ENGR-3000:
Renewable Energy, Technology, and Resource Economics

Solar Concentrators

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World Learning SIT Study Abroad

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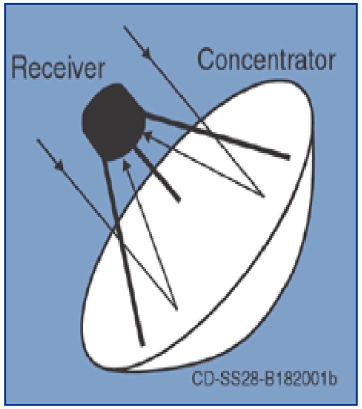
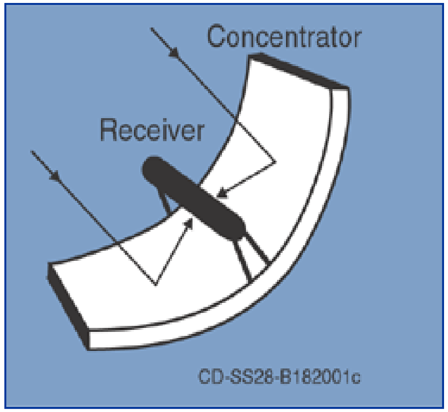
Solar Concentrators: Outline

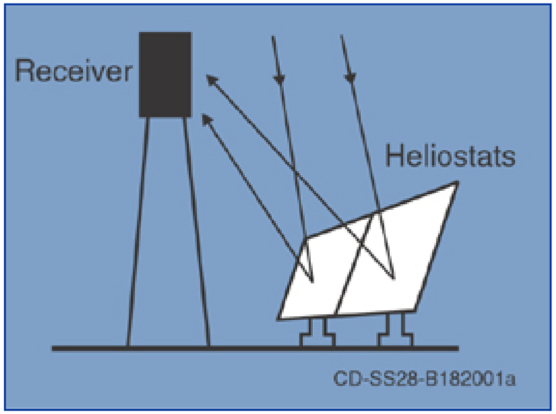
- Concentrating Solar Collectors
  - Solar Dish / Stirling
  - Parallel Trough
  - Central Tower: Heleostat
- CSP Systems and Installations
  - Thermal Storage

Concentrating Solar Power (CSP)

- Basic idea: Convert sunlight into thermal energy, use that energy to run a power cycle to get electricity
- Require direct sunlight to be effective
- Concentration is needed to get a hot enough temperature
- Three successfully demonstrated technologies:
  - Solar Dish / Sterling
  - Parabolic Trough
  - Solar Central Receiver







www.eere.energy.gov/de/csp.html

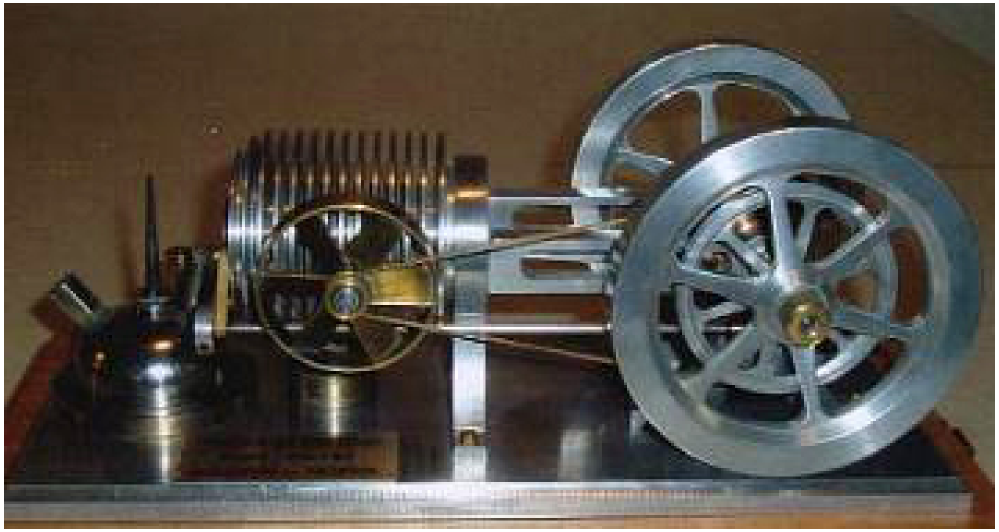
Solar Dish / Stirling

- Multiple mirrors that approximate a parabolic dish
- Receiver – absorbs solar energy & converts to heat
- Heat is delivered to Stirling engine

Source:http://commons.wikimedia.org

Stirling Engines

- An external combustion engine
- Energy is supplied to working fluid from a source outside the engine
- Used extensively until early 1900s
- Now – can convert concentrated sunlight into electricity



Stirling Engines

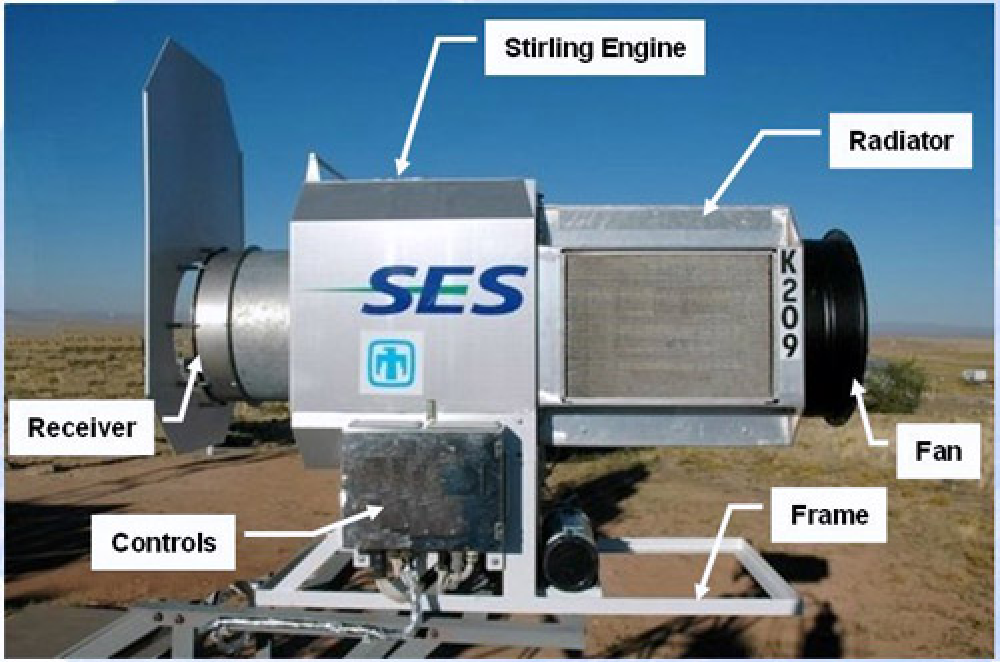
- Two pistons in same cylinder- left side hot, right side cold
- Regenerator – short term energy storage device between the pistons
- Working fluid permanently contained in the cylinder

5kW Stirling Engine:

http://sri.auburn.edu/alternativeenergy.htm

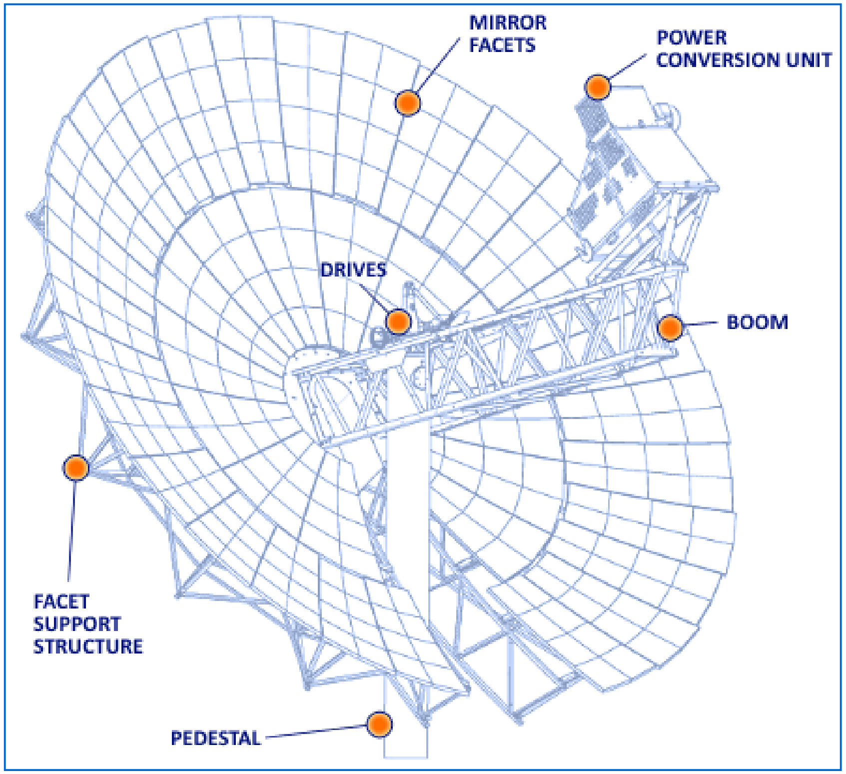
Stirling Engines

- Efficiency ~ 30%
- Less than 1 kW to ~25 kW
- Inherently quiet
- Cogeneration possible with cooling water for the cold sink



Solar Concentrator: Dish Systems

- Stirling Energy Systems (SES) Stirling Engine
- 25 kWe, 31.25% solar-to-grid conversion efficiency

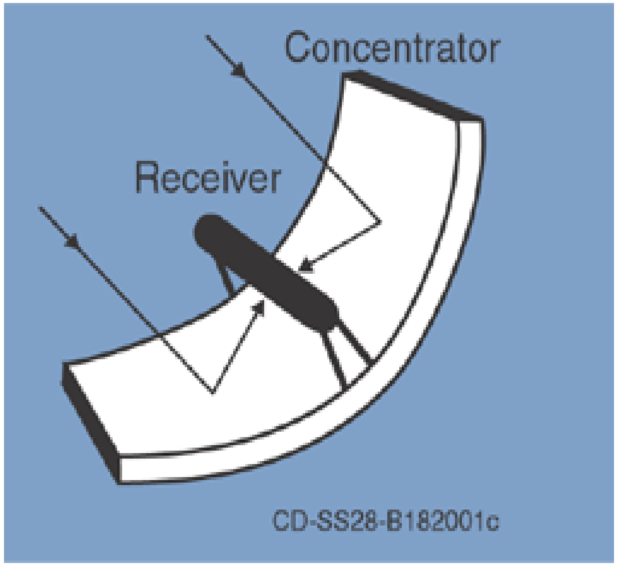


www.sandia.gov

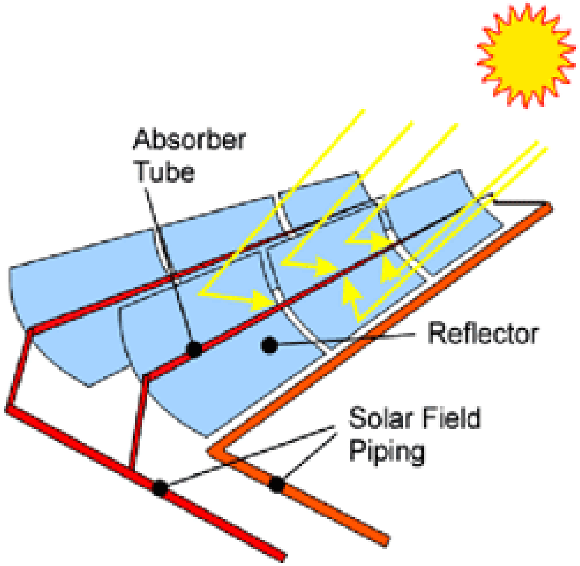
www.stirlingenergy.com

Parabolic Troughs

- Receivers are tubes – Heat collection elements (HCE)
- Heat transfer fluid circulates in the tubes
- Delivers collected energy to steam turbine/generator
- Parabolic mirrors rotate east to west to track the sun

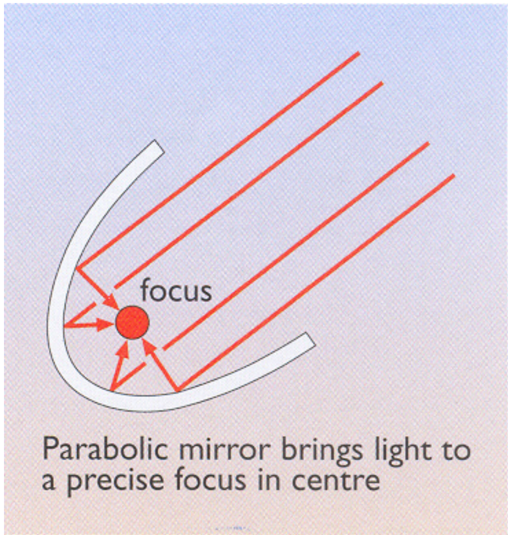


Source: http://www.eere.energy.gov/de/csp.html



Source: http://www.nrel.gov/csp/troughnet/solar_field.html

Solar Concentrators: Parabolic Trough



www.solitem.de/solitem.de/

Solar Energy Generating Systems - SEGS

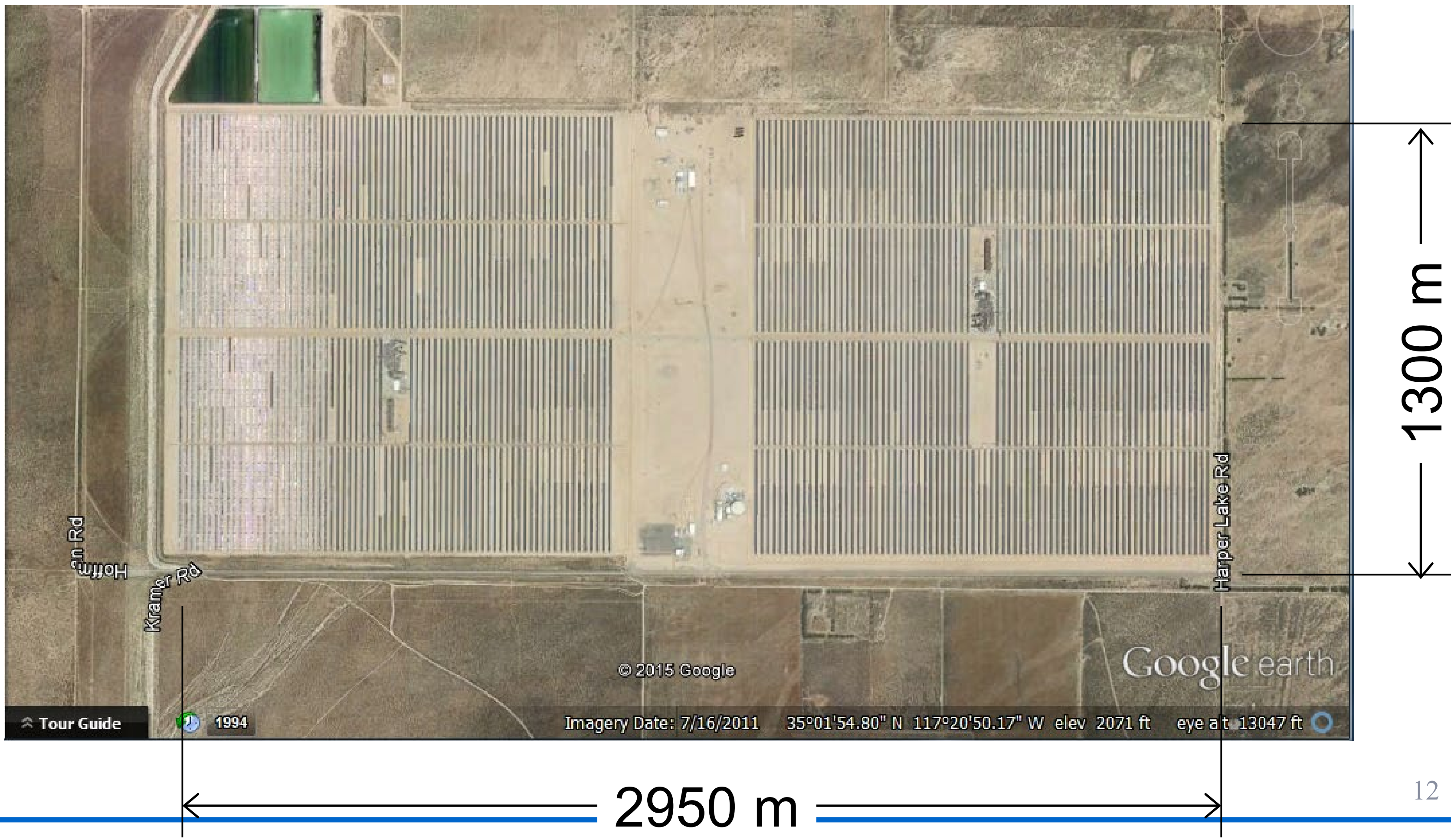
Source: http://www.flagsol.com/SEGS_tech.htm

- Mojave Desert, California
- 9 Plants: SEGS I - IX
- Total Net Capacity 354 MW
- 21% Capacity Factor

Source: http://www.flagsol.com/SEGS_tech.htm

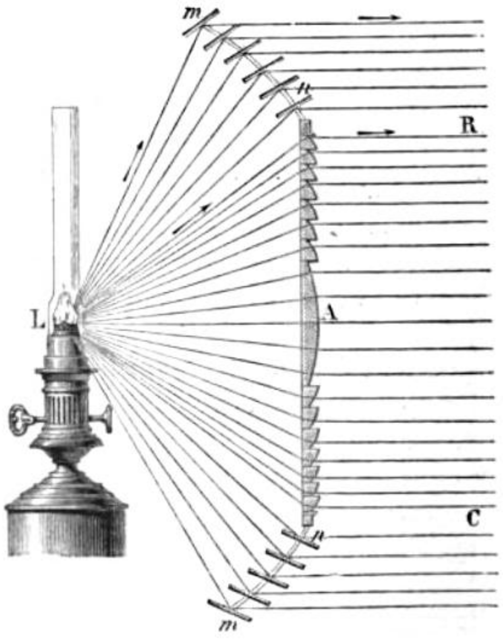
SEGS I and II Mojave: Google Earth

- Daggett, CA, 35 01’ 54.8”N ; 117 20’ 50.2” W
- 44 MW Capacity (14 MW + 30 MW)



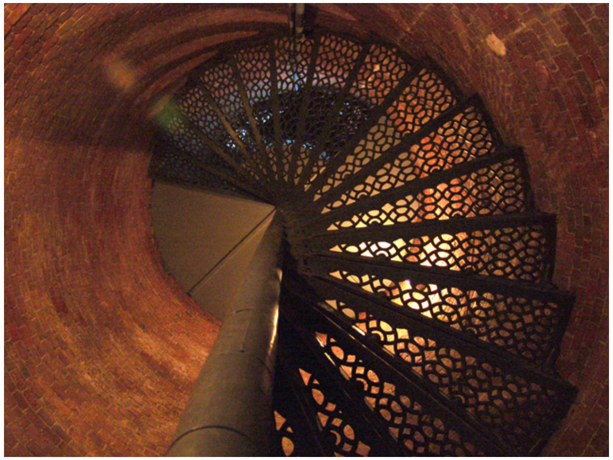
Solar Concentrator: Fresnel Systems

- Flat lenses or reflectors:
  - Lower cost than parabolic reflectors
  - Reduced wind loads (support cost)



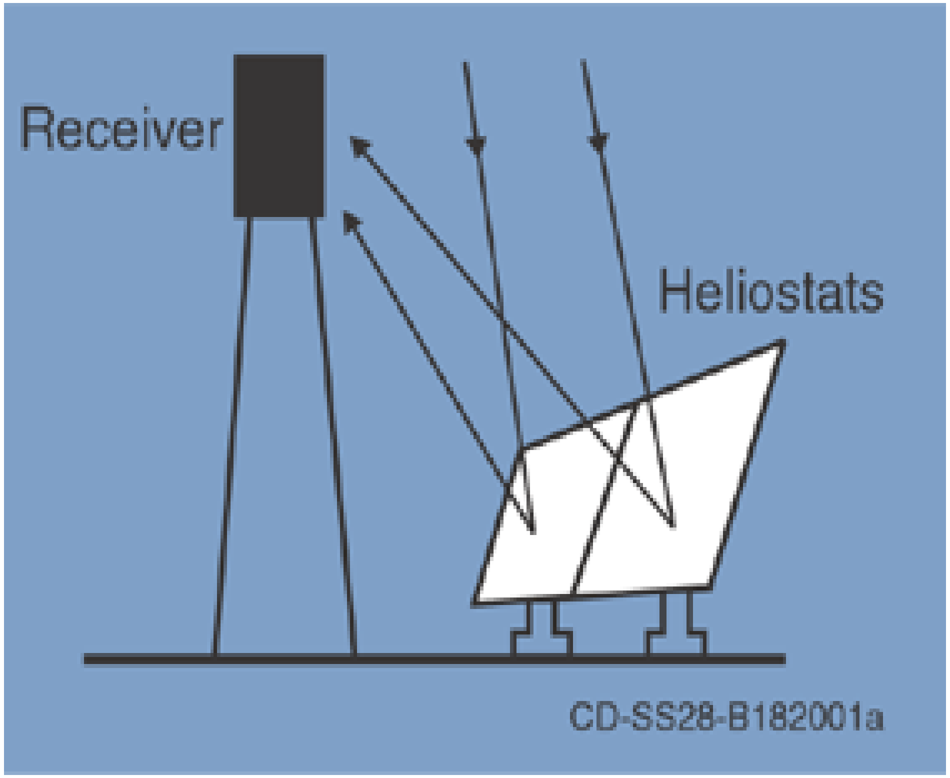
http://openfarmtech.org

Fresnel Lenses: Traditional Uses



Solar Central Receiver

- Also called Power Towers
- Heliostats – computer controlled mirrors
- Reflect sunlight onto receiver



Source: http://www.eere.energy.gov/de/csp.html

Solar Central Receiver – Solar Two

- 10 MW
- Two-tank, molten-salt thermal storage system
- Barstow, CA

Source: http://www.trec-uk.org.uk/csp.htm

Solar Concentrator: Tower Systems

- Seville, Spain, 20MWe

CSP Comparisons

- All use mirrored surfaces to concentrate sunlight onto a receiver to run a heat engine
- Higher temperature -> higher efficiency
- Actual Land Use depends on location and amount of storage

	Trough	Power Tower	Dish / Engine
Typical Operating Temp	390C	565C	800C
Utility scale (>50 MW)	x	x	x
Distributed (<10MW)			x
Energy Storage	x	x	
Water use for cleaning	x	x	x
Water use for cooling	preferred	preferred	
Land Use (acre/MW)*	5-9	3-9	8-9
Land Slope	<3%	<5%	<5%
Technical maturity	medium	low	low

www.nrel.gov/csp/

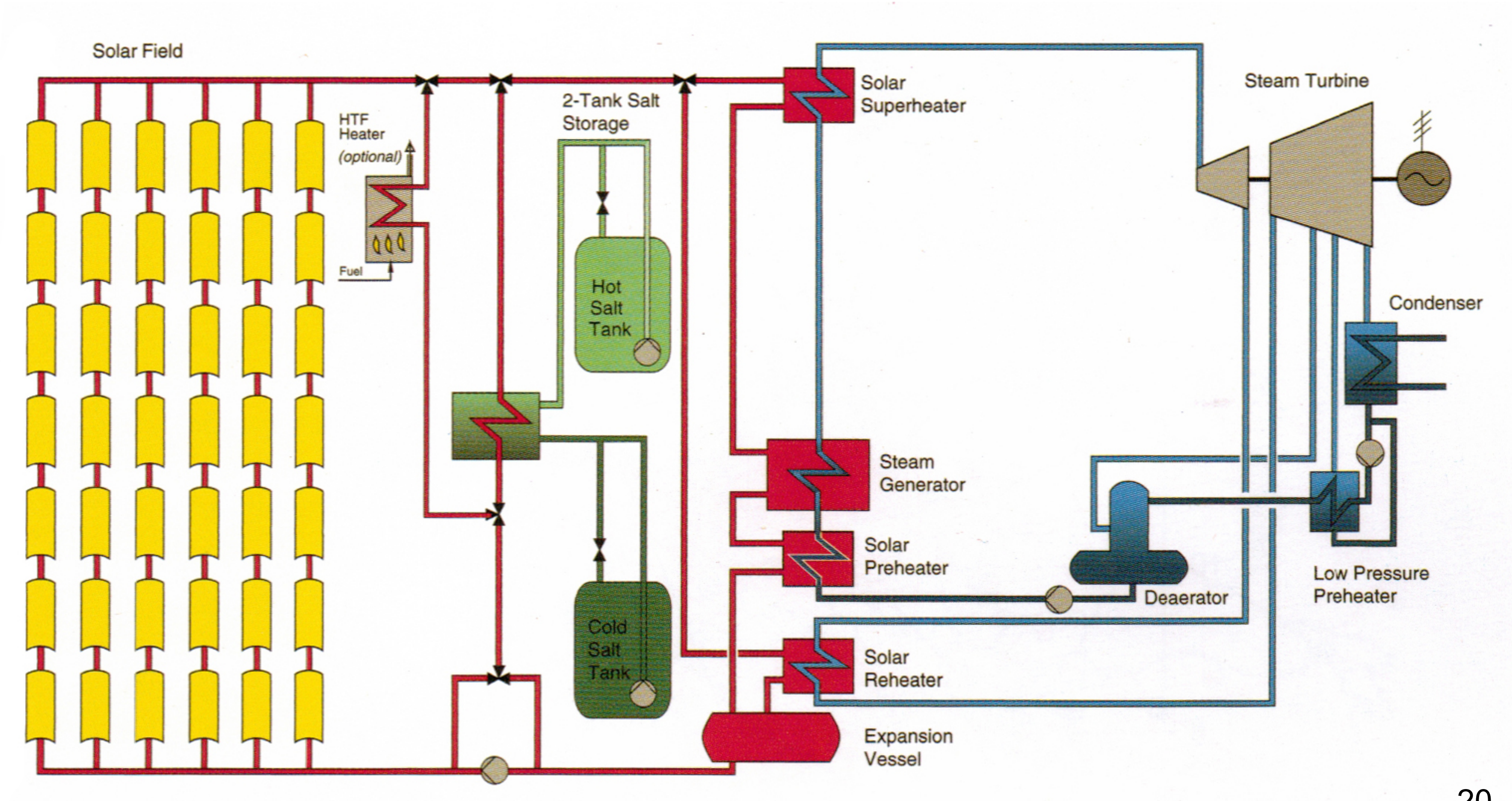
Power Generation: Levelized Costs $/MWh

Estimated Costs for New Generation Resources, 2022: Plant Type (Capacity Factor)	Capital Cost	Fixed O&M	Variable O&M (Incl. Fuel)	Transmission Investment	Total System Levelized Cost
Dispatchable Technologies					
Coal (85%)*	60.4	4.2	29.4	1.2	95.2
Combined Cycle (87%)	12.6	1.5	34.9	1.1	50.1
Advanced Nuclear (90%)	69.4	12.9	9.3	1.0	92.6
Geothermal (90%)	30.1	13.2	0.0	1.3	44.6
Biomass (83%)	39.2	15.2	39.6	1.1	95.3
Hydro (64%)	48.2	9.8	1.8	1.9	61.7
Non-Dispatchable					
Wind (41%)	43.1	13.4	0.0	2.5	59.1
Offshore Wind (45%)	115.8	19.9	0.0	2.3	138.0
Solar PV (29%)	51.2	8.7	0.0	3.3	63.2
Solar Thermal, CSP (25%)	128.4	32.6	0.0	4.1	165.1

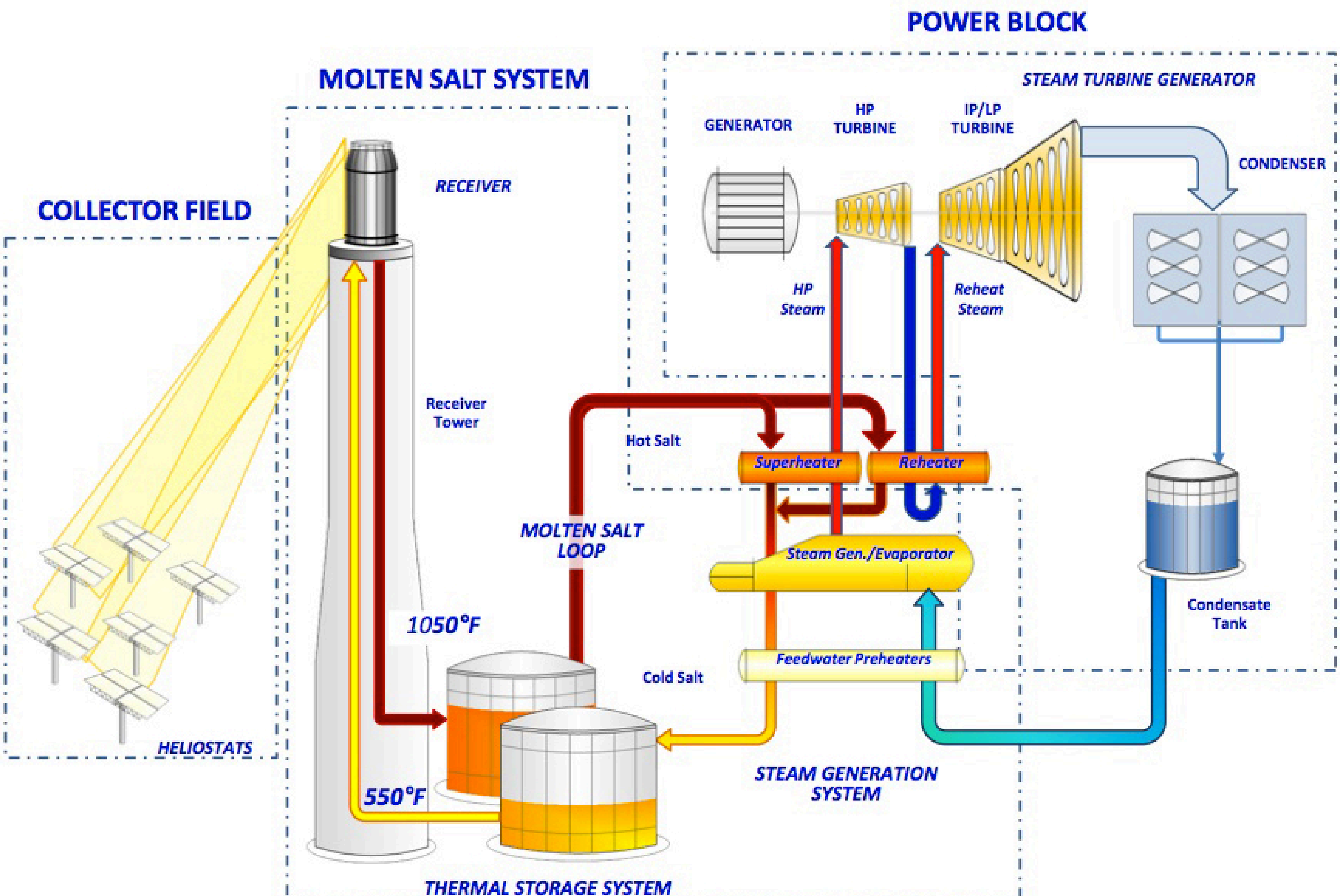
U.S. Energy Information Administration, Annual Energy Outlook 2015* & 2018.
www.eia.gov/forecasts/aeo/electricity_generation.cfm

Parabolic Trough System with Storage

- ANDASOL I (Spain) 50 MW_{el}, 7 hrs storage (molten salt)



CSP System with Molten Salt Energy Storage



www.renewablepowernews.com

Ivanpah Solar Energy Project

- 377 MW, three plants
- Max. Steam Temp. = 550°C
- Aperture Area = 2.6×10^6 m^2
- Completed Dec 2013

- Utilizes "dry cooling for steam condensation to minimize water use.

35°33'24.4" N; 115°28'12.2" W

http://www.brightsourceenergy.com/ivanpah-solar-project

CSIRO Heliostat, Australia

- June 2014, achieved supercritical steam conditions in receiver.
- 570°C at 23.5Mpa (critical pt. = 374°C at 22MPa)

http://www.csiro.au

Exercise: Andasol I Thermal Storage

- 2 Molten salt tanks, 28,500 tonnes each
- Molten salt:
  - 40% Sodium Nitrate, $NaNO_3$
  - 60% Potassium Nitrate KNO_3
  - Specific heat of salt mixture: $C_p = 1.47$ kJ/kg·K
- Tanks operate between 393°C and 293°C

➢ Calculate the energy stored in the tanks, in MWh

➢ How long can the plant operate at night at full capacity? Assume the 50 MW plant has an efficiency of 15%