ABENGOA SOLAR

Innovate technology solutions for sustainability

Concentrating Solar Power: State of the Art

Solar Beyond Grid Parity: Spectrum-Efficient Solar Energy for Dispatchable Electricity or Fuels Workshop

April 11, 2013

Concentrated Solar Power

Why is CSP special?

CSP is a dispatchable renewable energy without supply risks

	Solar Thermal	PV	Wind	Biomass
Dispatchability	High: - Thermal inertia - Storage - Hybridization (+)	None (-)	None (-)	High (+)
Forecasting	Average/high predictability (=)	Average/low predictability (-)	Low predictability (-)	High predictability (+)
Security of supply	High (30y price) (+)	High (+)	High (+)	Low (-)

Dispatchability

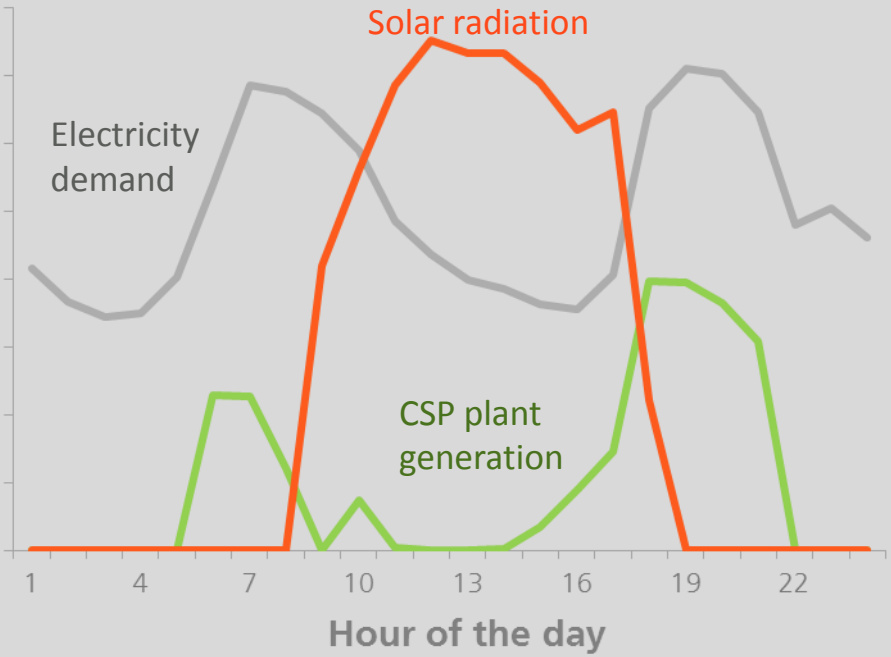
As renewables share in the energy mix becomes higher, CSP's dispatchability becomes more necessary and valued

CSP technology

Thermal energy storage

Hybridization with fossil fuels

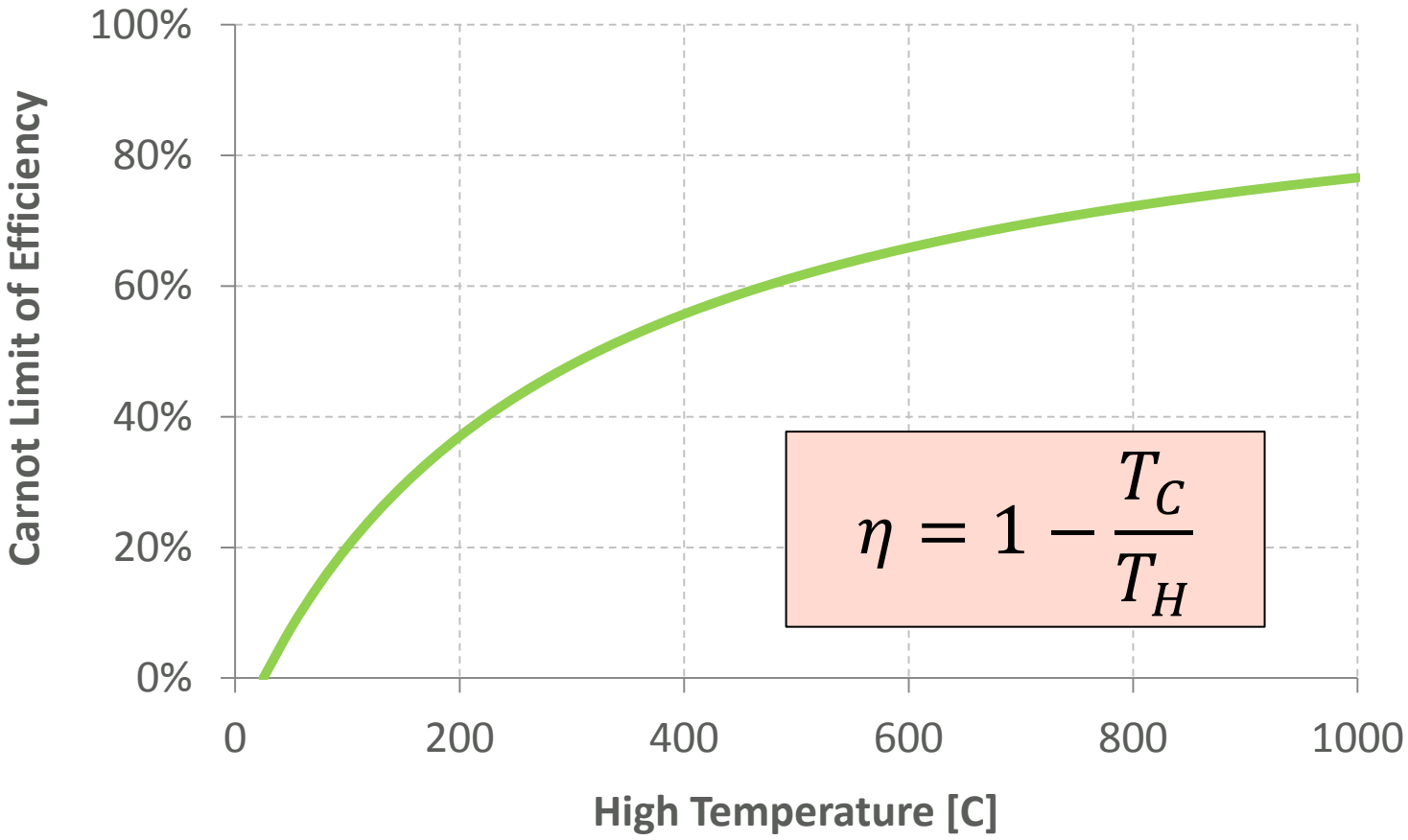
Solar plant in Arizona with storage vs utility system load - Winter Period



NREL* estimates the value of dispatchability in up to 4 cents/kWh relative to non-dispatchable energy sources

(*) NREL, 2012, "Tradeoffs and Synergies between CSP and PV at High Grid Penetration"

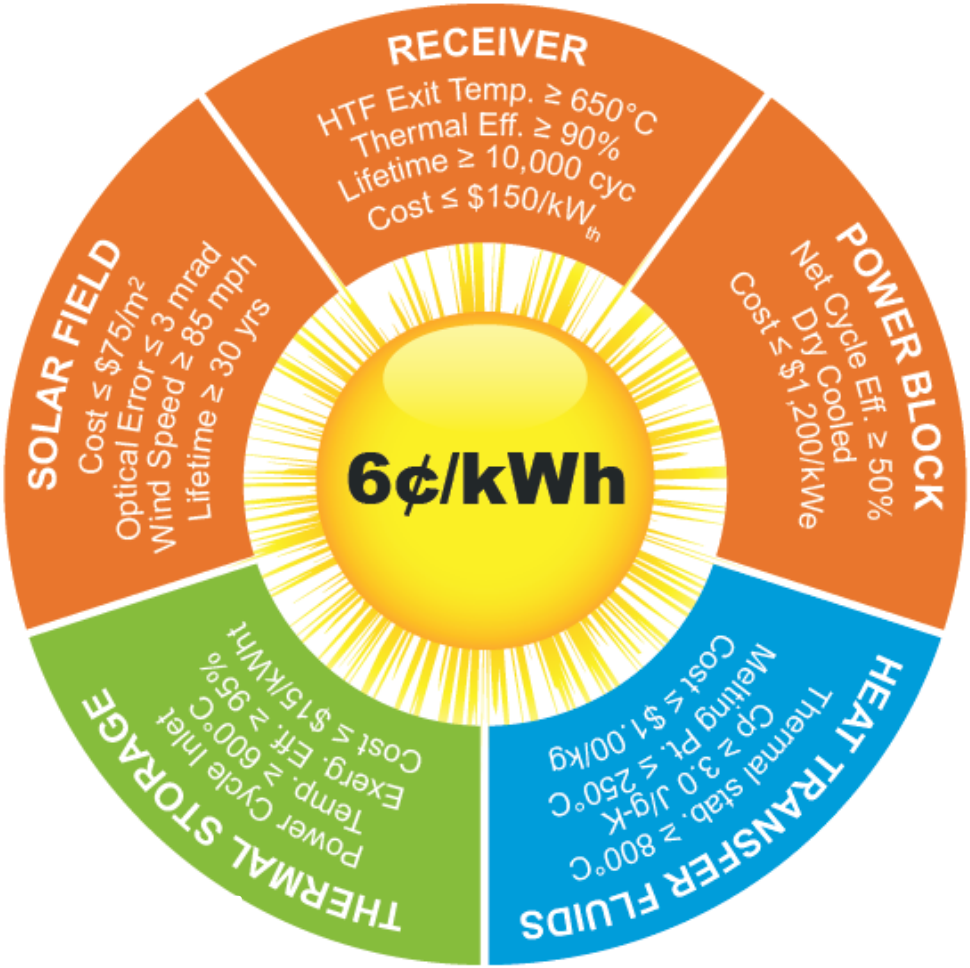
Fundamentals: Carnot



General CSP Objective: Collect light at high temperature, transfer it efficiently to a power cycle, and use it to make electricity

*Note: graph assumes low temperature of 25°C

SunShot CSP Targets



General CSP Objective: Collect light at high temperature, transfer it efficiently to a power cycle, and use it to make electricity

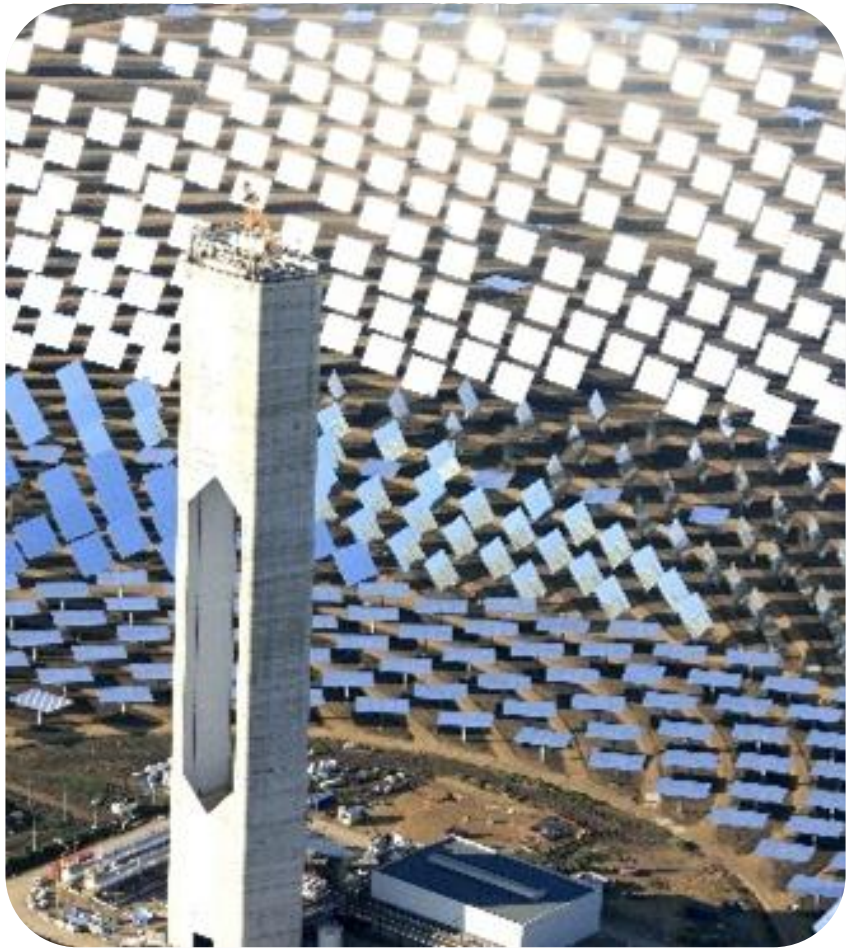
Source: http://www1.eere.energy.gov/solar/pdfs/sunshot_csp_poster.pdf

Concentrated Solar Power

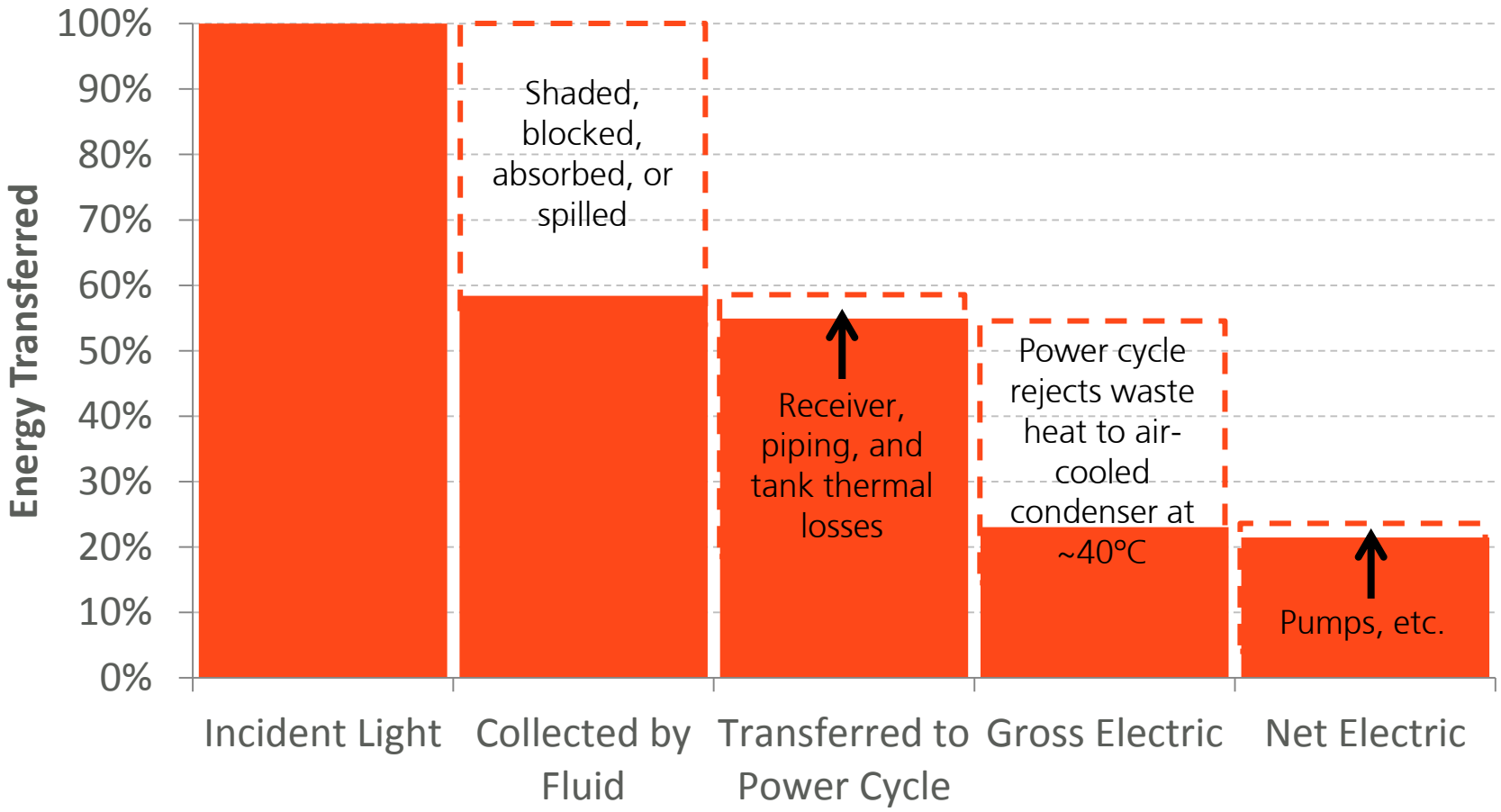
- Towers
  - 
  - Molten Salt
    - 
  - Direct Steam
    - 
- Troughs
  - 
- Dishes
  - 

Power Towers

- Field of mirrors called heliostats focus light on top of a tower (typically 500-1000x concentration)
- Light is absorbed by metal tubes then carried away by heat transfer fluid (typically water/steam or nitrate salt)
- Hot fluid is used to run a steam Rankine cycle or stored for later use



Representative Tower



Data based on 565°C molten nitrate salt tower with steam Rankine power cycle, design performance
Data source: Sandia National Laboratories, "An Evaluation of Molten-Salt Power Towers Including Results of the Solar Two Project." Table 4.2 Comparison of Peak Efficiencies http://prod.sandia.gov/techlib/access-control.cgi/2001/013674.pdf

Tower Specifications

	Nitrate Salt	Steam
Receiver	565°C [1]	~550°C [2]
Peak Flux on Receiver	1000 kW/m^2 [1]	>300 kW/m^2 [3]
Hot Storage	565°C [1] Ambient P	Depends on technology
Cold Storage	290°C [2] Ambient P	Depends on technology
Condenser	~40°C heat rejection	~40°C heat rejection

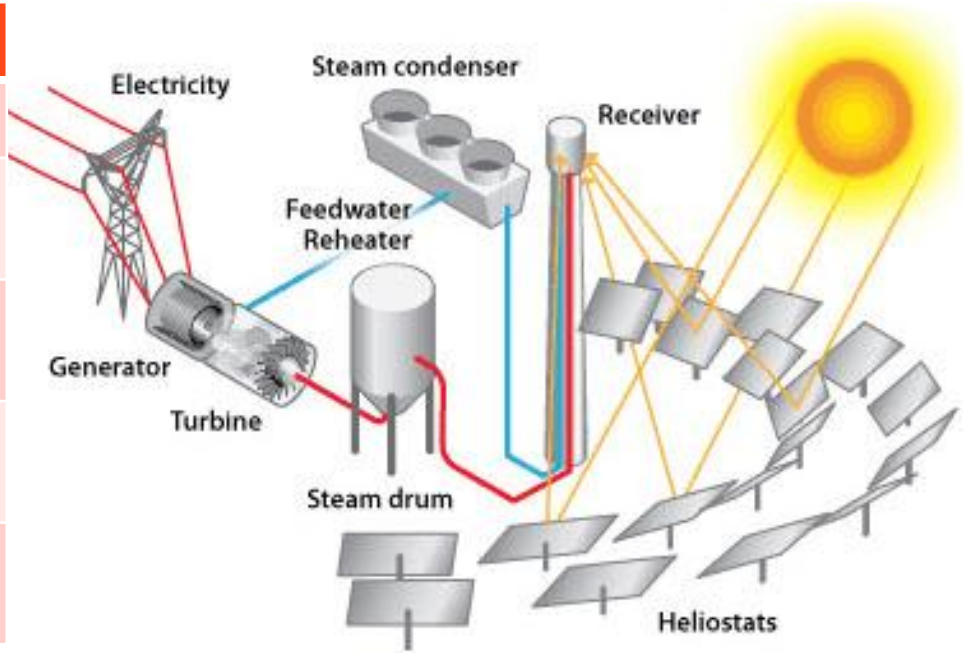


Image credit: http://www.eere.energy.gov/basics/renewable_energy/power_tower.html

[1] Sandia National Laboratories, "An Evaluation of Molten-Salt Power Towers Including Results of the Solar Two Project." Table 4.2 Comparison of Peak Efficiencies http://prod.sandia.gov/techlib/access-control.cgi/2001/013674.pdf

[2] DOE "Sunshot Vision Study" Chapter 5. http://www1.eere.energy.gov/solar/sunshot/vision_study.html

[3] Radosevich, L. "Final Report on the Power Production Phase of the 10 MWe Solar Thermal Central Receiver Pilot Plant." Sandia Report SAND-87-8022.

New Developments-Towers

- Supercritical steam [1] , supercritical carbon dioxide power cycles [2], or air Brayton cycles
  - Increase thermal-electric conversion efficiency
- Higher temperature heat transfer fluids
  - Higher temperature salt and steam towers
- Materials and manufacturing improvements to reduce costs

[1] Sandia National Laboratories "Incorporating Supercritical Steam Turbines into Advanced Molten-Salt Power Tower Plants: Feasibility and Performance." SAND2013-1960.
[2] NREL "10-Megawatt Supercritical Carbon Dioxide Turbine." SunShot-funded demonstration project.

Concentrated Solar Power

- Towers

- Molten Salt

- Troughs

- Direct Steam

- Dishes

- Oil

Parabolic Troughs

- Parabolic trough shaped mirrors focus light on a tube running down the focus line (typically ~80x concentration)
- Light is absorbed tube in a glass vacuum tube then carried away by heat transfer fluid (typically mineral oil)
- Hot fluid is used to run a steam Rankine cycle or stored for later use

Tower Specifications

	Oil	Nitrate Salt	Steam
Receiver Temperature	390°C [1]	500°C [2]	500°C [3]
Peak Flux on Receiver	~25 W/m^2 [4]	~25 W/m^2 [4]	~25 W/m^2 [4]
Hot Storage Tank	390°C [1]	500°C [2]	N/A
Cold Storage Tank	290°C [1]	300°C [2]	N/A
Condenser	~40C heat rejection	~40C heat rejection	~40C heat rejection

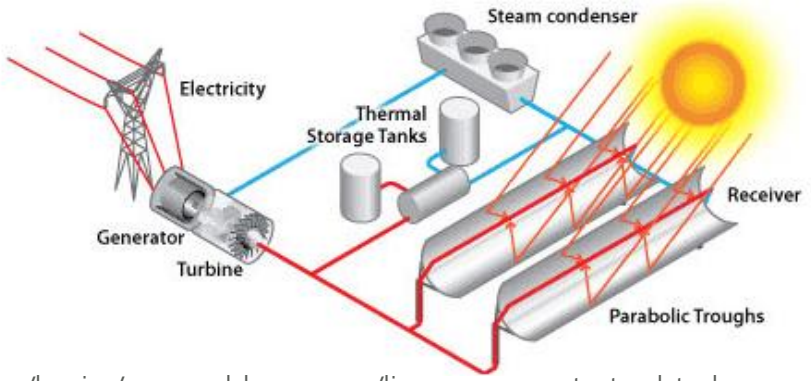


Image credit: http://www.eere.energy.gov/basics/renewable_energy/linear_concentrator.html

[1] DOE "Sunshot Vision Study" Chapter 5. http://www1.eere.energy.gov/solar/sunshot/vision_study.html
[2] NREL "Engineering Evaluation of a Molten Salt HTF in a Parabolic Trough Solar Field", http://www.nrel.gov/csp/troughnet/pdfs/ulf_herrmann_salt.pdf
[3] Feldhoff, et al. "Comparative System Analysis of Direct Steam Generation and Synthetic Oil Parabolic Trough Power Plants with Integrated Thermal Energy Storage" Solar Energy 86, 2012.
[4] Bendt, et al. "Optical Analysis and Optimization of Line Focus Solar Collectors," SERI 1979.

New Developments-Troughs

- New heat transfer fluids: molten nitrate salts and steam
- Supercritical carbon dioxide power cycles [2]
  - Increase thermal-electric conversion efficiency
- Materials and manufacturing improvements to reduce costs

[1] Sandia National Laboratories "Incorporating Supercritical Steam Turbines into Advanced Molten-Salt Power Tower Plants: Feasibility and Performance." SAND2013-1960.
[2] NREL "10-Megawatt Supercritical Carbon Dioxide Turbine." SunShot-funded demonstration project.
[3] Abengoa Solar "Conversion Tower for Dispatchable Solar Power." ARPA-e funded research project.

Concentrated Solar Power

Towers

Troughs

Dishes

Dish Stirling

- Parabolic dish shaped mirrors focus light to ~1000x concentration on a receiver heating a working fluid to drive a Stirling engine [1]
- Key advantage is high efficiency
  - Compact nature drives high optical efficiency [1]
- Cost and challenge of integrating storage have limited commercial deployment to date

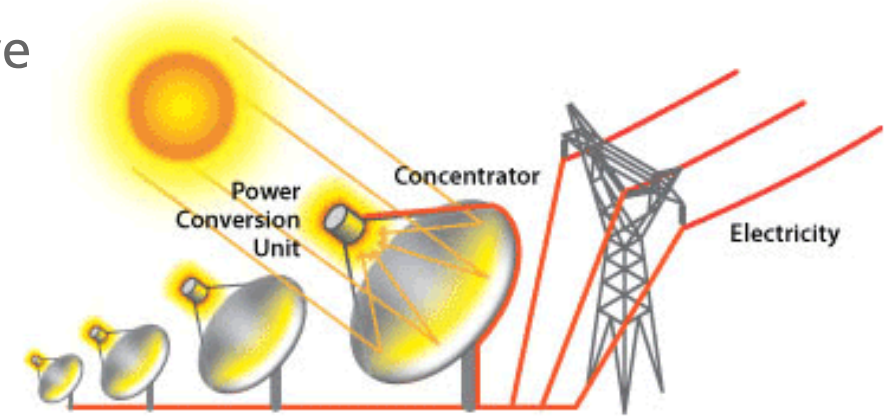


Image credit: http://http://www.eere.energy.gov/basics/renewable_energy/dish_engine.html

[1] Fraser, P. "Stirling Dish System Performance Prediction Model." 2008. MS Thesis, University of Wisconsin.

Questions?
Thank You