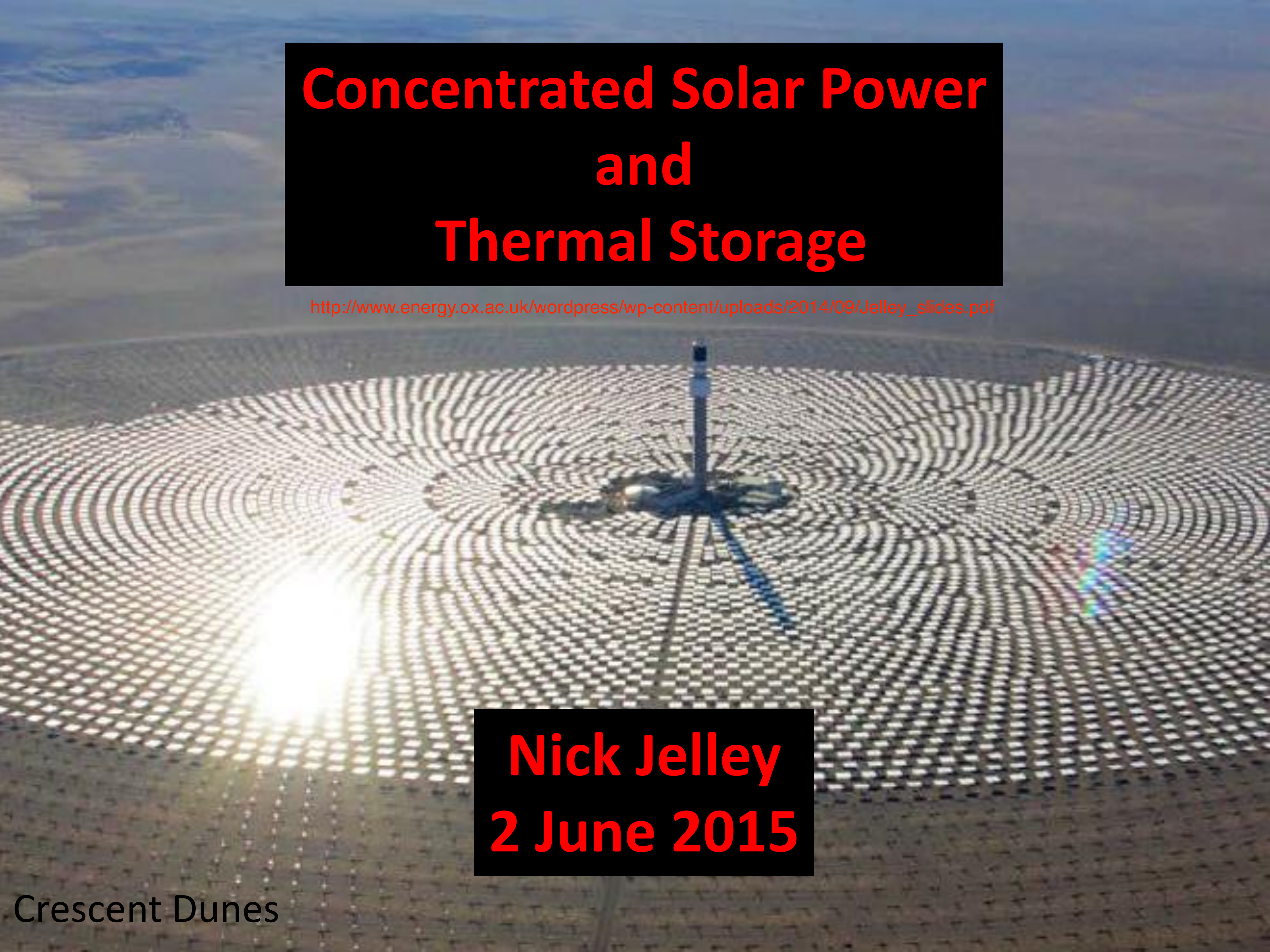
Concentrated Solar Power and Thermal Storage

http://www.energy.ox.ac.uk/wordpress/wp-content/uploads/2014/09/Jelley_slides.pdf

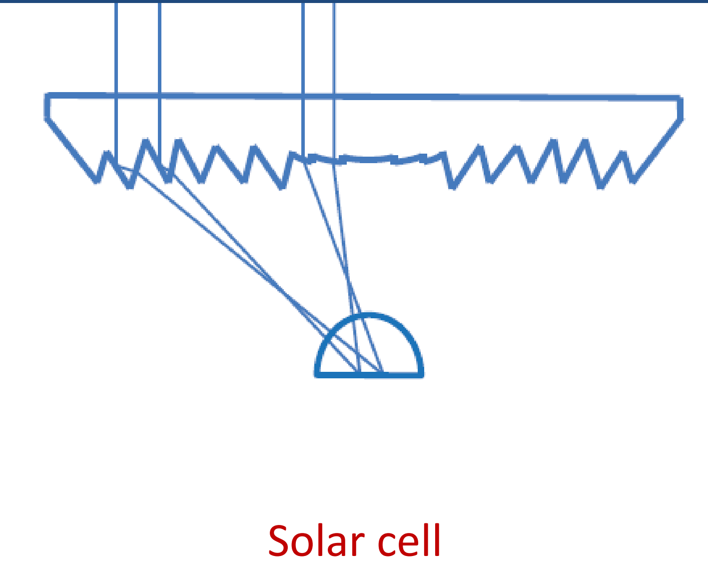


Nick Jelley
2 June 2015

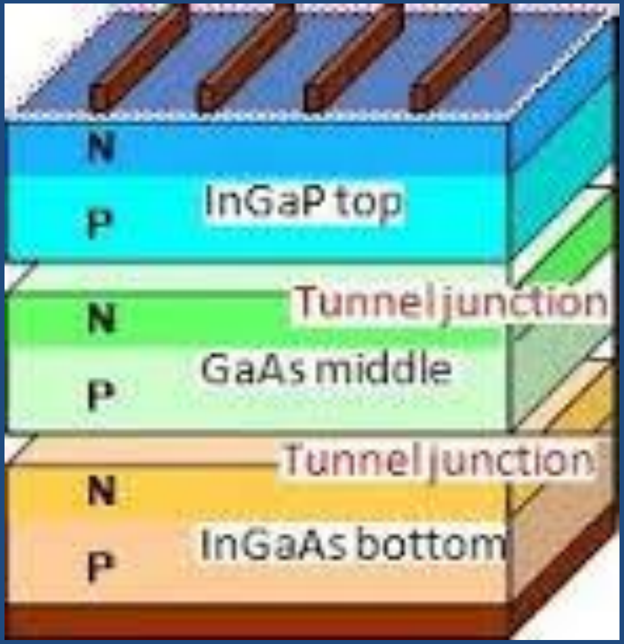
Crescent Dunes

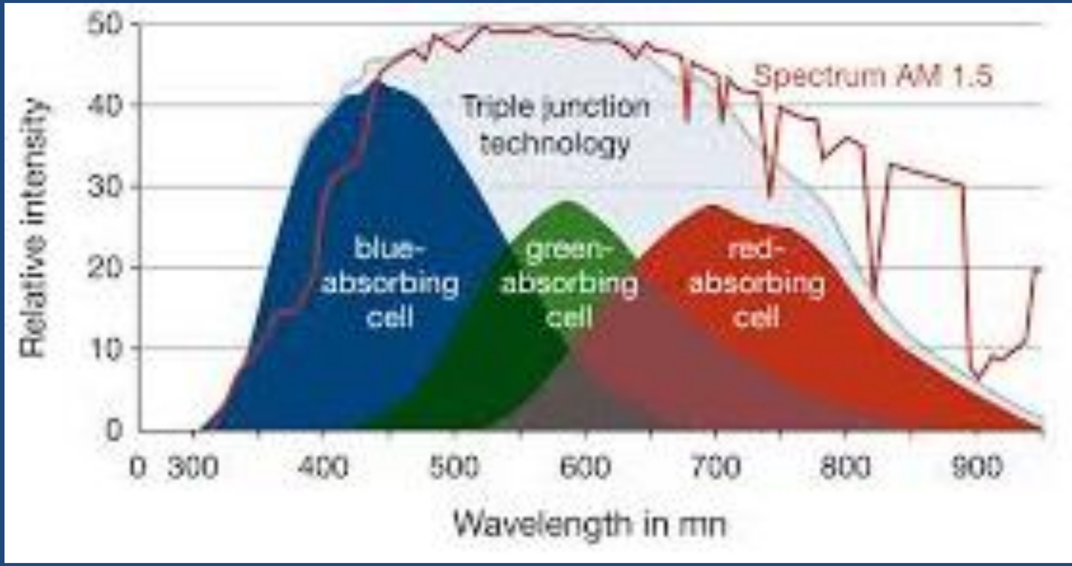
Concentrated Photovoltaics

- Offset cost of cell by low cost of optics plus tracker- 10 y ago cheaper than PV
- ~30mm x 30mm Fresnel lens concentrates sunlight ~x1000 onto ~1 mm^2 40% solar cell



CSP- a review , N Jelley and T Smith, IMech, *Part A:,4, 2015 0957650914566895*





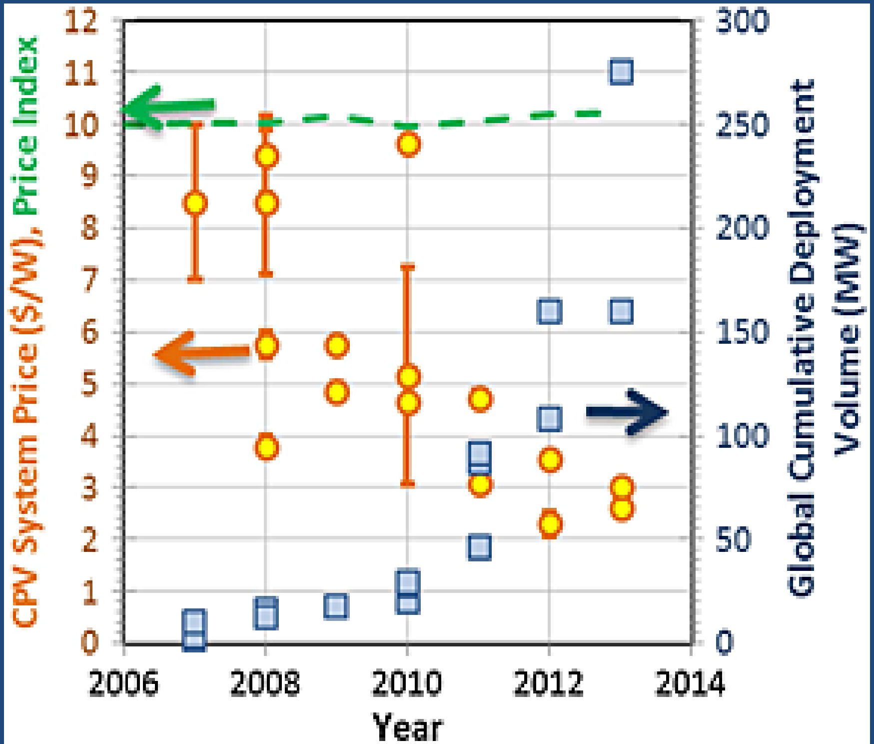
Concentrated Photovoltaics

AMONIX 8700 CPV 70 kW Solar Power Generator

Cogenera T14 30 MW LCPV Si

Concentrated Photovoltaics CPV

- Although plummeting silicon PV prices have severely hit CPV manufacturers, Fraunhofer Institute estimated CPV LCOE to fall from 11.5 (2013) to 6.2 c/kWh by 2030, cf 7 (2013) to 5.7 c/kWh for PV by 2030



Haysom et al DOI: 10.1002/pip.2567

IHS project CPV capacity 160MW (2013) to grow to >1.3GW in 2020

But need to maintain investment

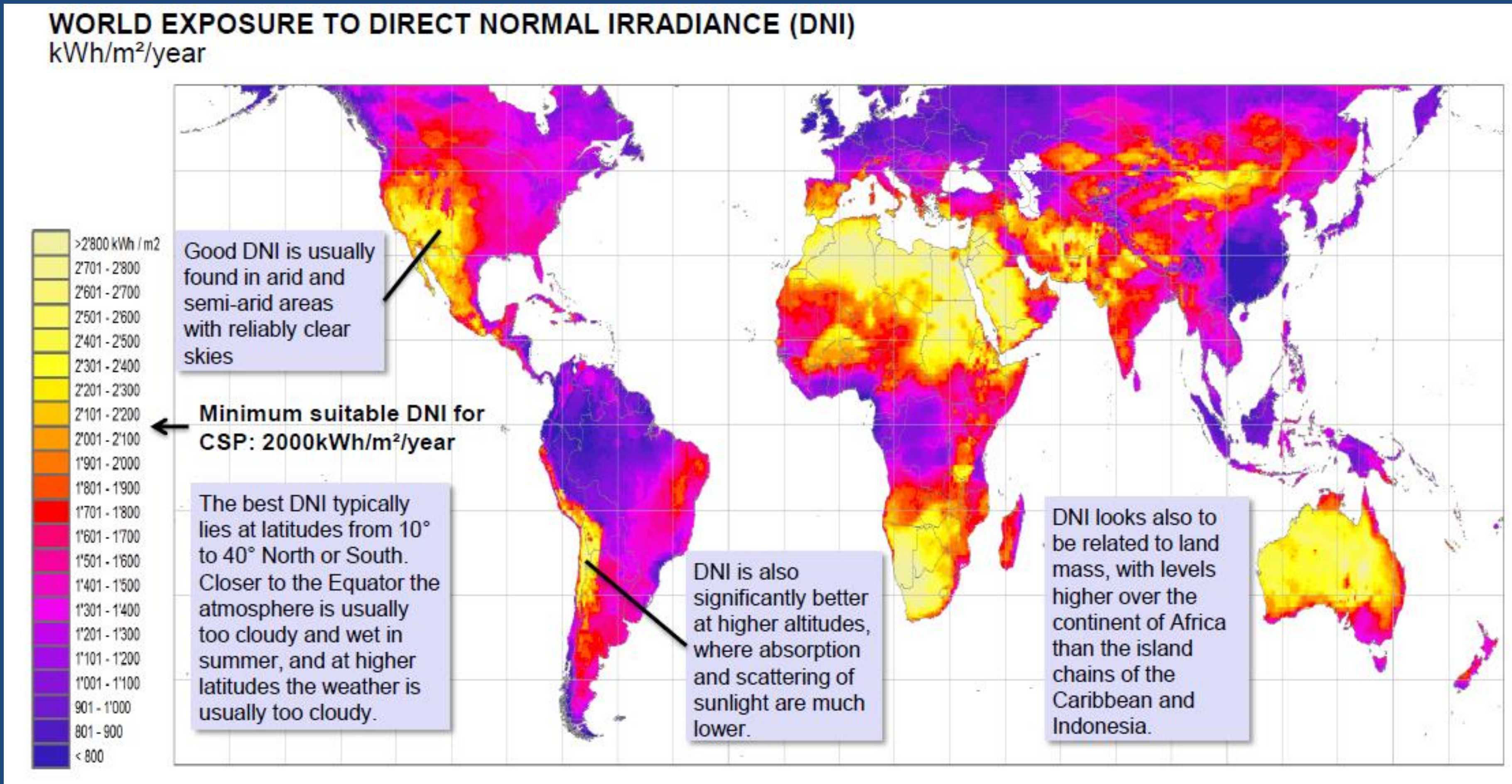
cf PV capacity ~180 GW (2014)

projected ~490GW (2020)

http://www.grandviewresearch.com/industry-analysis/solar-pv-industry

Location?

Suitable regions to deploy CSP

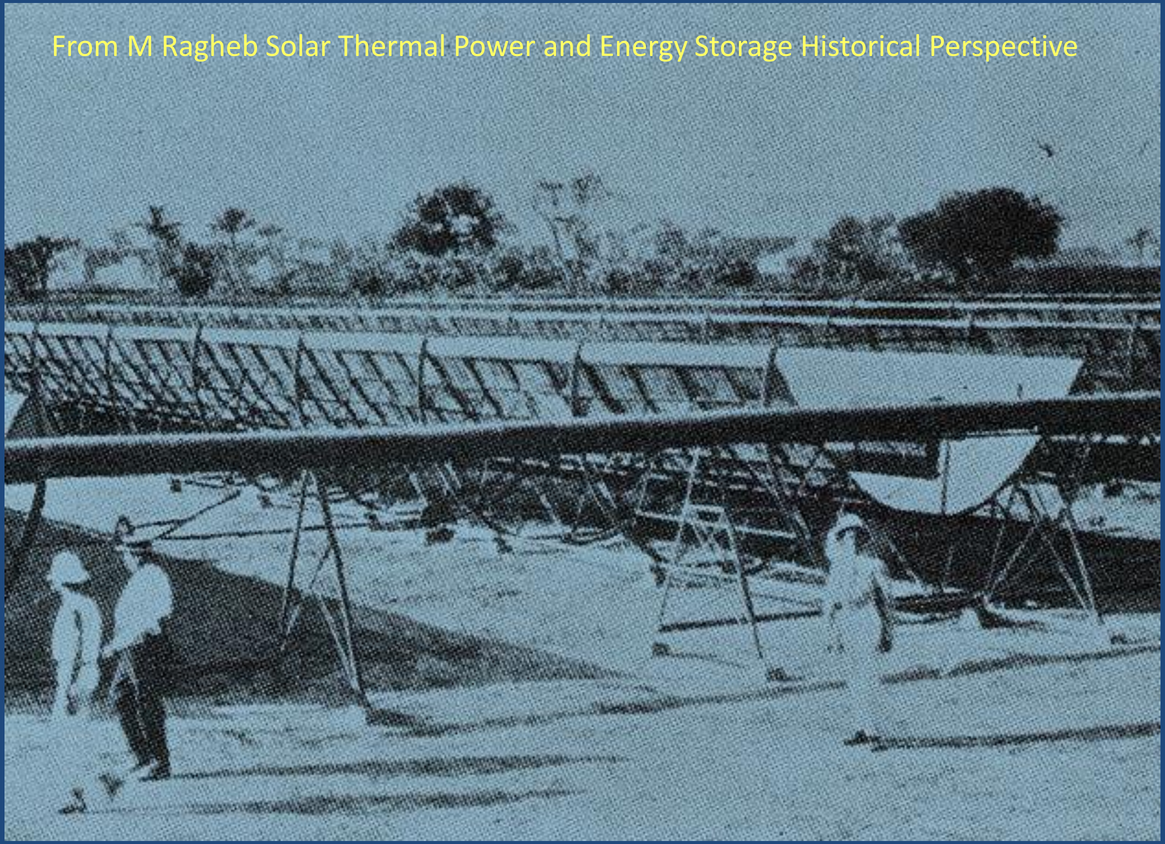


SBC Energy Institute_Solar_Factbook_Jun 2013.pdf

80 000 sq km (~ 1/10 Chile) of CSP plants would meet the global electricity demand ~2.5 TW

Concentrated Solar Thermal Power CSTP

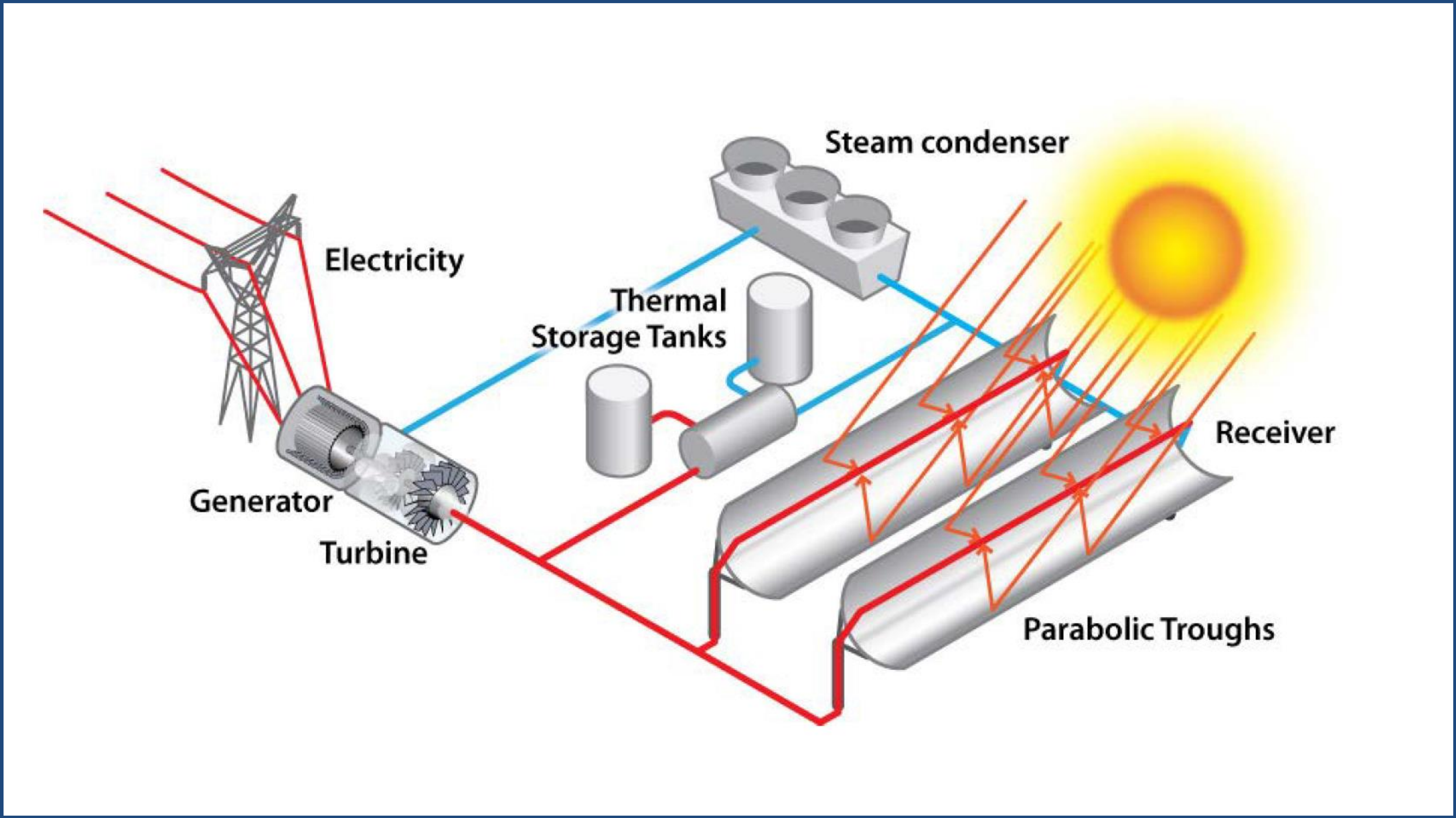
Early Development



Schuman's 100 HP Solar Engine One 1916
at Al Meadi, Cairo, Egypt

Most well-developed CSTP plant - Major early plant SEGs w/o storage 354 MW CF 21% 1984-91 Mojave Desert California

Parabolic Trough Plant with Thermal Energy Storage



2014:The Year of Concentrated Solar Power, US Department of Energy

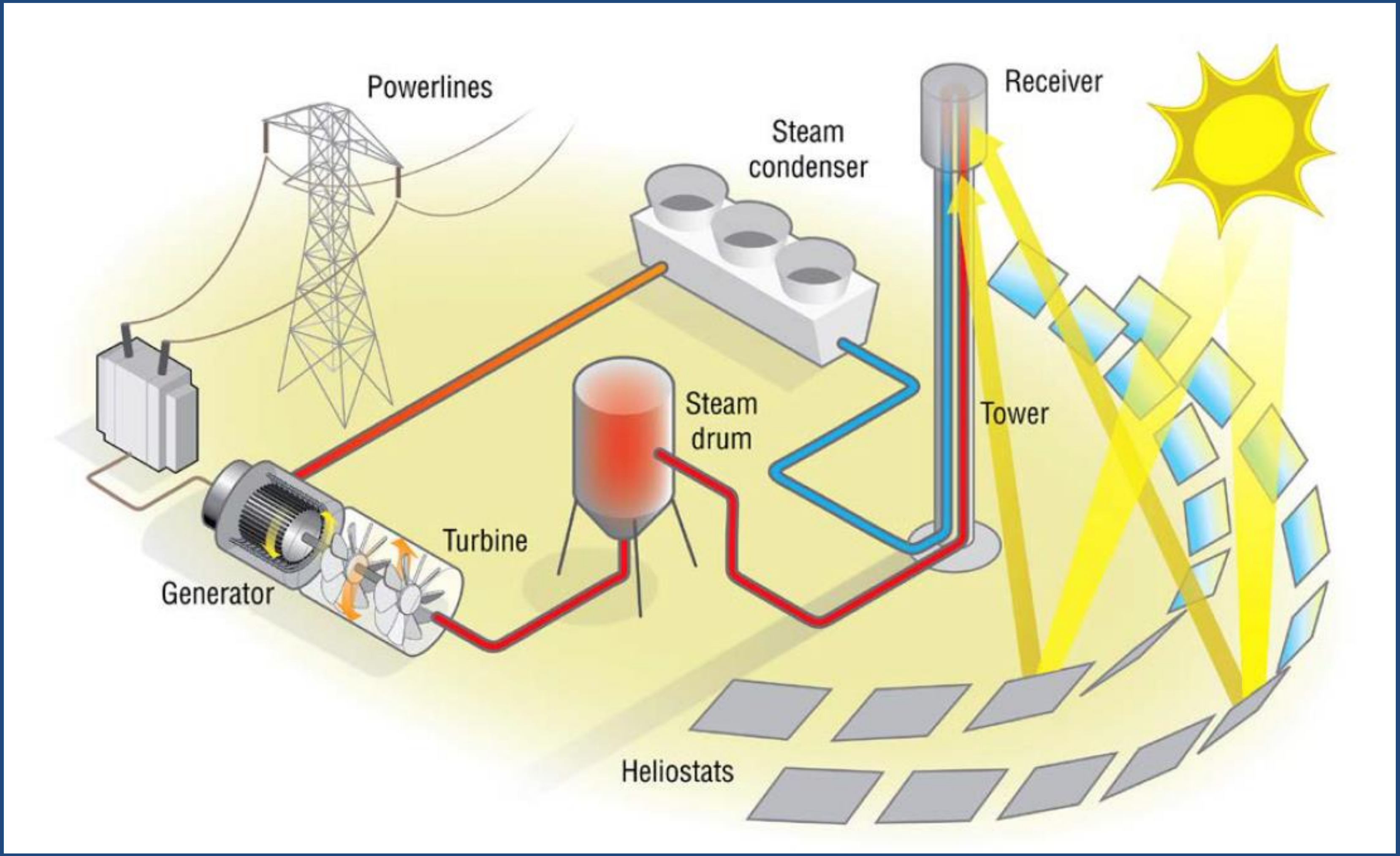
Alternatively plants can be hybridised with fossil fuel plants to give back-up

Solana 250 MW capacity parabolic trough, Arizona

Area 7.77 km^2 ; molten salt storage 6 hours, 393 C [Conc~100], Capital cost $2000 million

2014:The Year of Concentrated Solar Power, US Department of Energy

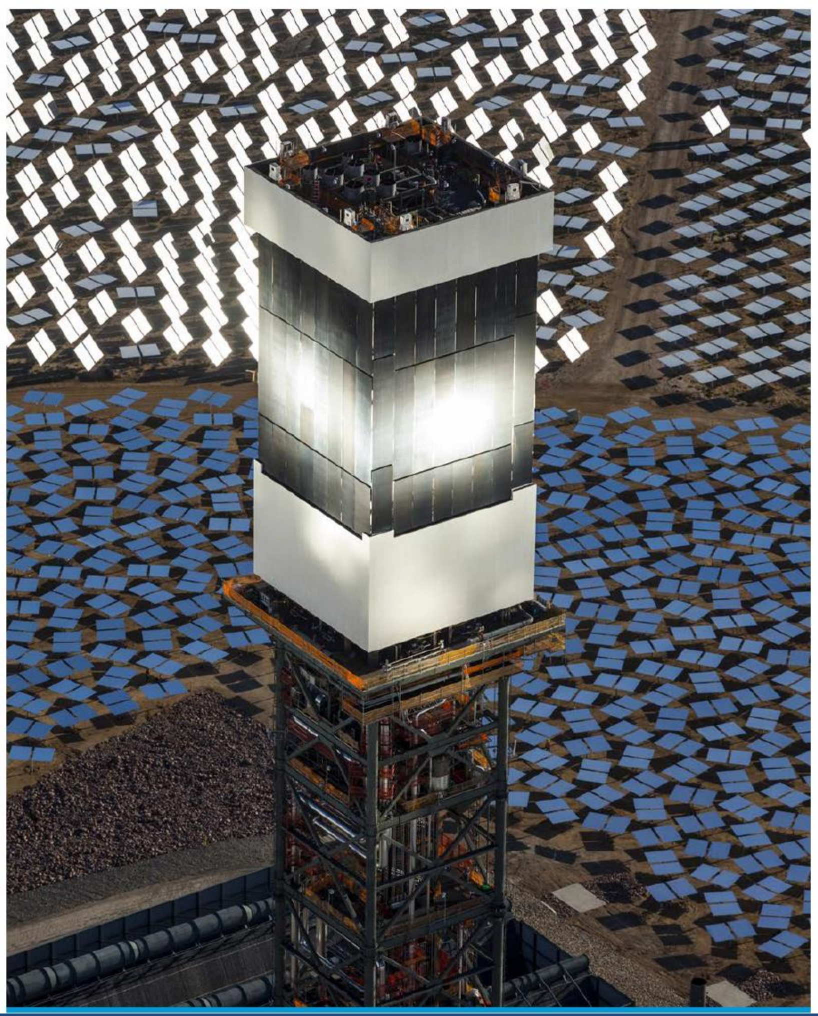
Power Tower without storage



Less capital without storage; water/air cooled; ~550C

2014:The Year of Concentrated Solar Power, US Department of Energy

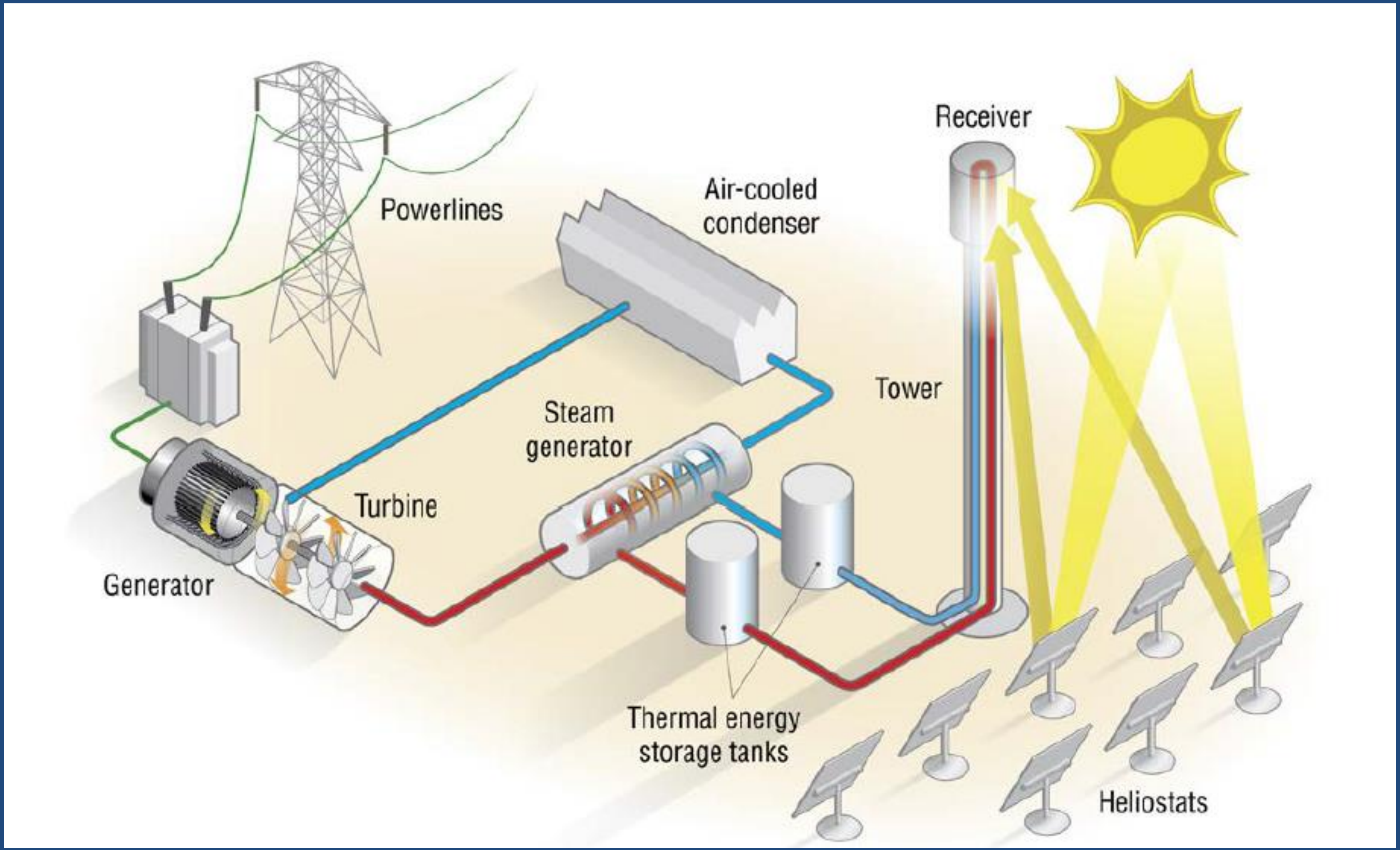
Ivanpah Power Tower: 392 MW capacity, California



Area 14 sq km, 173 500 heliostat array, 565 C
[Conc~400] Capital cost $2200 million

2014:The Year of Concentrated Solar Power, US Department of Energy

Power Tower with storage



Less pipework than in trough; storage dependent on utility value

2014:The Year of Concentrated Solar Power, US Department of Energy

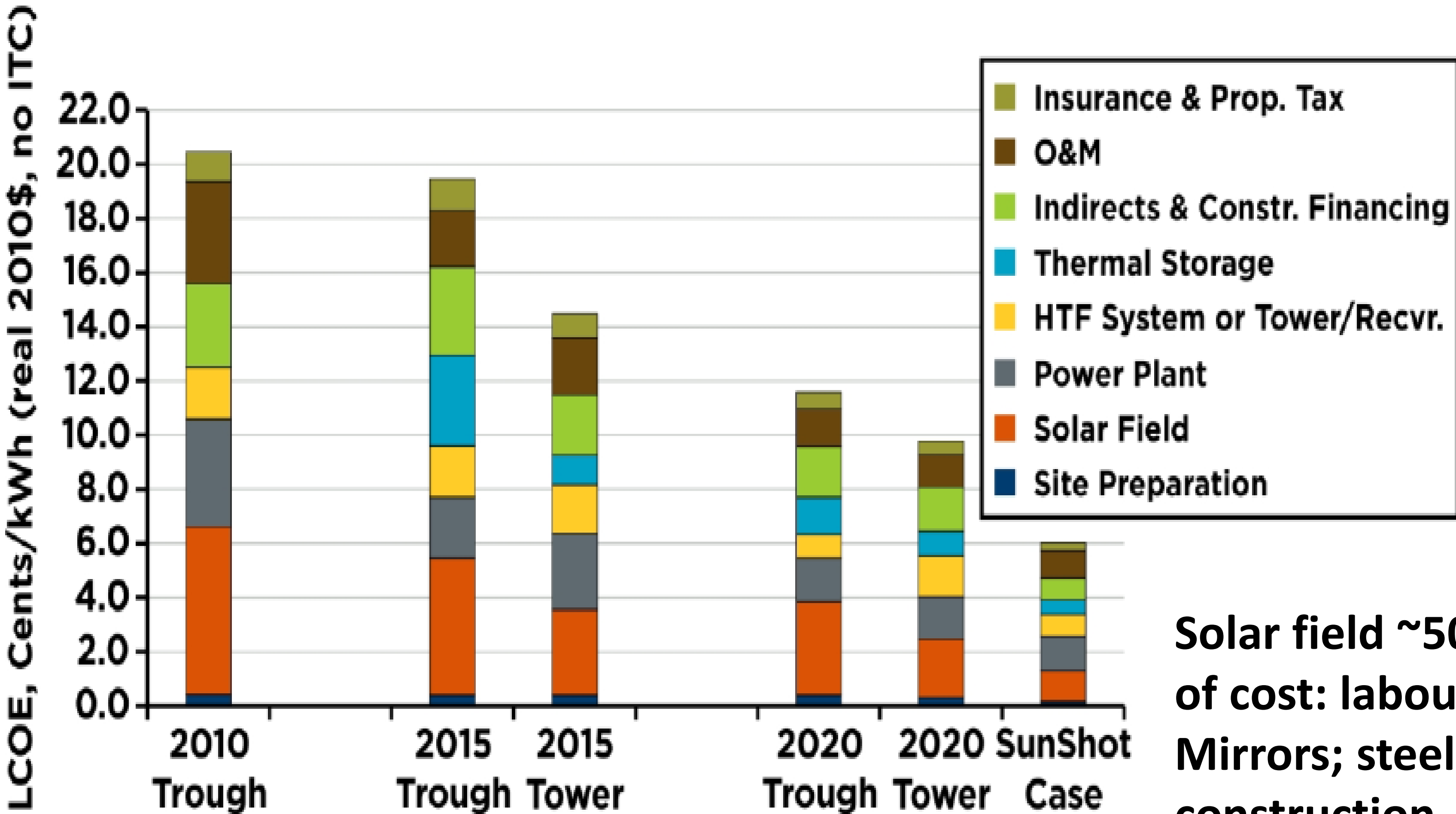
2014 Crescent Dunes 110 MW capacity , Nevada

Area 1 sq km; molten salt storage 10 hours capacity, 565 C
Capital cost $910 million ; ~$100/kWh storage (~1/3 Trough)

BUT LCOE ~12c/kWh , ~50% solar field

2014:The Year of Concentrated Solar Power, US Department of Energy

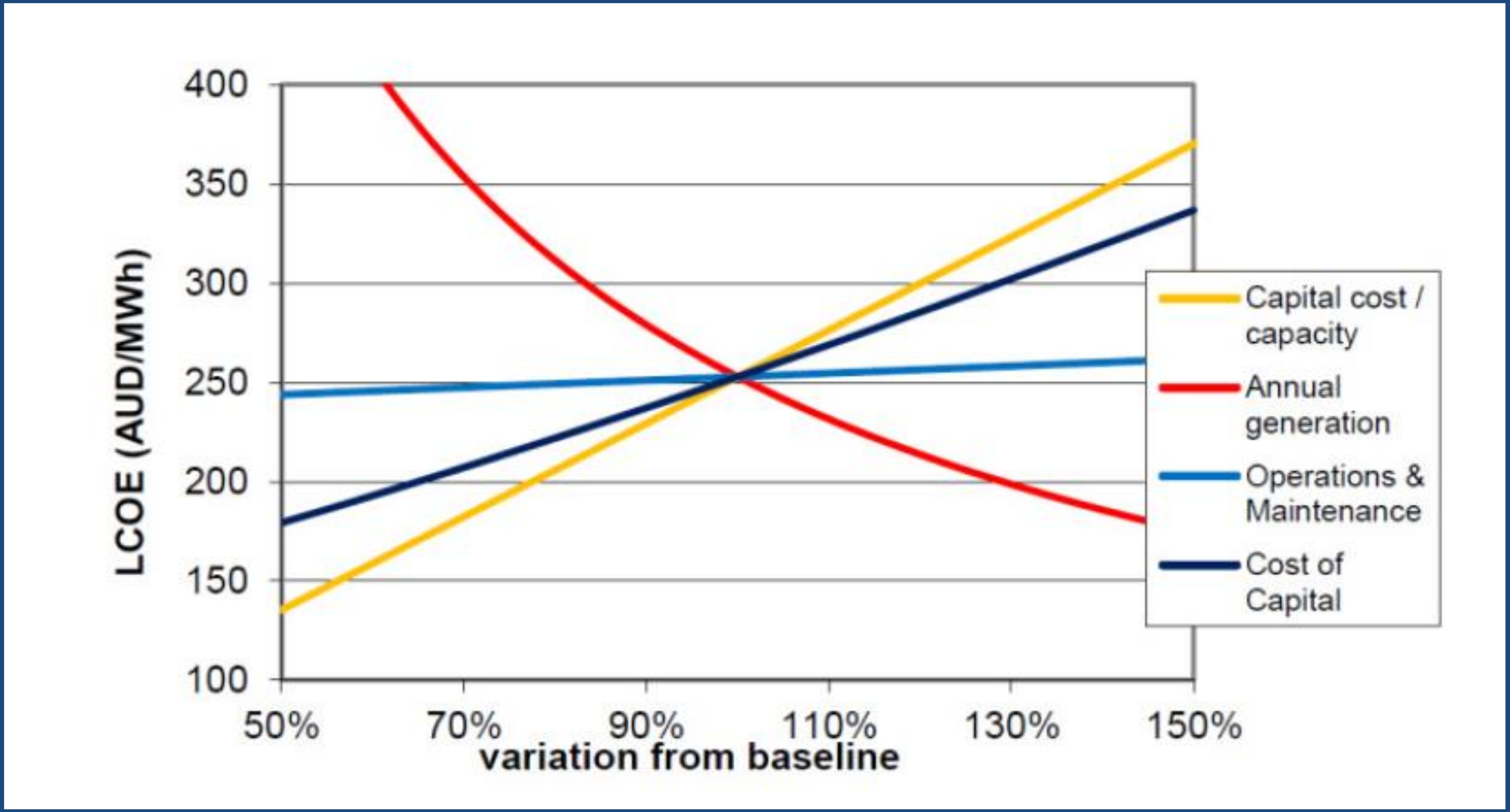
Current and Projected Costs for CSTP



Solar field ~50% of cost: labour; Mirrors; steel construction

SunShot Vision Study February 2012

Variation of Cost against LCOE baseline



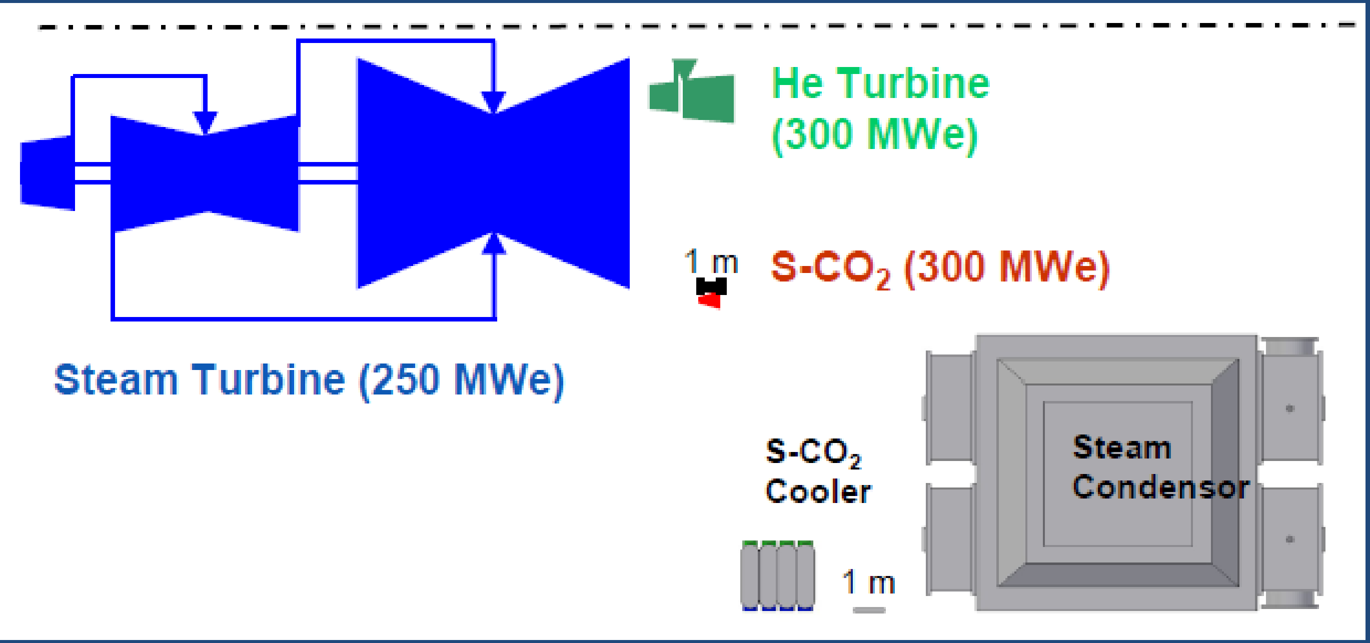
J Coventry and J Pye, Energy Procedia 49 (2014) 60-70

LCOE dominated by initial investment: 84% is annualised CAPEX

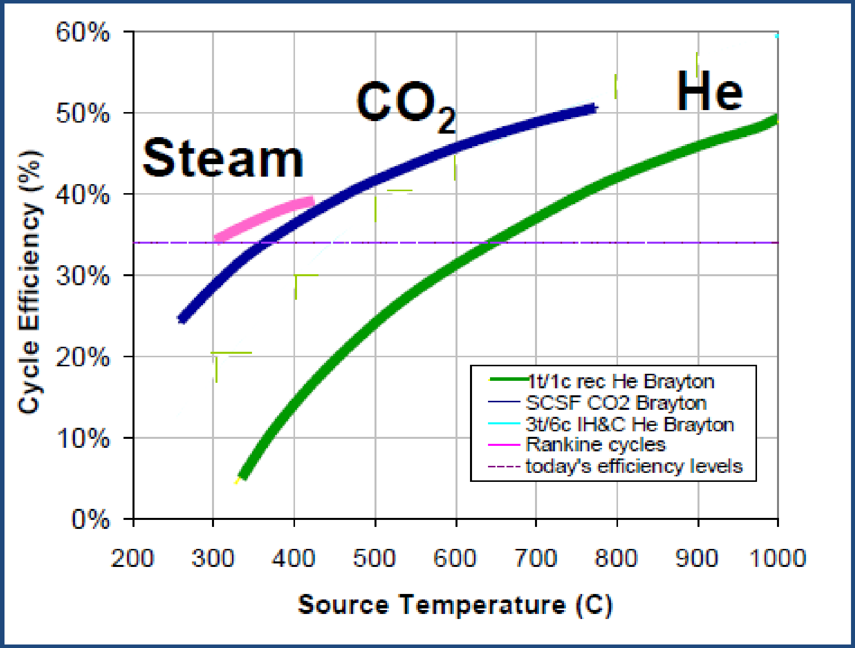
Discount rate 10% → 5.5% results in ~30% drop in LCOE

SBC Energy Institute Solar Factbook 2013

Super-critical CO_2 Power Plant



High density results in very small cheaper power system and high efficiency at moderate temperatures



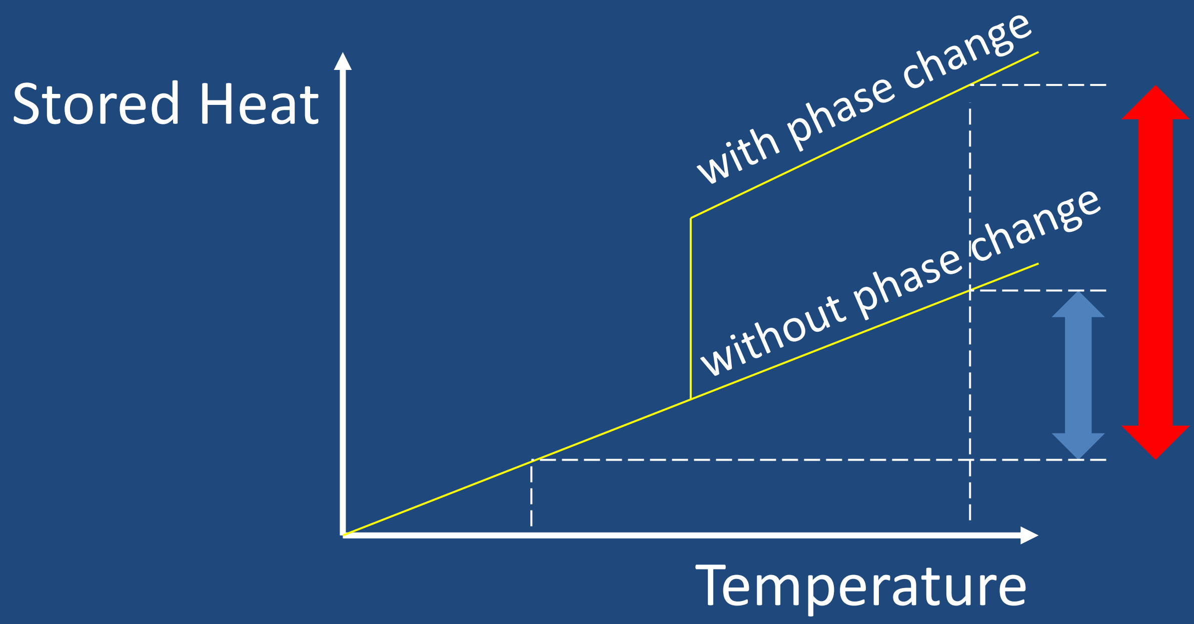
S.A. Wright et al. 2011

Thermal Energy Storage (TES)

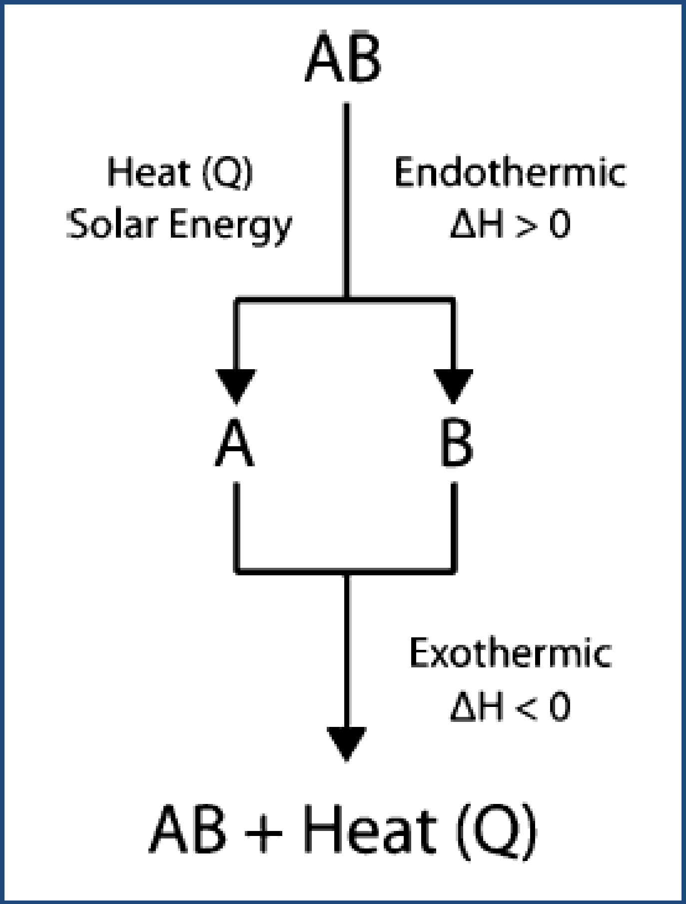
Techniques at the R&D stage

- **Phase Change Materials**

Solid to liquid occurs at constant temperature, but thermal conductivity in solid phase often low and stored heat only a factor of ~two better than sensible TES



• Thermochemical Energy Storage (TCS)



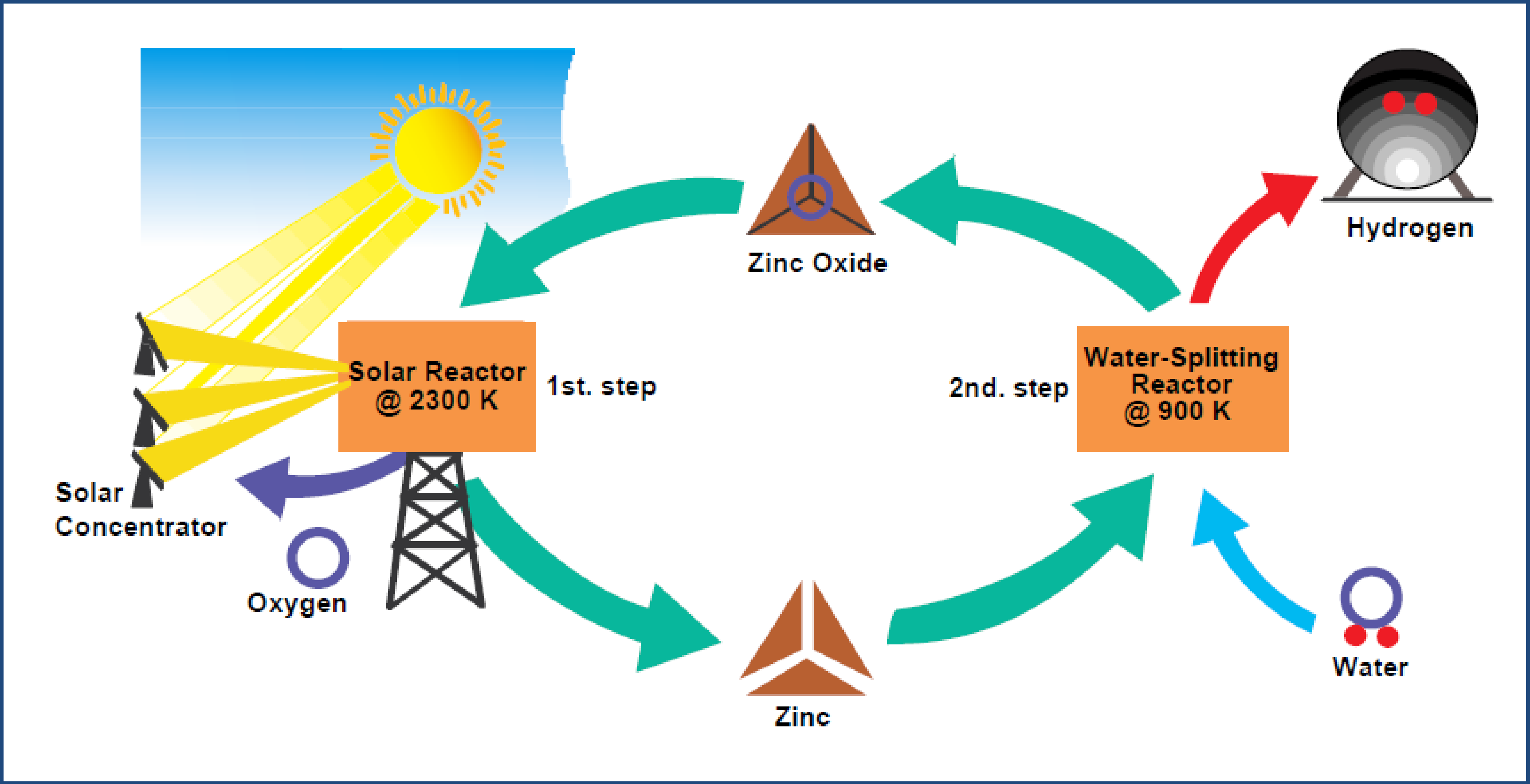
a) Metal oxides systems
eg MnO_3 requires only air for reverse exothermic reaction

b) Metal hydrides
Can absorb H_2 and release heat or desorb H_2 and absorb heat by changing P or T

Energy densities
~10x sensible TES

But difficult to get heat into oxides and hydrides very sensitive to O_2 and moisture
Also expensive

Solar Fuel: CSTP + Zinc Oxide → Hydrogen



Fuels from Sunlight and Water, A Steinfeld and R Palumbo, ETH & PSI

Easier: CH_3OH + solar heat (200-400C) → $CO + 2H_2$

Syngas → H_2 or chemical products [Tiancun Xiao ICL]

- **Sensible heat**

Molten salts (60% $NaNO_3$ + 40% KNO_3)

Andasol One 50 MW trough plant

28 500 tonnes 7 hours storage 41.5% CF

~12 kWh/tone ~385-290C

Gemasolar 19.9 MW tower plant

8 500 tonnes 15 hours storage 75% CF

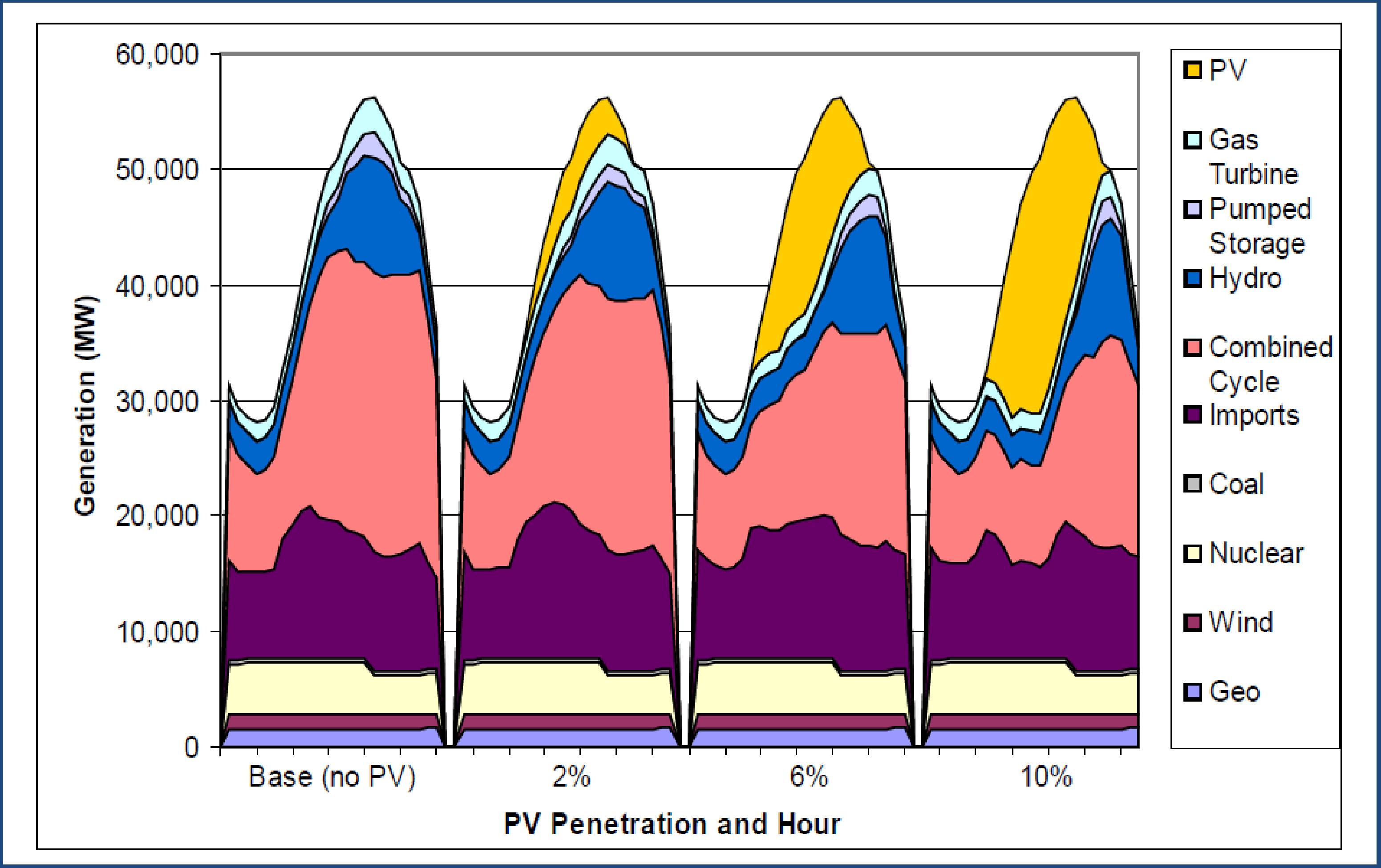
~35 kWh/tonne ~565-290C

Crescent Dunes 110 MW plant also ~35 kWh/tonne

Molten salt storage in Power Towers proven technology and cheap and may prove to be best option

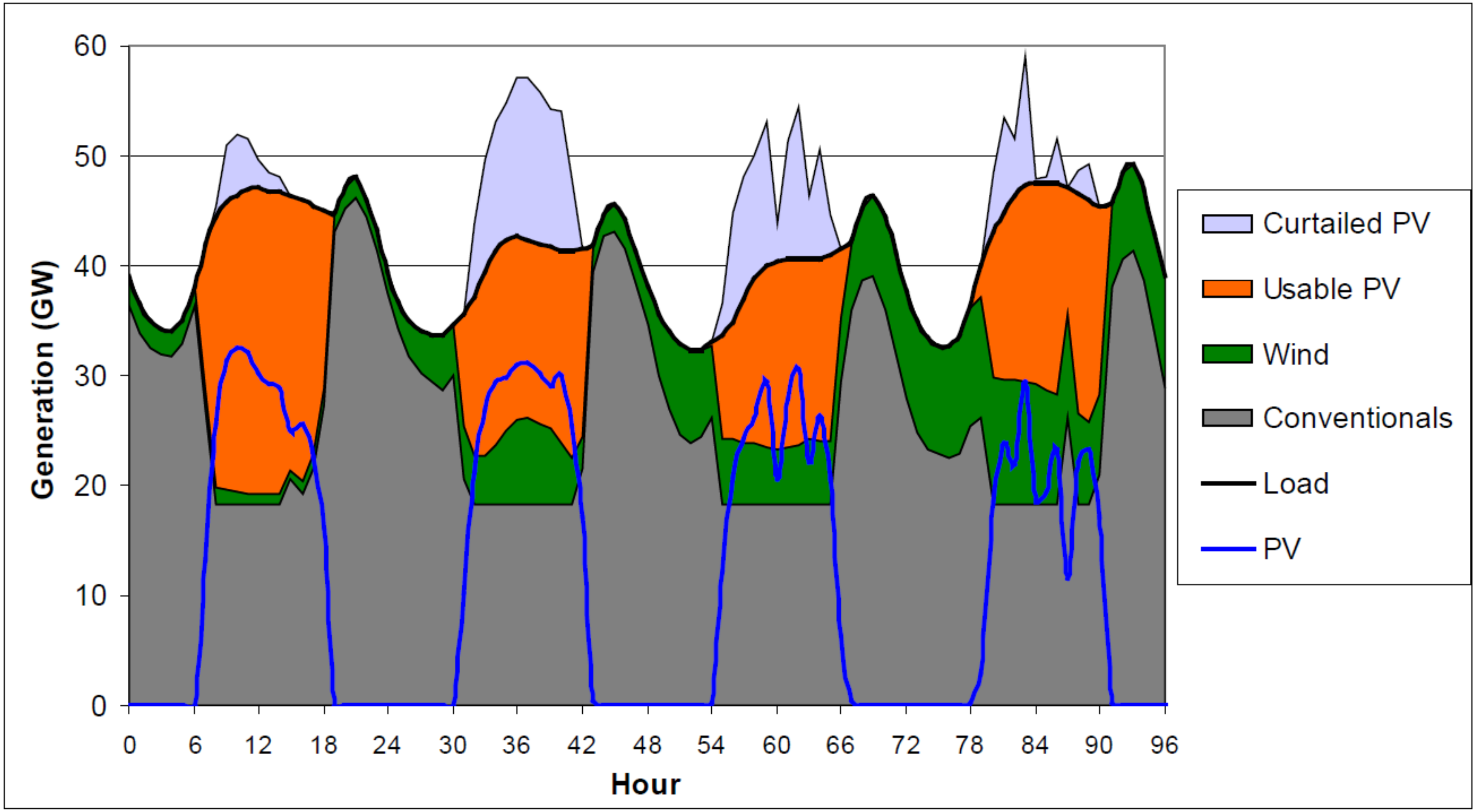
Advantage of Storage

Storage gives ability for generation at any time (dispatchability) so improves capacity factor. Not needed for low percentage contribution



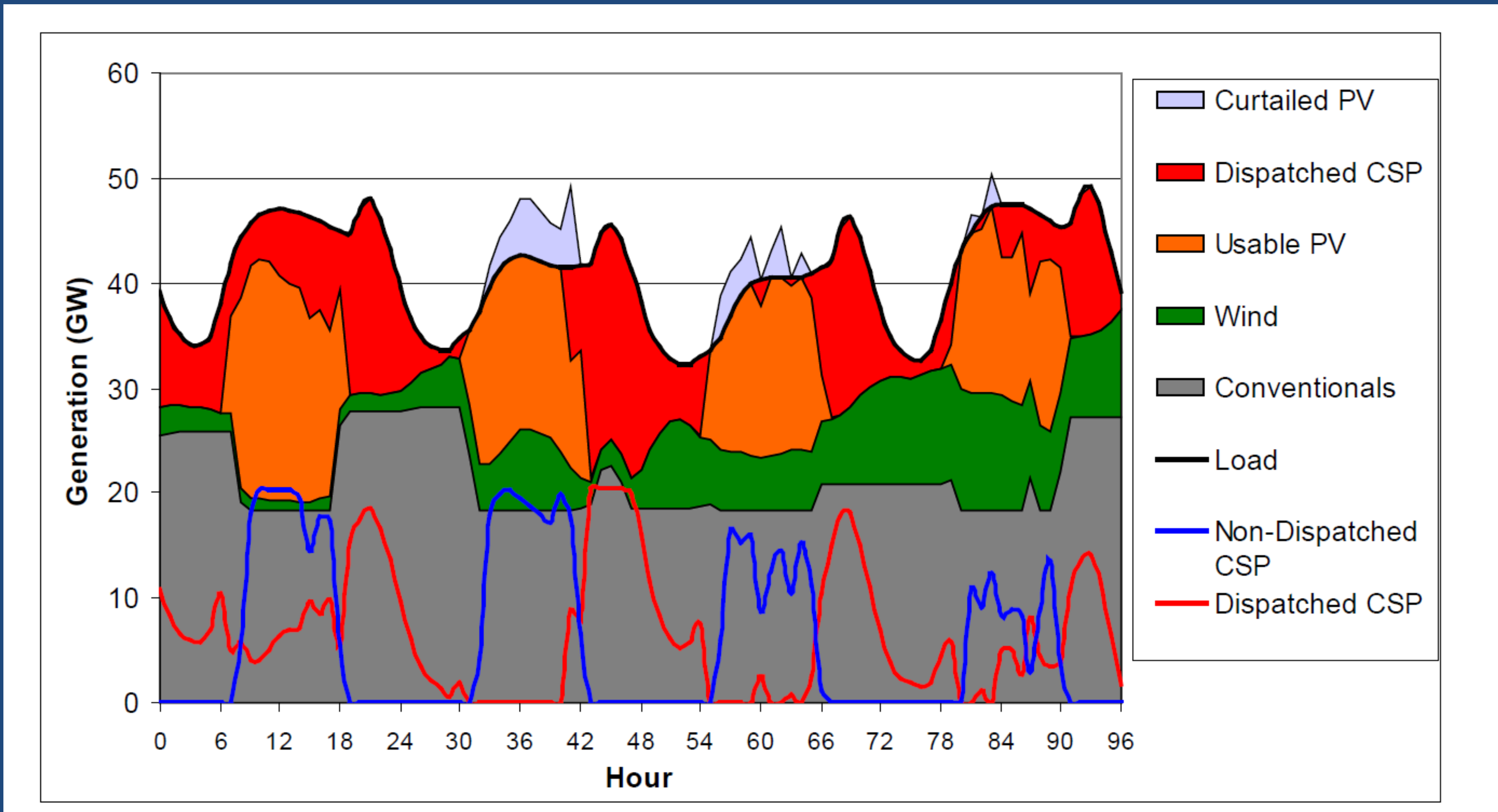
Enabling Greater Penetration of Solar Power via the Use of CSP with Thermal Energy Storage ,Paul Denholm and Mark Mehos, NREL/TP-6A20-52978, 2011

Curtailment of PV at 20% PV penetration in California



Enabling Greater Penetration of Solar Power via the Use of CSP with Thermal Energy Storage ,Paul Denholm and Mark Mehos, NREL/TP-6A20-52978, 2011

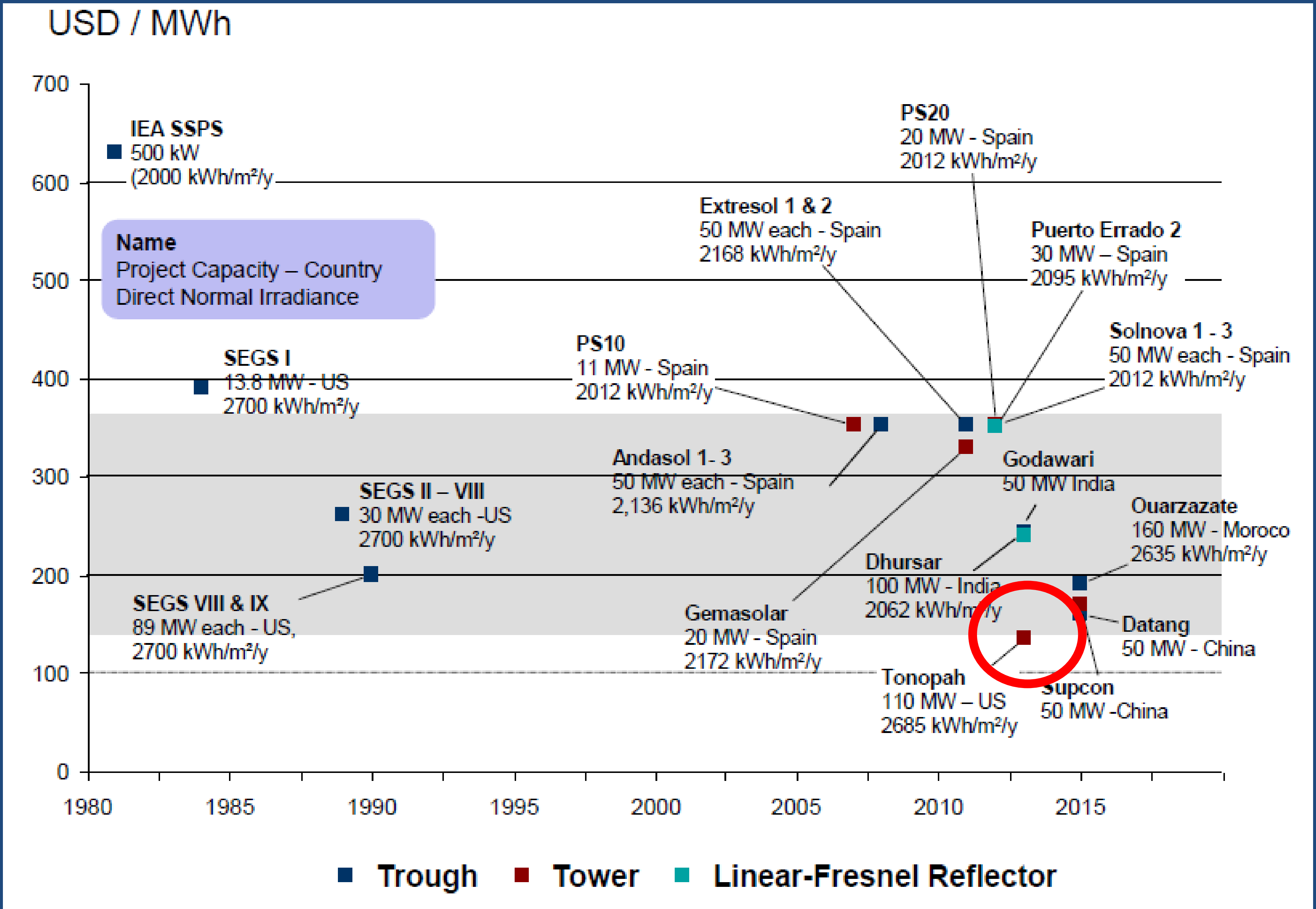
Reduce curtailment with 15%PV and 10% CSTP + TES



Relative value of CSTP +TES of about 5c/kWh greater than PV with 33% renewables and 6c/kWh greater with 40% renewables

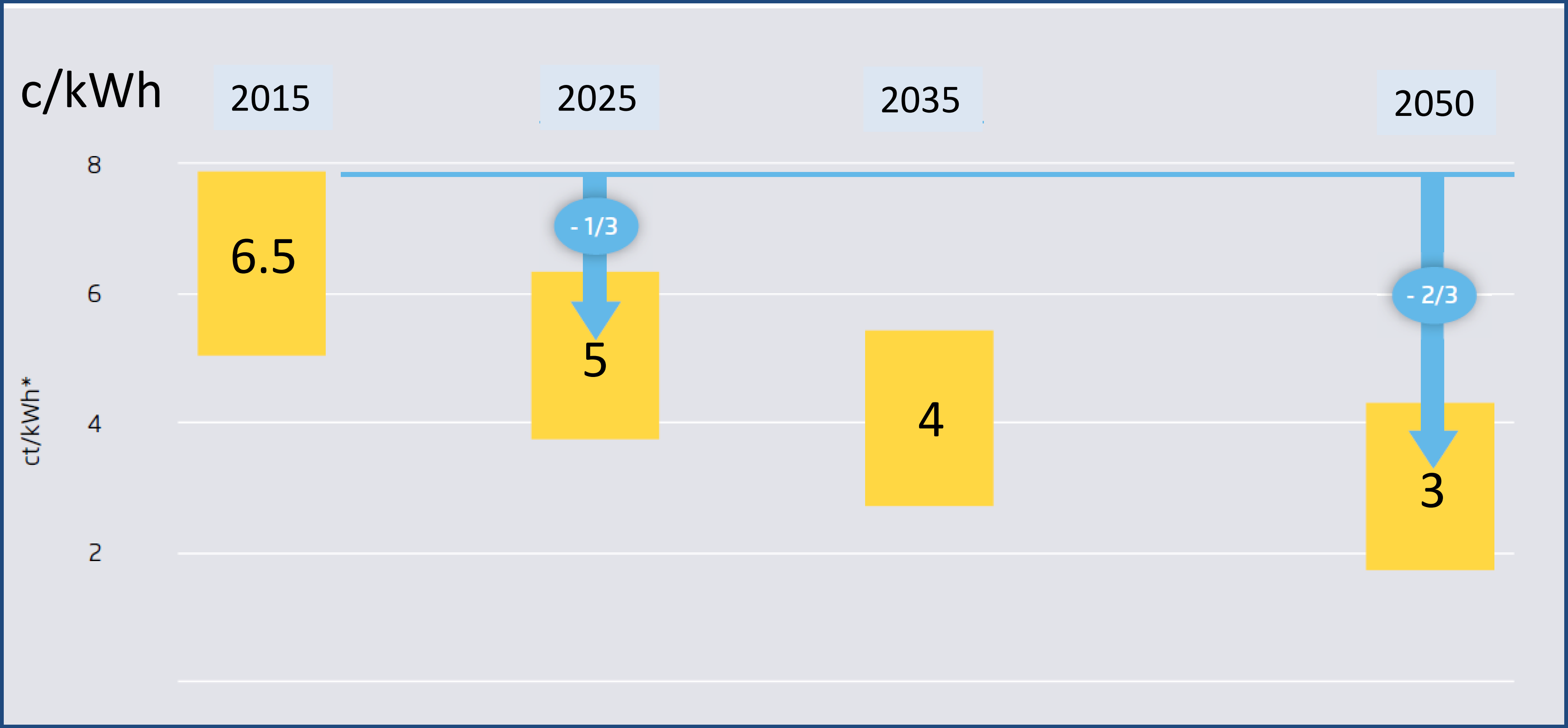
Estimating the Value of Utility-Scale Solar Technologies in California Under a 40% Renewable Portfolio Standard; J Jorgenson, P Denholm and M Mehos, 2014

Estimated LCOE for CSTP Plants



SBC Energy Institute Solar Factbook 2013

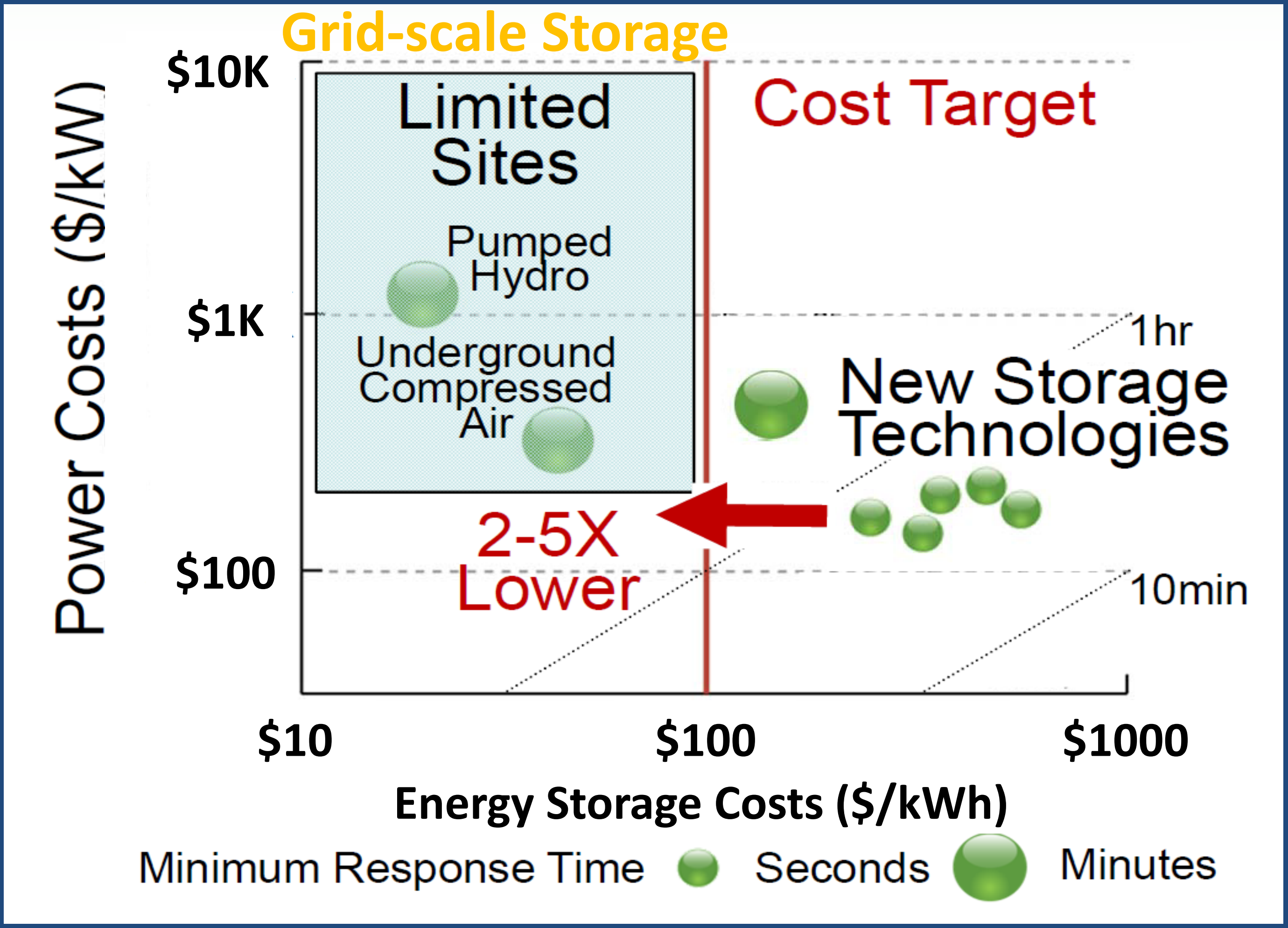
Cost of PV Electricity in Southern and Central Europe



5% cost of capital; variation includes location

1190 kWh/y S Germany, 1680 kWh/y S Spain

Fraunhofer ISE (2015): *Current and Future Cost of Photovoltaics*



Johnson, Overview of Gridscale Rampable Intermittent Dispatchable Storage (GRIDS) Program, US DoE, 2012

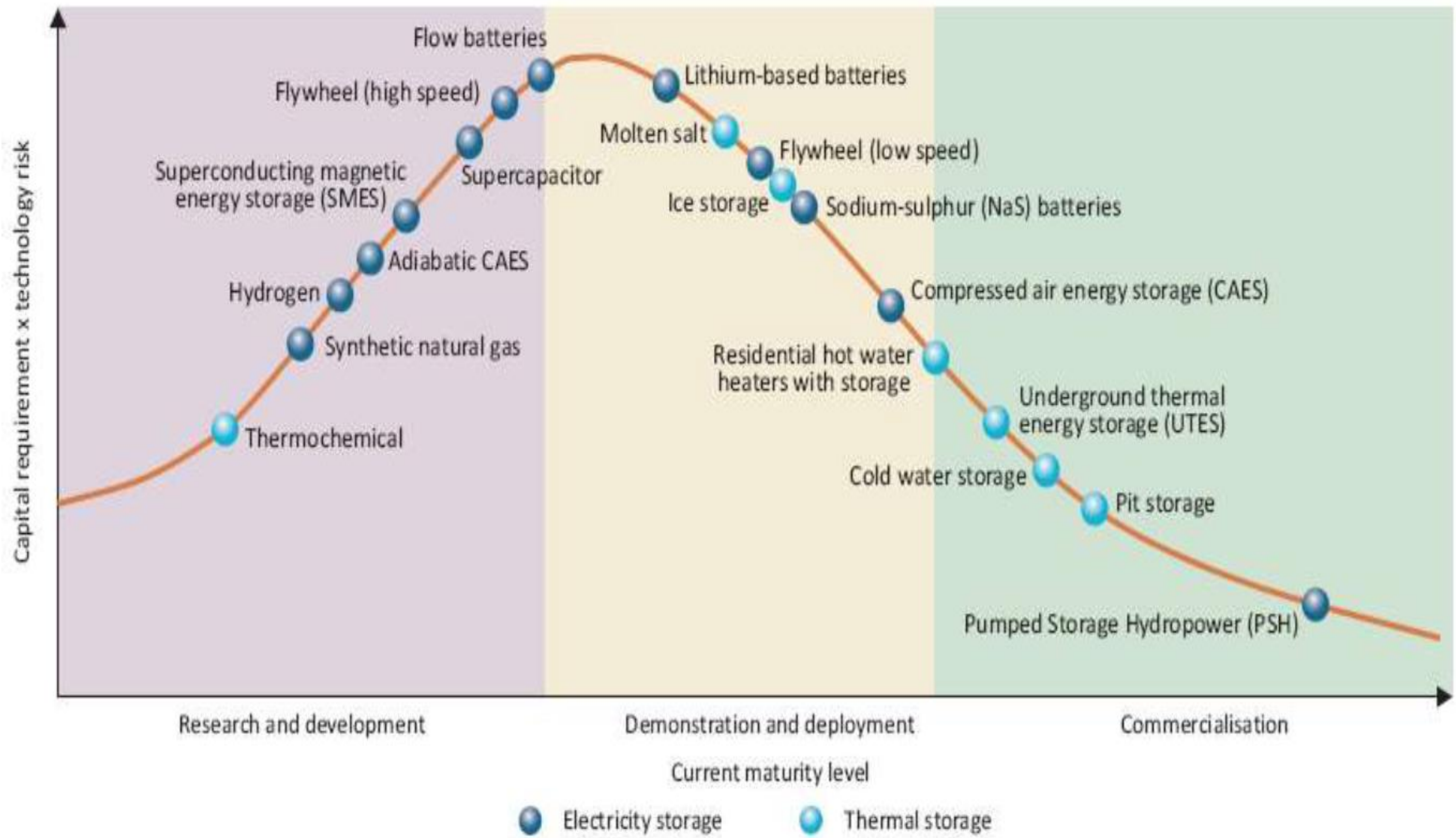
Li battery $250/kWh (TESLA), by 2030 ~$150/kWh

Nykvist and Nillson, Nature Climate Change, March 25th 2015

TES currently ~$75/kWh and large scale ~1000 MWh

Paul Denholm and Mark Mehos, NREL/TP-6A20-52978, 2011

Maturity of Energy Storage Technologies



IEA Energy Storage Technology Roadmap Technology Annex 2014

Thermal Energy Storage

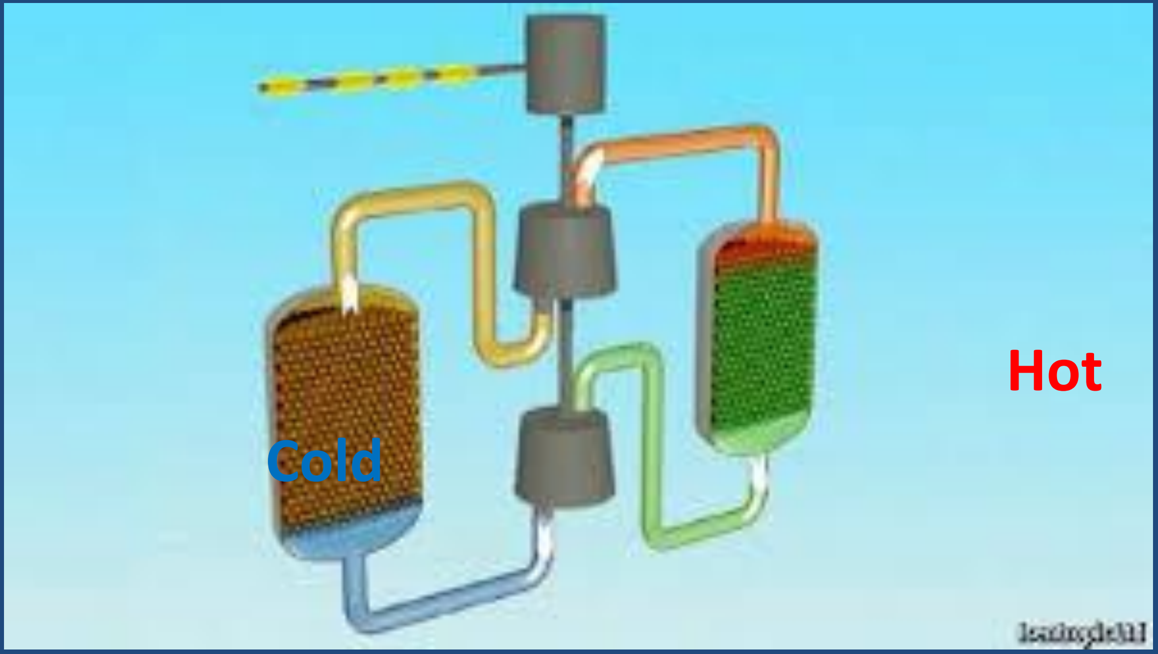
Pumped Heat Electricity Storage

Principle: Maximum heat Q pumped by work W from T1 into T2 is

$W \times T2/(T2-T1)$

Maximum work from heat engine with Q flowing from T2 to T1 is

$Q \times (T2-T1)/T2 = W$



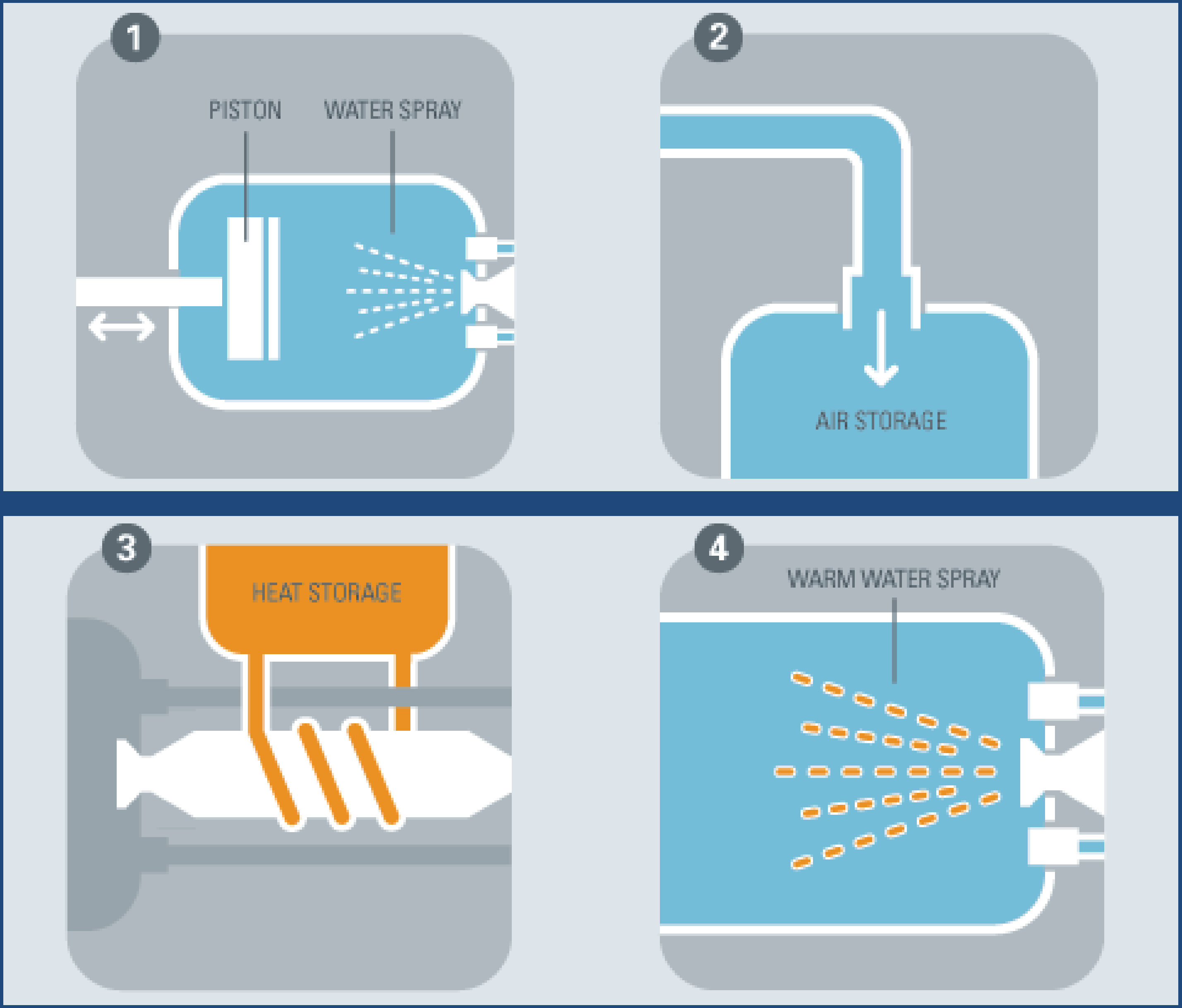
~40kWh/t
cf ~1 kWh/t
pumped hydro

Calculated Efficiency 50%-70%

http://www.isentropic.co.uk/

J D McTigue, A J White, C N Markides, Applied Energy 137 (2015) 800-811

Compressed Air Electricity Storage (with heat storage)



http://www.lightsail.com/

Calculated Efficiency 60%-75%

Thermal Energy Storage

Europe, ~1.4 million GWh/y saved & 0.4 Gt CO_2 avoided possible BUT cost a barrier (IEA-ETSAP and IRENA© 2013)

Sensible: most common- hot water tanks + electrical or solar heating; electrical storage heaters

Seasonal thermal storage- heat in summer stored for winter use or cold in winter stored for A/C in the summer

UK: ~50% of energy consumption used for heating

With present buildings, most heat used for space heating

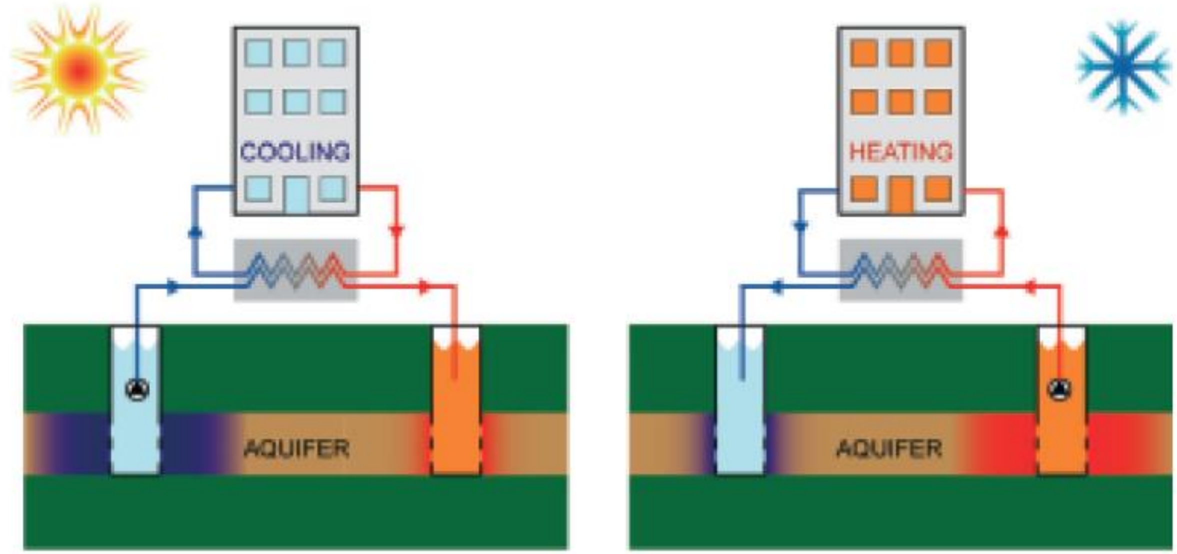
Water store 0.5-2.5m^3 for 3h storage + heat pump would reduce demand and smooth supply requirements

eg for 2 million homes would provide the equivalent of 36 GWh of electrical storage & need 12 GW extra capacity

The Future Role of Thermal Energy Storage in the UK Energy System, UKERC, 2014

Solar Thermal District Heating, Munich

Provides ~50% of heat demand ~2000 MWh/yr for 320 apartments 2750 m^2 flat plate collectors, 6000 m^3 hot water u/g store, + h/p



Summer: Cooling of office buildings / industrial processes

Winter: Heating of office buildings / industrial processes

IEA-ETSAP and IRENA© Technology Brief E17 – Jan 2013

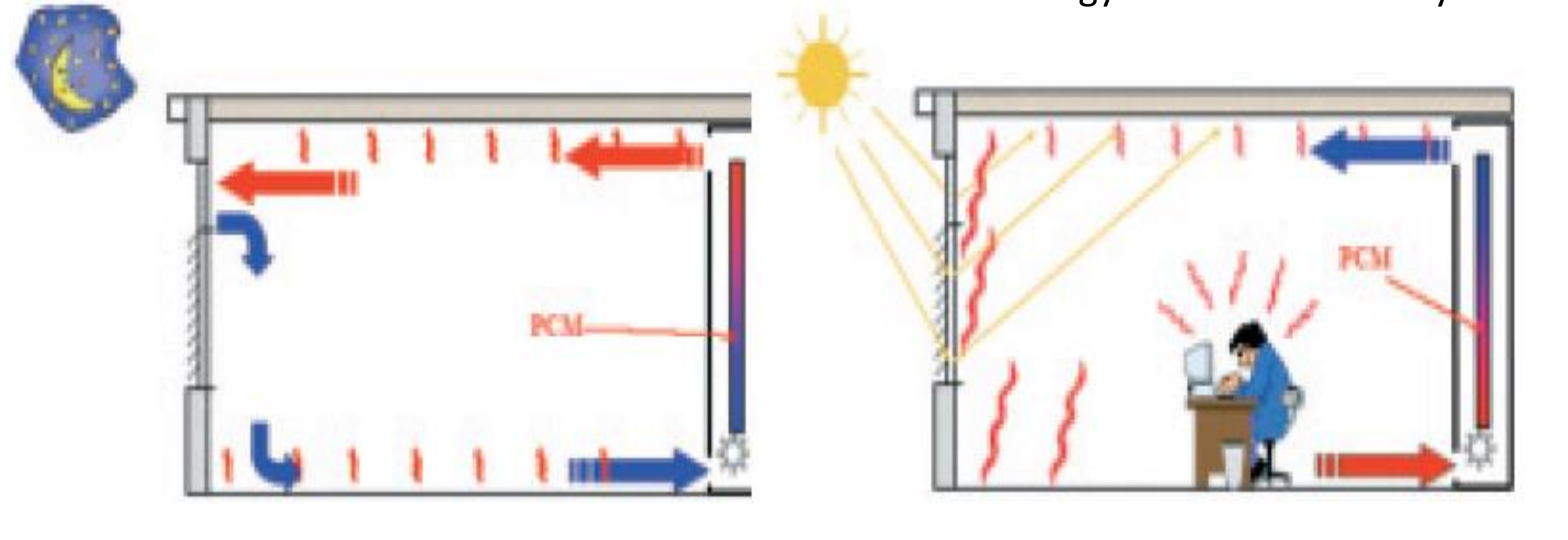
Also Borehole Storage- seasonal storage often combined with h/p

Phase Change Materials (PCM) for TES

PCMs ~100 kWh/m^3 c.f. Sensible heat storage ~25 kWh/m^3

e.g. Paraffin wax in plaster – passive cooling

IEA-ETSAP and IRENA© Technology Brief E17 – January 2013



Also producing ice (334MJ/t) at night for A/C in the day

BUT generally expensive

Future of CSP

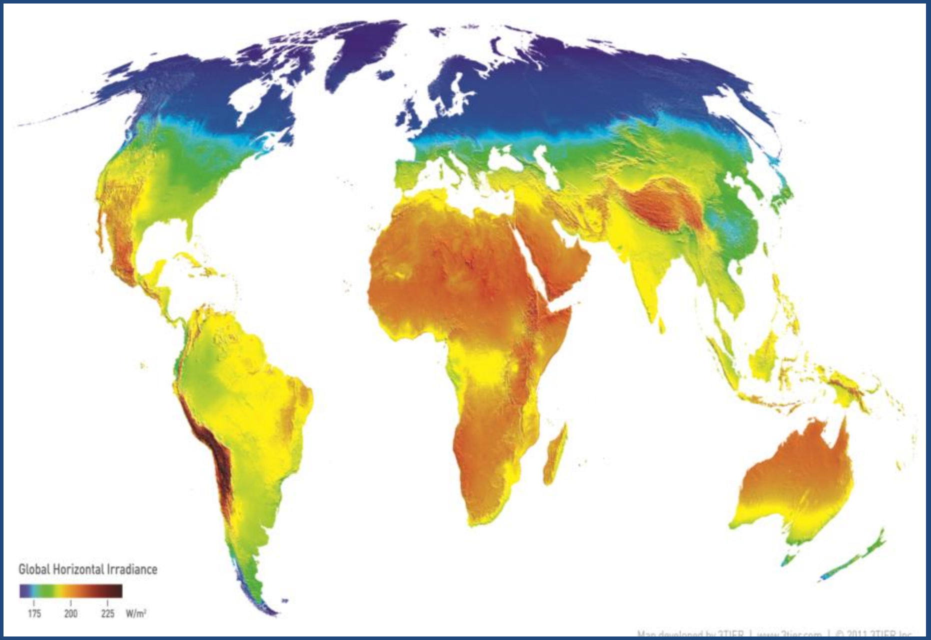
- CPV looks uncompetitive against PV as even with sufficient market penetration to obtain economies from learning LCOE probably too high
- CSTP+TES: immature technology- only ~4GW (2014) installed. Sunshot goal of 6c/kWh will require large investment which at 2015 LCOE of ~14c/kWh will be difficult**. Need CSTP guaranteed Feed-In Tariff (FIT) to stimulate production and lower LCOE**
- Gives dispatchable generation that enables greater penetration of PV and wind. Reduces need for extra capacity. But not valued at current penetration

Future of CSP

- HVDC grid to transmit CSTP to regions of poor DNI (<2000 kWh/y) looks uncompetitive with PV- eg collapse of DESERTEC
- TES currently v competitive as an energy store but CSTP+TES at risk without FIT from PV (+Battery) distributed generation with PV LCOE in 2035 predicted to be ~4c/kWh and batteries ~$150/kWh
- CSTP has niche applications: for process heat in developing countries (heat ~50% of electricity use); in water desalinization; in EOR; in hybridised plants; in providing fuels; in CHP
- Can be used for small scale heating processes

CSTP for Cooking

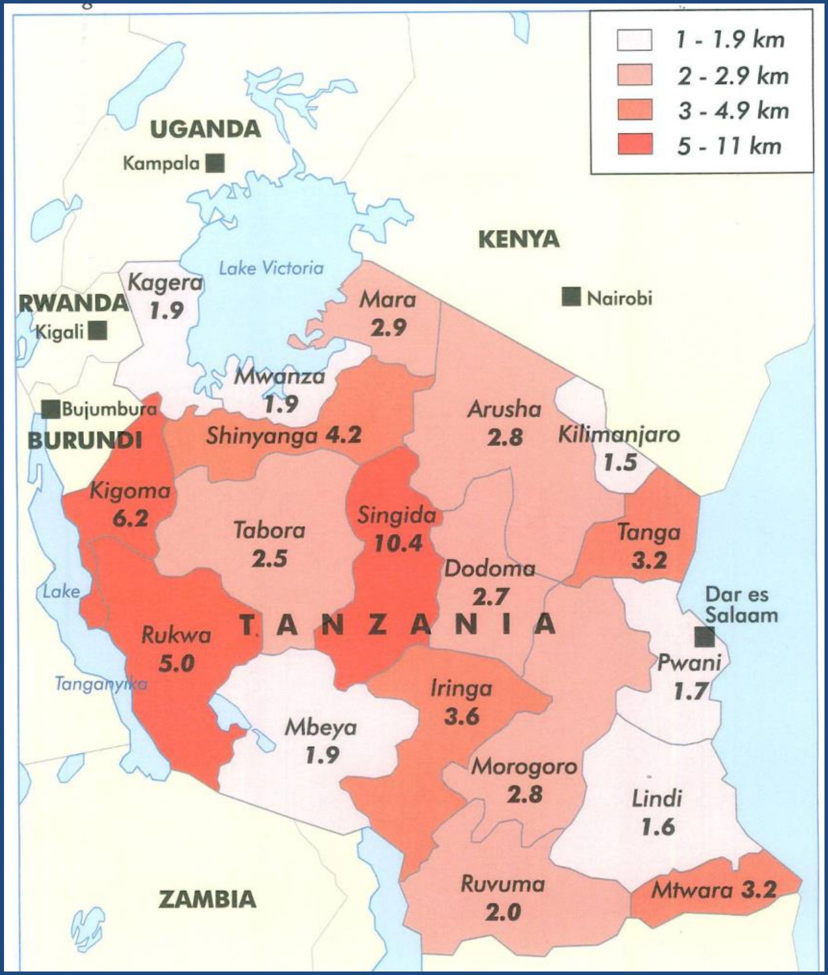
- **3 billion people** cook with solid bio-fuels everyday
- **CO_2 emissions** from deforestation
- **Opportunity cost** of time spent gathering fuel
- **4 million deaths per year** from cooking associated air-pollution (WHO)



Map of global irradiance

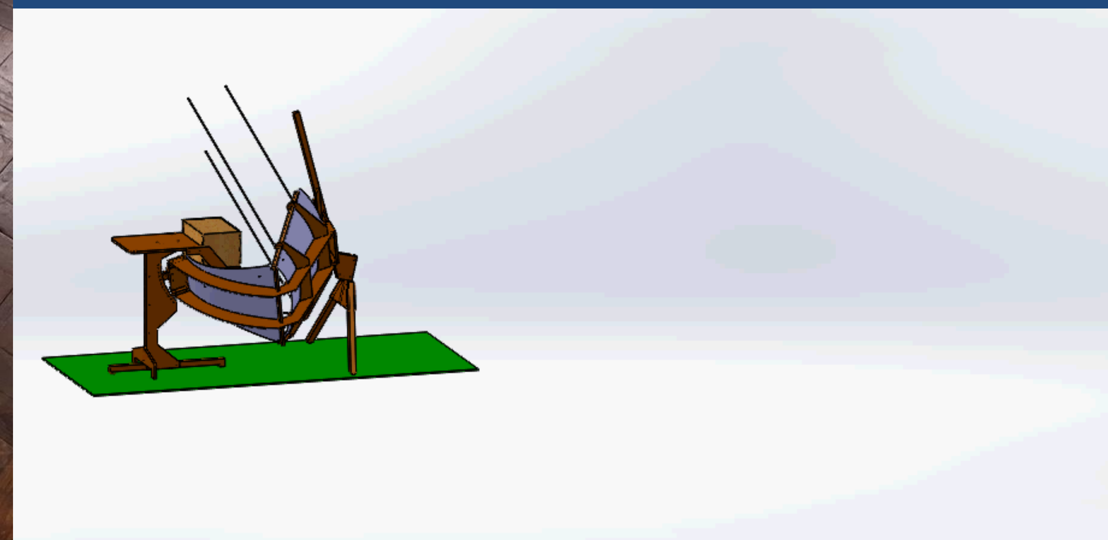
Climate Change 2007: The IPCC 4th Assessment Report. http://www.ipcc.ch/, 2007

Collecting Firewood



TANZANIA

African Trials in Tanzania



152x98x12 cm

Saturday June 13 in the Broad