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Introduction to Alternative and Renewable Energy

EST1830

3. Energy Production

3.1 Renewable Energy Technologies

3.1.1 Solar Energy

3. Energy Production

- 3.1.1 Solar Energy
  - 3.1.1a Sun's Position
  - 3.1.1b Sun Path
  - 3.1.1c Sun Path Charts
  - 3.1.1d Solar Panel Positioning
- 3.1.1.1 Photovoltaics
- 3.1.1.2 Solar Thermal
  - 3.1.1.2a Low Temperature Collectors
  - 3.1.1.2b Medium Temperature Collectors
  - 3.1.1.2c High Temperature Collectors

3.1.1.2 Solar Thermal

- Solar thermal collectors are divided into three categories:
  - Low-temperature collectors
    - Provide low-grade heat (< 110^{o}F), through either metallic or nonmetallic absorbers
    - Used in such applications as swimming pool heating and low-grade water and space heating.
  - Medium-temperature collectors
    - Provide medium-grade heat (> 110^{o}F, usually 140^{o}F ≤ T ≤180 ^{o}F),
    - Through glazed flat-plate collectors using air or liquid as the heat transfer instrument or concentrator collectors that concentrate the sun's heat.
    - Are mainly used for domestic hot water heating.
    - Evacuated-tube collectors are also included in this category.
  - High-temperature collectors
    - Parabolic dish and trough collectors designed to operate at T ≥180 ^{o}F
    - Primarily used by utilities and independent power producers to generate electricity for the grid.
    - Central Receivers (Power towers) are also included in this category.

Source: U.S. Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey."

3.1.1.2 Solar Thermal

- Solar thermal collector performance rating
  - An analytically-derived set of numbers representing the characteristic all-day energy output of the solar thermal collector.
  - Measured in Btu per square foot per day (Btu/ft^2 day).
- The 2008 average solar thermal performance rating for:
  - Low-temperature collectors
    - Metallic and nonmetallic: 1,196 Btu/ft^2 day
  - Medium-temperature
    - medium-temperature (air): 864 Btu/ft^2 day
    - medium-temperature (ICS/thermosiphon): 894 Btu/ft^2 day
    - medium-temperature (flat-plate): 988 Btu/ft^2 day
    - medium-temperature (evacuated-tube): 958 Btu/ft^2 day
    - medium-temperature (concentrator): 1,173 Btu/ft^2 day
  - High-temperature
    - Parabolic dish/trough: 828 Btu/ft^2 day

Source: U.S. Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey."

3.1.1.2 Solar Thermal

Average Thermal Performance Rating of Solar Thermal Collectors by Type Shipped in 2008

(Btu per square foot per day)

Year	Type							
	Low-Temperature	Medium-Temperature					High-Temperature	Central Receivers (Power Tower)
	Liquid/Air	Air	Liquid				Parabolic Dish/Trough	
	Metallic and Nonmetallic		ICS/Thermosiphon	Flat-Plate (Pumped)	Evacuated Tube	Concentrator		
2008	1,196	864	894	988	958	1,173	828	

- = No data reported.
Source: U.S. Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Source: U.S. Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey."

3.1.1.2 Solar Thermal

Thermal conductivities of several substances. Notice the difference between Air/Water and Copper/Steel

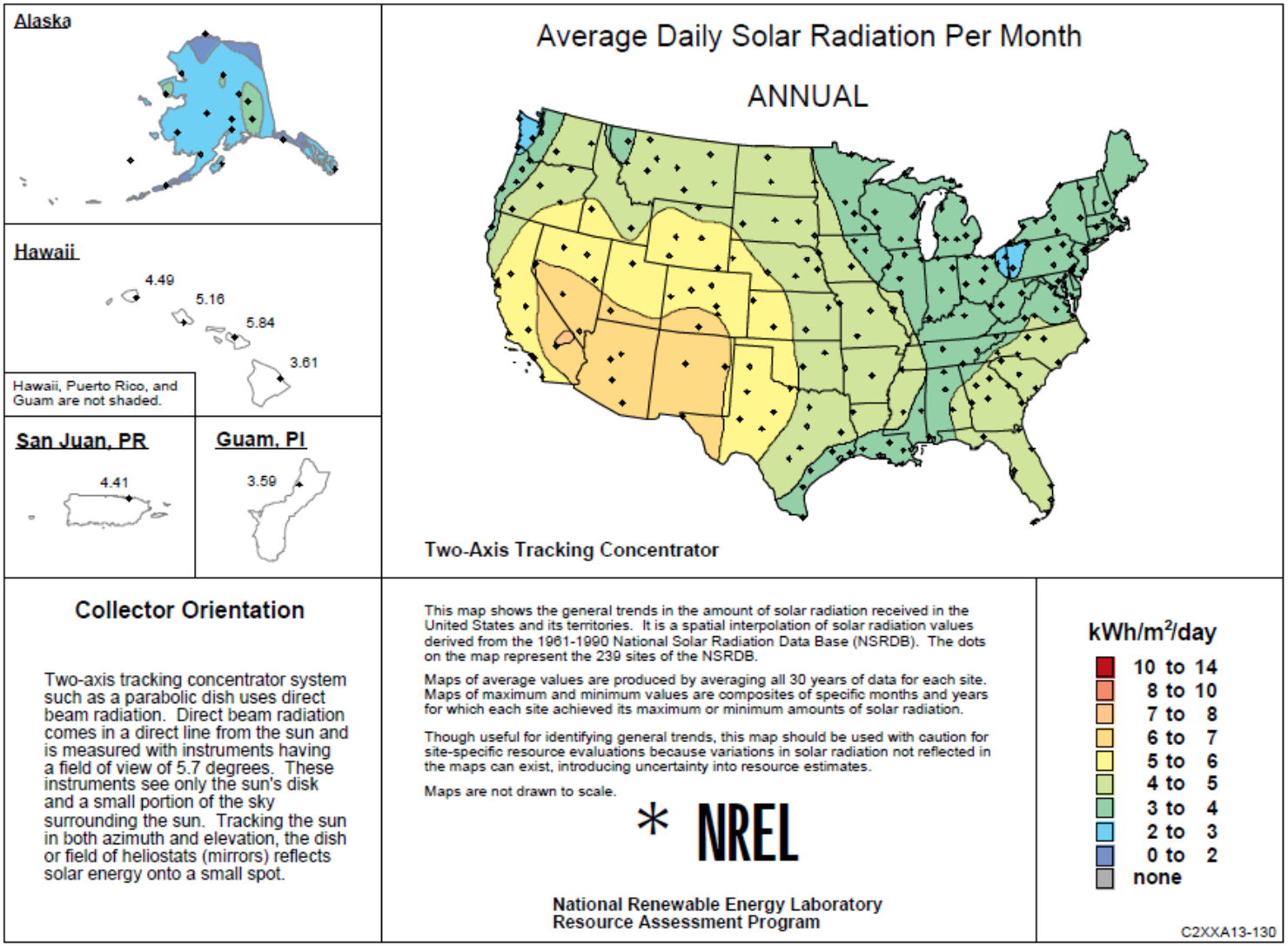
Thermal Conductivity - k - (W/mK)			
	Temperature (oC)		
Material/Substance	25	125	225
Air	0.024		
Aluminum	250	255	250
Asbestos-cement board	0.744		
Asbestos-cement	2.07		
Asbestos, loosely packed	0.15		
Asphalt	0.75		
Brass	109		
Brick dense	1.31		
Carbon	1.7		
Cement, mortar	1.73		
Chalk	0.09		
Chrome Nickel Steel (18% Cr, 8 % Ni)	16.3		
Clay, dry to moist	0.15 - 1.8		
Clay, saturated	0.6 - 2.5		
Concrete, light	0.42		
Concrete, stone	1.7		
Copper	401	400	398
Corian (ceramic filled)	1.06		

Thermal Conductivity - k - (W/mK)			
	Temperature (oC)		
Material/Substance	25	125	225
PVC	0.19		
Steel, Carbon 1%	43		
Stainless Steel	16	17	19
Styrofoam	0.033		
Water	0.58		

http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

1 W/(m K) = 1 W/(m°C) = 0.85984 kcal/(h m °C) = 0.5779 Btu/(ft h °F)

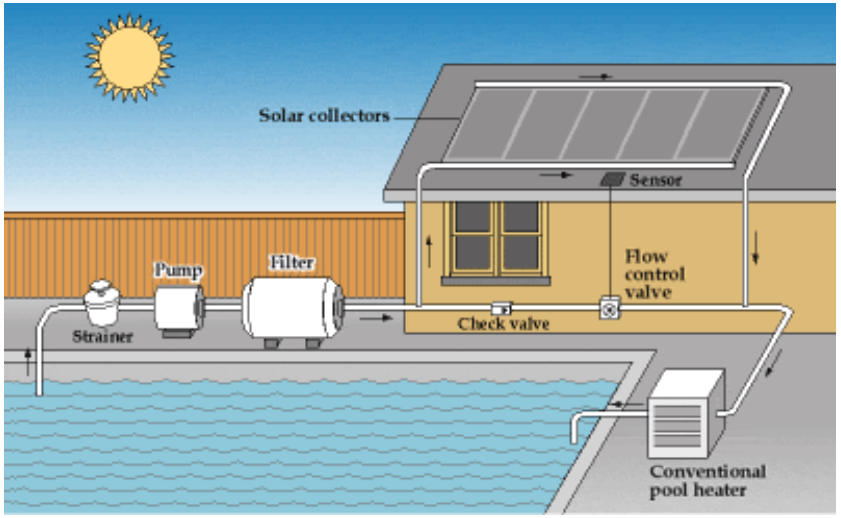
3.1.1.2 Solar Thermal



Source: http://www1.eere.energy.gov/maps_data/renewable_resources.html

3.1.1.2a Low Temperature Collectors

Swimming Pool Heating: Rise in T~0-18°F depends on solar collector area



http://www.ipc-solar.com/solar_pool_heating.html

Pool water temperatures typically range from 78ºF to 82ºF. Young children and the elderly may require a temperature of 80ºF or higher.

How They Work

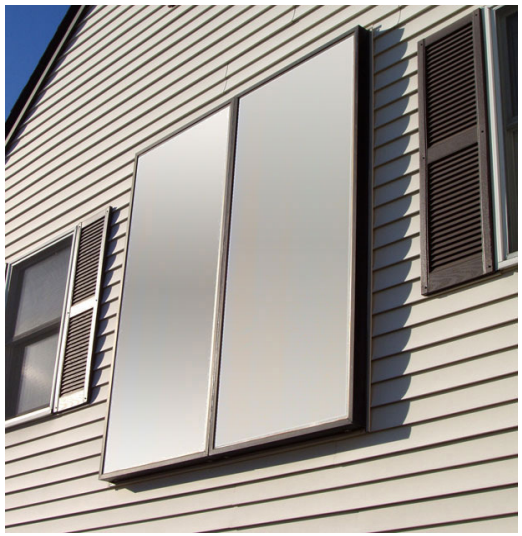
Most solar pool heating systems include the following:

- A solar collector — the device through which pool water is circulated to be heated by the sun
- A filter — removes debris before water is pumped through the collector
- A pump — circulates water through the filter and collector and back to the pool
- A flow control valve — automatic or manual device that diverts pool water through the solar collector.

http://solarcostarica.com/assets/images/FG-pool-solar.jpg

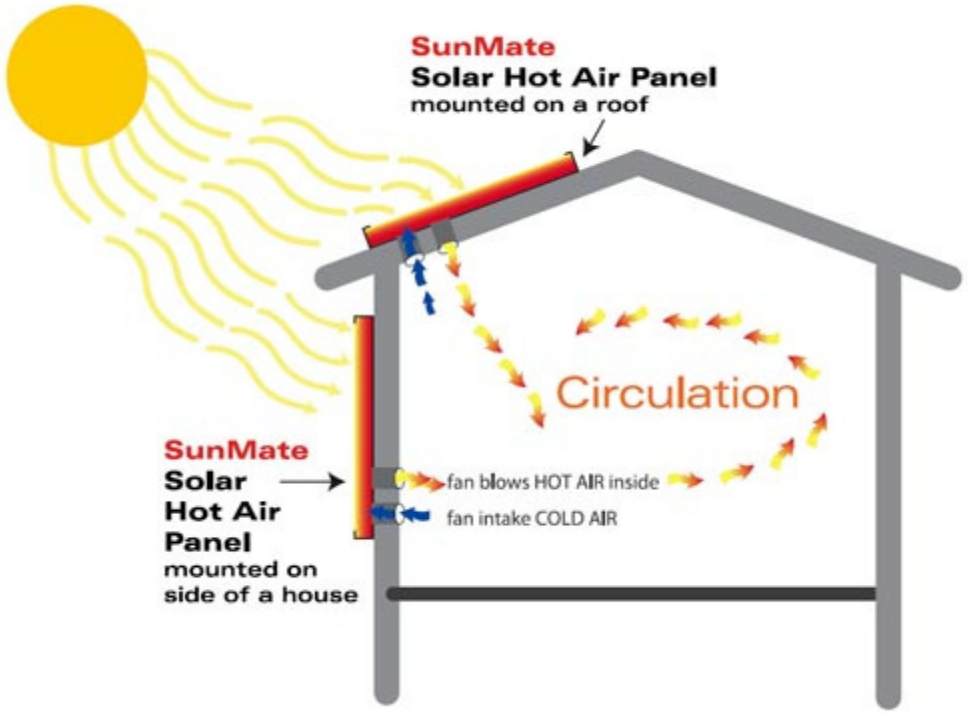
http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13230

3.1.1.2a Low Temperature Collectors



Space Heating

SunMate Solar Hot Air Panel



Pulls cool air from your home, channels it through the absorber plate where it's warmed by energy from the sun, then circulates it back into your home. A built-in thermostat, automatically turns on a blower when the absorber plate reaches 110° F and shuts off the blower at 90°F.

http://sunmatesolarpanels.com/component/option,com_frontpage/Itemid,1/

3.1.1.2b Medium Temperature Collectors

- There are two general categories of medium temperature collectors
  - Passive Collectors
  - Active Collectors
- Passive Collectors
  - ICS/Thermosyphon
  - Fluid flows through natural convection and/or gravity
- Active Collectors
  - Flat plate: Air or Liquid
  - Evacuated Tubes
  - Concentrators
  - Forced fluid usually flows through a system of heat exchangers.

3.1.1.2b Medium Temperature Collectors

ICS/Thermosyphon Collectors

Passive solar water heating systems are typically less expensive than active systems, but they're usually not as efficient. However, passive systems can be more reliable and may last longer.

There are two basic types of passive systems

- **Integral collector-storage passive systems (ICS) or Batch.**
- **Thermosyphon systems**

http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850

3.1.1.2b Medium Temperature Collectors

Integral collector-storage passive systems (ICS)

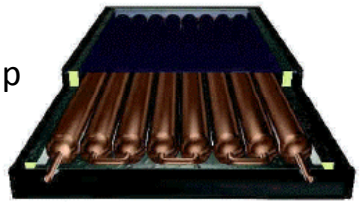
These are passive solar water heating systems

Integral collector-storage systems

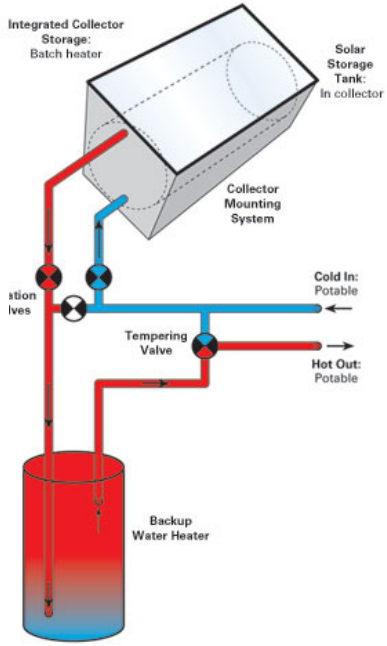
http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850

Also known as ICS or *batch* systems feature one or more black tanks or tubes in an insulated, glazed box.

- Cold water first passes through the solar collector, which preheats the water.
- The water then continues on to the conventional backup water heater, providing a reliable source of hot water.
- They should be installed only in mild-freeze climates because the outdoor pipes could freeze in severe, cold weather.



ICS unit by SunEarth



http://homepower.com/basics/hotwater/

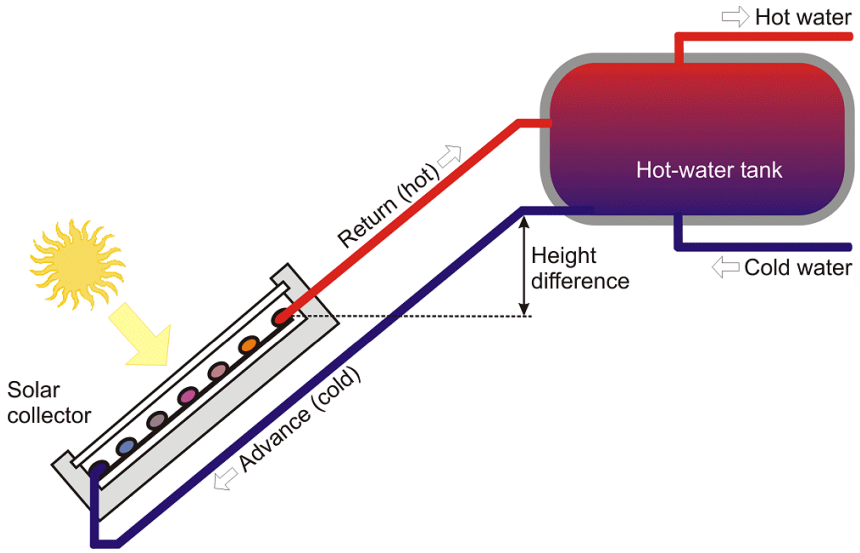
http://www.azsolarcenter.org/images/articles/passive/002.jpg

http://www.fsec.ucf.edu/en/research/solarthermal/front_porch/images/ics.jpg

3.1.1.2b Medium Temperature Collectors

Thermosyphon Collectors

Volker Quaschning - Understanding Renewable Energy Systems - Earthscan, London, 2005



Based on natural convection

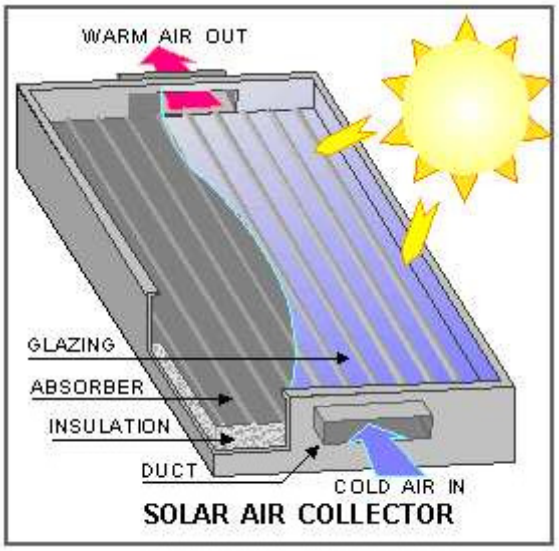
http://solarhotwater.siliconsolar.com/thermosyphon-solar-systems.php

Water flows through the system when warm water rises as cooler water sinks. The collector must be installed below the storage tank so that warm water will rise into the tank. These systems are reliable, but contractors must pay careful attention to the roof design because of the heavy storage tank. They are usually more expensive than integral collector-storage passive systems.

These are passive solar water heating systems

3.1.1.2b Medium Temperature Collectors

Air Flat-Plate Collectors



Air based solar collectors use air instead of liquids as the energy transfer medium

Air based systems begin producing heat earlier and lasts longer during the day than liquid bases systems of approximately the same size. Consequently, ventilation, heating and preheating is possible earlier. Besides heating individual spaces, heated air can also heat air passing into air recovery ventilators or air converters of heat pump systems.

Advantages

- Fast-reacting heat transfer
- Absence of energy transfer fluid, piping and associated control equipment
- No problem with boiling or freeze ups
- Little maintenance required
- Expect long service life
- Low system cost

Disadvantages

- **Air is less a efficient heat exchange medium than liquid**
- **Air Collectors are not as common because of low heat storage capacity**
- Temperatures may be difficult to regulate
- Balancing the amounts of thermal mass is essential for system stability

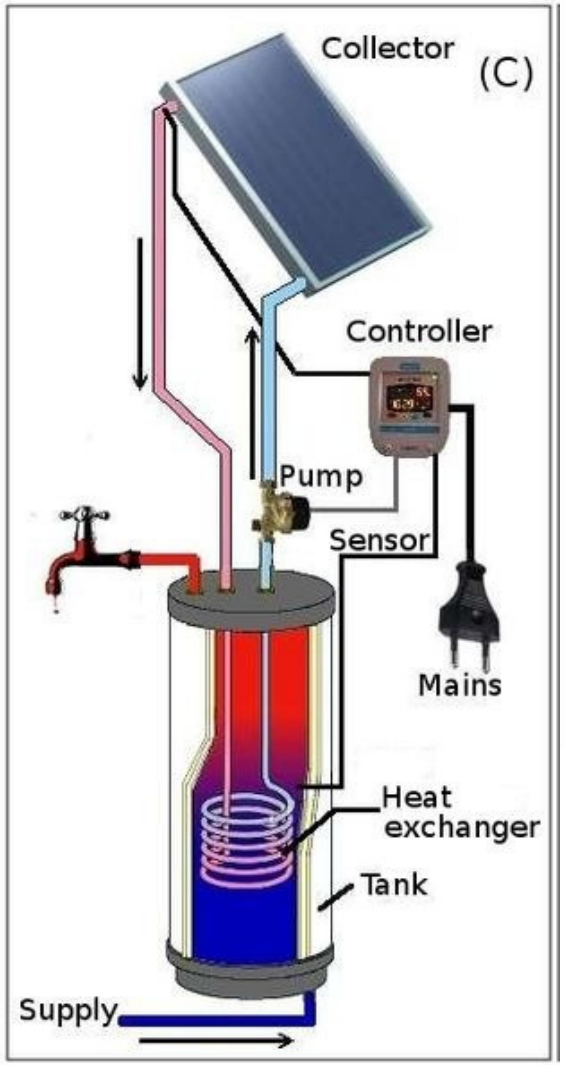
These are active solar heating systems

http://www.five-shades-of-green-energy.com/solar_collectors.html

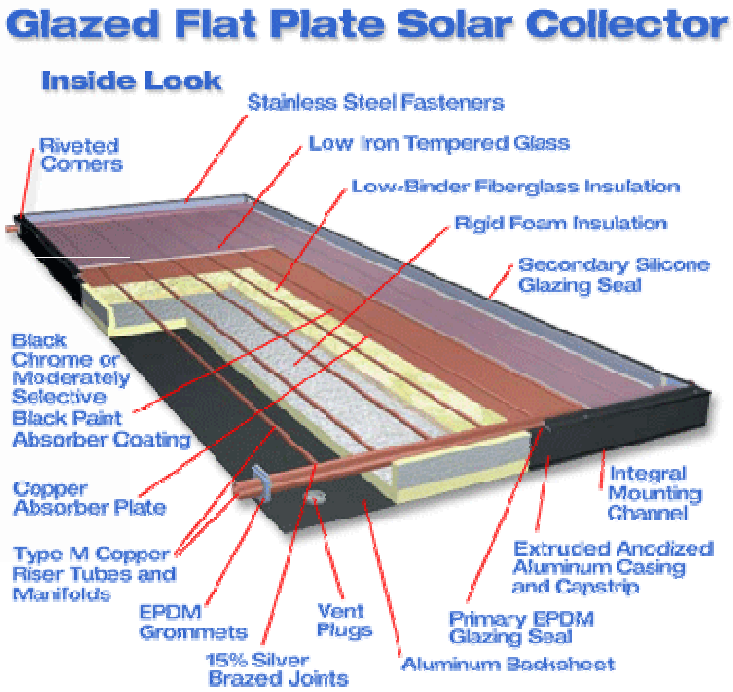
3.1.1.2b Medium Temperature Collectors

Indirect circulation system

Water Heaters: Flat-Plate



http://en.wikipedia.org/wiki/Solar_water_heating



http://shop.solardirect.com/product_info.php?products_id=191

These are active solar water heating systems

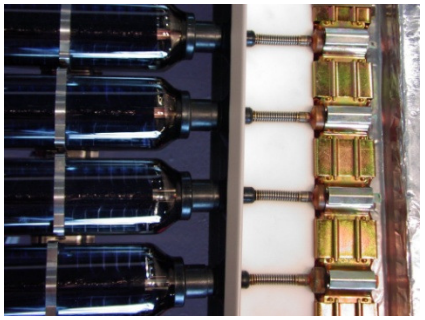
3.1.1.2b Medium Temperature Collectors

Evacuated-tube solar collectors feature parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin's coating absorbs solar energy but inhibits radiative heat loss. These collectors are used more frequently for U.S. commercial applications. By evacuating the air, heat loss through the glass tube is reduced. Capturing solar radiation during cloudy weather is not a problem, because infrared radiation passes through the clouds.

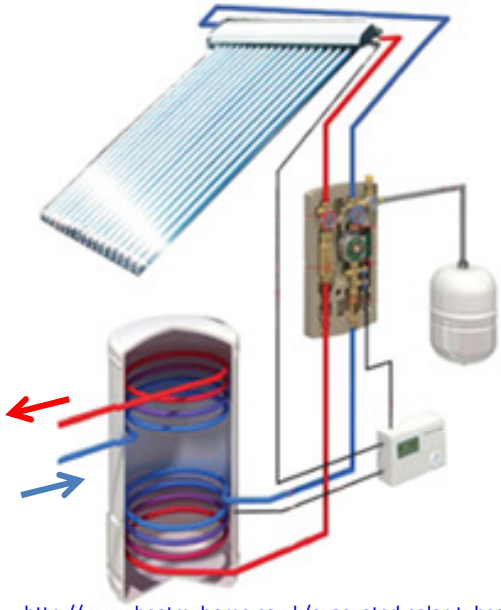
http://en.wikipedia.org/wiki/File:Collectors_flatplate_evactube.jpg

http://www.solar.net.cn/evacuated-tube-solar-collector.html

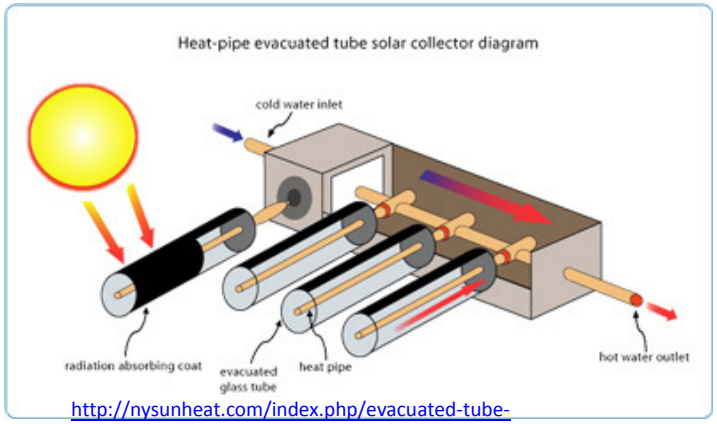
Can produce temperatures from 125°F to over 300°F



Evacuated Tube Collectors



http://www.heatmyhome.co.uk/evacuated-solar-tubes.htm

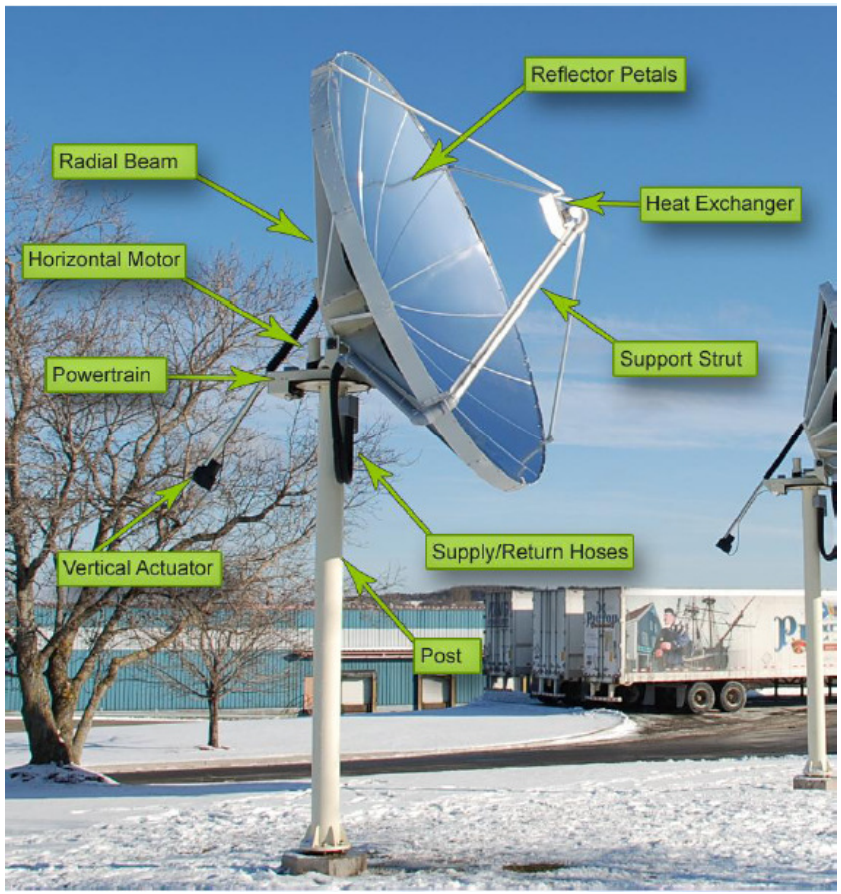


http://nysunheat.com/index.php/evacuated-tube-technology?tmpl=component&print=1&page=

Volker Quaschning - Understanding Renewable Energy Systems - Earthscan, London, 2005

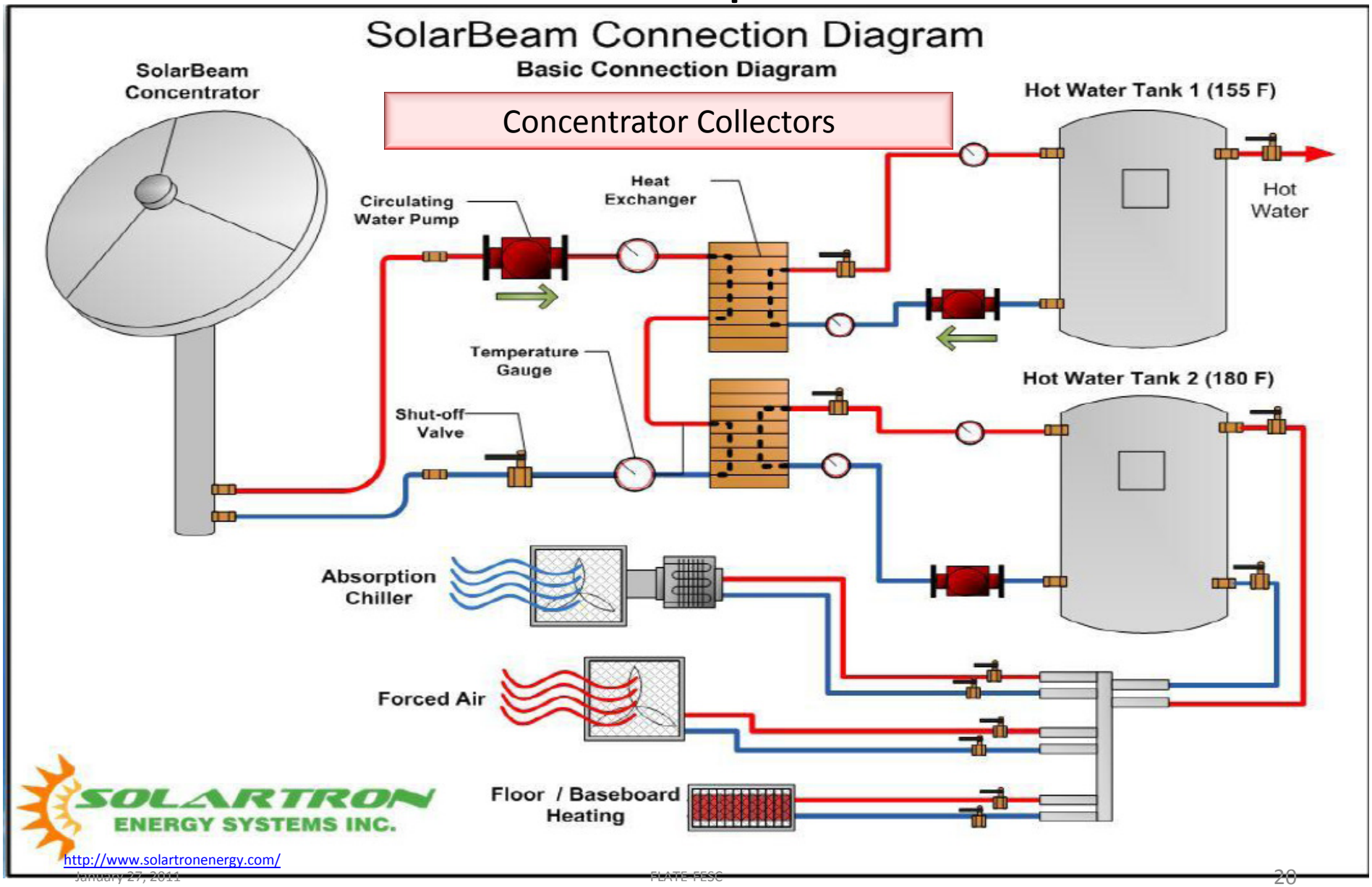
3.1.1.2b Medium Temperature Collectors

Concentrator Collectors



http://www.solartronenergy.com/

3.1.1.2b Medium Temperature Collectors

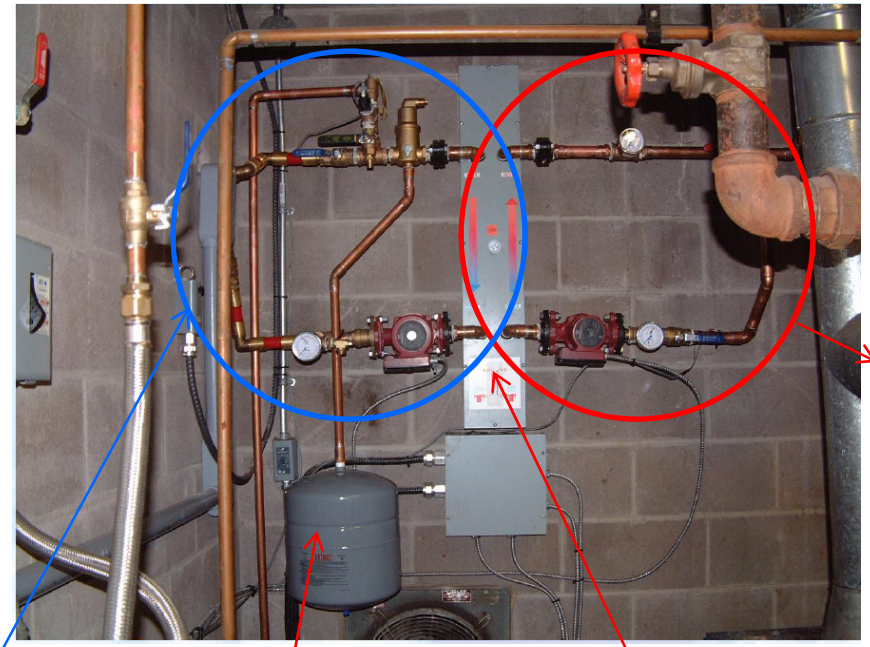


3.1.1.2b Medium Temperature Collectors

Concentrator Collectors

Storage Tanks

Heat Exchanger



Tank flow circuit

Dish flow circuit

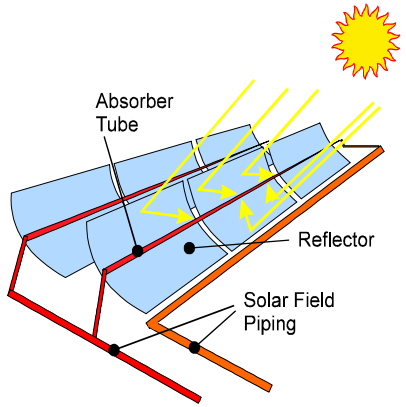
Expansion tank

Heat Exchanger

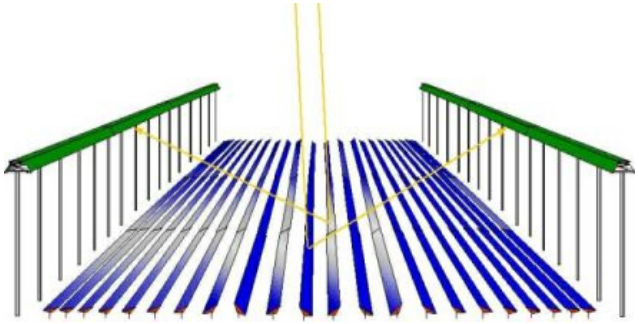
http://www.solartronenergy.com/

3.1.1.2c High Temperature Collectors

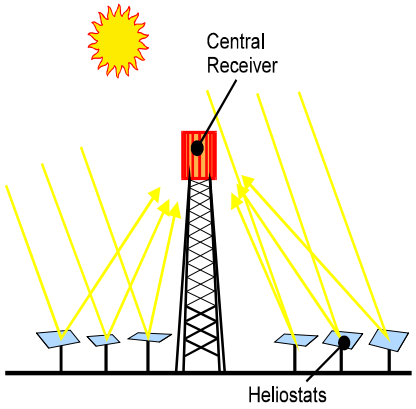
- There are four major types of high temperature collectors (also called Concentrating Solar Power (CSP) units).
  - Parabolic Dish
  - Parabolic Trough
  - Linear Fresnel
  - Power Tower (heliostat reflectors)
- Primarily used for commercial electricity generation



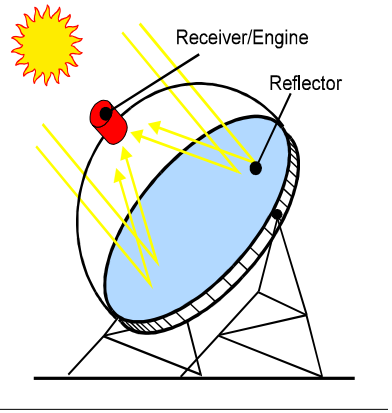
Parabolic troughs



Linear Fresnel Reflectors



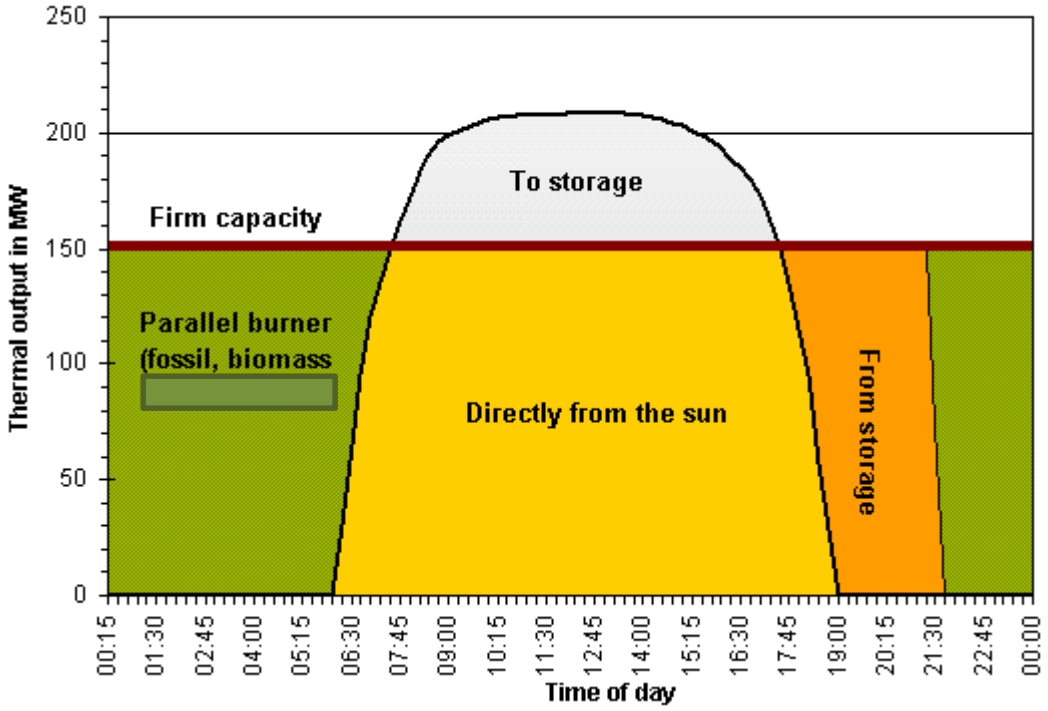
Central Receiver / Heliostats



Parabolic dishes

3.1.1.2c High Temperature Collectors

- Except for parabolic dish systems that use sterling engines to generate electricity directly, thermal systems typically contain a heat storage subsystem.
- Heat could be stored in
  - concrete or
  - phase change of storage material such as molten salt.

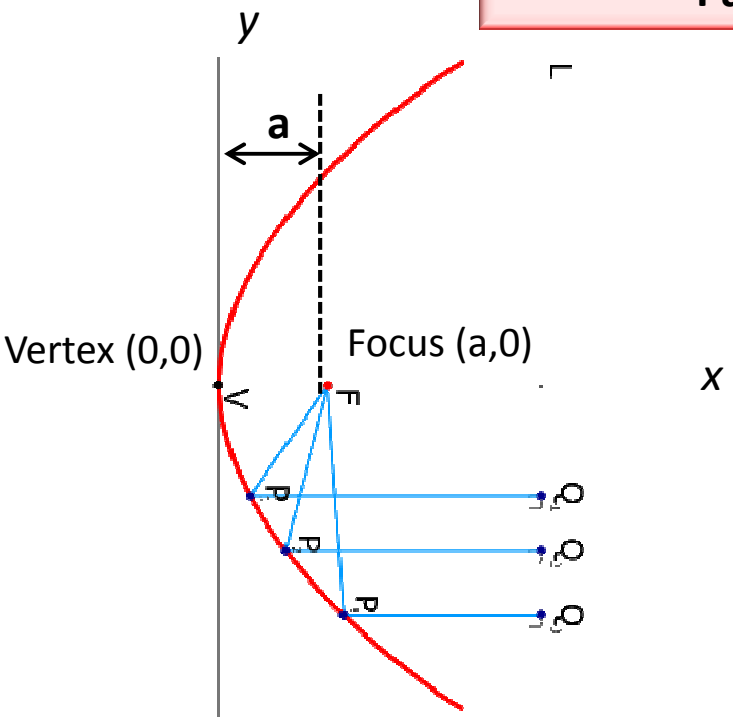


Typical output of a solar thermal power plant with two-hour thermal storage and backup heating system to guarantee capacity.

http://www.volker-quaschning.de/articles/fundamentals2/index.php

3.1.1.2c High Temperature Collectors

Parabolic systems



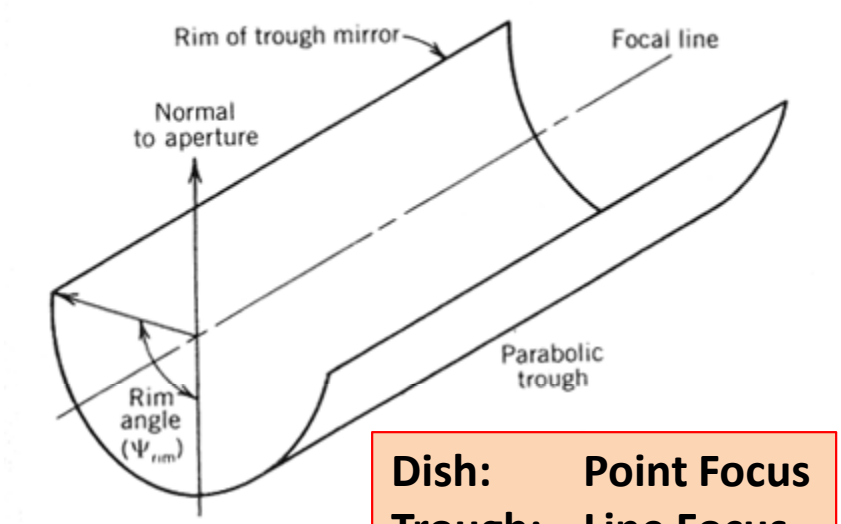
http://en.wikipedia.org/wiki/Parabola

1a. $\sqrt{(x-a)^2 + y^2} = x + a$

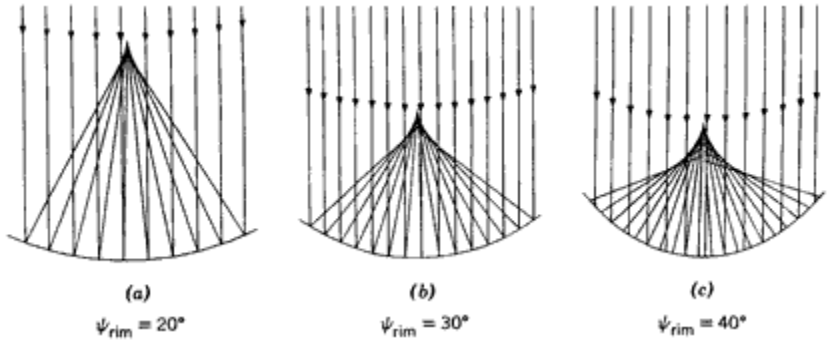
b. $(x - a)^2 + y^2 = (x + a)^2$

c. $x^2 - 2ax + a^2 + y^2 = x^2 + 2ax + a^2$

2. $\boldsymbol{y^2 = 4ax}$



Dish: Point Focus
Trough: Line Focus



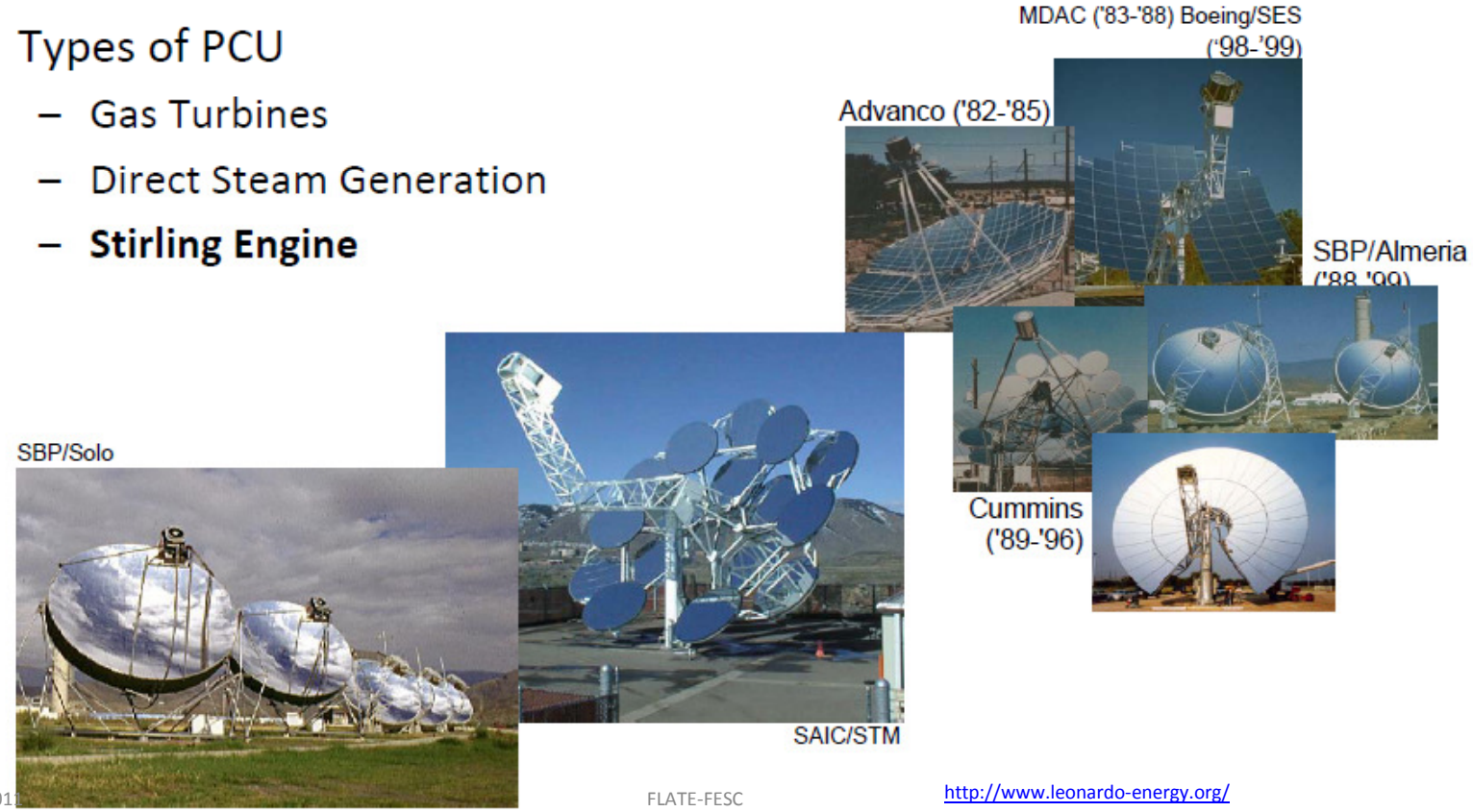
Focusing of parallel rays of light using circular mirrors with different rim angles

http://www.powerfromthesun.net/book.htm

3.1.1.2c High Temperature Collectors

Parabolic dish systems

- Combine a paraboloidal concentrator (parabolic dish) with a Power Conversion Unit (PCU) directly attached to the concentrator
- Types of PCU
  - Gas Turbines
  - Direct Steam Generation
  - **Stirling Engine**

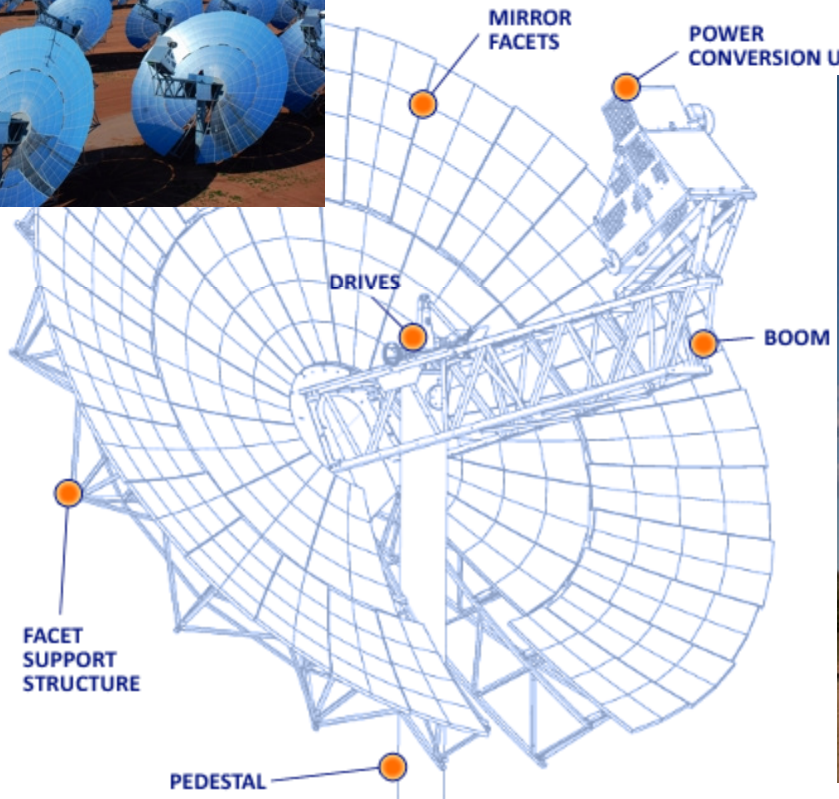


http://www.leonardo-energy.org/

Parabolic dishes

3.1.1.2c High Temperature Collectors

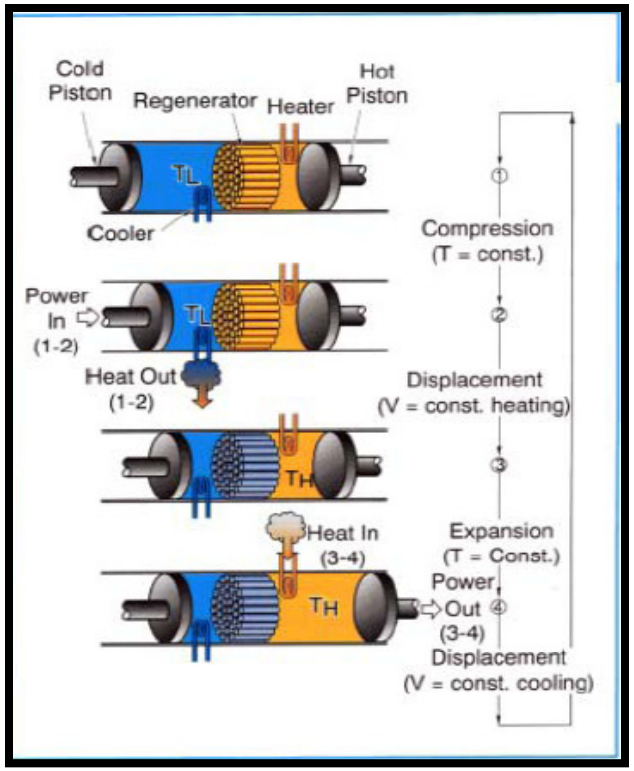
Concentrated temperatures of 2000°F are possible. Parabolic Dish Concentrators are capable of achieving the highest efficiency of any concentrating system.



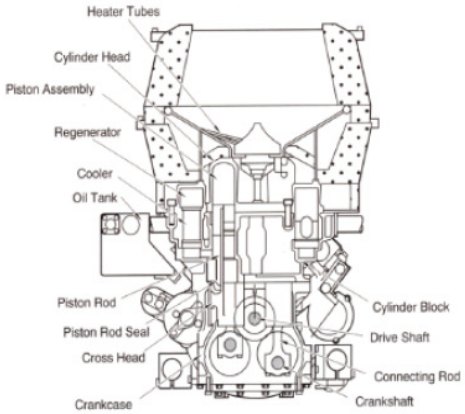
The SunCatcher™ is a 25-kilowatt-electrical (kWe) solar dish Stirling system which consists of a radial solar concentrator dish structure that supports an array of curved glass mirror facets, designed to automatically track the sun, collect and focus solar energy onto a Power Conversion Unit (PCU). The PCU is coupled with, and powered by, a **Stirling engine that generates electricity**.

http://www.tesserasolar.com/international/index.htm http://www.stirlingenergy.com/progress.htm

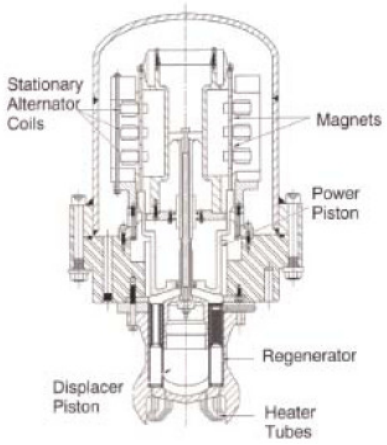
3.1.1.2c High Temperature Collectors



http://www.leonardo-energy.org/

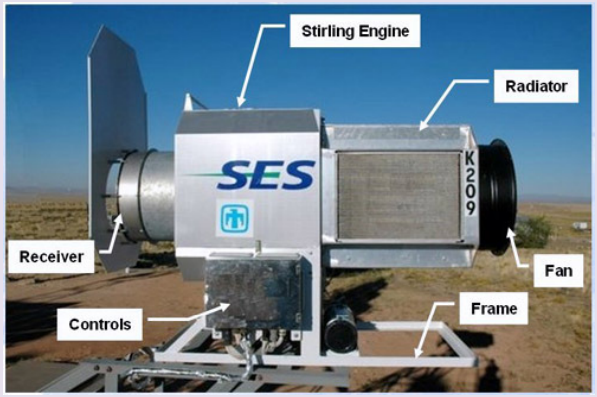


Kinematic: rotary induction generator



Free-piston: Linear generator

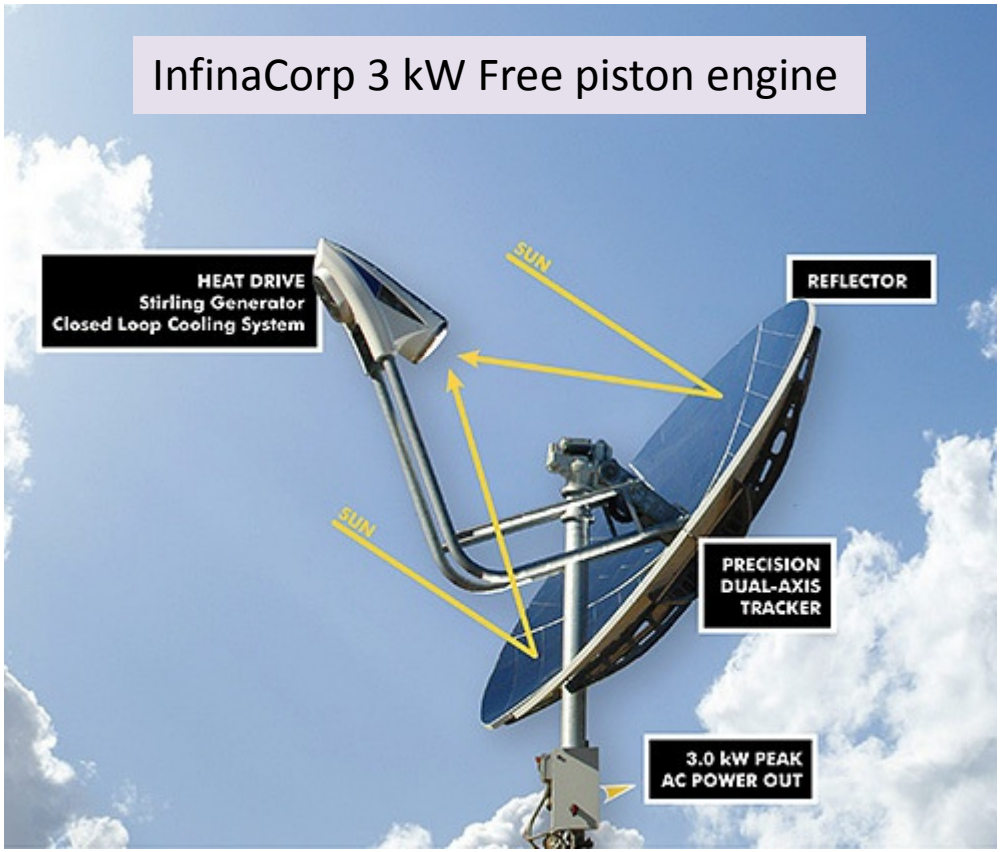
Power Conversion Unit (PCU)



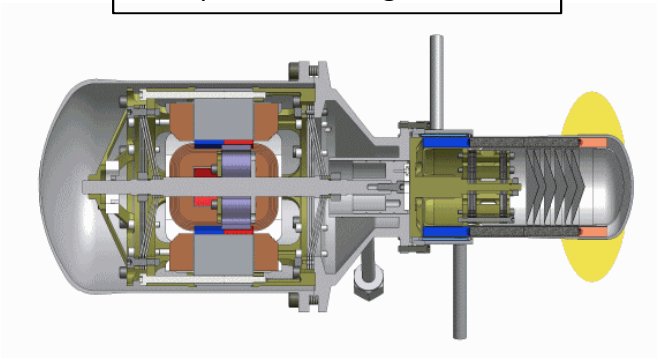
- The PCU has an external heat exchanger that absorbs the incoming solar thermal energy.
- The PCU measures the temperature variation among the dish's quadrants and adjusts accordingly to equalize.
- The conversion process is performed utilizing a working fluid being recycled within a closed loop, consisting of four reciprocating pistons that power the Stirling engine.

3.1.1.2c High Temperature Collectors

Power Conversion Unit (PCU)



Free-piston: Linear generator



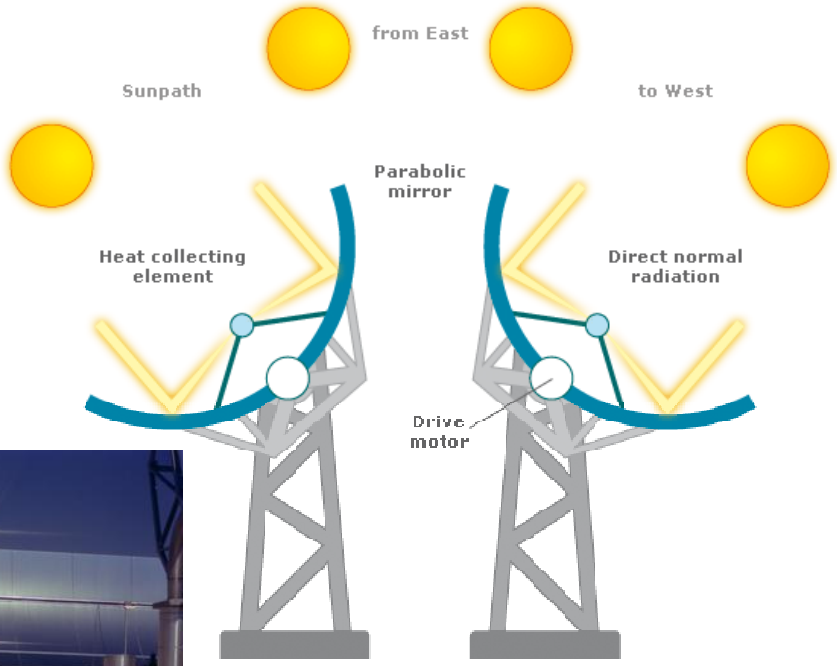
Stirling Engines

http://www.infiniacorp.com/powerdish.html

3.1.1.2c High Temperature Collectors

Parabolic Troughs

http://www.nrel.gov/data/pix/Jpegs/04242.jpg

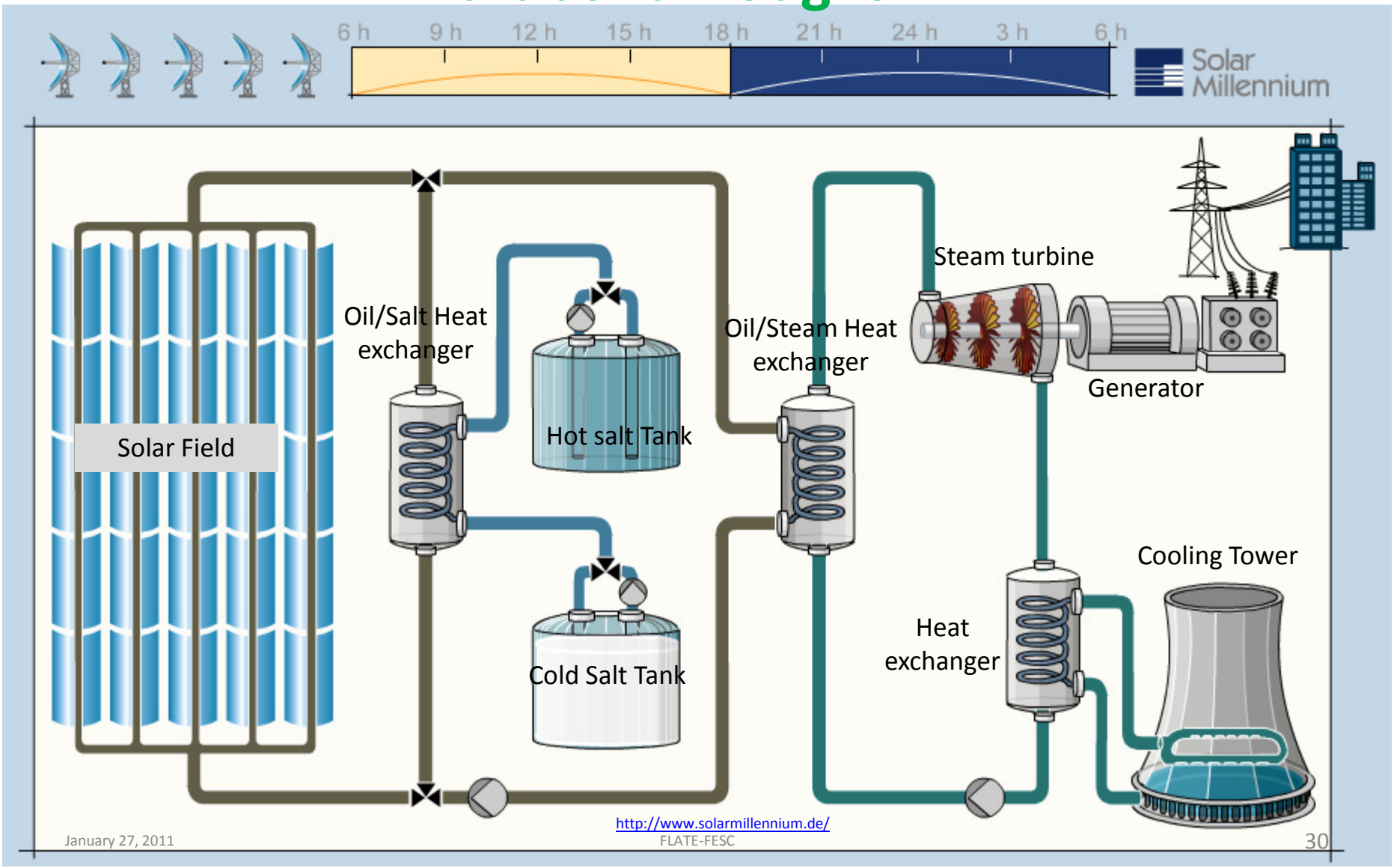


http://www.abengoasolar.com/corp/web/en/technologies/concentrated_solar_power/parabolic_trough/index.html

One of nine plants with combined output of 354 MW, the largest being 80MW, operated by Kramer Junction Power

3.1.1.2c High Temperature Collectors

Parabolic Troughs



3.1.1.2c High Temperature Collectors

Parabolic Troughs

1. During the day, collectors follow the sun and focus sunlight unto absorber tubes which contain synthetic oil as a heat transfer fluid. This fluid transfers its thermal energy to heat exchangers where steam is generated. That steam drives a turbine, which drives a generator.
2. When there is enough insolation, the storage system can be filled up. Cold salt (at about 280^{o}C) is pumped through an oil/salt heat exchanger to a hot storage tank (380^{o}C).
3. In the evenings the solar field AND the storage system together can supply the thermal energy to generate steam and drive the turbine.
4. For at minimum a couple of hours at night thermal energy is supplied exclusively by the storage system. As a back up, thermal energy can also be supplied by a fossil fuel or biomass plant.

http://www.solarmillennium.de/

3.1.1.2c High Temperature Collectors

Linear Fresnel Reflectors

- Basically the same concept as a Parabolic Trough except parabolic mirrors are replaced by a series of linear mirrors that focus light onto the tube making use of a fresnel lens concept.
- Mirrors are less expensive to manufacture since they use less material and weigh less
- But more complexity and focus error aggregation reduces efficiency of focus.

http://www.nrel.gov/csp/troughnet/wkshp_power_2007.html#linear

http://www.ausra.com/technology/

3.1.1.2c High Temperature Collectors

Central Receivers/Power Tower

http://www.nrel.gov/data/pix/Jpegs/00036.jpg

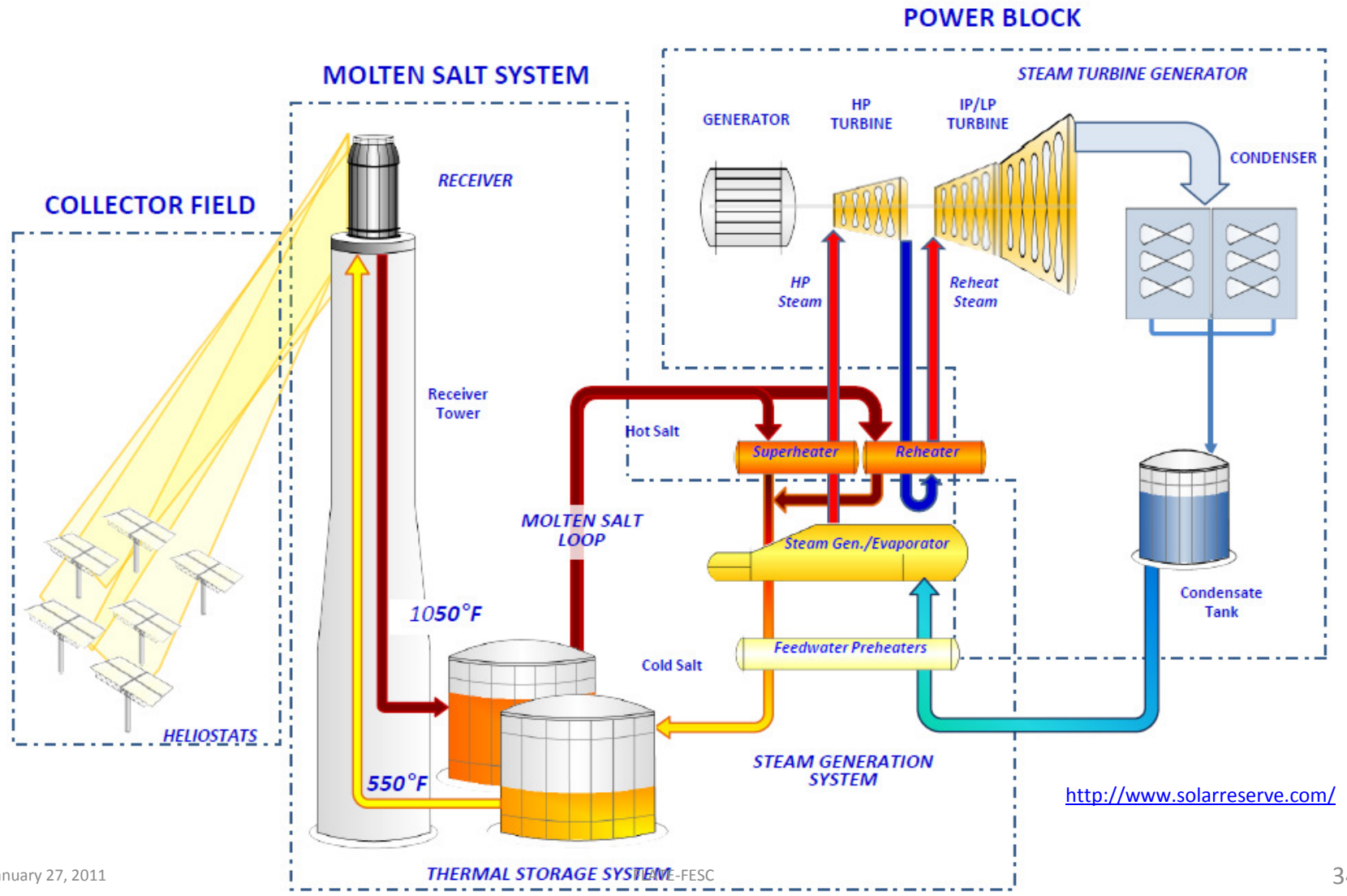
http://upload.wikimedia.org/wikipedia/commons/3/36/Esolar_13.jpg

http://www.nrel.gov/data/pix/Jpegs/02159.jpg

http://www.nrel.gov/csp/troughnet/pdfs/2007/osuna_ps10-20_power_towers.pdf

3.1.1.2c High Temperature Collectors

Central Receivers/Power Tower



http://www.solarreserve.com/