SFERA-III

Solar Facilities for the European Research Area

1st Summer School "Thermal energy storage systems, solar fields and new cycles for future CSP plants"
WP1 Capacity building and training activities
Odeillo, France, September 9th-11th 2019

Next generation of CSP plants: technology developments and market opportunities

Manuel Romero, IMDEA Energy, Spain

NETWORKING

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO 823802

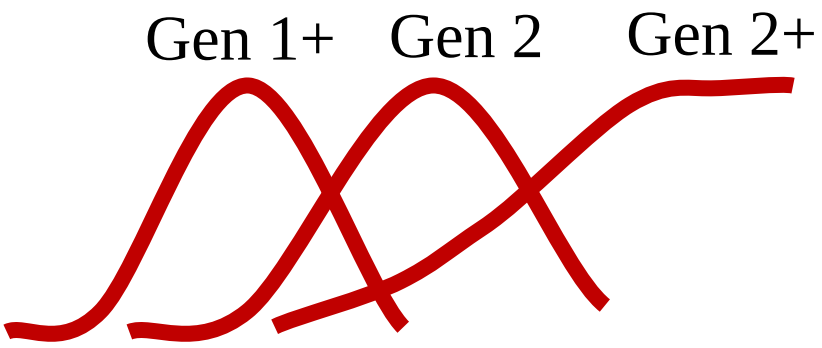
Structure presentation

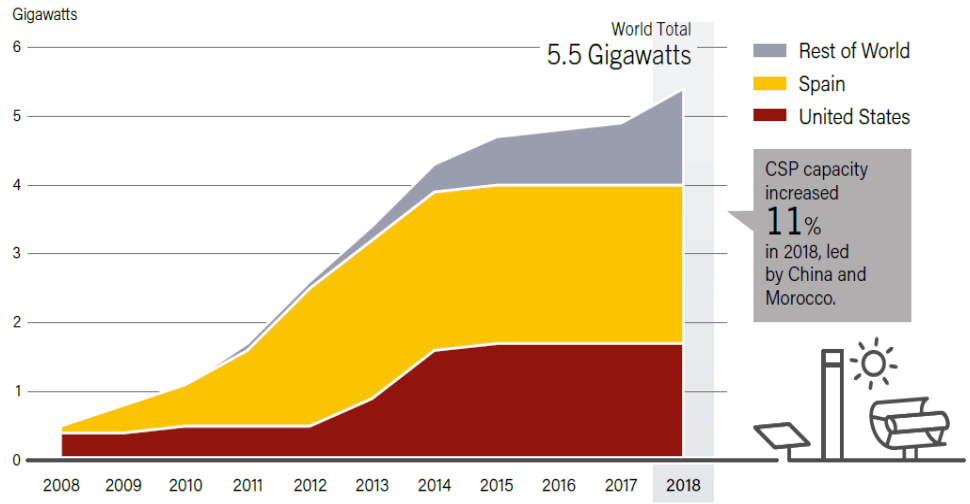
-Where are we coming from?

- Where are we now?

-Where are we going to?

Three market waves in few years!
CSP market experience mostly happened in just 13 years





Spain 2007-2013

- Early market
- Routine operation
- Industrial network
- 50 MW units
- Storage/capacity factor
- Feed-In-Tariff (FIT)

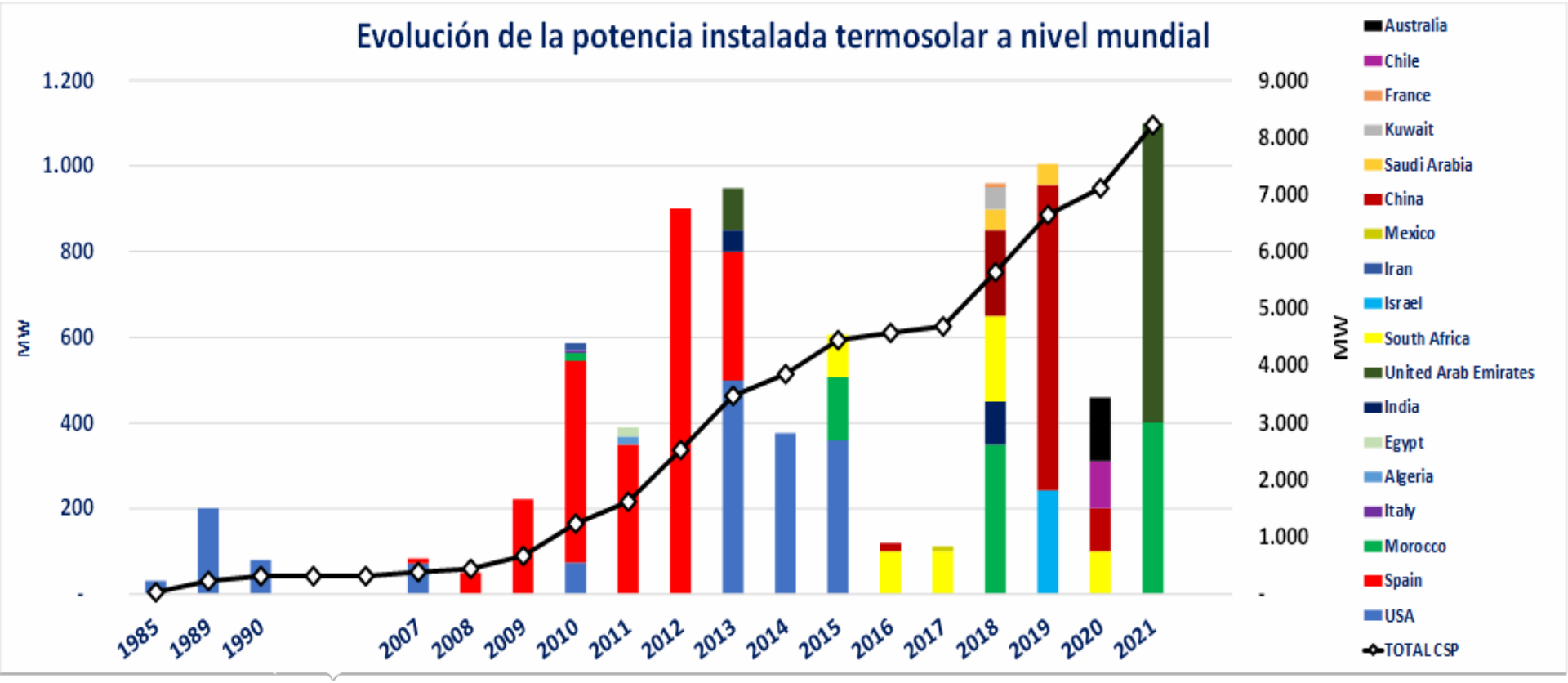
USA 2013-2015

- Scaling-up
- 100-400 MW
- Utility PPA
- Dispatchability value
- Environmental impact

World 2015-2022

- Globalization (MENA, SA, Chile, India, China)
- Indigenization
- Market competition
- Hybridization (CSP/PV, Bio, Fossil)

There are few projects in the short term pipeline but ambitious programs are expected when a thorough approach for the Energy Transition will be done in Sunbelt countries



FRANCE

Slowly, almost imperceptibly, the platform bearing a handful of white powder rose until it reached the focal point of the parabolic mirror overhead. Then, before the eyes of scientists and engineers at the recent Mont-Louis solar energy symposium, the powder suddenly burst into white heat brighter than any diamond.

The powder was zirconium oxide with a melting point

steel daily for it will turn solar heat into the equivalent of 1,000 kilowatts of electrical energy.

Prof. Trombe, who gave these facts in an interview, is a tall, lean man in his forties and far more at home tinkering with a parabolic mirror than presiding over an international symposium. This probably explained the success of the symposium—where tea was brewed in laboratory beakers and the future of solar energy discussed in a handsome 17th century room heated by the crackling logs of a huge fireplace.

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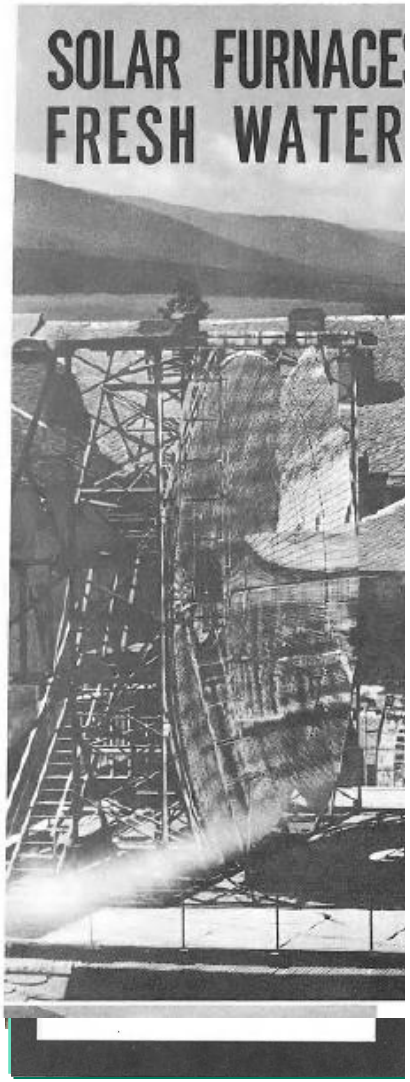


THE WORLD'S FIRST SUN-OPERATED INDUSTRIAL PLANT

ISRAEL

The world's first industrial plant operating on solar energy is now under construction in Israel at ancient Beersheba, the home of the Negev Institute for Arid Zone Research.

This is one of the applications of the solar energy programme which Israel is now carrying out on a broad front described by Dr. Harry Tabor, director of the National Physical Laboratory in Jerusalem and one of the fifty scientists and engineers who participated in the Mont-Louis Solar Energy Symposium.

A lean, alert man who obviously has little use for the "science fiction" approach to solar energy, Dr. Tabor methodically traced, in an interview, the practical steps which his sun-baked country is taking to put the sun to work.

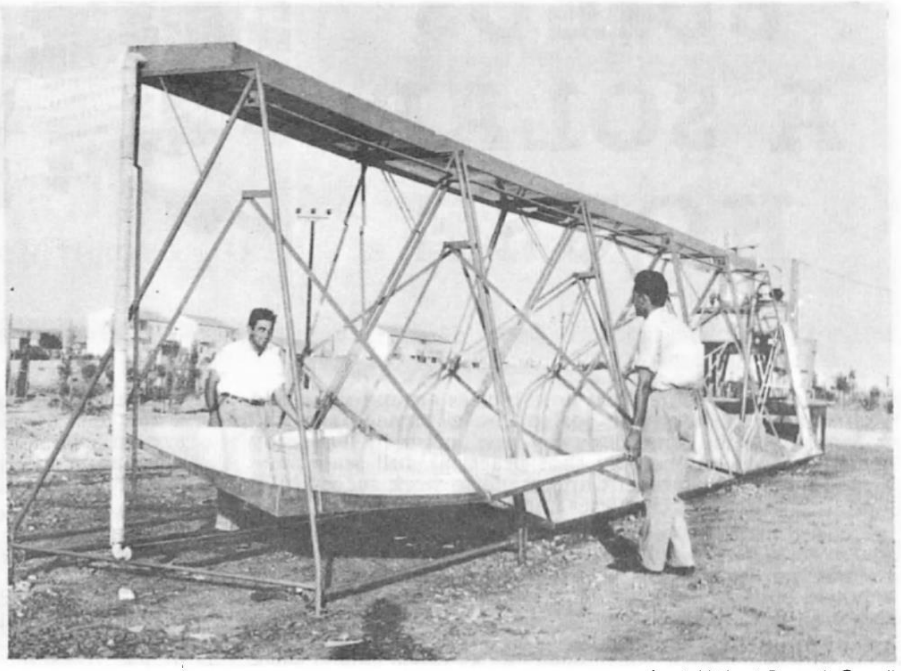
"We are trying to answer four questions at the Negev Institute", he stated, and then he ticked them off :

— Can we use solar energy to cool houses ?

— Can we use solar energy to generate steam for a factory ?

— Can we use it to run a small power unit for farmers ?

— What are the long-term prospects of building a solar power station ?



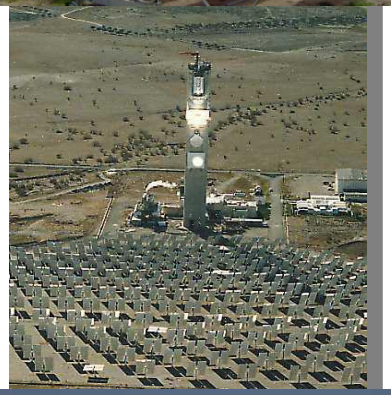
Israel National Research Council

FUEL-POOR BUT SUN-RICH, Israel has embarked on a broad programme of solar energy research including the development of steam for industries and the production of small power units. At the Negev Research Institute, Israeli scientists have built the new type of solar energy collector unit shown above. This consists of simple curved mirrors which reflect heat upwards to collectors fixed overhead. Use of black surfaces cuts heat losses by about four fifths, enabling unit to compete with more expensive systems. Five hundred units will save about 500 tons of fuel oil a year.

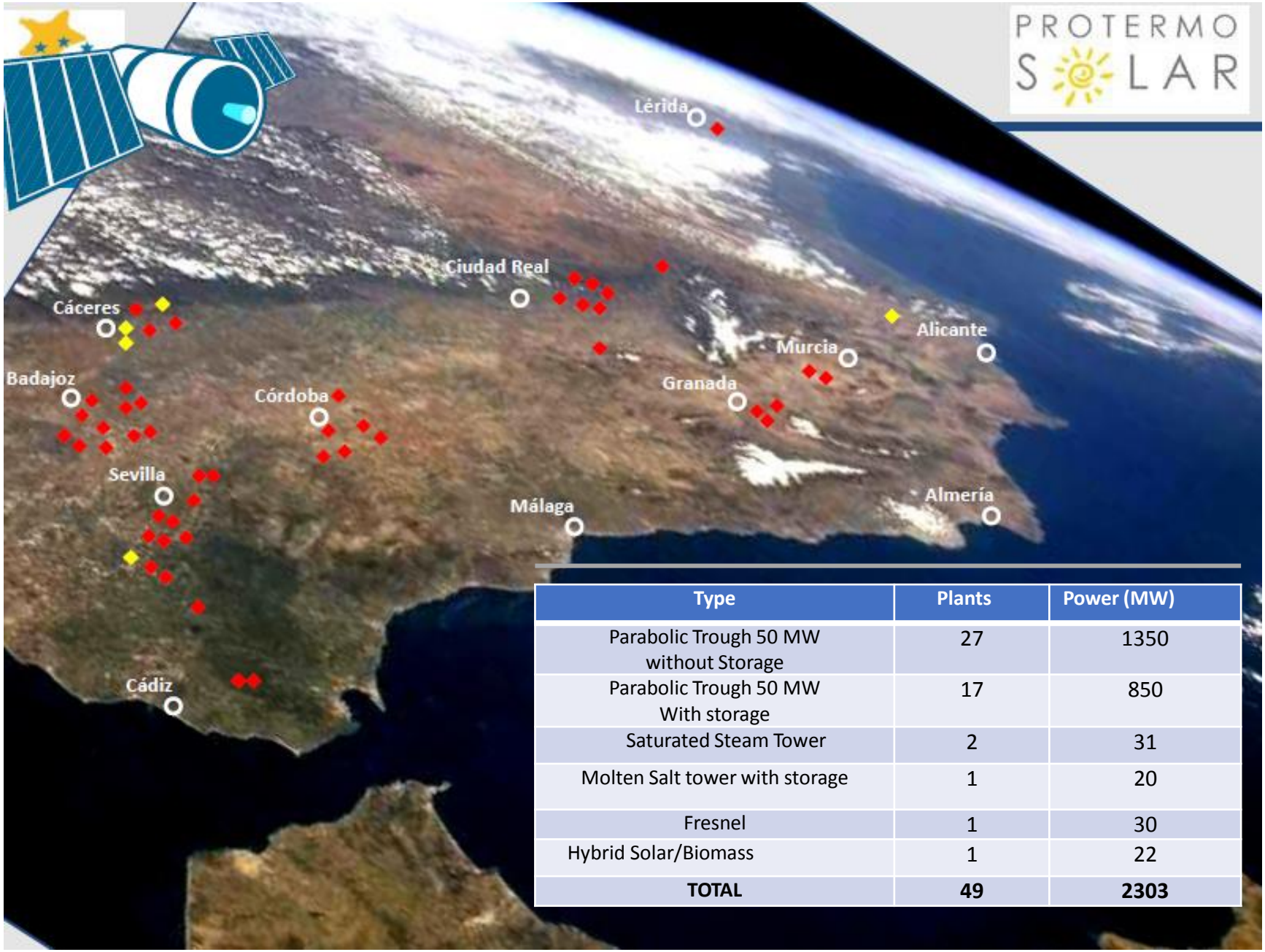
Gen 1 → Gen 1+

Decades of R&D leading to early markets

Spain 2007-2013



Early market
Routine operation
Industrial network
50 MW units
Storage/capacity factor
Feed-In-Tariff (FIT)



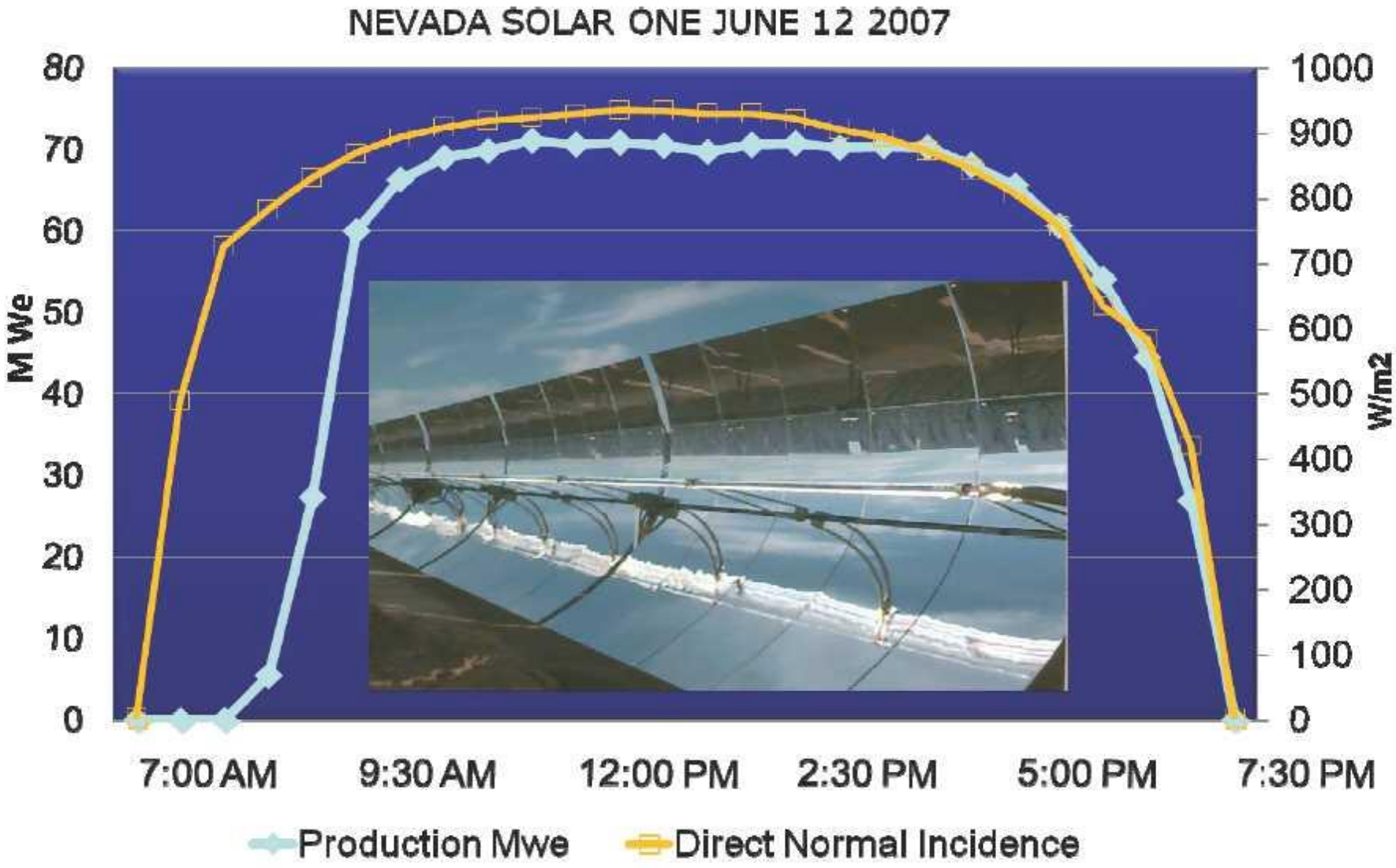
Type	Plants	Power (MW)
Parabolic Trough 50 MW without Storage	27	1350
Parabolic Trough 50 MW With storage	17	850
Saturated Steam Tower	2	31
Molten Salt tower with storage	1	20
Fresnel	1	30
Hybrid Solar/Biomass	1	22
TOTAL	**49**	**2303**

75-MW Solar Thermal Power Plant in Nevada

Nevada Solar One – 75 MW

NEVADA SOLAR ONE - ACCIONA SOLAR POWER

PERFORMANCE TESTING



Acciona/ Mitsubishi Corp (Alvarado, Badajoz)

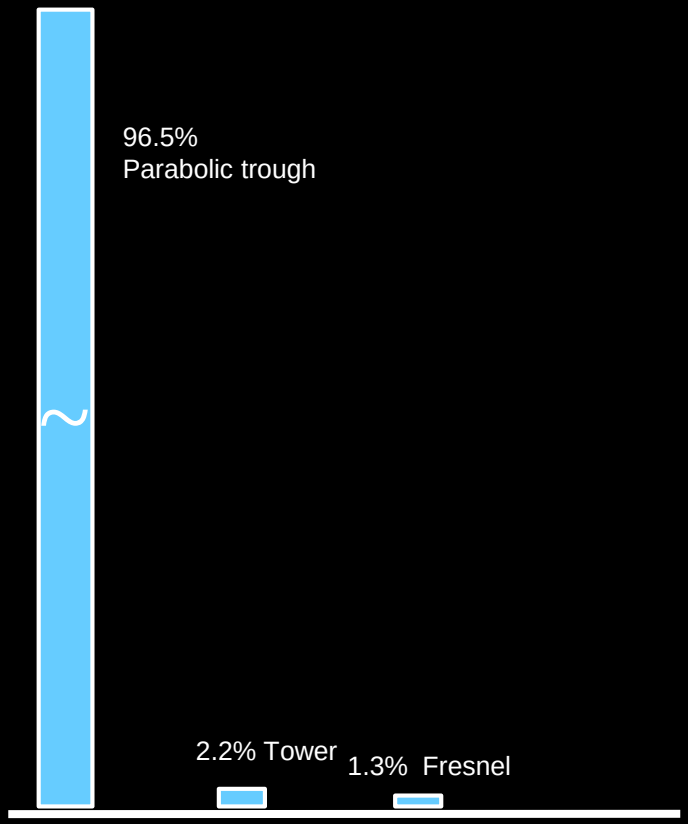
Break Ground Date December 2007

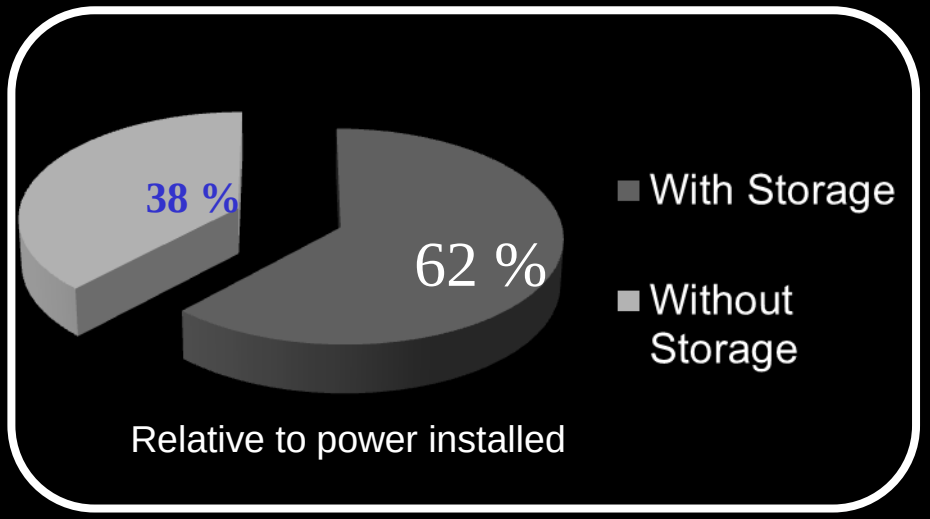
Start Production Date June 2009

La Risca, Alvarado

DISPATCHABILITY:

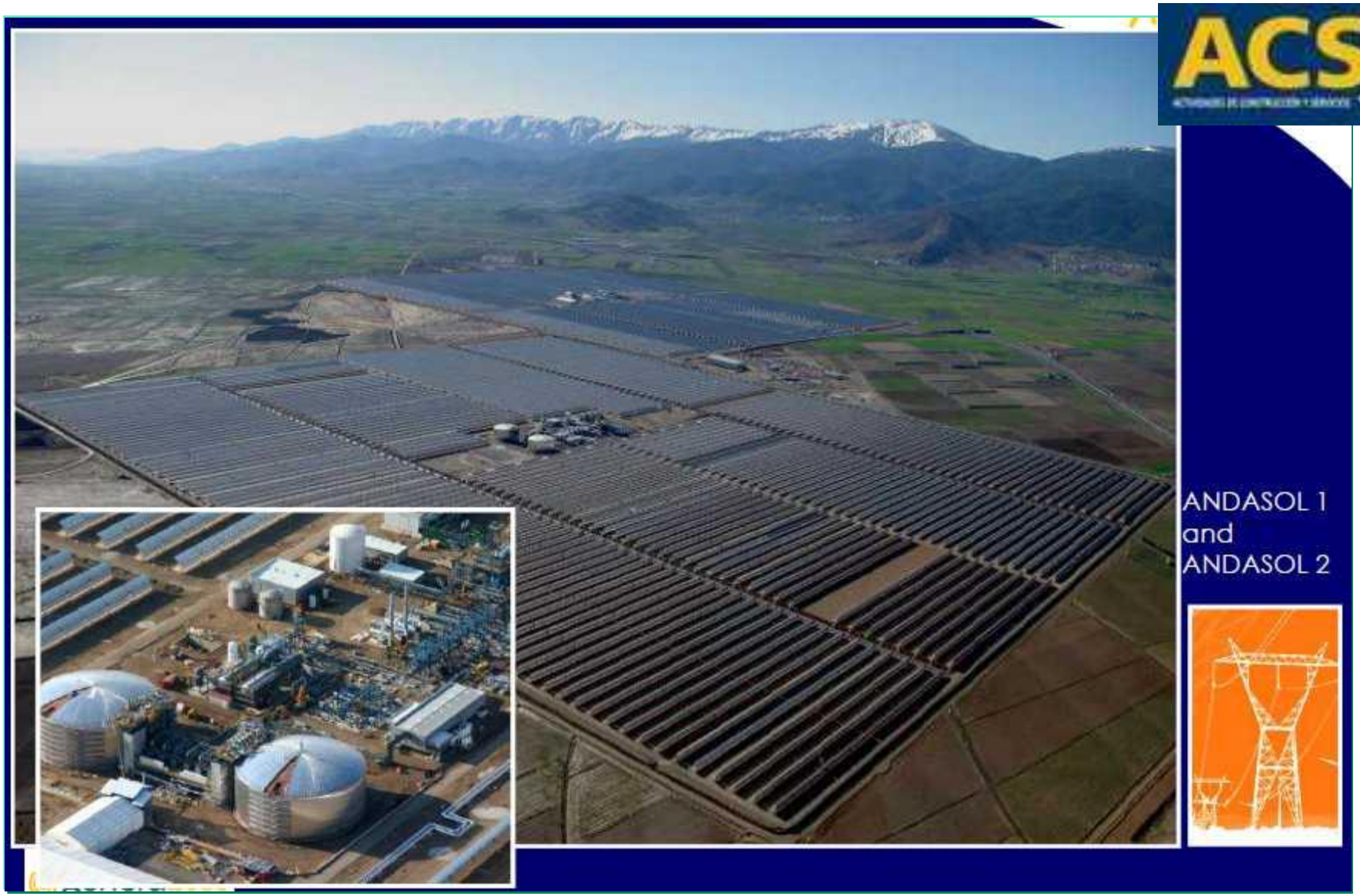
Breakdown of CSP plants in Spain





Power: 2303 MW
Production: 4500 GWh/year
CO_2 Emissions avoided: 4 Mt/year

Andasol 1 and 2: Thermal storage with molten salts



Break Ground Date July 3, 2006

Start Production Date November 26, 2008

SOLUCAR

Plant PS10

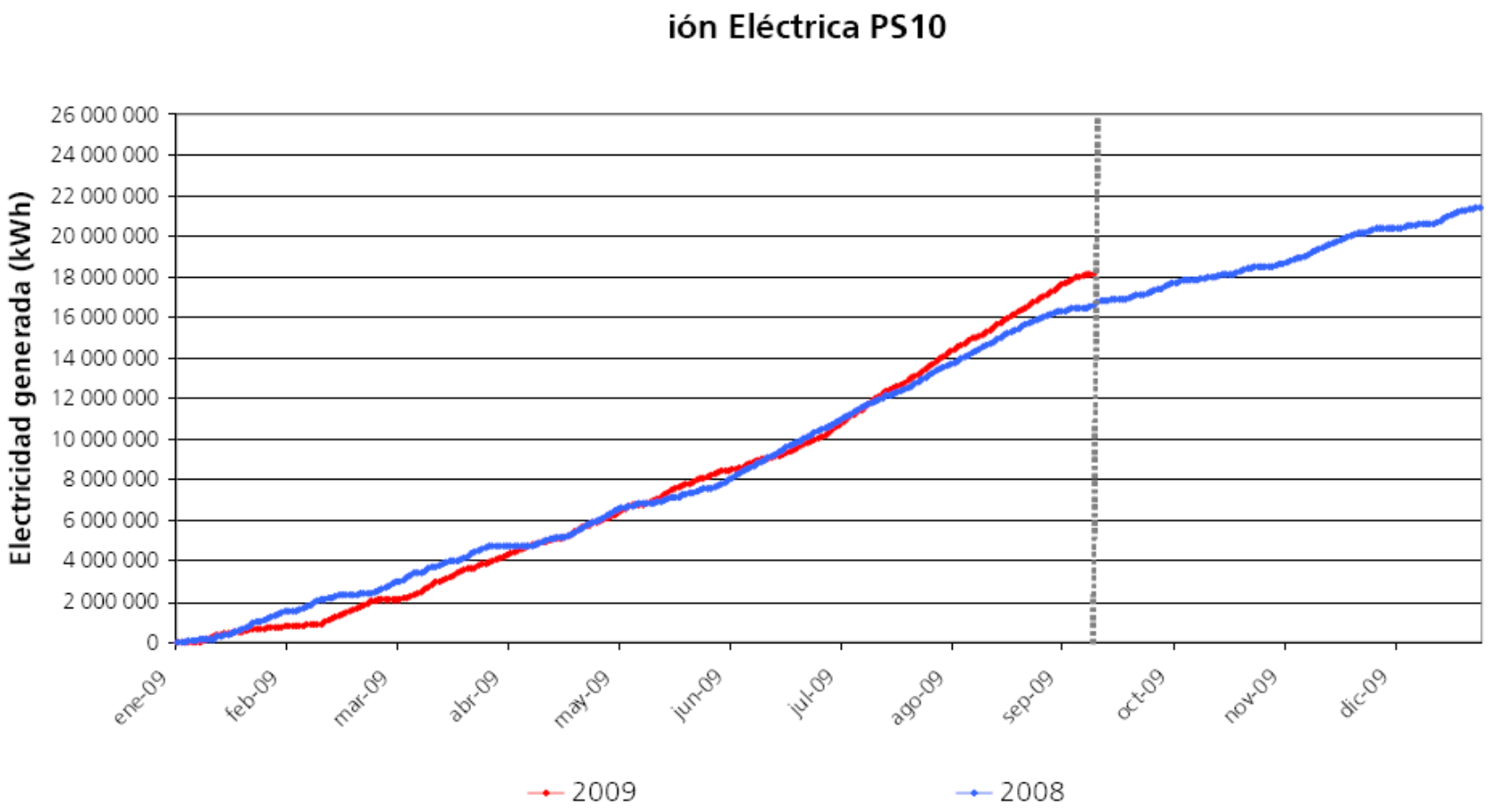
PS10
Sanlucar Solar Project

Nominal Rate Operation		
Optical Efficiency	77.0%	67.5MW -> 51.9MW
Receiver and Heat Handling Efficiency	92.0%	51.9MW -> 47.7MW
Thermal Power to Storage		11.9MW
Thermal Power to Turbine		35.8MW
Thermal Pow. -> Electric Pow. Efficiency	30.7%	35.8MW -> 11.0MW
Total Efficiency at Nominal Rate	21.7%	
Energetical Balance in Annual Basis		
Mean Annual Optical Efficiency	64.0%	148.63GWh(useful) -> 95.12GWh
Mean Annual Receiver&Heat Handling Efficiency	90.2%	95.12GWh -> 85.80GWh
Operational Efficiency (Starts Up/Stops)	92.0%	85.80GWh -> 78.94GWh
Operational Efficiency (Breakages, O&M)	95.0%	78.94GWh -> 75.00GWh
Mean Annual Thermal Ener. -> Electric Efficiency	30.6%	75.00GWh -> 23.0GWh
Total Annual Efficiency	15.4%	

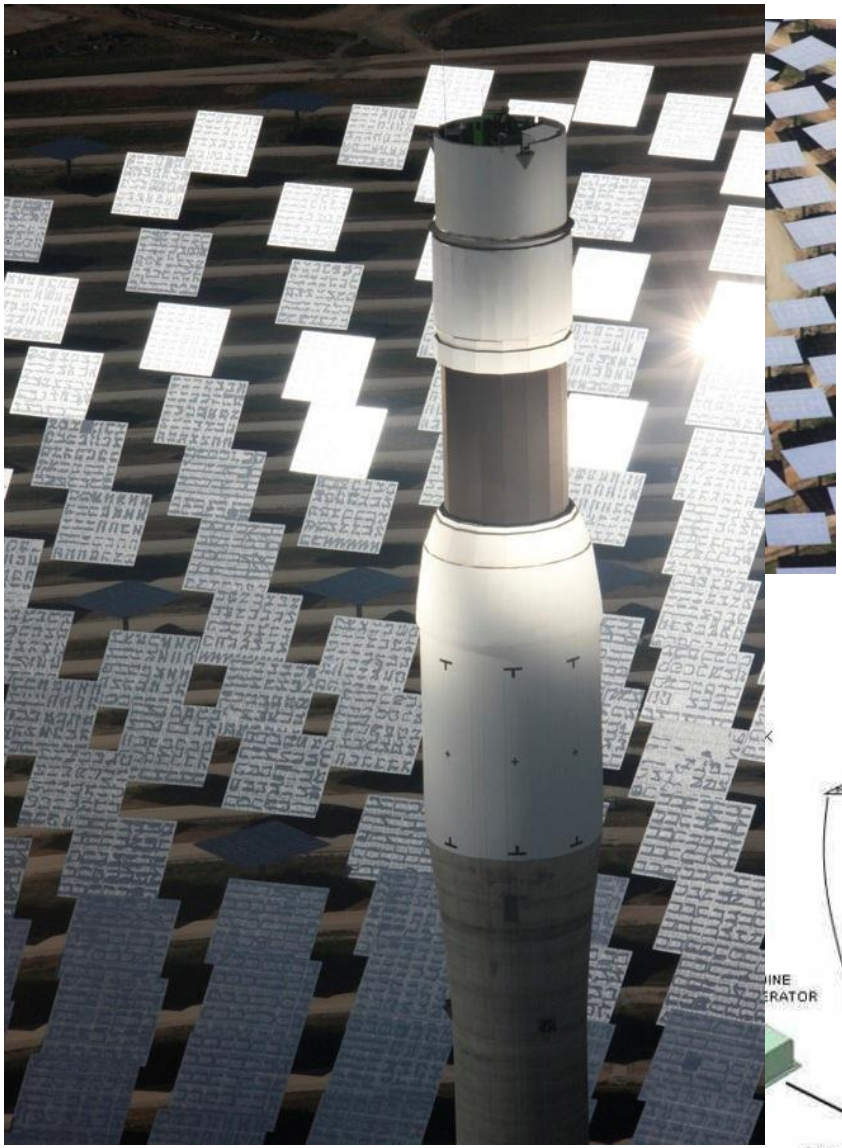
Plataforma Solúcar

PS20: La mayor torre en construcción

PS10 Generation in 2009

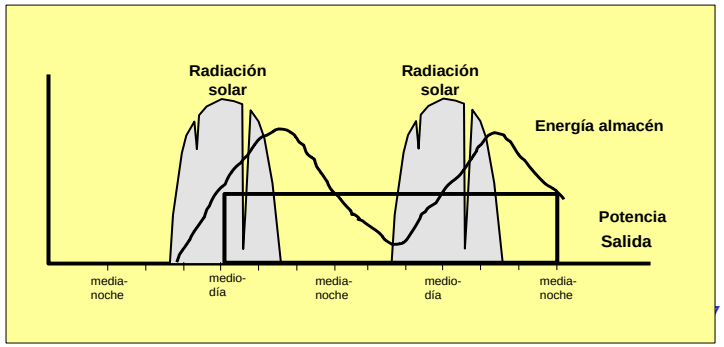


Solar Towers and storage: Gemasolar plant

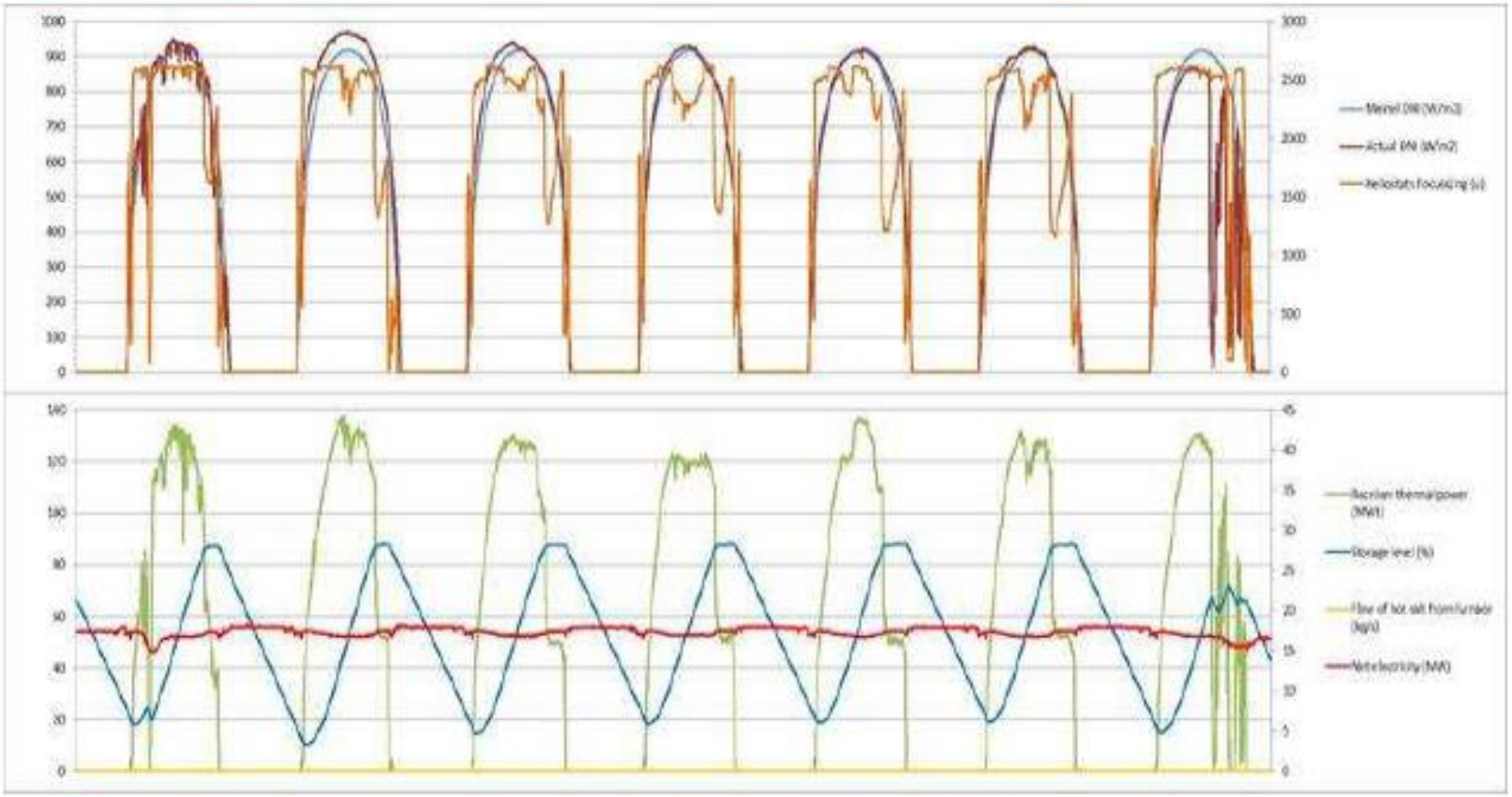


DESIGN PARAMETERS	
Total Reflective Area	**304.750 m^2**
Number of heliostats	**2650**
Total Area covered by Heliostat Field	**195 ha**
Thermal output of the Receiver	**120 MW**
Tower height	**140 m**
Heat Storage Capacity	**15 hours**
Steam Turbine power gross	**19.9 MWe**

Projected Operative Figures	
Annual solar irradiance	**2062 kWh/m^2**
Annual Energy sales	**80,000 MWhe**
CO2 savings	**30.000 t/y**
Capacity factor	**55%**

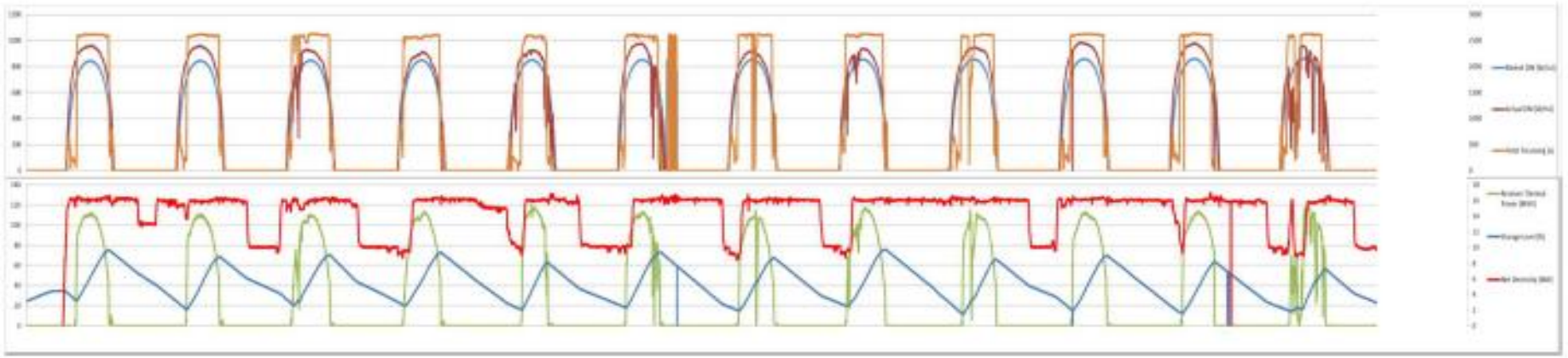


Plant operation



- Turbine at nominal power continuously running in summer

Plant operation



- Non-stop operation in winter time.

Gen 1+ → Gen 2

Where are we coming from?

USA 2013-2015

- Scaling-up
- 100-400 MW
- Utility PPA
- Dispatchability value
- Environmental impact

Second wave: USA the Scaling-Up





Project	Ivanpah	Genesis	Solana	Crescent Dunes	Mojave
Utility	SCE + PG&E	PG&E	APS	NVE	PG&E
State	California	California	Arizona	Nevada	California
Size	390 MW	250 MW	280 MW	110 MW	280 MW
Technology	Power Tower	Trough	Trough/ Storage	Power Tower/Storage	Trough
Price kWh	?	?	$0.14	$0.135	?
Cost	$2.18 B	$1.20 B	$2.00 B	$0.91 B	$1.6 B
Company	BrightSource	NextEra	Abengoa	SolarReserve	Abengoa
	Total CSP in operation 1,804 MW				

Second wave: USA the Scaling-Up

- Large plants: 100-400 MW per unit
- Land: Solana occupies 774 hectares; Ivanpha 1600 ha.
- Typical Power Purchase Agreement with utilities (Time of Delivery value) with selling price $0.14/kWh
- Commissioning and routine operation more complex (3-4 years from groundbreaking to start up)
- Environment: Visual impact, glint and glare, birds, water

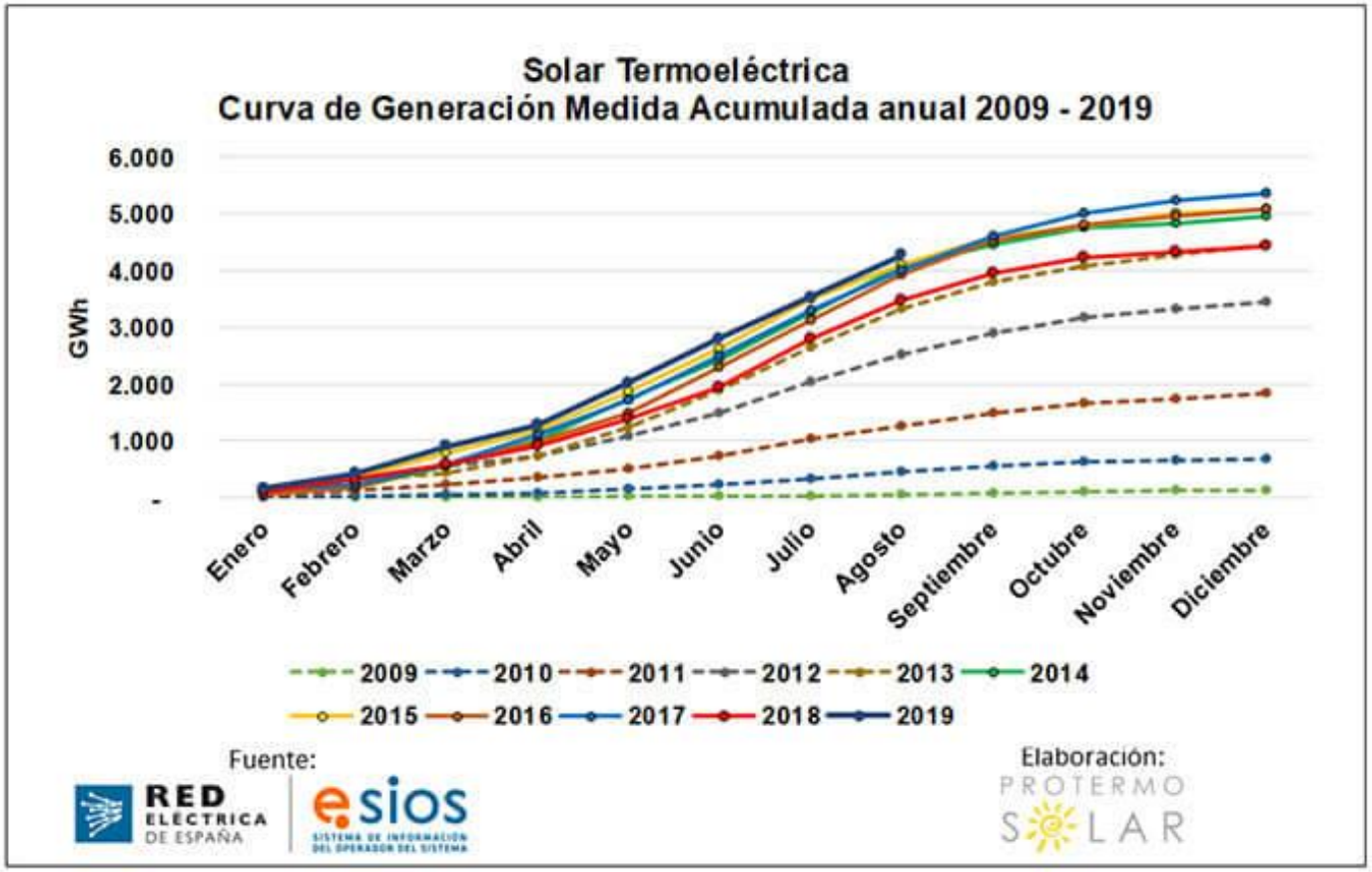
Prospects

- Strong competition with PV at the short term
- Future STE plants will depend on the position of the utilities regarding dispatchability.

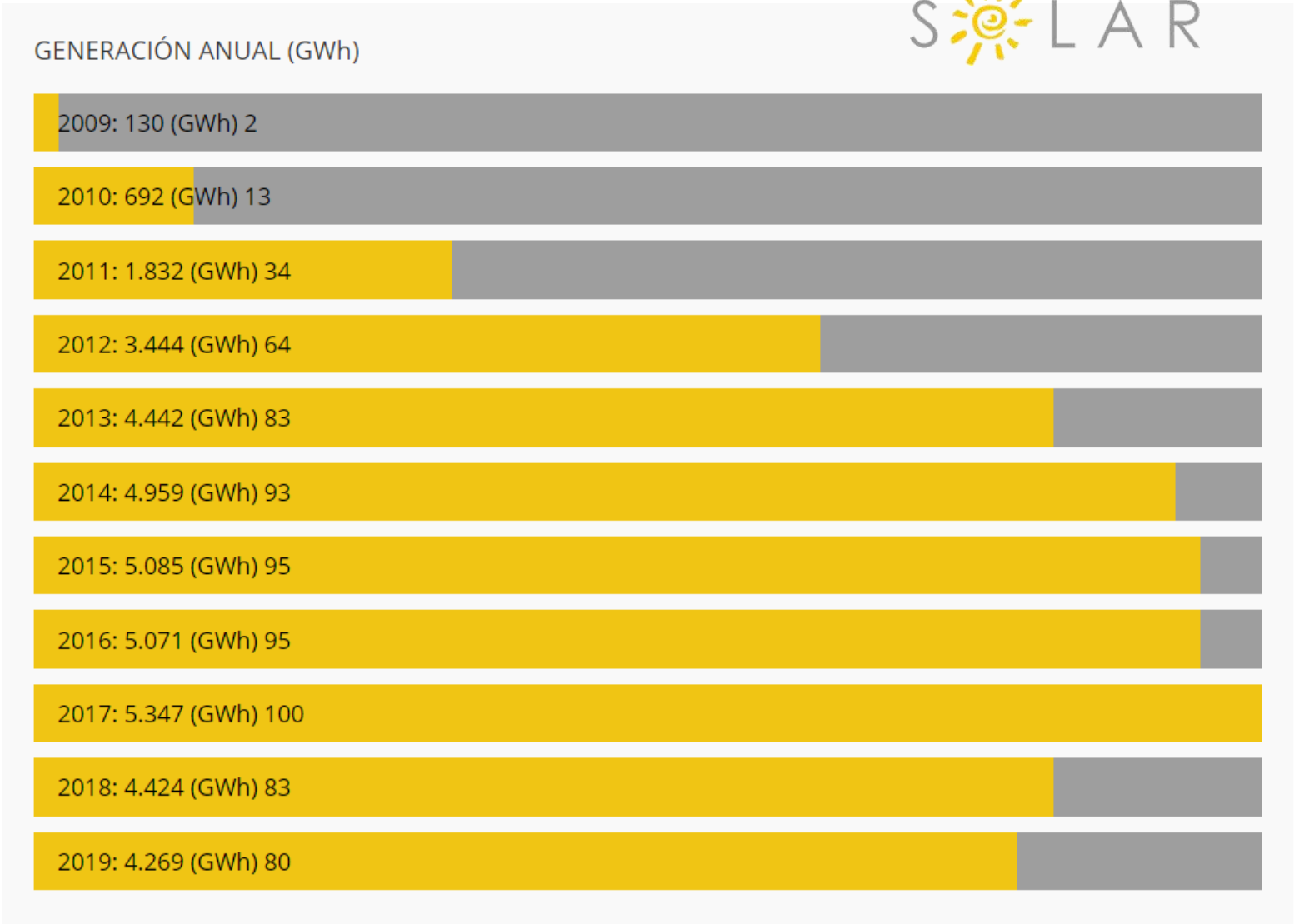
- Routine operation of Gen 1+ in Spain
- Early feedback from Gen 2 in US
- Aggresively fighting for globalization (Gen 2+)

Routine operation of Gen 1+ in Spain

- The plants don't show degradation signs and they are continuously breaking specific records. 2019 is getting the maximum cumulative yield
- Lessons learned on specific operational issues are part of the knowhow of the Spanish companies for design and operation of future plants

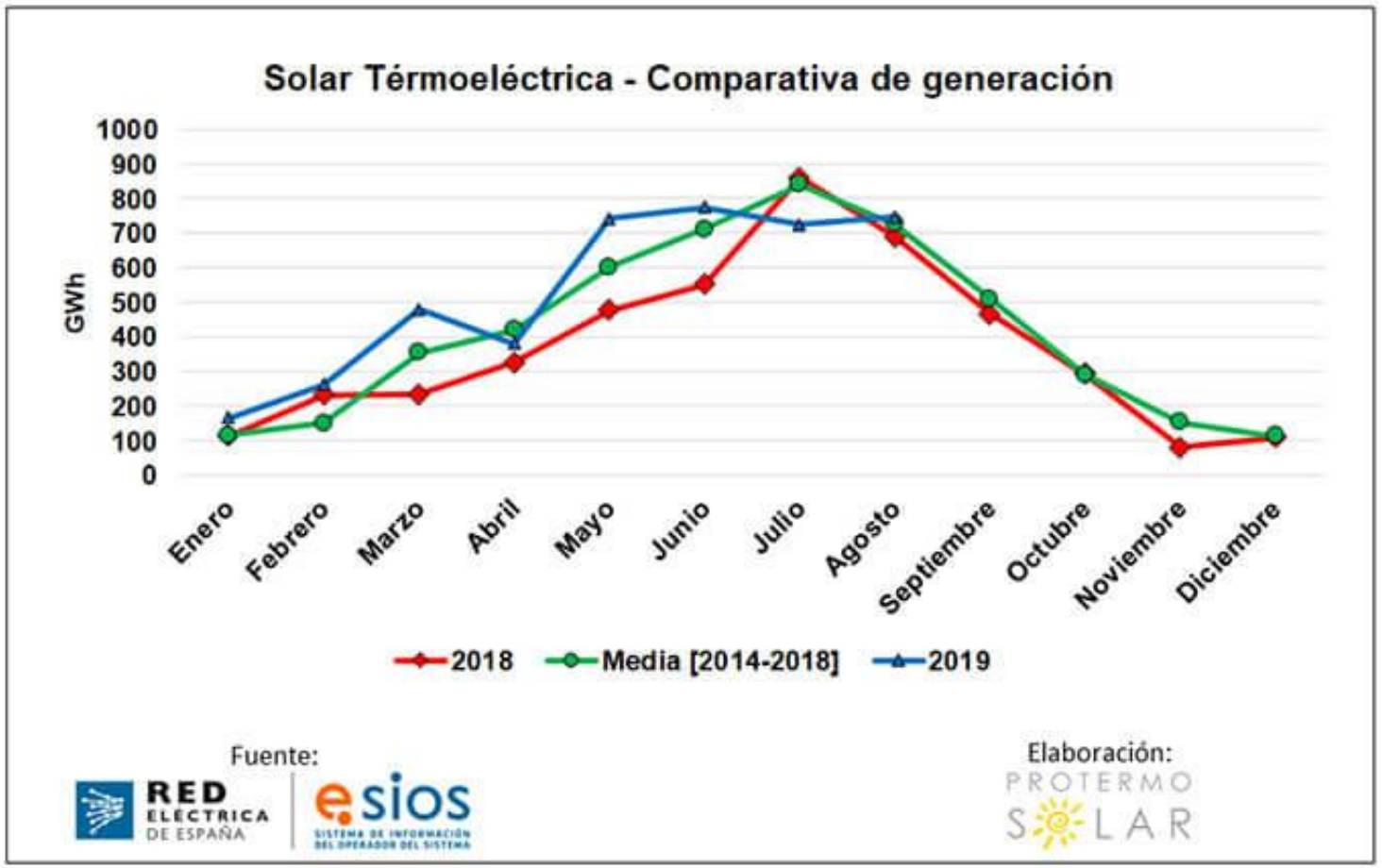


Routine operation of Gen 1+ in Spain



Operational Experience in Spain

- ✓ 10% of instantaneous contribution has been achieved. 8% is oftenly achieved in summer months. 5% daily max achieved.
- ✓ 3 weeks have been running some plants in a non stop 24/7 mode. Gemasolar, in particular, reached 36 non stop days at nominal power
- ✓ Montly contribution raised 3.65% in August 2019.
- ✓ 5,300 direct employment in 2017.



First market wave: Features

- Performing as planned
- Typical size 50 MW (land > 1 km^2)
- Already 6-7 hours nominal storage

BUT…..

- 96.5% installed capacity in parabolic troughs
- Efficiencies below 20% nominal solar to electricity,
- Only feasible with FIT of 27 c€/kWh
- High water consumption (0.5-1 million m^3 per year and plant),
- The limitation to reach the temperatures needed for thermochemical routes of solar fuels.

Extresol 1 and 2 (ACS/Cobra)

Nevada Solar One 75 MW (Acciona)

Early feedback from Gen 2 in US

NATURE

This Solar Plant Accidentally Incinerates Up to 6,000 Birds a Year

JOSH HRALA 15 SEP 2016

A solar power plant in California is accidentally killing up to 6,000 birds every year, with staff reporting that the birds keep flying into its concentrated beams of sunlight, and spontaneously bursting into flames.

The problem has been going on since the site opened in 2014, and the team says it's trying everything to save the birds from a fiery fate. But so far, the perfect solution has eluded them.

TABLE 1. Number of avian detections at ISEGS during the first year of monitoring.[10]

	Number of Detections				
Cause	**Winter**	**Spring**	**Summer**	**Fall**	**Total**
Singed	27	100	42	147	316
Collision	14	15	10	45	84
Other*	5	5	2	3	15
Unknown	51	82	61	94	288
Total	**97**	**202**	**115**	**289**	**703**

* Includes detections in ACC buildings without evidence of singeing or collision effects.

Ho. CK, AIP Conference Proceedings **1734**, 070017 (2016)

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SolarReserve's CSP technology with storage struggles to stay online

Author Jeffrey Ryser
Editor Richard Rubin
Commodity Electric Power

HIGHLIGHTS

110-MW Crescent Dunes facility out most of Q1

Company offers no comments about current operations

The 110-MW Crescent Dunes Concentrated Solar Power facility near Tonopah, Nevada, was offline most of the second quarter of this year 2019,

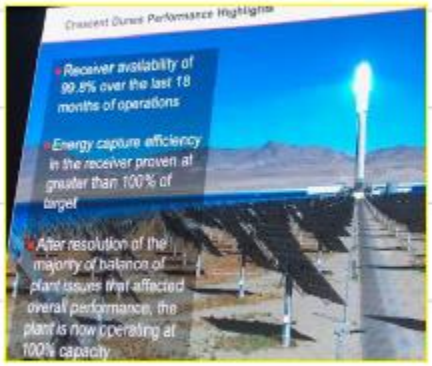
The facility has experienced outages before. It reported no wholesale sales in November and December 2016 after a leak in a tank filled with molten salt forced a shutdown.

It also has a 25-year power purchase agreement with NV Energy subsidiary Nevada Power for power priced at 13.5 cents/kWh. An NV Energy spokeswoman on Friday declined to comment on the status of the Crescent Dunes facility.

Solar Reserve's subsidiary Tonopah Solar Energy, which owns the facility, reported no wholesale power sales to FERC in the entire first half of 2017. It had a slow operational rebound, with capacity factors of just 4% and 5% in Q4 2017 and Q1 2018, respectively.

The facility's highest average quarterly capacity rates have come in the summer of 2016 and 2018. Its record high quarterly capacity average was 36.7% in Q3 2018.

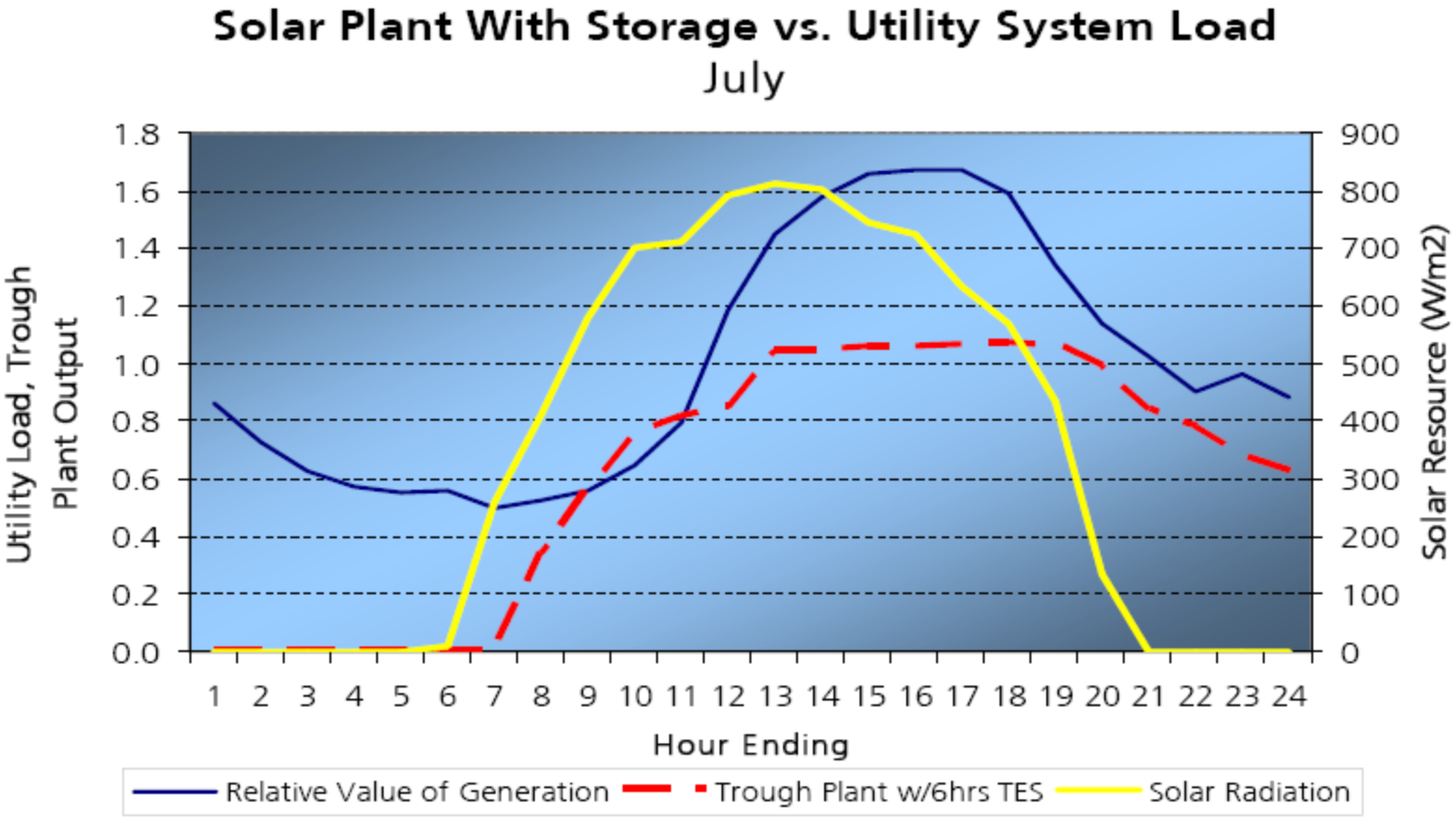
CSP Plant CRESCENT DUNES monthly generation over the last 2 years



eia Independent Statistics & Analysis U.S. Energy Information Administration

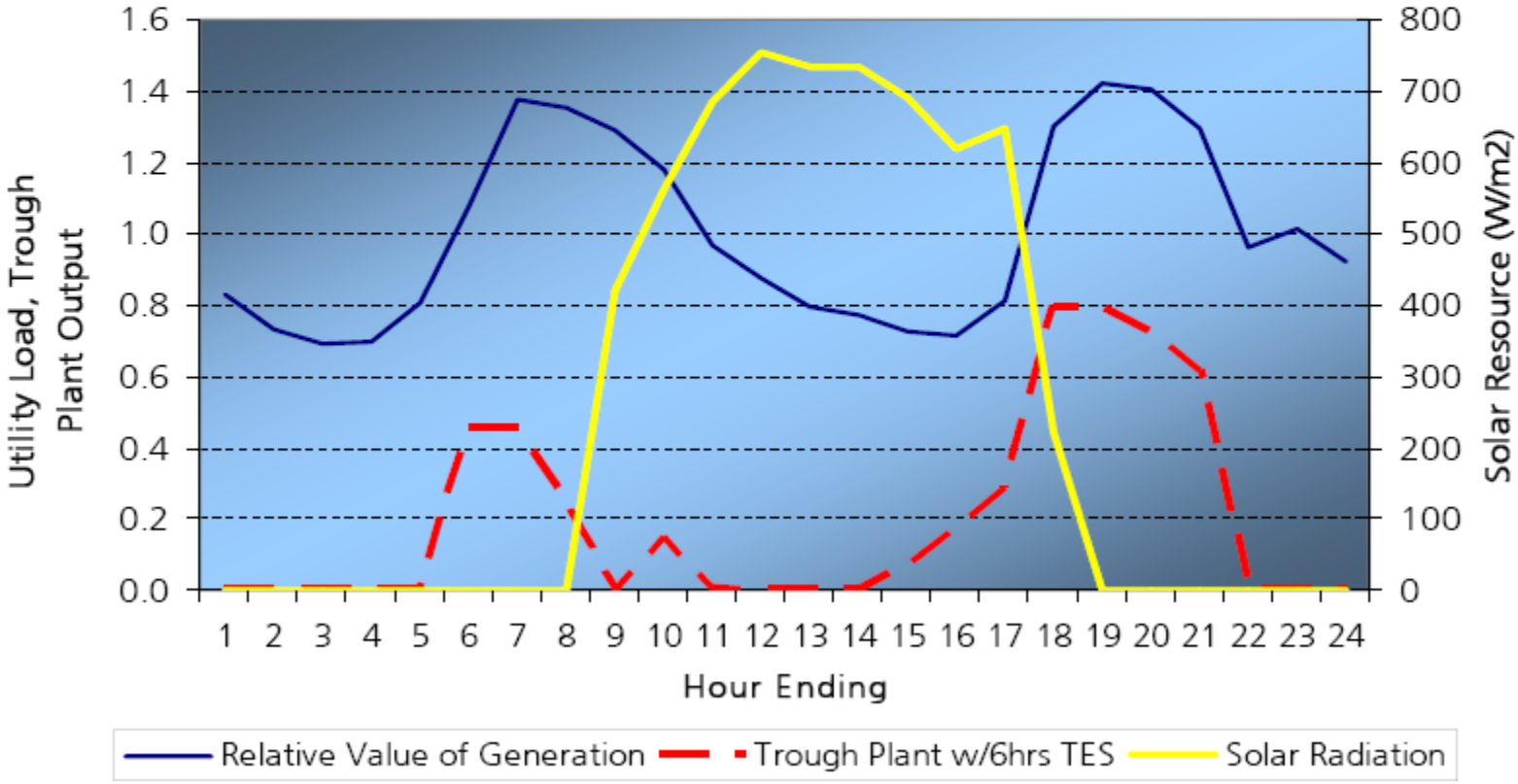
Solana (280 MW) in Arizona

Dispatchability – Summer Loading

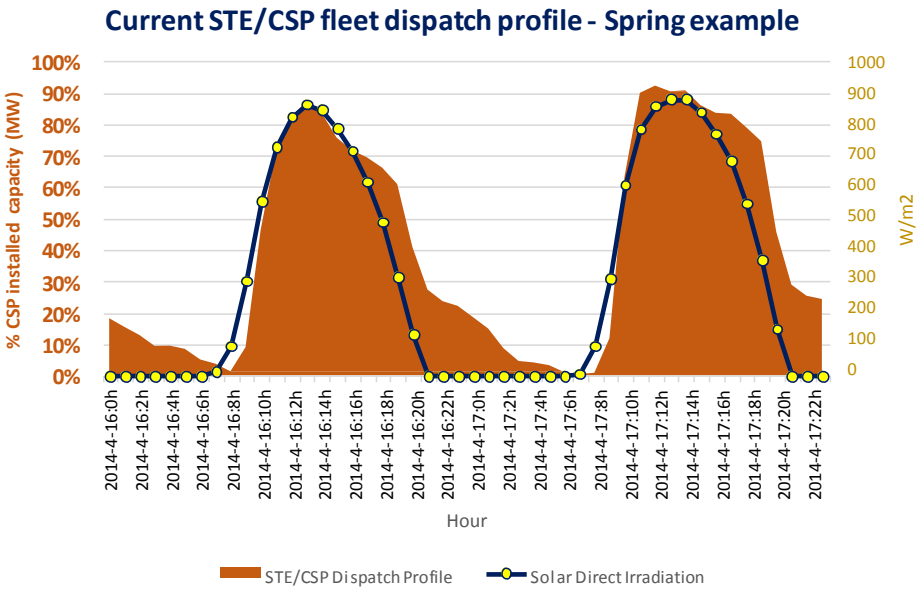


Solar Plant With Storage vs. Utility System Load

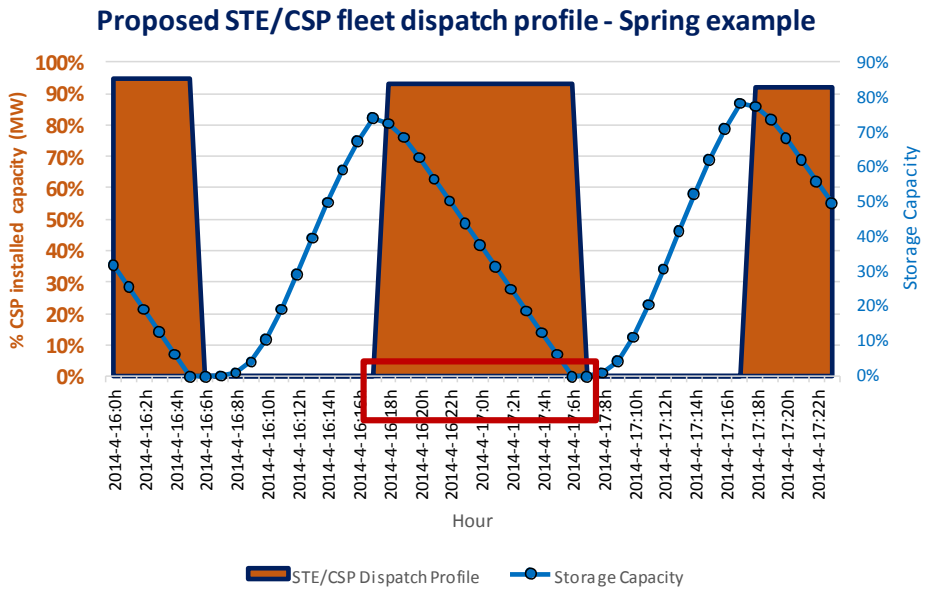
January



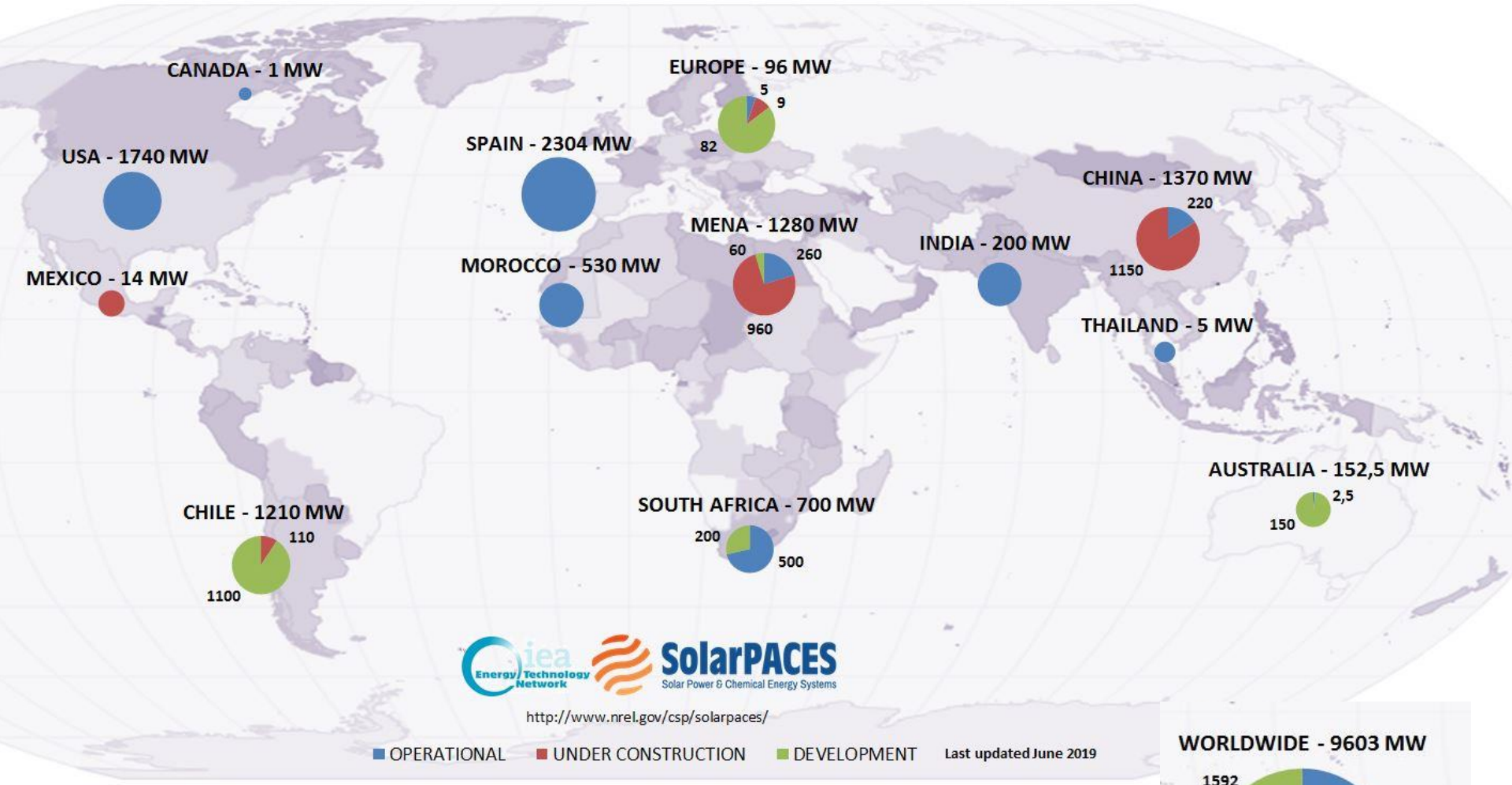
Current and – most likely – future STE/CSP dispatch profiles by year 2030 (Spanish Case)



Current fleet consist of 1/3 plants with 7,5 hours of storage and 2/3 without storage



Future CSP plants would be constructed with 10 – 12 hours of storage



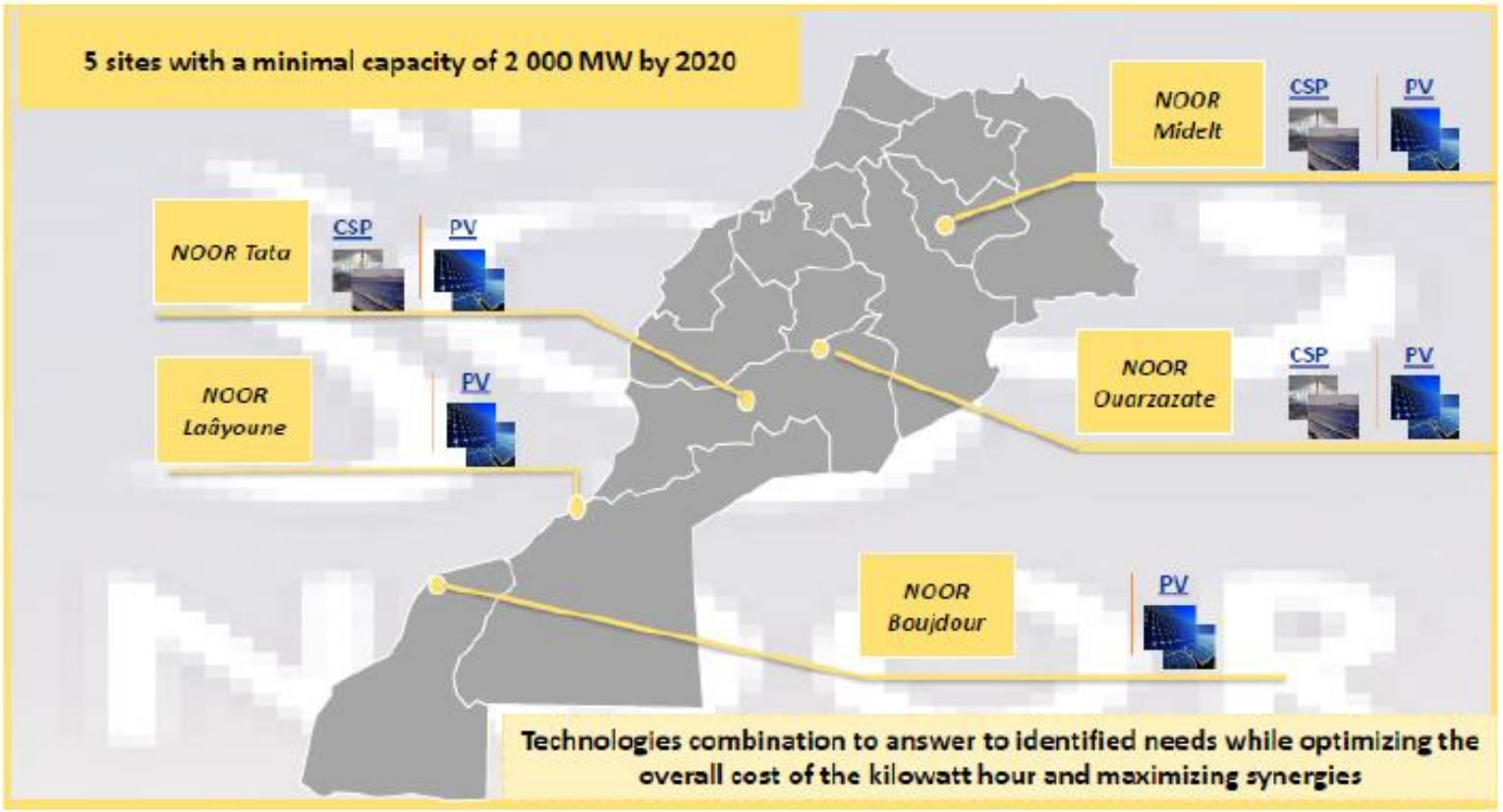
Globalization (Gen 2+) or just China/MENA receiving the baton?

Globalization (Gen 2+)

CSP in Chile: Market

- CSP projects have participated in energy tenders for distribution companies:
  - Abengoa (Tender 2015-02)
    - Won a contract for 38,8 GWh/yr at a price of 97 US$ MW/h
    - Weighted average price of the tender was 79,3 US$/MWh
  - Solar Reserve (Tender 2015-01)
    - Offered 67,86 USD/MWh for 8.360 GWh/yr
    - Didn´t win energy blocks
    - Offer was 5,97 US$/MWh, below the average of LNG and coal offers.
    - Weighted average price of the contracts that were awarded was 47,6 US$/MWh

NOOR, A MULTI-SITE AND MULTI-TECHNOLOGY PLAN



New developers in the field

NOORo I PLANT IN OPERATION

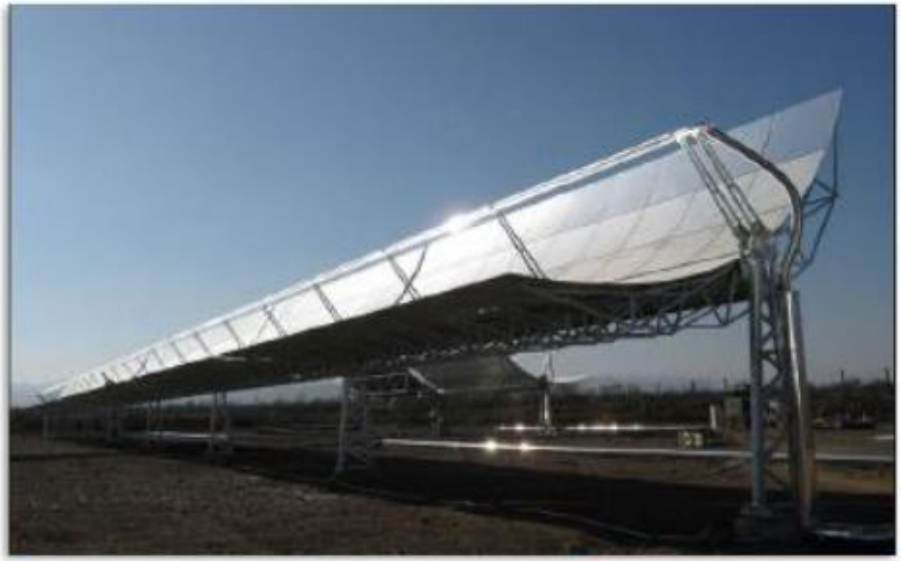
Techno.	Concentrated Solar Power using parabolic trough
Capacity	160 MWe Gross Capacity
Storage	3 hours Thermal Energy Storage

Financial Institutions

afd
KFW
KFW
THE WORLD BANK

New EPCs in the field

NOOR II, UNDER CONSTRUCTION *Techno.*



Techno.	Concentrated Solar Power using parabolic trough
Capacity	200 MW Gross Capacity
Storage	> 7 hours

Developer	ACWA POWER
EPC	SENER, sepcoIII 山东电建, POWERCHINA

Financial Institutions

KFW, THE WORLD BANK

New EPCs in the field

NOORo III, UNDER CONSTRUCTION

Techno.	Concentrated Solar Power using tower
Capacity	150 MW Gross capacity
Storage	> 7 hours

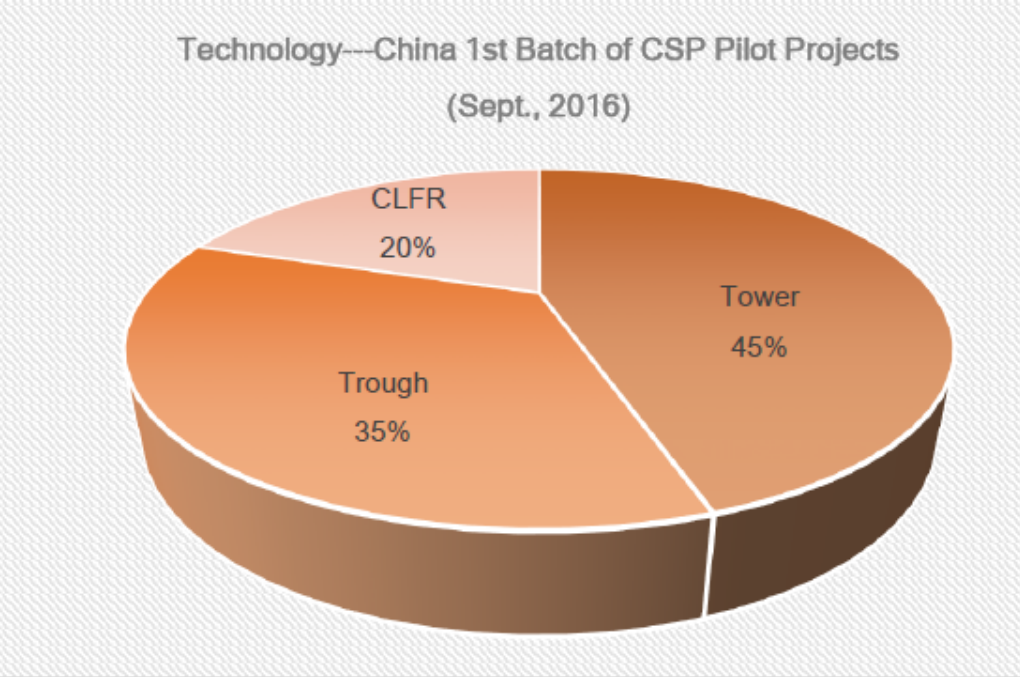
Developer	ACWA POWER
EPC	SENER, sepcoIII 山东电建, POWERCHINA

Financial Institutions

afd, Banque européenne d'investissement, CLEAN TECHNOLOGY FUND, KFW, THE WORLD BANK

China National Solar Thermal Energy Alliance

- 1.3 GW/ 20 demonstration Projects
- 200MW already grid connected in 2018



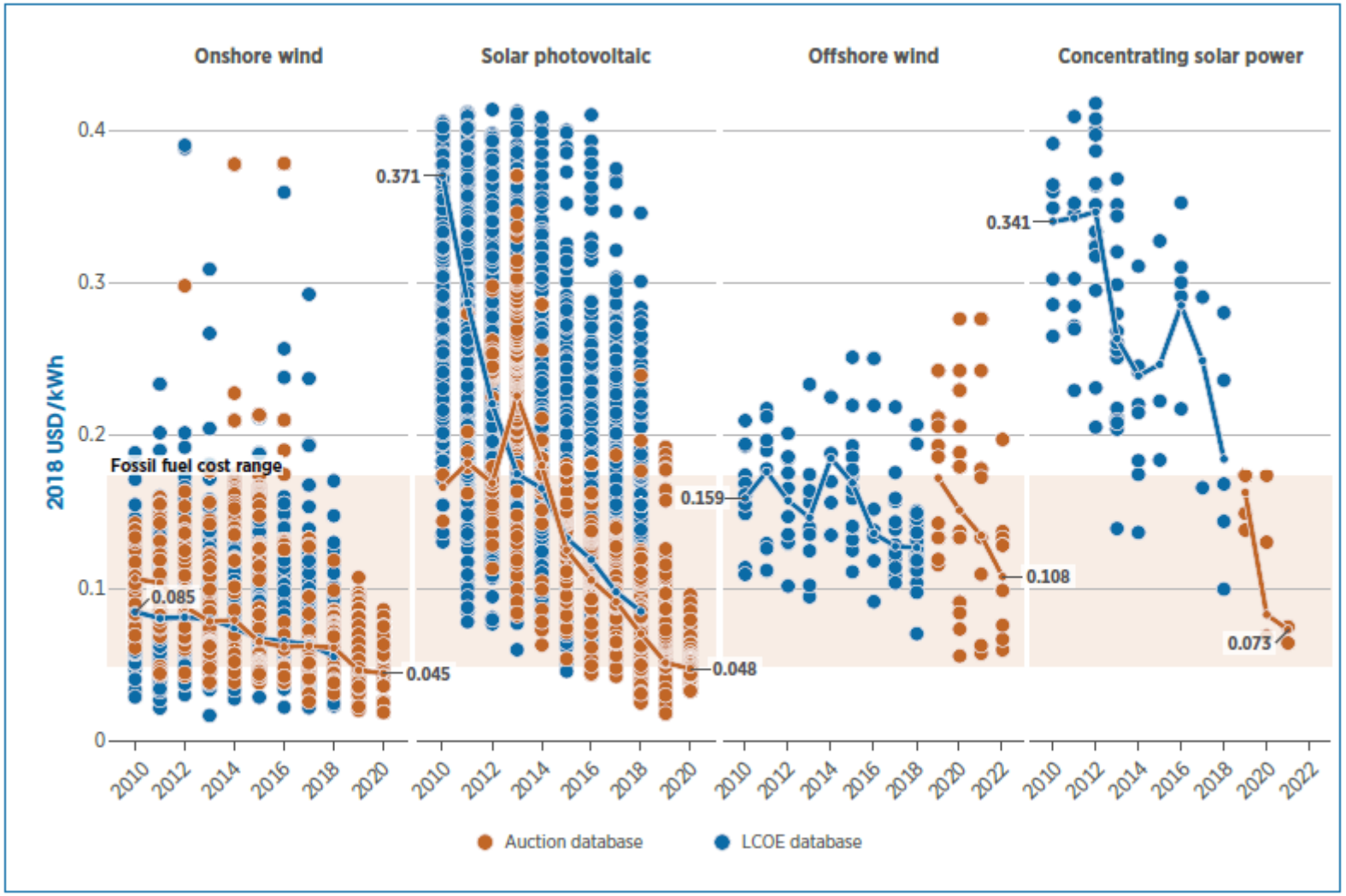
The first batch of CSP demonstration projects which are completed and put into operation by December 31, 2018, will have on-grid price of RMB 1.15/kWh (inclusive of taxes).

- An electricity price reduction mechanism for overdue projects in operation:
  - since January 1, 2019 1.14 RMB /kWh,
  - since January 1, 2020 till December 31, 2021 1.10 RMB/kWh.
  - It's expected there'll be 6 projects (350MW) put into operation in 2019.

China National Solar Thermal Energy Alliance

200MW were completed and connected to the grid, in one year (2018):

- CGN Delingha 50MW Parabolic Trough CSP project—June 30th
- Shouhang Dunhuang 100MW Molten Salt Tower CSP project—December 28th
- SUPCON Delingha 50MW Molten Salt Tower CSP project—December 30th

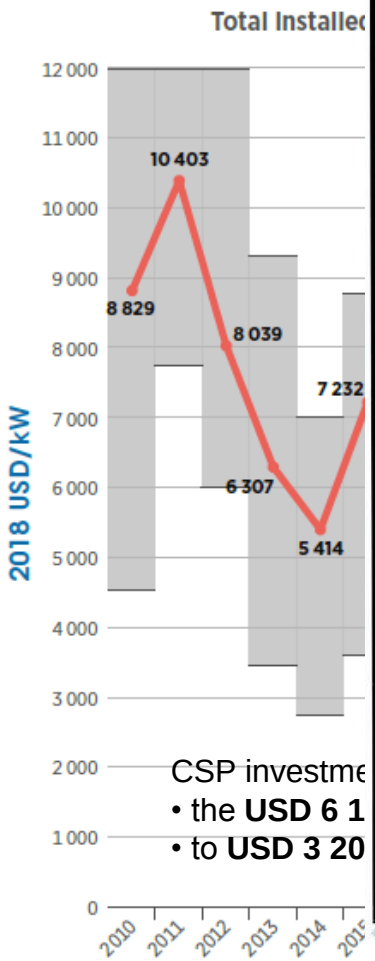


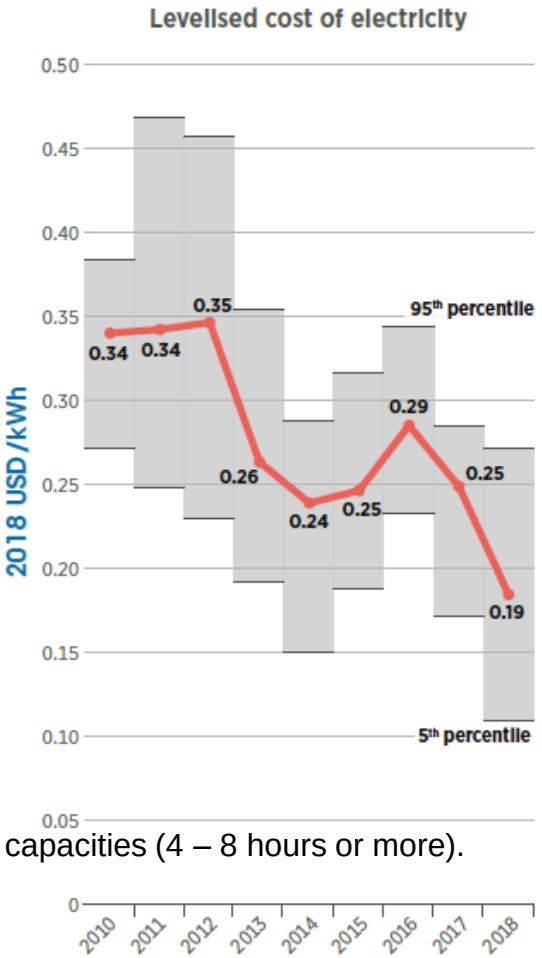
In 2018, around 500 MW of new concentrating solar power was commissioned – predominantly in China, Morocco and South Africa. The global weighted average LCOE in 2018 was USD 0.185/kWh – 26% lower than in 2017 and 46% lower than in 2010.

IRENA
International Renewable Energy Agency

Global weighted average total installed costs, capacity factors and LCOE for CSP, 2010–2018

IRENA
International Renewable Energy Agency





CSP investme
• the **USD 6 1**
• to **USD 3 20**

ge capacities (4 – 8 hours or more).

What Does the Future Look Like for CSP? That's anybody's guess!

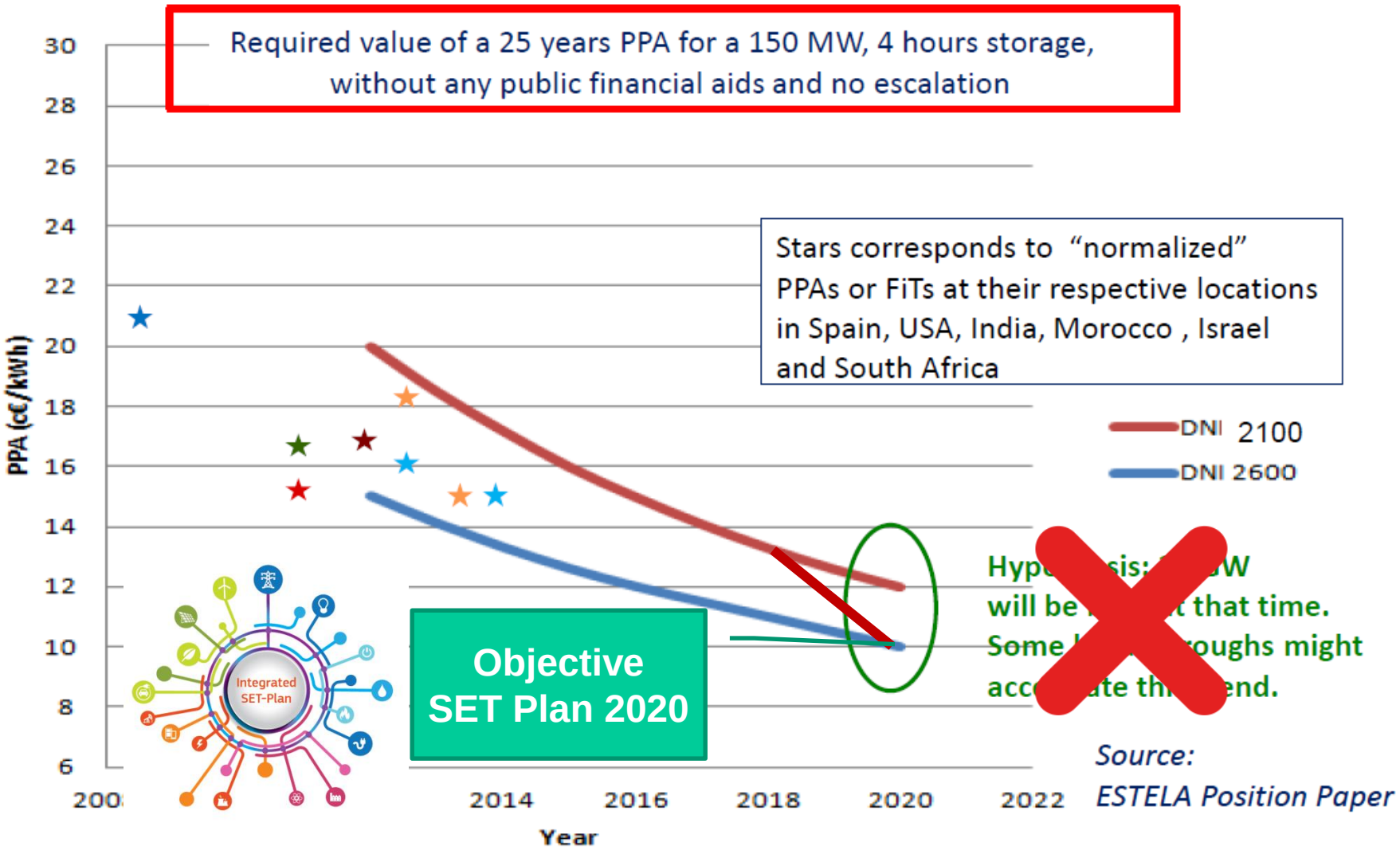
Gen 2++ or Gen 3?

Roadmaps: “The EU style”

European Solar Thermal Electricity Association

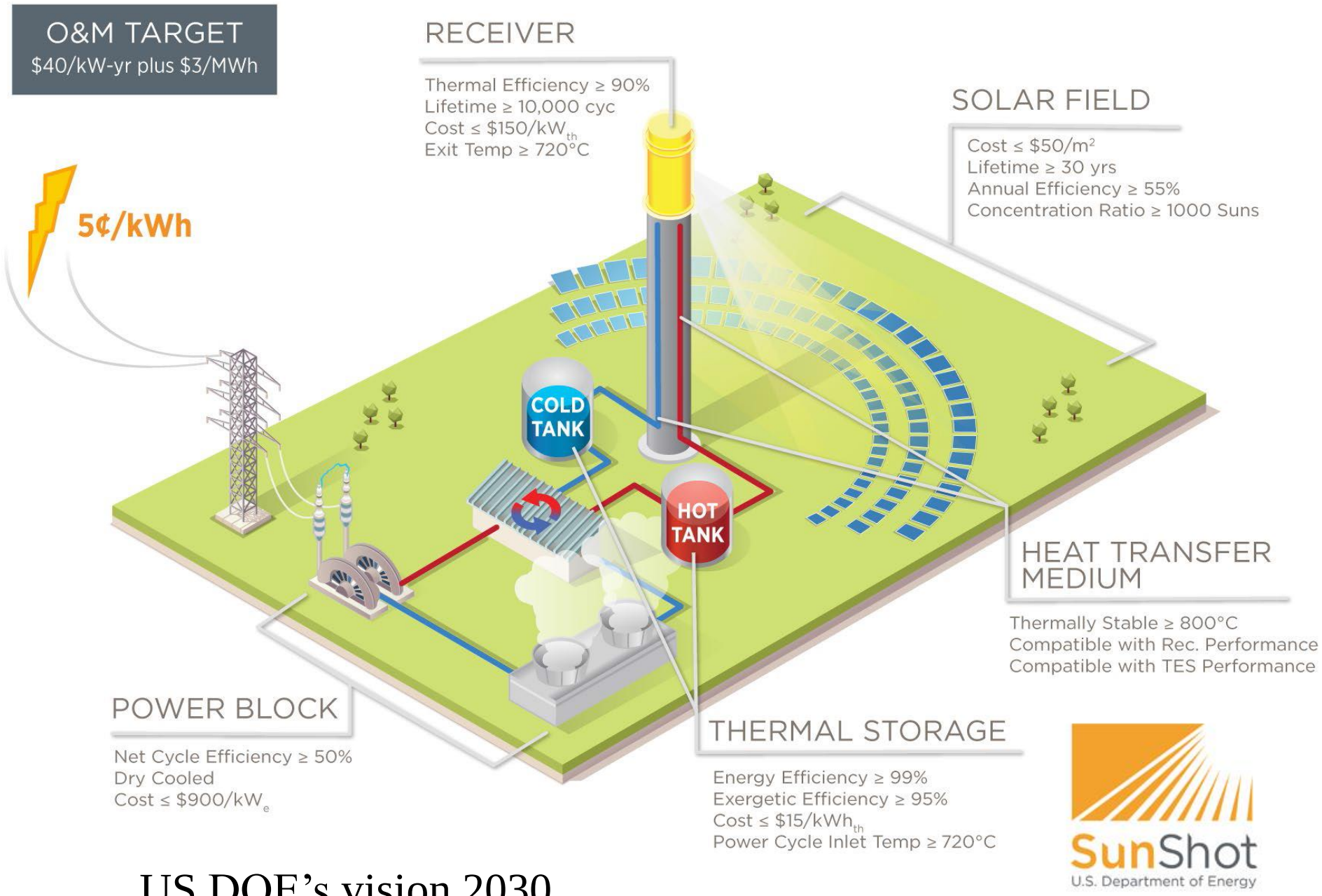
ESTELA

Cost reduction estimations: The view from the European Industry



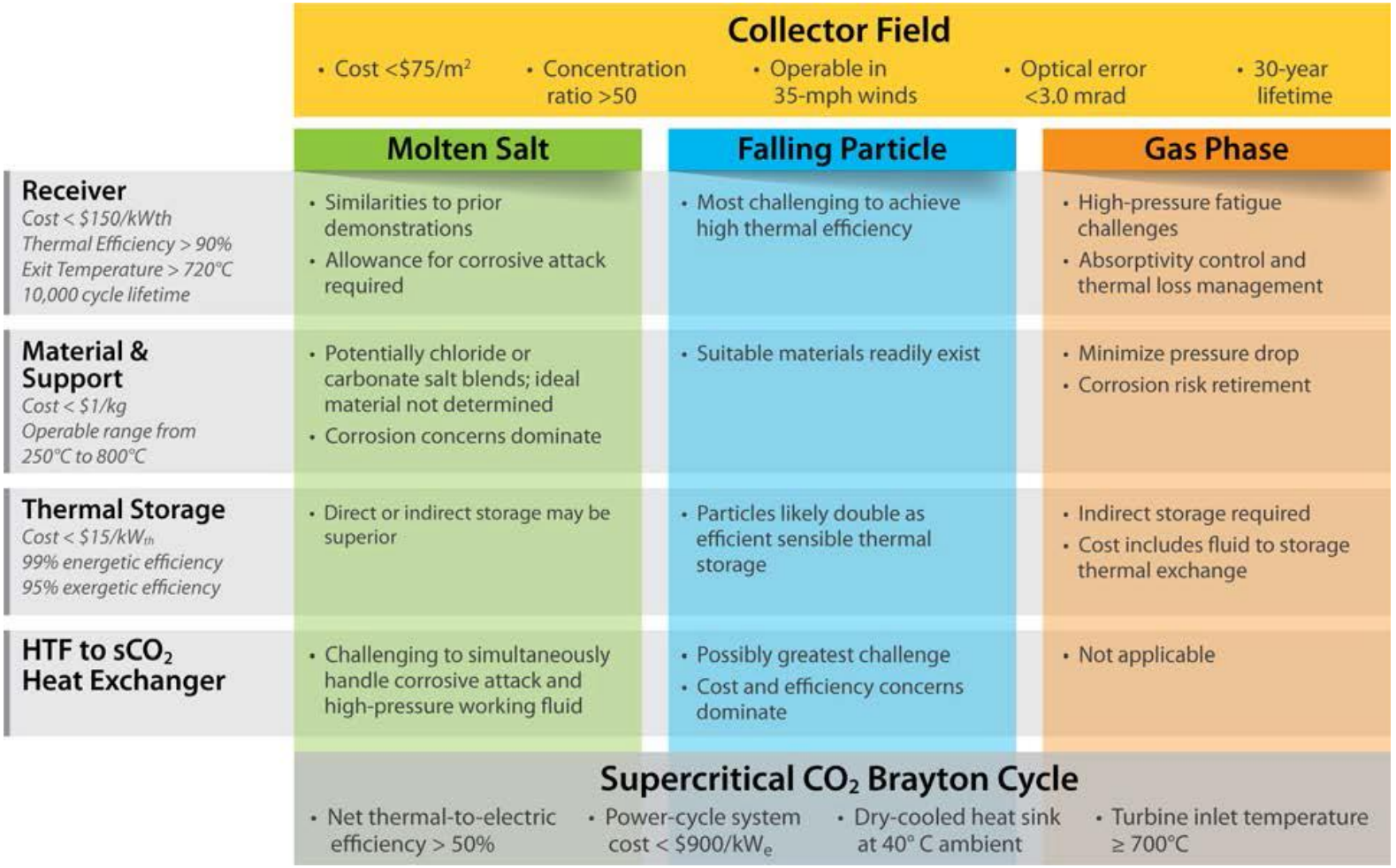
Initiative for Global Leadership in Concentrated Solar Power Implementation Plan

1. Advanced **Linear Concentrator Fresnel** technology with direct molten salt circulation as HTF and for high temperature thermal energy storage
2. **Parabolic Trough** with Molten Salt
3. **Parabolic Trough** with Silicon Oil
4. Solar Tower Power Plant to commercially scale-up and optimize the core components of the **Open Volumetric Air Receiver** technology
5. Improved **Central Receiver Molten Salt** technology
6. **Next Generation of Central Receiver** power plants
7. **Pressurized Air Cycles** for high efficiency solar thermal power plants
8. Multi-Tower Central Receiver **Beam Down** System
9. Thermal Energy **Storage**
10. Development of innovative concepts for **supercritical turbine** trains for CSP
11. Development of advanced concepts for **improved flexibility in CSP** applications
12. Development and Field Test of **CSP Hybrid Brayton Turbine Combined Cycle sCO2** System



US DOE's vision 2030

Concentrating Solar Power Gen3 Demonstration Roadmap (**Technical Report.**NREL/TP-5500-67464 January 2017



Various pathways for CSP Gen3 technology. No one pathway through all sub-systems exists without at least one significant technical, economic, or reliability risk.

Does it make sense to build large plants?

Solana was built large to take advantages of economies of scale.

- Economy of scale achieved in solar field assembly.
- Economy of scale not achieved as well in other areas:
  - Two 140 MW steam turbines
  - Four steam generators – two 50% trains per steam turbine
  - 6 parallel thermal energy storage (TES) units
  - 8 solar fields and 2 HTF pump groups
- The HTF system is large and complex
  - Twice the HTF per m^2 of collector area relative to 50 MW plant.
- Schedule – Took almost 3 years to build
- O&M – Large complex plant
  - Lots of equipment to operate and maintain
  - Takes time to get around.

→ **Build smaller plants in a power park configuration**

Hank Price - Solar Dynamics LLC/Abengoa
Sunshot CSP Program Summit 2016

Modularity: Multitowers

graphite energy

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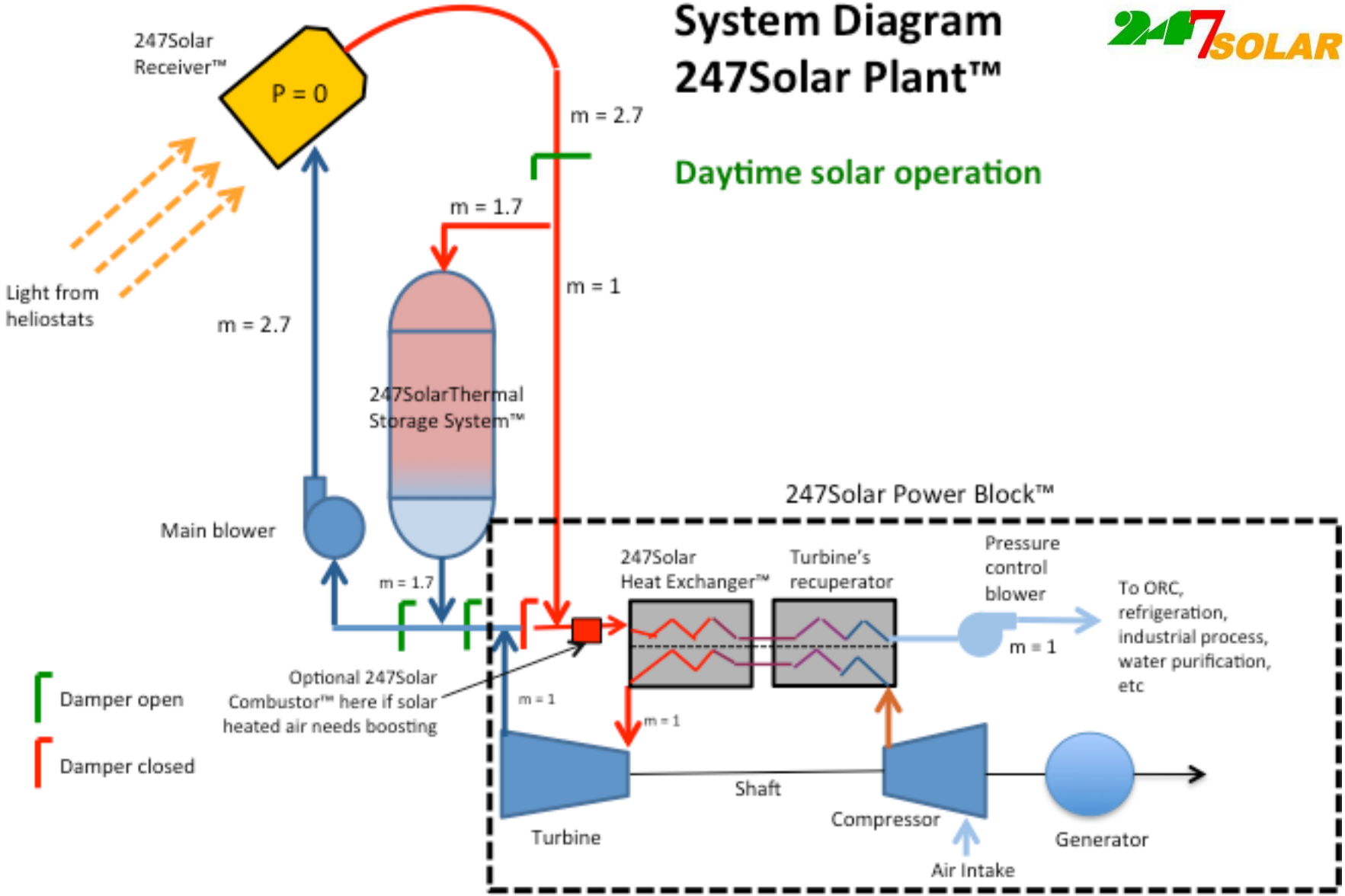
SOLAR ENERGY LOCAL POWER

System Diagram
247Solar Plant™

Daytime solar operation



50MW Beam-down molten salt tower in Yumen, Gansu

-15 mirror field Modules, and each module consists of 17MWth solar filed and one beam-down tower, totaling 50MWe.
- One 9-hour molten salt thermal storage system & steam turbine set are also equipped in the project.

It is expected that No.1-3 Modules will be completed and connected to the grid in September 2019.

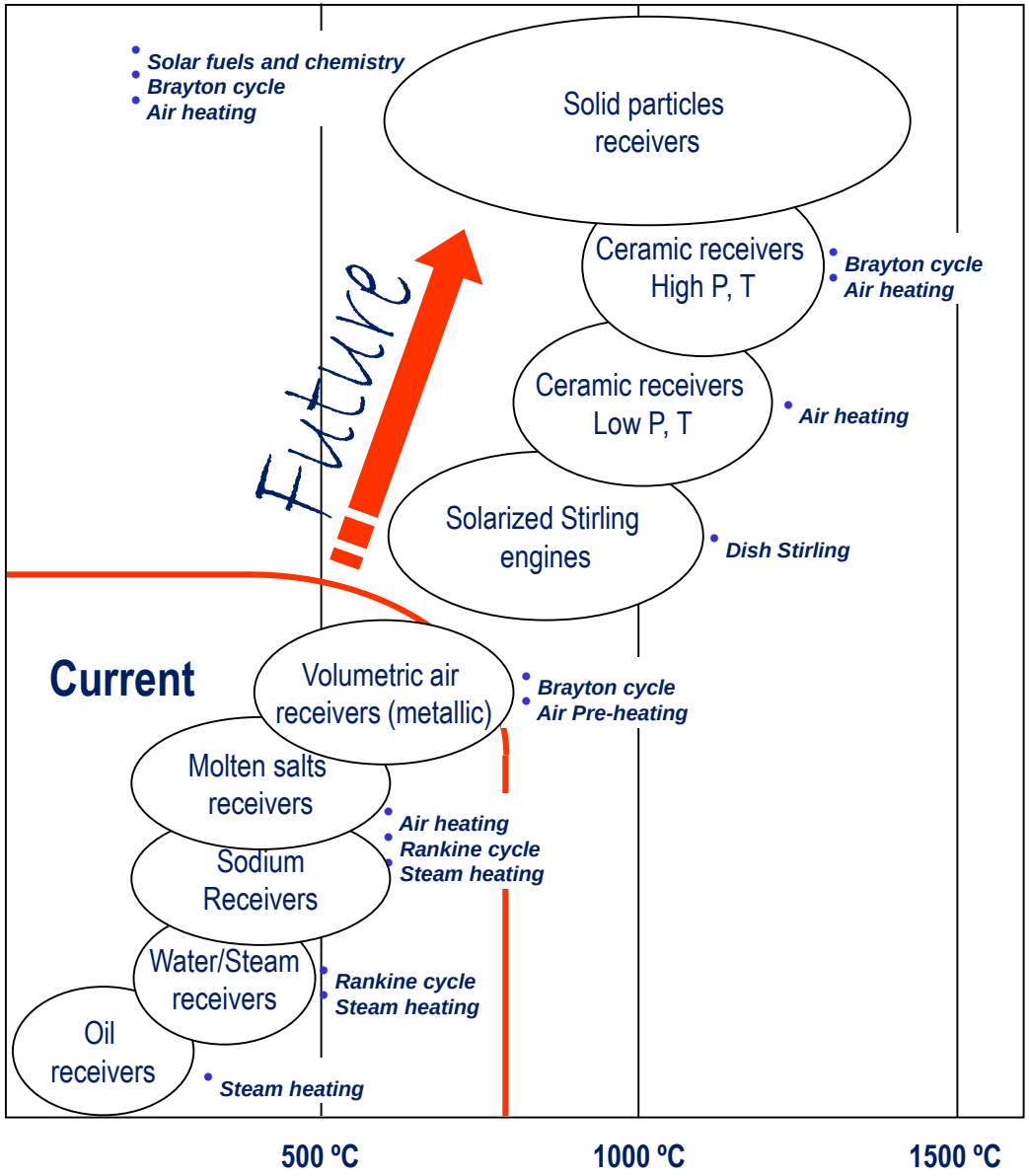
Solar Thermal Electricity

… to Market Implementation of Advanced Technologies

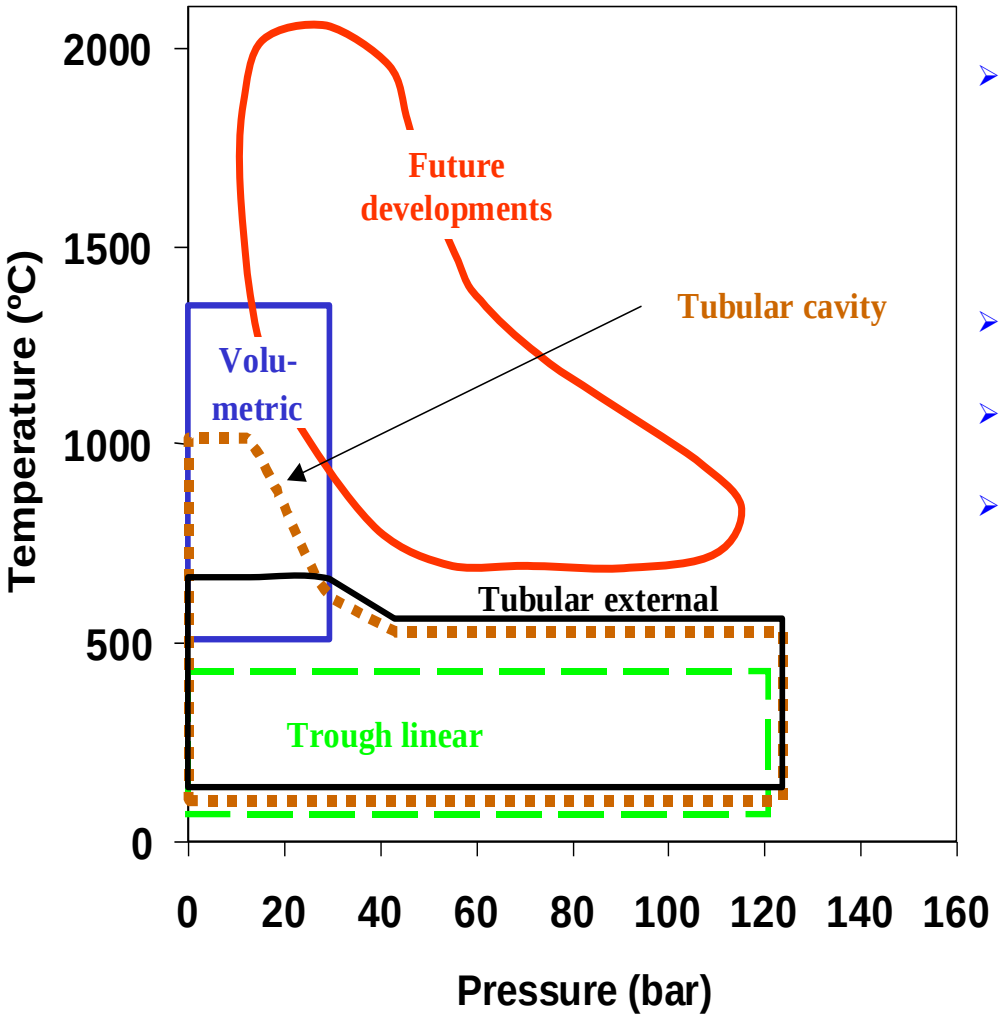
- Efficiency (high-temperature /high-flux/new HTF/solar receivers)
- Integration in advanced cycles and direct conversion systems

SPAIN
AORA
SOLAR ENERGY. LOCAL POWER.

WILSON
SOLARPOWER



Solar receiver: Reliable black-body is the key



- All should accumulate operational experience and long-term endurance tests.
- Volumetric
- Particle receivers
- Pressurized

Source: A. Kribus

Thank you very much for your attention!

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