Concentrated Solar Power

In partnership with the Clean Energy Solutions Center (CESC)

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Overview of the expert

Factor is an international group, specialized in providing global, innovative and sustainable solutions in areas such as climate change, energy, sustainability, trading and innovation.

Our key value is our people. We have offices in six countries, where our interdisciplinary team works for public and private stakeholders, international organizations and non-profit entities.

Our own history and experiences are based on constant innovation. This helps us target our services, by combining academic knowledge, technology and practical experience.

Factor
Ideas for change

Hugo Lucas Porta
Head of Energy Dept, Factor
20 years in RE Sector
- Worked for governments and private sector on energy transition strategies

Training Course Material

This Training is part of Module 2, and focuses on the Concentrated Solar Power

Eight Modules

Expert Content and Analysis

Up-to-date Market Insights

1. Policies for Distributed PV
2. Policies for Large-Scale PV
3. The Future of Solar Policy
4. Technical Integration of Solar
5. Market Integration
6. Socio-Economic Aspects
7. Off-grid Solar
8. Solar Heating & Cooling

Overview of the Training

1. Introduction: Learning Objective
2. Understanding Concentrated Solar Power
3. Main body of presentation
4. Concluding Remarks
5. Further Reading
6. Knowledge Check: Multiple-Choice Questions

1. Introduction: Learning Objective

Learning Objective

This lecture provides:

1 An overview of CSP technologies

2 Status and trends of CSP markets over the world

3 Discussion on the costs of CSP

4 Research and Development programs for CSP

2. Understanding Concentrated Solar Power

Understanding Concentrated Solar Power

Concentrated Solar Power (CSP), also called Solar Thermal Power Generation, plants produce electric power by using mirror to concentrate a large area of sunlight onto a small area, the boiler.

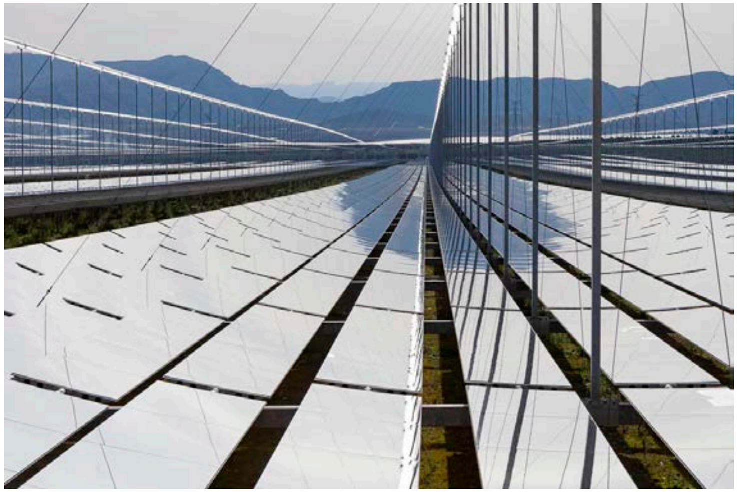
Electricity is generated when the concentrated light is converted to heat, which drives a heat engine (usually a steam turbine) connected to an electrical power generator.

Source: La Dehesa plant

Understanding Concentrated Solar Power

Concentrated solar power (CSP) plants **can integrate thermal energy storage** systems to generate electricity during cloudy periods or even several hours after the sunset. CSP systems can be also **combined with combined cycle** power plants resulting in hybrid power plants which provide high-value, dispatchable power.

Concentrated Solar Power systems can be sized for village power (10 kilowatts) or grid-connected applications (more than 100 megawatts).



Calasparra plant. Fresnel technology

Understanding Concentrated Solar Power

Worldwide historical evolution:

- At the **beginning of the 70s**, with the rapid increase in oil prices, is when the **great impulse to solar concentration technologies** takes place.
- High intensity of **research activity** in Solar Concentration Systems was developed between **the mid 70's** and **the end of the 80's.**
- During the **1980s and 1990s**, the **first commercial initiatives** were built in the USA. (SEGS plants, in the Mojave desert of California).
- The thermoelectric solar sector is **currently** in the commercial **takeoff phase** throughout the world, and especially in Spain.

Understanding Concentrated Solar Power

Research and development centers

- The **Solar Platform of Almería (PSA), Spain** belongs to the Center for Energy, Environmental and Technological Research (CIEMAT). It is the largest public research and testing center dedicated to solar concentration technologies.
- **The Solar Platform Sanlúcar la Mayor (SOLUCAR):** It belongs to the Abengoa group and it is the largest private centre of solar energy, with technologies of all the solar areas, mainly solar thermoelectric.
- **Sandia National Laboratories**, **in EE.UU.:** carries out the NSTTF (National Solar Thermal Test Facility), near Alburquerque in New Mexico with a tower plant of 5 MW for component tests.
- **Other centers with tower plants of 1-2 MW** such as: **Weizmann Institute, in Israel**, in Rehovot, **Colonia (Germany)** and soon in the **French Pyrenees (former THEMIS plant).**

3. Main Body of Presentation

Main Body of Presentation

1 An overview of CSP technologies

2 Status and trends of CSP markets

3 Costs of CSP

4 Research and Development programs for CSP

An overview of CSP technologies

Thermoelectric solar energy groups four technological areas with different commercial maturity and different potential:

- **TOWER**
- **PARABOLIC TROUGH**
- **PARABOLIC DISH**
- **LINEAR FRESNEL COLLECTOR**

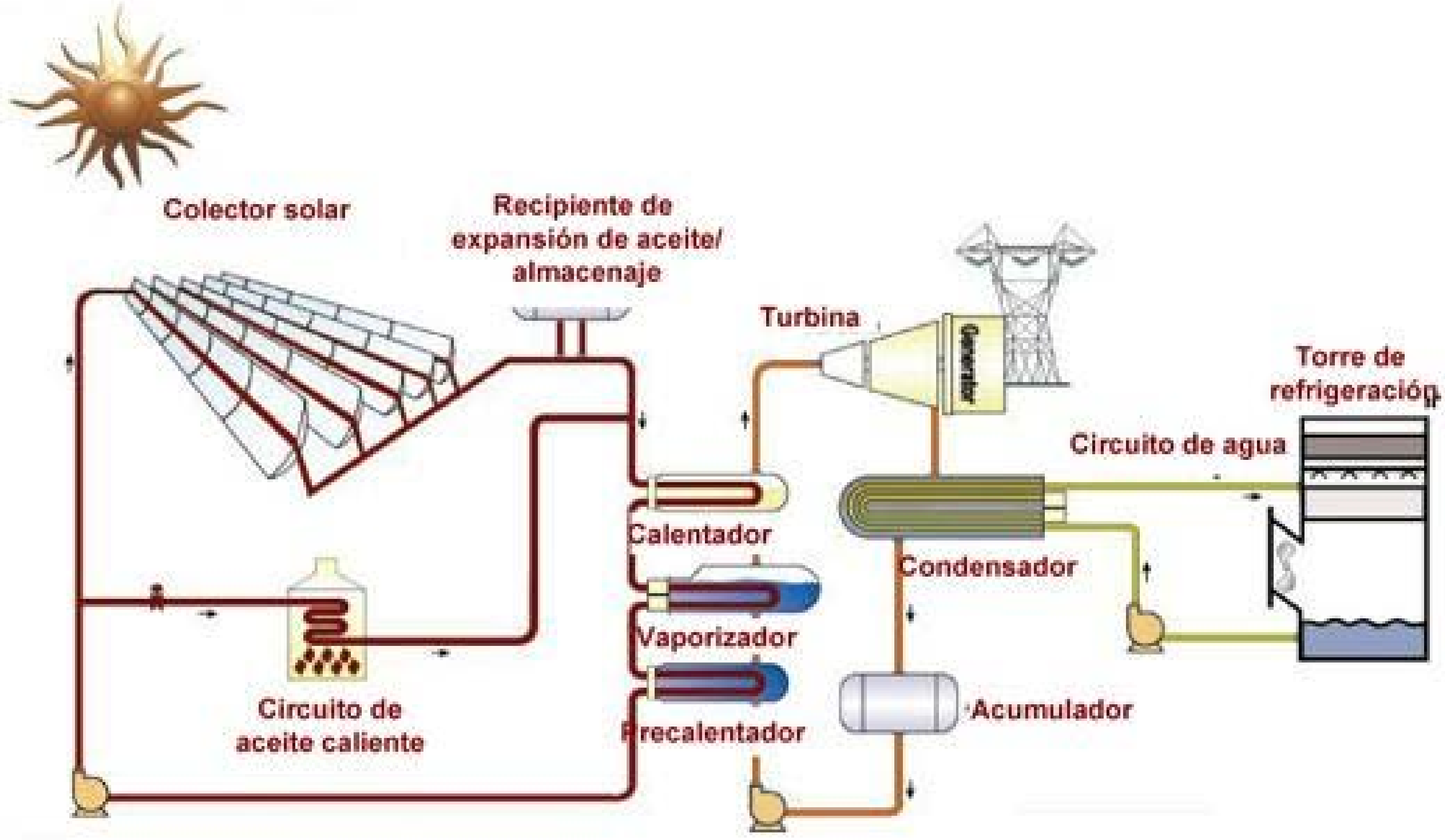



An overview of CSP technologies

Technology	PT	LF	DS	CT
Typical size (MW)	10 – 280	1 – 125	1	10 – 135
Concentration Factor	70 – 80	25 – 100	600 – 4000	600 – 1200
Capacity Factor (%)	30 – 50	20 – 30	20 – 30	40 – 70
Operation Temperature (ºC)	293 – 393	140 – 275	250 – 700	290 – 565
Solar → Electric perf. (%)	16 – 18	9 – 11	12 – 25	16 – 20
Installed worldwide (MW)	4,336	319	3	689
Use of land (MWh/(ha·year))	600 – 1,000	600 – 1,000	400 – 800	400 – 800
Maturity	Commercial	Commercial	Demo	Commercial
Reflector	Parabolic mirror	Flat/curved mirror	Paraboloid mirror	Curved mirror
Receiver	Absorber tube w/ vacuum cover	Absorber tube w/ concentrator	Stirling engine / gas turbine	External / Cavity
HTF	Thermal oil	Saturated steam	Air	Molten salt / Water-steam
TES	Molten salts, indirect	Steam accumulator	N/A	Molten salts, direct / steam accumulator
TES capacity	4 – 12 hours	< 1 hour	N/A	6 – 14 / < 1 hours
Hybridization capable	Yes, existing	Yes	Unlikely	Yes

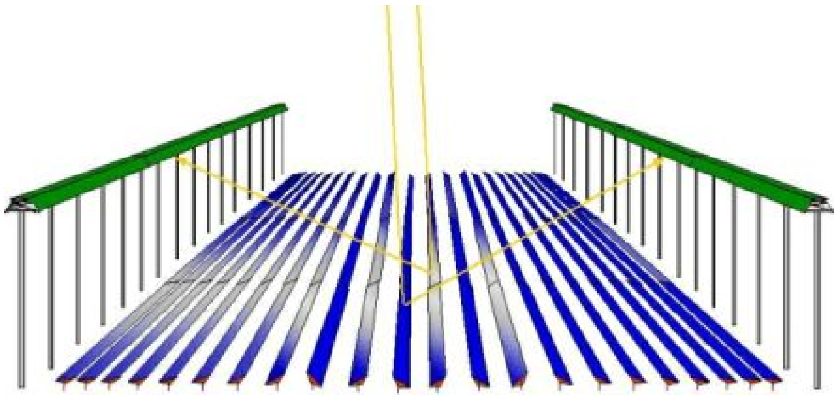
An overview of CSP technologies

Parabolic trough



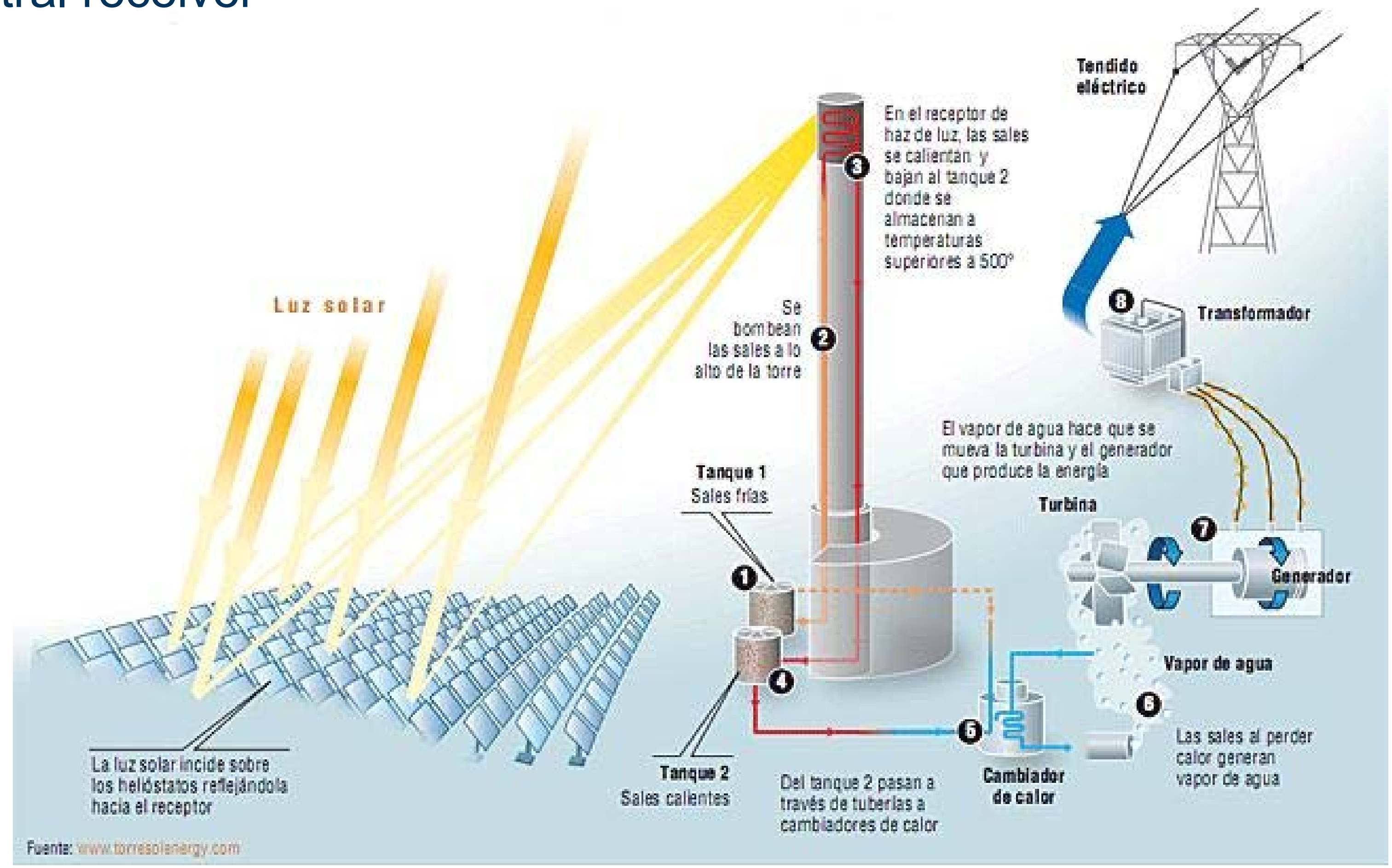
An overview of CSP technologies

Linear Fresnel Collectors



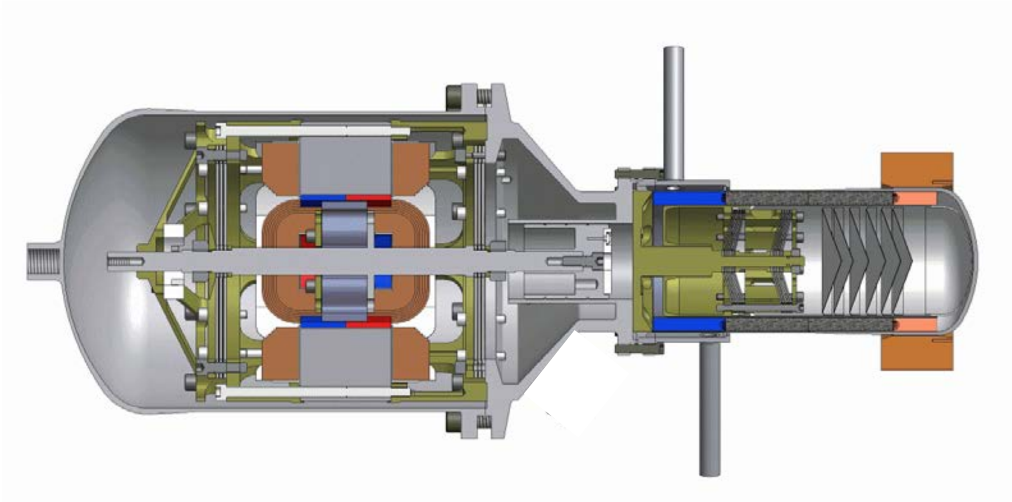
An overview of CSP technologies

Power tower
Central receiver



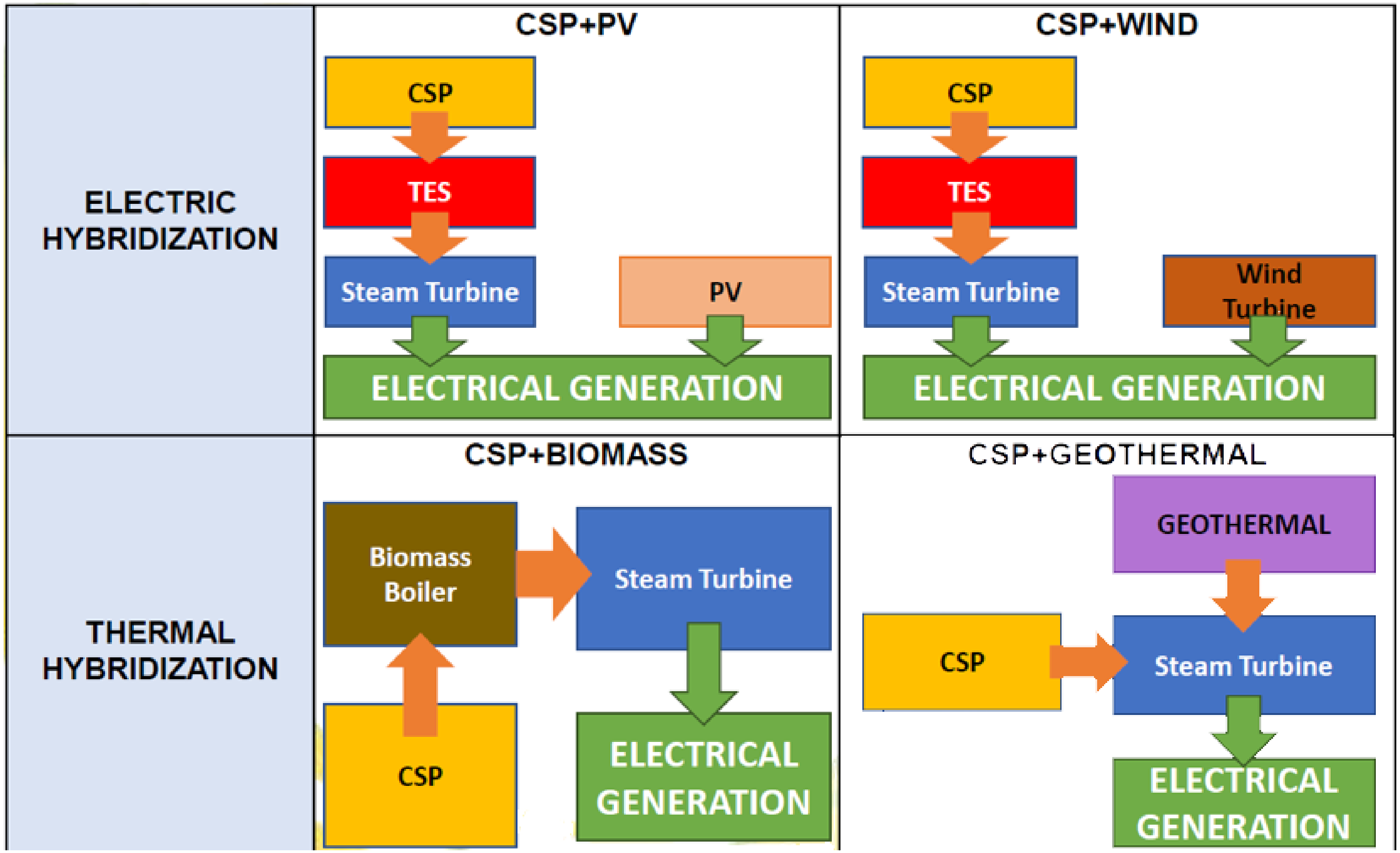
An overview of CSP technologies

Parabolic dish



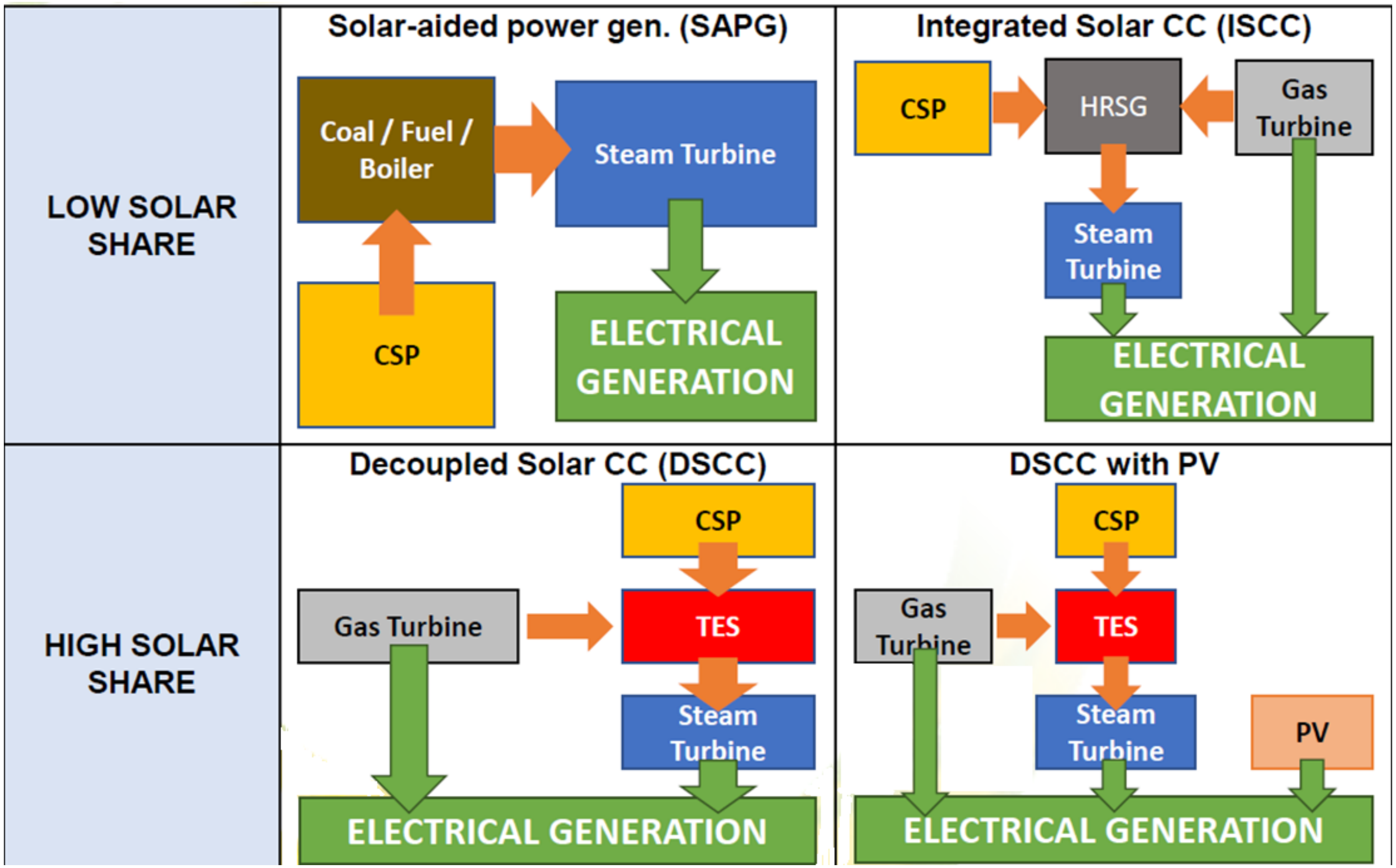
An overview of CSP technologies

Hybridizing CSP – 100% renewable



An overview of CSP technologies

Hybridizing CSP-fossil fuels



An overview of CSP technologies

CSP, PV or Hybrid

- On production cost alone, PV is, today, significantly cheaper than CSP. It is also more modular and easier to design, construct, maintain and operate.
- When dispatchability is required, CSP+TES is cheaper to install and to run than PV with batteries, which gives CSP a competitive advantage. Nevertheless this is changing fast.
- Hybridizing CSP with fuels can ease the path, reducing emissions while providing track record to CSP, and time to amortize plants in operation.

Main Body of Presentation

1 An overview of CSP technologies

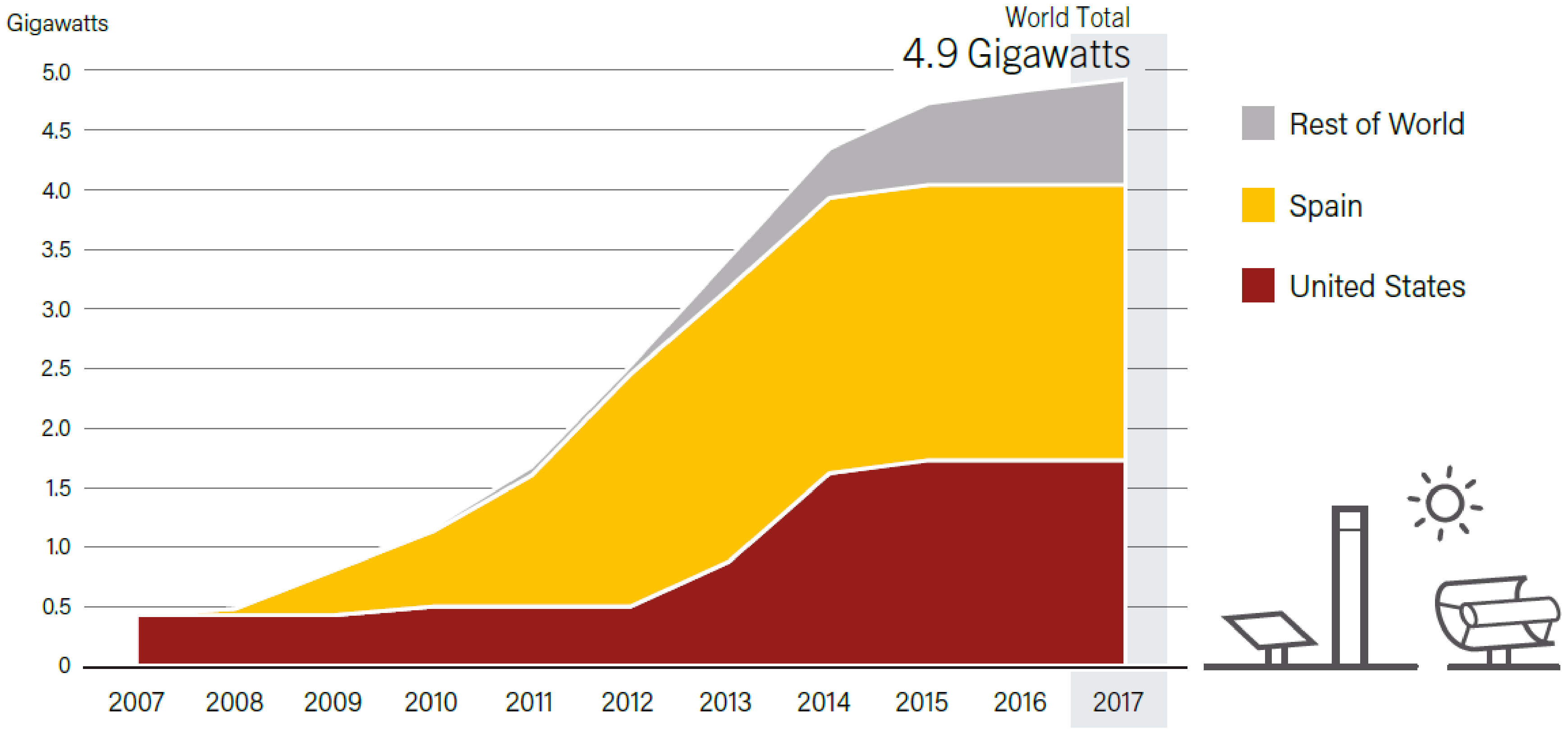
2 Status and trends of CSP markets

3 Costs of CSP

4 Research and Development programs for CSP

Status and trends of CSP markets

Global Capacity by Country and Region, 2007-2017



Source: REN21 Renewables 2018 – Global Status Report

Status and trends of CSP markets over the world

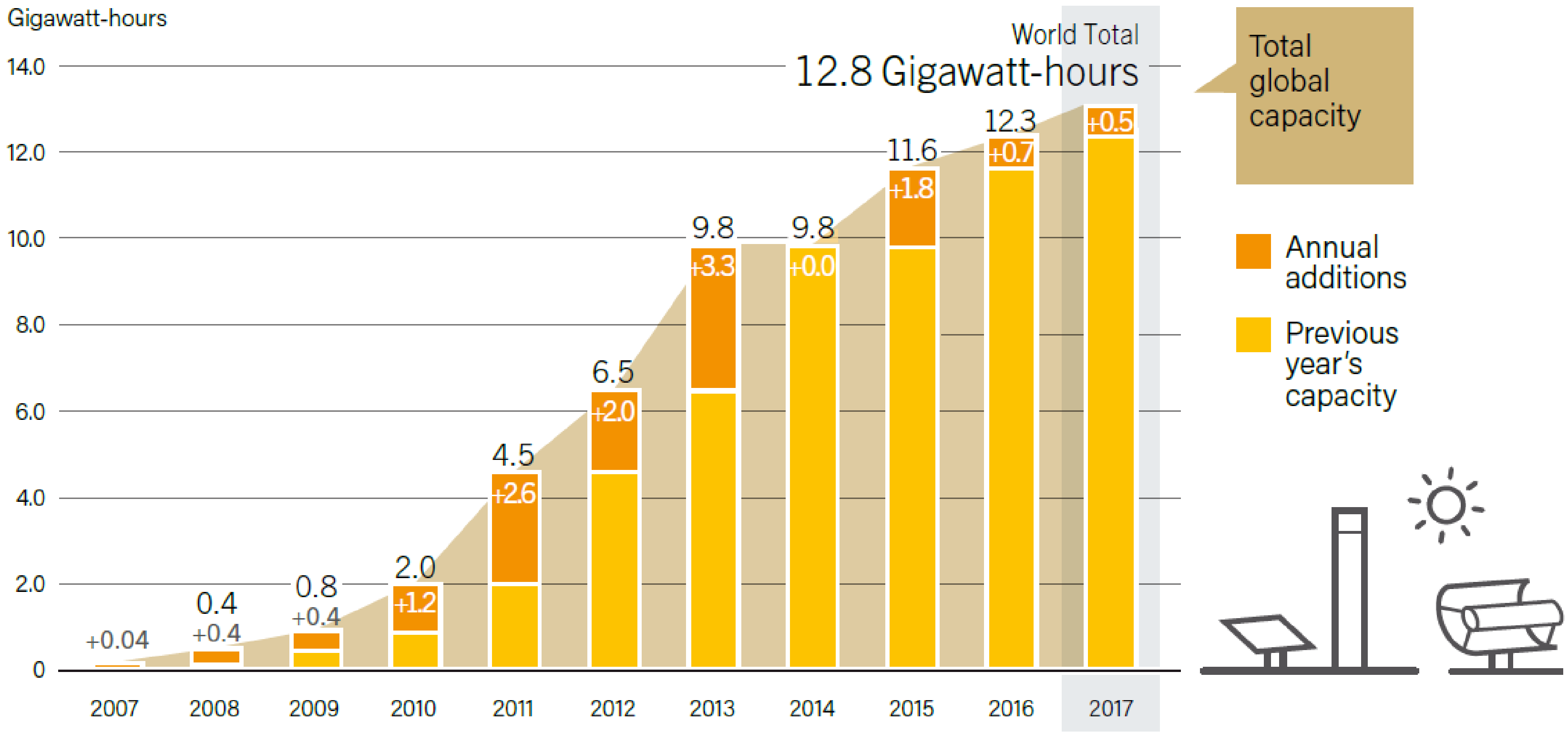
Global Capacity and Additions, 2017

Country	Total End-2016	Added 2017	Total End-2017
		MW	
Spain	2,304	0	2,304
United States	1,738	0	1,738
South Africa	200	100	300
India	225	0	225
Morocco	166	0	166
United Arab Emirates	100	0	100
Algeria	20	0	20
Egypt	20	0	20
Iran	17	0	17
China	20	0	20
World Total	**4,810**	**100**	**4,910**

Source: REN21 Renewables 2018 – Global Status Report

Status and trends of CSP markets

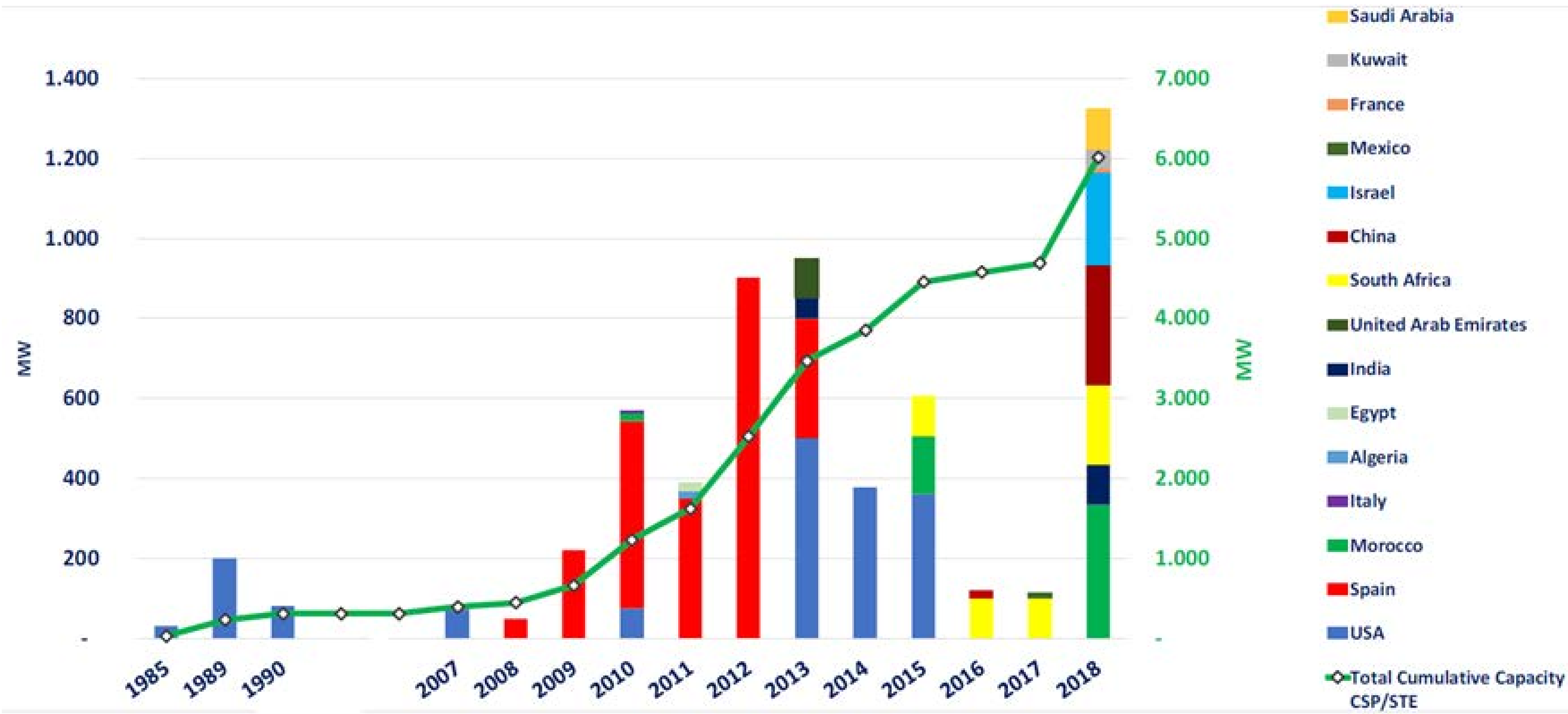
CSP Thermal Energy Storage Global Capacity and Annual Additions, 2007-2017



Source: REN21 Renewables 2018 – Global Status Report

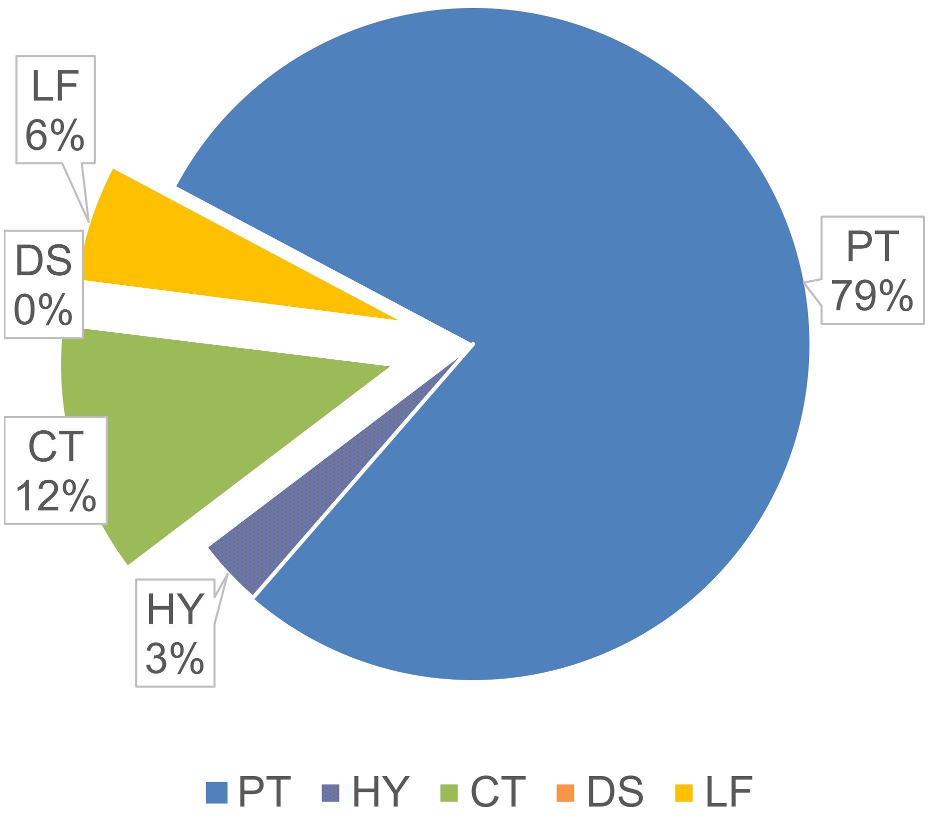
Status and trends of CSP markets

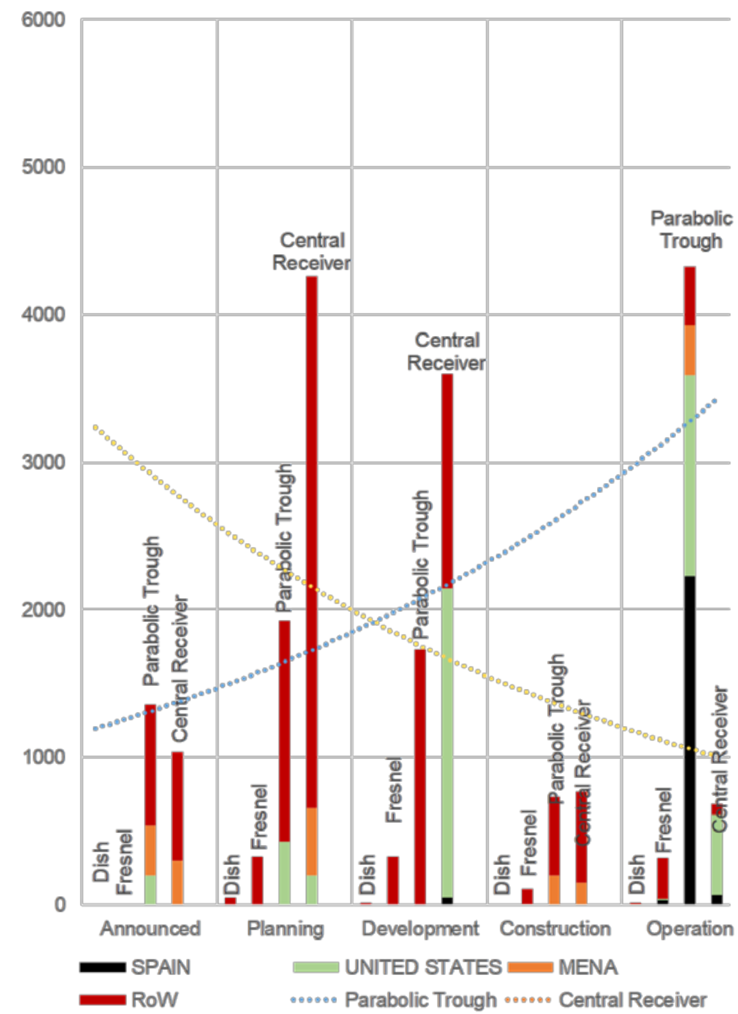
Evolution of the thermosolar capacity installed



Status and trends of CSP

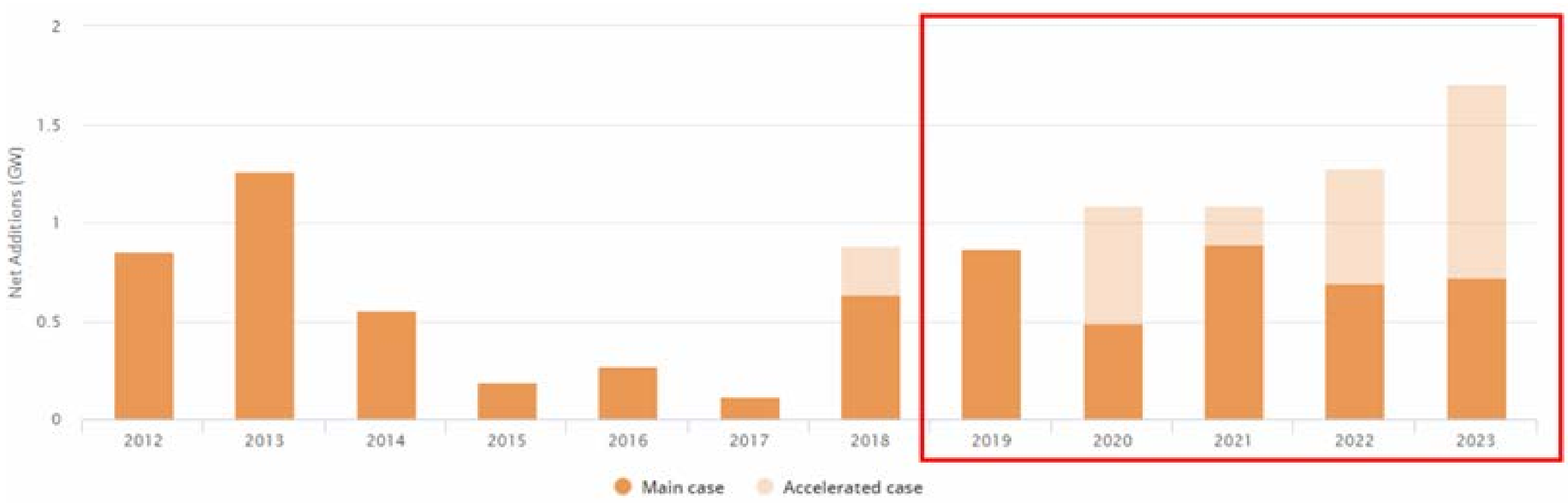
Trends in technology choice





Status and trends of CSP

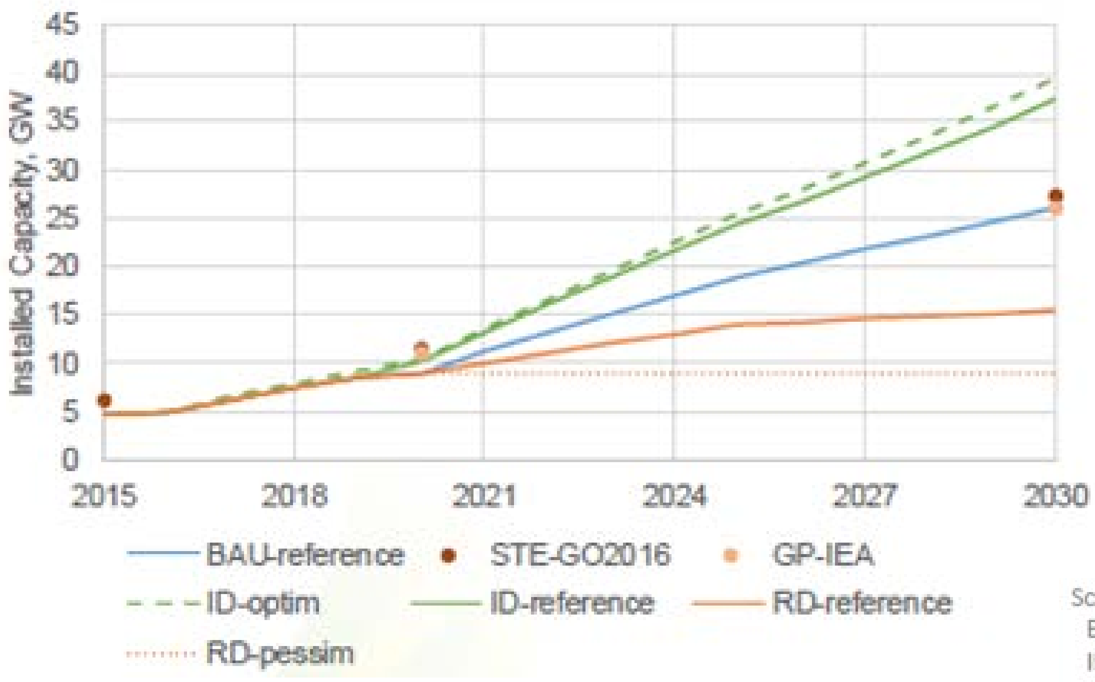
Net CSP capacity additions
Main and accelerated case, 2012-2023



Source: International Energy Agency

Status and trends of CSP markets

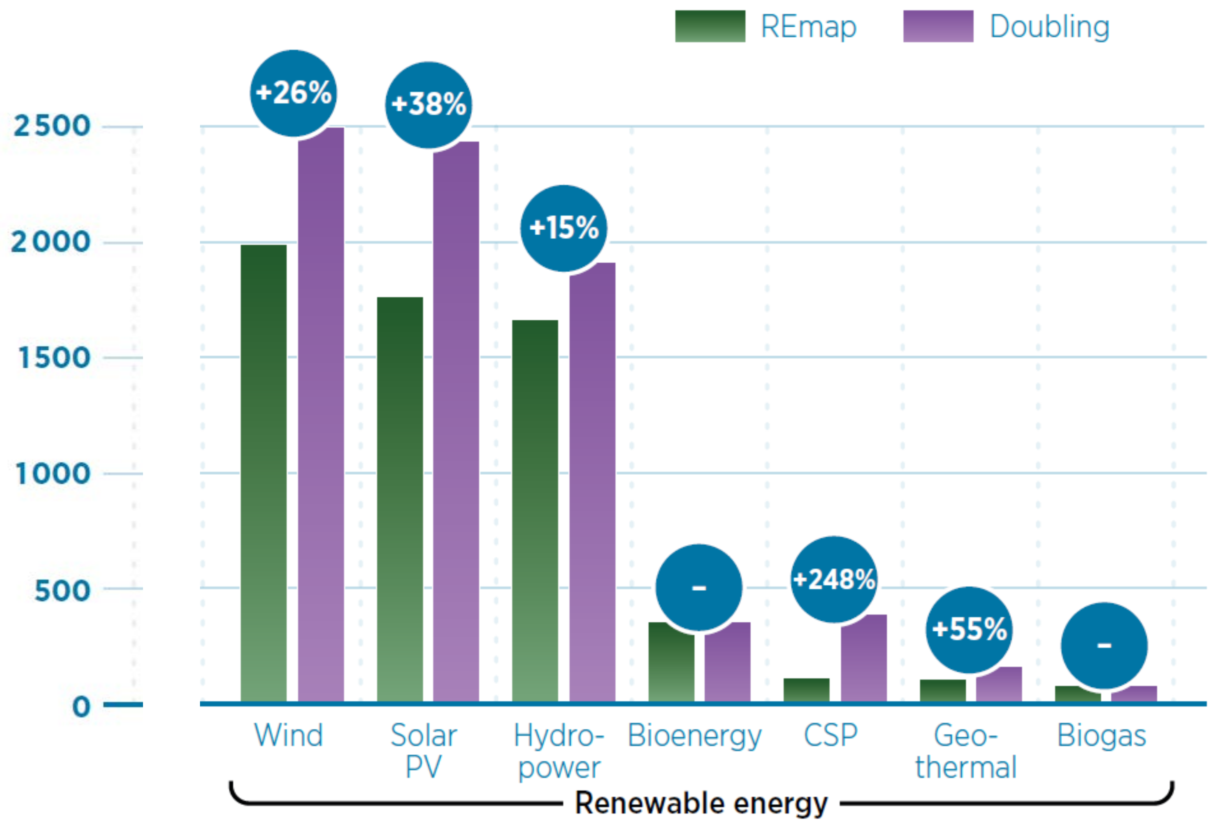
Uncertainty in projections



Scenarios:
BAU: business as usual
ID: increased deployment
RD: reduced deployment
STE-GO: Solar Thermal Electricity Global Outlook 2016
GP-IEA: Greenpeace-IEA

Status and trends of CSP markets

Power generation capacity
(GW installed by 2030)



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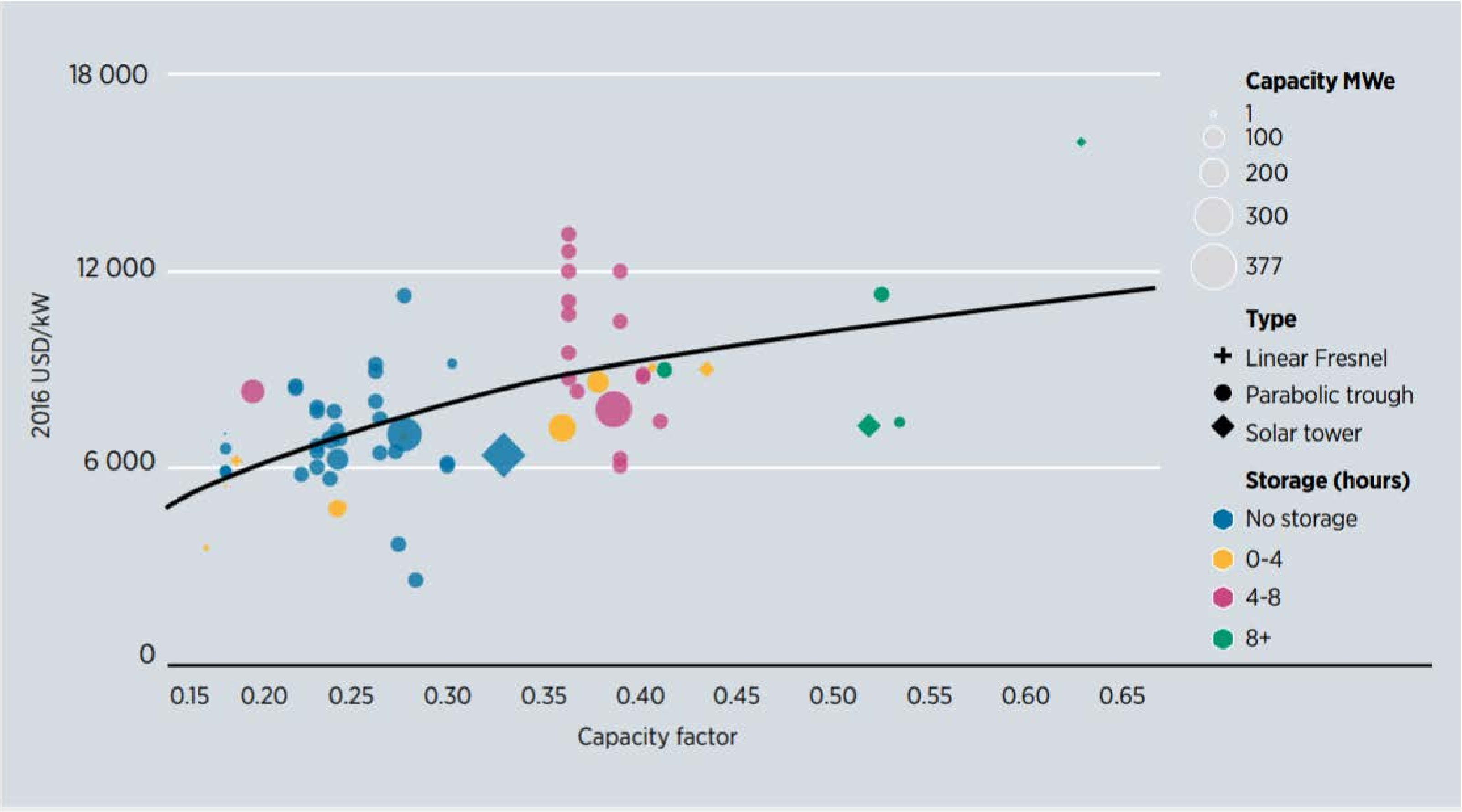
Costs of CSP

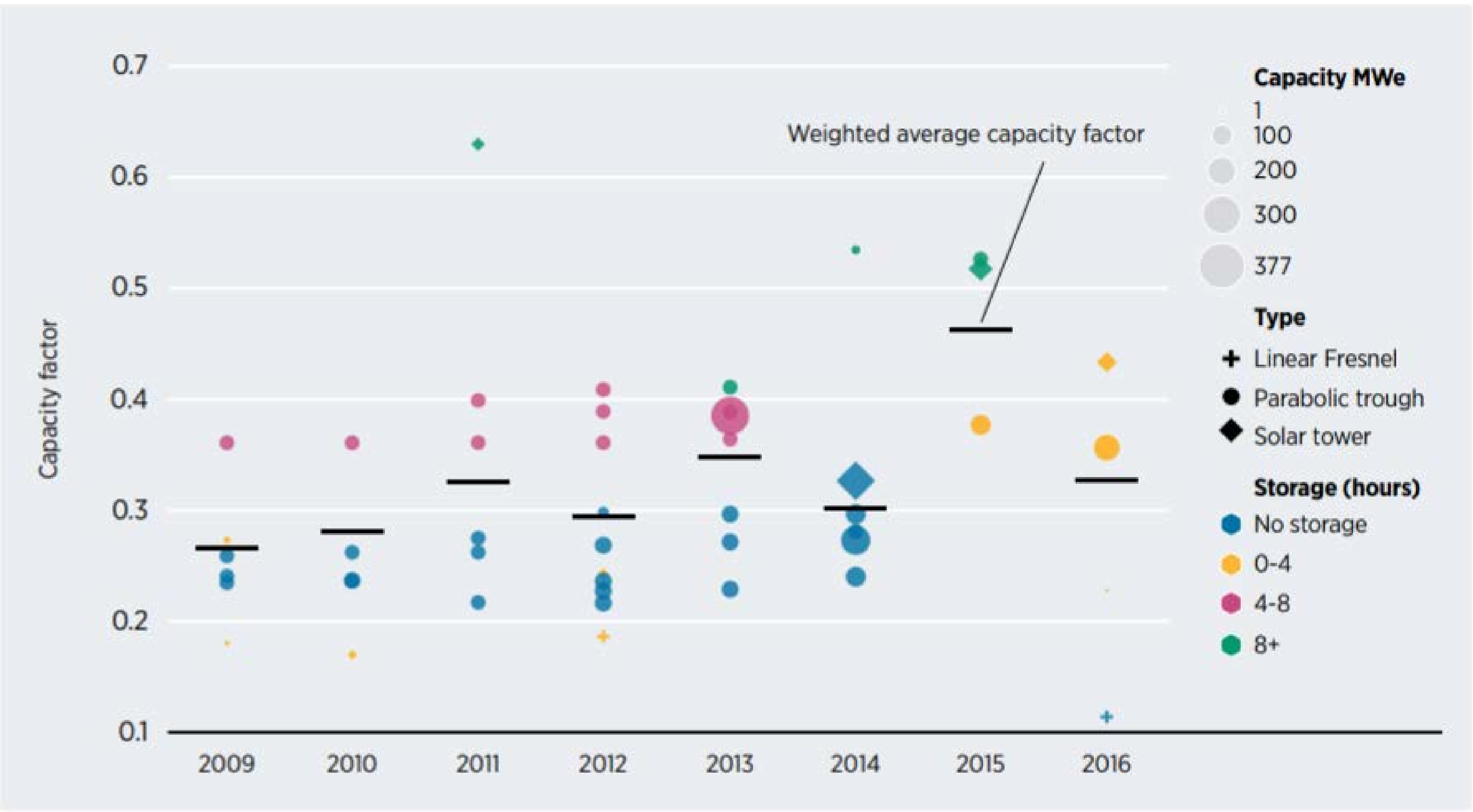
Figure 4.3 Installed costs and capacity factors of CSP projects by their quantity of storage, 1984-2016.



Source: IRENA Renewable Cost Database.

Costs of CSP

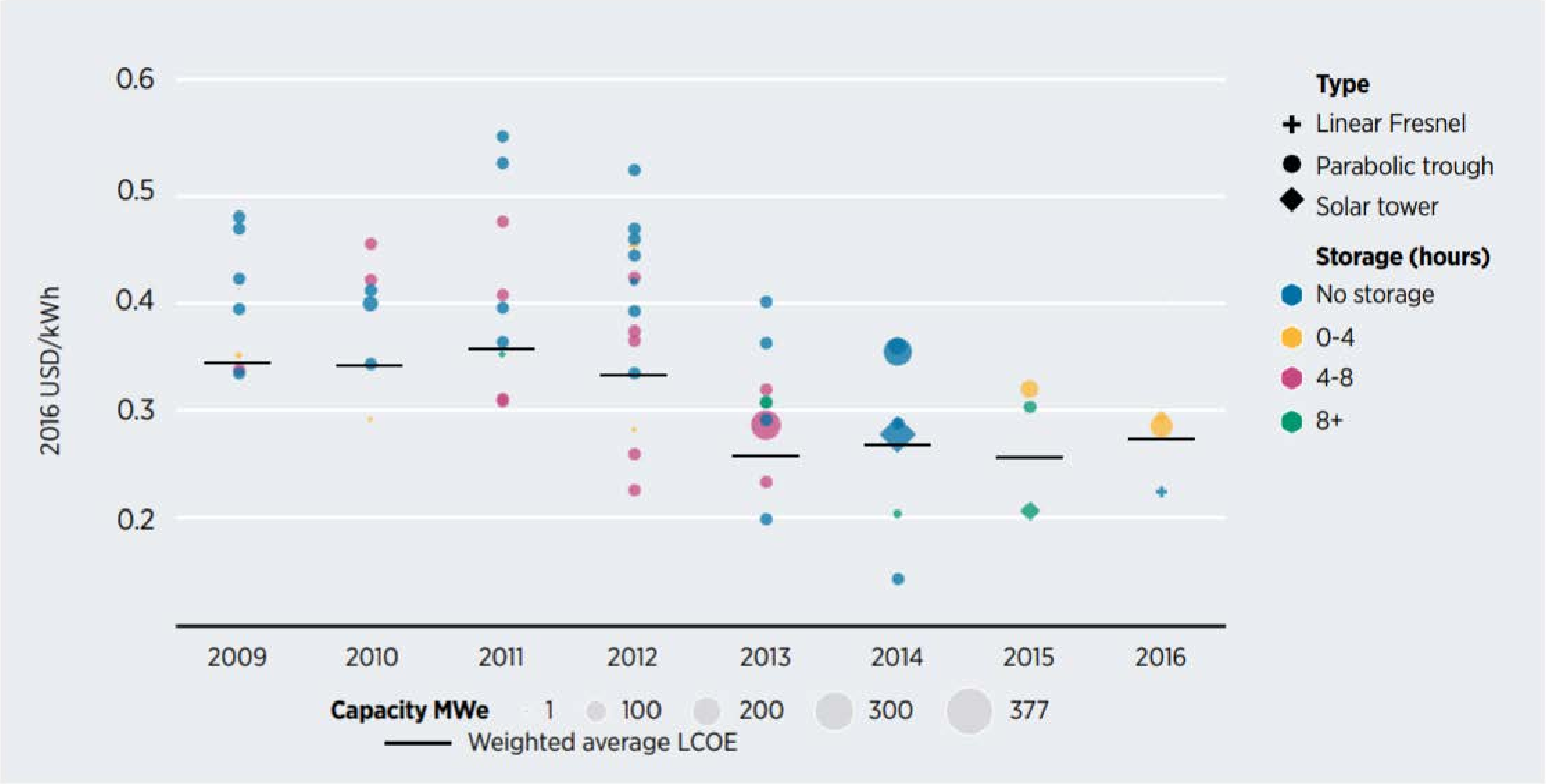
Figure 4.7 Capacity factor trends for CSP plants, 2009-2016



Source: IRENA Renewable Cost Database.

Costs of CSP

Figure 4.9 The levelised cost of electricity for CSP projects, 2009-2016



Source: IRENA Renewable Cost Database.

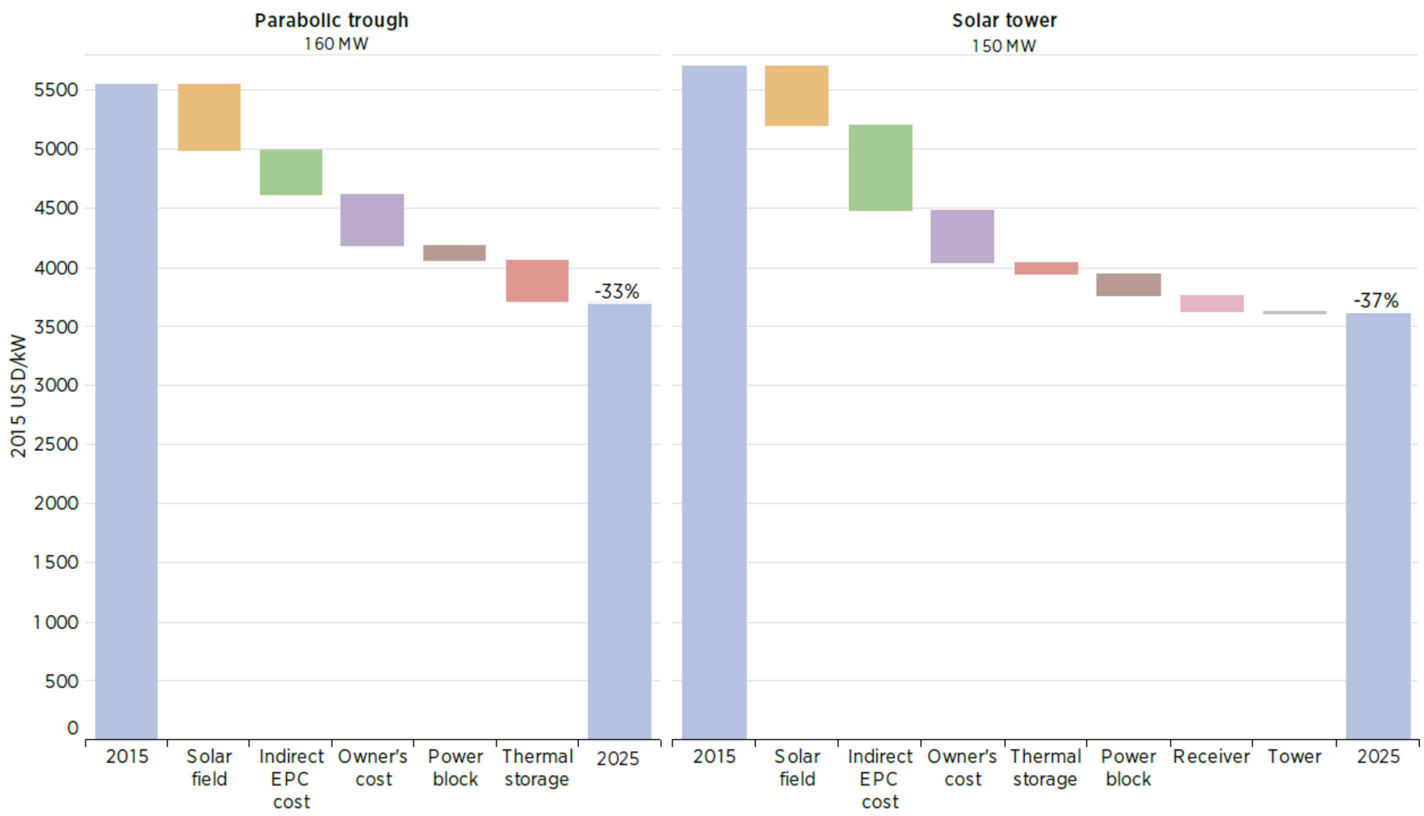
Costs of CSP

Figure 4.10 Levelised cost of electricity and auction price trends for CSP, 2010-2022

Costs of CSP

Cost reduction potential

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

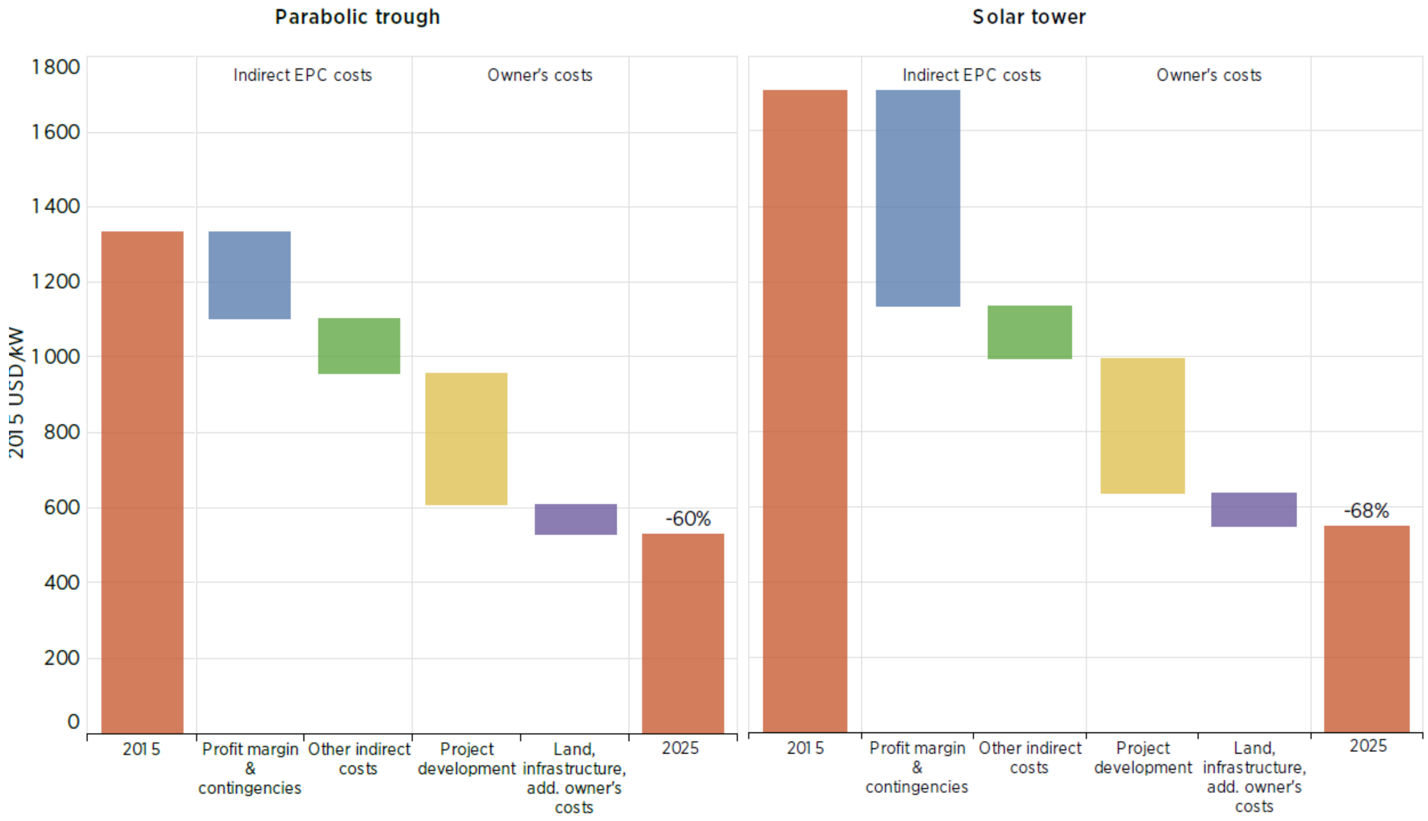


Source: IRENA and DLR, 2016.

Costs of CSP

Indirect EPC & owners costs

cost reductions for CSP plants to 2025

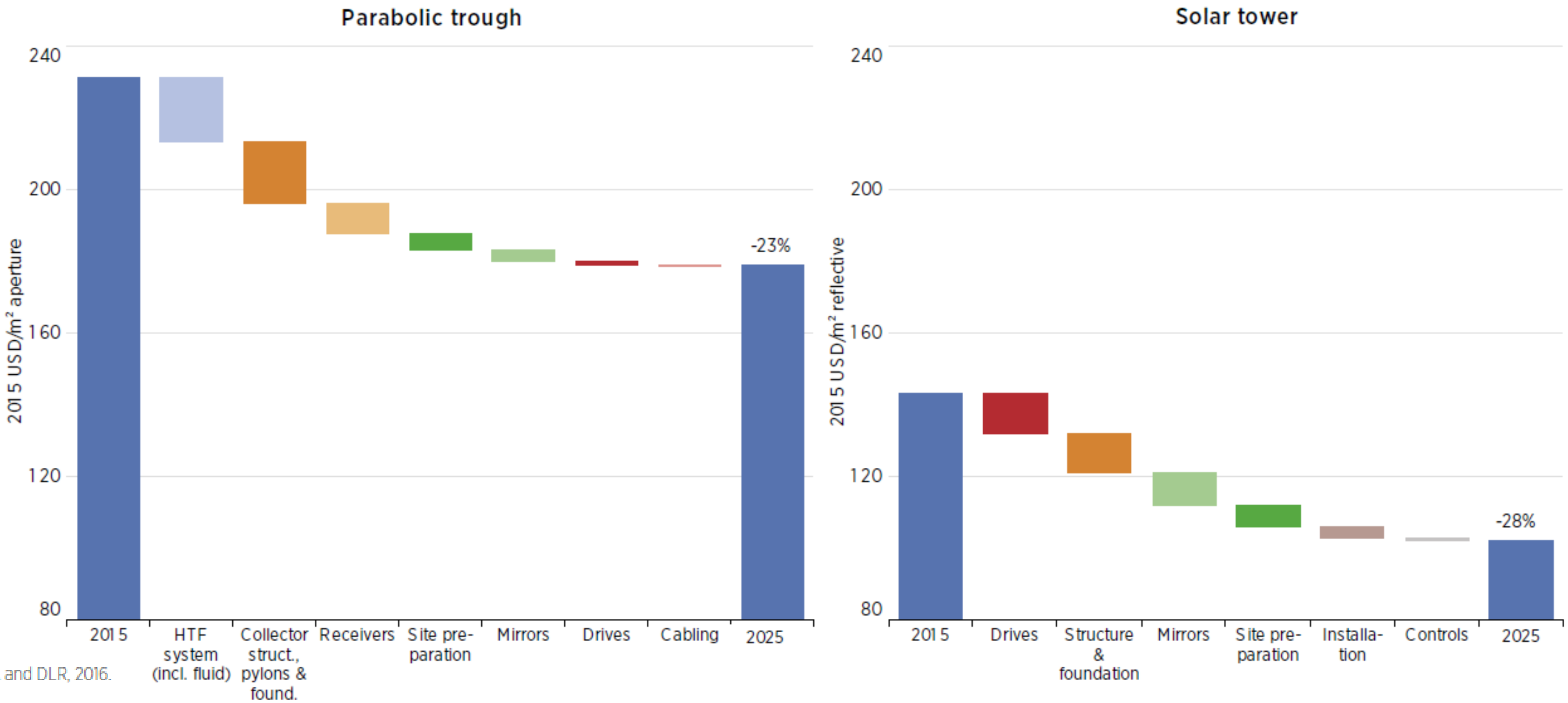


Source: IRENA and DLR, 2016.

Costs of CSP

Solar field components

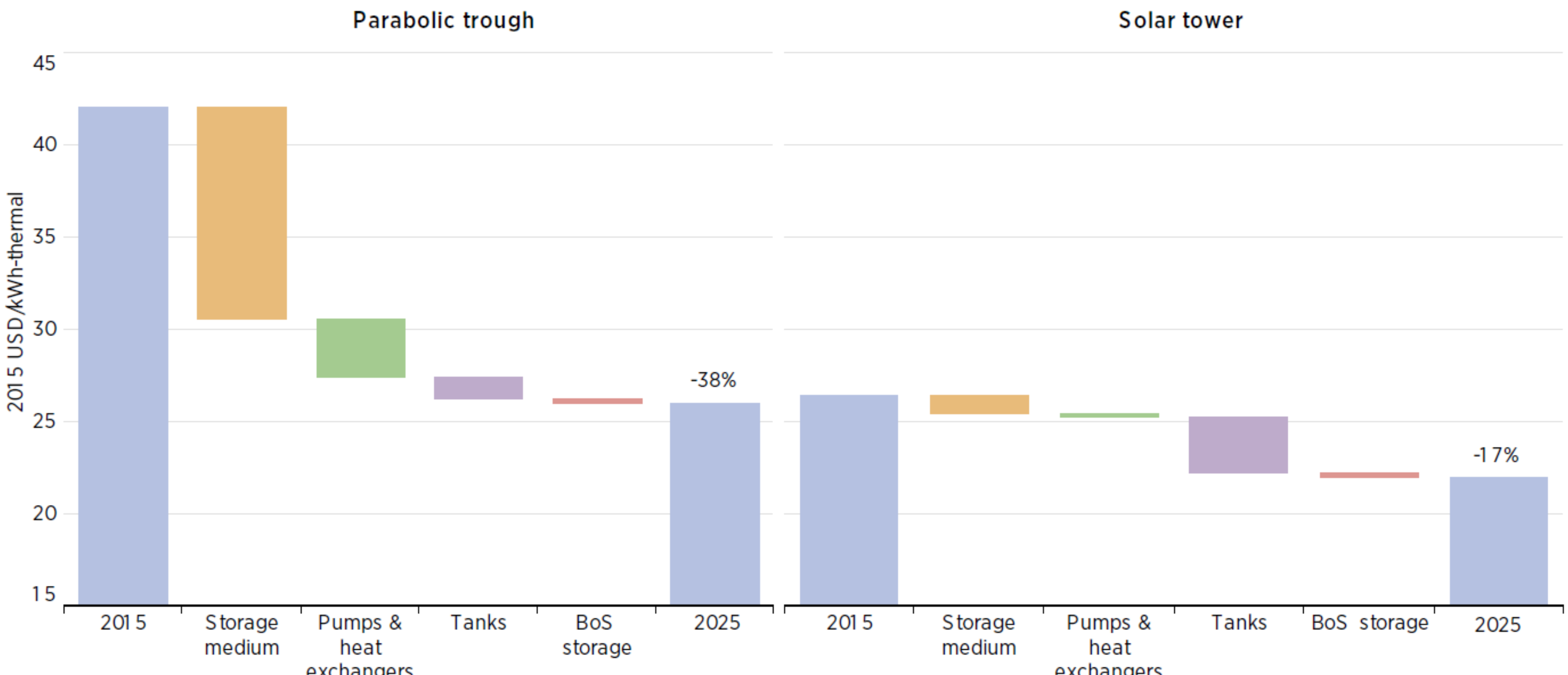
Cost reduction potentials of the solar field component of PTC and ST CSP plants by source, 2015-2025



Source: IRENA and DLR, 2016.

Costs of CSP

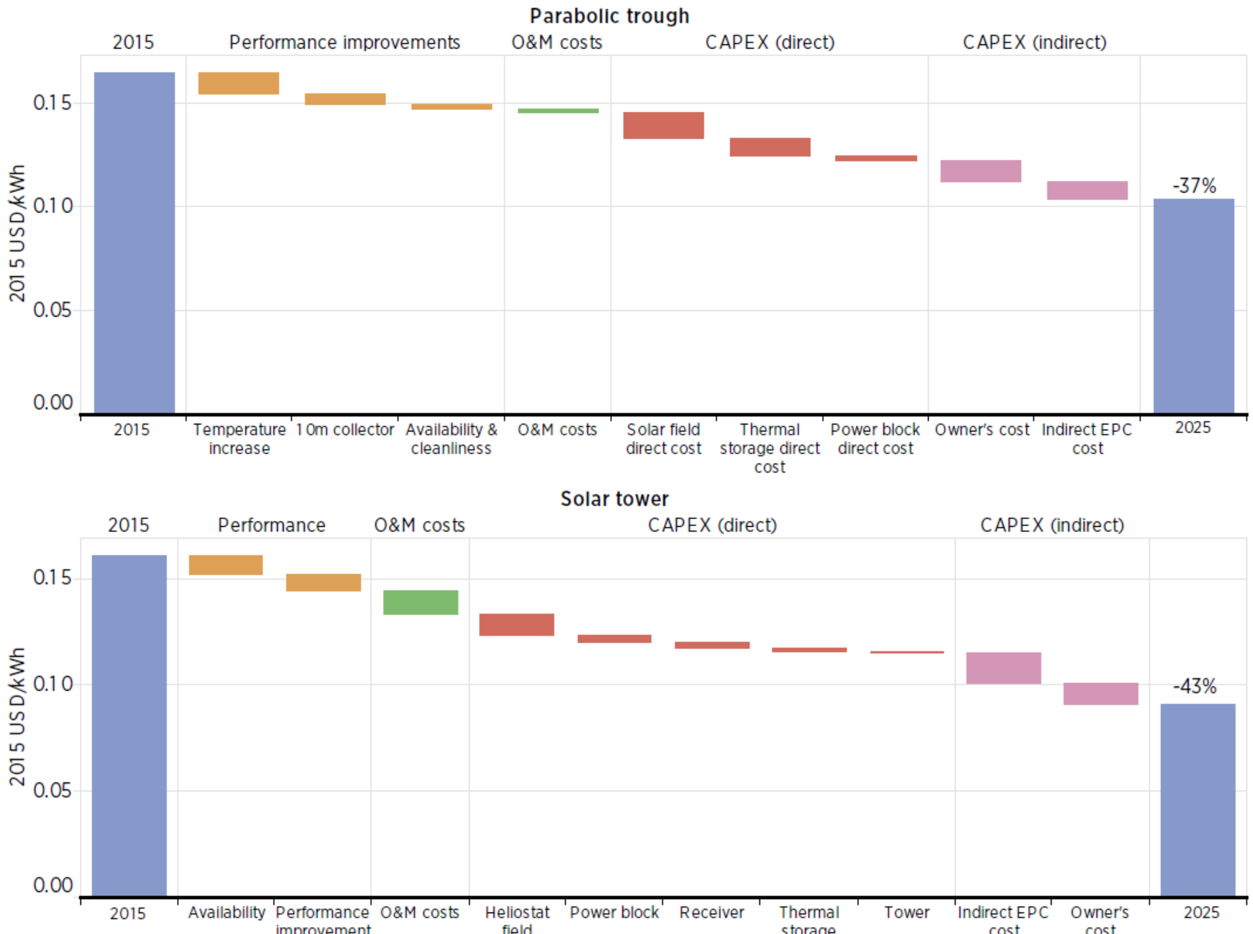
Thermal energy storage



Source: IRENA and DLR, 2016.

Costs of CSP

LCOE reduction potential

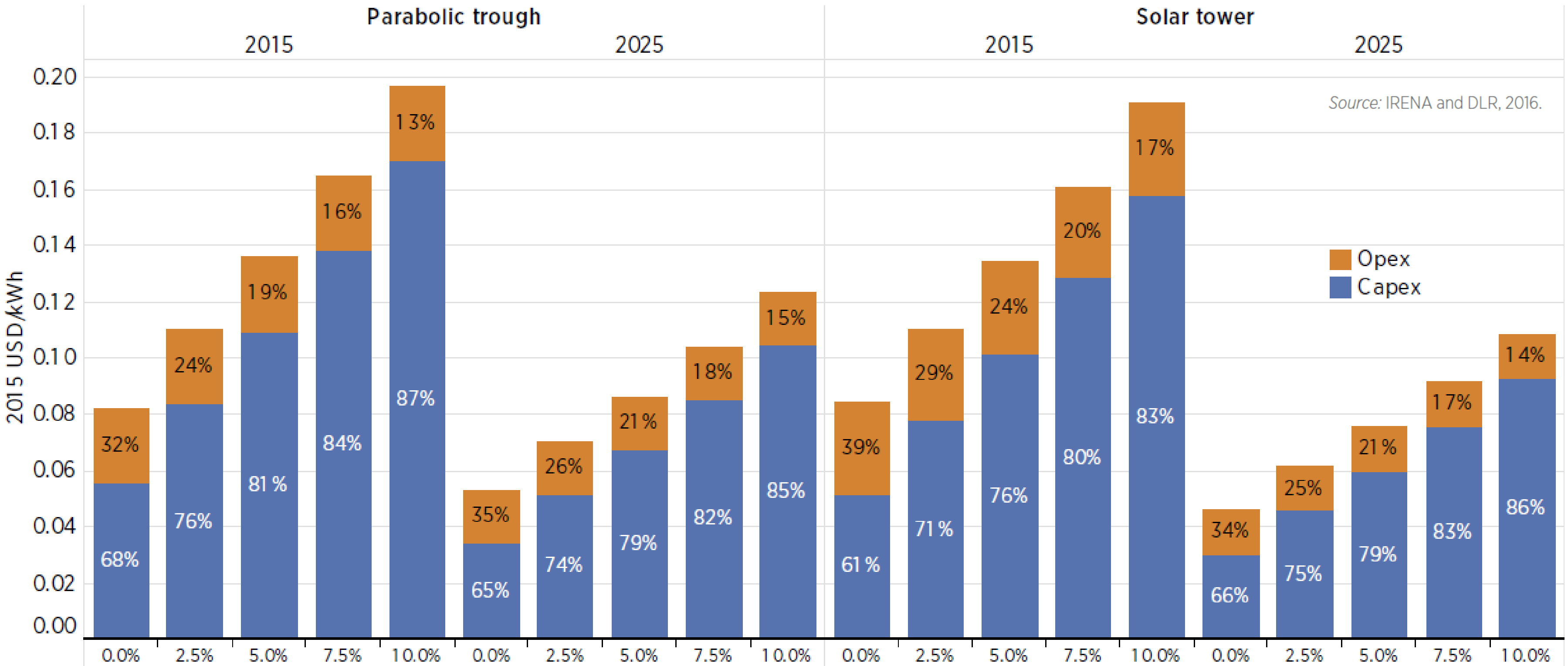


Source: IRENA and DLR, 2016.

Costs of CSP

LCOE sensitivity to WACC

Sensitivity of the levelised cost of electricity of PTC and ST plants to variations in the WACC, 2015 and 2025



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R&D Programmes for CSP

Equipment

- New heat transfer fluids
- Structures and trackers
- Reflectors
- Receiver
- Thermal Energy Storage

System

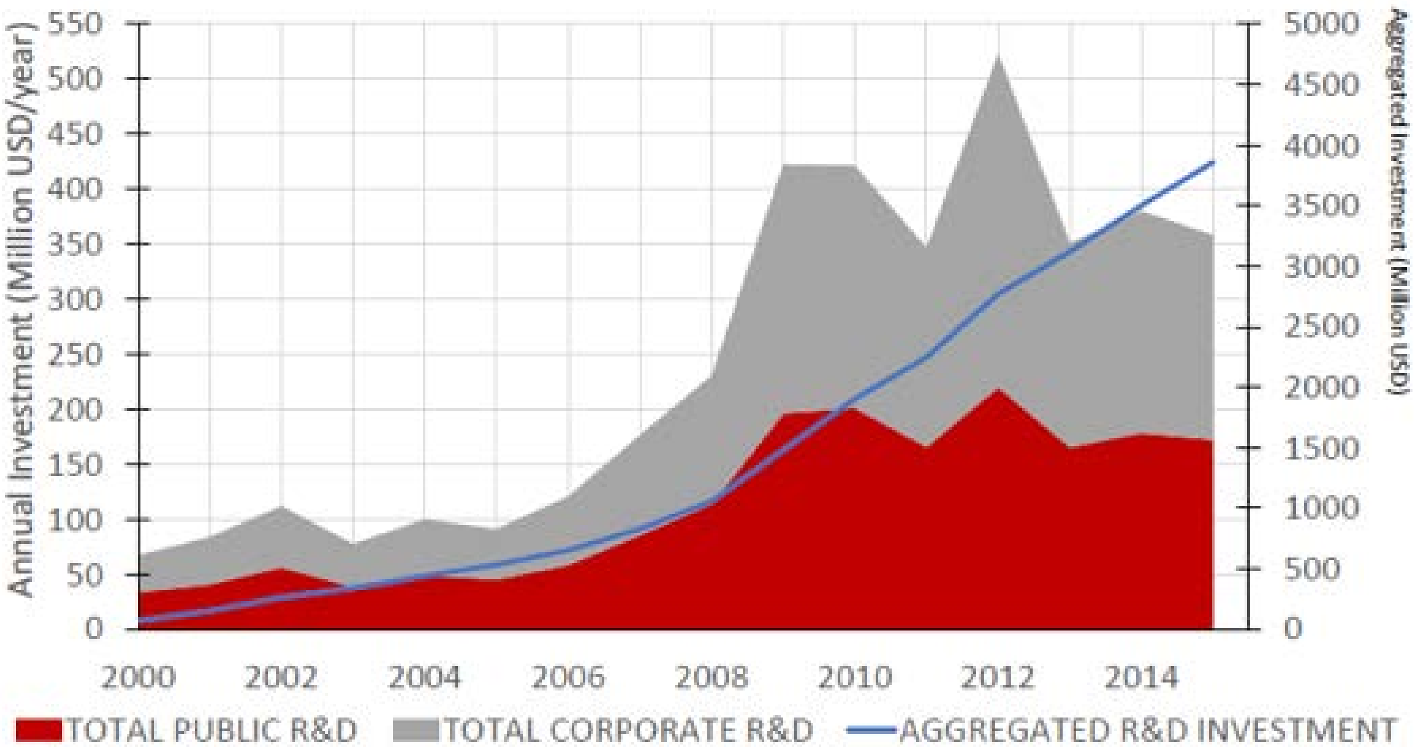
- Dispatchability
- Scales limits
- Use of water
- Hybridization

Some key aspects are not included in typical R&D

- Soft costs in development and EPC
- Risk reductions/ cost of capital
- New business models

R&D Programs for CSP

Evolution of R&D private investment and aggregated



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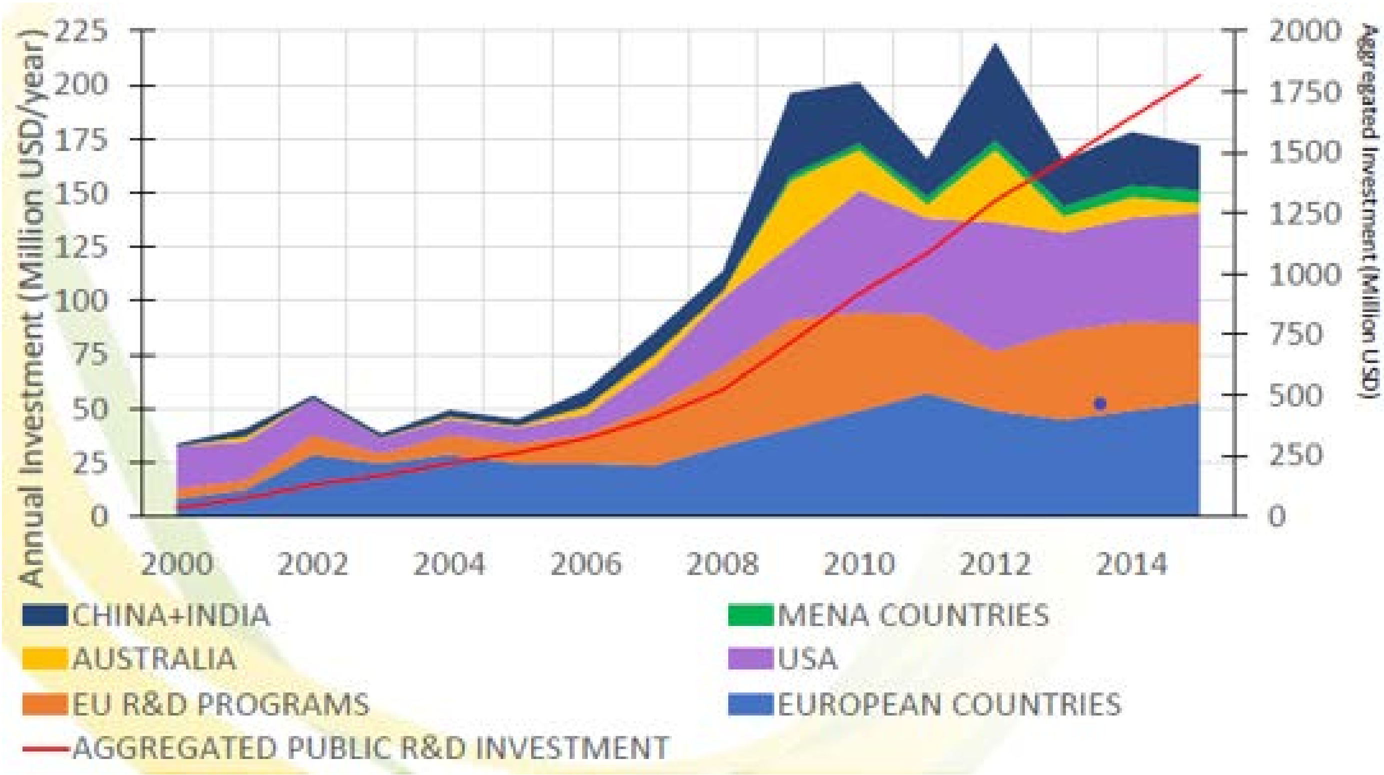
R&D Programs for CSP

Evolution of R&D public investment



4. Concluding Remarks

Concluding Remarks

- Half a decade ago, expectations for CSP deployment were higher than the current situation: most long-term forecasts and country plans have not been fulfilled.
- There is not only one reason for this:
  - ✓ the quick cost reduction of PV made it a more attractive alternative (so some efforts were moved from CSP to PV);
  - ✓ several other initiatives were halted, hoping that a PV-like cost reduction would bring CSP's LCOE closer to grid parity;
  - ✓ when the cost reduction was not as quick as expected, the sector risked entering a vicious circle as a slower deployment further slowed cost reduction.

Concluding Remarks

- The future development of CSP is linked to its ability to provide value to the electric system in comparison with other alternatives.
- CSP's strengths, beyond possible cost break through, are:
  - ✓ cheap storage;
  - ✓ demand management capabilities;
  - ✓ ancillary services, etc.
- There is potential for cost reduction in both hard and soft costs, but some chapters (civil works, power block, BoP, EPC cost and Owner's cost) have barely improved despite its significant impact.
- Soft costs are not a typical target in R&D programs.

Concluding Remarks

Hybridization can be a key to the future of CSP:

- Hybridizing CSP with fuels can ease the path, reducing emissions while providing track record to CSP, and time to amortize plants in operation;
- CSP integration costs are as low as conventional, especially if hybridized;
- Risk is concentrated on investment in CSP, and on operation in conventional; hybrids can have a better balance between both, diluting them.

5. Further Reading

REN21 - Renewables 2018 Global Status Report. http://www.ren21.net/gsr-2018/

IRENA – Renewable Power Generation Costs in 2017. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf

NREL – "A Guide to Implementing Concentrating Solar Power in Production Cost Models" (2018). https://www.nrel.gov/docs/fy19osti/68527.pdf

ERSHUN DU, NING ZHANG, BRI-MATHIAS HODGE, CHONGQING KANG, BENJAMIN KROPOSKI, QING XIA – "Economic justification of concentrating solar power in high renewable energy penetrated power systems". (2018). https://www.sciencedirect.com/science/article/pii/S0306261918305099?via%3Dihub

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ESTELA – "The Value of Solar Thermal Electricity. Cost vs. Value Approach". (2016). http://www.estelasolar.org/Docs/2016_ESTELA_STE-CSP_Value_Final.pdf

NREL – “Methods for Analyzing the Economic Value of Concentrating Solar Power with Thermal Energy Storage”. (2015).
https://www.nrel.gov/docs/fy15osti/64256.pdf

IEA – “Technology Roadmap – Concentrating Solar Power”. (2010).
http://www.solarpaces.org/wp-content/uploads/csp_roadmap.pdf

6. Knowledge Checkpoint: Multiple Choice Questions