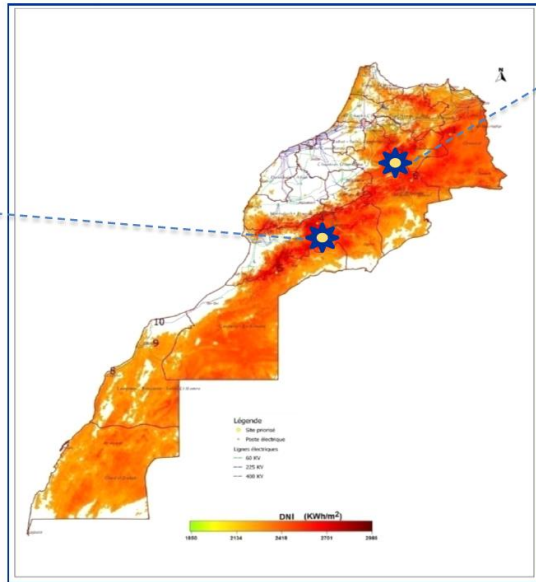


**Combination of CSP and PV gives Dubai world's cheapest 24 hour dispatchable solar power at an average Price of some 5UScent/kWh!!!**

# Upcoming: 2x 150-190MW hybrid CSP&PV projects at Midelt, Morocco

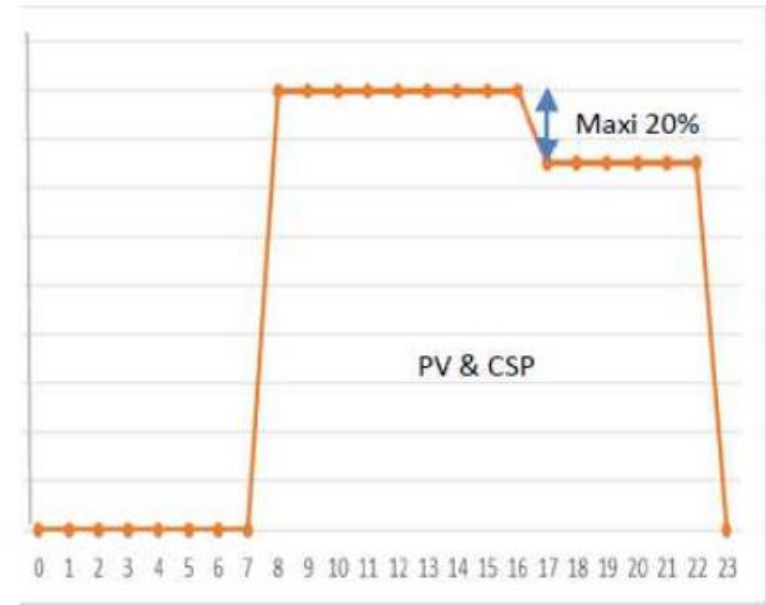
**2. NOOR Tata**

- A combination of CSP and PV plants to be developed
- Call for expression of interest to be launched in 2016



**1. NOOR Midelt**

- A combination of CSP and PV plants to be developed
- Call for expression of interest launched in 2015
- Request for qualification & Tender process to be launched in Q2 2016



	Peak	Shoulder	Off peak
Tariff	100%	85%	0%
Hours per day	5	From 11,5 to 13,5 depending on the month	From 7,5 to 5,5 depending on the month
Time	Varies from 17:00 -22:00 in winter to 19:00 - 00:00 in summer	Varies from 7:30 -17:00 in winter to 05:30 - 19:00 in summer	Rest of the day



# Chile's first step to hybrid PV-CSP plants: 100MW PV and 110MW CSP Cerro Dominador



# Next 110MW Cerro Denominador (formerly Atacama-1), Atacama Desert Chile with 17.5 hour 565°C storage

**110 MW Cerro Denominador (Atacama-1)**  
Sponsor EIG; Technologist Abengoa; EPC Abengoa + Acciona  
Molten Salt Tower with 1.484.000m<sup>2</sup> heliostat field  
290°C to receiver; 565°C receiver outlet

Storage  
Storage  
Planned

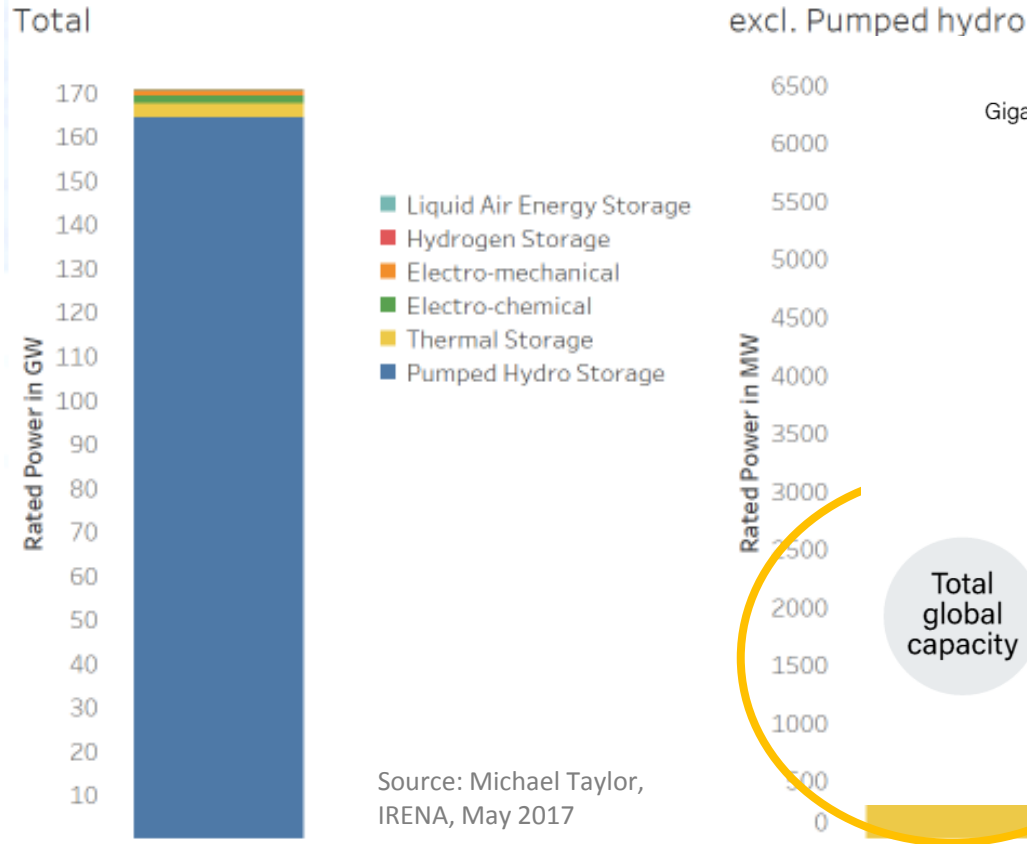


**Location: Calama , Chile (DNI 3.300kWh/m<sup>2</sup>yr)**

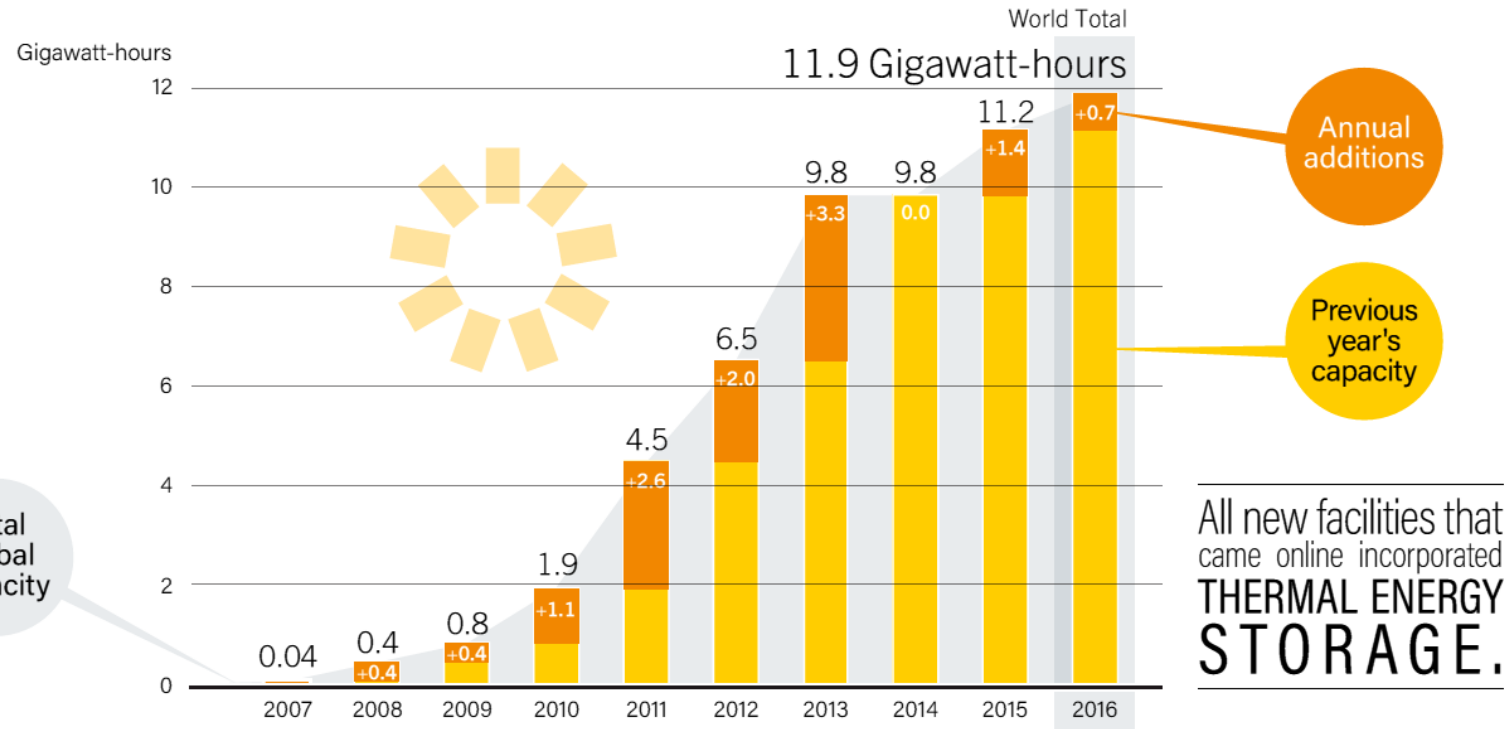


# By 2017 there was more molten salt storage than stationary electro chemical storage

World Storage Capacity in MW by 2017



World Thermal Energy Storage Capacity in GWh by 2016



Source: REN21. 2017. Renewables 2017 Global Status Report (Paris: REN21 Secretariat). ISBN 978-3-9818107-6-9

[http://www.ren21.net/wp-content/uploads/2017/06/17-8399\\_GSR\\_2017\\_Full\\_Report\\_0621\\_Opt.pdf](http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf)

<https://www.irena.org/-/media/Files/IRENA/Costs/Slides/Battery-storage-Council-23-May-2017-MICHAEL-TAYLOR-PDF.pdf?la=en&hash=B61257FC3AB1AF0C516EA8D241890DD426980974>



# Advantages of molten salt thermal storage over batteries and pumped hydro



- Low cost – its components are mass used as fertilizer
- Inert – low corrosion with carbon steel
- Non Toxic / non penetrating in ground soil – its freezing at contact
- Durable – good for 35 years charge discharge cycles
- Capable of achieving high temperatures at ambient pressure
- Can be used as heat transfer fluid and easily exchange heat with other working fluids (water/steam, HTF)
- High mass specific energy density – magnitudes higher than water in pumped hydro and in comparable range of batteries
- Abundant availability
- Reusable





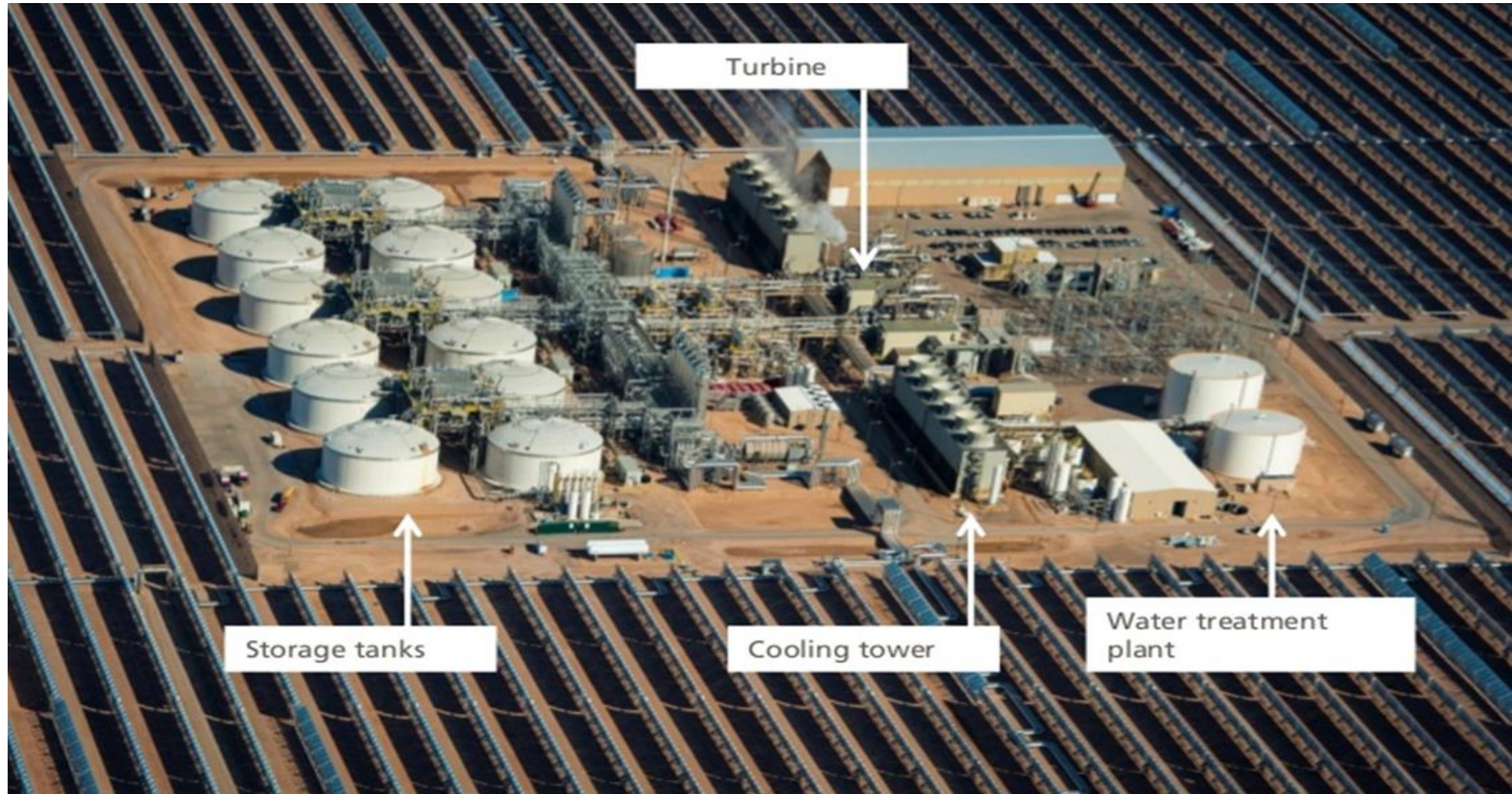
# The CSP MS tower technology is commercially mature - first commercial tower molten salt system started operation in 2011 - Gemasolar in Spain

**19,9 MW Gemasolar**  
**Sponsor Masdar+Sener; Technologist Sener; EPC Cobra + Sener**  
**Molten Salt Tower with 304,750m<sup>2</sup> heliostat field**  
**15 hours storage; 8.500t molten salt**  
**25 year feed in tariff**  
**COD April 2011**



Location: Fuentes de Andalucía , Spain (DNI 2.172 kWh/m<sup>2</sup>kWh/m<sup>2</sup>y)

# In 2012 world's largest molten salt storage system started operation - the 6-hour storage of 280-MW Solana plant in Arizona



Source: Abengoa



# In 2012 world's largest molten salt storage system started operation - the 6-hour storage of 280-MW Solana plant in Arizona

**280 MW Solana**  
Owner Atlantica Yield; Techn  
2.200.000m<sup>2</sup> parabolic trough  
6 hours storage; 125.000tm s  
30 year PPA  
0,14 US/kWh  
Break ground 2010  
COD 2012



**Location: Maricopa County, Arizona (DNI 2.680kWh/m<sup>2</sup>·yr)**

# Most recent: 150MWe molten salt tower at Noor 3 in Morocco - with 7.5 hour 565°C high temperature molten salt storage



Location: Oarzazate , Morocco (DNI 2.635kWh/m<sup>2</sup>yr)



**Most recent: 150MWe molten salt tower at Noor 3 in Morocco  
- with 7.5 hour 565°C high temperature molten salt storage**



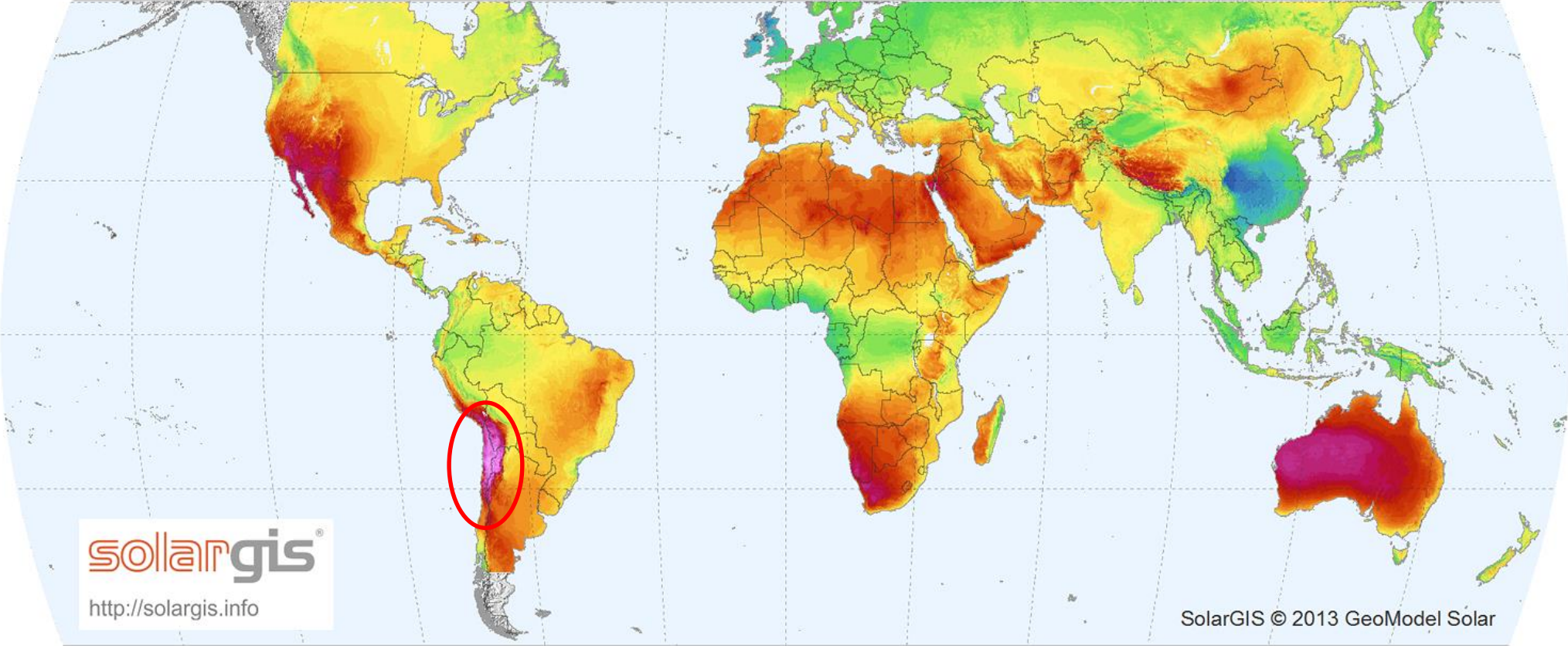
Source: Waberi, Nowa, Jener



# Chile has geographic space and world best direct normal irradiation

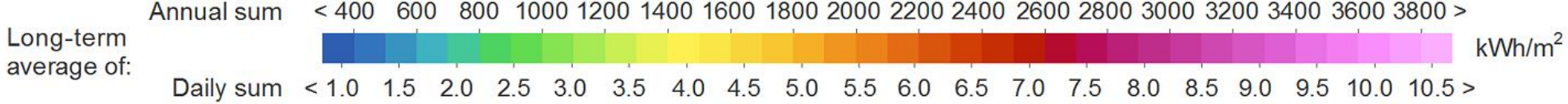
## WORLD MAP OF DIRECT NORMAL IRRADIATION

GeoModel  
SOLAR

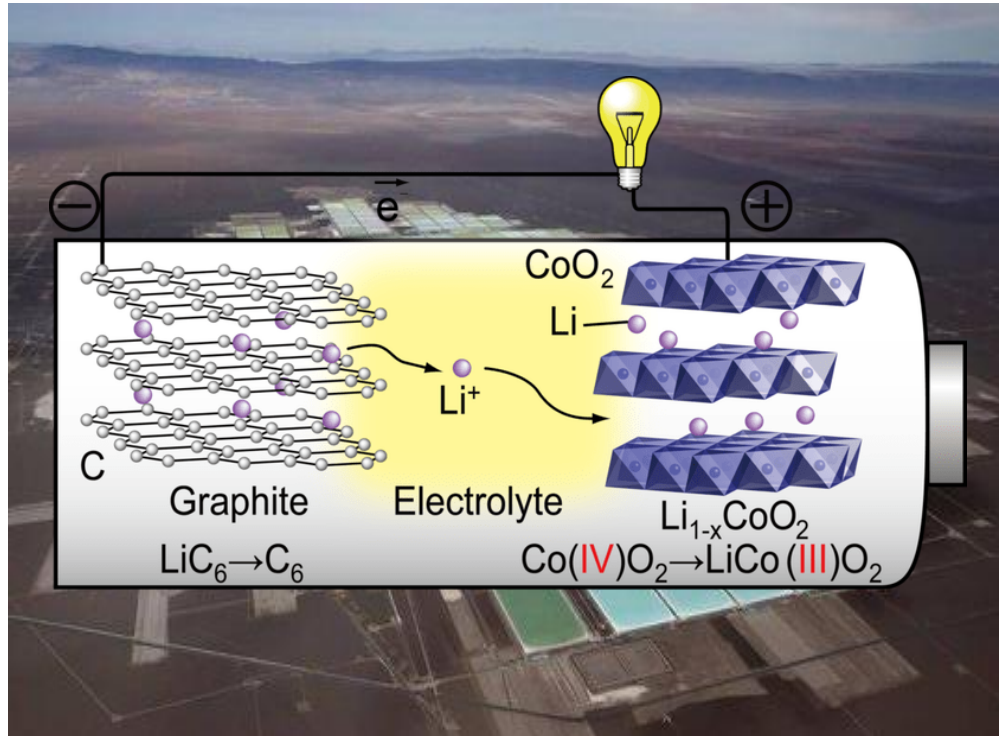


**solarGIS**  
<http://solargis.info>

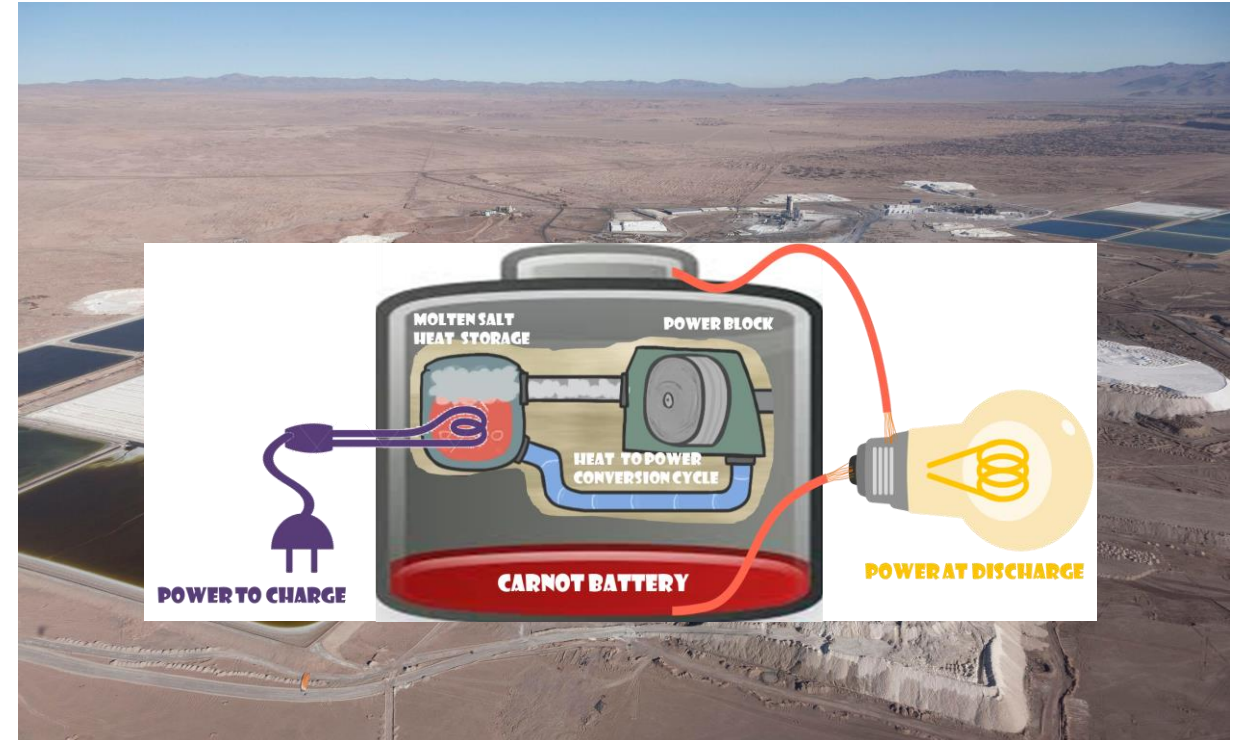
SolarGIS © 2013 GeoModel Solar



# Chile has also world best mineral resources for electricity storage systems

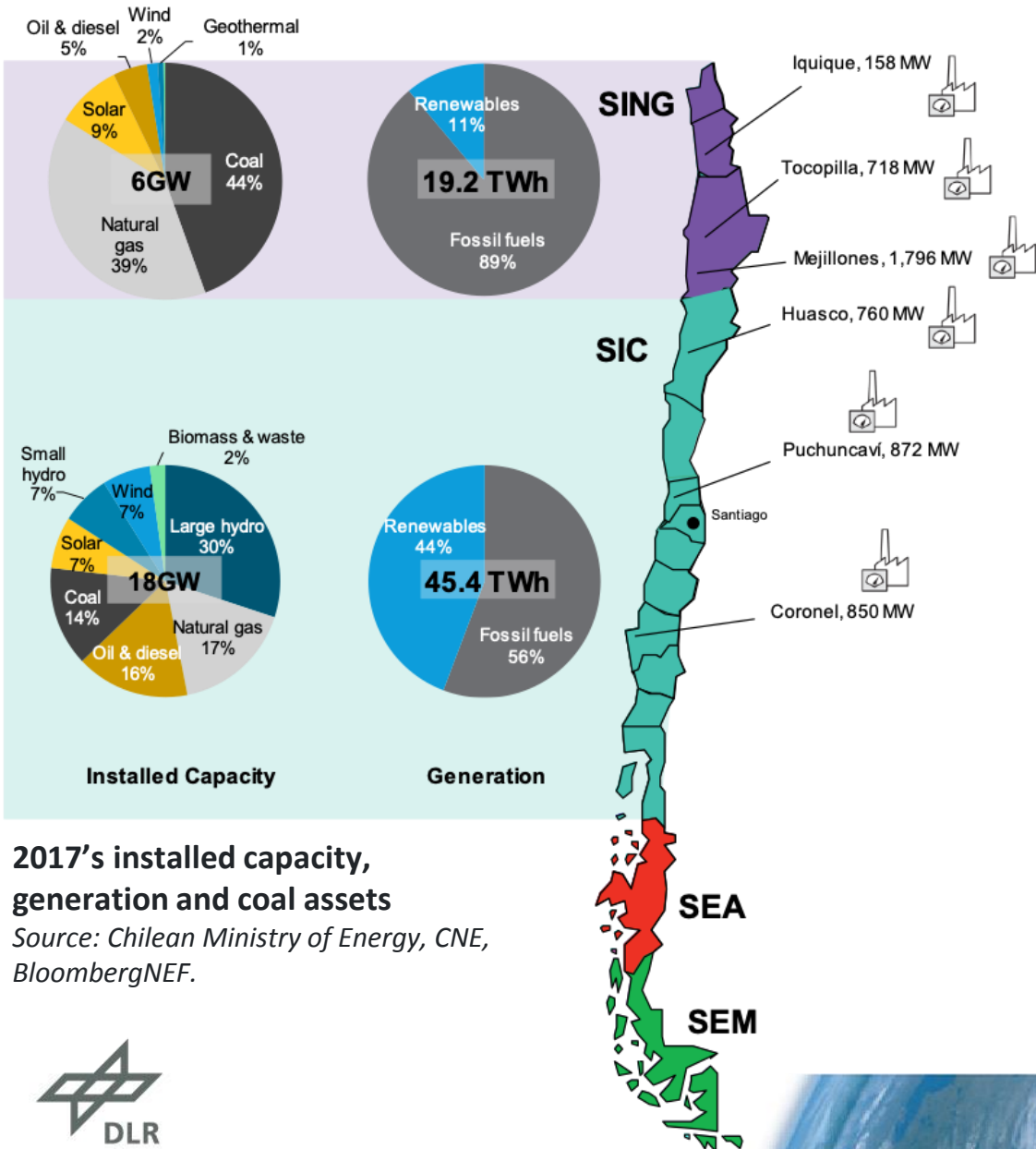


Lithium Mining in the Atacama



Solar Salt Mining ( $\text{NaNO}_3$  and  $\text{KNO}_3$ ) in the Atacama

# Conclusions and Recommendations



- Today, Chile's region with world's highest solar resource has lowest renewable share (9% as of 2017)
- Fossil production cost (coal and natural gas) are high
- Excellent potential to substitute fossil power production by dispatchable solar power production (hybrids of PV, CSP and storage)
- Next PPA tenders should consider a 24hour block for CO2 emission free power generation for a term of 25+ years – that would give developers an opportunity to bid hybrid PV-CSP-storage systems like have been bid in Dubai and Morocco.
- Extending the PPA term beyond 30years like in Dubai would further lower the cost

