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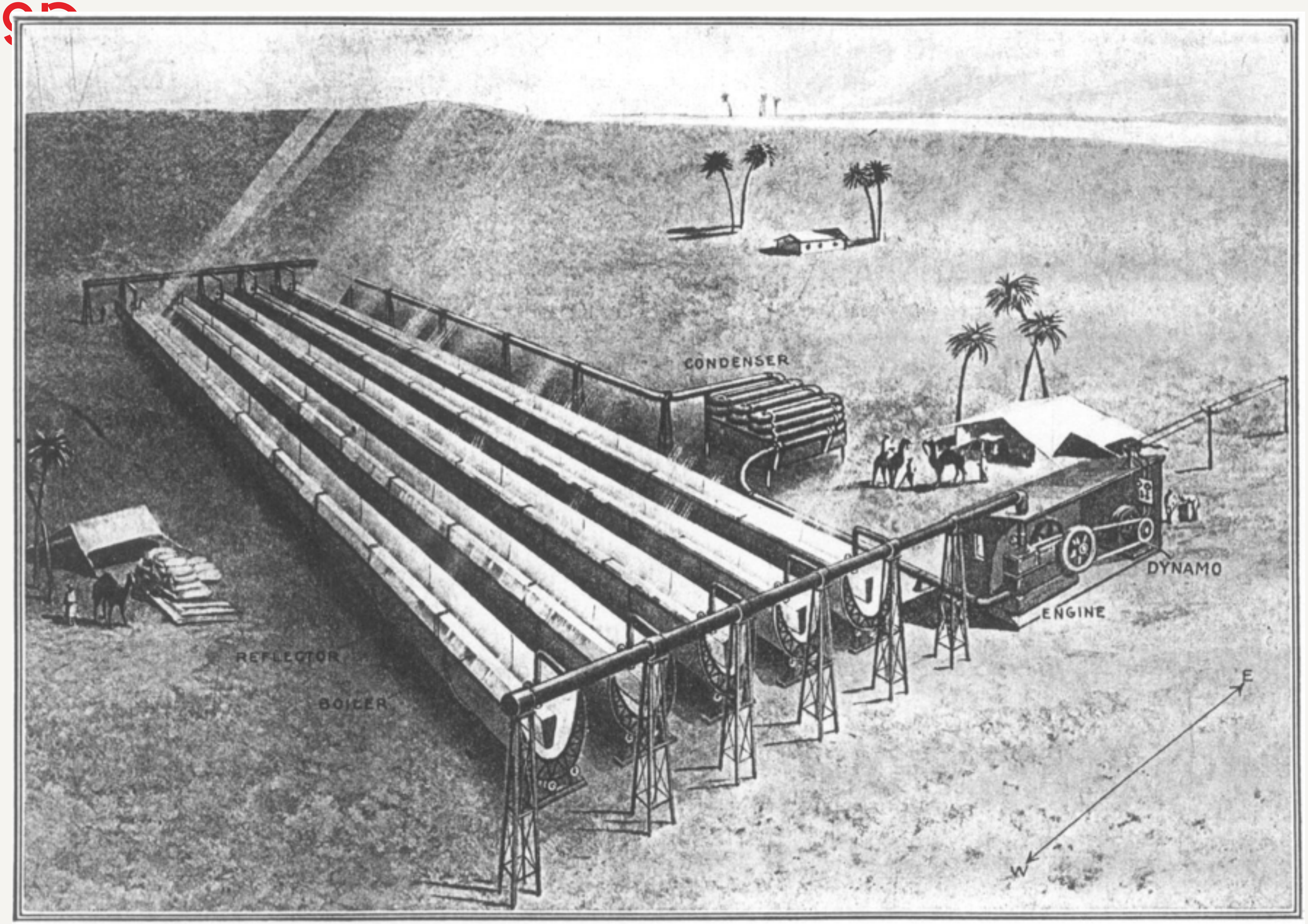
University of Applied Sciences
HSD

29. September 2015

Solarenergie

Solarkraftwerke

Solarkraftwerke



Source: http://www.teslacollection.com/tesla_articles/1916/electrical_experimenter/hugo_gernsback/the_utilization_of_the_sun_s_energy

THE ELECTRICAL EXPERIMENTER

Vol. III. Whole No. | MARCH, 1916 | Number 11

T… gy

Years Ago Man Endeav… —Even Tesla, the Electrical Wizard, Has Patented a Sun Motor, While the Shuman-Boy's Engine and Sun Boiler Has Developed 100 H. P. There Is Great Promise Held Forth to Future Engineers Who May Work on This Problem.

IT has been given to astrophysicists to measure the heat generated by the sun and calculate the force emanating from it. We know that the surface of our luminary gives out a heat estimated to be about 6,000° centigrade, and that its light equals that of 27,000,000,000 candlepower a quarter of a mile away. The heat which the earth receives from the sun in the course of a year would suffice to melt a belt of ice about 55 yards in thickness extending clear around the earth. Only the 2,735-millionth part of the total energy given off by the sun reaches our earth and, if this were lacking, our planet, with all its thousandfold life, its thick forests and fruitful plains, would turn into a dead, rigid ball of rock, for the average annual temperature, which is now one of 13° centigrade of warmth for Europe, would, without the heat of the sun, sink to 73° centigrade of frost, it is calculated.

Every sort of light with which we illuminate our home when the greater light has sunk beneath the horizon, every fire that warms us when the solar rays can no longer do so, is a product originating in the sun. The chip of wood with which the untaught son of nature brightens his hut, the twigs with which he stokes his fire, what are they but pieces of trees that grew in the sunlight? The gas of the city dweller, the coals with which he heats his house and from which the gas has been sucked, what are they but transformed sunbeams? The coal in the grate is the petrified wood of perished forests that covered the earth's surface millions of years ago, and flourished in the rays of the same sun that ripens our corn to-day. Petroleum, that mysterious earth-oil, comes from the bodies of millions of dead and

A Successful 100 H.P. Sun Power Plant Located at Meadi, on the Nile, Egypt.

Source: http://www.teslacollection.com/tesla_articles/1916/electrical_experimenter/hugo_gernsback/the_utilization_of_the_sun_s_energy

Solarkraftwerke

PV-Kraftwerk

Source: http://www.lmbv.de/index.php/solarpark-senftenberg.html

Solarkraftwerk

Source: http://www.ivanpahsolar.com/photos-and-videos

Solar Thermal Power Plants

- No heat generation, but electric power.
- Basically, only the heat source in a solar power plant is different to a conventional power plant.
- Instead of burning coal or oil the heat comes from the sun.
- The generator part of the plant is conventional design.
- Also possible are hybrid power plants: conventional coal plant with solar support to save fuel.

Ivanpah Solar Thermal Plant, Mojave Desert, USA

Siemens Dampfturbine Serie SST-900

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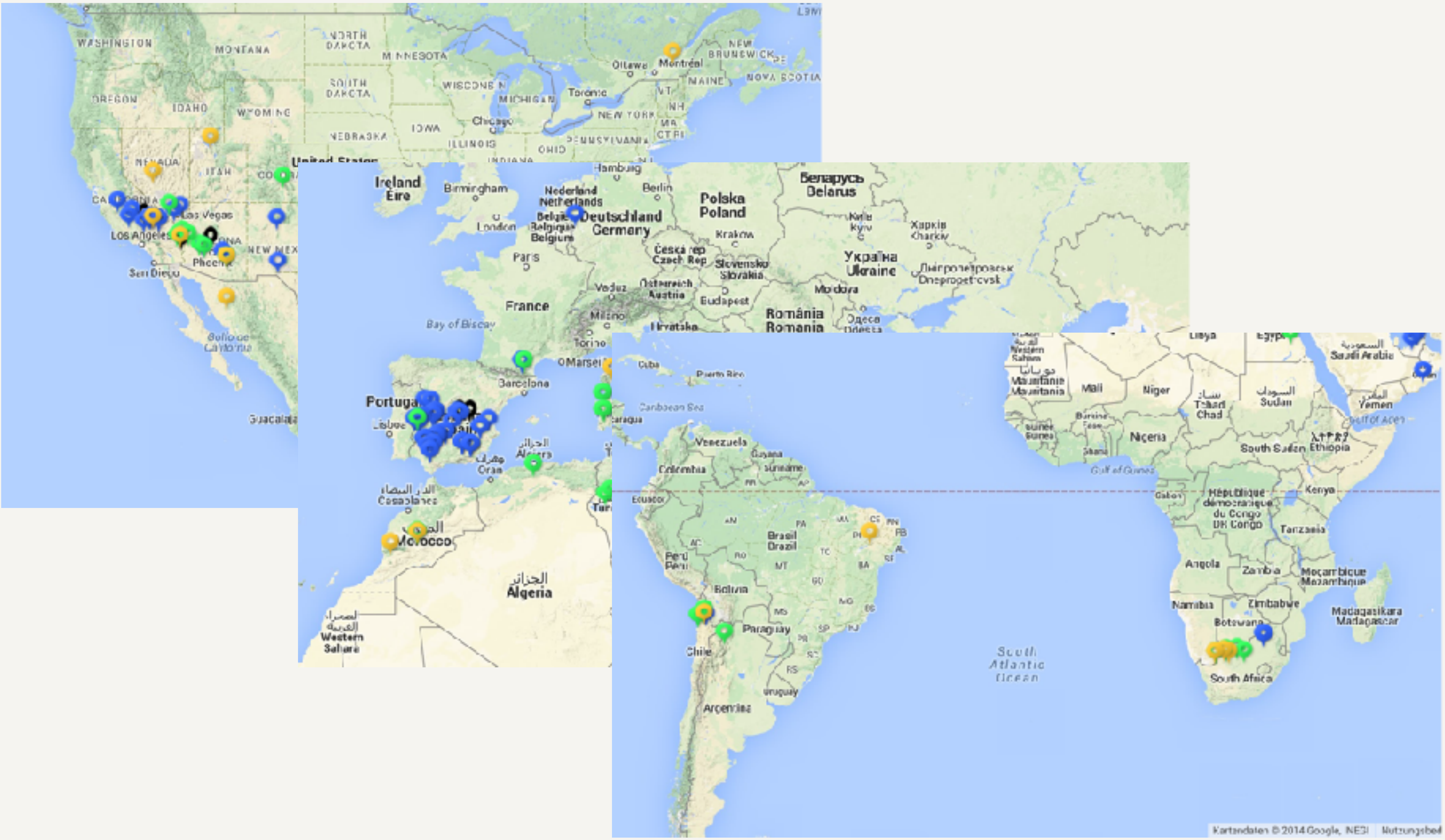
CSP-Solarkraftwerke heute

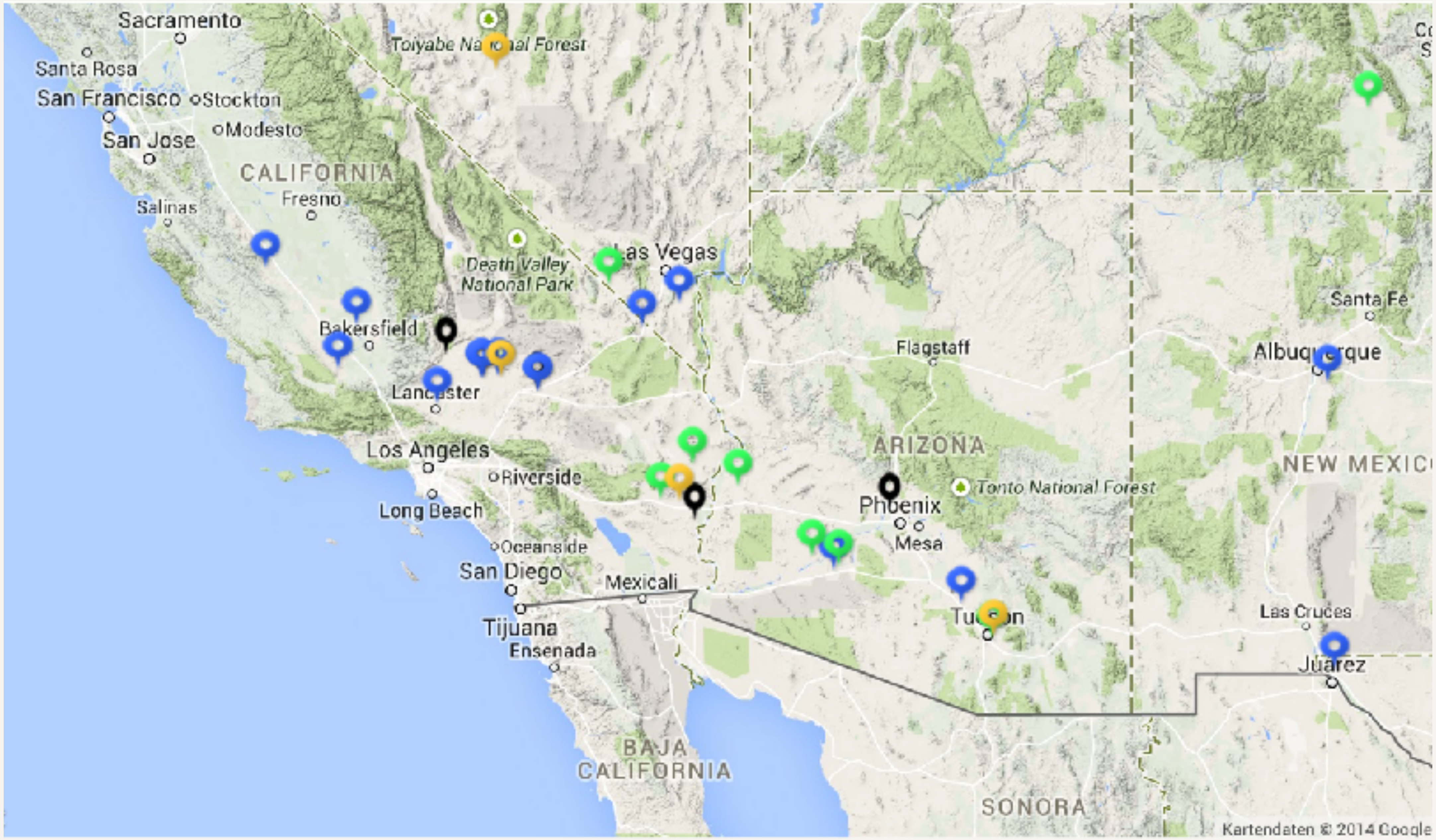


http://www.csp-world.com/cspworldmap

Solarkraftwerke in Spanien

http://www.csp-world.com/cspworldmap

Solarkraftwerke in Kalifornien



http://www.csp-world.com/cspworldmap

Solar Thermal Power Plants

Technologies

Technology

- ☑ Central receiver (power tower)
- ☑ Central receiver (power tower) - Biomass
- ☑ Dish Stirling
- ☑ Fresnel
- ☑ Linear Fresnel - ISCC
- ☑ Parabolic Dish
- ☑ Parabolic trough

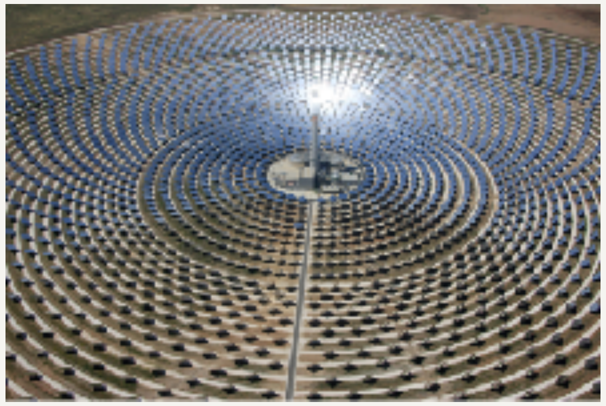
http://www.csp-world.com/cspworldmap

Solar Thermal Power Plants

- Different plant types.
- Here: only concentrating solar power (CSP)
- Requires a minimum size to power a standard steam turbine.
- Only industrial-sized plants.
- Can be used to support conventional power plants to save fuel (hybrid plants)

Parabolic Trough

Solar Tower



Fresnel Reflector

How hot can it get?

Thermodynamic Equilibrium

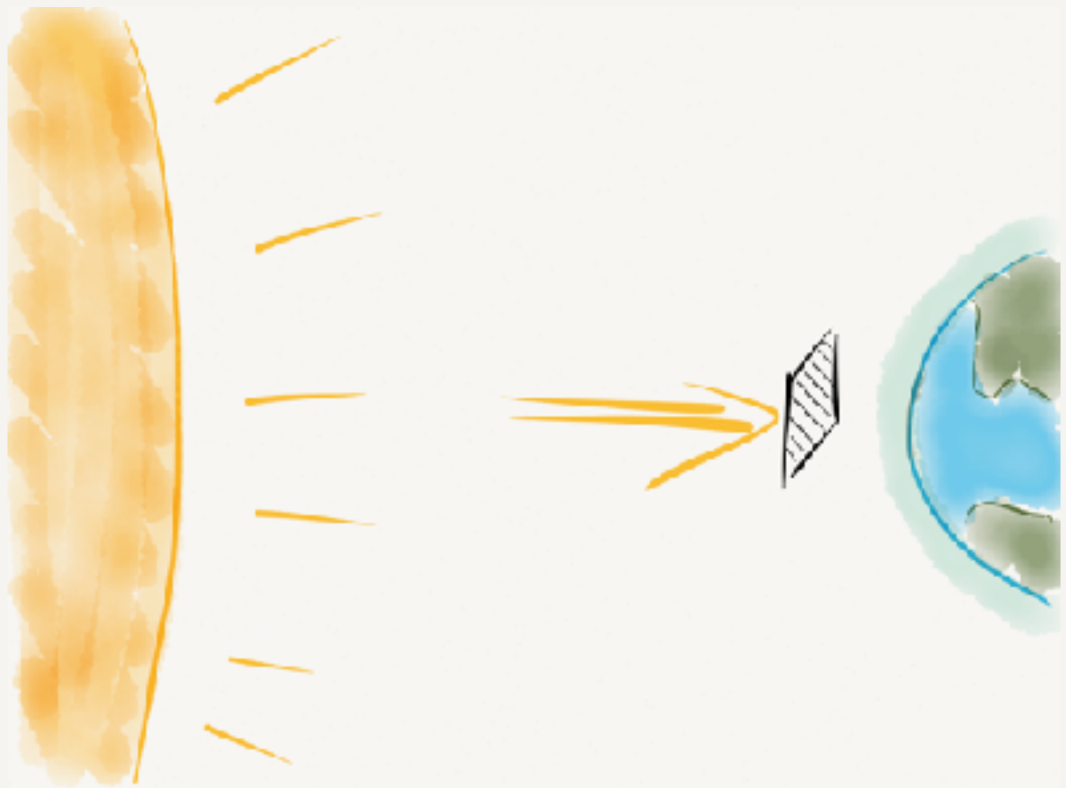
- How hot can a black body in the sun get?
- Assume a bright sunny day in summertime.

How hot can it get?

- Two blackbodies are in thermal equilibrium when the radiation rates for absorption and emission are equal.
- The power is simply a function of the temperature.
- The incoming radiation is not the suns direct temperature power at $5700\mathrm{K}$ because of the distance sun - earth.
- The solar constant gives $1367\ \mathrm{W/m}^2$.
- The actual value depends on the amount of radiation reaching the position of the absorbing black body.

Stefan-Boltzmann's law

$$P = \sigma \cdot A \cdot T^4$$



$$\frac{1367\,\mathrm{W/m^2}}{5.67 \cdot 10^{-8}\,\mathrm{W/(m^2K^4)}} \approx 394\,\mathrm{K}$$

$$\approx 121\,^{\circ}\mathrm{C}$$

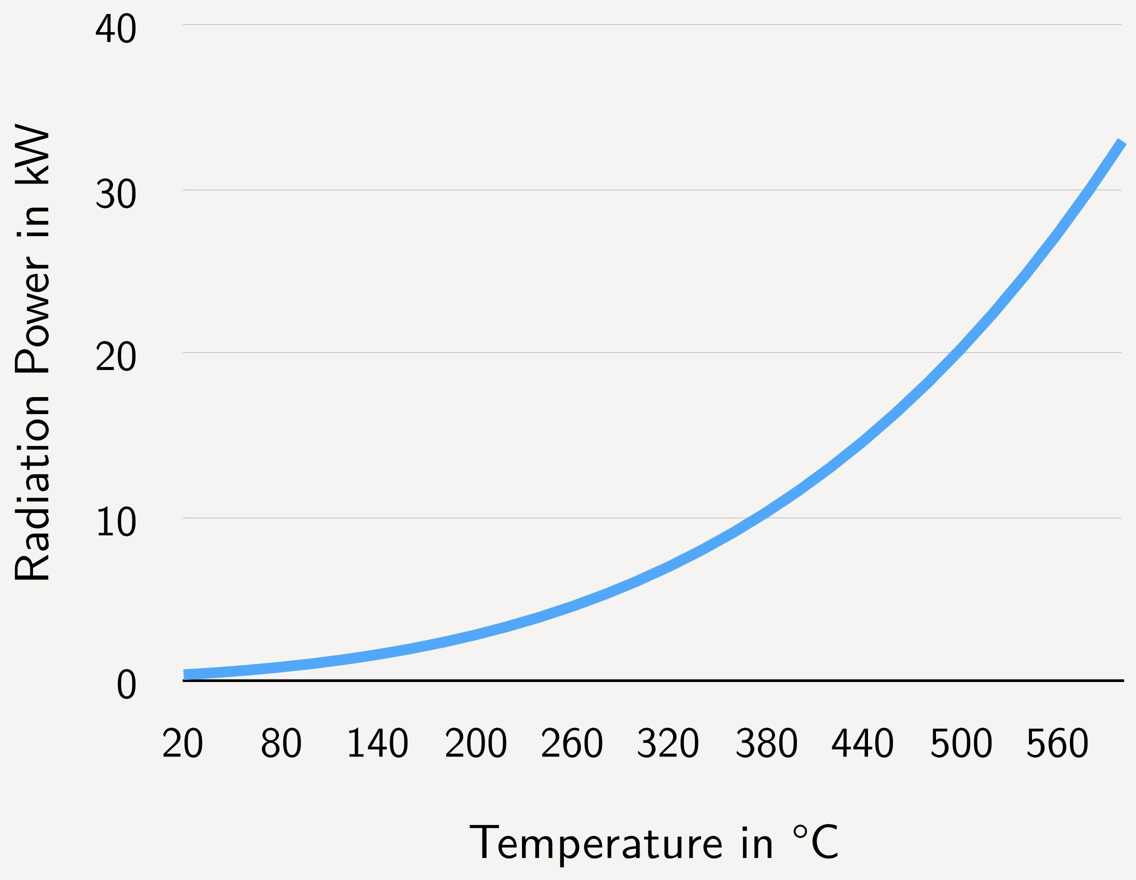
Recap: Stefan-Boltzmann's Law

- Due to the fourth power the black body radiation quickly becomes the dominant source of losses for higher temperatures.
- The working temperature of solar thermal plants is:
  - Domestic: 50°C - 100°C
  - Parabolic trough: 400°C
  - Tower: 565°C

Stefan-Boltzmann's law

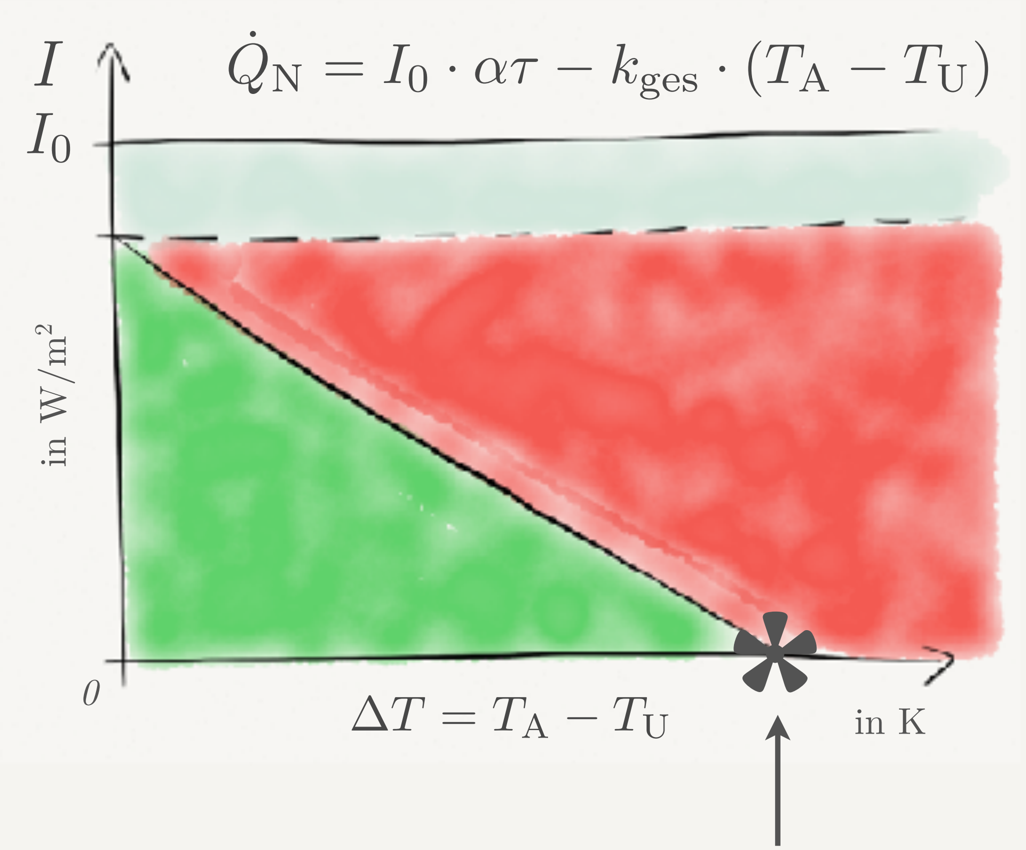
$$P = \sigma \cdot A \cdot T^4$$

Radiation power of a black body with a surface of $1\mathrm{m}^2$.



Increasing the Temperature

- Solar thermal collectors increase the temperature by insulating the absorber and reducing heat losses.
- Temperatures above 200°C are possible.
- In a vacuum tube collector with **selective absorbers** and / or **IR-coating** the stagnation temperature can reach almost 300°C.

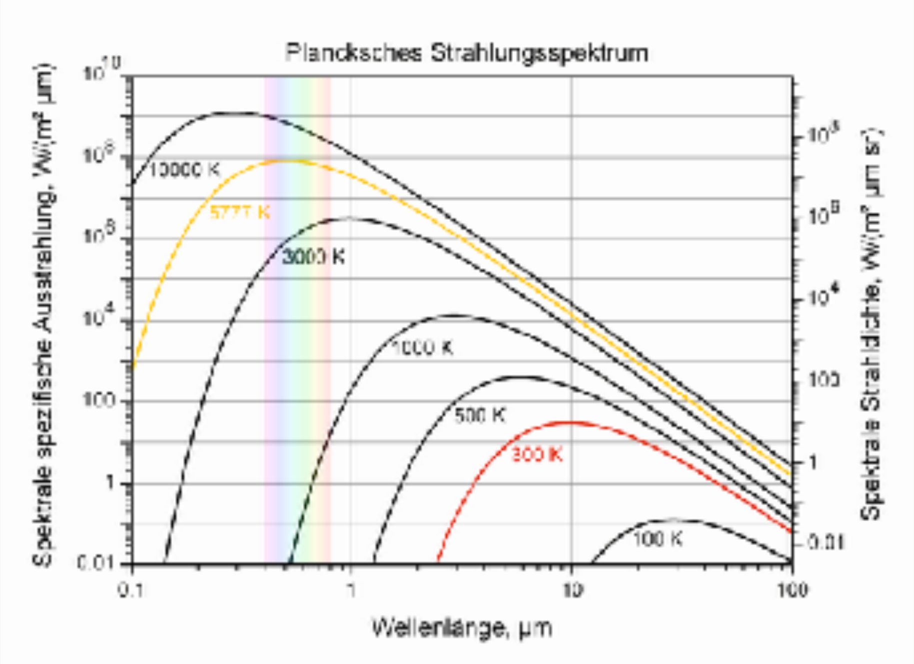


Stagnation temperature

How hot do you want it?

- The peak of the black body spectrum (of the losses) moves to smaller wavelengths.
- At $885°C$ the wavelength is approx. $2.5\mu m$.
- Then all selective absorbers and IR-coatings are **not useable** any more.

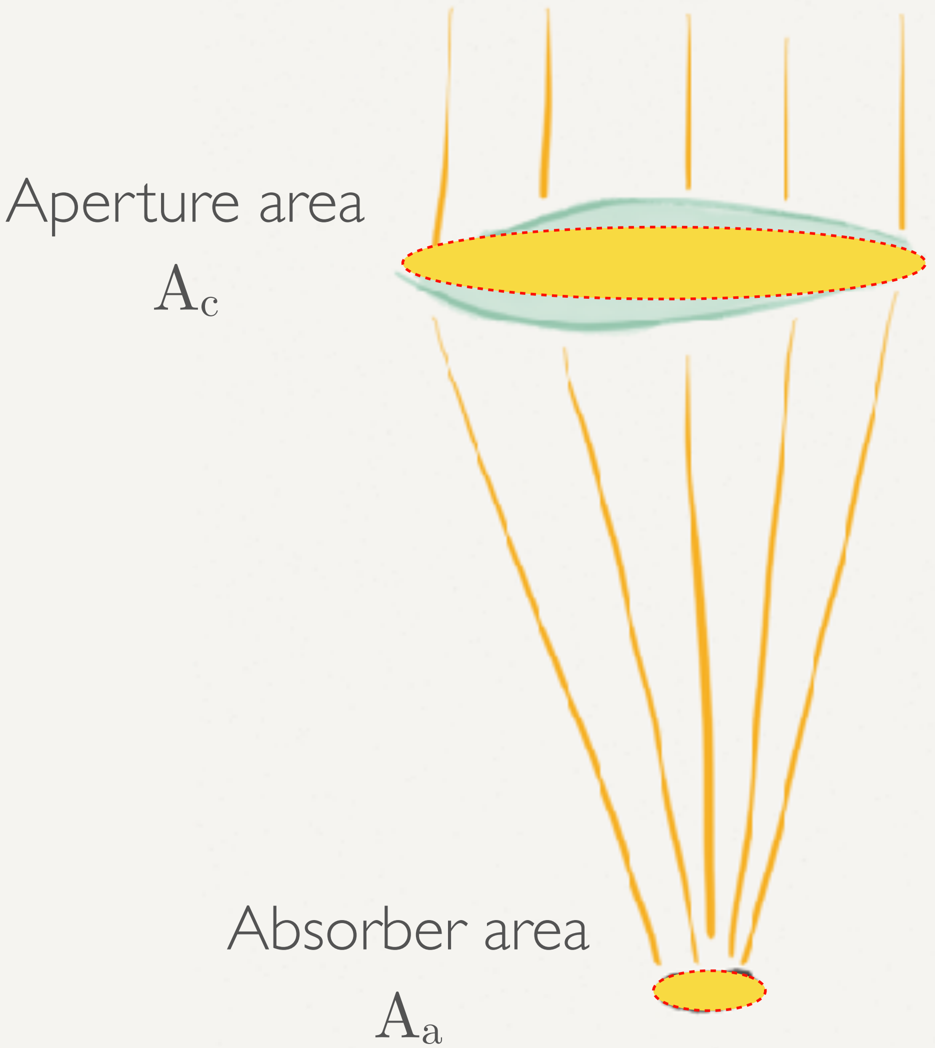
$$\lambda_{max} \cdot T = 2898\,\mu mK$$



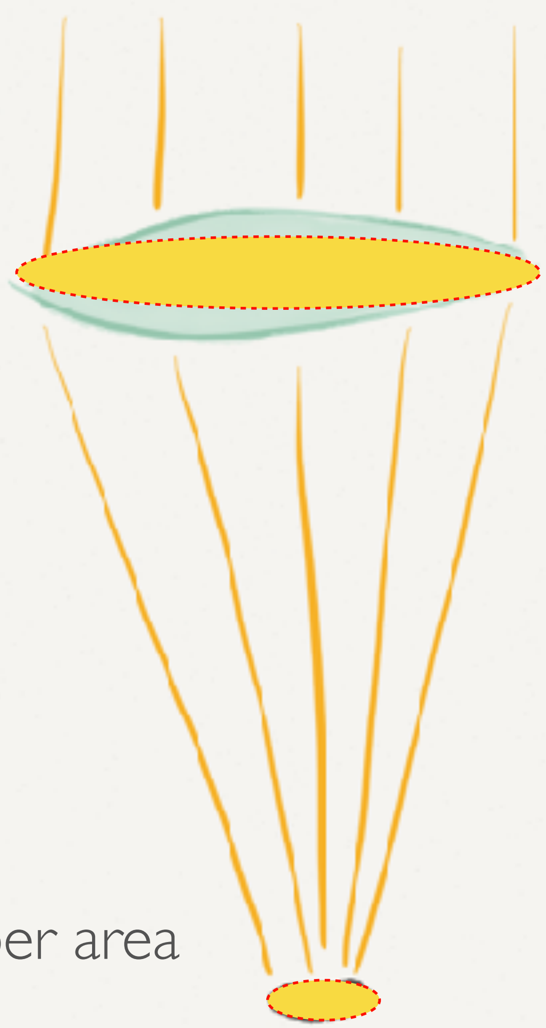
Concentrating Sunlight

Concentrating Sunlight

- To further increase the temperature it is necessary to focus sunlight from a large collecting area (*aperture*) to a small absorbing surface (*absorber*).
- This increases the radiation power by the **concentration factor** k.



Concentrating Sunlight



$$k = \frac{A_c}{A_a}$$

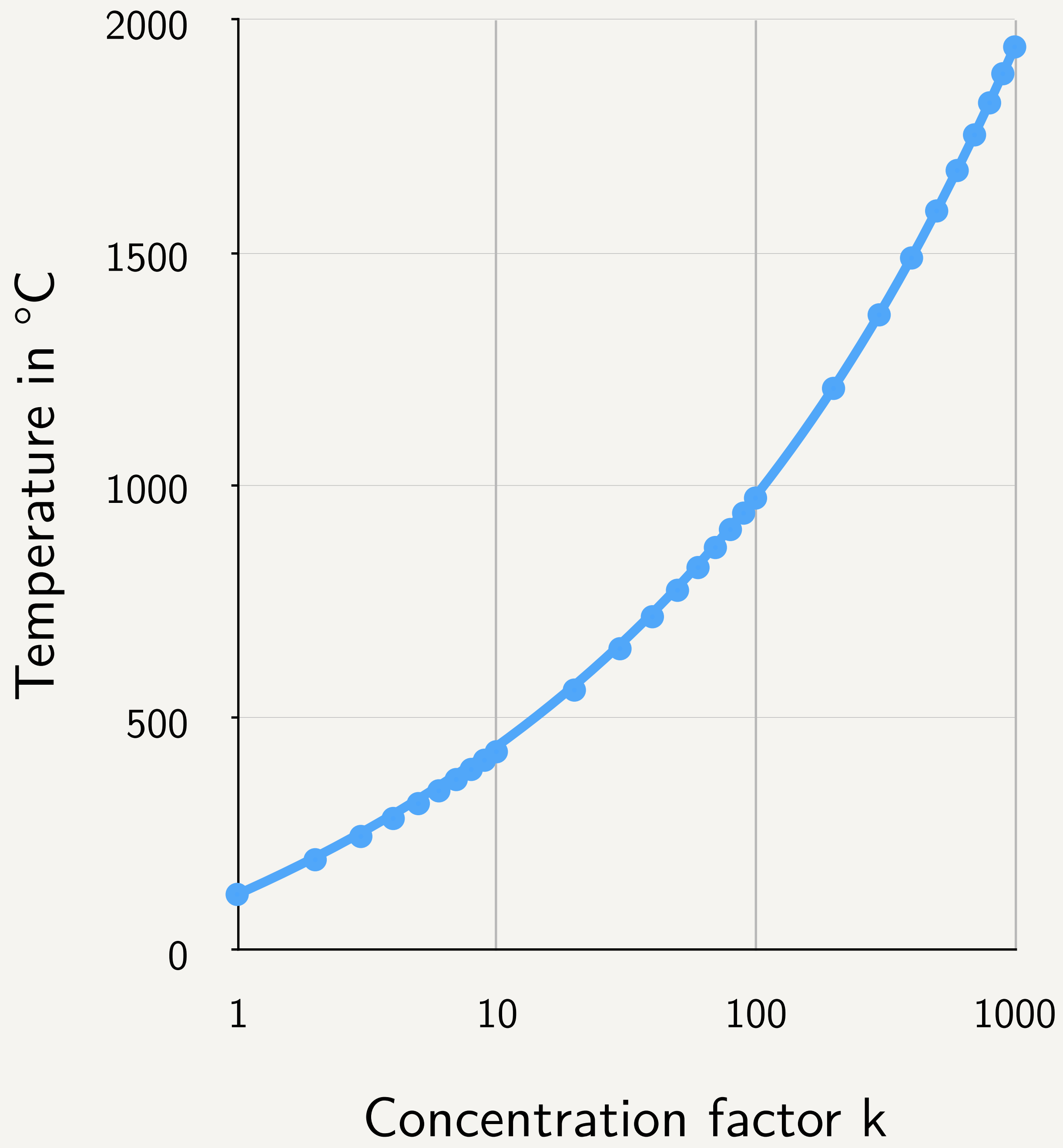
$$P_c = k \cdot P$$
$$= \sigma \cdot A_a \cdot T_a^4$$

Caveat: actually it is not the absorber area but the area of the **image** of the sun!

How hot can it get?

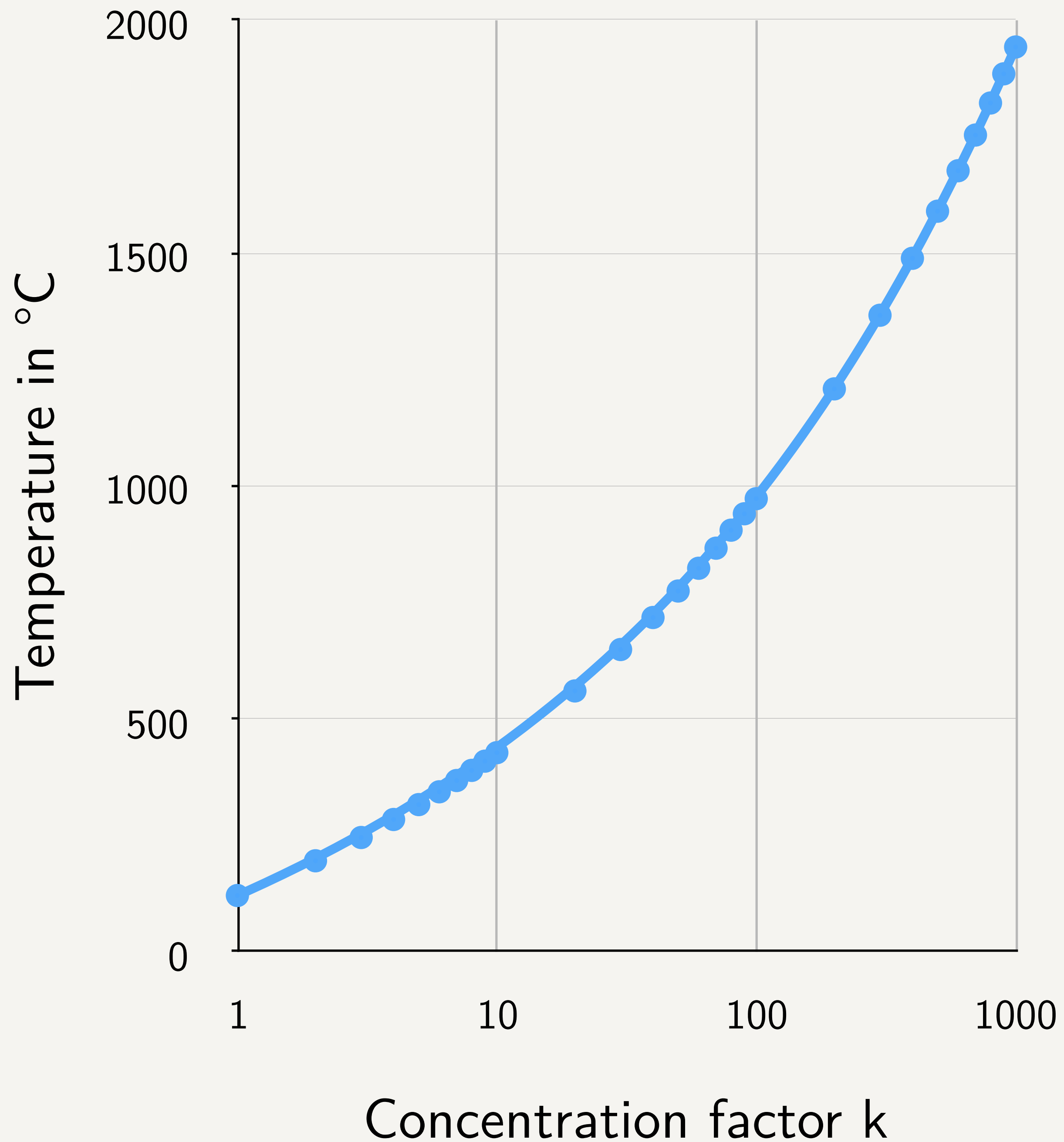
$$P_c = k \cdot P$$
$$= \sigma \cdot A_a \cdot T_a^4$$

$$\Rightarrow T_a = \sqrt[4]{\frac{k \cdot P}{\sigma \cdot A_a}}$$



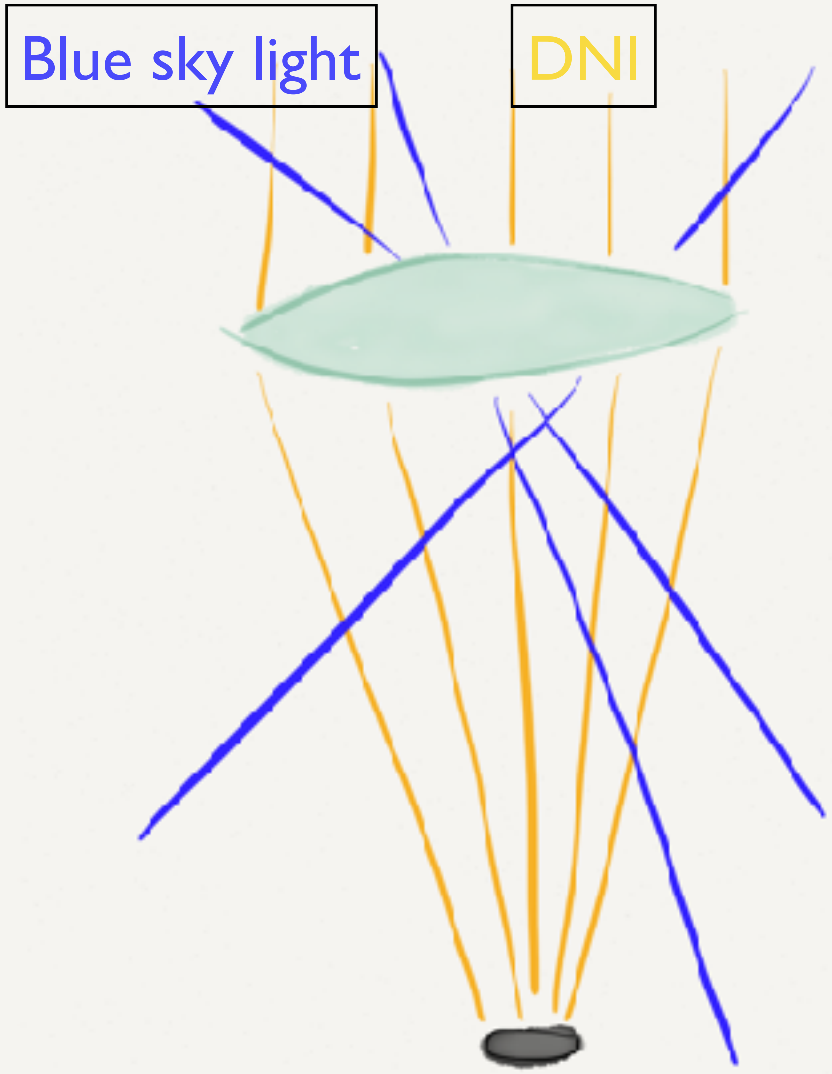
How hot can it get?

- Very simple model!
  - No shadowing due to absorber
  - No optical efficiency
  - No selective absorber or emissivity
  - Sun at $1367\ \mathrm{W/m^2}$.
  - No isolation assumed
- Concentration factors of 100 realistic for parabolic trough
- Concentration factors of 1000 realistic for dish systems.



DNI and diffuse radiation

- Only direct sunlight may be focussed!
- *Direct Normal Incident* (DNI)
- Indirect (diffuse) sunlight is not useable for concentrating systems.
- In Düsseldorf the ratio direct / diffuse radiation is (approx.) 50 - 50.



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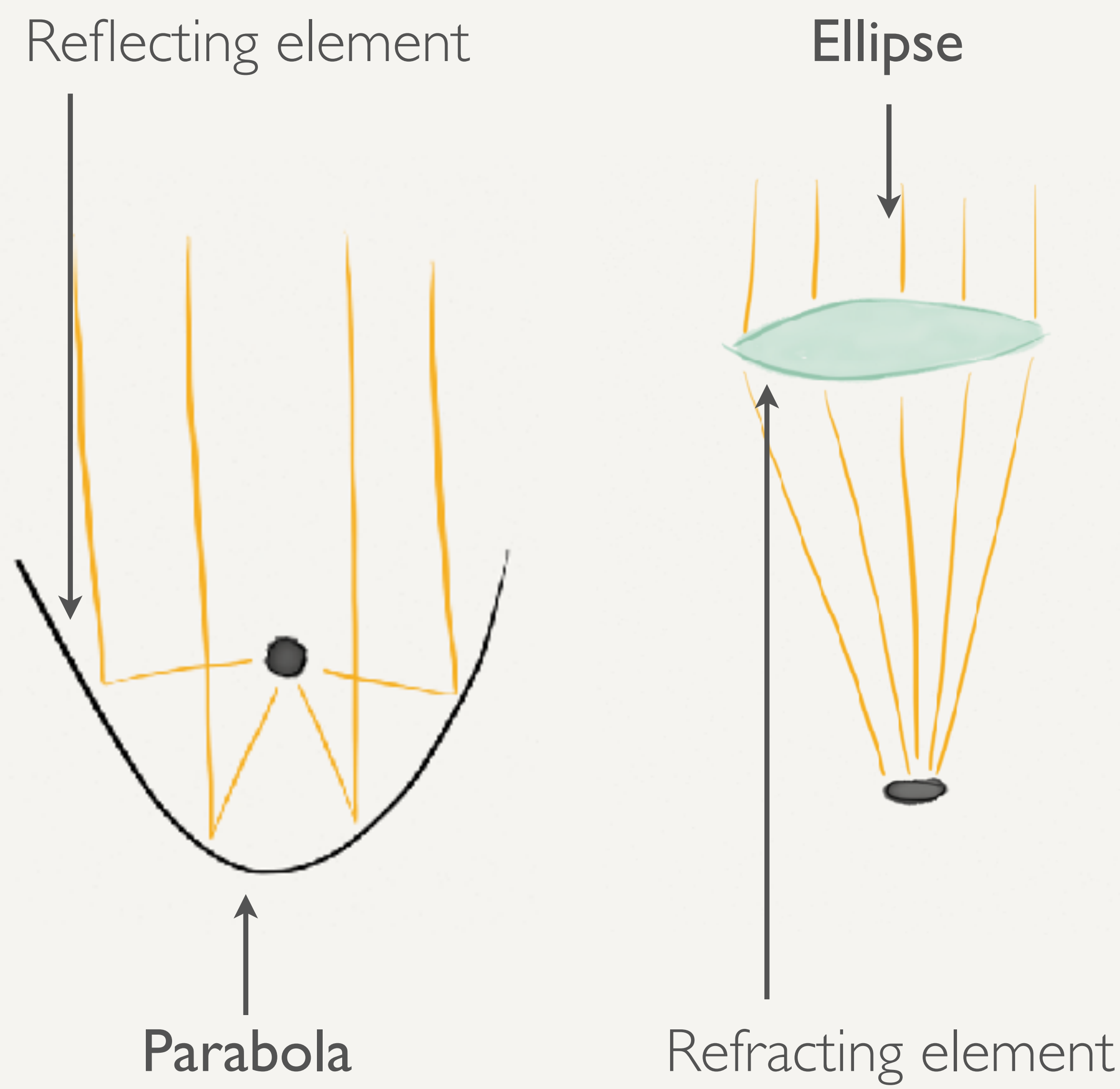
Optics

- Fermat's law tells us there are two forms to focus parallel light rays with high precision:
  - **reflecting parabola**
  - **refracting ellipse**
- In practice spherical elements are often used
  - easier to manufacture
  - decreased focus quality or limited aperture
  - lower concentration factor k



Tracking

- Only light rays that are parallel to the optical axis of the system are focussed onto the absorber.
- As the sun moves the focus moves away.
- Therefore the optical system needs to track the suns position.

Tracking DIY

http://www.ffwdm.com/solar/solar-index.htm

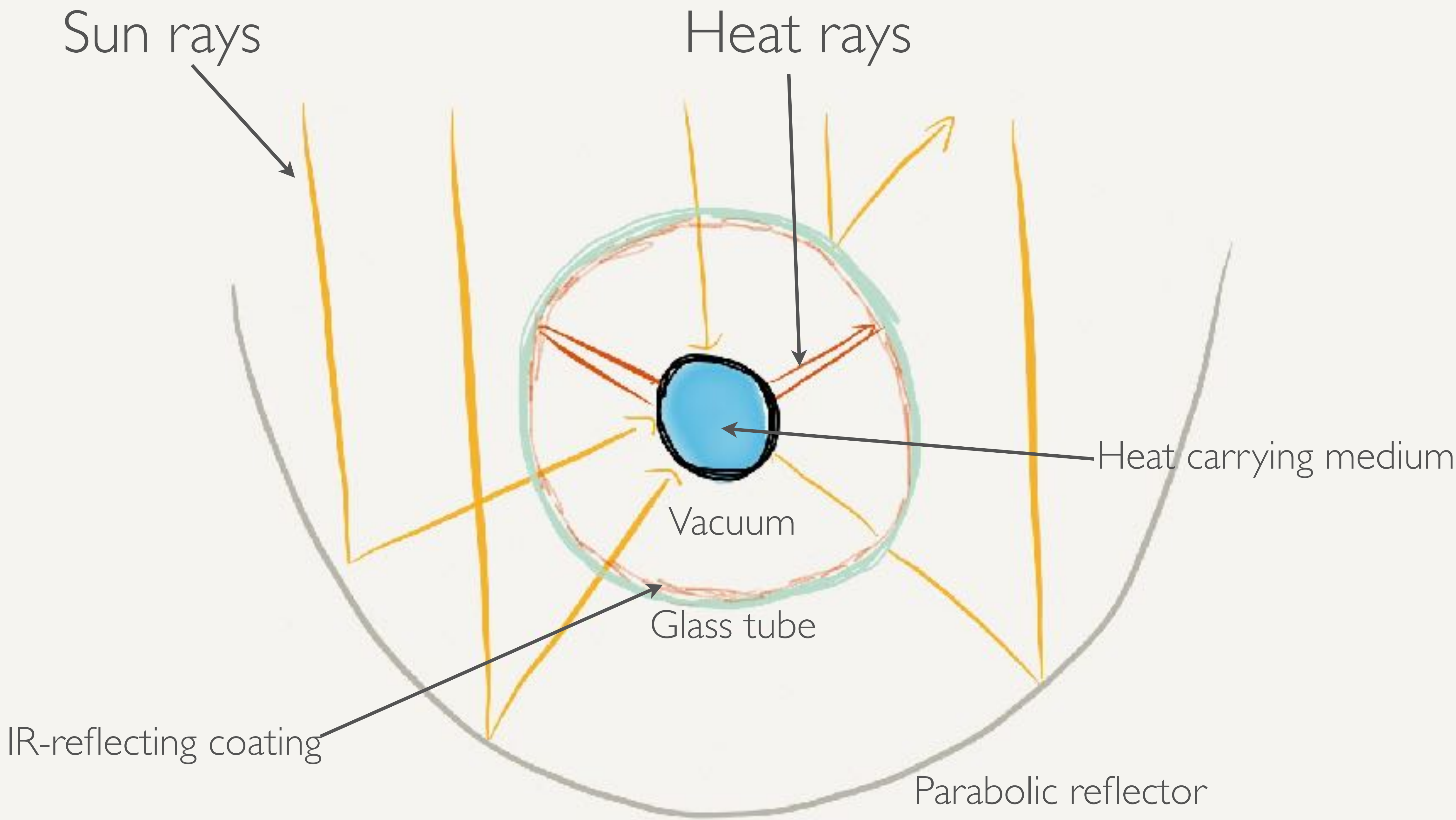
Summary Concentrating Light

- The incident power is increased by the **concentration factor** k.
- Factors of 100 for linear and 1000 for two-dimensional concentration are practical. Temperatures can reach $1000°C$ or $2000°C$ respectively.
- Only **direct normal light** can be focussed. The diffuse light (blue sky) cannot be used.
- The optics needs to **track** the **suns position** to keep the incident normal.

Parabolic Trough Technology

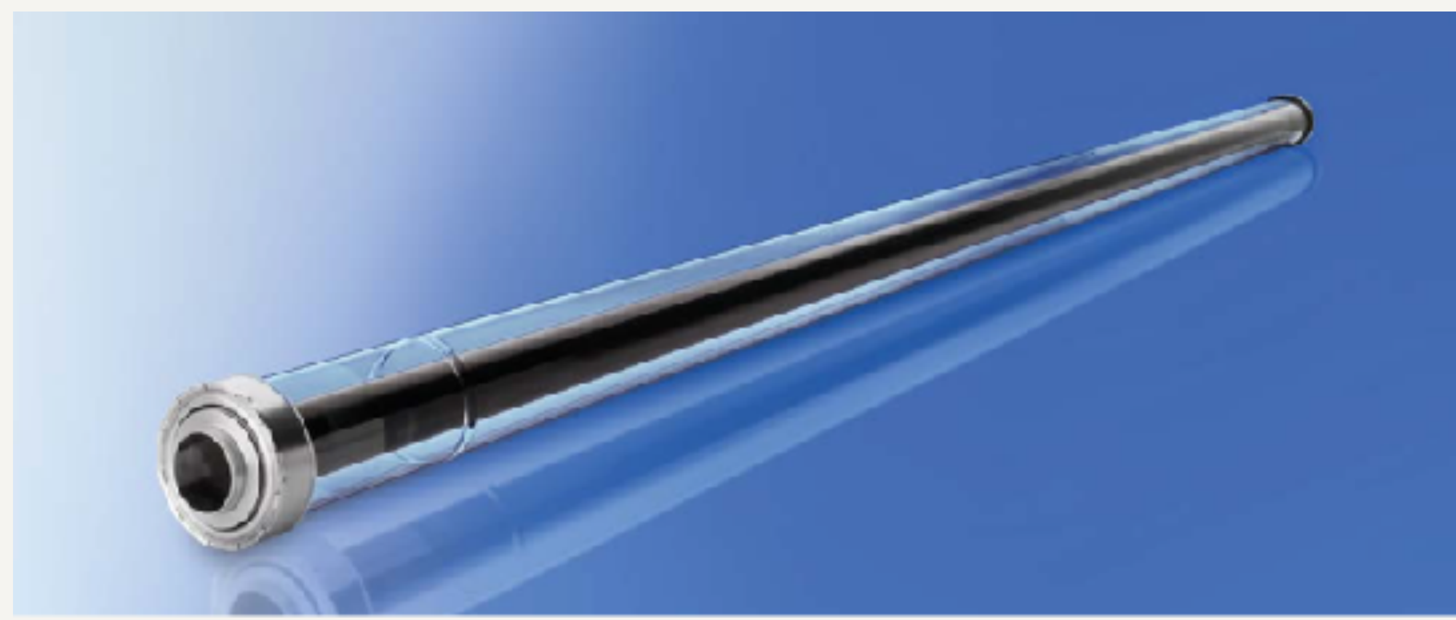
Vaccum Tube Collectors

Optics



Vacuum Tube Collectors

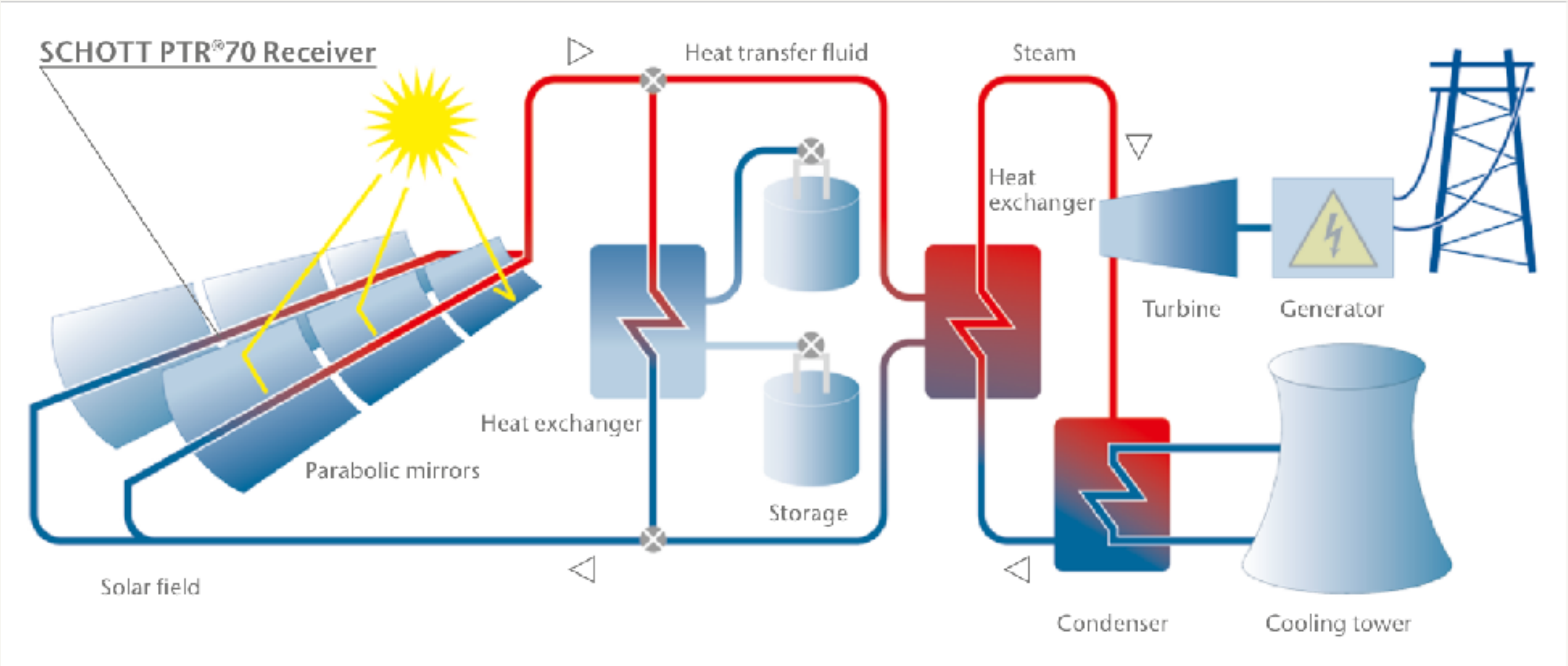
Real Example



Source: http://www.schott.com/csp/english/download/schott_ptr70_4th_generation_brochure.pdf

Parabolic Trough Power Plant

Netter Werbefilm: http://www.youtube.com/watch?v=GFJLbDpRu3U



Source: http://www.schott.com/csp/english/download/schott_ptr70_4th_generation_brochure.pdf

List of Parabolic Trough Power Plants

http://www.nrel.gov/csp/solarpaces/parabolic_trough.cfm

Parabolic Trough Plant Properties

	Andasol I	SEGS I	Solana
Place	Sevilla, Spain		Phoenix, Arizona
Power / MW	50	13.8	280
Generation / MWh	158000		944000
Area / m^2	510 120	82 960	2 200 000
# Receivers	11232		32320
Temperature	293°C - 393°C	307°C	293°C - 393°C
Start date	2008	1984	2013

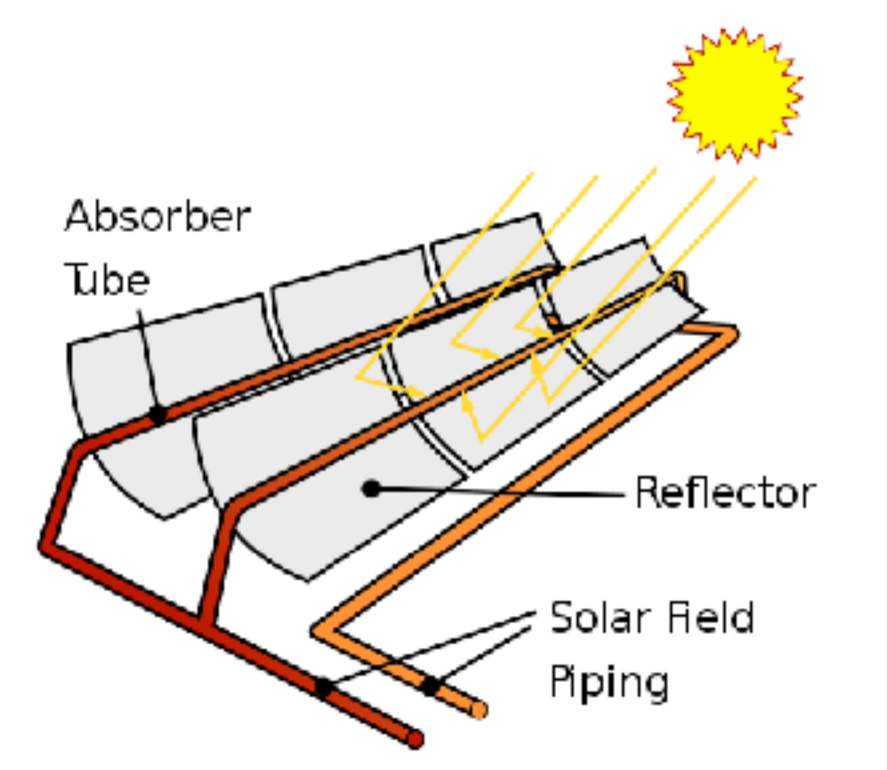
http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=3

http://www.csp-world.com/cspworldmap/solana

http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=28

Some technical details

- Heat transfer fluid is currently a thermo-oil with approx. 400°C (max)
- One project by Abengoa to use Direct Steam Generation with temperatures up to 550°C
- Tracking is necessary:
    - seasonal tracking (west - east)
    - daily tracking (north - south)

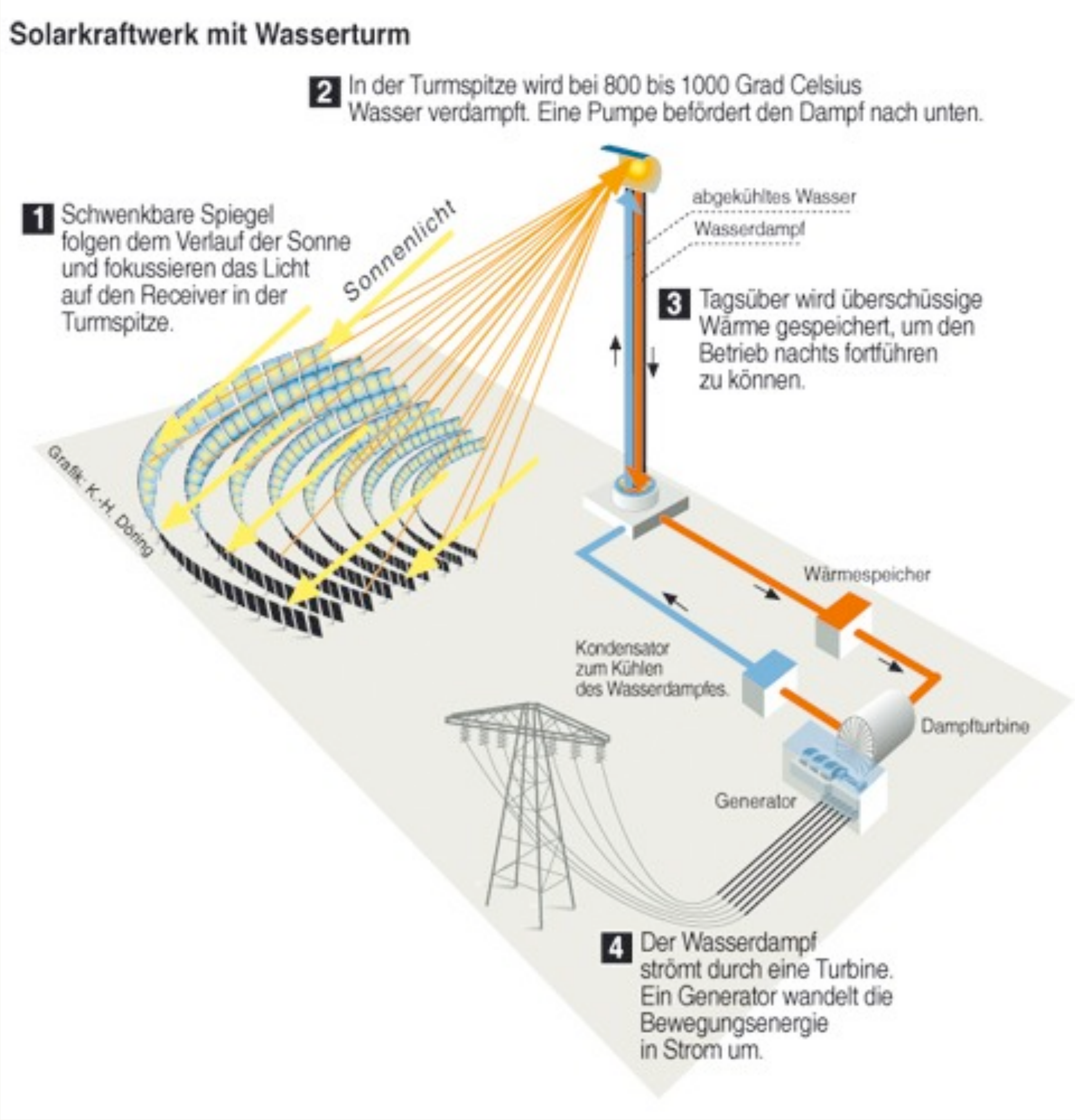


http://www.schott.com/csp/german/schott-solar-ptr-70-receivers.html

Solar Tower

Solar Tower Power Plant

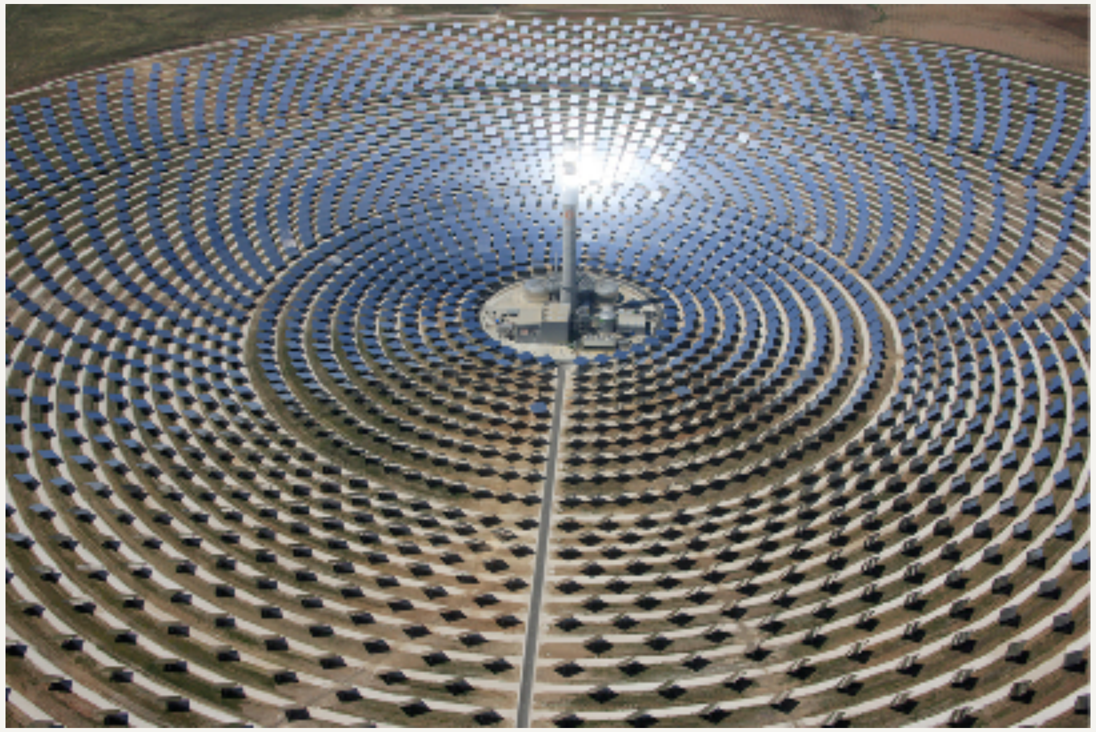
- Many mirrors reflect the light onto a single absorber.
- Extreme temperatures are theoretically possible (several 1000°C)
- Typical operation temperature 565°C (vapor turbine).
- Requires two-axis tracking for every (!) mirror.
- Heat transfer medium: molten salt, steam, air.



http://www.aerogie-solar.de/index.php?id=8,21,0,0,1,0

Solar Tower Gemasolar, Sevilla, Spain

- 2600 Heliostats (318.000 m^2)
- Tower height 140 m
- 19.9 MW
- Heat transfer fluid: molten salt @ 500°C
- Heat storage for 15h (!) operation.



Solar Tower Jülich

- 2153 Heliostats
- Tower height 60 m
- 1.5 MW
- Experimental plant as technology demonstrator
- Heat transfer fluid: air.
- Special ceramic absorber and storage.

http://www.spiegel.de/fotostrecke/desertec-strom-aus-der-wueste-fotostrecke-49258-3.html

Ivanpah

Source: http://www.ivanpahsolar.com/photos-and-videos

Solar Tower Plant Properties

	Ivanpah	Gemasolar	Jülich
Place	Ivanpah Dry Lake, Calif.	Sevilla, Spain	Jülich, Deutschland
Power / MW	392	20	1.5
Generation / MWh	1 079 232	110 000	
Area / m^2	2 600 000	304 750	17 650
# Heliostats	173 500 / 3	2650	2153
Temperature	565°C	565°C	680°C
Start date	2014	2011	2008

http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=62

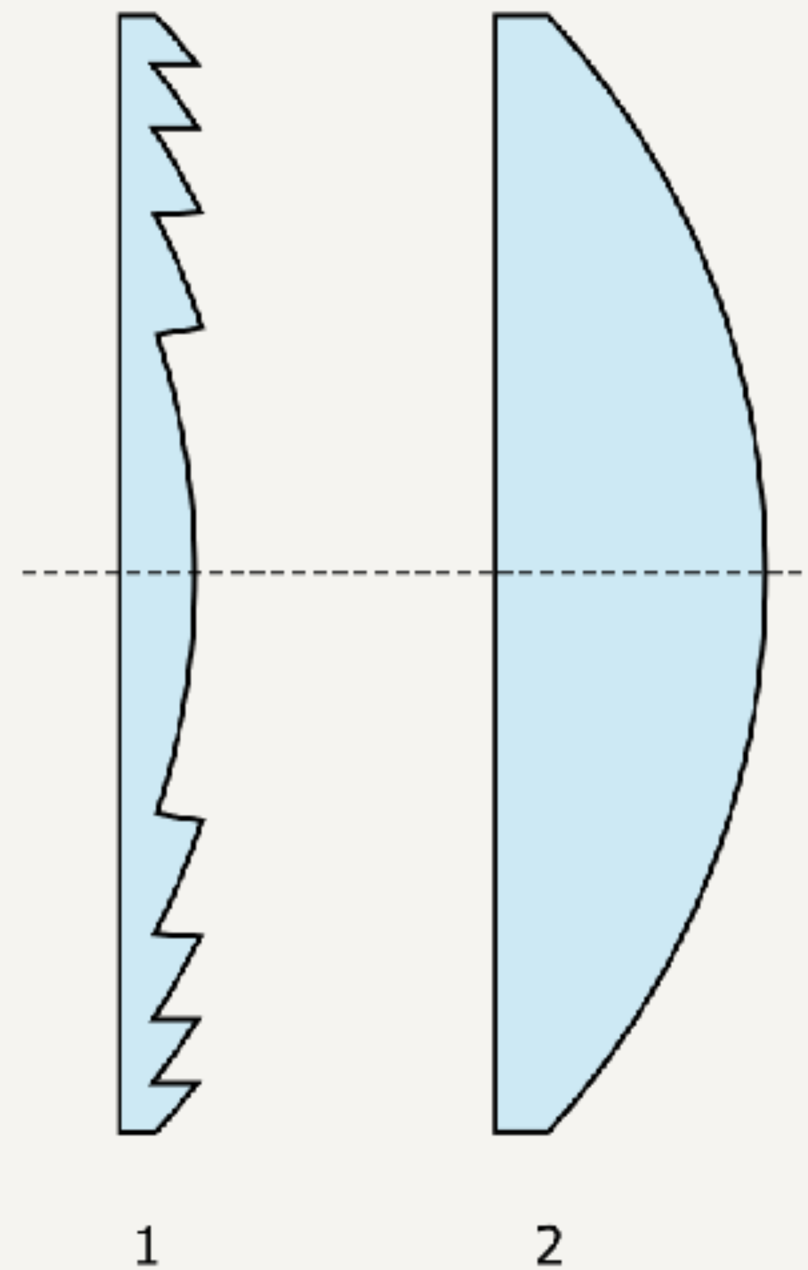
http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=40

http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=246

Fresnel Reflector

Fresnel Lens

- For large optics (lighthouse) the glass becomes too heavy.
- Fresnel thought of a way to reduce the weight: simply eliminate the middle part of the lens and only keep the surface.
- Yields lower optical performance but much reduced material and weight.
- Not good for camera optics, but very useful for lighting.



WIKIPEDIA

Fresnel Lens

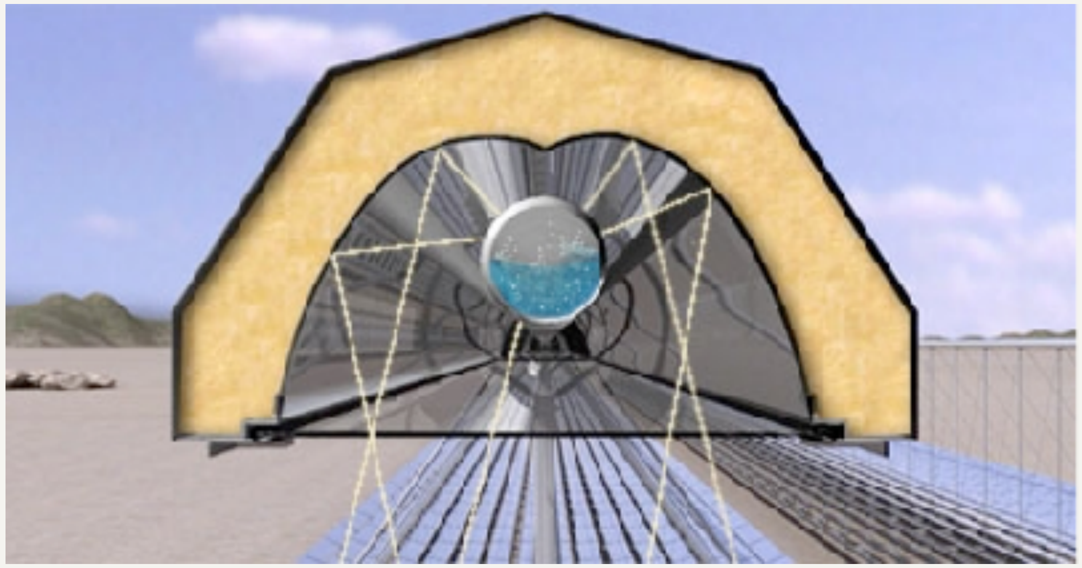
Lighthouse

Car Rear Light

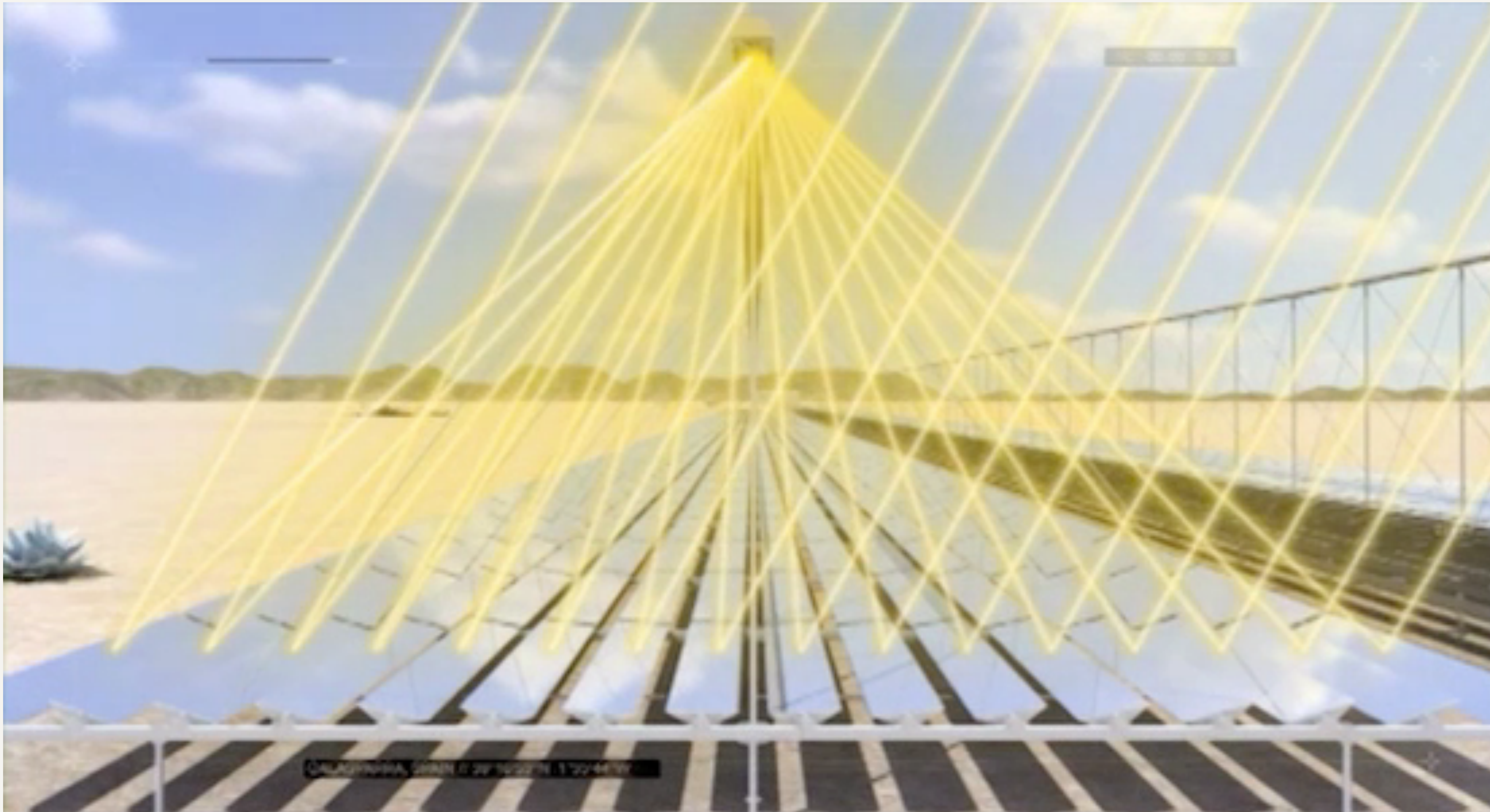
Fresnel Optics+ Parabolic Trough

- Many flat long mirrors reflect the sunlight onto the absorber
- Larger aperture (= collecting area) possible in comparison to parabolic trough (per row) allows for higher energy density.
- Flat metal mirrors easier to produce and handle.
- Secondary mirror increases efficiency.

http://www.novatecsolar.com/20-0-Nova-1.html



Fresnel-Konzentrator



http://www.novatecsolar.com/20-0-Nova-1.html

100MW CSP in India

- **Last year**: last week India officially connected the largest CSP plant with Fresnel reflectors.
- 100MW nominal power rating.

Source: http://www.pv-tech.org/news/the_worlds_largest_solar_project_with_clfr_technology_connected_to_the_grid?utm_source=pvtech-feeds&utm_medium=rss&utm_campaign=everything-rss-feed

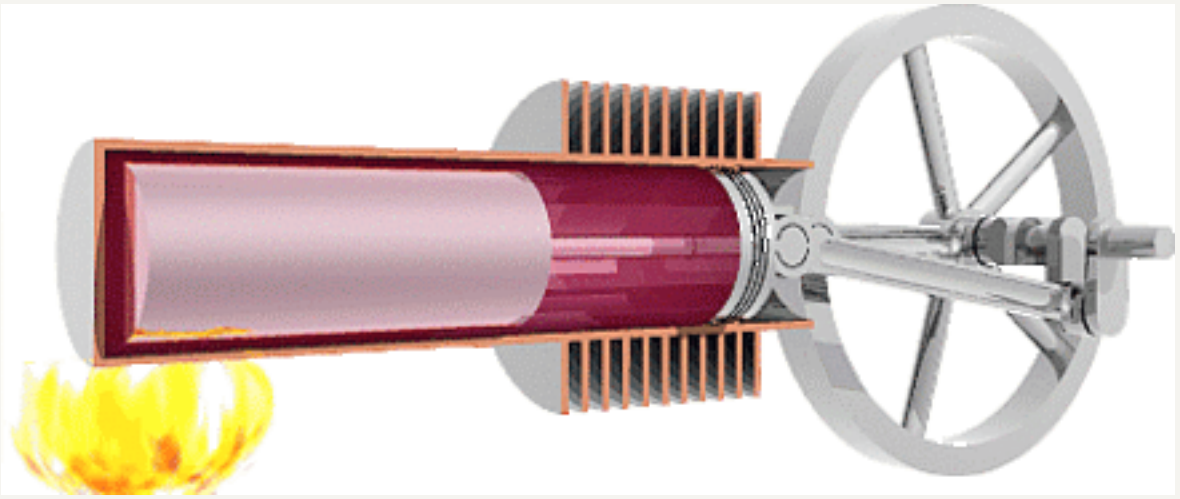
Dish Sterling

Dish Sterling

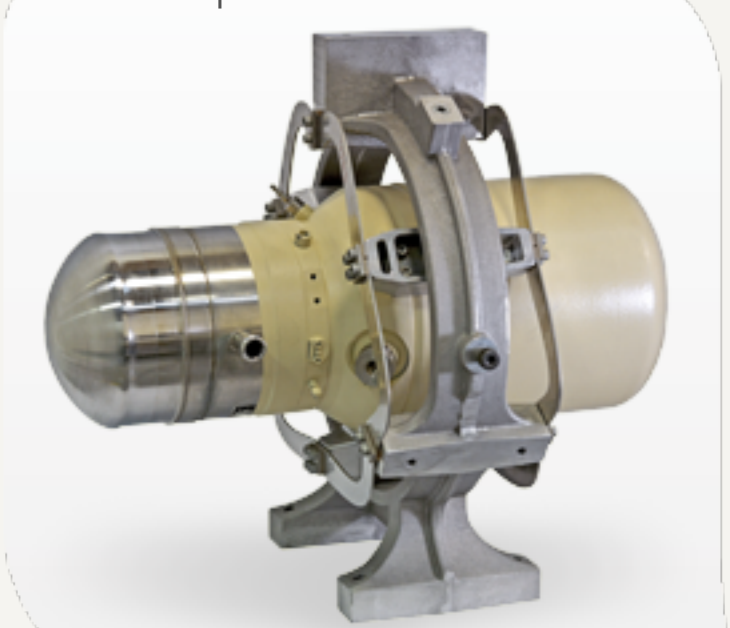
- Parabolic mirror: two-dimensional concentration
- A Stirling motor sits at the focal point of the mirror.
- Requires sun tracking.

Sterling Motor

- Works not with internal combustion but with external heat source.
- Accordingly **any** heat source can be used: gas, oil, sun, industry waste heat, ...
- Efficiency for solar heat on par with photovoltaics (20%)



In development: Linear Sterling!



http://www.qnergy.com/stirling

Solar Power Plants with Thermal Energy Storage

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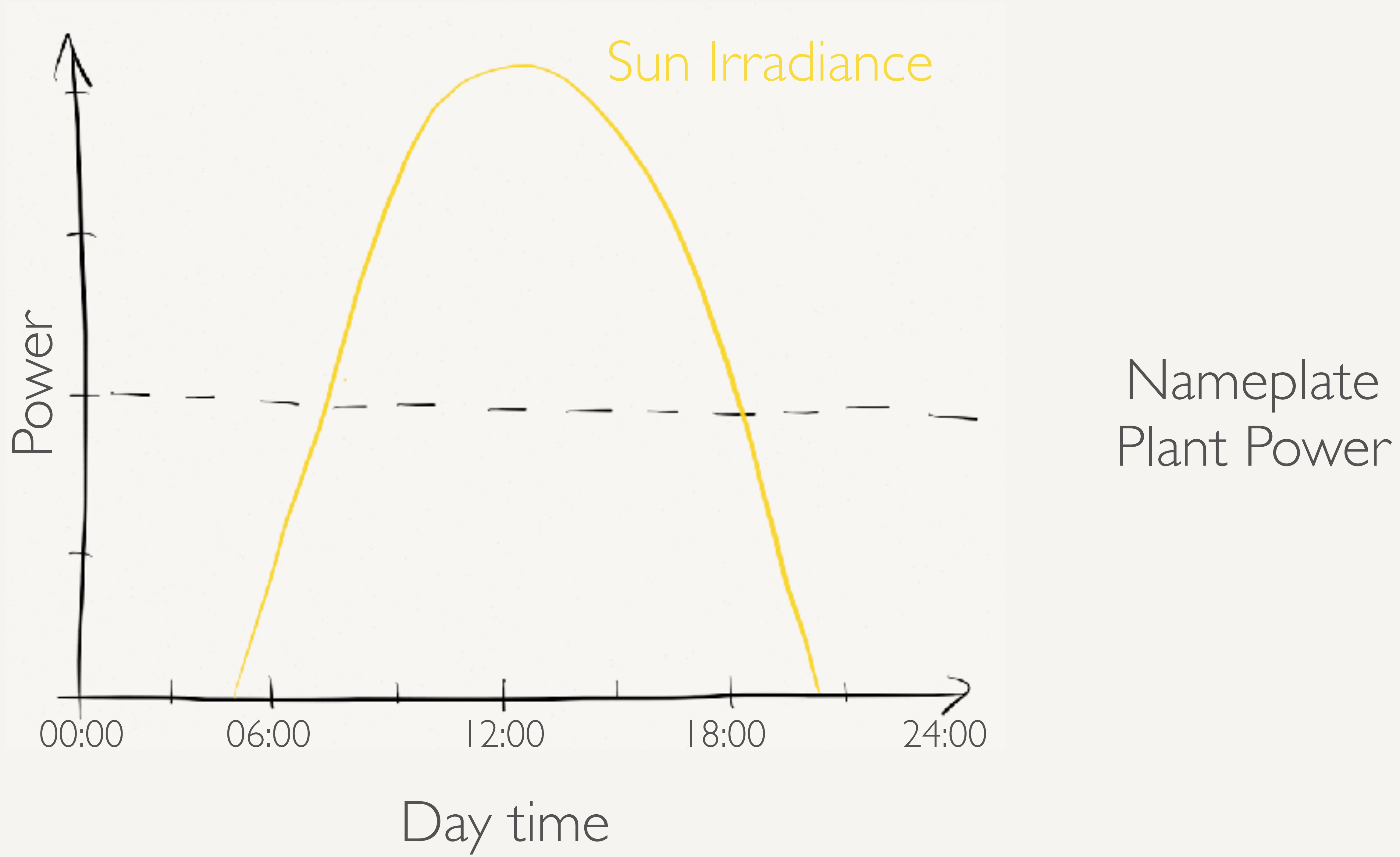
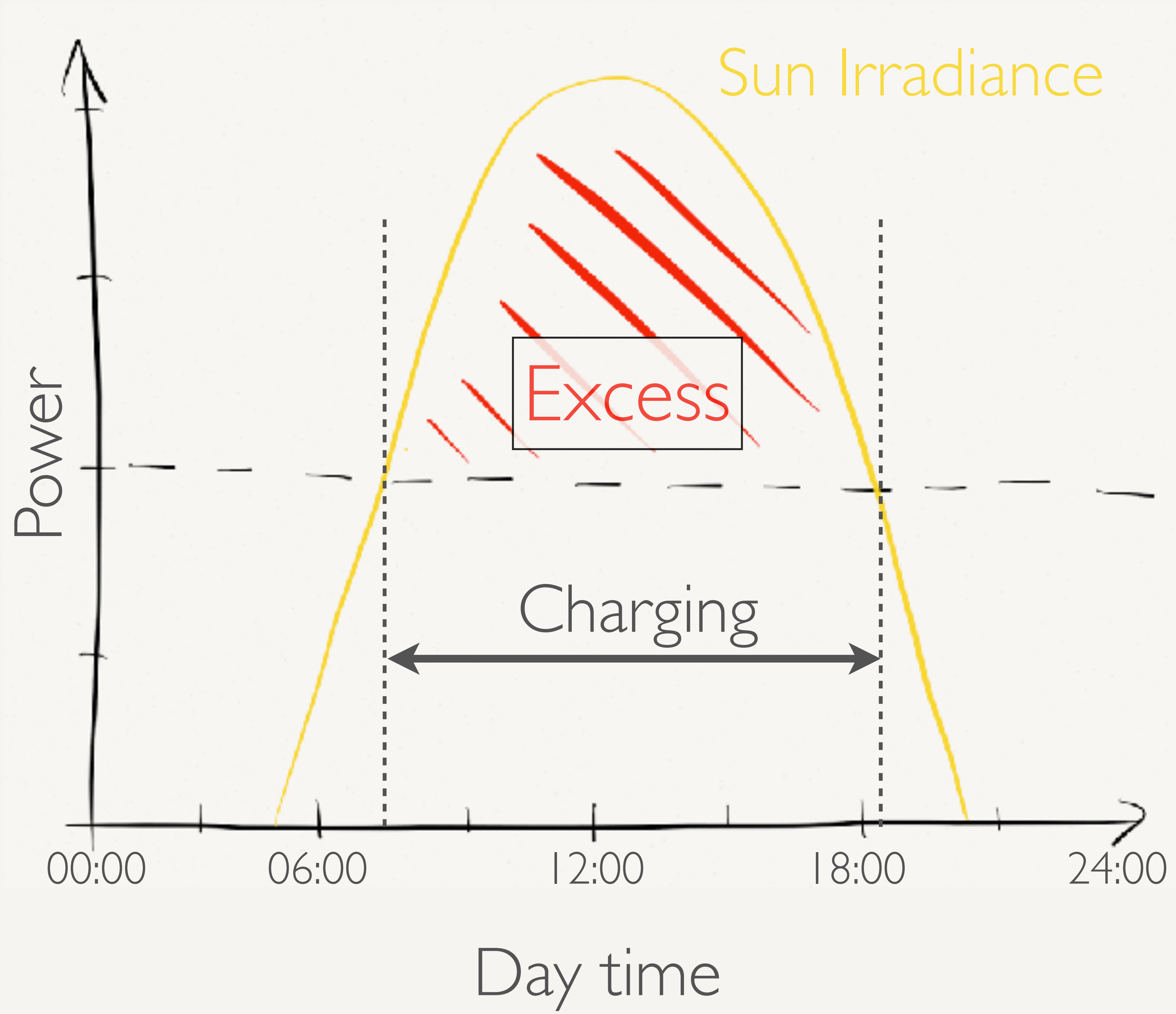
Solar Power Plant with Night Mode

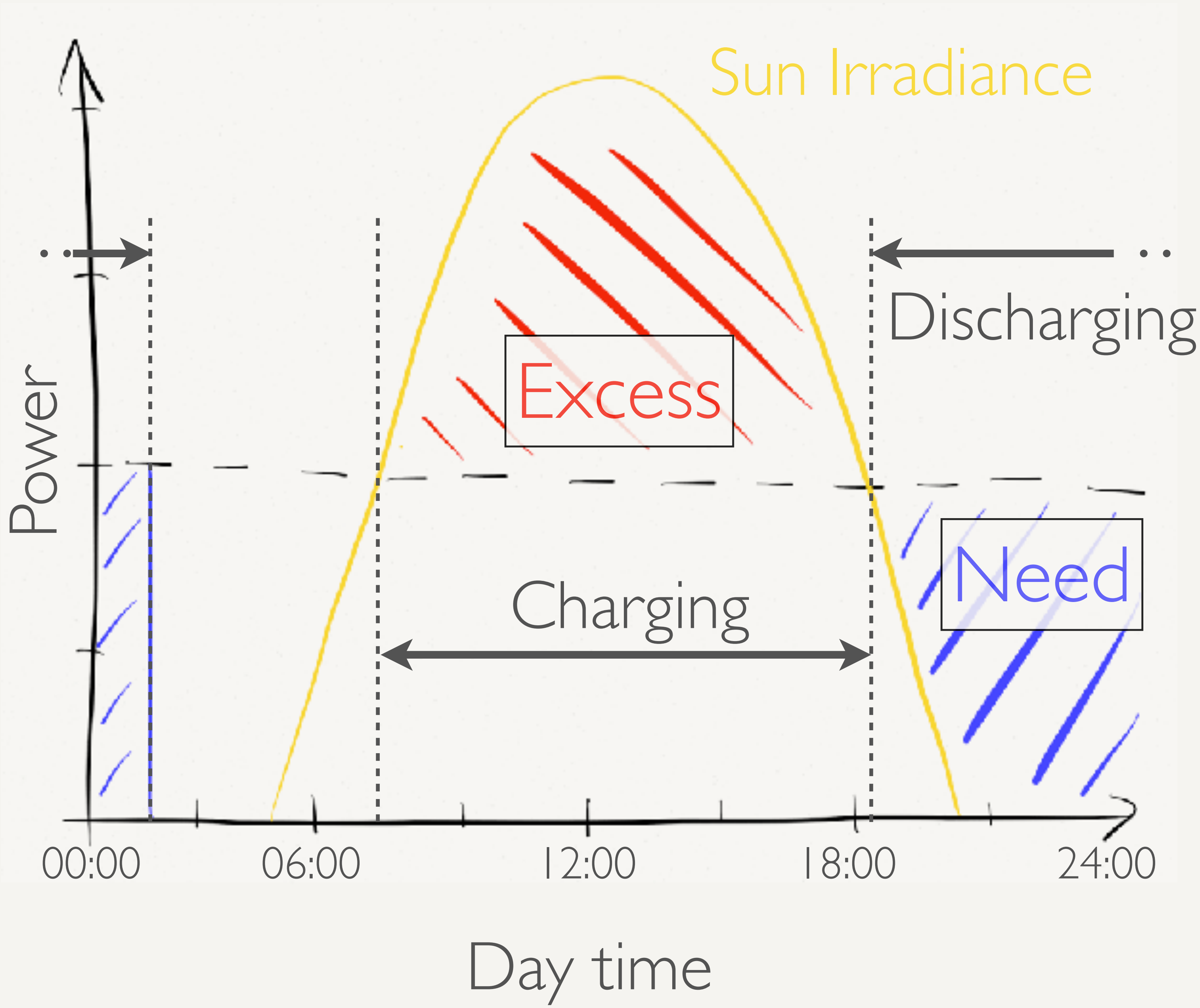


Solarkraftwerk mit Nachtbetrieb



Nameplate
Plant Power

Solarkraftwerk mit Nachtbetrieb



Nameplate Plant Power