CENTRE FOR RENEWABLE &
SUSTAINABLE ENERGY STUDIES

Solar Energy

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Department:
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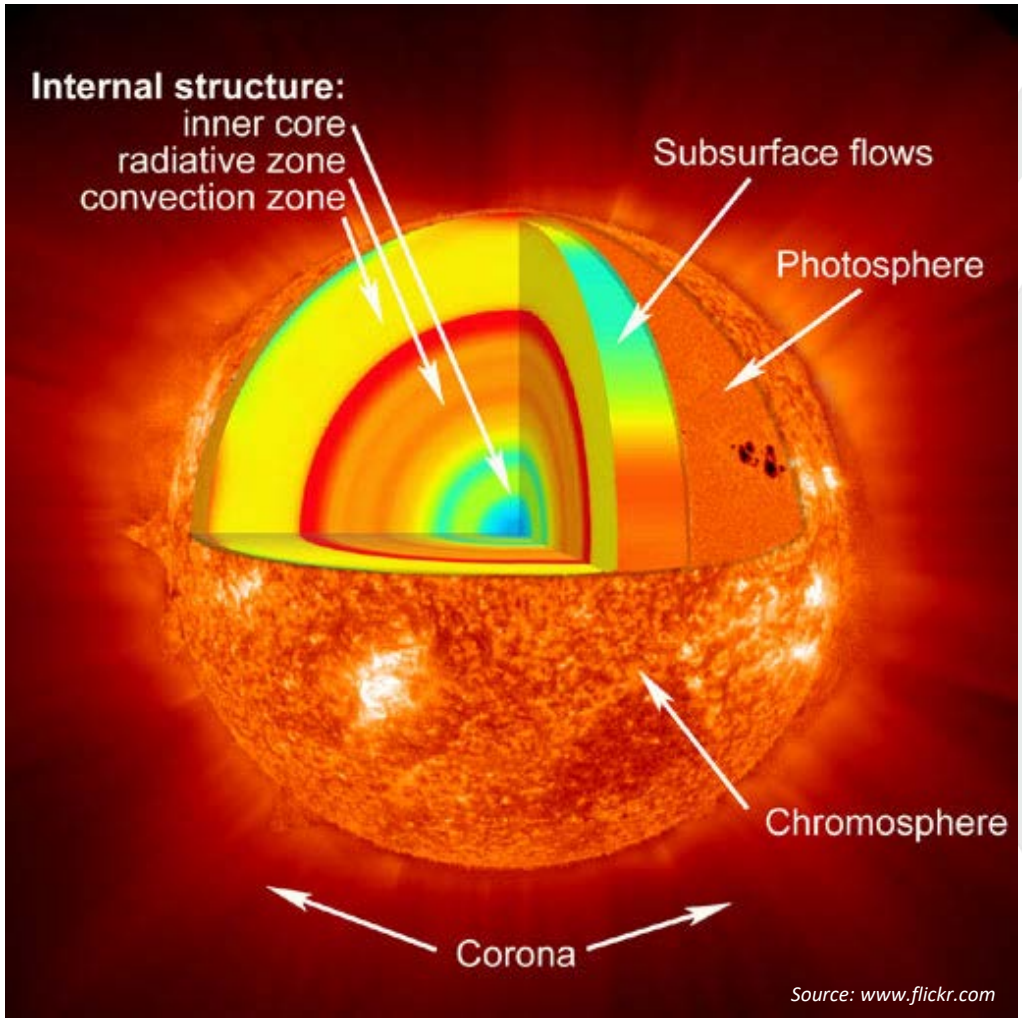
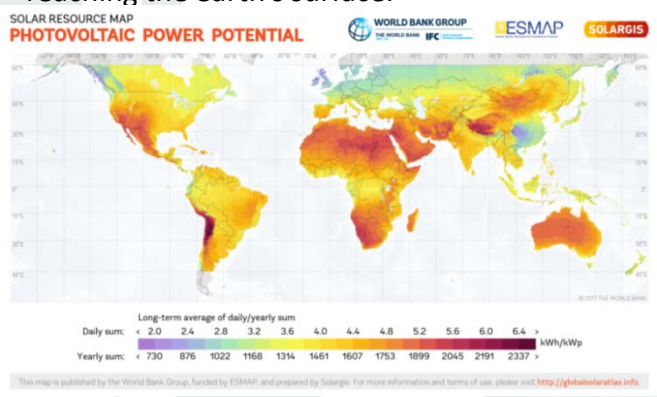
Solar Energy: The Sun

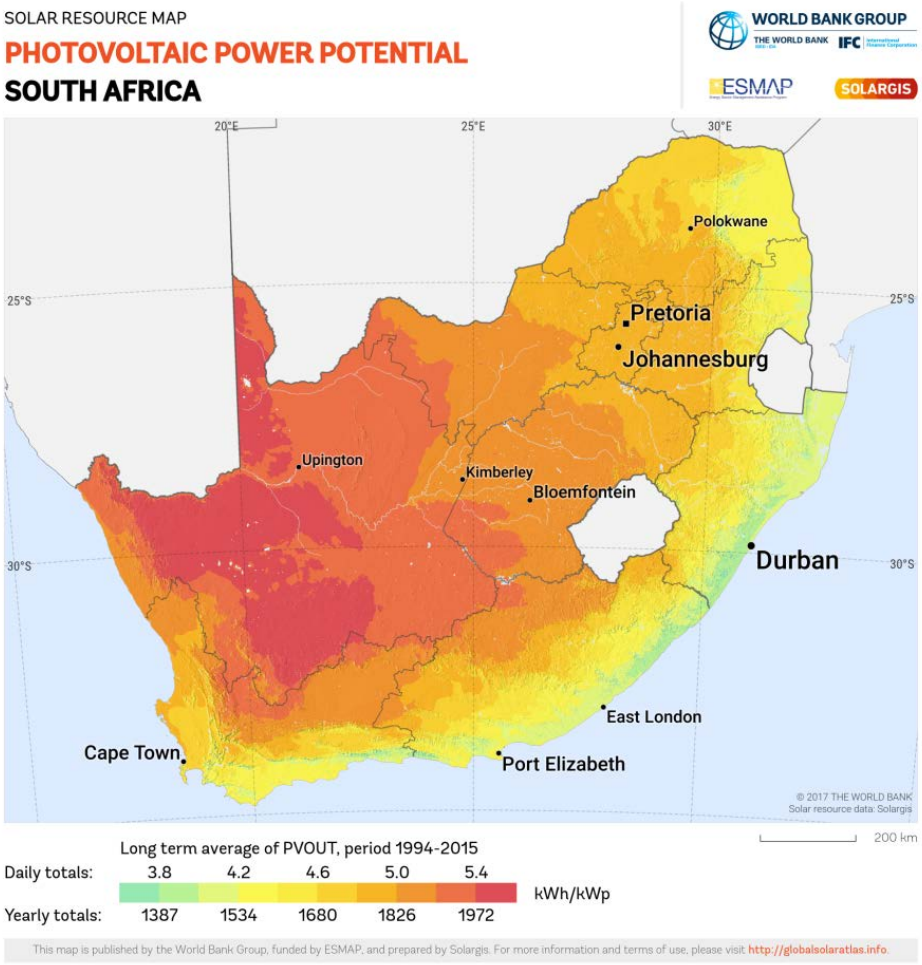


- The **sun** is the source of all life on planet Earth.
- The source of energy in the sun is at its **core.**
- This energy is **released** into space primarily as **electromagnetic radiation.**
- We experience this **radiation** as **heat** and **light.**
- Life exists on our planet because of its distance from the sun, resulting in acceptable **average temperatures** and the **greenhouse effect**.
- The earth is protected by an **Ozone layer** which absorbs most of the ultraviolet rays before reaching the earth's surface.



Ref: https://globalsolaratlas.info/downloads/world

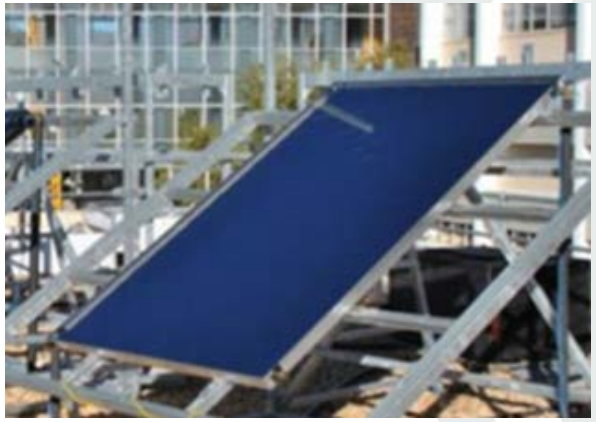
Solar Energy: How Powerful Is It?



Ref: https://globalsolaratlas.info/downloads/south-africa

- **Every hour** enough **sunlight energy** reaches the earth to meet the **world's energy demand** for a **whole year.**
- Even though only a percentage of this potential is accessible, it is still enough to provide just under **six times** the power the world currently requires.
- Remember, this energy is **distributed** over the complete spherical surface of the earth.
- It is mainly a question of how to convert solar energy as **efficiently, sustainably** and **cost-effectively** as possible into electricity and hot water.
- South Africa has the perfect climate for **solar energy**, one of the best in the world.
- South Africa has on average more than 2 500 hours of sunshine every year.

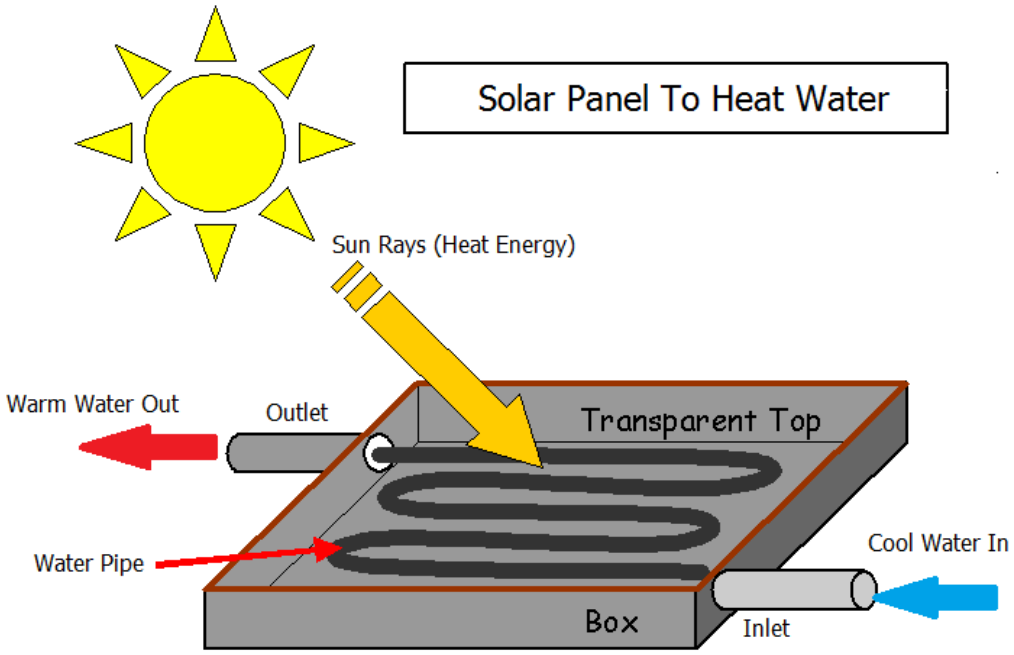
Solar Energy: Types and Uses

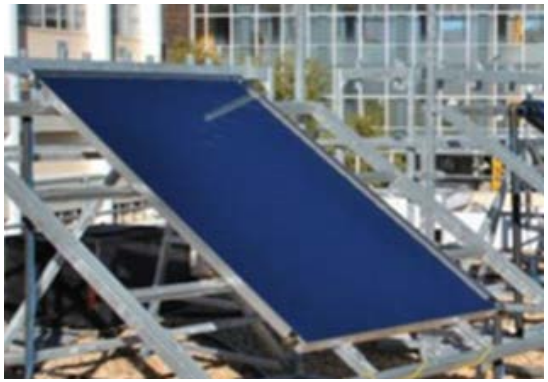


Three main types and uses:

- **Solar electric** for instance **photovoltaic (PV):** This type of solar energy is used to produce electricity from direct sun light using photovoltaic cells.
- **Concentrated Solar Power (CSP):** This typed is used to produce very high temperatures, for heating to temperatures above100^{o}C. The heat can then also be used to produce steam that can be used to produce electricity using steam turbines.
- **Solar thermal (ST):** for instance domestic solar water heater (SWH), heating temperature below 100^{o}C.

Solar Water Heating: Flat Panel Collector

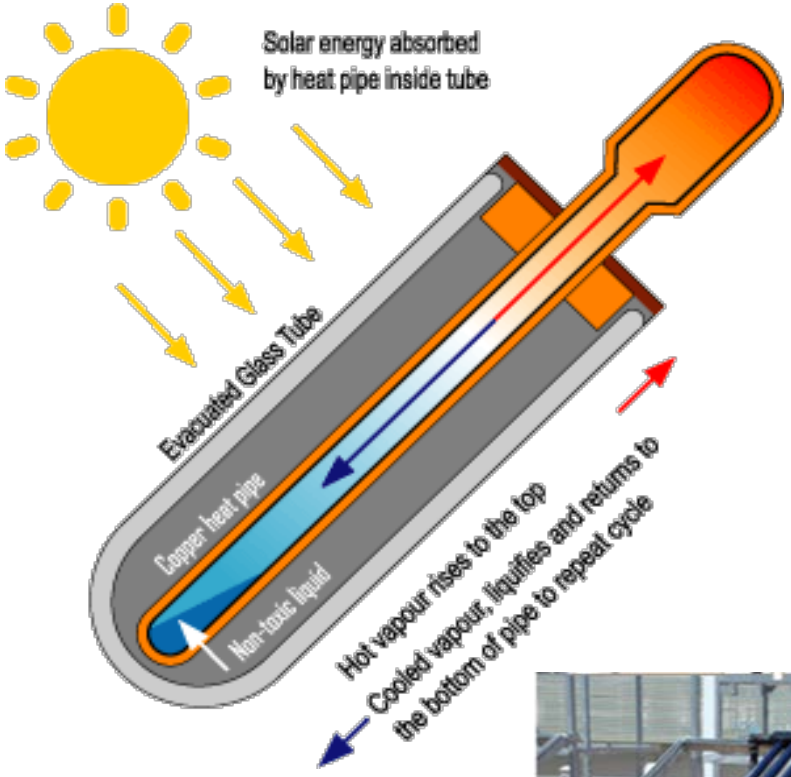




Flat panel collectors – how they work:

- A **flat panel solar water** heater is a 'box' with a glass cover. Inside is a series of copper tubes attached to a **sheet metal absorber**.
- The sheet metal absorber is coated in a black substance designed to capture the sun's rays – this is called a **selective surface**. Black paint can also be used.
- The **collector** has insulation on the back and on the sides, to prevent the heat from being lost to **ambient temperature.**
- Via the **absorber**, the sun rays heat up the water which circulates from the collector to an **insulated tank**, ready to be used.
- It can be used for anything from **heating domestic hot water** and living spaces, to heating swimming pools.
- Sometimes the panels are also used for **solar-assisted cooling, industrial processes** and the **desalination of drinking water.**

Solar Water Heating: Evacuated Tube Collector



Evacuated tube collectors – how they work:

- Consists of multiple **evacuated glass tubes** with **solar absorbers** that collect the heat energy from **sun.**
- The vacuum between the inner and outer tubes serves as a form of **insulation** to minimise heat loss.
- The **absorber** inside the vacuum tube **absorbs** the **radiation** from the **sun** and heats up the heat transfer fluid inside the copper pipe via conductive heat transfer fins.
- Additional **radiation** is picked up from the **reflector** behind the tubes.
- Whatever the angle of the sun, the round shape of the vacuum tube allows it to reach the absorber.
- Even on a **cloudy day**, when the light is coming from many angles at once, the vacuum tube collector can still be effective.

Solar Water Heating: Direct vs Indirect

Evacuated cube collector

Flat plate collector

Source: commons.wikimedia.org

There are two main ways of heating water in a solar water heater:

1. **Indirect system**:
   - Indirect systems use a **heat transfer fluid** (typically a mixture of water and ethylene glycol) to move the heat from the solar collector to the tank.
   - The **solar loop** of indirect systems is **freeze resistant**, but they have a higher **capital cost** compared to direct systems.
2. **Direct system**:
   - Direct systems **heat the water** that is consumed or stored in the collector.
   - Direct systems should be **limited to warm climates** or those areas that experience only a couple of freezing days per year as the water freezing in the pipes can damage the system.

Solar Water Heating: Direct vs Indirect

Evacuated cube collector

Flat plate collector

In **direct systems**, the water circulation through the collector can be realized by two ways:

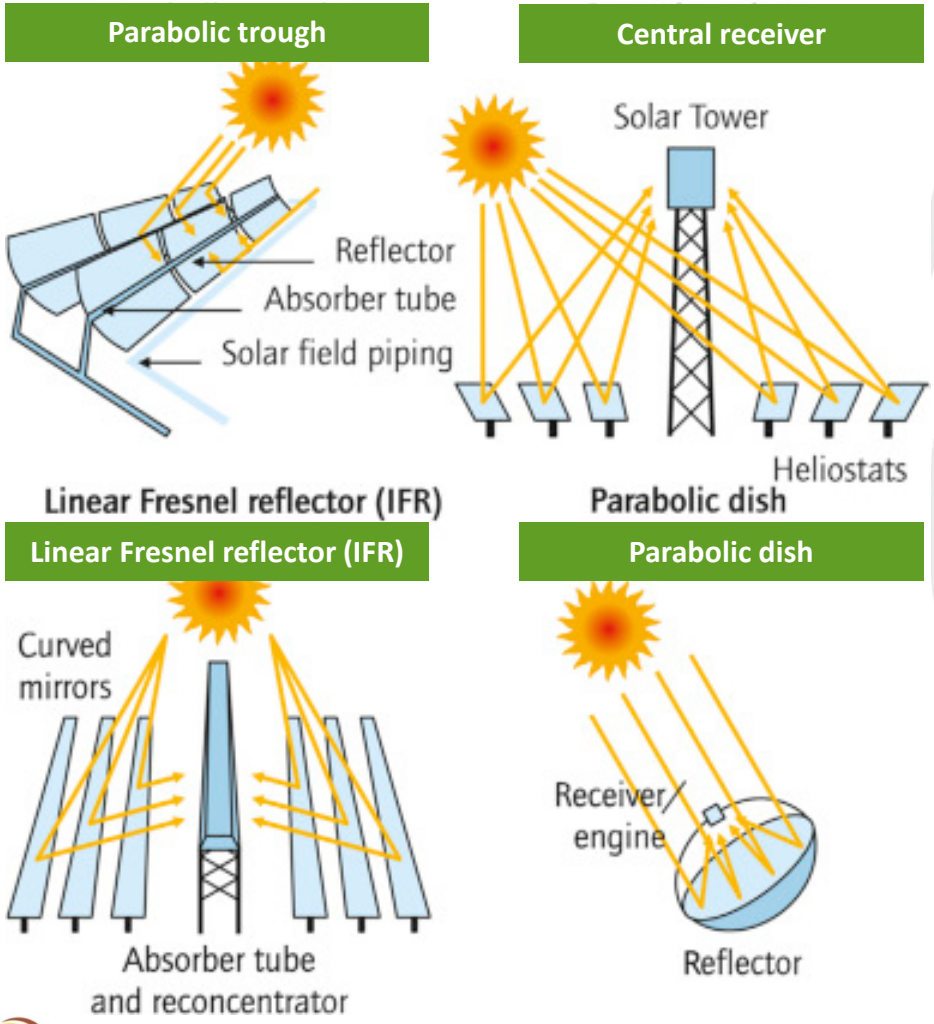
2.1 Active system:

- An active system has a **solar water heating system** with a circulation pump to transfer heat from the collector to the solar storage tank.

2.2 Passive system:

- This system uses no pump or control system, but **natural circulation** (thermosiphon). Differences in the temperature of the water cause circulation between the heated water in the solar collector and the storage tank.
- **Electrical water heating** accounts for a large portion of the energy use in the average South African household.
- Water heating comes mainly from electricity derived from **fossil fuels** and releases 4,5 tons of CO_2 per year.
- If solar energy were to be used instead, households would not only **save money,** but also **electricity**, which would in turn benefit the environment in which we live.

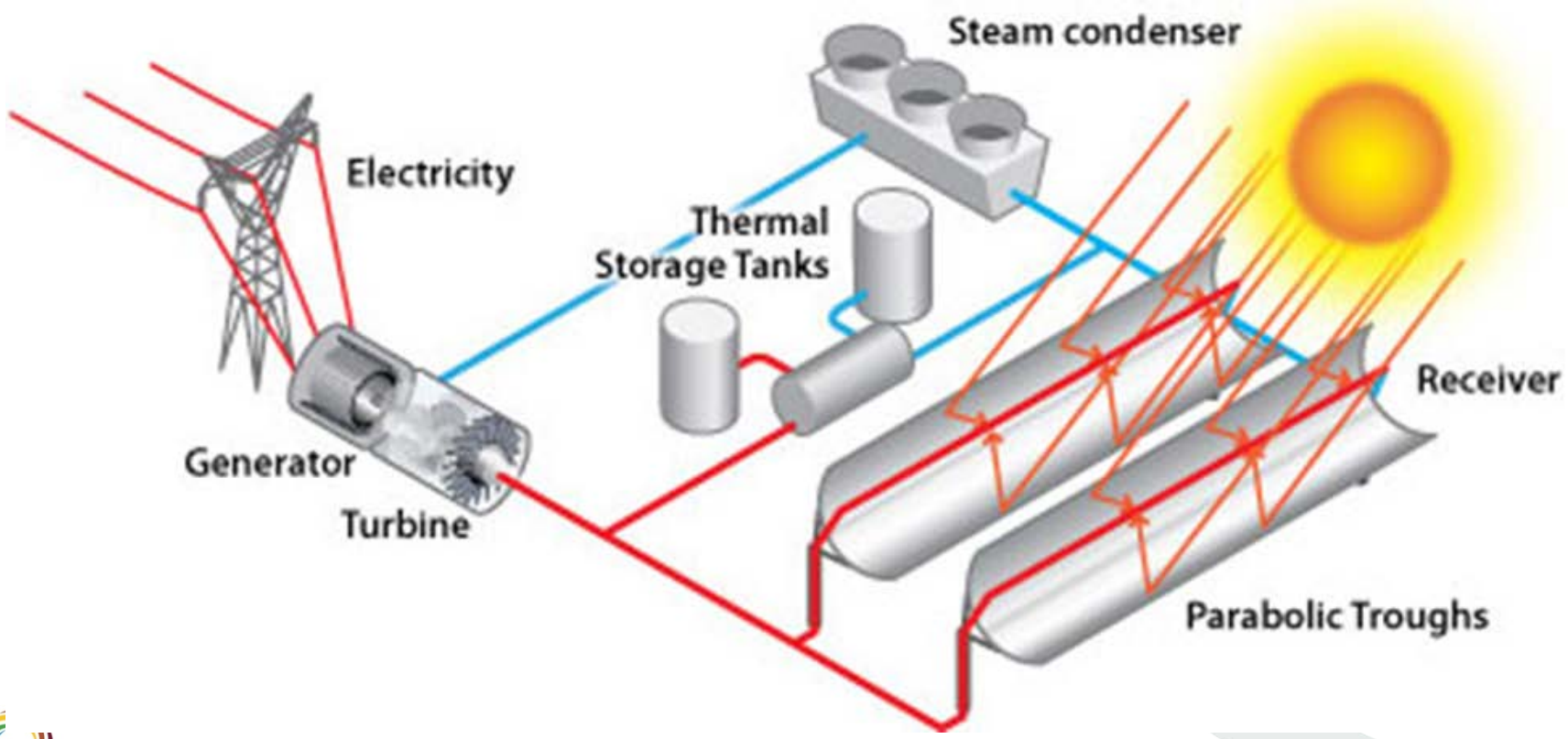
Concentrated Solar Thermal Power Plants (CSP): Concentrated Solar Energy



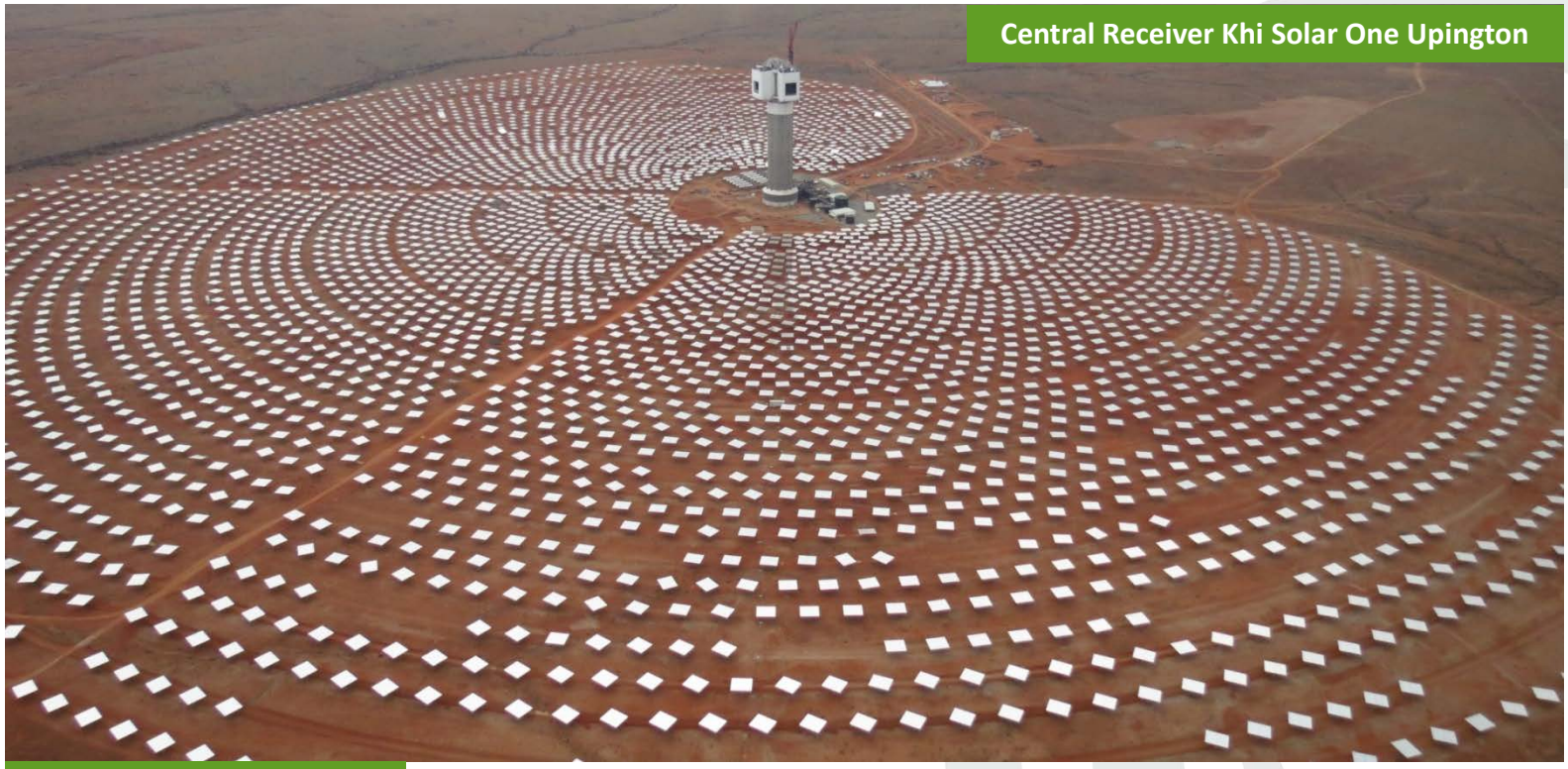
- **Concentrated Solar Thermal Power Plants (CSP)** makes use of concentrated solar energy.
- **Solar energy** can be **concentrated** onto a **point or line** receiver with the following technologies:
  - Parabolic trough
  - Fresnel reflectors
  - Central receiver
  - Parabolic dish

Concentrated Solar Thermal Power Plants (CSP): Converting Solar Energy into Electricity

- A **concentrated solar thermal power plant** converts solar heat into electricity.
- The temperature in a concentrated solar thermal power station is high enough to **produce steam**.
- The steam is fed into a steam turbine which drives an **electric generator** to generate electricity.
- Similar systems are used in coal and nuclear power stations, where **coal** and **nuclear energy** are used to produce the heat.



Central Receiver Khi Solar One Upington



Central Receiver Helio100 Mariendahl Stellenbosch University

Parabolic Trough Kaxu Solar One Upington

Khi Solar One Upington

Concentrated Solar Thermal Power Plants (CSP)

Parabolic Trough Kaxu Solar One Upington

Parabolic Trough Kaxu Solar One Upington

Benefits:

- Using **solar energy** from the sun does not cause pollution.
- Solar energy is a **renewable resource**, so it will never run out.
- Fossil fuels are conserved, thus **limiting harmful emissions** and **climate change.**
- The energy of the sun is **free** and it can be used whenever the sun is shining, from your back garden right up into space.
- **Thermal storage** (heat) makes it possible for solar thermal power stations to generate electricity at night.
- CSPs can deliver **dispatchable electricity** 24/7 because of the heat storage.

Problems:

- The electricity-generation **costs** of solar thermal power stations are still **high**, but the more the technology is developed, the cheaper it becomes, especially in light of the fact that the fuel, the sun, is free of charge.

Concentrated Solar Thermal Power Plants in South Africa

Khi Solar One 50 MW Upington Central Receiver

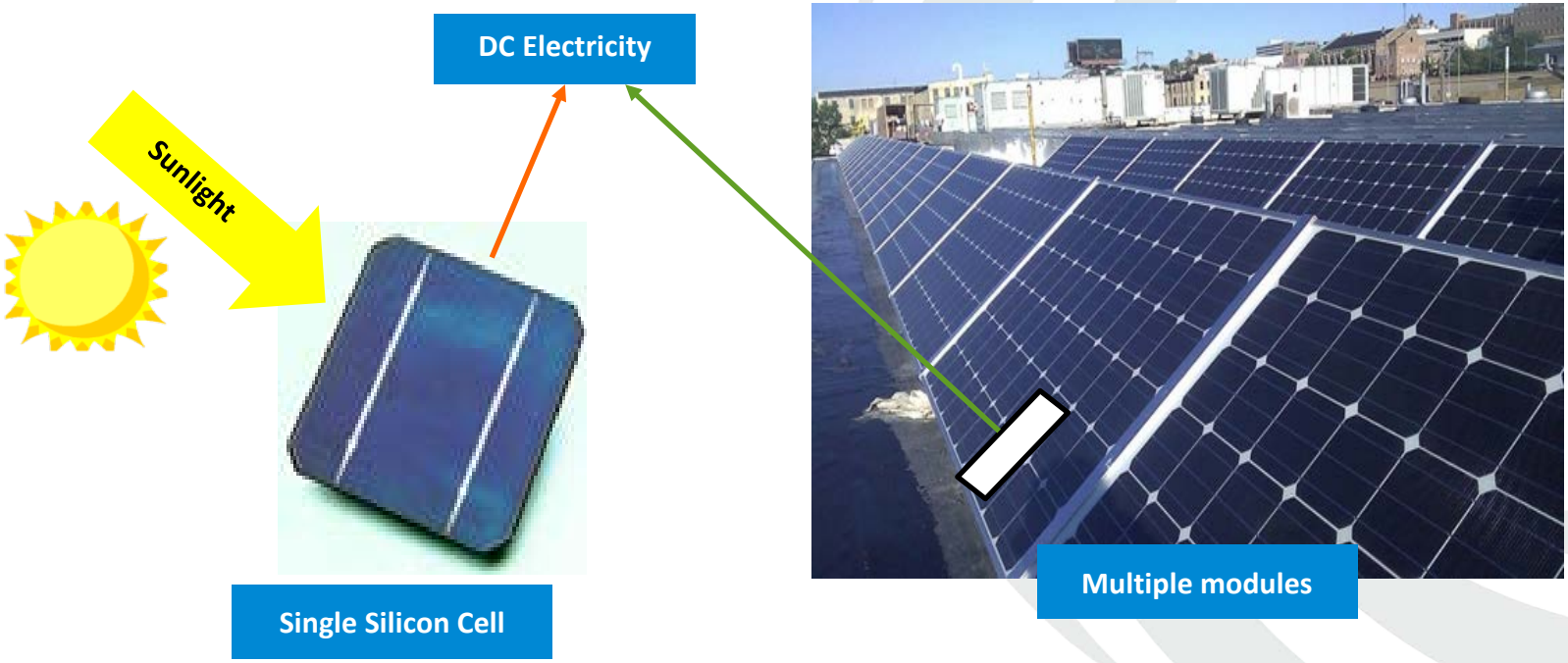
KaXu Solar One 100 MW Upington Parabolic Trough

- **REIPPPP: R**enewable **E**nergy **I**ndependent **P**ower **P**roducer **P**rocurement **P**rogramme
- The first bidding round of the REIPPPP started in 2011; to date four bidding rounds have been completed.
- Refer to this website for a map which provides the details of each REIPPPP project in South Africa: www.eskom.co.za/Whatweredoing/Pages/RE_IPP_Procurement_Programme.aspx
- The following details can be viewed on the website:
  - Name of the project
  - Type of technology being build
  - The capacity of the power plant and the

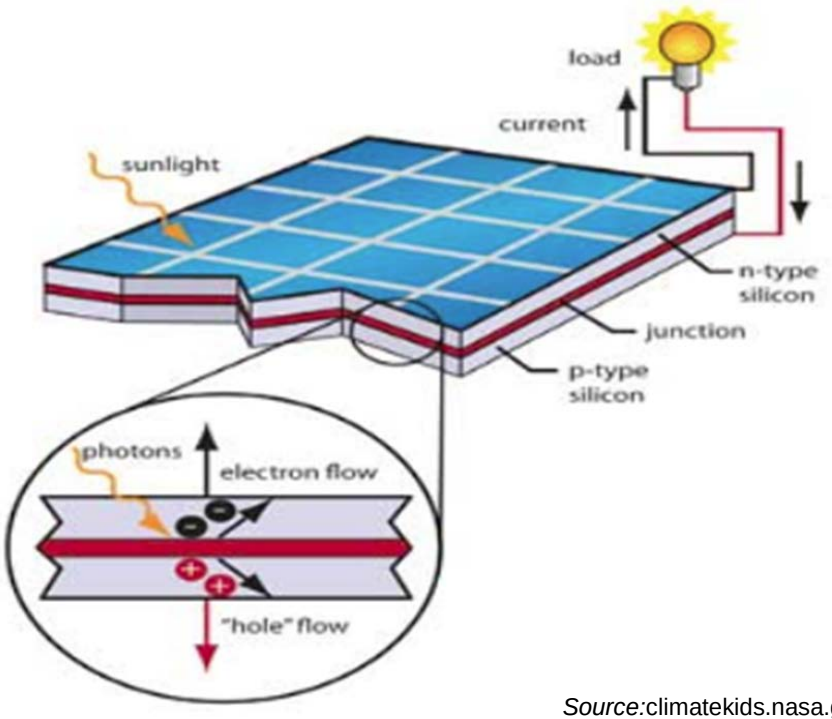
Bidding rounds	Capacity allocated (MW)	Number of Projects
Window 1	150	2
Window 2	50	1
Window 3	200	2
Window 3.5	100	1
Window 4&4b	-	-
Total	**500MW**	**6**

Photovoltaic Panels: Photovoltaic effect

- **Converting solar energy (light)** to **electrical energy** by means of solar cells is known as the **photovoltaic effect.**
- A **solar panel** consists of a group of **solar cells**, which convert solar energy into electricity.
- **Solar cells** are predominantly made from silicon, a semiconductor, the same type of material used to make computer chips.
- When these materials absorb solar energy (photons), tiny electrically charged particles called **electrons** are caused to move through them.



Photovoltaic (PV) Panels: Converting Solar Energy (light) into Electricity



Source:climatekids.nasa.gov

- PV panels consist of semiconductors.
- Each cell consists of two types of semiconductor layers, one positive and one negative.
- When light shines on the semiconductor, the electric field across the junction between these two layers causes an electric current to flow.
- The p-type tends to get rid of the electrons.
- The n-type tries to collect them.
- Light gives the energy for electrons to move between the two layers, and this flow generates electricity.
- The greater the intensity of light, the greater the flow of electricity.

Photovoltaic (PV) Panels: Small-scale Systems

How a Solar System Works

Lourensford Wine Estate

- Small PV systems can generate electricity for your household and business, but a DC (Direct Current) to AC (Alternative Current) converter is needed.
- This solar electricity can power all electricity appliances in the house (e.g. computer, geyser, fridge, freezer, washing machine, stove, lights.)
- If the PV system produces more electricity than is currently needed, Batteries can store PV electricity for times when sun is not shining
- The PV system can feed PV electricity back into the grid (allowed in some of the Western Cape municipalities)
- Independent PV panels can also be used to retrofit your existing geyser (only the geyser's heating element has to be exchanged to work on AC and DC, no converter needed).

Photovoltaic Power Plants in South Africa

Source: Stephen Forder

Sishen Solar Farm 74 MW

Source: Stephen Forder

Konkoonsies, Pofadder, 10 MW

Cost of energy-generation technologies:

- The best measure to compare energy-generation technologies is the electricity generation costs (ct/kWh) over the lifetime of a plant.
- In South Africa, the costs of renewable solutions have been decreasing rapidly, especially of PV.
- Because of the free-energy carrier, the sun's rays, these costs are highly predictable in comparison to a coal-fired power plant for example, where you have to take uncertainties in future fuel prices into account.
- PV today is significantly cheaper than nuclear energy generation, even when excluding all additional costs of nuclear waste treatment and transport.
- Thus, the electricity costs from renewable energy are much more predictable than those of fossil or nuclear energy.
- Research by the CSIR (Council for Scientific and Industrial Research) also shows that residential-sized photovoltaic systems are already a cost-competitive alternative to other new-built options, coming in at an estimated 81 cents a kilowatt hour (kWh) versus 80 cents at Medupi or Kusile. This solar power cost includes financing at an interest rate of 9% (CSIR, 2015).

References

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