06b – Renewable energy

Definition, main features and conversion systems

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MECA H417 / MECA H530 – Sustainable energy
A. General overview

http://atm.ulb.ac.be

Lesson plan

Content

a. Renewable energy definition, list and main features
b. Conversion RES into final energy (electricity, heat, fuels) or storable form of energy

General learning outcome

You are able :

- To describe renewable energy sources and their energy conversion aspects

Specific learning outcomes

- To describe the presented concepts
- To define renewable energy and comment main features compare to conventional
- To enumerate main conversion systems into mechanical energy, electricity or heat
- To comment storability of renewable energy
- To describe the main conversion principles
- OoM: Belgian annual energy per area and variability: Sun, Wind, Hydro, Natural heat, Biomass

Bibliography extract

EVERETT

HERMANS

- Part2. Chap. 8. Solar energy – Chap 9 Wind power – Chap 10 Energy from water and soil

MACKAY

Other material

- L. FRERIS, D. INFIELD - *Renewable energy in power systems* - Wiley edition, 2008. 284p. - ISBN 978-0-470-01749-4
- G. BOYLE - *Renewable Energy : Power for a Sustainable Future* - Oxford University Press third edition, 2012. 584p. - ISBN 978-0-19-954533-9
- IEA – *World energy outlook: Renewable energy* - Free download : http://www.worldenergyoutlook.org/media/weowebsite/2013/WEO2013_Ch06_Renewables.pdf

a. Renewable Energy - Definitions

Renewable energy can be defined as **final energy obtained from energy flows that regenerate permanently by the sun** and its derivatives (wind, watercourses, waves, ocean currents, natural heat and biomass growth), and also by the **tides** and the **geothermal heat**.

Renewable energy sources can be defined as **energy flows which are replenished at the same rate as they are used** (Sorensen, 2000)

DIRECTIVE 2009/28/EC : Energy from renewable sources means energy from renewable non-fossil sources, namely **wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases.**

Aerothermal energy means energy stored in the form of heat in the ambient air; **Geothermal** -> heat beneath the surface of solid earth; **hydrothermal** -> heat in surface water;

Biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste;

http://eur-lex.europa.eu/

DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

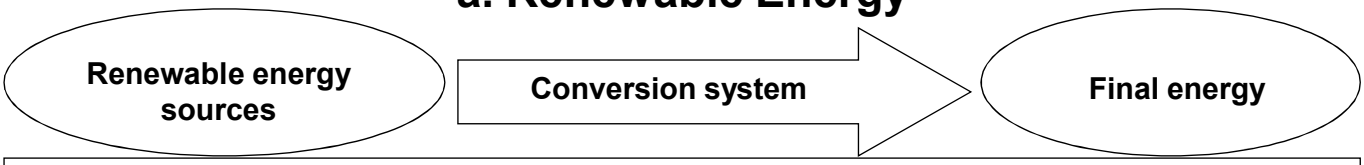
of 23 April 2009

on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

(Text with EEA relevance)

Renewable energy encompass a wide series of conversion systems.

a. Renewable Energy



Wind		Wind turbine (windfarm, isolated windturbine) Water pumping, windmill, sail	**Electricity** **Work**
Watercourse **Tide – Wave – Ocean current** **Salinity gradient**		Water mill, hydropower plant, Tidal/ocean power station Power station (PRO-RED)	**Work or electricity**
Sun		Solar water heater, solar oven and dryer Photovoltaic system, thermodynamic power plant Solar cooling	**Heat** **Electricity** **Cold**
Biomass	Food	Metabolism	**Work - Heat**
	Solid fuel	Burning equipment	**Heat**
	Biogas	Engine	**Work or electricity**
	Biofuel	Cogeneration	**Heat and electricity**
« Natural » Heat Flow/Reservoir (geothermal, oceanic or indirect solar heat)		Bioclimatic architecture natural ventilation, ground-coupled heat exchanger Heat pump Geothermal well	**Heat** **Heat or cold** **Heat** **Heat (electricity)**

a. Main Features of RE

Ref. IEA Outlook 2013 page 226

In comparison to conventional energy (fossil fuels and nuclear), renewable energy aspects:

Energy supply

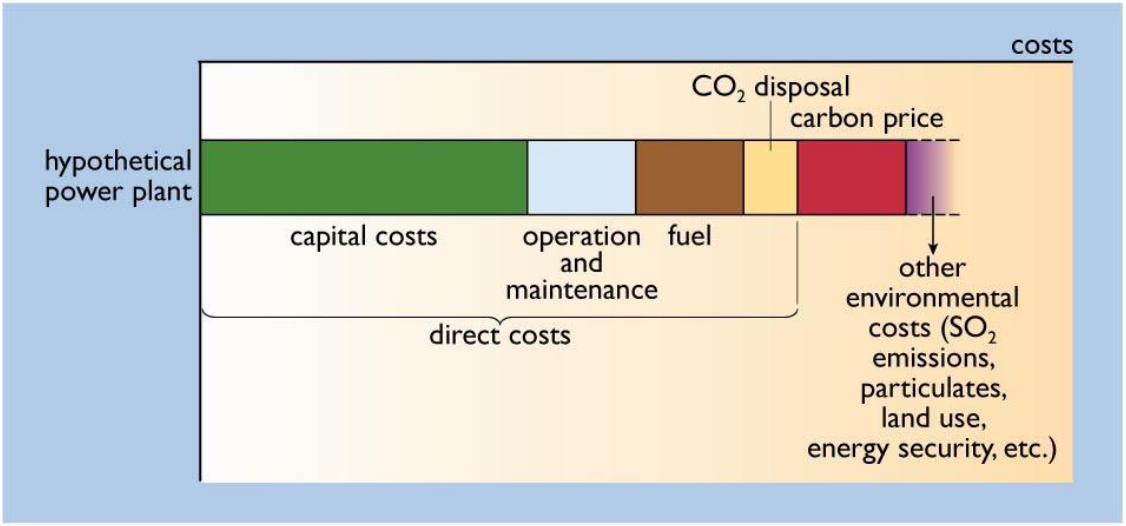
- **Unlimited energy** : flow energy means **no limit resource for future** (+)
- **Limited power** : flow of energy varies and generation is tied to the flow availability. It requires either to be used immediately or to be stored physically or virtually (for example, through demand-side management) (-)
- **Lower energy density**: their energy **density** is lower (-)

Environment

RE **environmental impacts** are different, generally :
(+) CO_2, pollution, risk management, natural resources depletion: RE reduce these impacts
(-) Land use impact: RE increase impacts
Note: Considering the whole **energy chain** of conversion : N1.a Resource energy chain; N1.b Post conversion waste management; N2. conversion; N3. Equipment life cycle

Socio economic

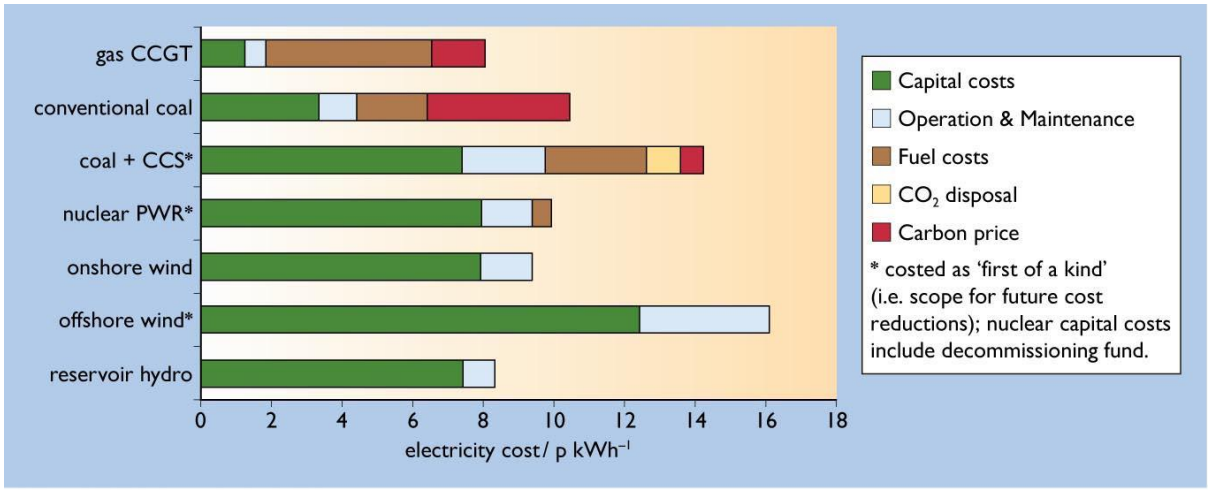
- **Energy security and diversity**: RE production is **local** (+)
- **Energy service access** : RE production is **decentralised** (+ close to consumer; - central management)
- **Economic benefits** (green growth):
  - RE provide a greater proportion of **jobs** (at equivalent production output) : (+ macroecomic ; – microeconomic because of the cost of jobs)
  - RE represent a stimulating **economic activity for SMEs** (production of equipment)
- **Affordability:** RE require substantial investment (**High CAPEX**), but have reduced exploitation costs (**Low OPEX**)



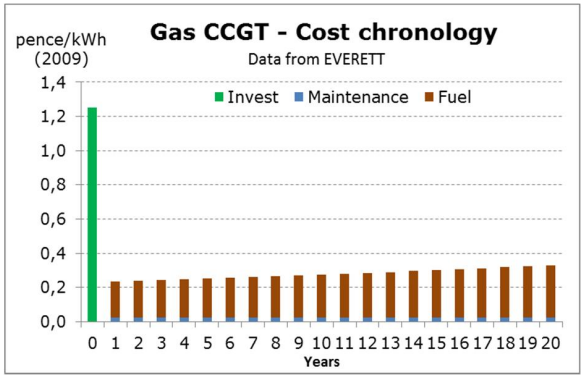
EVERETT, p.527

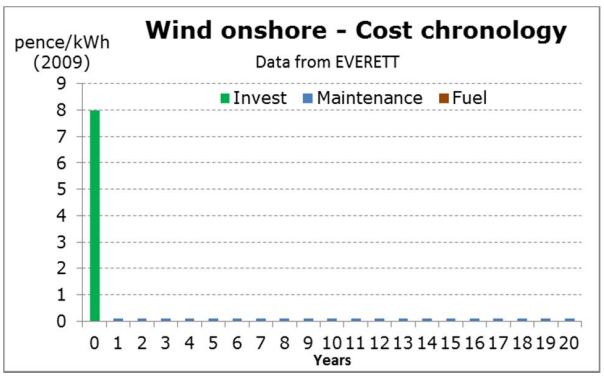
CAPEX: Capital costs (including decommissioning)
OPEX: Operation and maintenance costs, fuel costs (including those of waste)

Note: CO2 disposal costs, Carbon price and other externalities could be in the future additional operating costs



EVERETT, p.528





b. Conversion RES into final energy

Electricity : E-SER: Conversion RES into mechanical energy or electricity

1. Horizontal fluid flow -> mechanical energy -> electricity
2. Water fall flow -> mechanical energy -> electricity
3. RES heat flow -> mechanical energy -> electricity
4. Sun spectra -> electricity
5. Salinity gradient -> electricity

Heat or Cool : H-RES: Conversion RES into heat or cold

1. Sun radiation -> low t° heat in fluid flow (Low t° ≈ 20°C -150°C)
2. Fuels -> high t° heat in fluid flow
3. Natural heat or fatal heat (direct recovery) -> low t° heat in fluid flow
4. Natural heat or fatal heat (recovery through a refrigeration cycle) -> low t° heat in fluid flow
5. E-SER -> high t° heat fluid flow

(Fatal heat = heat losses from process)

Fuel - Conversion RES into fuels
Objective : on board storage (Biofuels, Battery, H_2, CH_4 from biomass or synthesis)

b. Conversion RES into storable energy

To store energy means to reduce its sensibility (short term) or to transform into potential energy (long term)

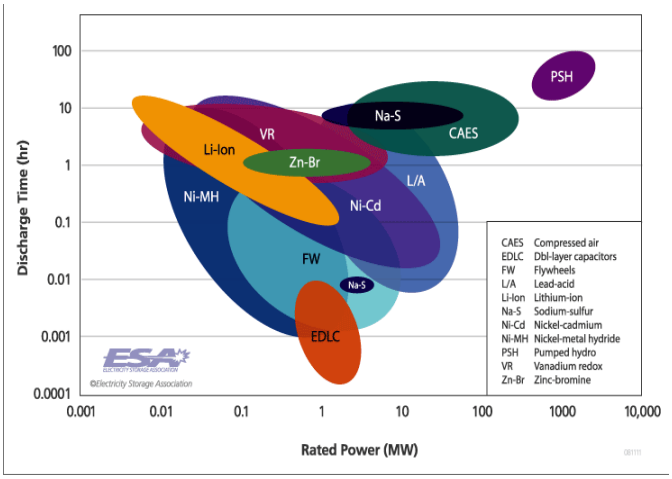
RES	Store RES	Reduce sensibility	Transform in Potential
Wind	-	Mechanical (kinetic)	Mechanical (gravitational)
Water flow	Gravitational (Dam)	-	Gravitational (Dam)
Sun	-	Heat	Latent heat
Biomass	Biomass	-	Fuels
Natural heat	Heat	Heat	Latent heat

Electricity can't be stored but it can be transformed in storable form : gravitational, elastic, chemical (electro-chemical reaction), electrostatic, magnetic.

Storage conditions are crucial to maintain the energy content (ie wood moisture, gas or liquid leaks, flywheel friction losses)

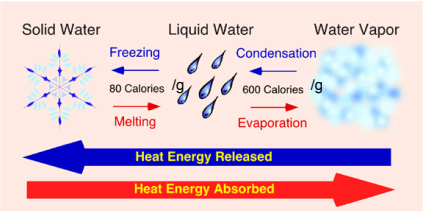
Electricity storage solutions

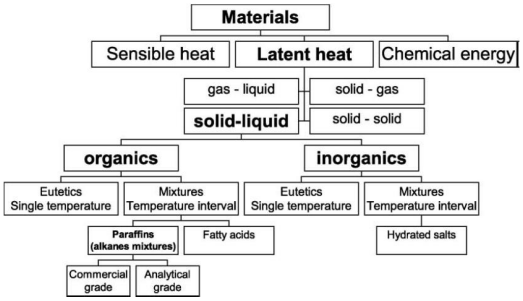
- Gravitational, elastic (CAES, FW, PSH)
- Chemical (NaS, VR, Zn-Br, Ni-MH, L/A, Ni-Cd)
- Chemical/fuels (H_2, synthesis CH_4)
- Electrostatic (EDLC)

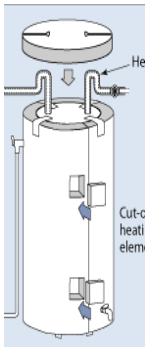


Heat storage solutions

- Sensible Heat
- Latent heat
- Chemical energy
- Chemical/fuels







E-RES 1: Air or water flow (principle of conversion)

RES
Wind, horizontal water current

Conversion system

Final energy

Kinetic energy | **Turbine** | **Work ->Electricity**

Principle : Rotor blades slow down the flow (air or water) and recover a mechanical energy (torque). The mechanical energy is converted in electricity by an electrical generator.

Flow

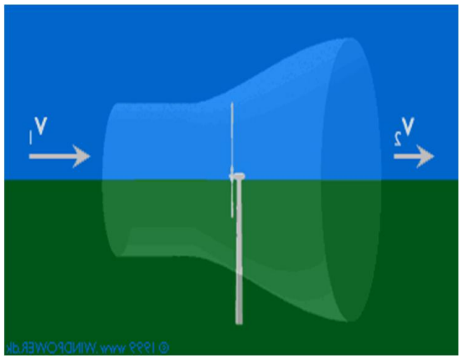
$P_{flow} = ½ m' u^2$

$m' = \rho S u$

m' = mass flow

$P_{flow} = ½ \rho S u^3$

ρ_{air} = 1.2 kg/m³ (20°C)
ρ_{water} = 1,000 kg/m³
$\rho_{seawater}$ = 1,025 kg/m³



v1 v2

Deliverable power

$P_{rotor} = Cp\ P_{flow}$

Cp = Power coefficient
Cp max = 0,593 *(Betz limit)*

The maximum fraction of power in the wind that can theoretically be extracted is when v2 = 1/3 v1. Than Cp =16/27

Conversion systems









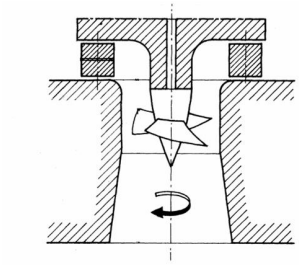
E-RES 2: Water fall flow (principle of conversion)

Principle : Flowing water is directed on to the blades of a turbine, creating a force on the blades. Since it is spinning, the force acts through a distance (force acting through a distance = work). In this way, **energy is transferred from the water flow to the turbine**.
Water turbines are divided into two groups; reaction turbines and impulse turbines.
Reaction turbines are acted on by water, which changes pressure as it moves through the turbine and gives up its energy.
Impulse turbines change the velocity of a water jet.
The mechanical energy is converted into electricity by an electrical generator.

Gravitational energy

Waterfall: $P_{hydro} = \rho g Q H$

Turbine , Wheel

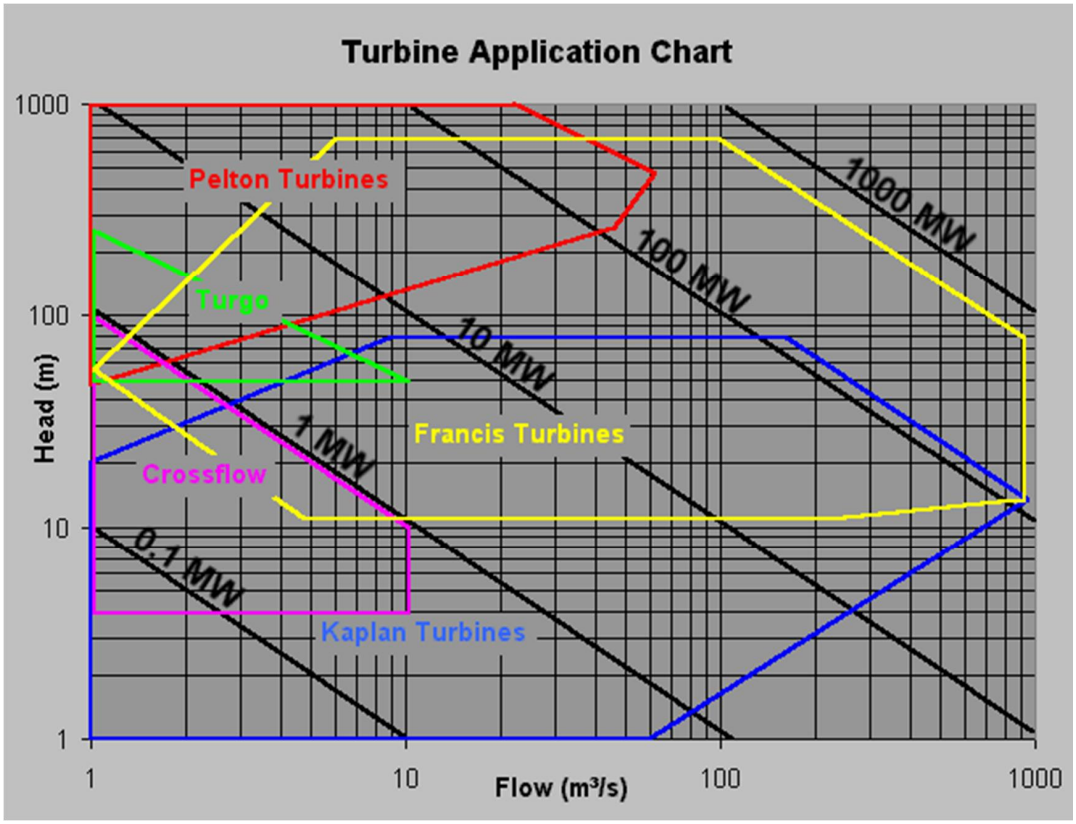


Work
Electricity
Compressed air

Deliverable power

Protor = ηP_{hydro}

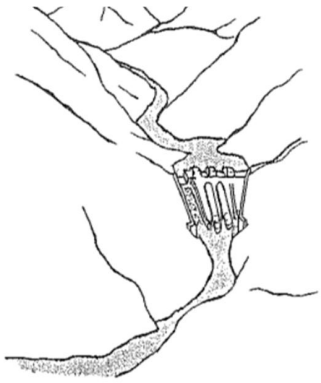
Hydro: conversion systems



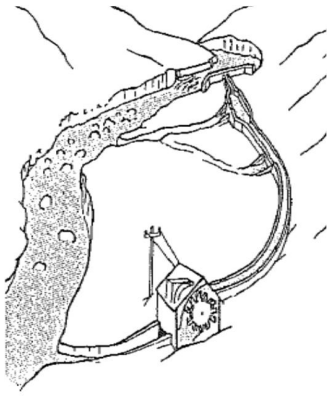
River hydropower

Various possibilities of hydro scheme

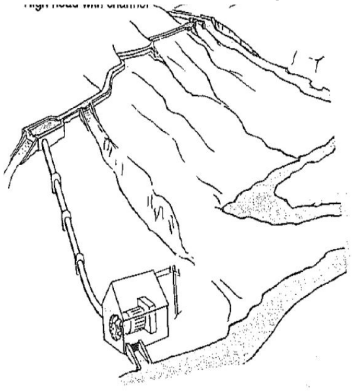
Head with barrage



Head with channel



Head with channel and penstock



Ref : Micro-hydro design manual ; Adam HARVEY

E-RES 3: RES Heat (principle of conversion)

RES heat from sun, biomass or geothermal (high enthalpy) → **Conversion system** → **Final energy**

Principle : Heat is converted into mechanical energy by a thermal engine (thermodynamic cycle). The mechanical energy is converted into electricity by electrical generator.

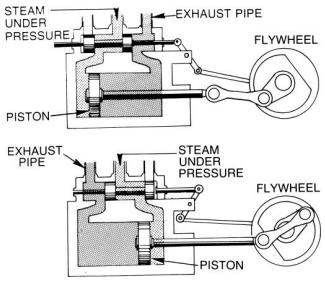
Heat (high enthalpy)

From
- biomass NCV
- solar flow
- geothermal heat flow

Thermal engine
(steam engine, stirling engine, steam turbine, ...)

Work -> Electricity

+ Heat loss

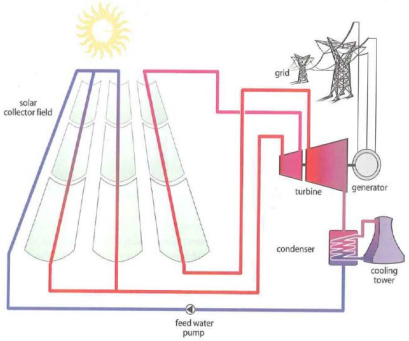


Deliverable power
$Pe = \eta H$

Carnot coefficient : $\theta = 1 - T_a/T_h$.
Ta = temperature ambiance or cold
Th = temperature hot source

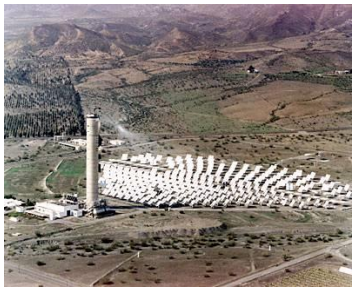
CSP : Concentrated Solar Power -> Electricity

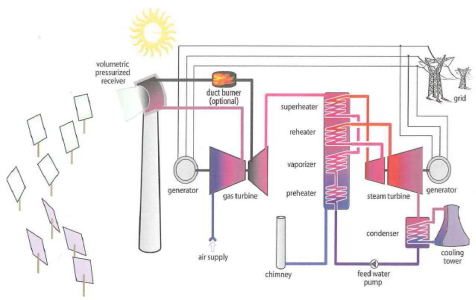
Parabolic through concentrator system



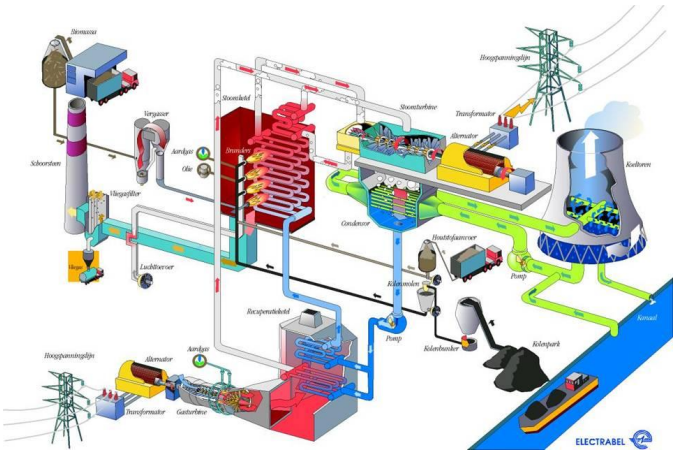
Parabolic dish concentrator system
Solar-powered stirling engine

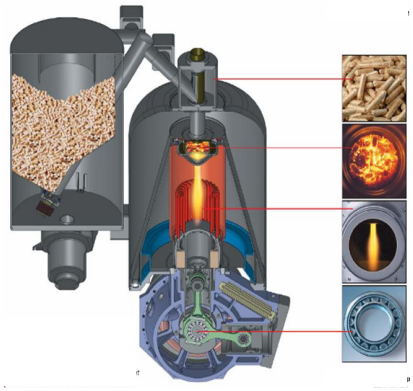
Needs solar direct radiation (!!! Dust in atmosphere !!!)
Thermal cycle needs two thermal sources (hot and cold)





Biomass conversion system -> Electricity

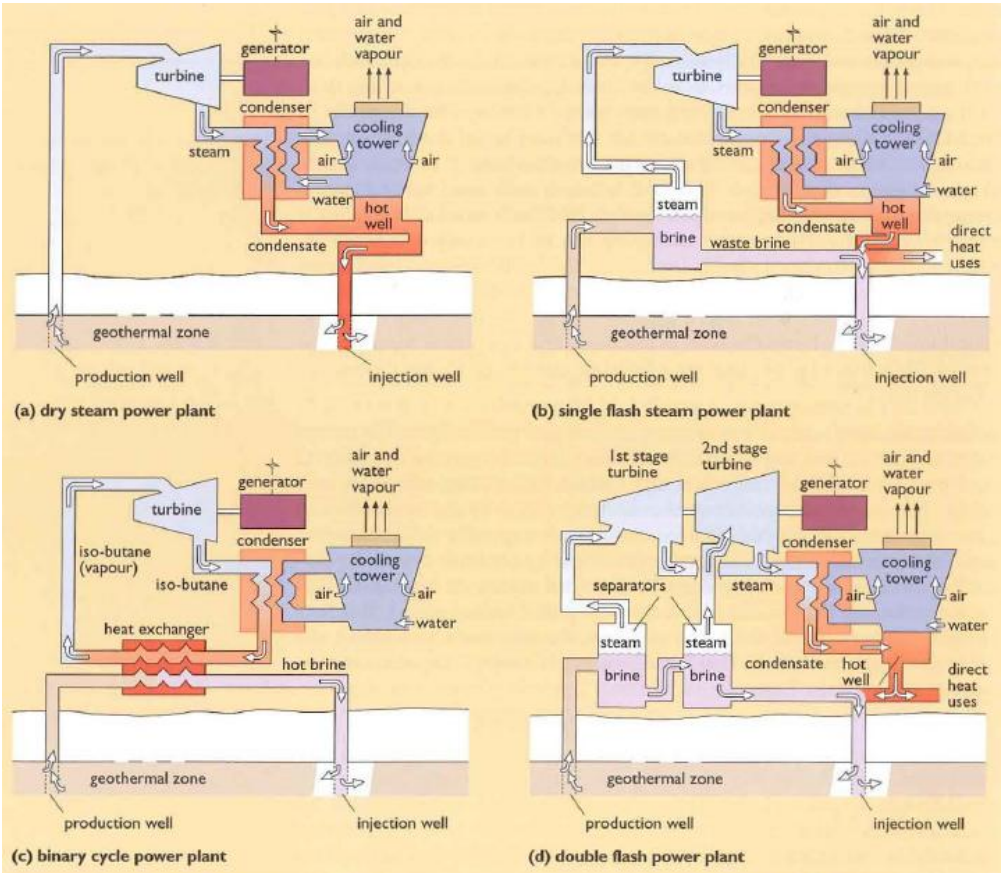




www.sunmachine.de

1 - 4 kWe – 2.5 - 10 kWth

Geothermal conversion system -> Electricity



Ref RE Boyle

E-SER 4: Photovoltaic (principle of conversion)

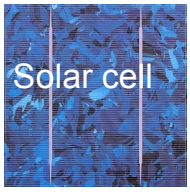
RES
Sun

→ **Conversion system** →

Final energy

Principle : Photovoltaic effect converts light into electric current. A pn junction creates an electrostatic field. In a semiconductor, photons with suitable wavelength (band gap) can transfer their energy to electrons. If there is an external circuit, it generates an electric current.

Sun
(Light spectra)

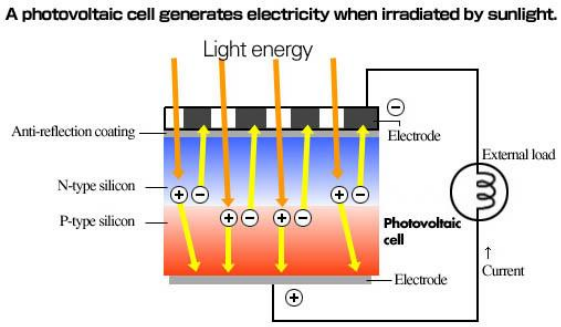


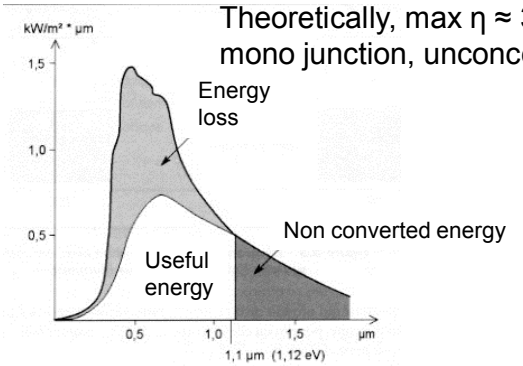
Electricity (DC)

$P = \eta P_{sun}$

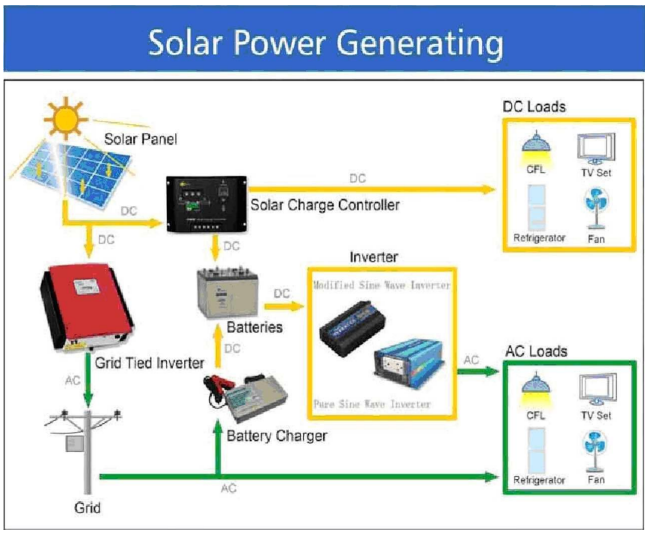
Market : $\eta Si_c \approx 12\text{-}20\%$

Theoretically, max $\eta \approx 30\%$ with mono junction, unconcentrated sun



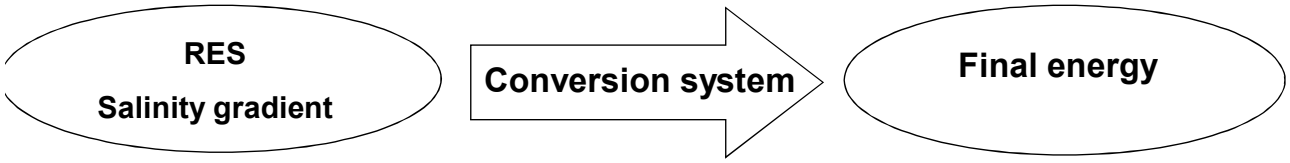


Conversion systems

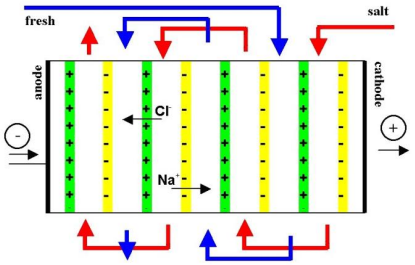


In Belgium, Tracker can generate +30%

E-SER 5: Salinity gradient (principle of conversion)

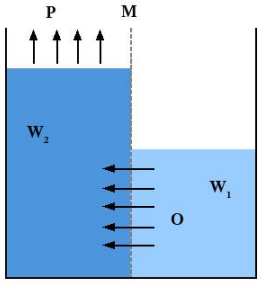


Principle : To convert salinity gradient into electricity, two main techniques exist: Pressure-Retarded Osmosis (PRO) and Reverse Electrodialysis (RED).



Salinity gradient

Electricity (DC)

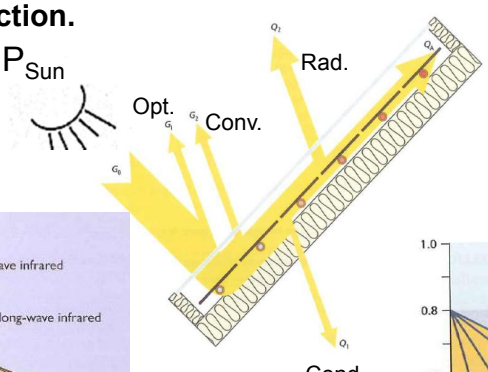


H-RES 1: Solar thermal (principle of conversion)

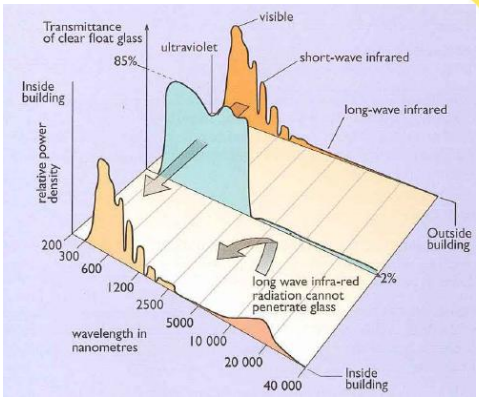
Sun (solar spectra) → **Solar thermal collector** → **Heat water flow**

Principle: Radiation is converted into thermal energy. Heated collector is cooled by fluid flows (generally water + antifreeze). Heat water flow is the final energy generally stored in an insulted tank. **Solar panel is designed to reduce thermal losses through radiation, convection and conduction.**

P_{Sun}

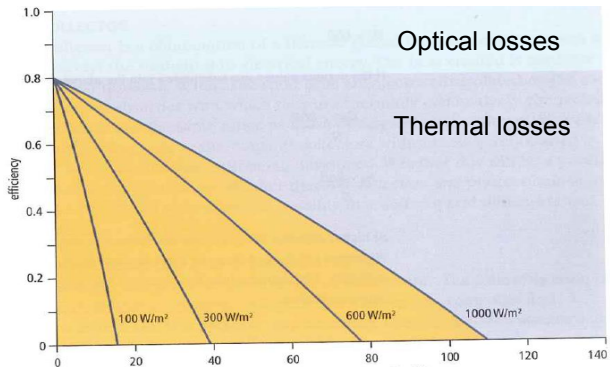


$P_{collector} = \eta P_{Sun}$



Ref RE Boyle p29

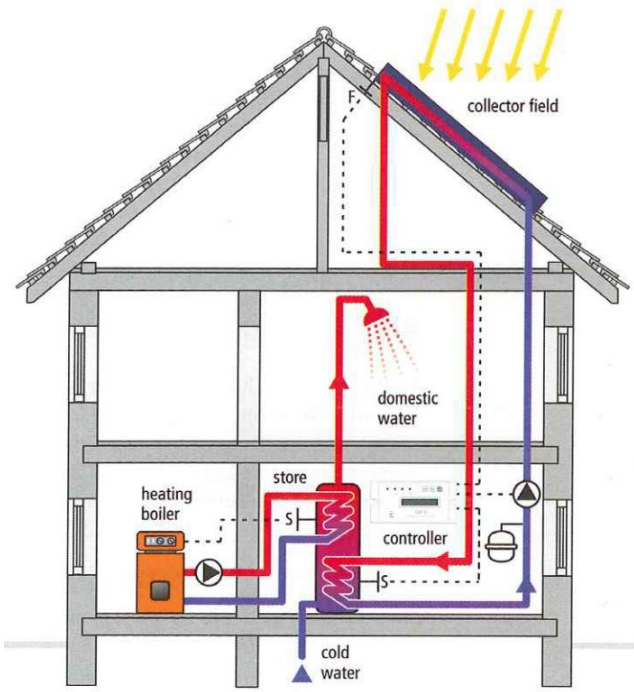
η (DT) : Collector efficiency

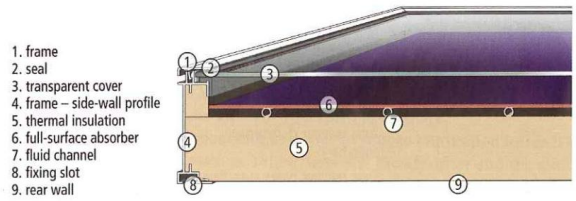


DT : Temperature difference between absorber and air (K)

Standard solar water heating system

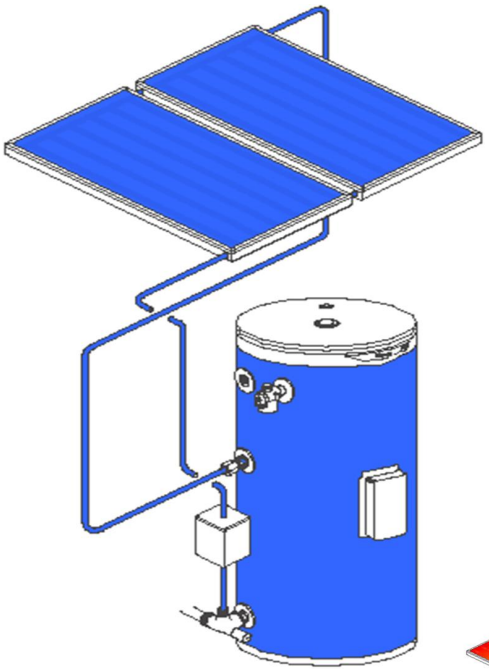
p



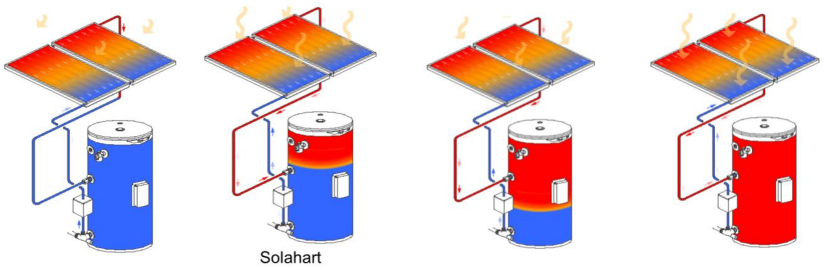


From "Planning and installing Solar thermal Systems" JamesXJames, 2005

Figure 2.1. Standard solar water heating system with heating boiler for additional heating (S = temperature sensor)



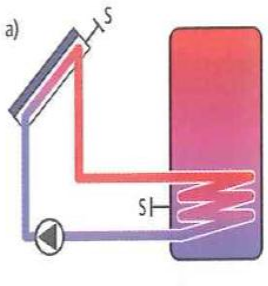
Source : Solahart



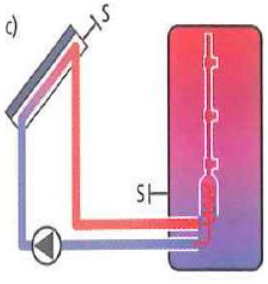
Solahart

Solar water heater : Heat transfer and storage

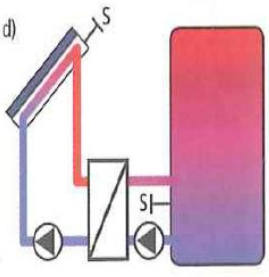
The heat collected at the collector is transferred to the exchanger by the hydraulic circuit. The heat exchanger transfers the heat into the water of the tank. Tank insulation reduces the heat losses of the storage.



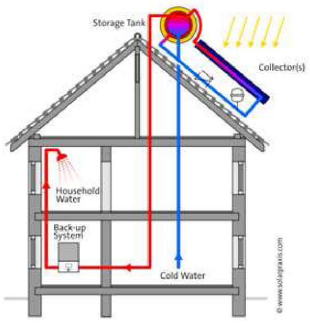
Internal solar heat exchanger



Internal solar heat exchanger with stratified charger



External solar heat exchanger



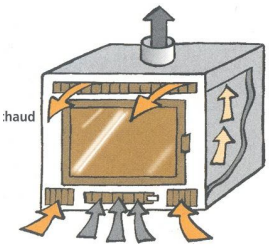
Thermosyphon solar water heater.
No pump
Outdoors -> No frost resistant

H-RES 2: Biomass (principle of conversion)

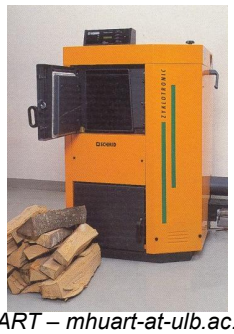
Biomass Fuel → **Conversion system** → **« Useful » heat**

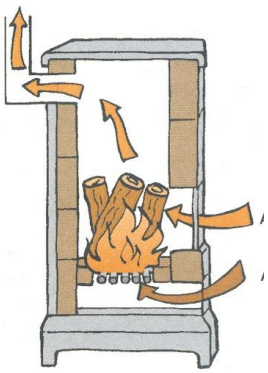
Biomass Caloric value (CV) | Burning equipment | **Heat = η CV**

Principle: The burning equipments transfer combustion heat in a useful heat flow (room heating or hot water flows (boiler). They are designed to reduce thermal losses through smokes and surrounding.



- **Open firewood - chimney** (**η** less than 10%)
- **Closed fire – Insert** (**η**: 40 - 70%)
- **Wood stove** (1 - 2 Combustion chamber , 1 - 2 – 3 preheated air inlet, catalyser, heat accumulation) (**η :** 40 - 90 %)
- **Wood boiler** (**η** : 40 - 90%)

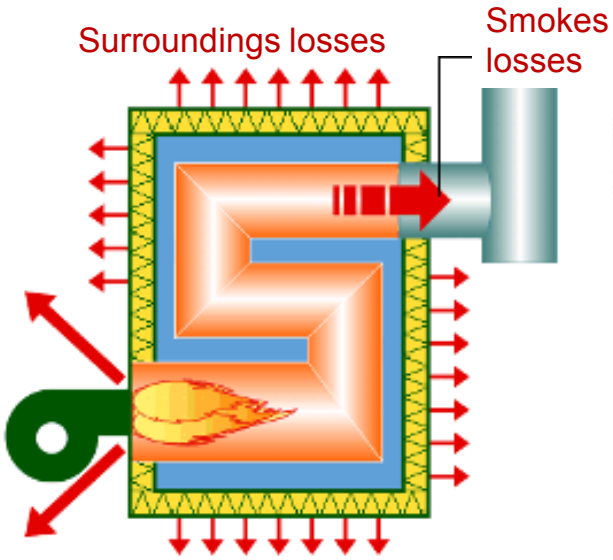




Combustion efficiency

Losses = Surroundings + Smokes

Smokes' losses = Thermal (air excess and et smokes temperature) + Unburned



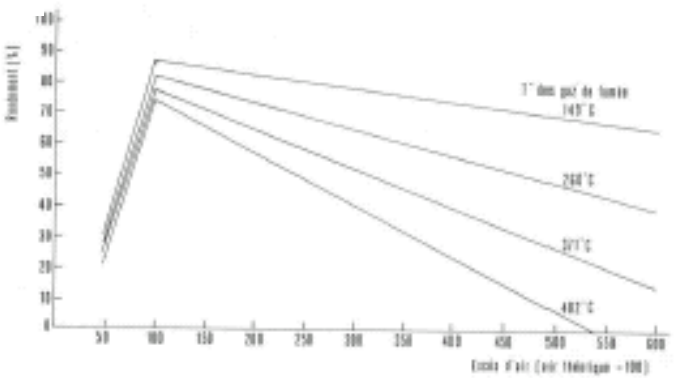


Figure 5 : Rendement de la combustion du bois en fonction de l'excès d'air et de la température des fumées (source : Maxwell et al. 1981 Dans CRA 1991)

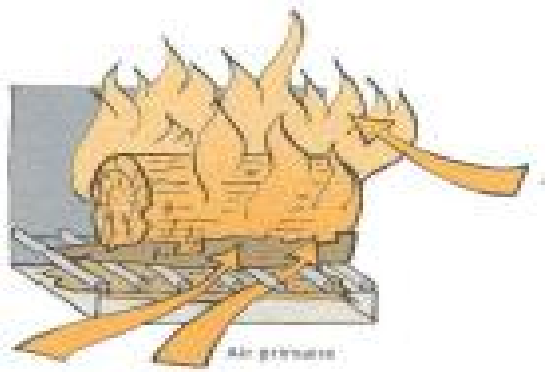
Objective: To implement the conditions for an optimal combustion
Precise control air flow inlet, furnace temperature at 800°C and homogeneous, pre-heating of the air inlet, catalyst.

Wood combustion

Pyrolisis : Under heat effect, solid wood breaks up into releasing from the gas compounds (Volatile matter)

Gas Combustion : Under certain conditions, COV oxidize in contact with oxygen in air. (The flame is the manifestation of combustion)

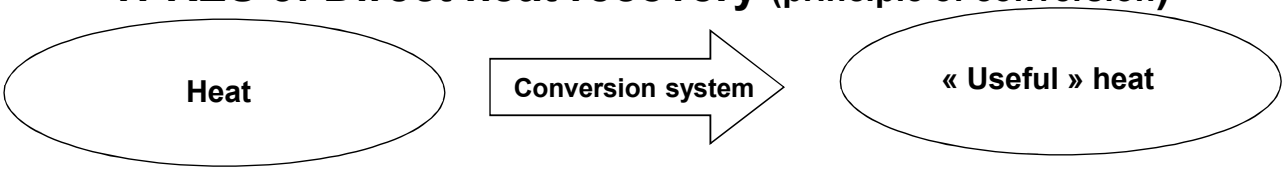
Solid combustion : Oxidation of carbon (solid) with oxygen in air. (No flame)



Precautions

• It is necessary that the furnace reaches at least 800°C to allow a good decomposition of solid wood.
• Fuel gases must burn if not those will be emitted in atmosphere and of composed such as the tar will settle in the chimney flue.
• Unburned residues are obviously responsible of energy losses.
• Combustion of wet wood causes an incomplete combustion, is not very profitable and is polluting.

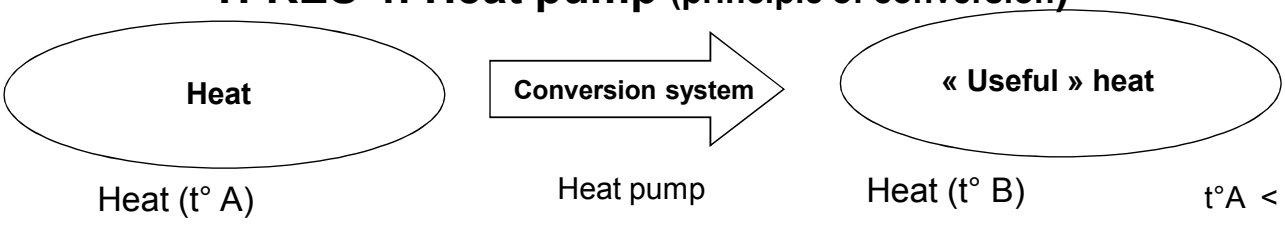
H-RES 3: Direct heat recovery (principle of conversion)



Res Heat — Heat exchanger — **Heat**

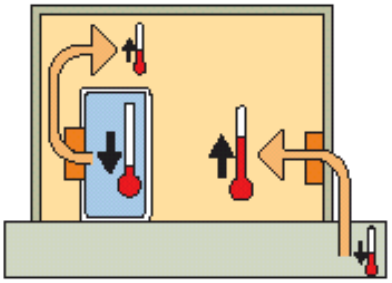
Principle: spontaneous heat flow through heat exchanger

H-RES 4: Heat pump (principle of conversion)



Heat (t° A) Heat pump Heat (t° B) t°A < t°B

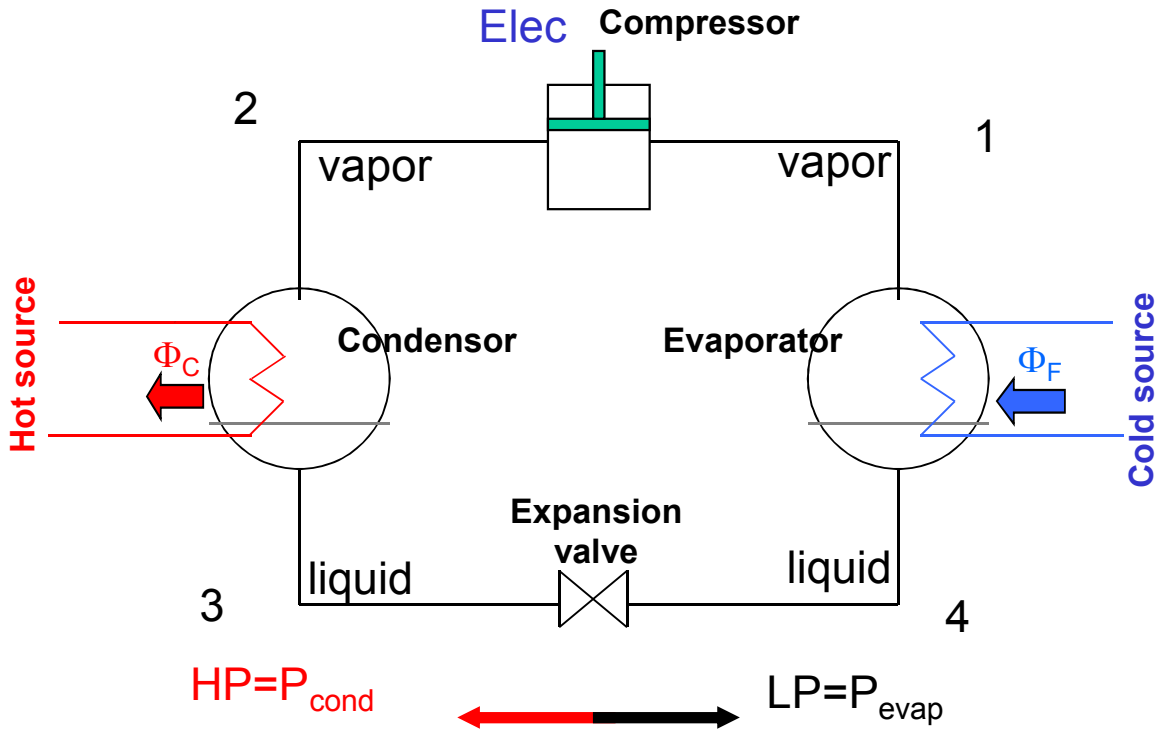
Heat pump is an heating system that can absorb heat from a cold space and release it to a warmer one. (as a refrigerator)



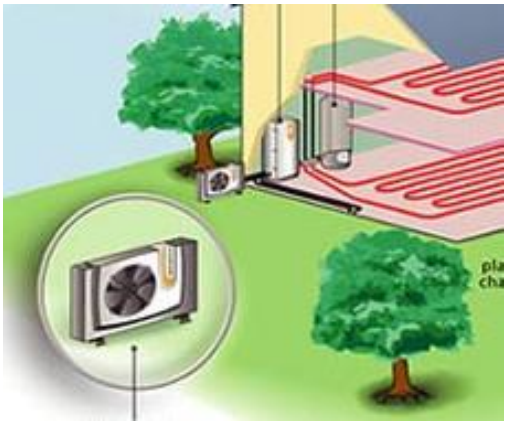
Principle: Heat pump uses the **latent heat** of evaporation to absorb heat outside and to release it by condensation inside.
It uses a **refrigerant** that boils at low temperature (low pressure) and condenses at high temperature (high pressure).
To work, it requires some amount of high-grade-energy (low entropy) generally **electricity** to run the compressor.
Most of the energy for heating comes from the external source, and only a fraction comes from electricity (or some other high-grade energy source required to run a compressor).
In electrically powered heat pumps, the heat transfer can be three or four times larger than the electrical power consumed, giving the system a coefficient of performance (COP) of 3 or 4.
In a heat pump the evaporator or the heat exchanger connected to the evaporator is located somewhere in the external source (air, water, ground)

COP: coefficient of performance = Heat output/Elec input

Heat pump - Operational principle (1)



Heat pump - Air

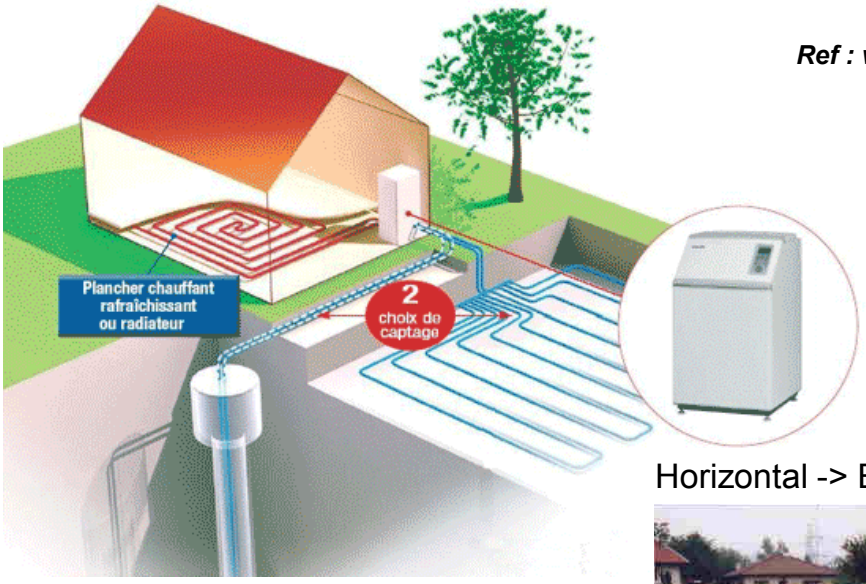


Fan-coil unit

Static coil unit

Heat pump – Ground (water)

Ref : www.gd-climatisation.com



Horizontal -> Excavation work

Vertical -> Drilling