ASTRI
AUSTRALIAN SOLAR THERMAL RESEARCH INITIATIVE

Concentrating Solar Thermal

Developments and Research Needs

Sarah Miller | Chief Operating Officer
3 September 2015

Harnessing solar energy

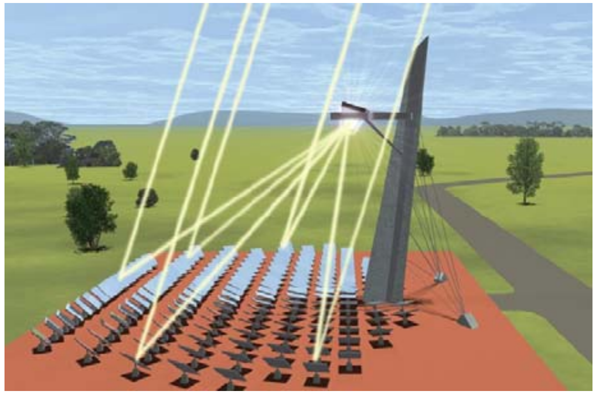
Photovoltaics

sunlight

electricity

Solar Thermal Energy

sunlight

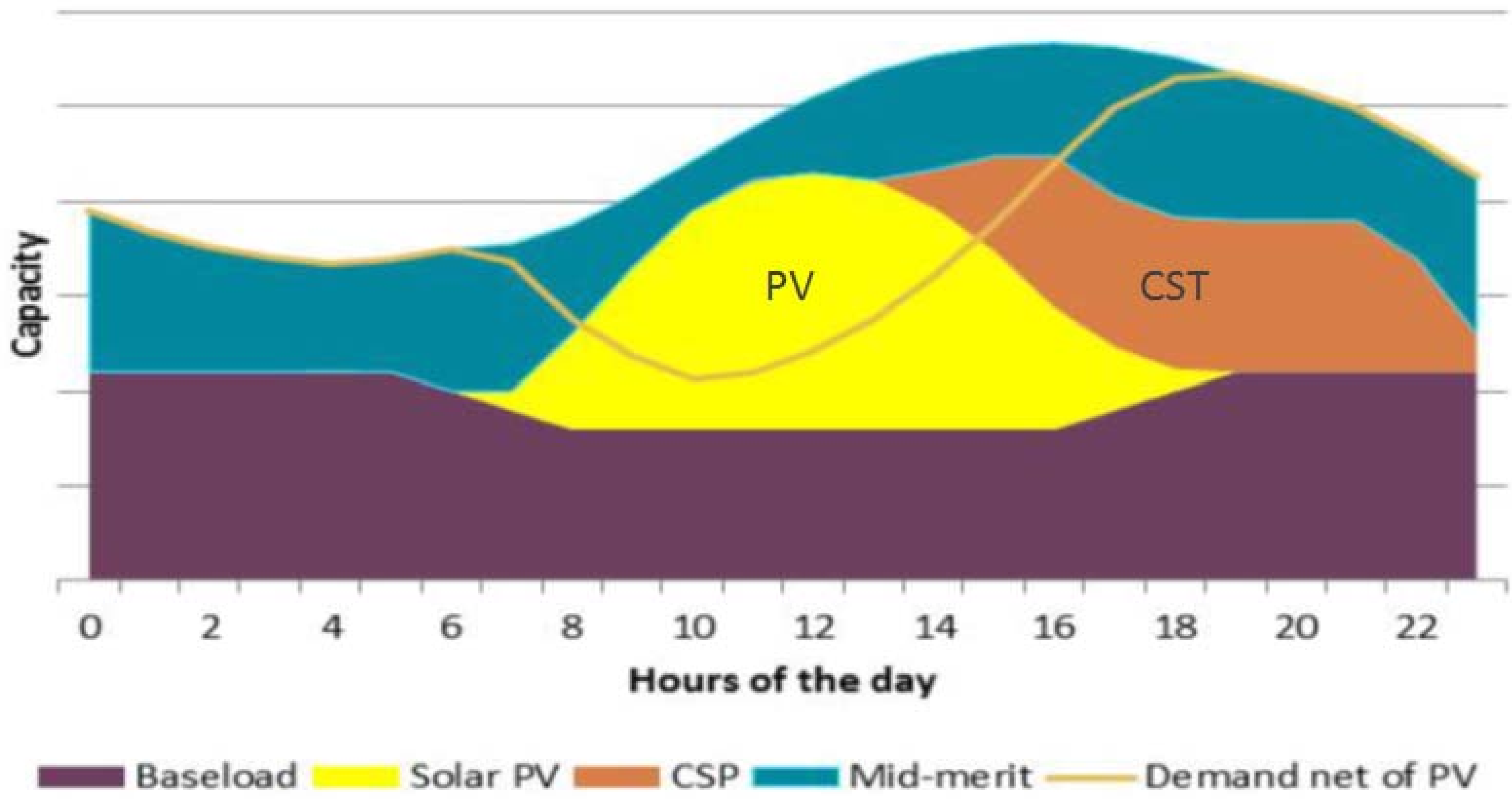


heat

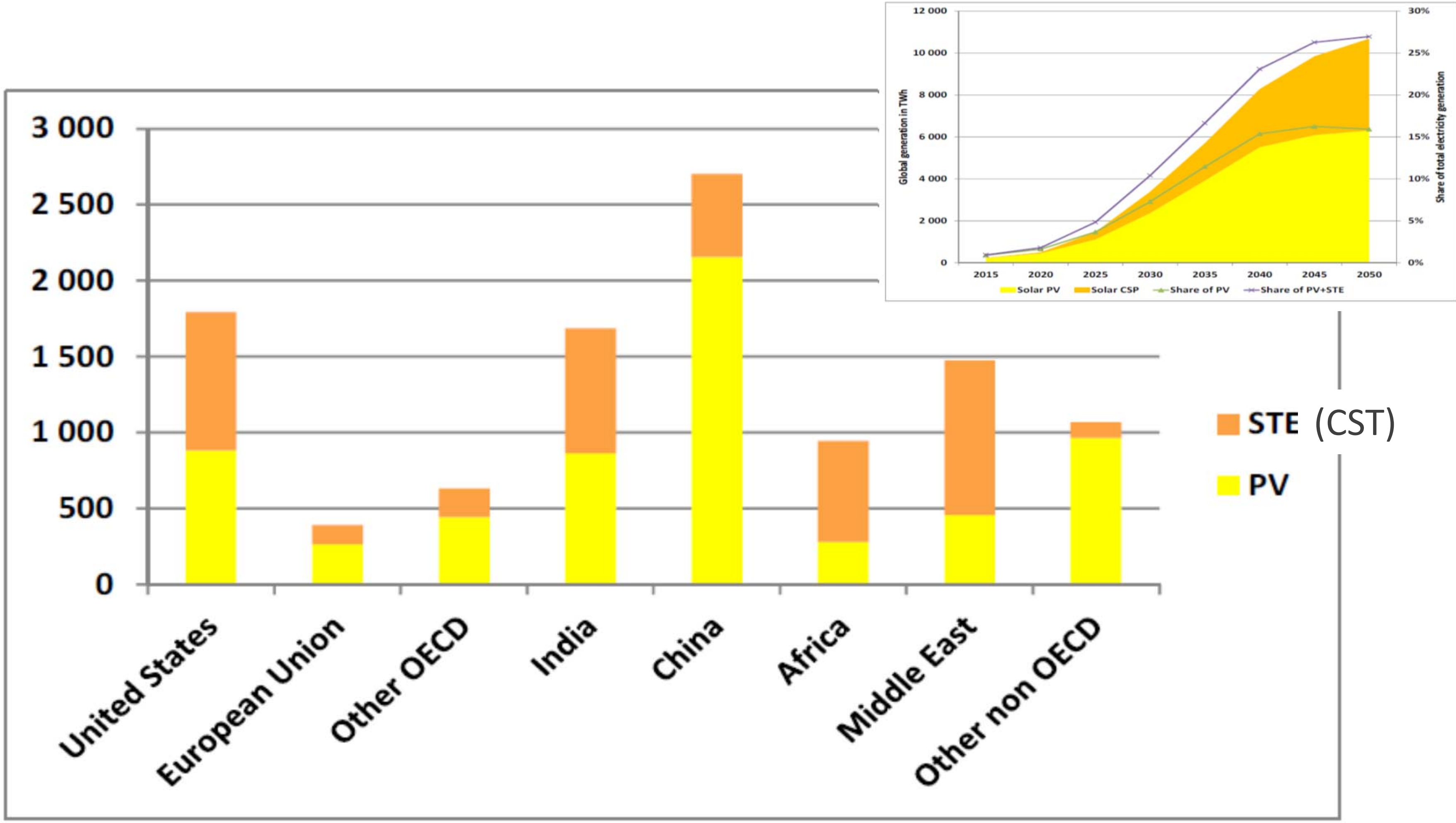
other uses

electricity

IEA Solar Technology Roadmap (2014)



IEA Solar Technology Roadmap (2014)

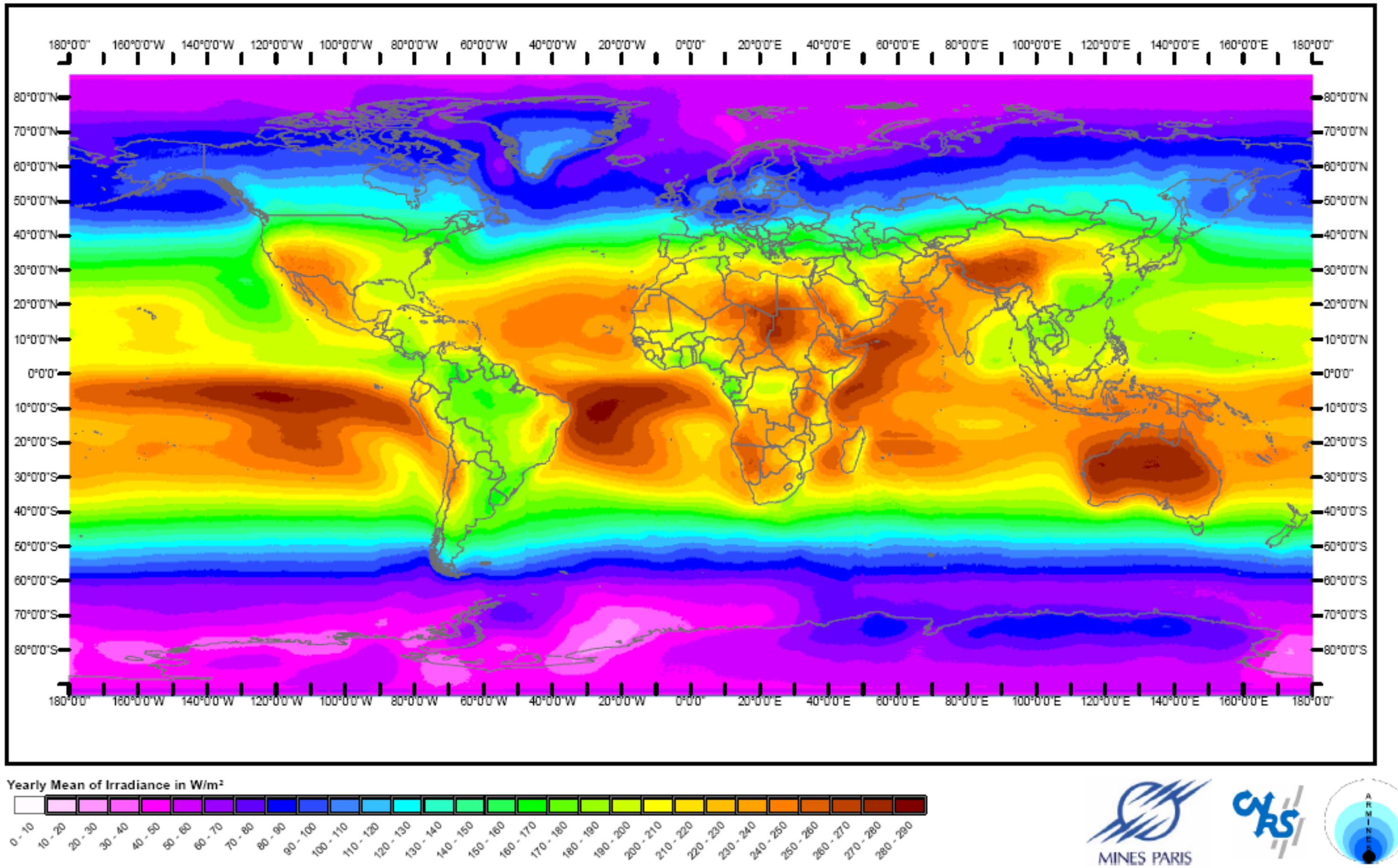


Photovoltaic Energy

Solar Thermal Electricity

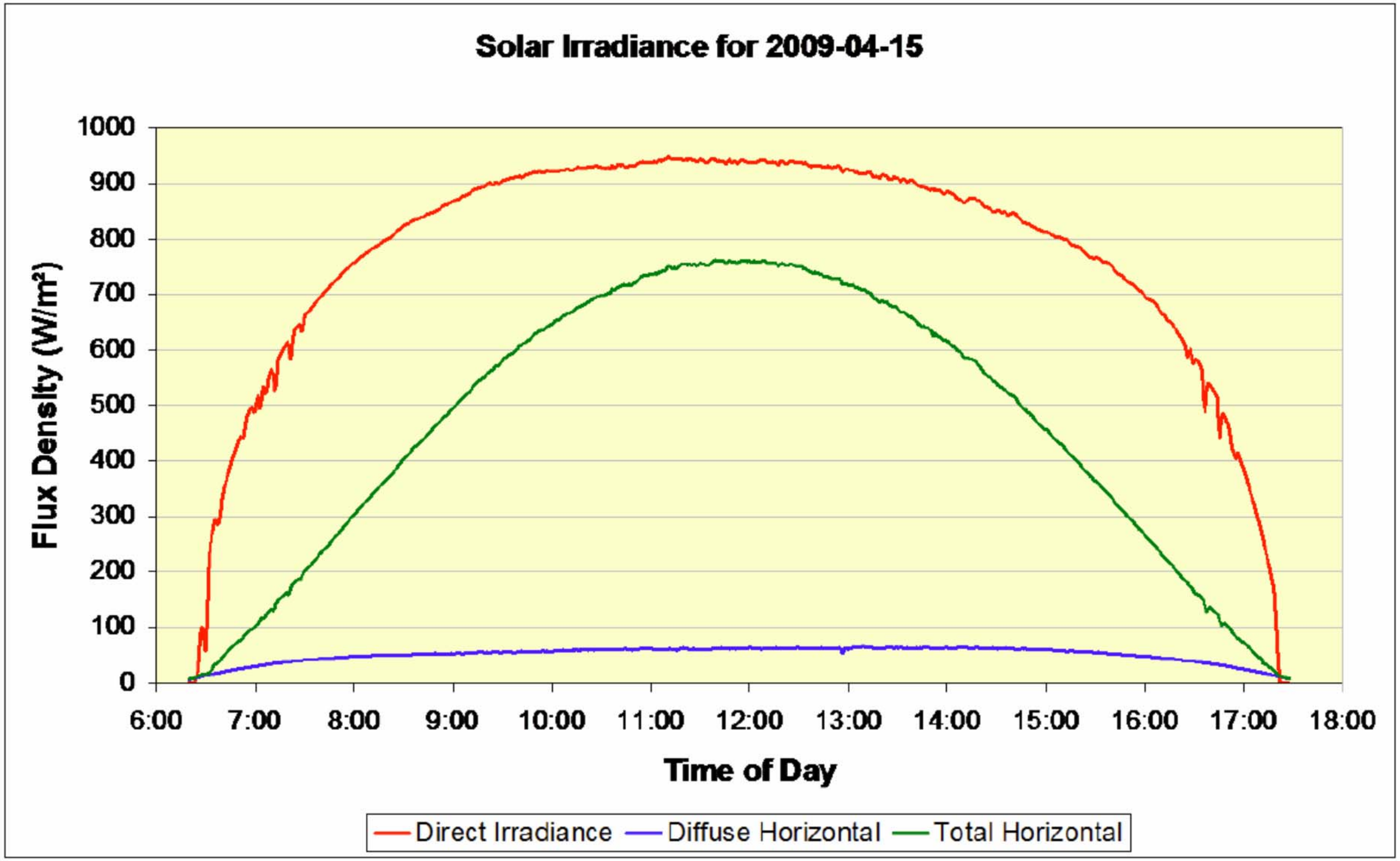
World Sunbelt

DNI >= 1800 kWh/m2/year
~ the “sunbelt” (+/-40º lat)



Realized by Michel Albuisson, Mireille Lefèvre, Lucien Wald.
Edited and produced by Thierry Ranchin. Date of production: 23 November 2006.
Centre for Energy and Processes, Ecole des Mines de Paris / Armines / CNRS.

Solar Energy



Utilising solar thermal energy

>1000°C

Point-focus concentrators

200 - 400°C

Linear-focus concentrators

100°C

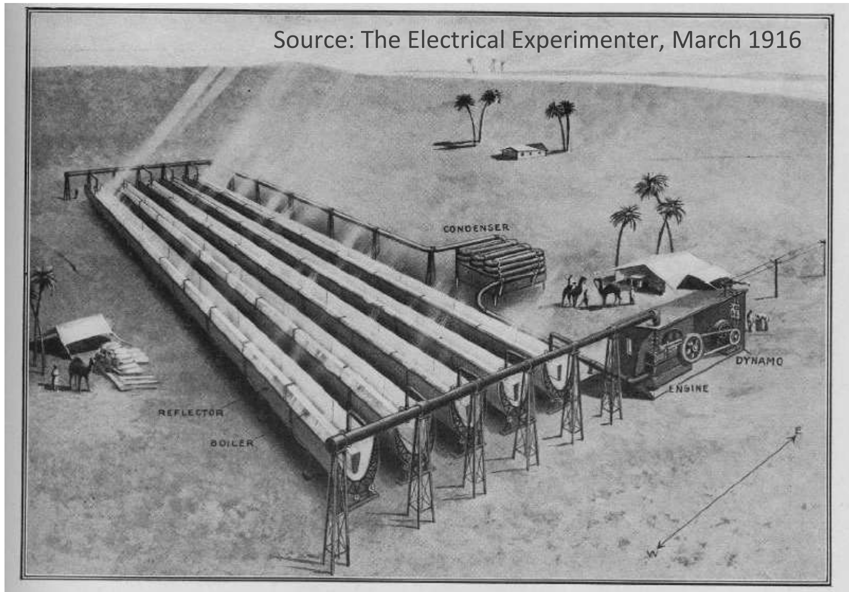
Non-concentrated solar energy

Content

- Historical Perspective
- Benefits and Challenges
- Australian Developments
- Australian Solar Thermal Research Initiative (ASTRI)

Historical Perspective

Egypt 1913: Shuman-Boys Solar Engine On



Source: The Electrical Experimenter, March 1916

Fig. 1.8 A view from the south of the Shuman-Boys solar collector system constructed at Meadi, Egypt, in 1913.

- Location: Al Meadi, Egypt

- Net Output : ~40 kW
- Concentration ratio: 4.5
- Temperature: low
- Fluid: water/steam

- Collection efficiency: ~40%
- Engine efficiency: ~10%
- Peak System Efficiency: ~4%

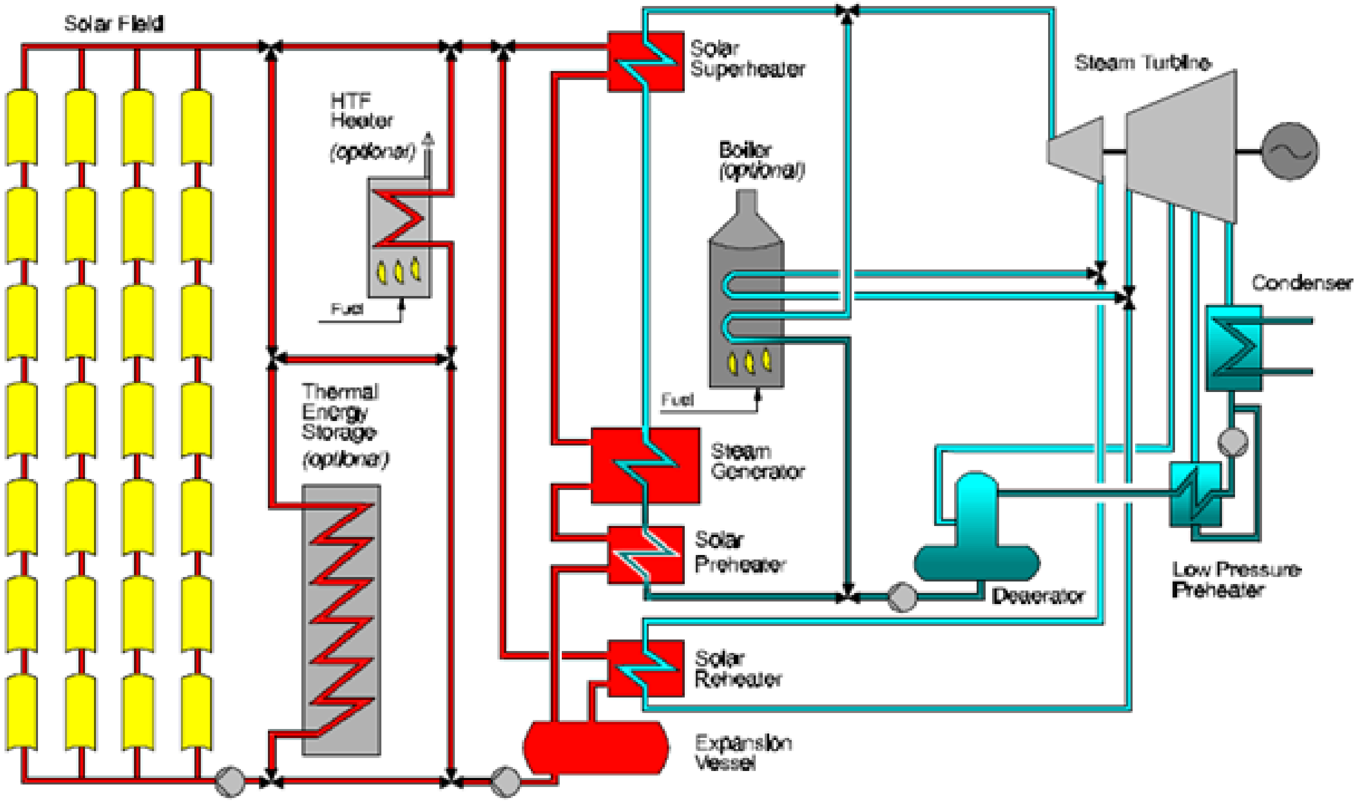
Source: http://www.freeenergynews.com/Directory/Solar/Tesla/Meadi-Egypt_1913.jpg

Australia 1982: Meekatharra (WA)

- MAN STEPS-100 Solar diesel power station
  - With waste heat recovery plant
- Net Output: ~100 kW
- Concentration ratio: 40
- Fluid: thermal oil
- Temperature: 200-290°C
- Collection efficiency: 50-55%
- Turbine/Engine:
  - low temperature steam screw expander, Pressure of 16 bar
  - Efficiency 13.5%
- Peak System Efficiency: ~7%

Source: National Library of Australia

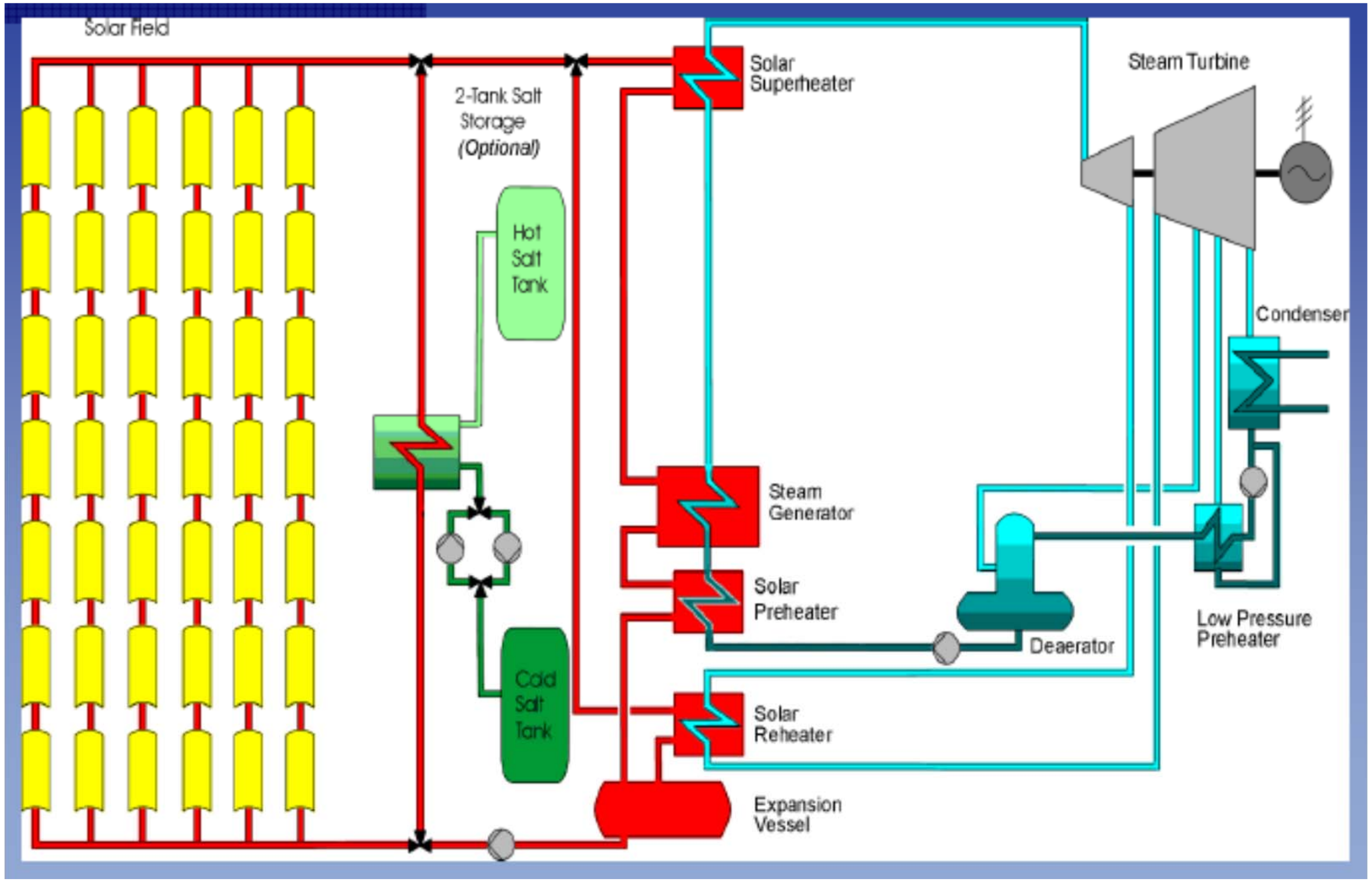
USA 1980's: Solar Electric Generating Systems (SEGS)



- Net Output : 30 MW (SEGS VI)
- Solar Field Temperature 390°C
- Steam Turbine Efficiency: 37.5%
- Peak Plant Efficiency: ~19%

Source: Pilkington Solar International, 1996

Spain: Andasol 1 (2008)



- Net Output: 50 MW
- Solar Field Temperature 393°C
- Steam Turbine Efficiency: 38.1%
- Peak Plant Efficiency: ~28%

Source: Geyer (2006)

Evolution of Trough Collector Assemblies

	1st Generation (1984)	2nd Generation (1986)	3rd Generation (1989)	4th Generation (Prototype)
Aperture	2.5m	5m	5.76m	10.5m
SCA Length	50 m	48m	99m	49m
Distance Between Pylons	6 m	12-15m	17.3m	25 m
Reflecting Surface	$128 m^2$	$235 m^2$	$545 m^2$	$504 m^2$
Fluid Temperature	307°C	350°C	390°C	390-450°C

Source: Pilkington (1996)

Utilising solar thermal energy

>1000°C

Point-focus concentrators



200 - 400°C

Linear-focus concentrators



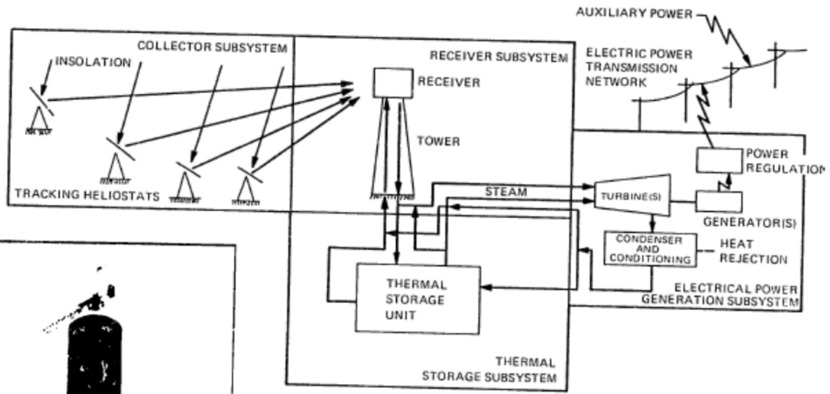
100°C

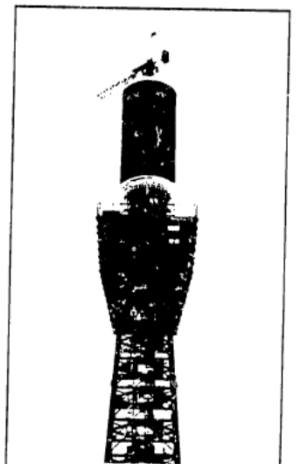
Non-concentrated solar energy




US: 10MWe Barstow Steam Plant

- Net Output : 10MWe
- Temperature: 516°C
- Fluid: water/steam (10MPa)



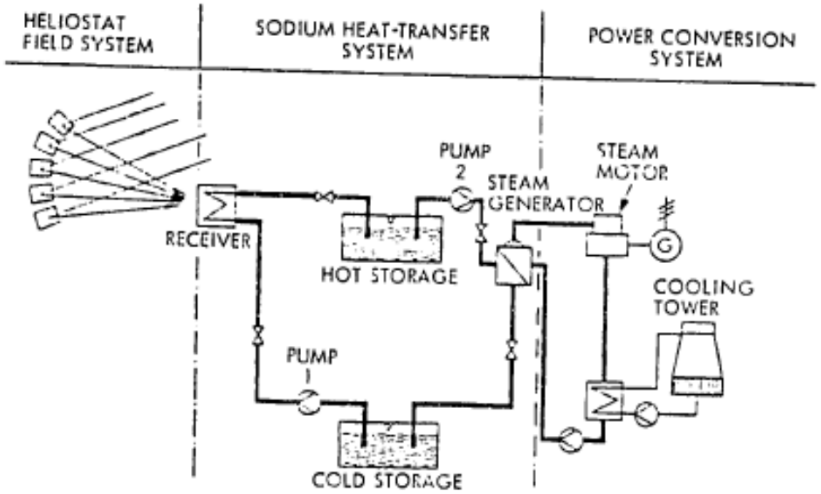


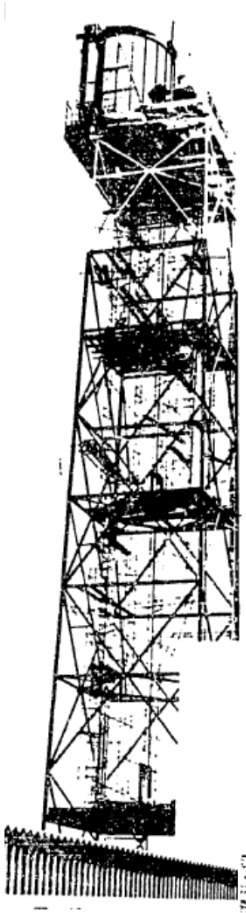
View of the tower with the boiler receiver mounted at its apex. A man is standing beneath and to the left of the receiver behind the railing. [2]

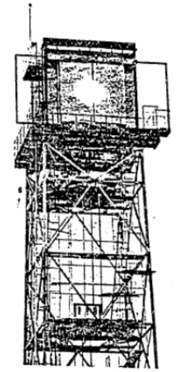
Source: Duffie and Beckman (1974)

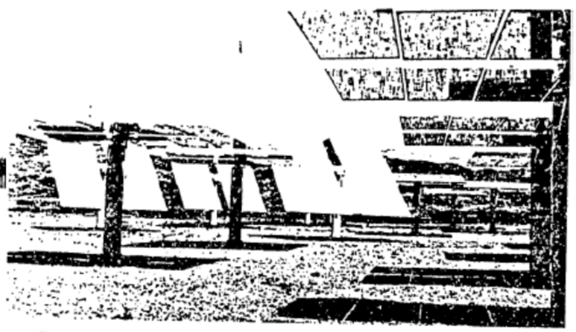
Spain: SPSS -CRS plant

- Net Output : 500kWe
- Temperature: 530°C
- Fluid: sodium









Spain: PS10 (2007)

- Location: Seville, Spain

- Net Output : 11 MW
- Temperature: 250-300°C
- Fluid: water/steam

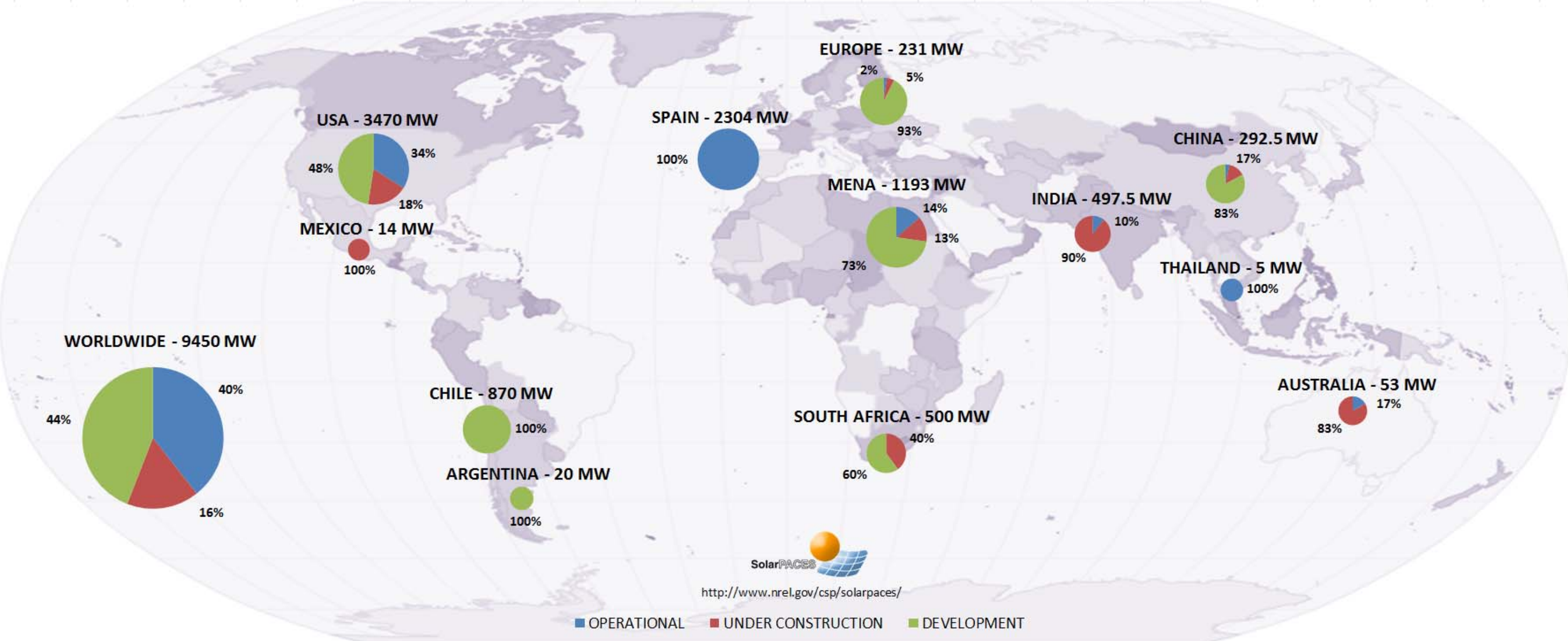
Source: Wikipedia

Spain: Gemasolar (2011)

- Location: Andalucía, Spain
- Net Output : 20 MW
- Temperature: 565°C
- Fluid: molten salt
- First commercial-scale solar plant in the world to operate for 24h

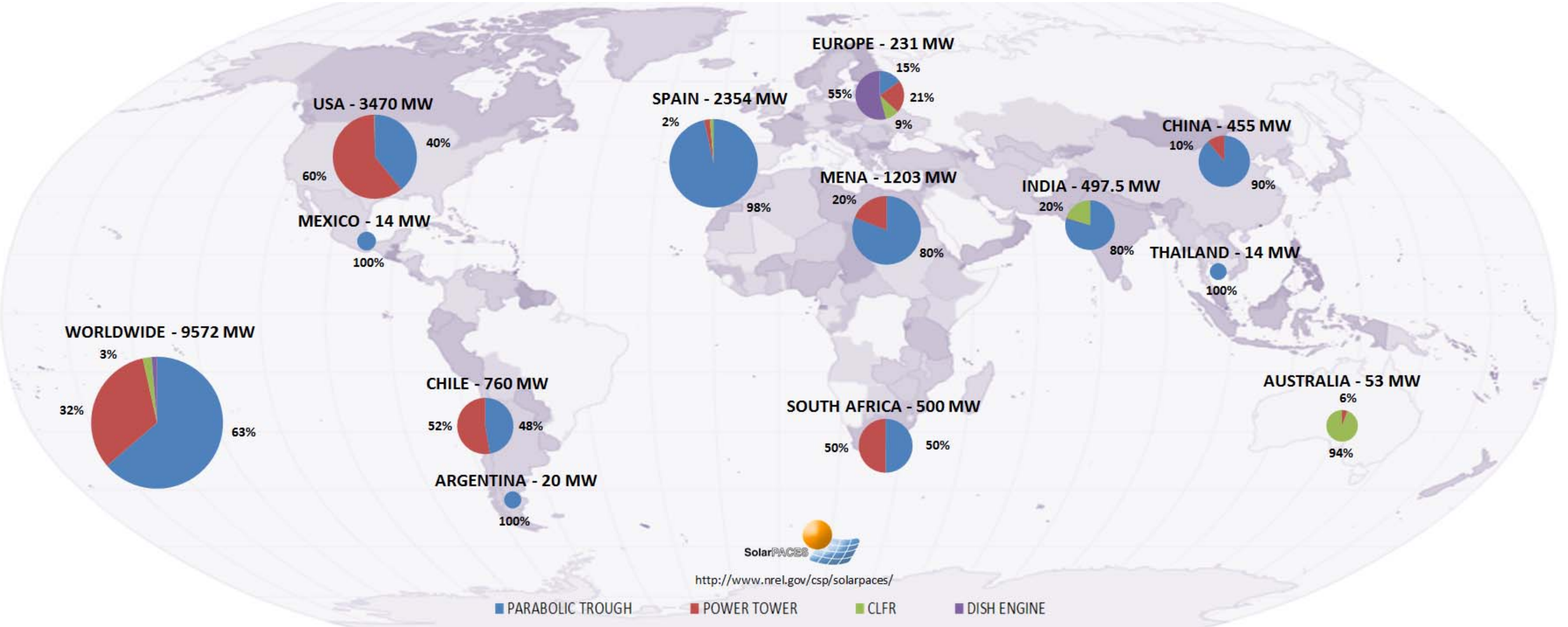
Source: Torresol Energy

World CST Project Status



***Source**: SolarPACES / NREL. For additional information, please, visit: http://www.nrel.gov/csp/solarpaces/by_country.cfm*

CST Technology Status



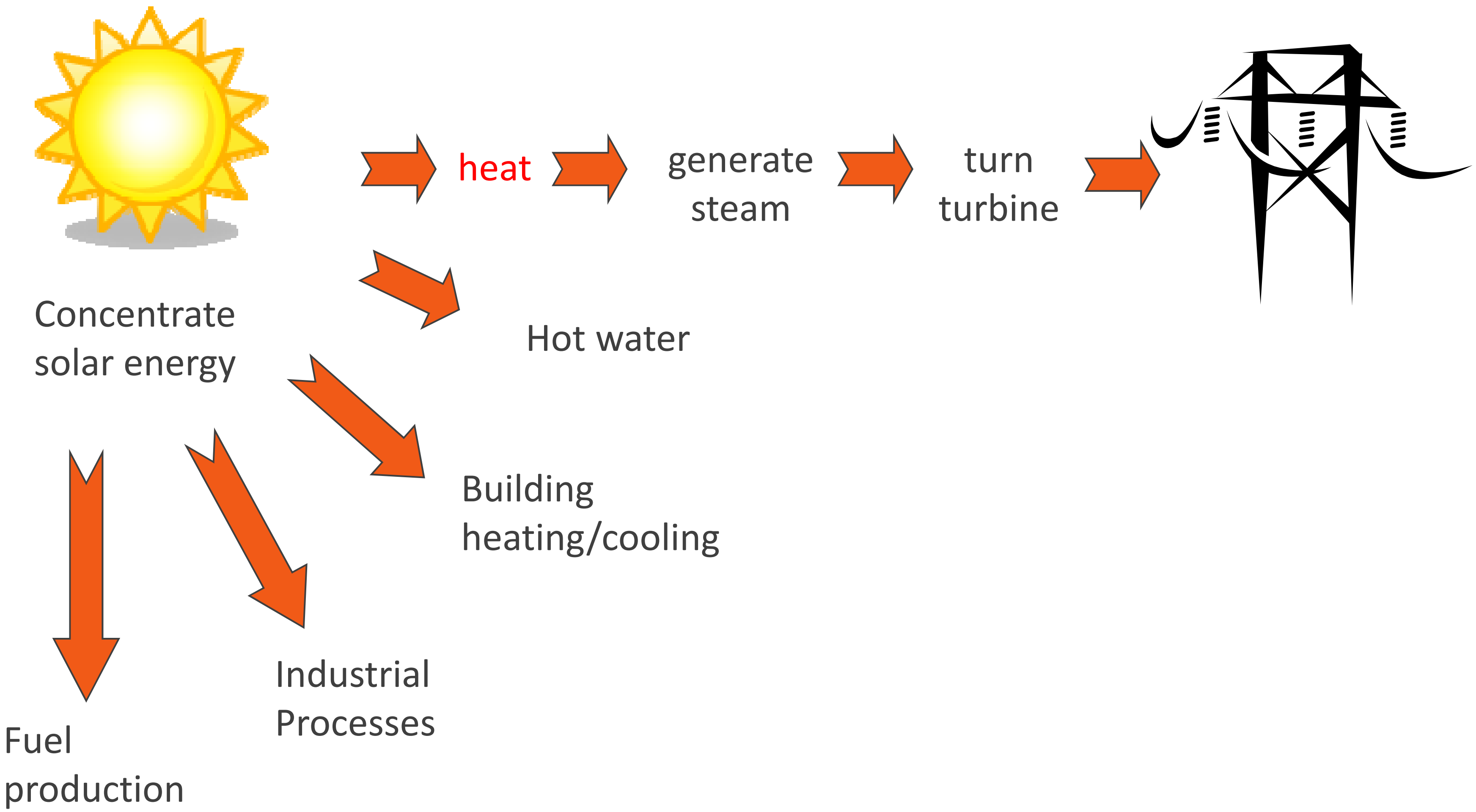
Source: *SolarPACES / NREL. For additional information, please, visit: http://www.nrel.gov/csp/solarpaces/by_country.cfm*

Benefits and Challenges

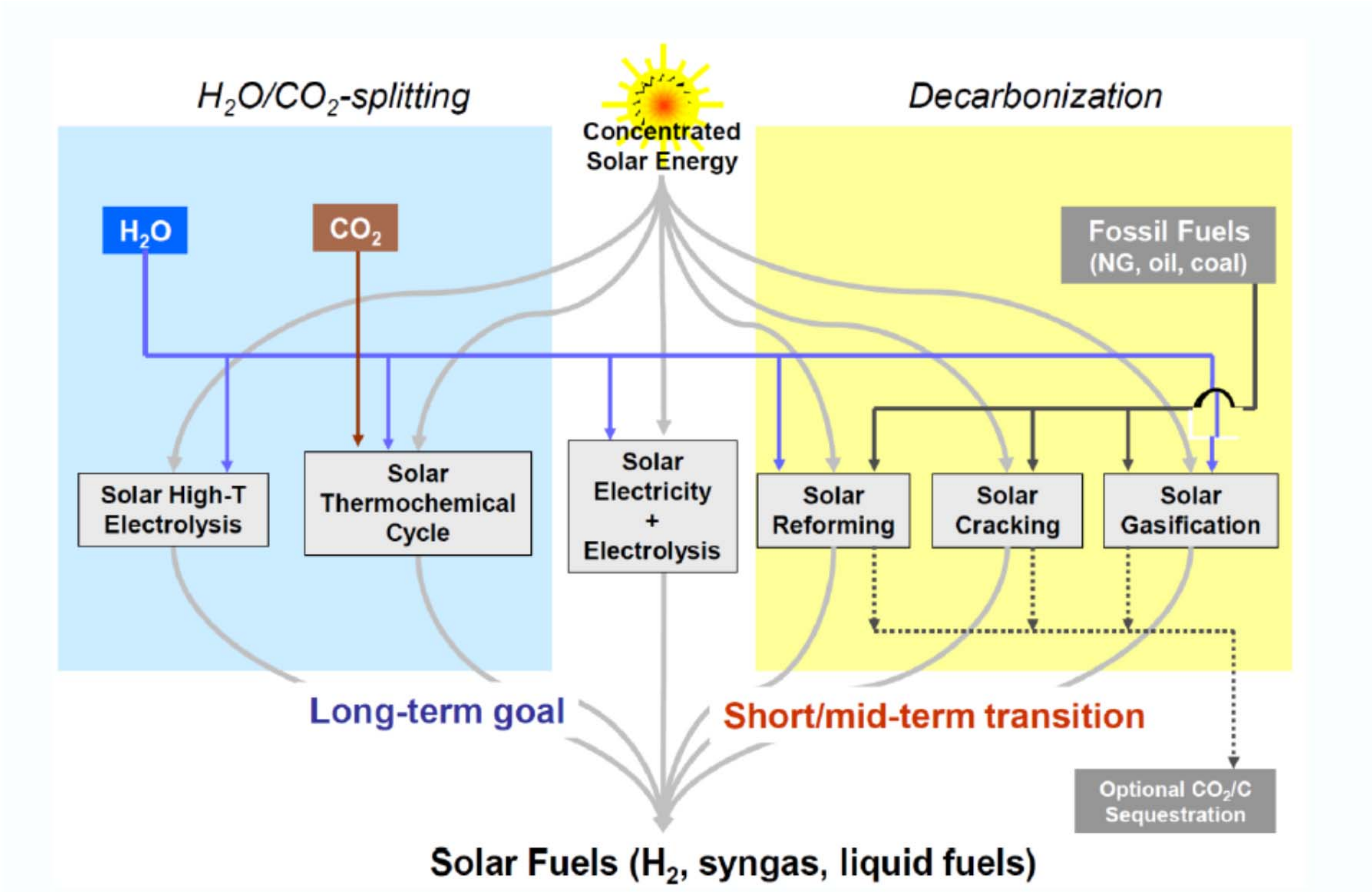
Key Technical Benefits of CST

- Dispatchable renewable power generation
  - Store thermal energy and convert it to electricity when needed
- Uses established technology concepts
  - mirrors, tubes, steam and gas turbines and electrical generators
  - Allows integration with
    - Biomass or biogas to deliver renewable hybrid power stations
    - Coal and/or gas as fuel backup
    - Coal and/or gas to boost conventional power stations as a transition towards a renewable energy future
- Create industrial heat for direct or indirect use
  - Industrial steam
  - Endothermic chemical processes

Utilising solar thermal energy



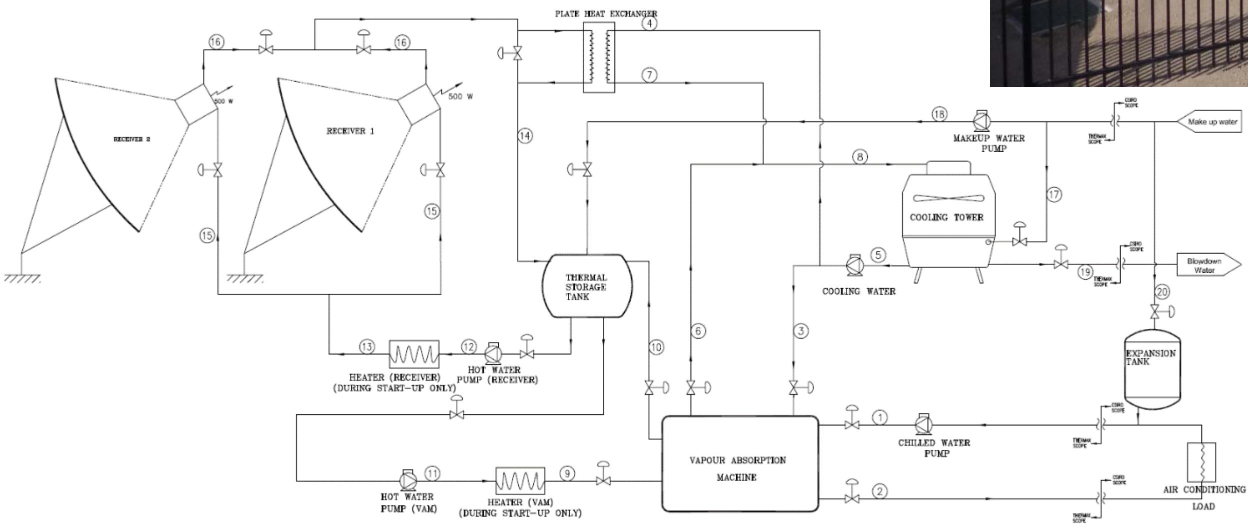
Solar Chemistry



Source: Steinfeld

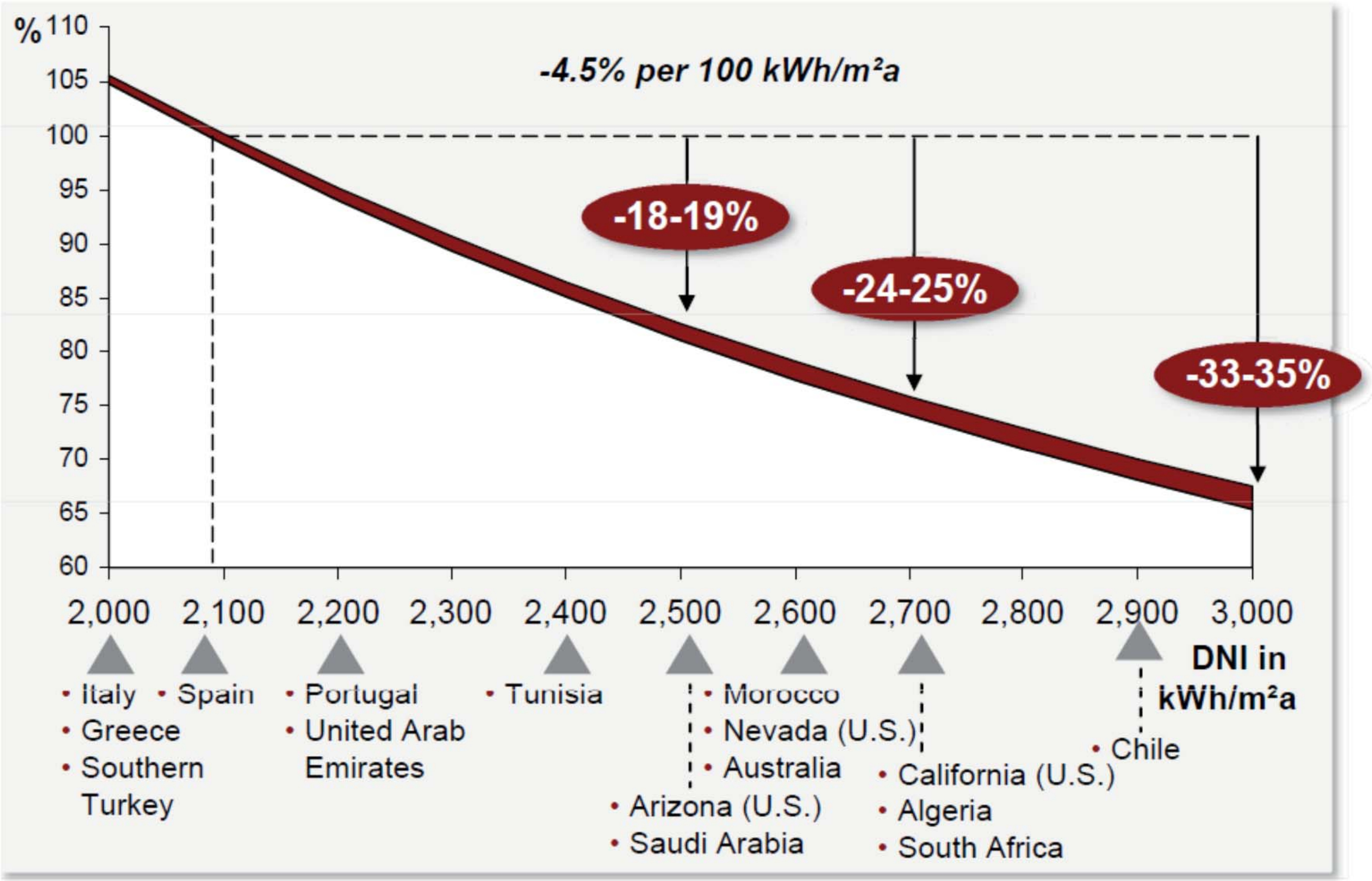
Polygeneration

- Dish with thermoelectric topping cycle and chiller bottoming cycle
  - Seebeck device in receiver
  - Absorption chiller in container
- Designed for remote communities



Key Challenge is to Reduce Cost

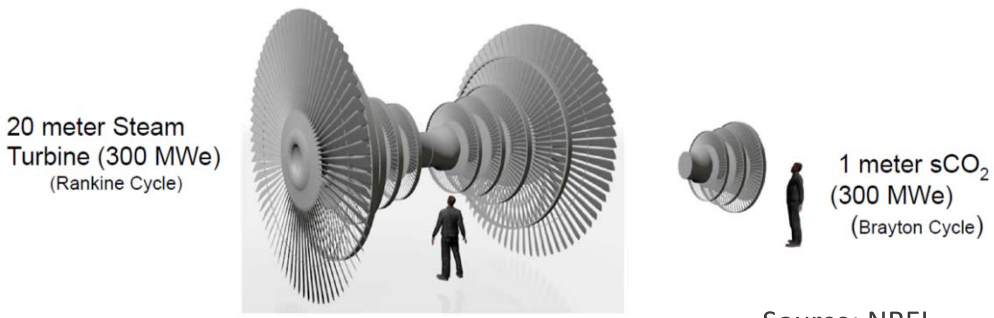
Levelised cost of electricity (LCOE) depends on annual solar irradiance (DNI)



Source: A.T. Kearney (2010)

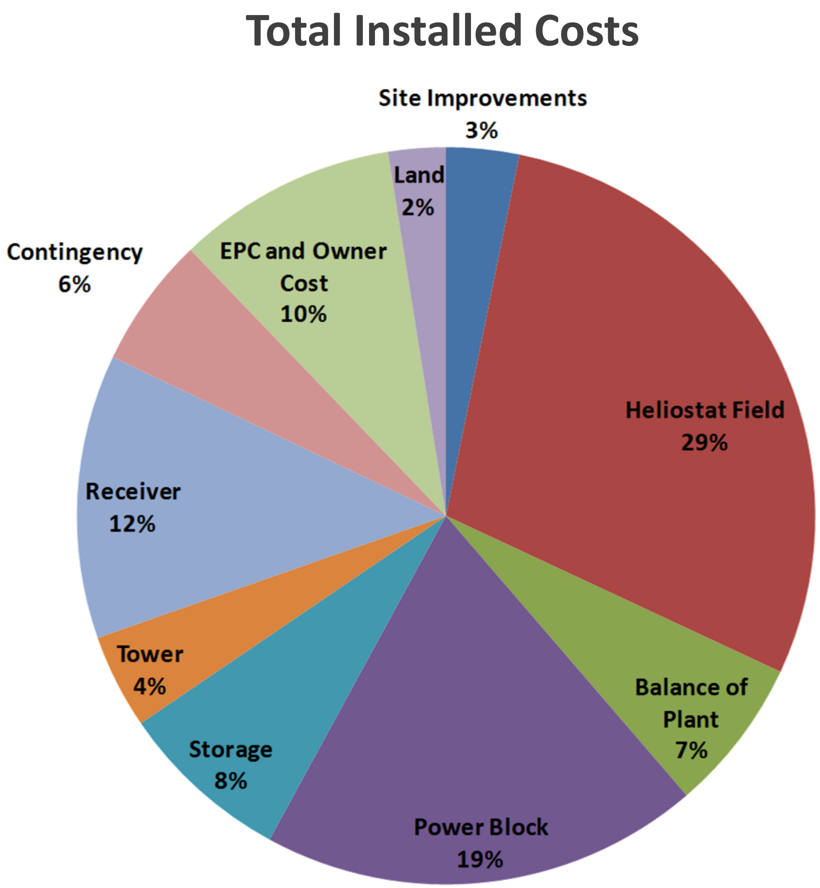
How to reduce LCOE

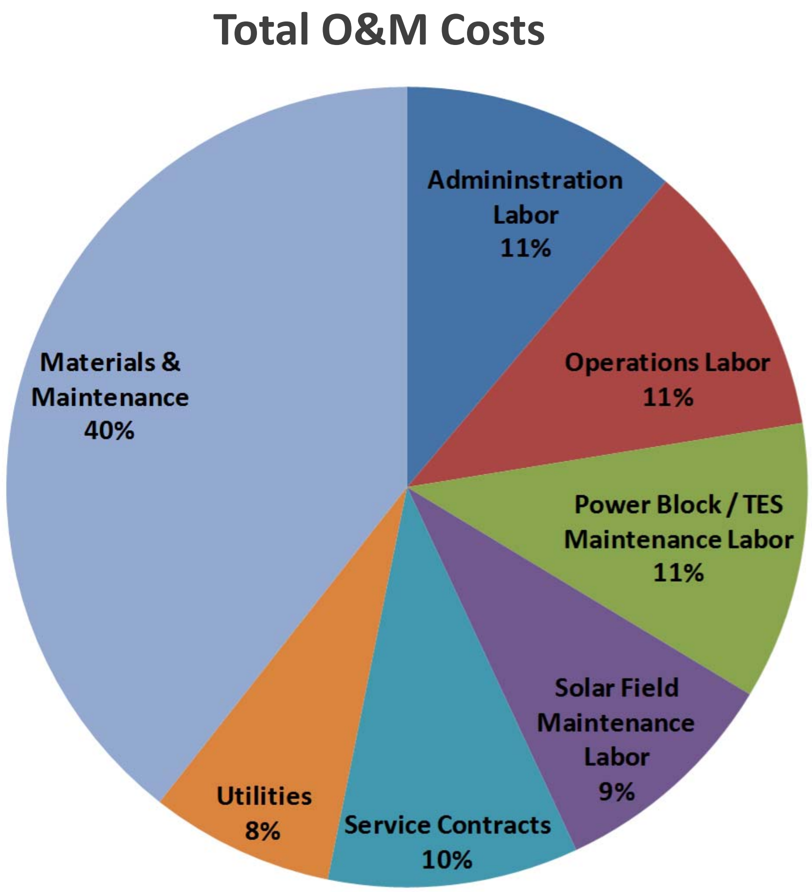
- Reduce capital costs (CapEx)
  - Main cost is collection, concentration and conversion of [free] solar energy into thermal energy
- Increase capacity factor (utilisation factor)
  - Need storage (otherwise plant is a solar peaking plant)
- Improve efficiency
  - Higher temperatures increase Carnot efficiency
- Add Product Value
  - Dispatchability
    - From storage
    - From hybridisation
  - Reduce operating costs
  - Produce higher value products



Source: NREL

Distribution of Tower Costs





Australian Developments

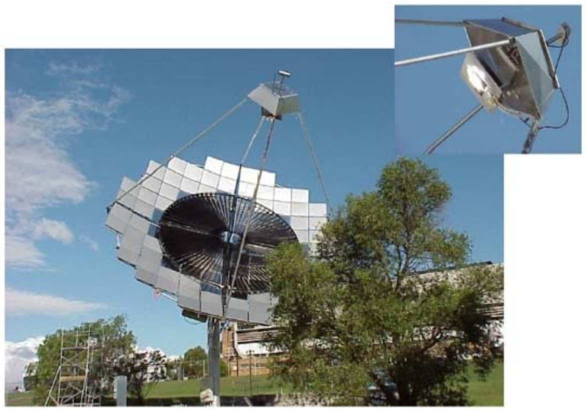
Early CST Activity in Australia

- 1994: ANU began “Big Dish” development
  - SG3 400m²
  - Ammonia (NH_3) cycle
- 2009
  - SG4 500m²

Source: ANU

Early CST Activity in Australia

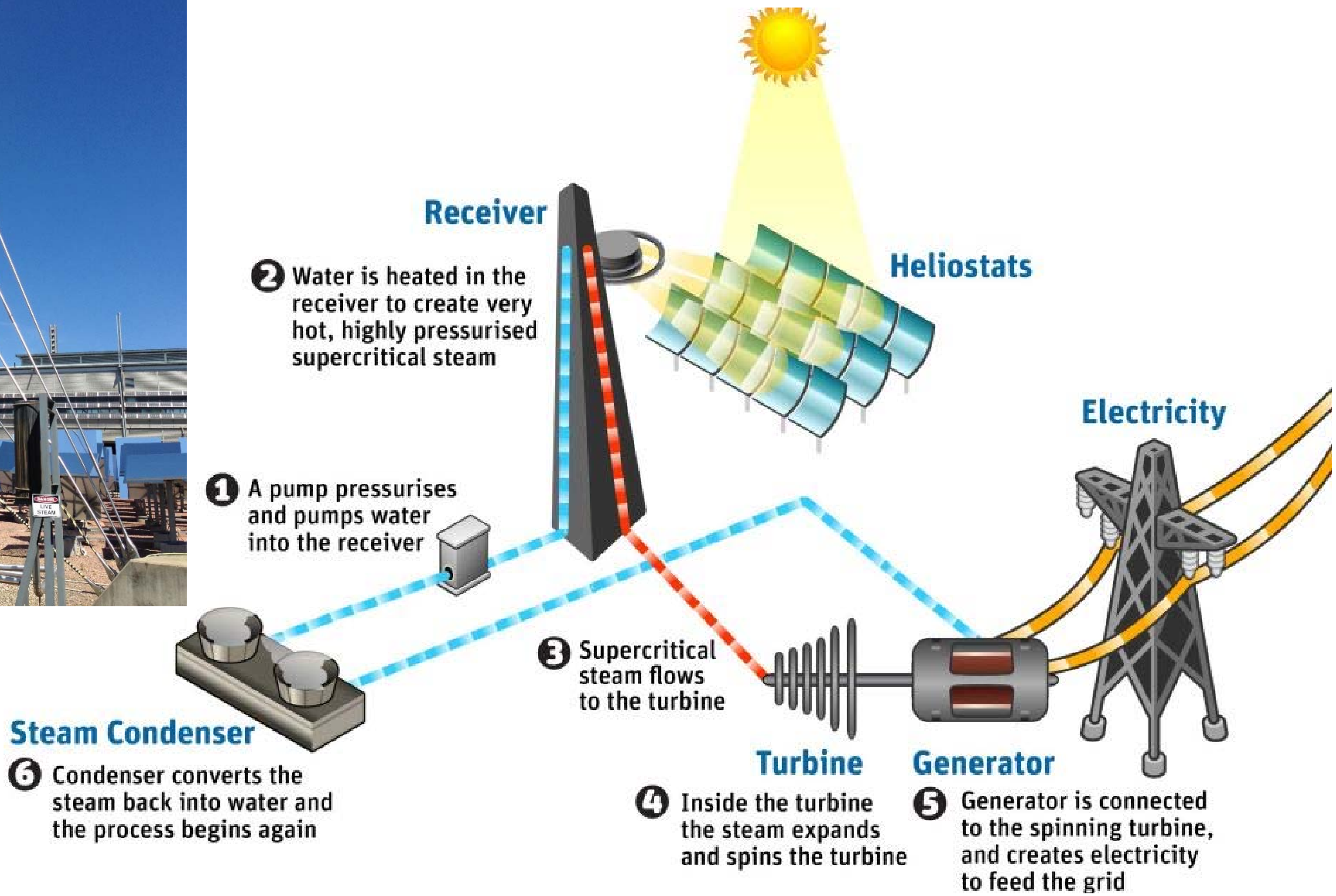
- 1997-2002: CSIRO steam reforming methane
  - 20kW dish
- 2004-2006: SolarGas™
  - 500kW tower
- 2008-2012: SolarGas™
  - 20 to 200kW receiver



Australian Research Projects

- Tower
  - Advanced Steam
  - Advanced Storage
  - Brayton Air Turbine
  - Supercritical CO_2 Brayton
  - Hybrid Fuels
  - Graphite receiver
  - Tower storage system
  - Phase change test bed
  - Allam Cycle
- Dish
  - Thermoelectric Generator
  - Receiver design
- Trough
  - Supercritical ORC
  - CCS demonstration
- Other
  - Thermionics
- Scholarships
  - Techno-economic models
  - Phase change storage
  - Solar gasification
  - Heat exchanger

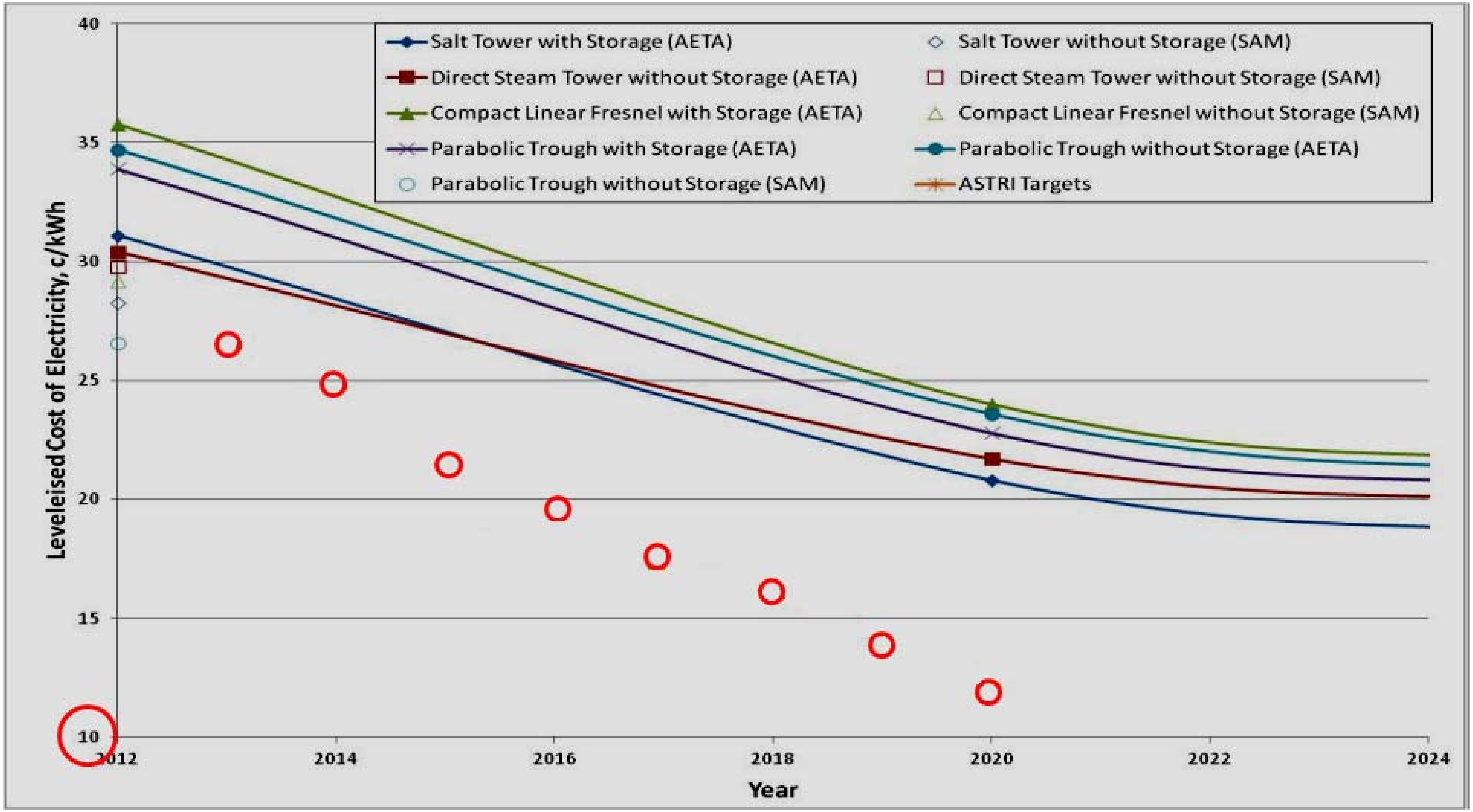
Supercritical Steam



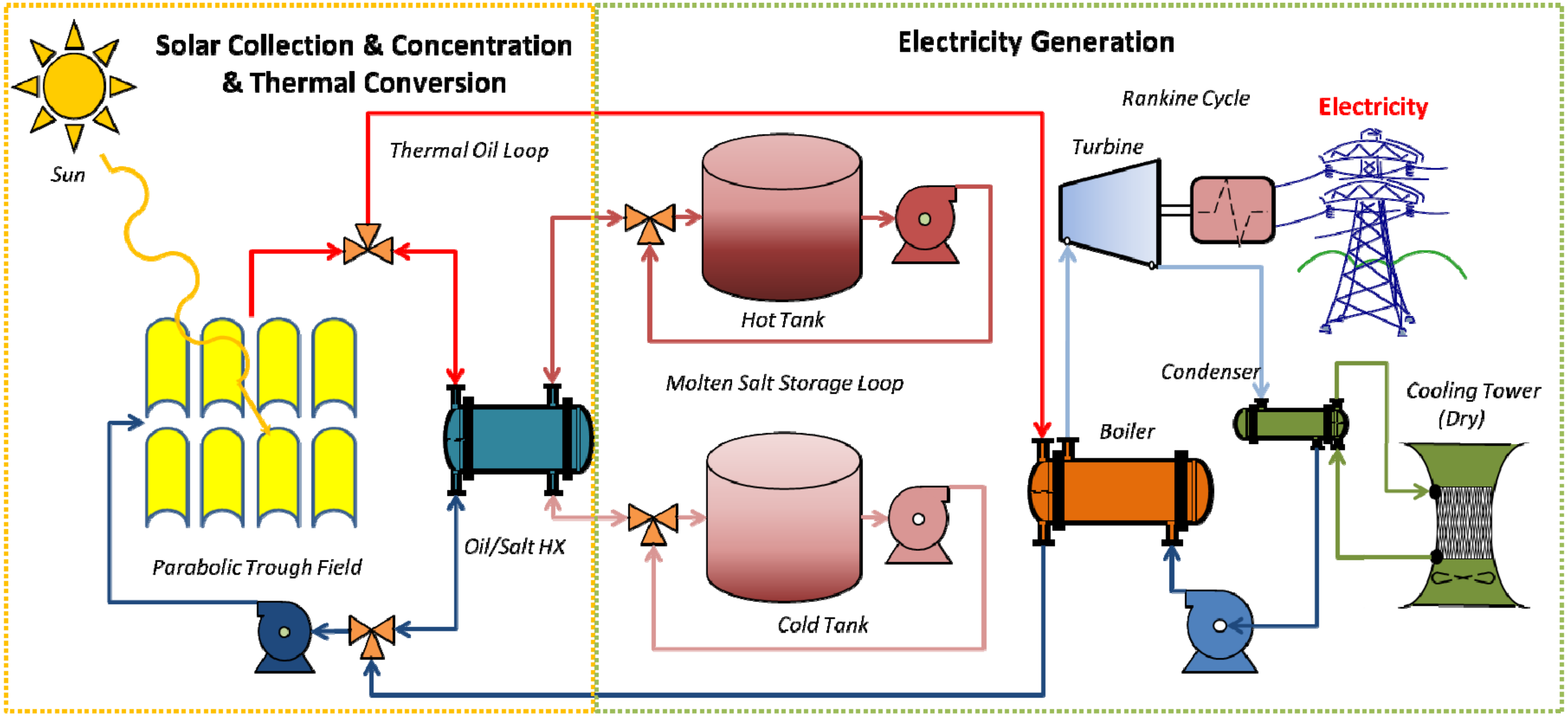
Australian Solar Thermal Research Initiative

ASTRI

ASTRI LCOE KPIs

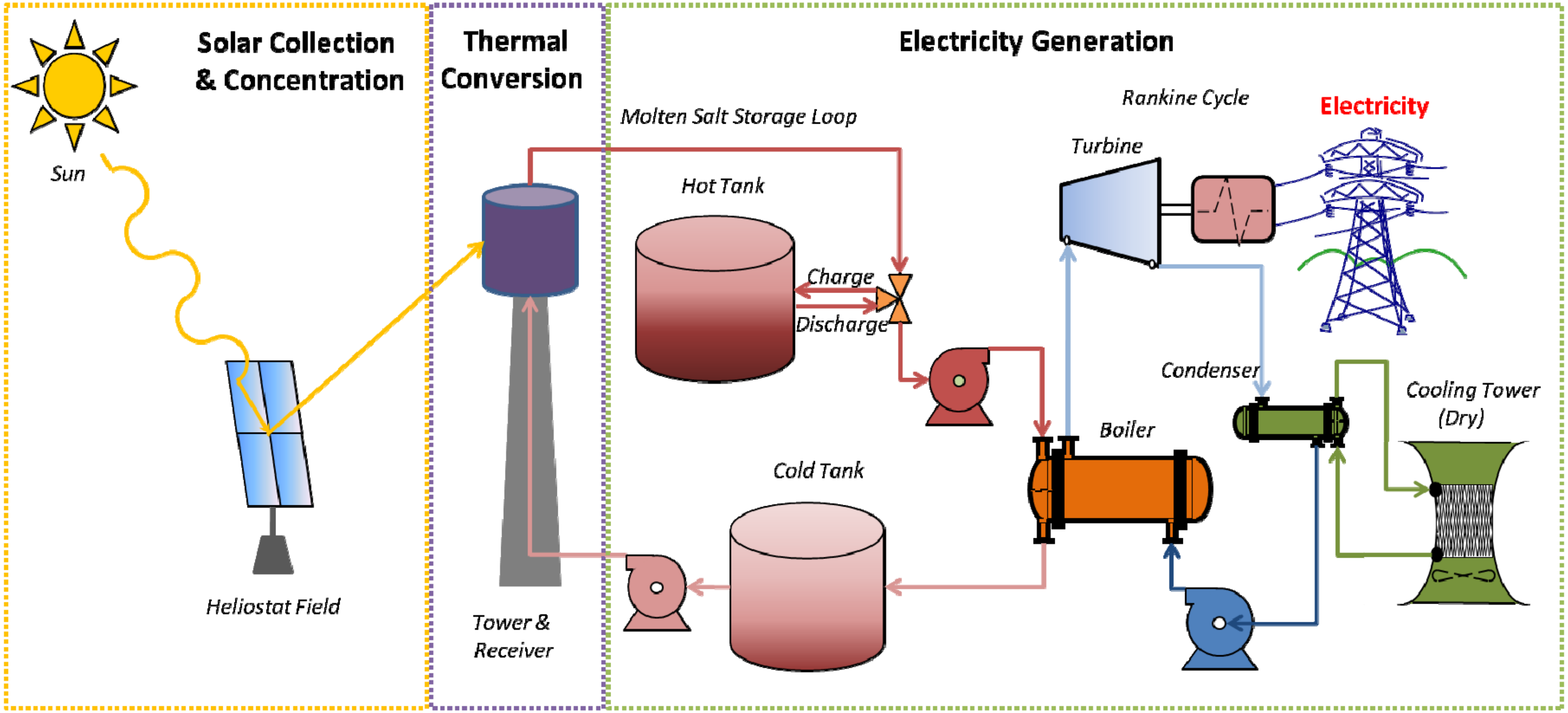


Trough Baseline Plant



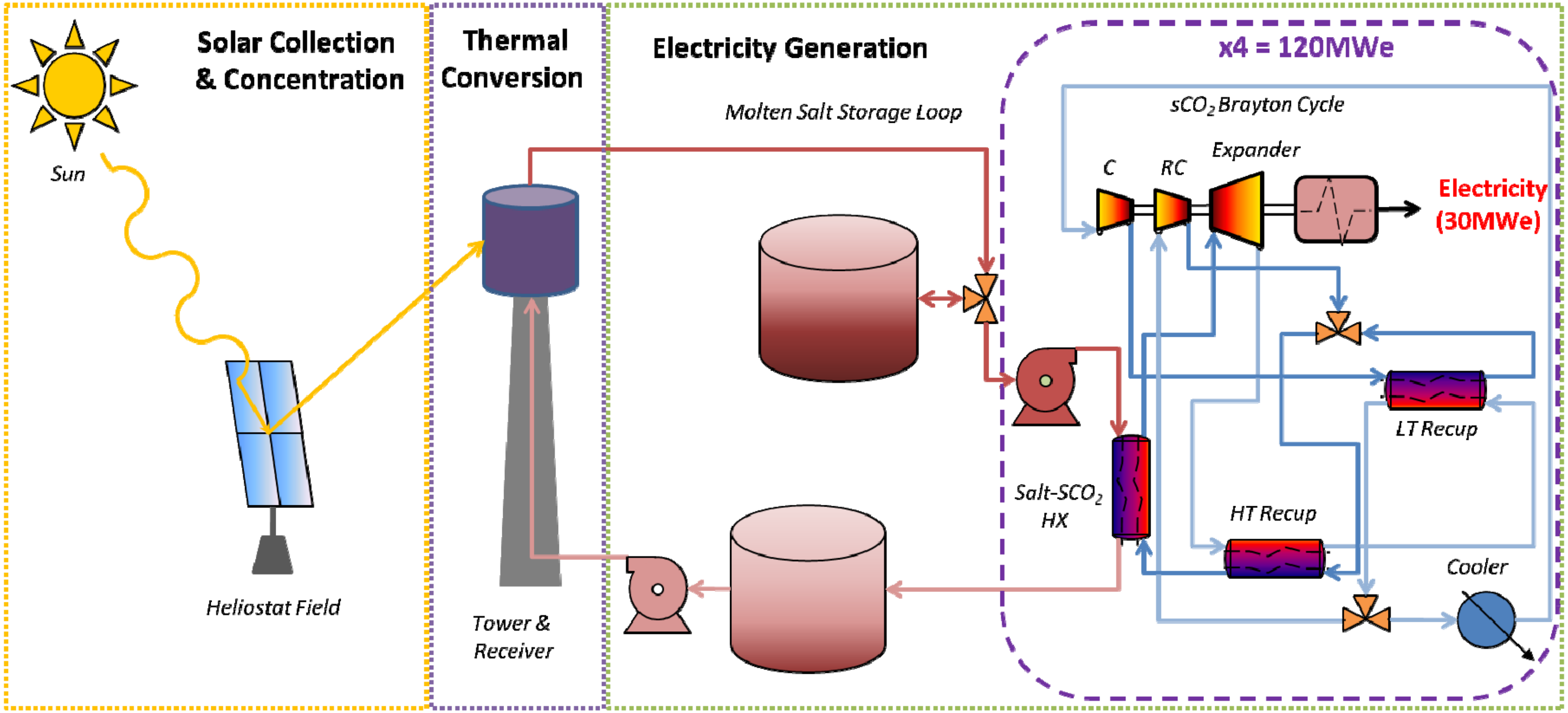
Tower Reference Plant

LCOE = 22.5c/kWh
Thermal energy = 17.2 $/GJ

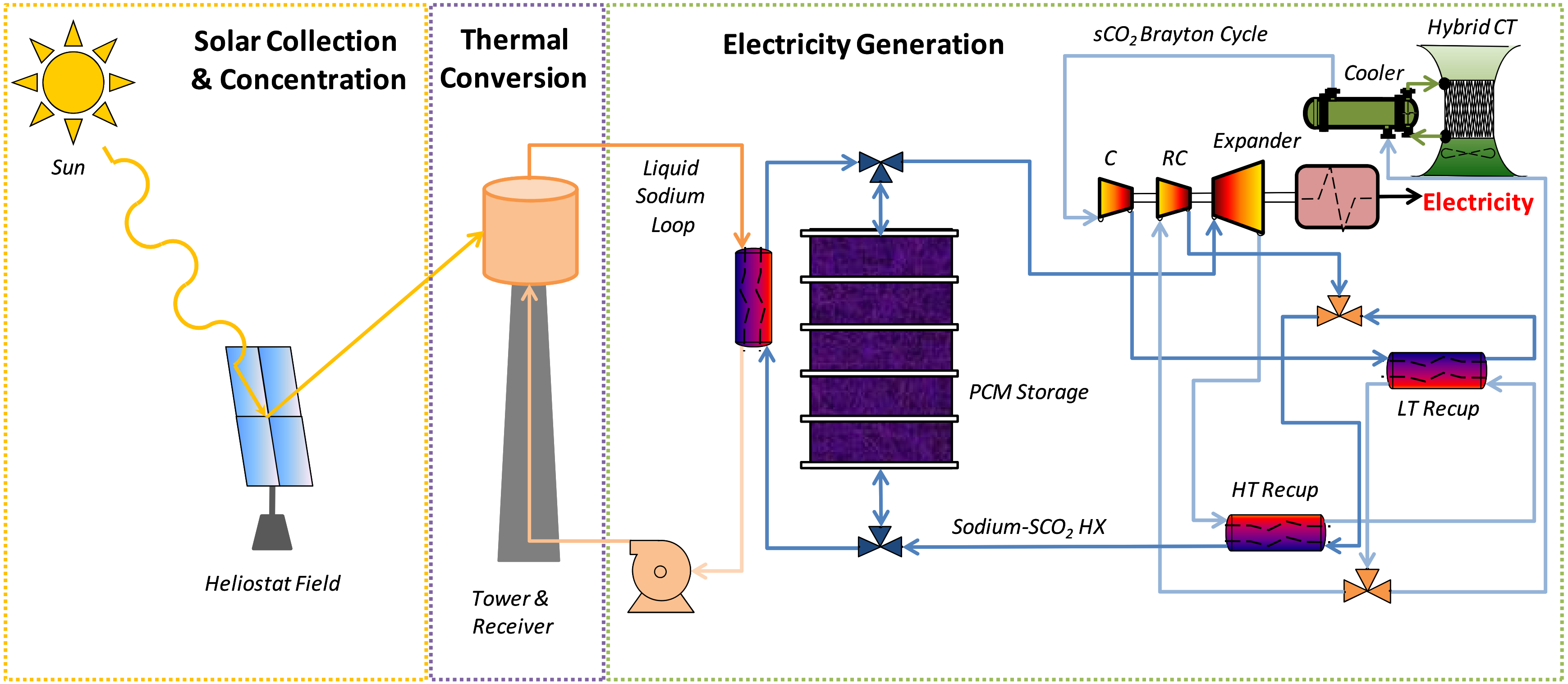


Molten Salt sCO_2 Plant

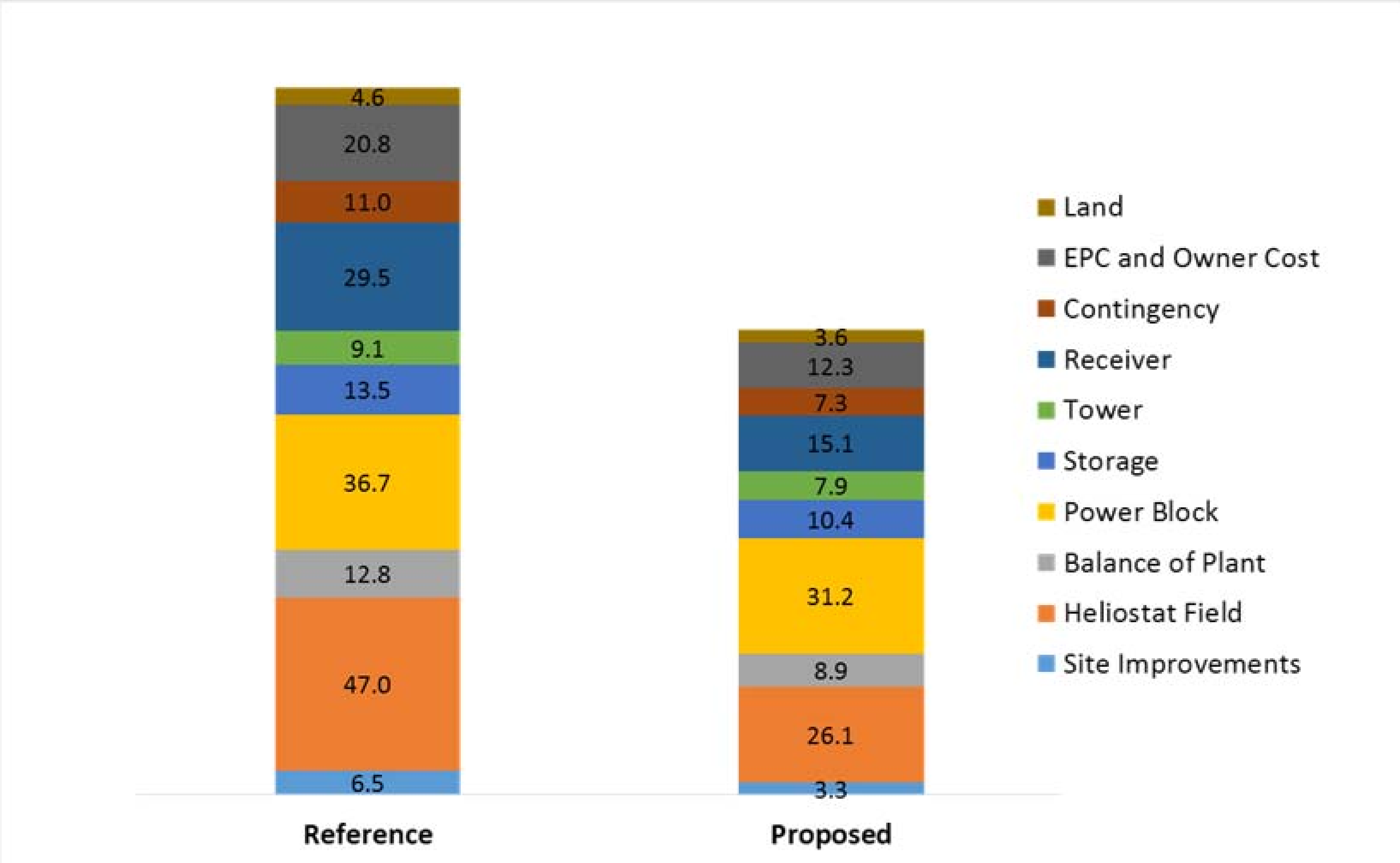
LCOE = 21.9c/kWh



Proposed ASTRI System for 12c/kWh

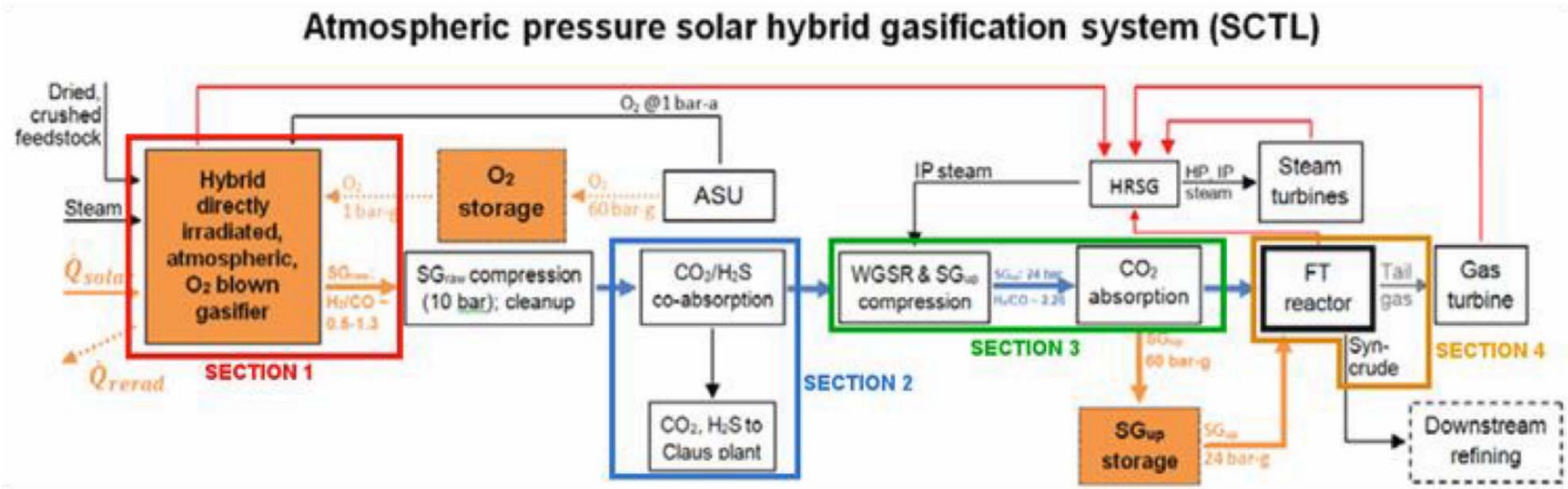


Potential Capital Cost Reduction



ASTRI Targets for Solar Fuel costs

- $1.20/L for fossil fuel feedstock
  - with life-cycle emission of CO_2 at least 10% lower than conventional diesel
- $2.50/L for future renewable feedstock
  - with life-cycle emission of CO_2 at least 50% lower than conventional diesel



Key Message

- Concentrating solar thermal technology is a viable clean energy solution for Australia and the world

- There are three key technical benefits of solar thermal over other renewable and non-renewable energy sources:
  - Dispatchable renewable power generation from thermal storage
  - Uses established technology concepts that allows integration with
    - Biomass or biogas to deliver renewable hybrid power stations
    - Coal and/or gas as fuel backup or boost to conventional power
  - Create industrial heat for drive chemical processes

- Key Challenge is to Reduce Cost
  - This requires a coordinated systems approach

ASTRI Partners

Funding partner

ARENA

Australian Government

Australian Renewable Energy Agency

The Australian Solar Thermal Research Initiative (ASTRI) Program is supported by the Australian Government through the Australian Renewable Energy Agency (ARENA)

Australian partners

CSIRO

Australian National University

Flinders University

QUT

The University of Adelaide

University of South Australia

The University of Queensland Australia

US collaborators

Sandia National Laboratories

Arizona State University

NREL National Renewable Energy Laboratory

Thank you

Sarah Miller
ASTRI Chief Operating Officer
t +61 2 4960 6084
e sarah.miller@csiro.au

w www.astri.org.au