Steam Power Generation

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Welcome students of the international course on
Power Generation
Groeningen The netherlands

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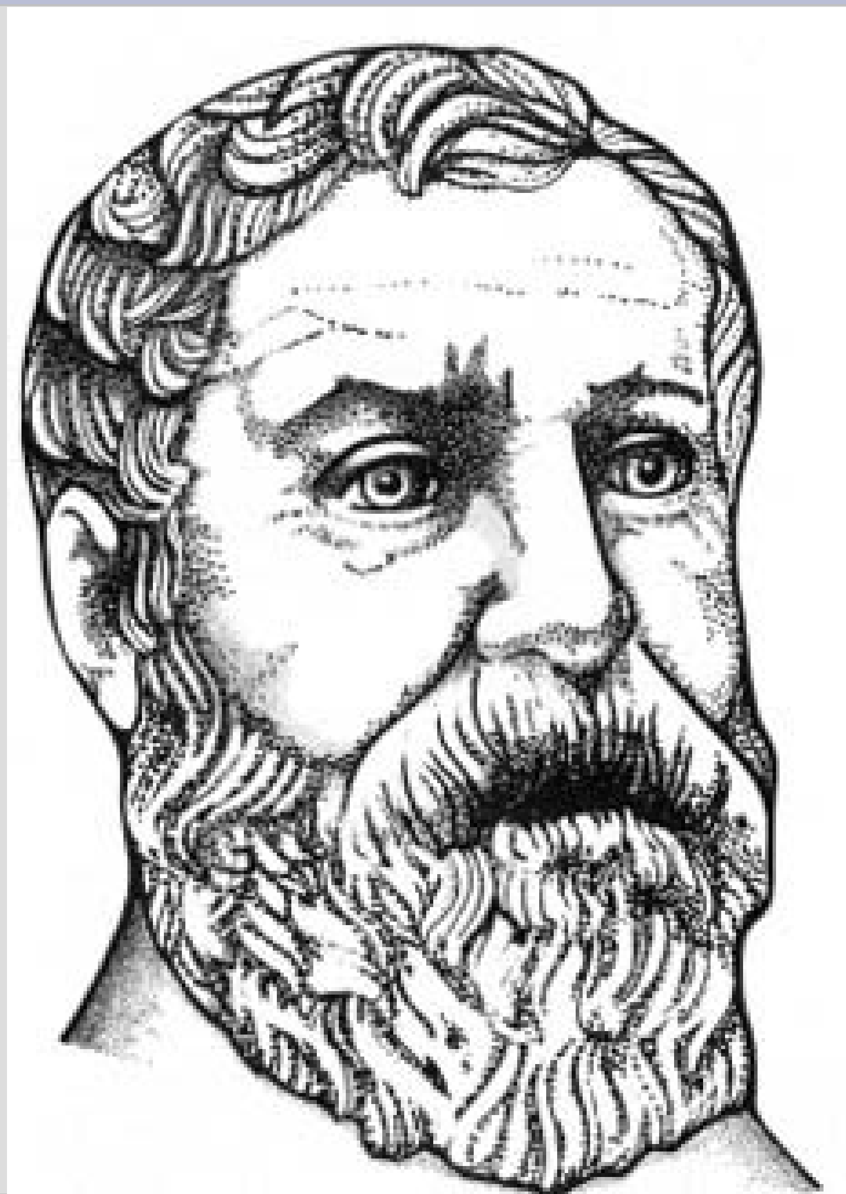
Outline

- A bit of history
- Basics
  - First law: Internal Energy
  - Second Law: Entropy
  - Heat Engine: Thermodynamic cycle
  - Fluid flow: Enthalpy
  - Liquid vapor Equilibrium: Water and Steam
- Power plants
  - A schematic Steam Power Plant
  - Simple Rankine cycle
  - Power calculations
  - Superheating
  - ReSuperheating
  - Back pressure turbine
  - Regenerative cycle

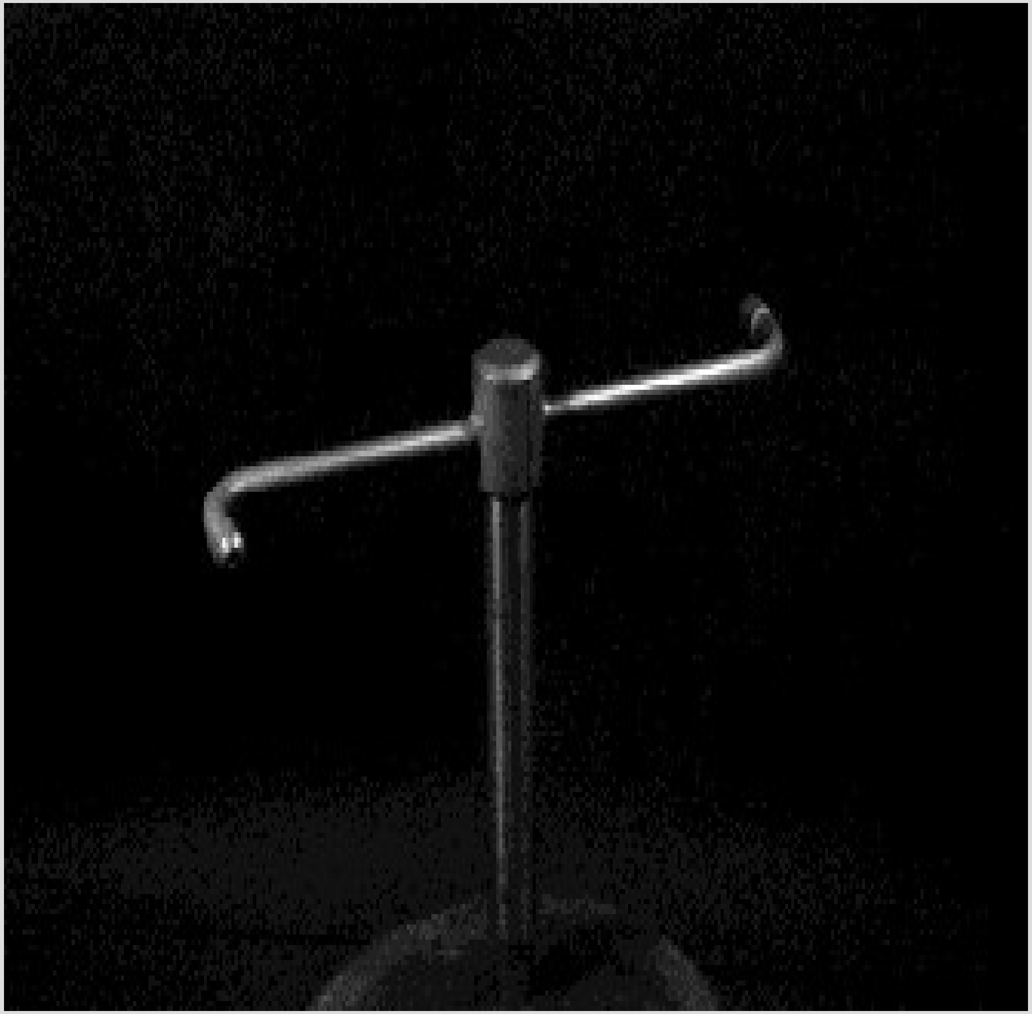
A BIT OF HISTORY

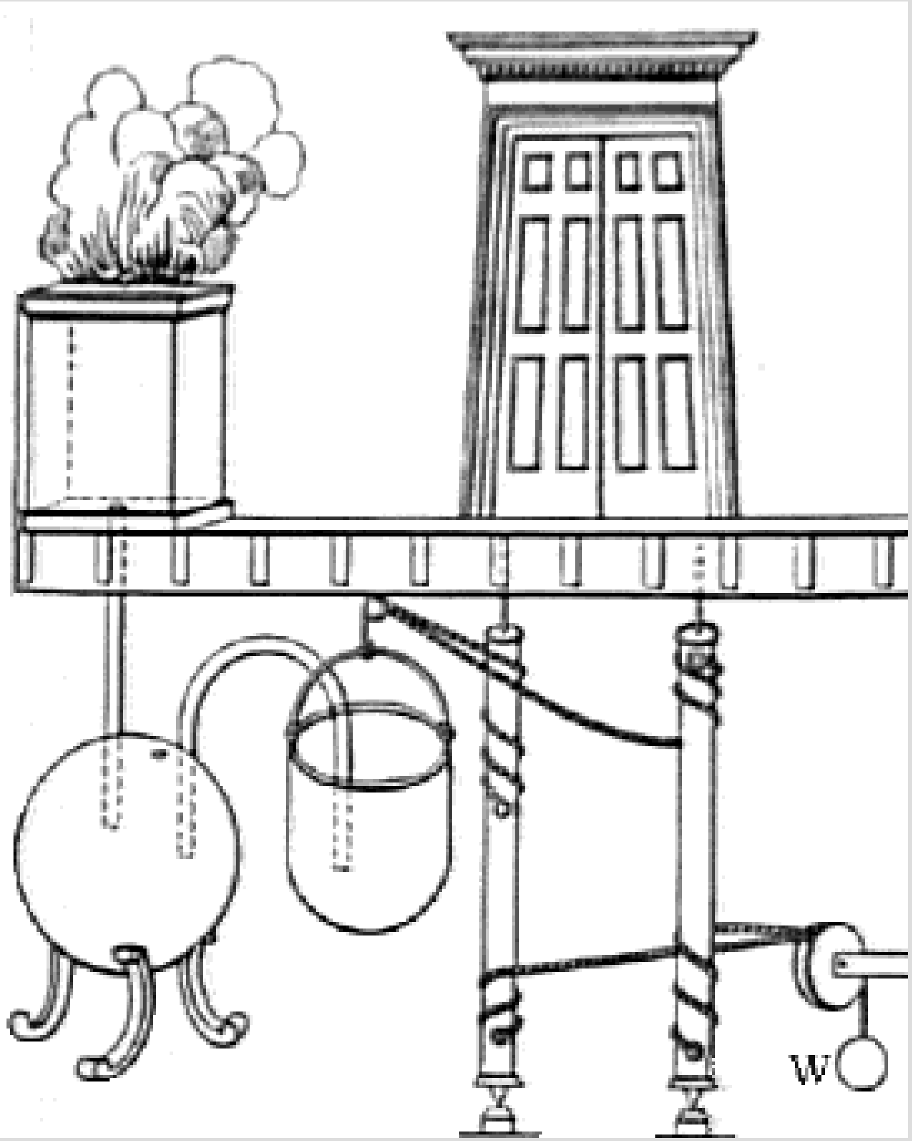
Hero of Alexandria: First century b.c.



A BIT OF HISTORY (Continued)

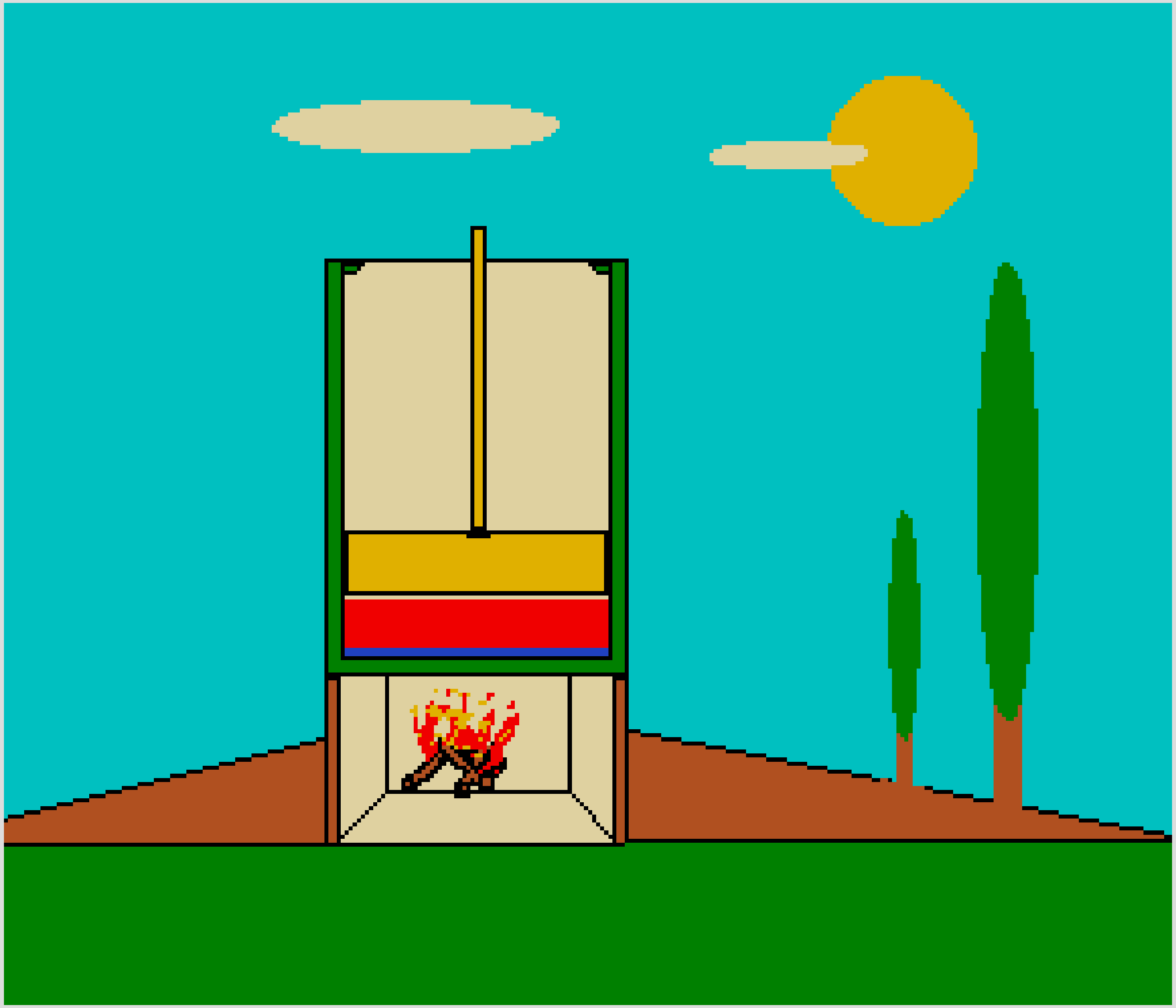
Hero of Alexandria: First century b.c.





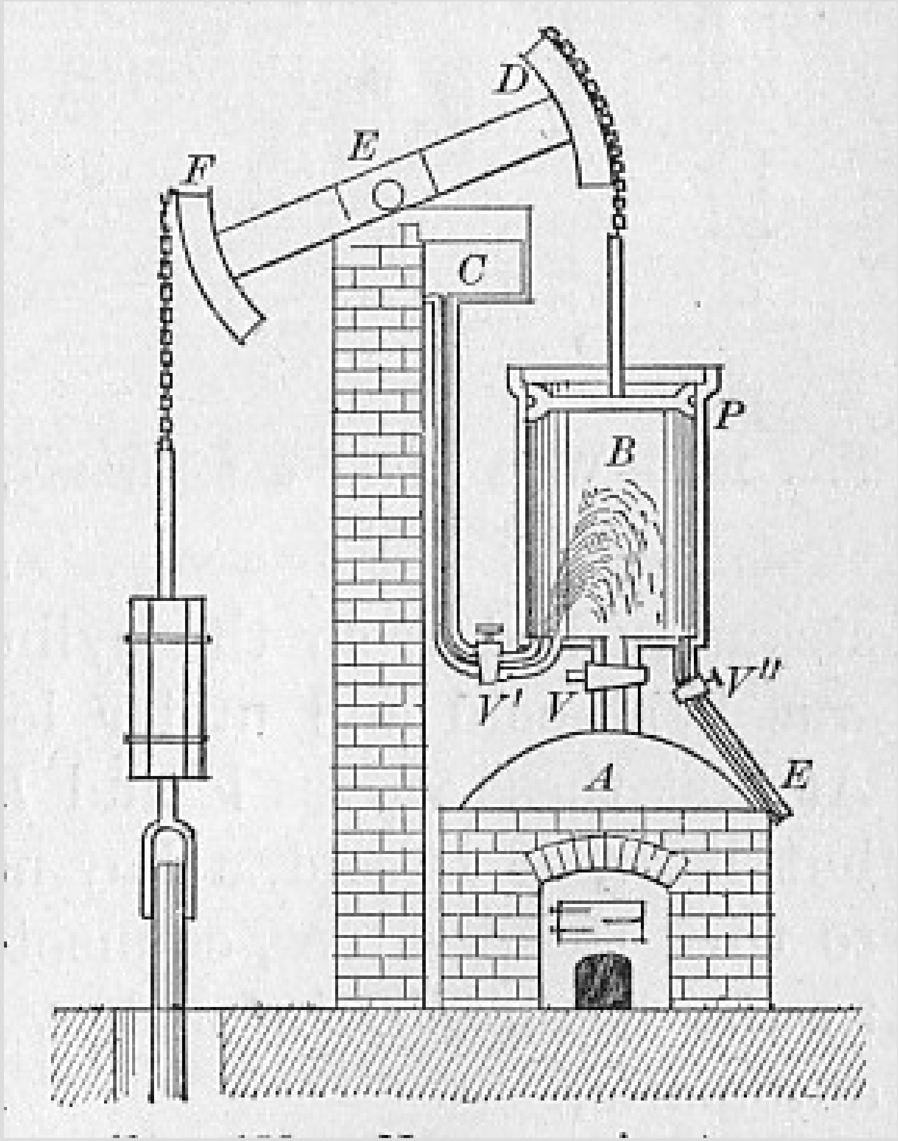
A BIT OF HISTORY (Continued)

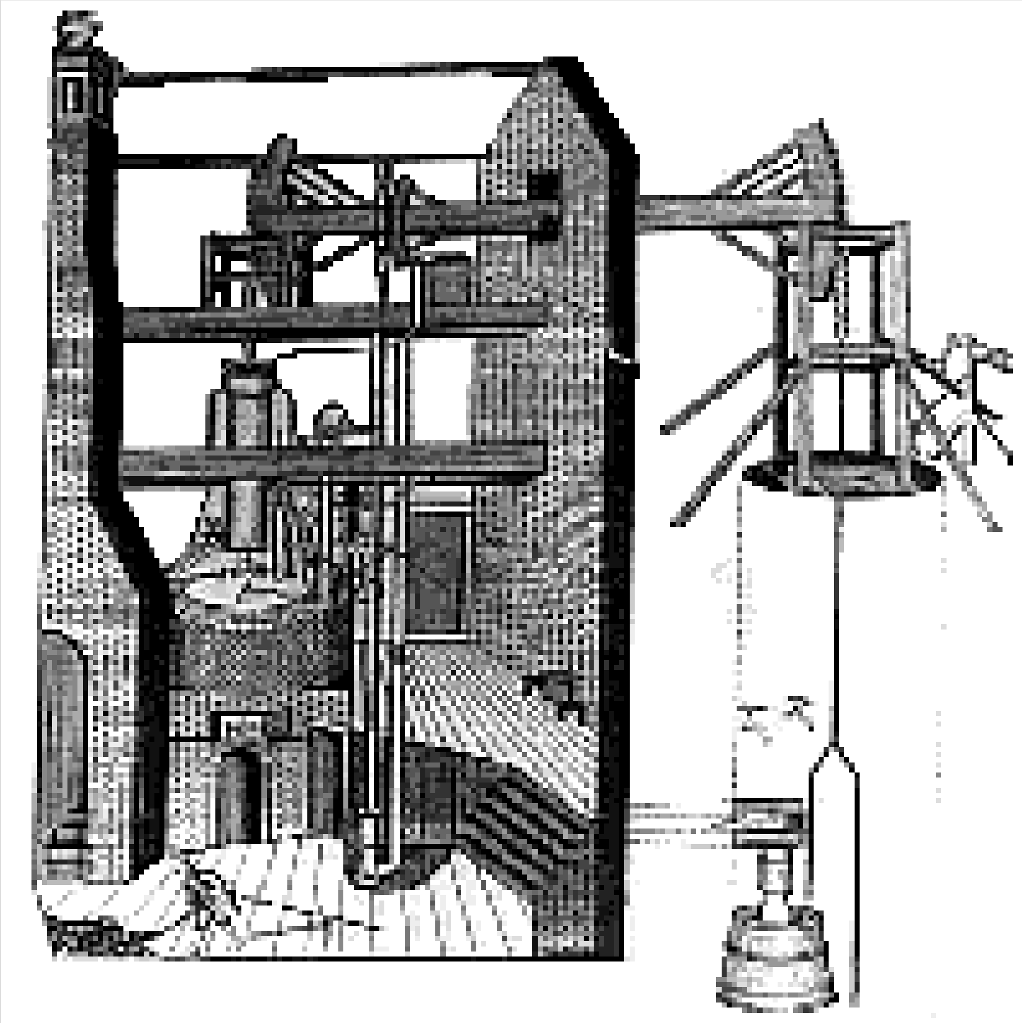
Denis PAPIN (1647- 1712)



A BIT OF HISTORY (Continued)

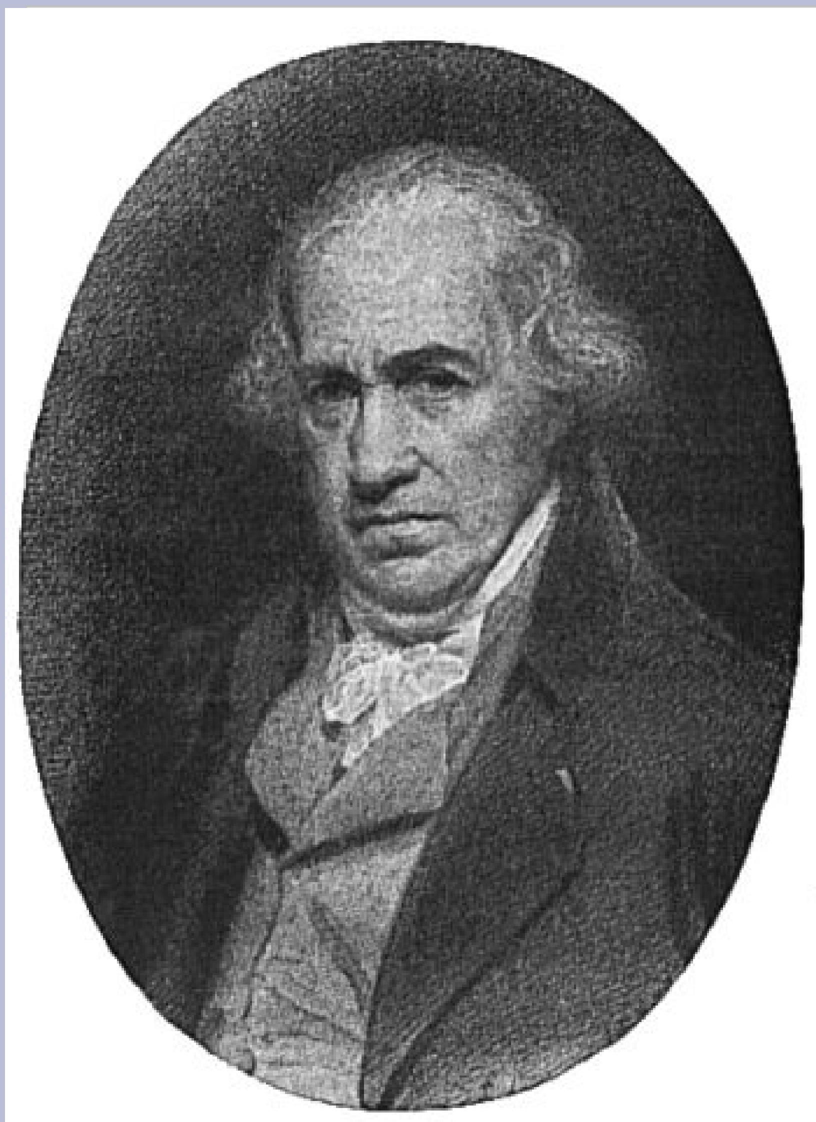
Newcommen (1712)

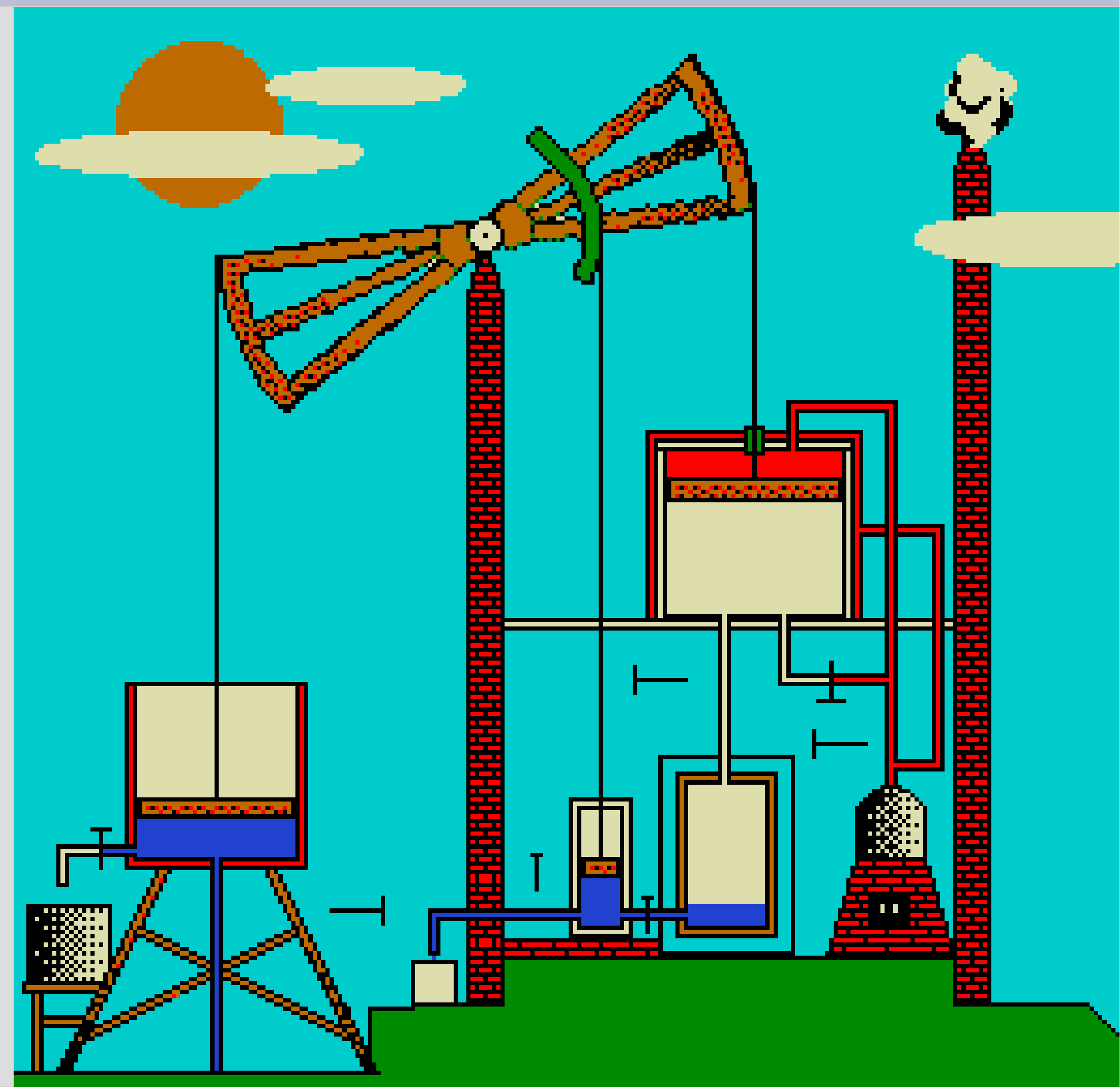




A BIT OF HISTORY (Continued)

Watt (1769)





First Law of Thermodynamics

Energy is a constant

If the internal energy (U) of a system increases, then it may have been increased by addition of

- heat
- Work

from the outer world

$$U_2 - U_1 = W + Q$$

Second law of Thermodynamics

- Entropy (S) of an isolated system increases

- It will eventually increase until equilibrium is reached

- If entropy decreases in a given system then entropy of the outer world must have been increased by a greater amount. This may be possible only because there are energy exchanges between the system and the outer world

$$\int \frac{\delta Q}{T_e} \leq S_2 - S_1$$

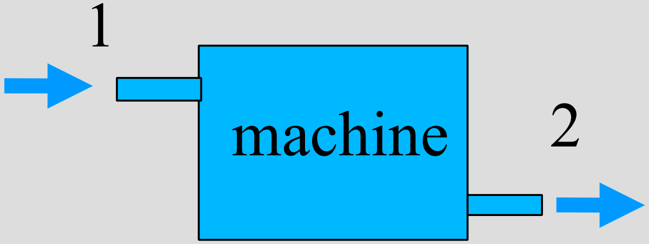
- The equality stands for a reversible transformation

Fluid Flow and Enthalpy

- Fluid flowing through a machine

$$h_2 - h_1 + \frac{V_2^2}{2} - \frac{V_1^2}{2} = w_u + q$$

h = specific enthalpy
V = Velocity
w_u = Usable work per unit mass of fluid
q = Heat per unit mass of fluid

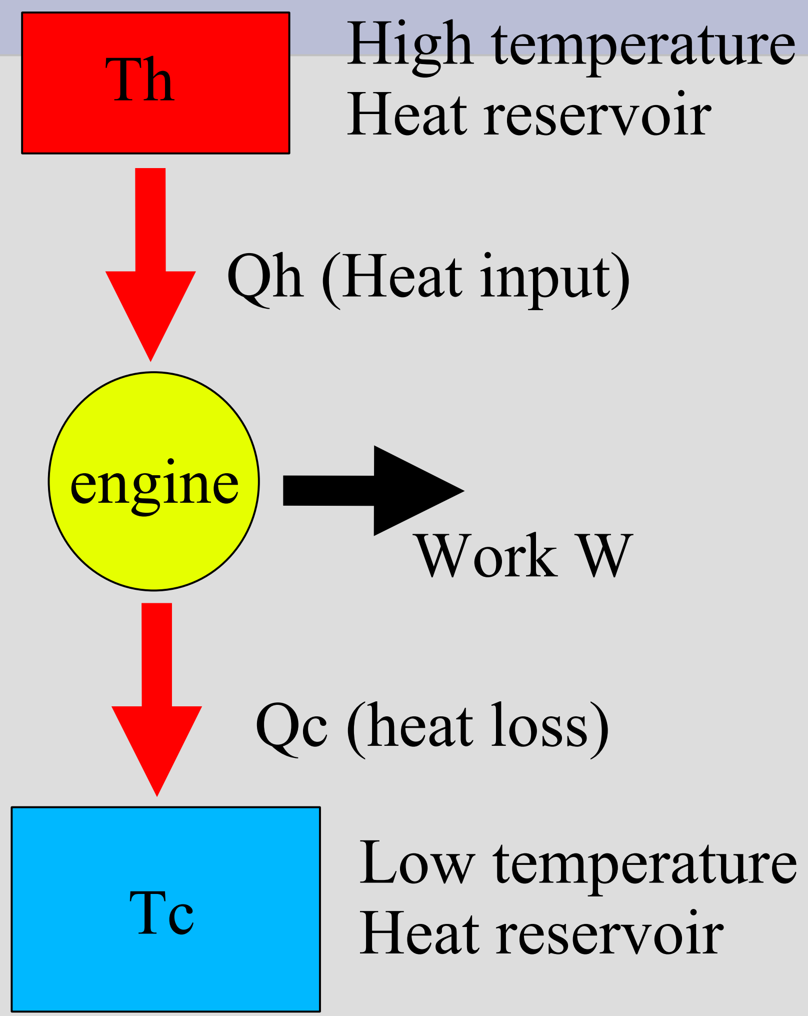


- In terms of Power:

$$\dot{m}\left(h_2 - h_1 + \frac{V_2^2}{2} - \frac{V_1^2}{2}\right) = \dot{W} + \dot{Q}$$

$\dot{W}$ = mechanical power
$\dot{Q}$ = heating power

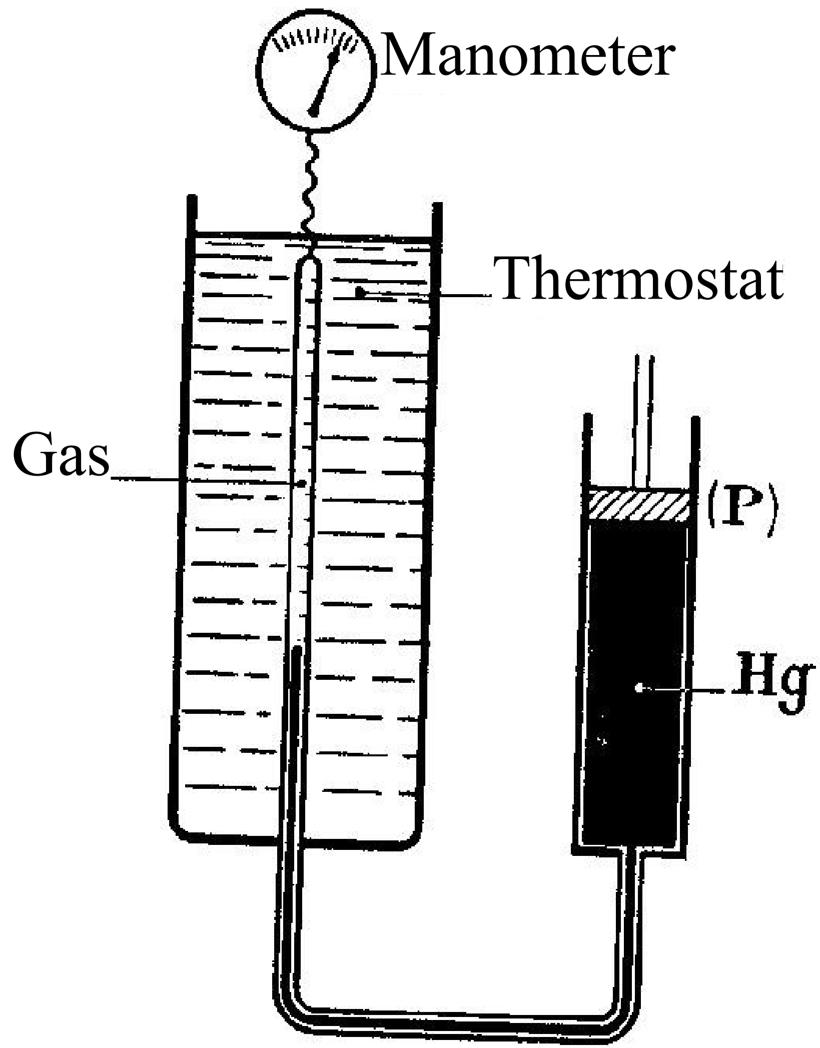
HEAT ENGINE
THERMODYNAMIC CYCLE

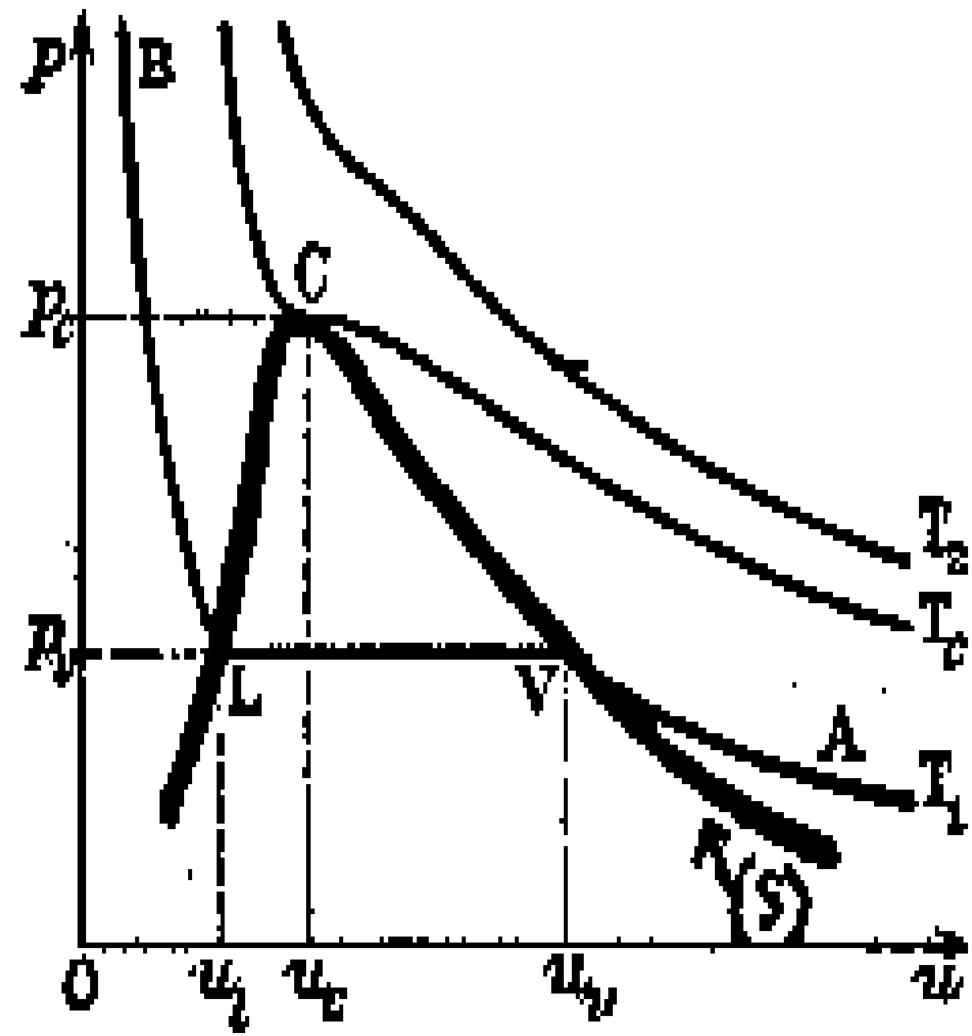


Efficiency $\rho = \left| \frac{W}{Q_h} \right|$

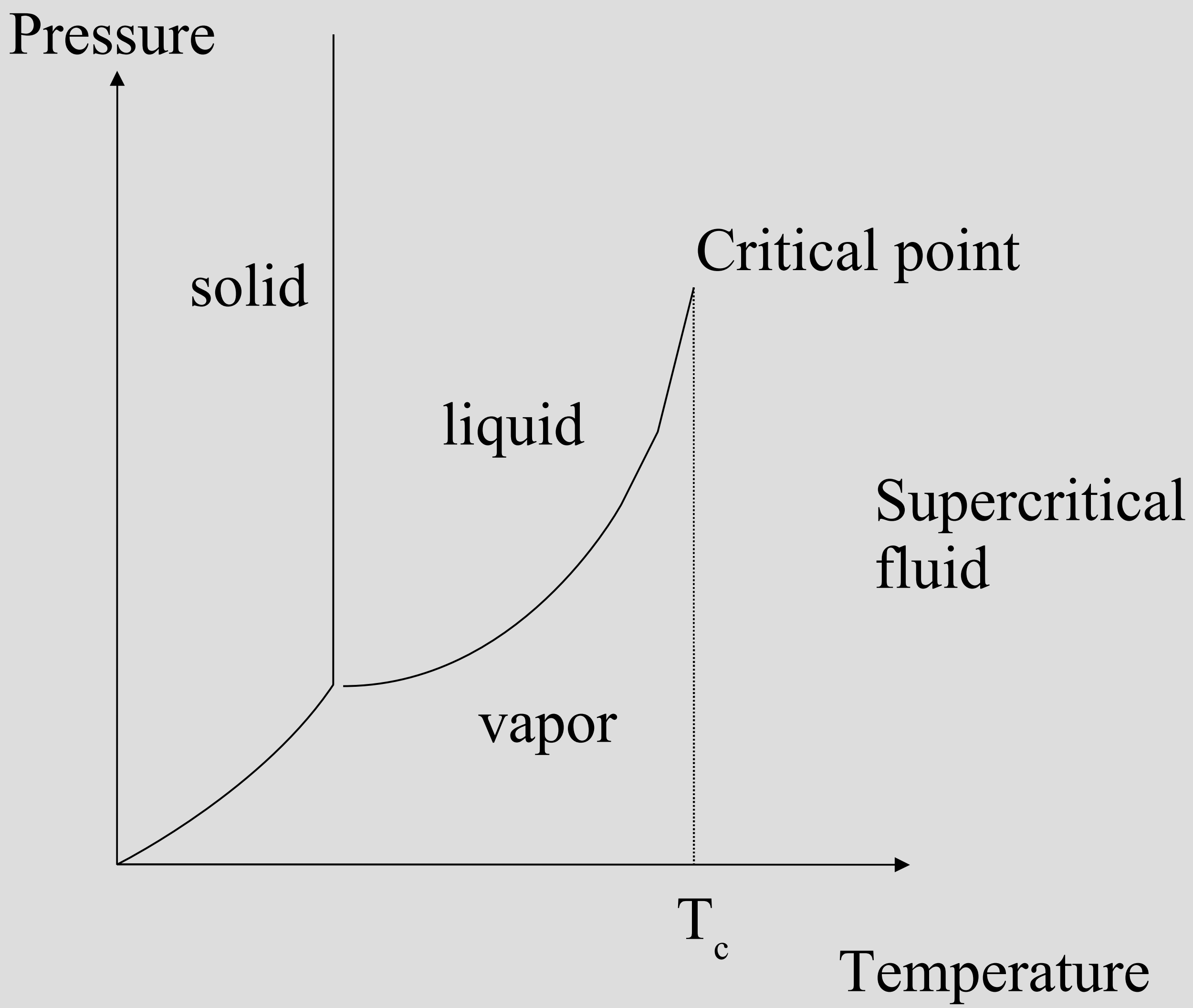
Carnot: $\rho \leq 1 - \frac{T_c}{T_h}$

Liquid - vapour equilibrium



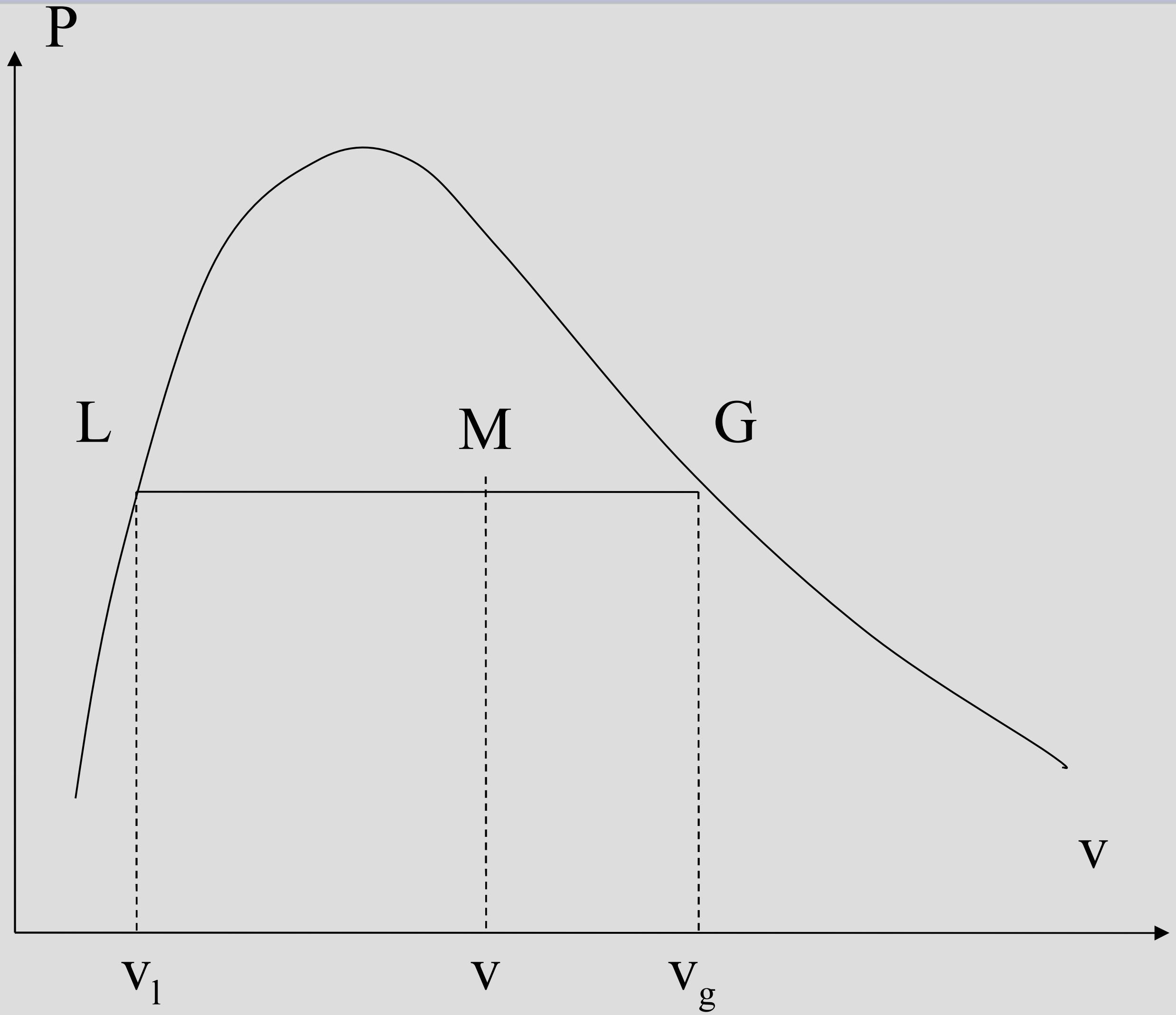


Vapour pressure curve



Dryness fraction

Definition: $$x = \frac{m_g}{m_g + m_l}$$ (m = mass)



Properties

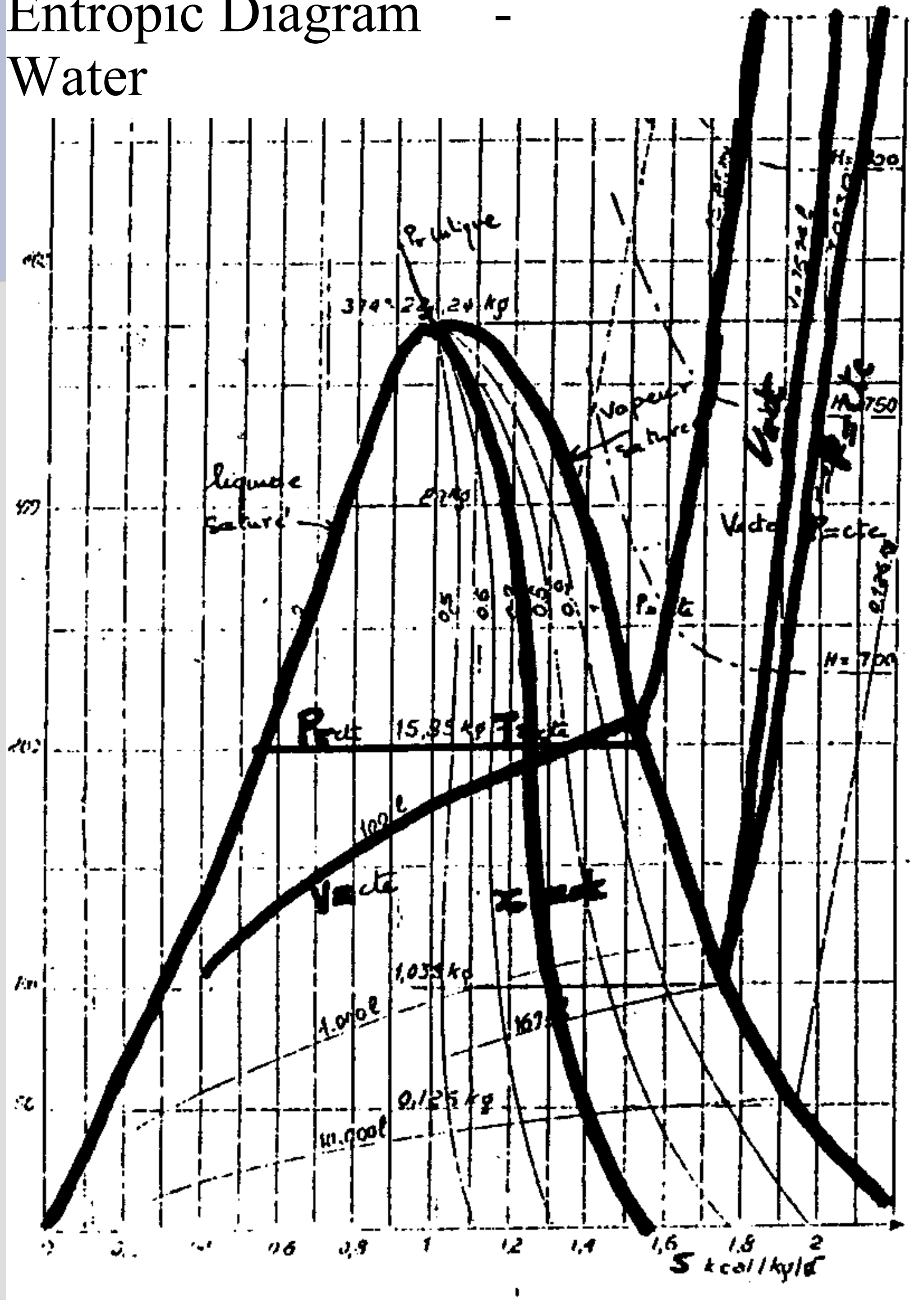
$$x = \frac{v - v_l}{v_g - v_l}$$

$$x = \frac{h - h_l}{h_g - h_l}$$

v = specific volume

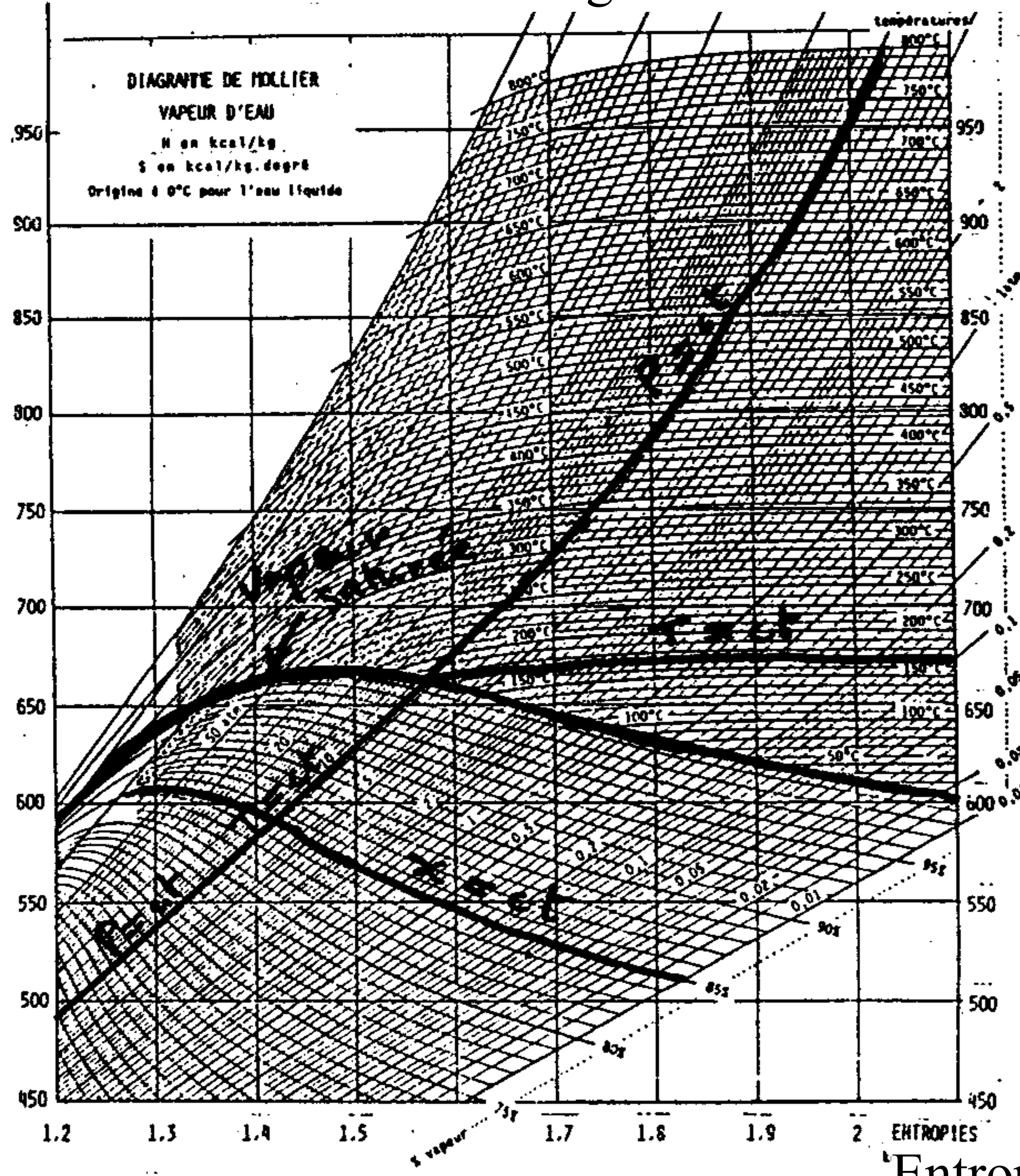
h = specific enthalpy

Entropic Diagram - Water



Mollier Diagram - Steam

Enthalpy



Entropy

Data on the internet

NIST Webbook

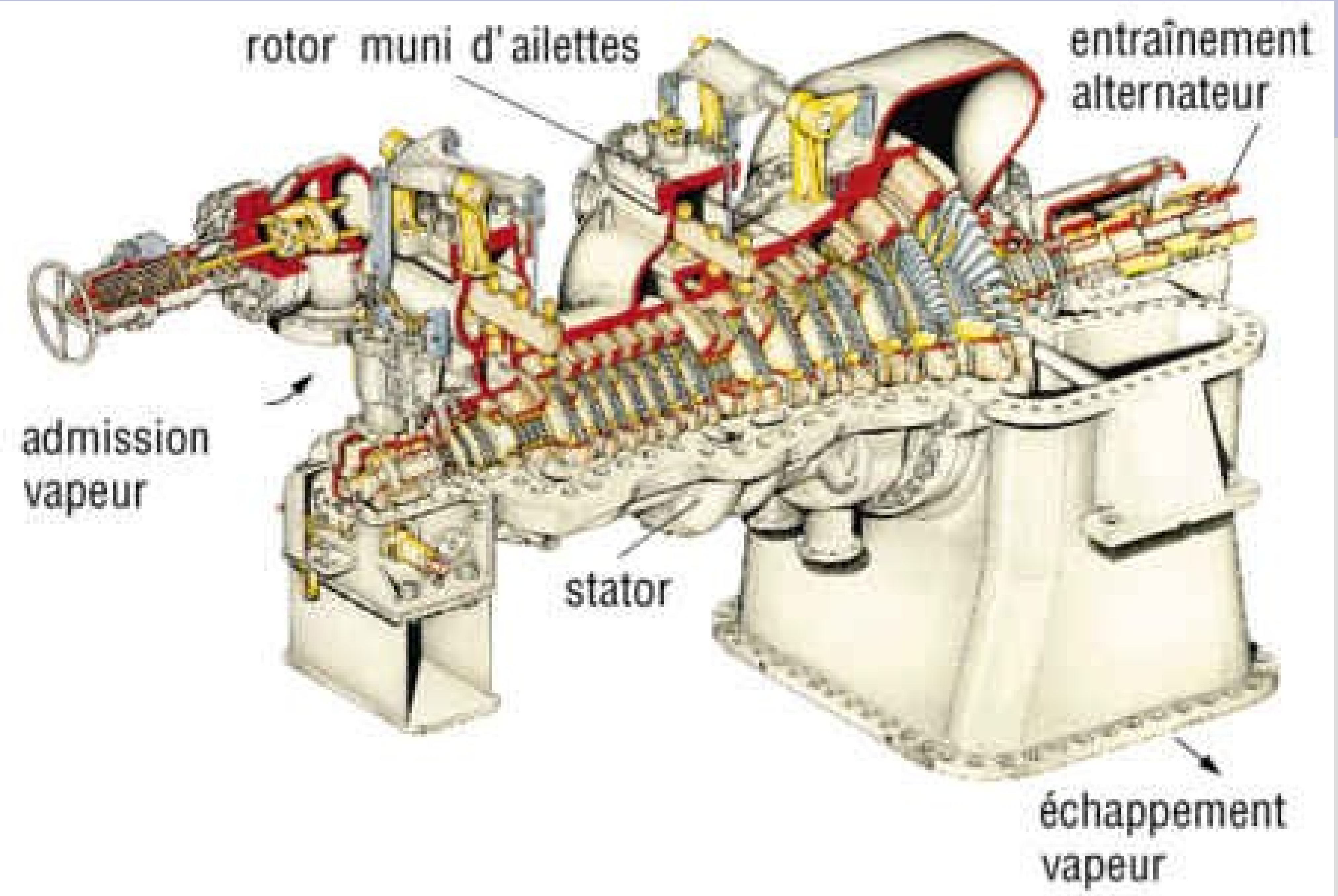
http://webbook.nist.gov/chemistry/

Many physical properties
including saturation properties as a function of Temperature
and superheated vapor properties.

Page of this department

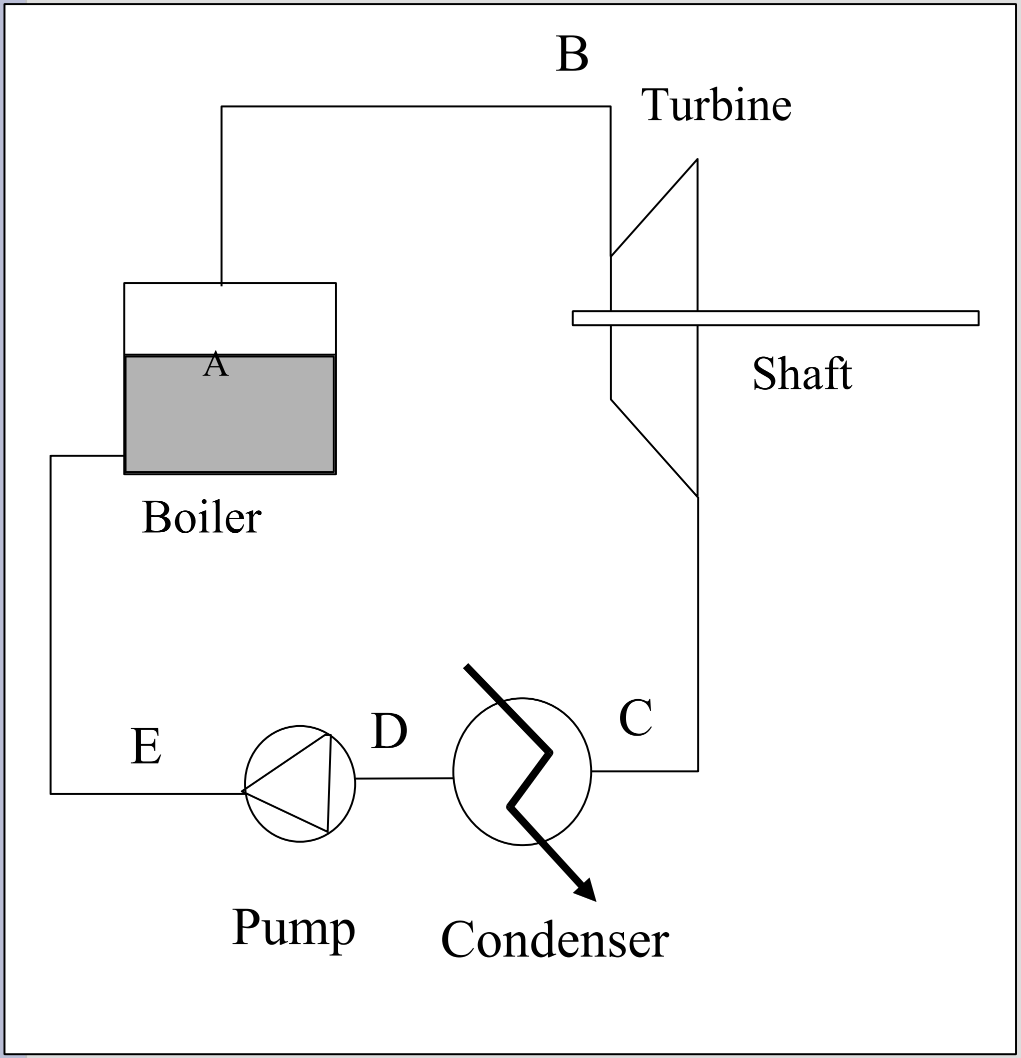
http://www-gim.iut-stdenis.univ-paris13.fr/thermo/thermo.html

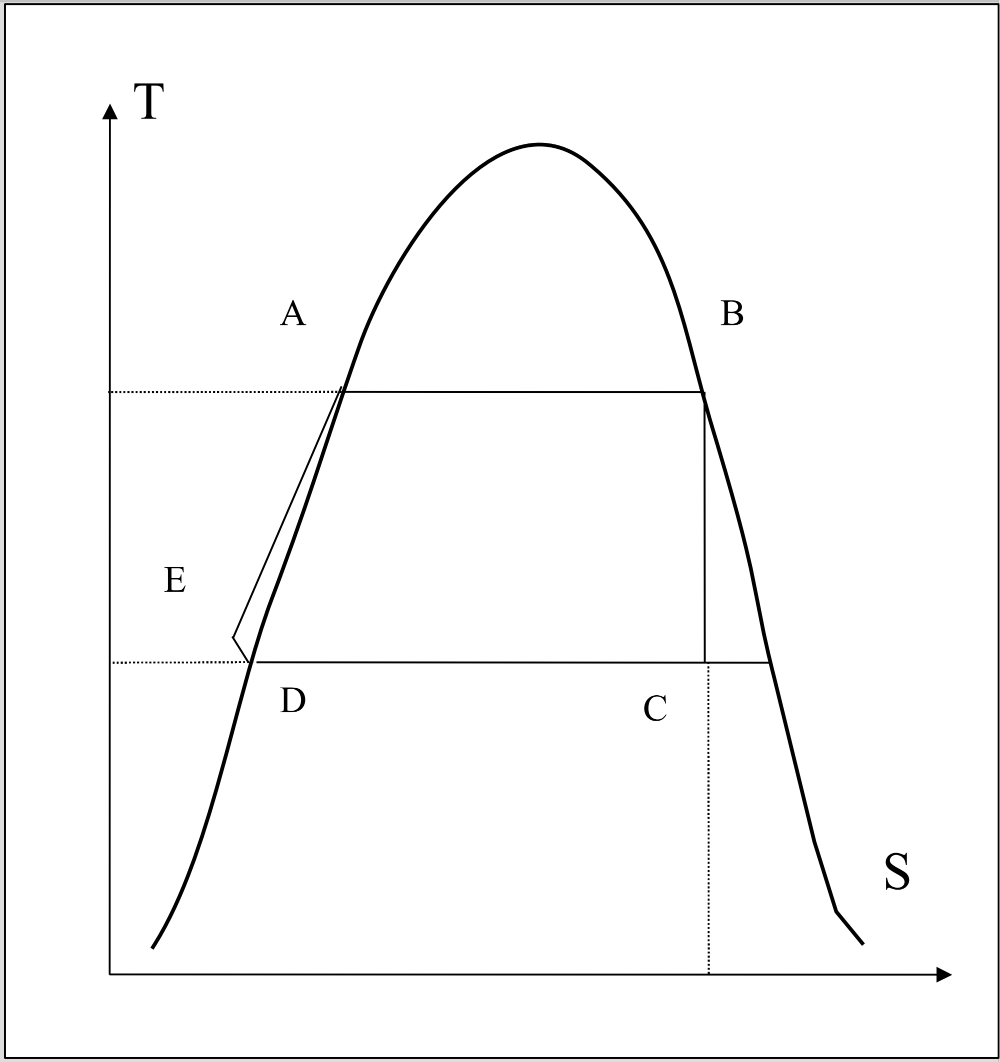
Steam Turbine



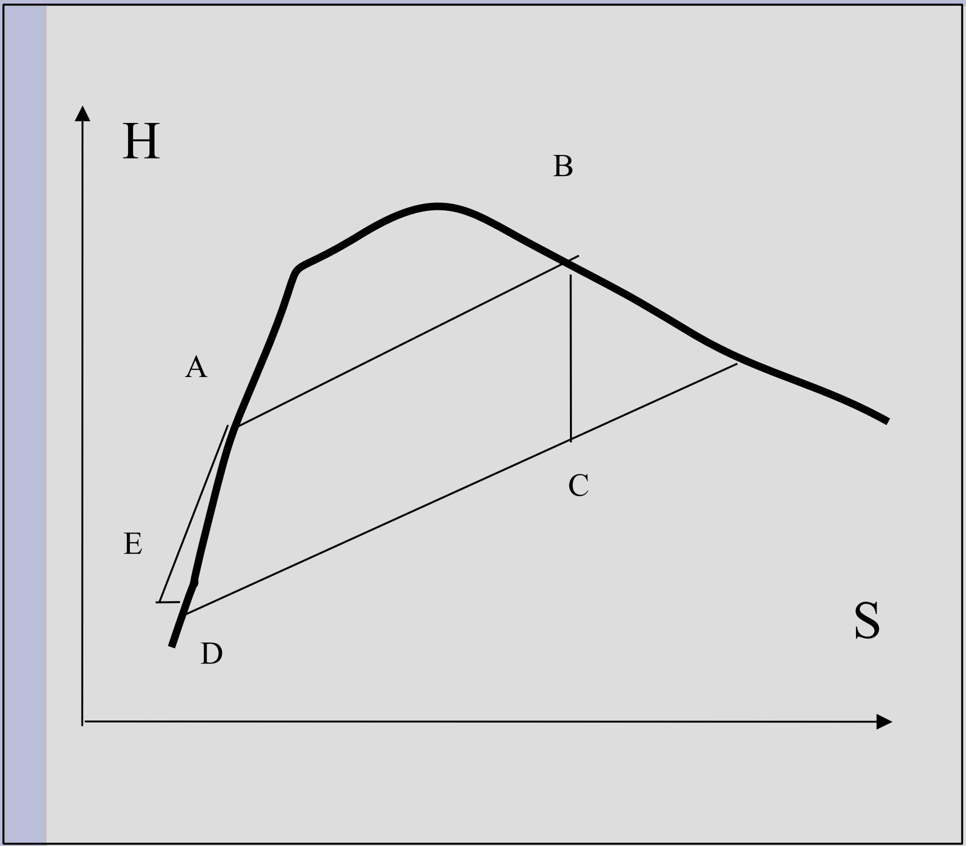
Steam Turbine Rotor

Rankine cycle (Wet)





Energy and power calculations



Mollier Diagram

Turbine

Energy $$h_C - h_B + \frac{V_C^2}{2} - \frac{V_B^2}{2} = w_u + q$$

Power $$\dot{W} = \dot{m}\, w_u = \dot{m}\left(h_C - h_B\right)$$

Boiler

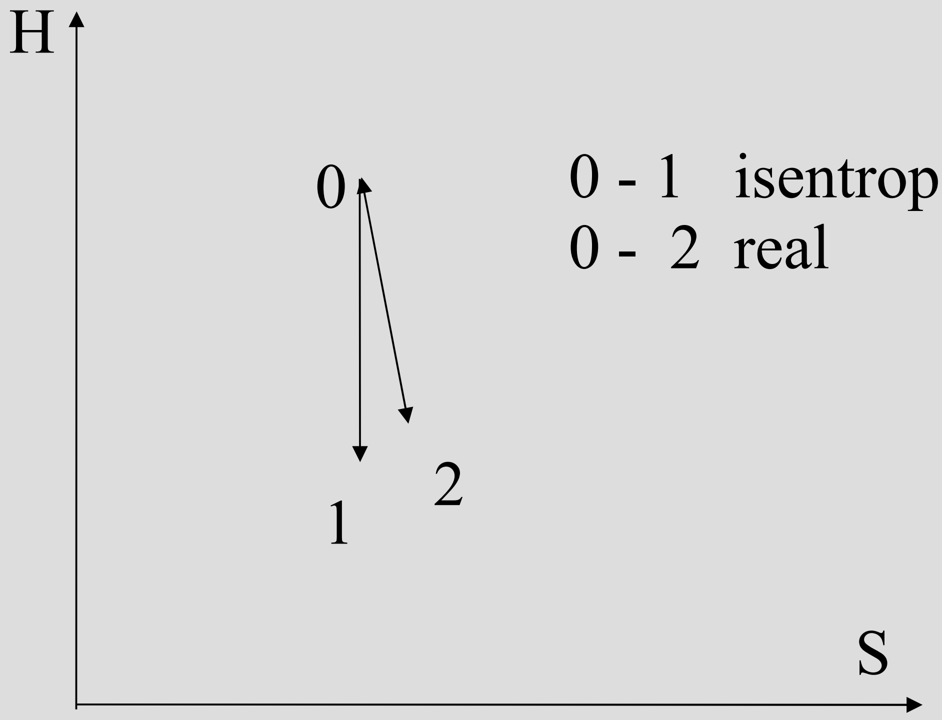
Energy $$h_B - h_E + \frac{V_B^2}{2} - \frac{V_E^2}{2} = w_u + q$$

Power $$\dot{Q} = \dot{m}\, q = \dot{m}\left(h_B - h_D\right)$$

Isentropic efficiency

- Is not an efficiency
- ratio of real work to ideal (isentropic) one (with same final pressure)

$$\rho_s = \frac{W_r}{W_s}$$

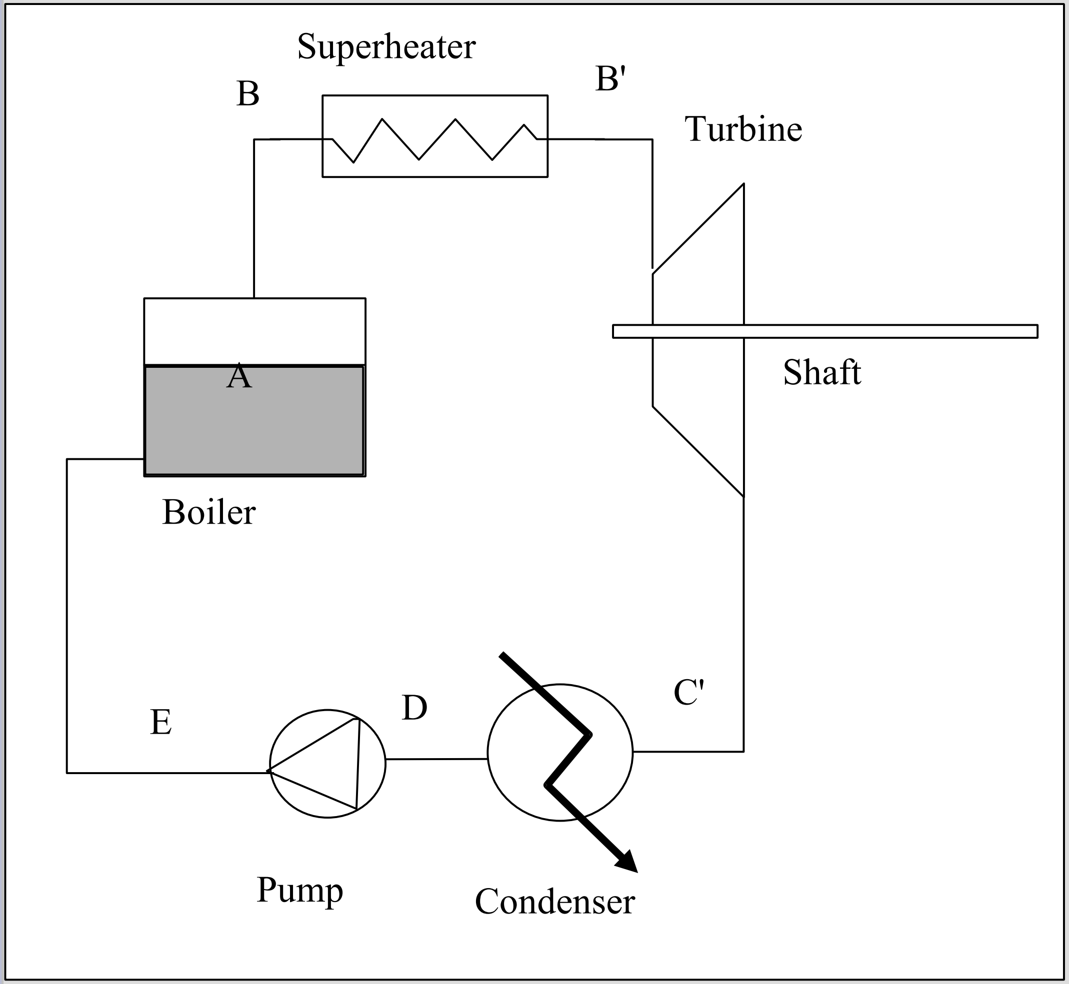


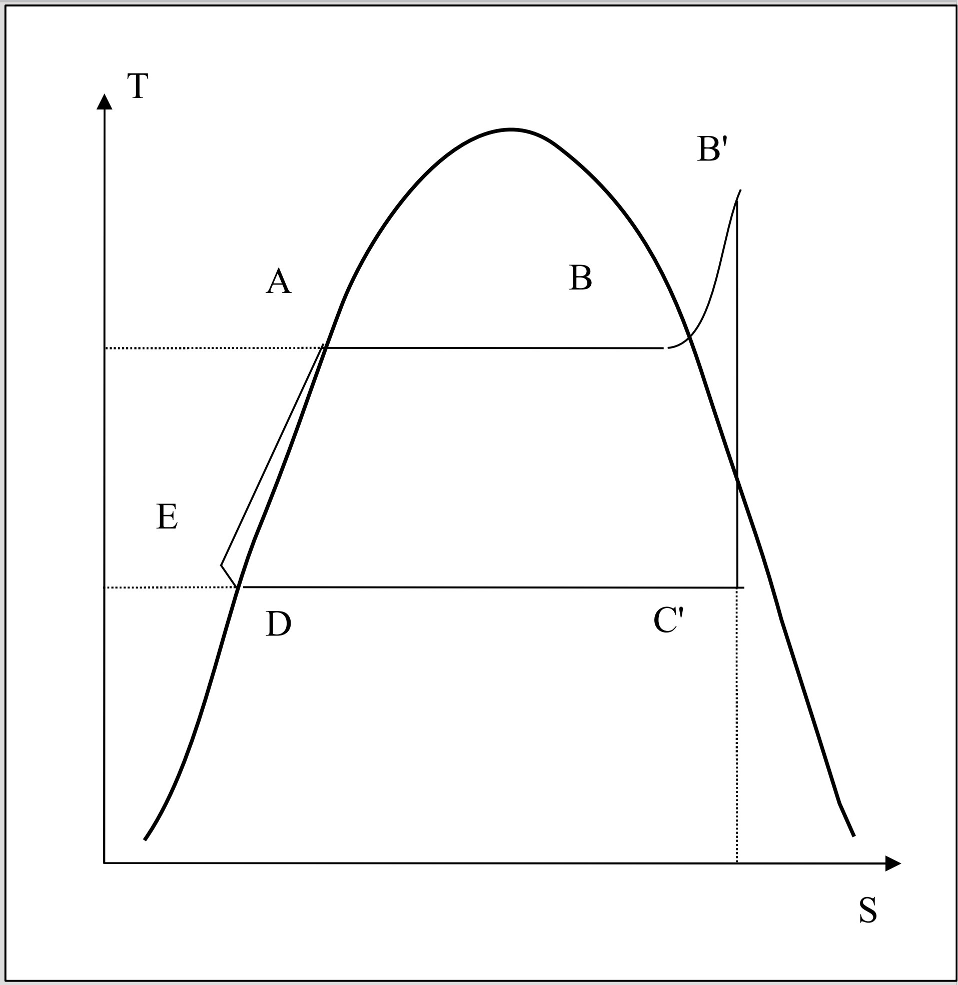
0 - 1 isentropic
0 - 2 real

Mollier diagram

Rankine Cycle with superheat

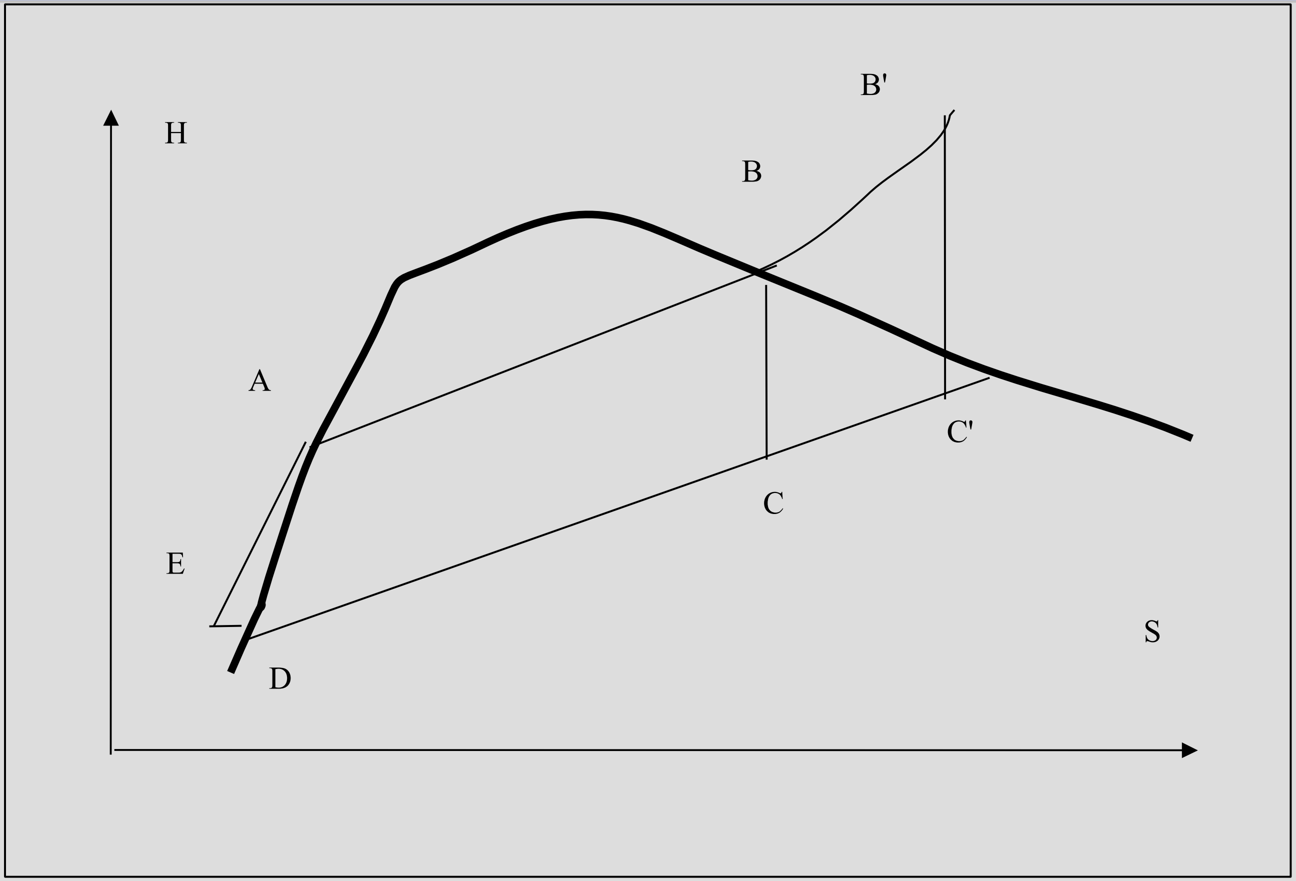
Sometimes called Hirn Cycle





Energy

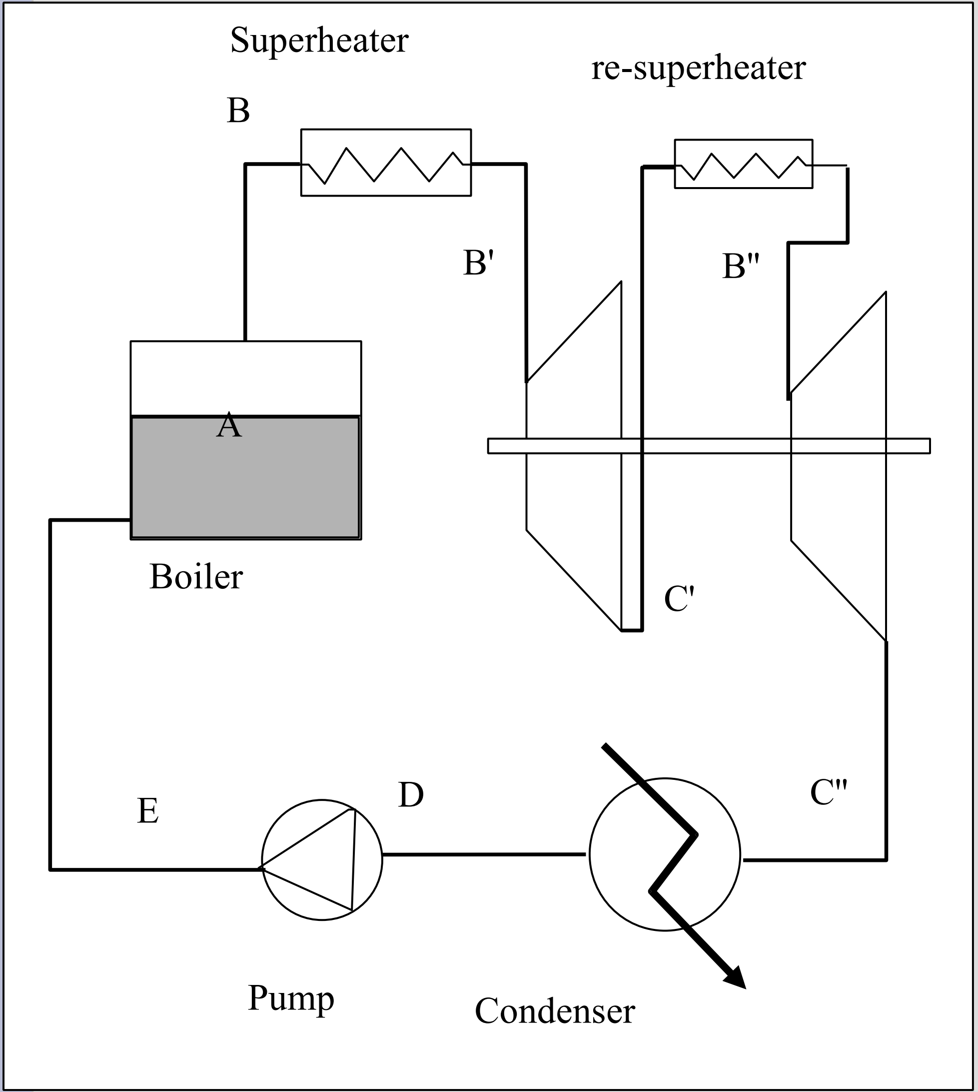
Rankine cycle + superheat

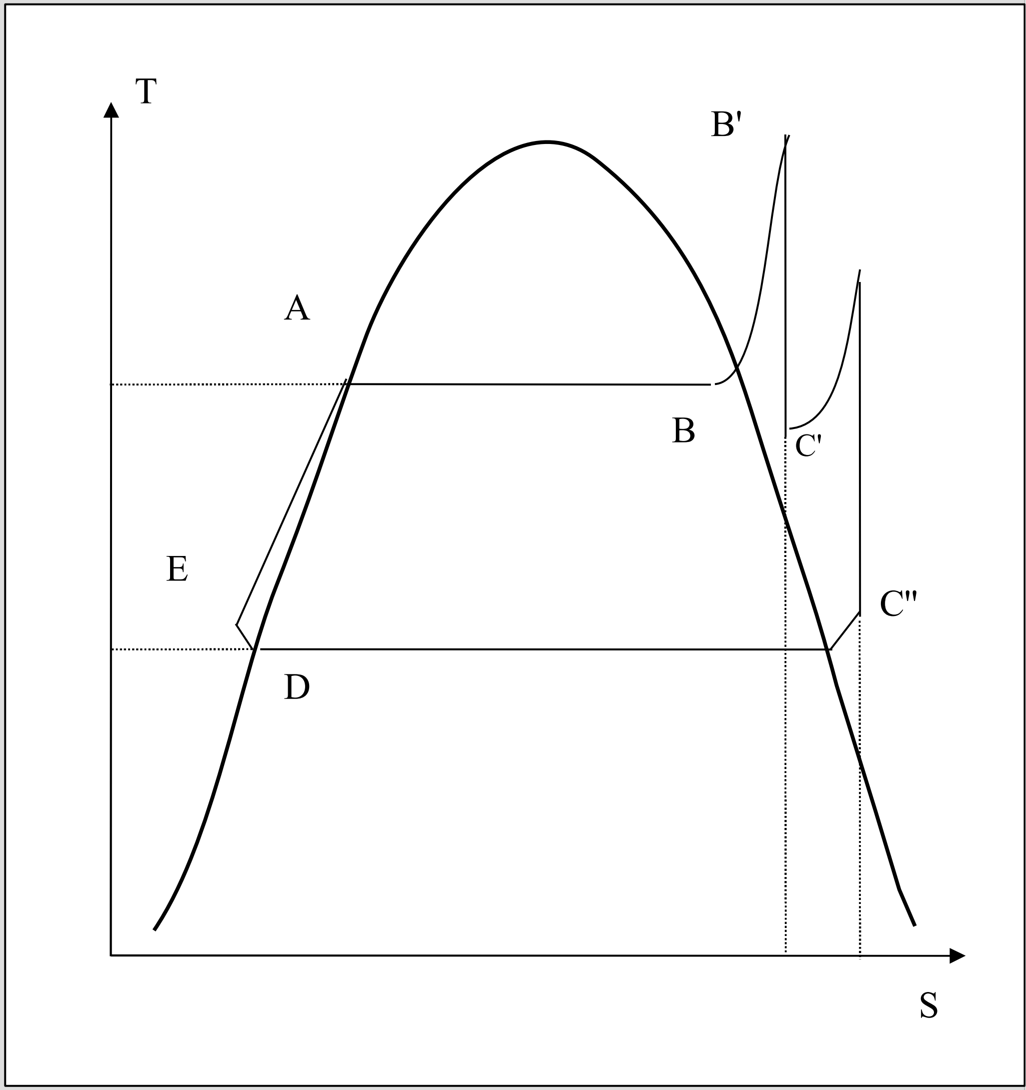


Hot reservoir $q_c = q_{boiler} + q_{superheater} = h_B - h_D + h_B' - h_B = h_B' - h_D$

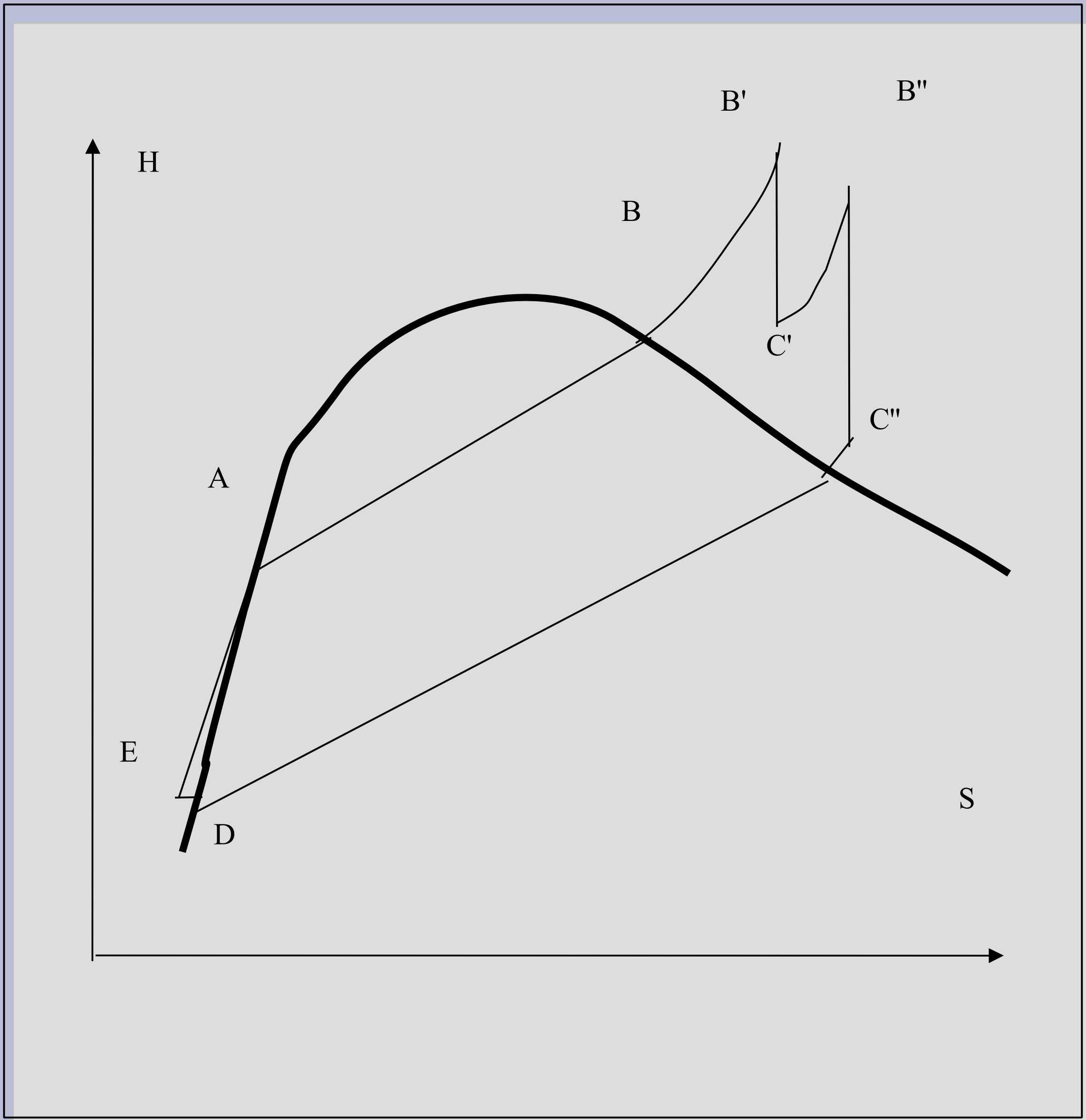
The reheat cycle

- Double stage expansion in double stage turbines
- Superheat again before the second expansion





Energy



Hot Reservoir

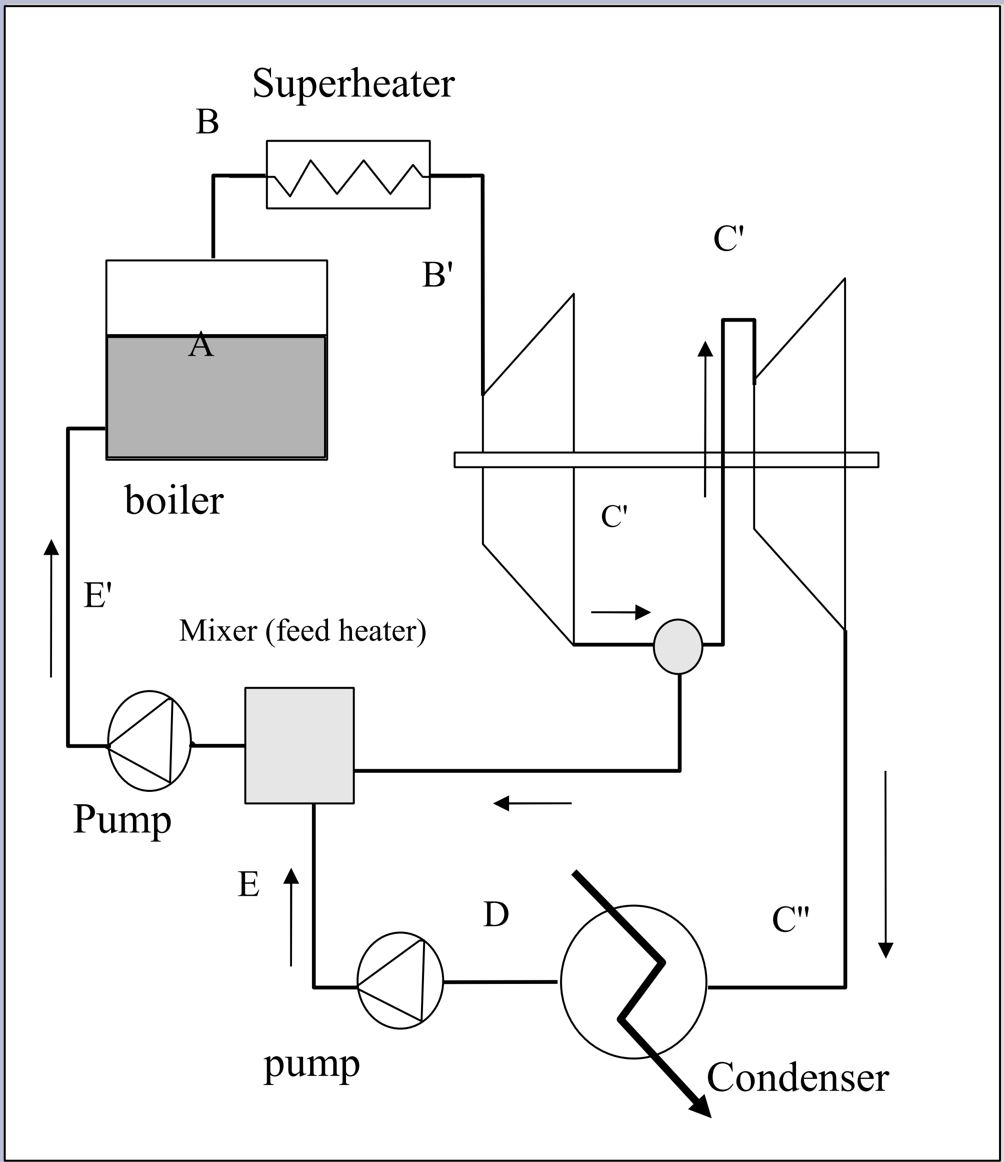
E – B' + C' – B''

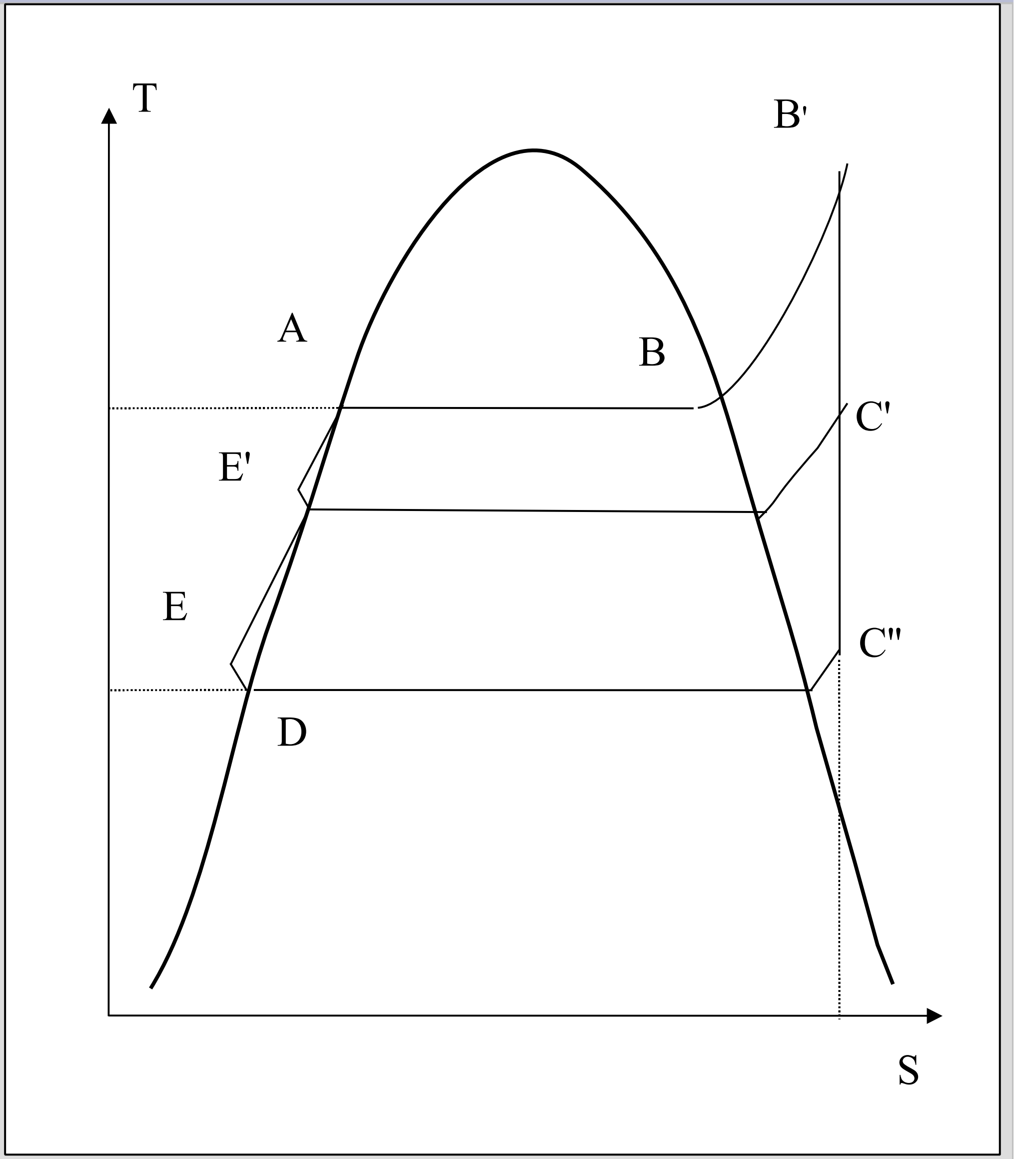
Turbine

B' - C' + B'' – C''

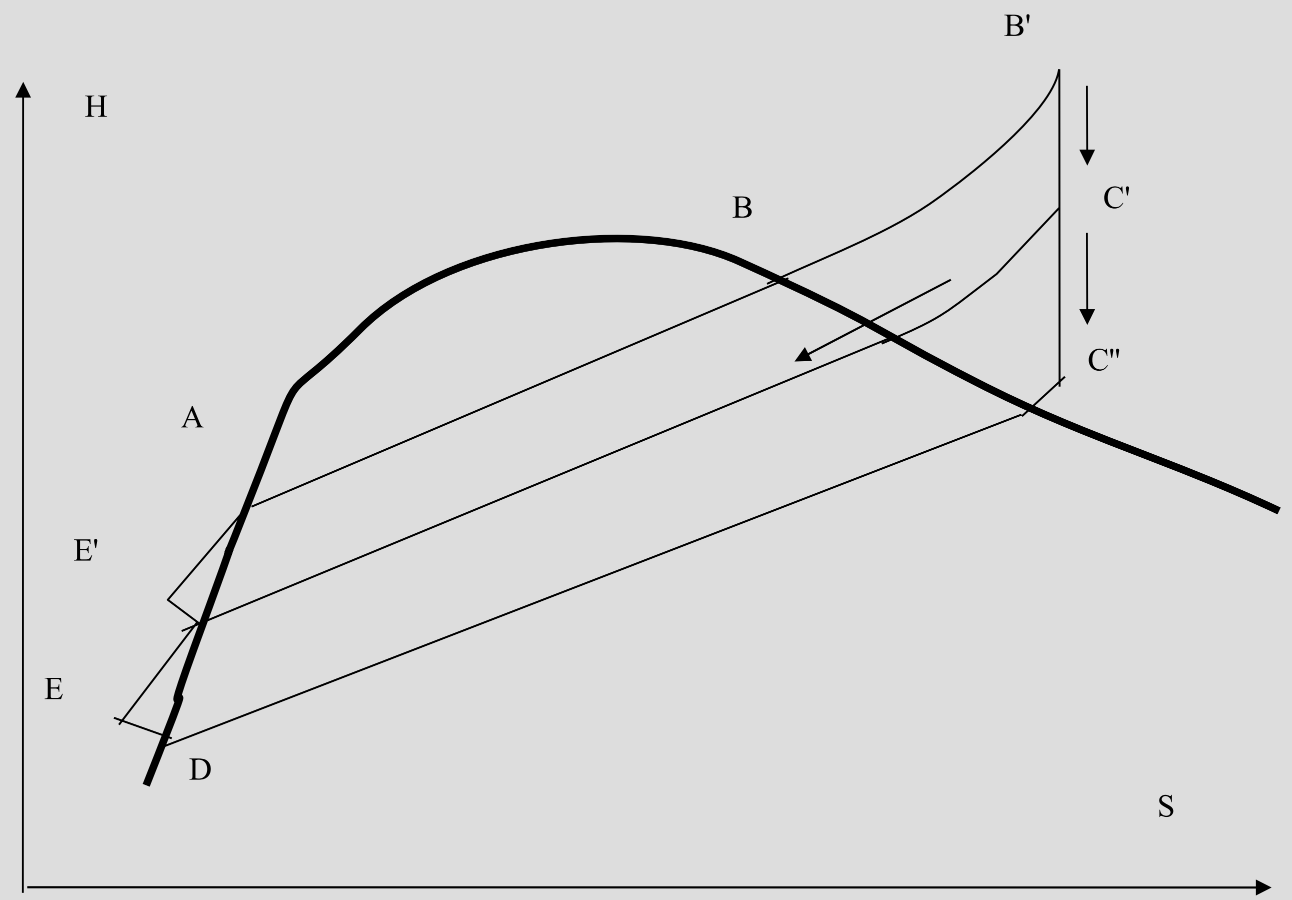
The regenerative cycle

- Extract a fraction of the vapor before complete expansion
- Partially heat the feeding water with that vapor





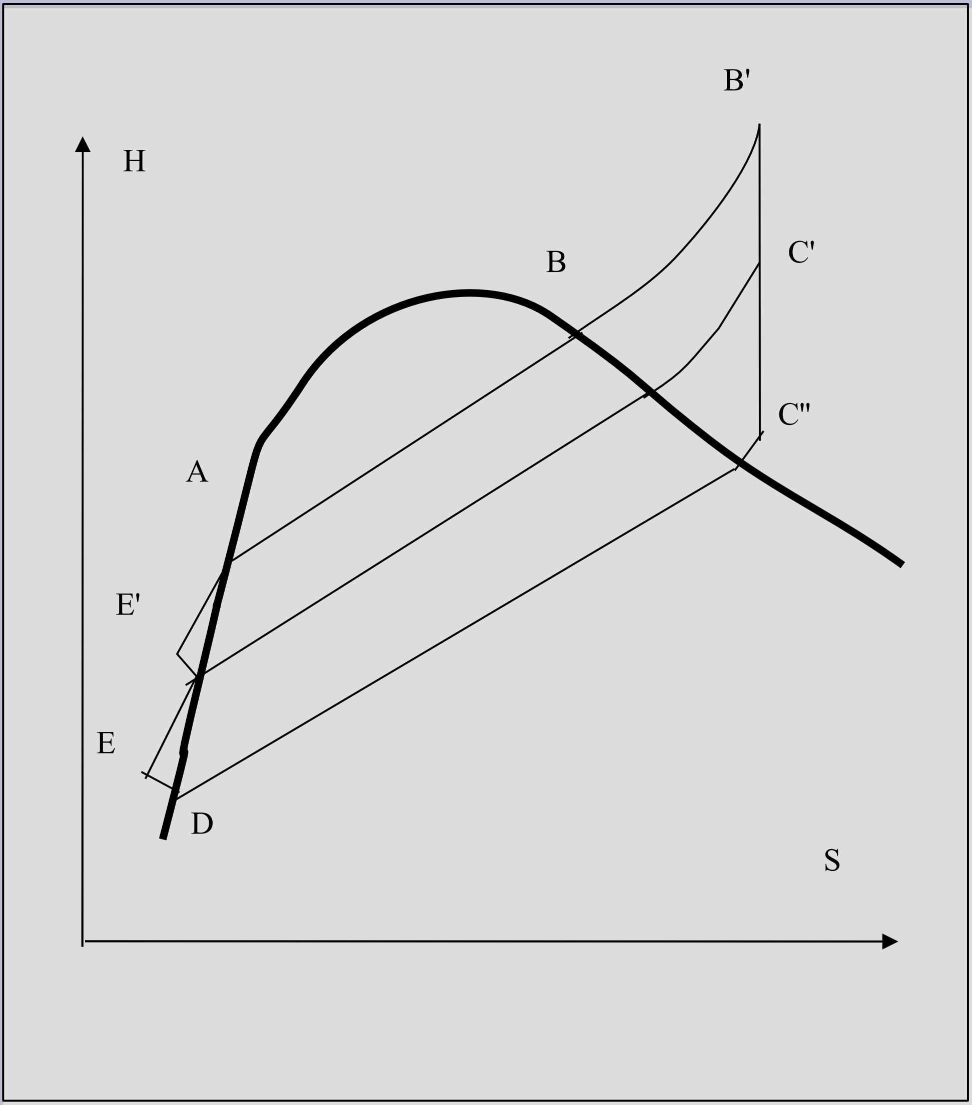
Regenerative cycle (continued)



Back-pressure turbine

- Exhaust at high pressure
- Hence at high temperature

→ Combined Heat and Power (CHP)
Or cogeneration



Heat $q = h_{D'} - h_{C'}$ usable

While $q = h_{C''} - h_D$

would not be usable

Primary energy sources

At the boiler:

- Traditional

- Nuclear
- Oil
- Coal
- Natural gas

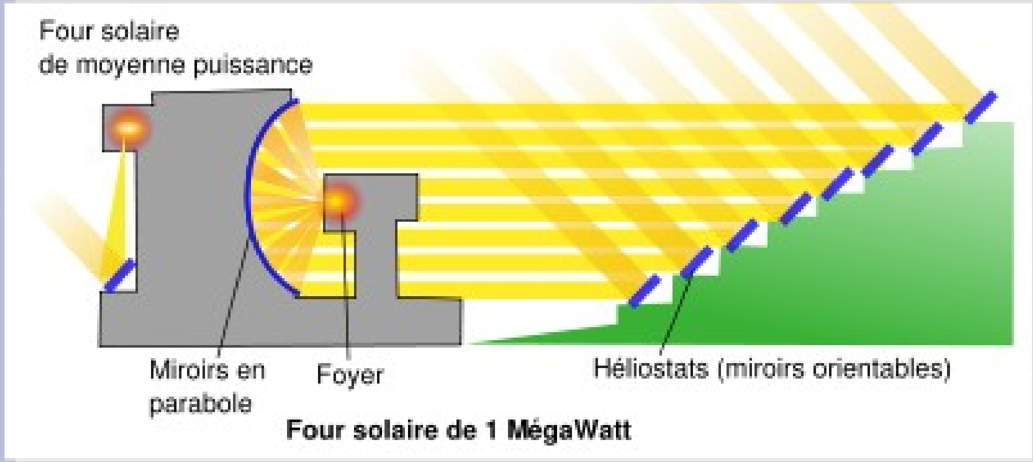
- Renewable

- Solar (concentration)
- Geothermal
- Biomass
- Waste enhancement

Radiation Concentration

- Paraboloiidic mirors
- Cylindro-parabolic mirors
- Miror fields
- Advantages
  - High temperatures
  - Thermodynamic cycles
  - Rankine cycle
  - Stirling cycle

Concentration



- Four Solaire
- Odeillo (Pyrénées)

Centrale Thémis (Pyrénées)

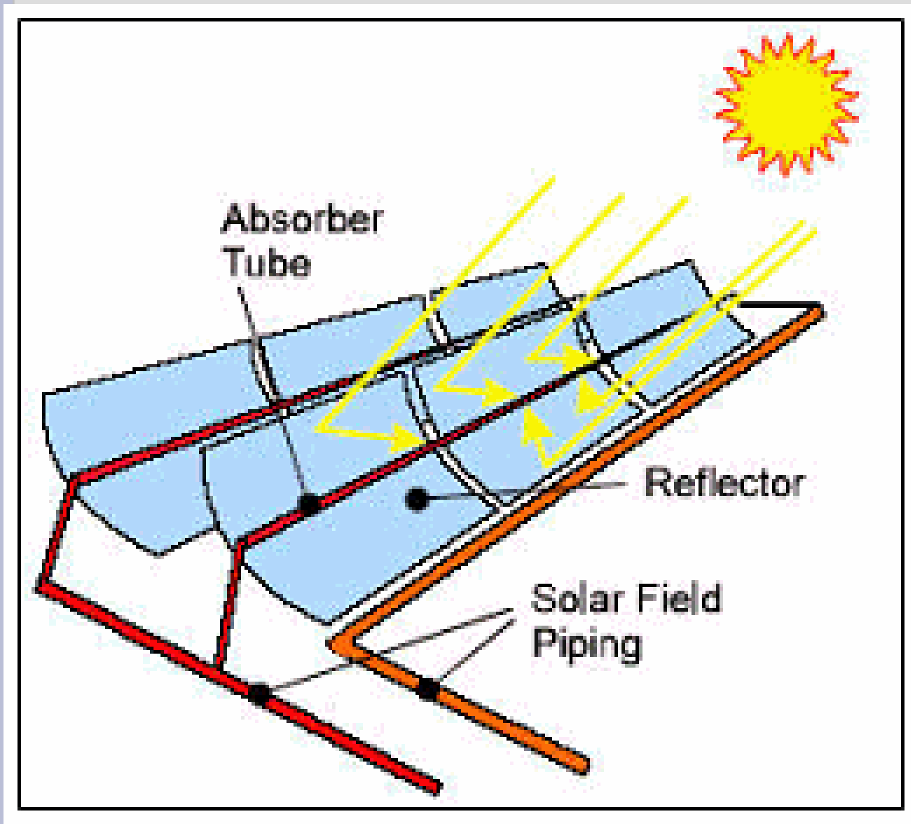
Solar two (U.S.A.)

Solar Two

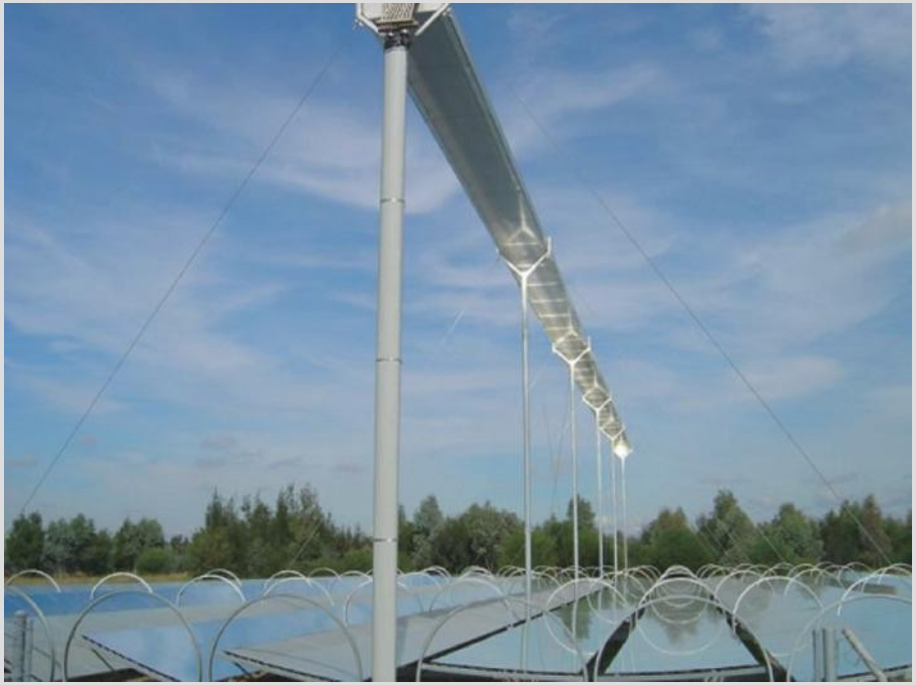
Centrale à tour

Concentration

Cylindro-parabolic mirors

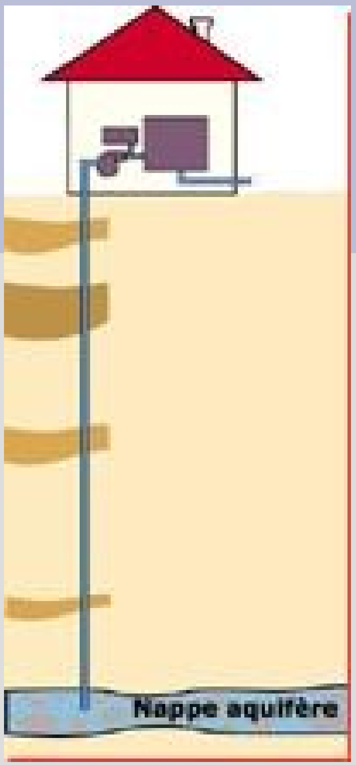


Alméria (espagne)



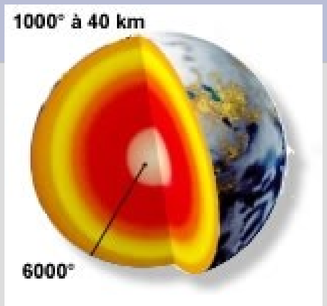
Installing pipe at the focus

Geothermal energy

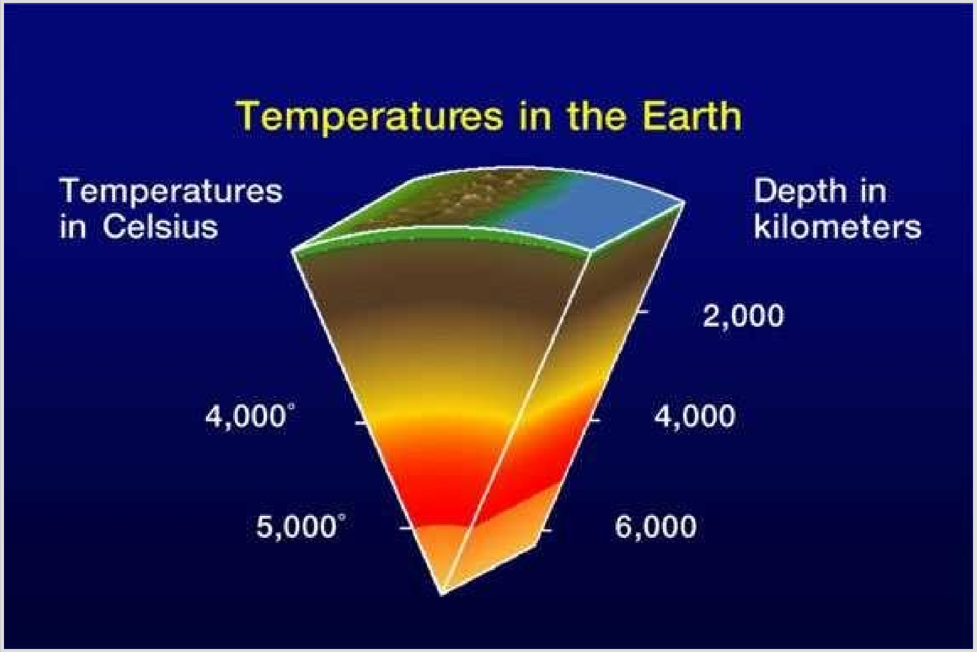


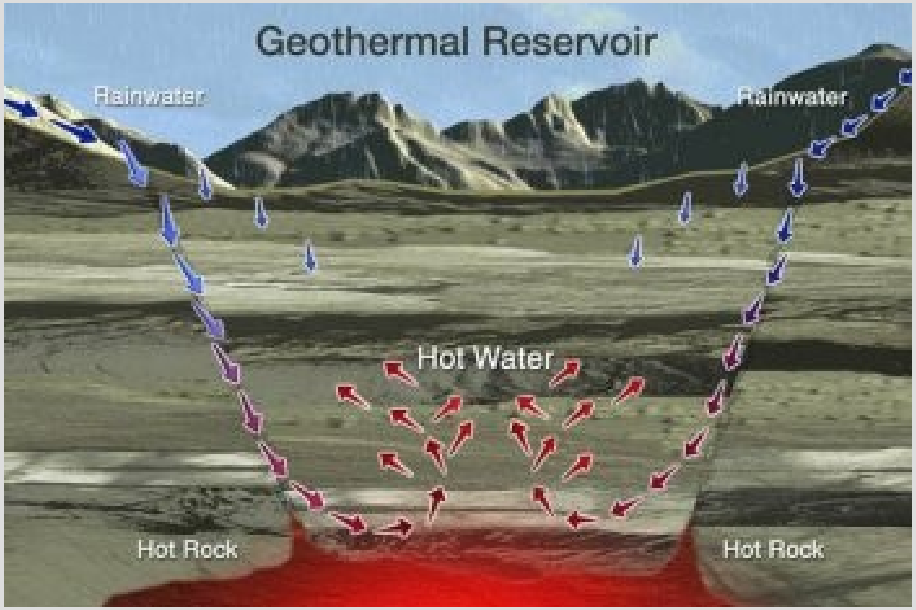
- High temperature (>150°C)
  - Vapour → thermodynamic cycles
  - Combined heat and power
- Medium Températures (<150°C)
  - Urban heating
  - Pump – heat exchanger – reinject
- Low temperatures
  - Geothermal heat pump

Géothermie



- Geothermal gradient
- Aqueous reservoirs



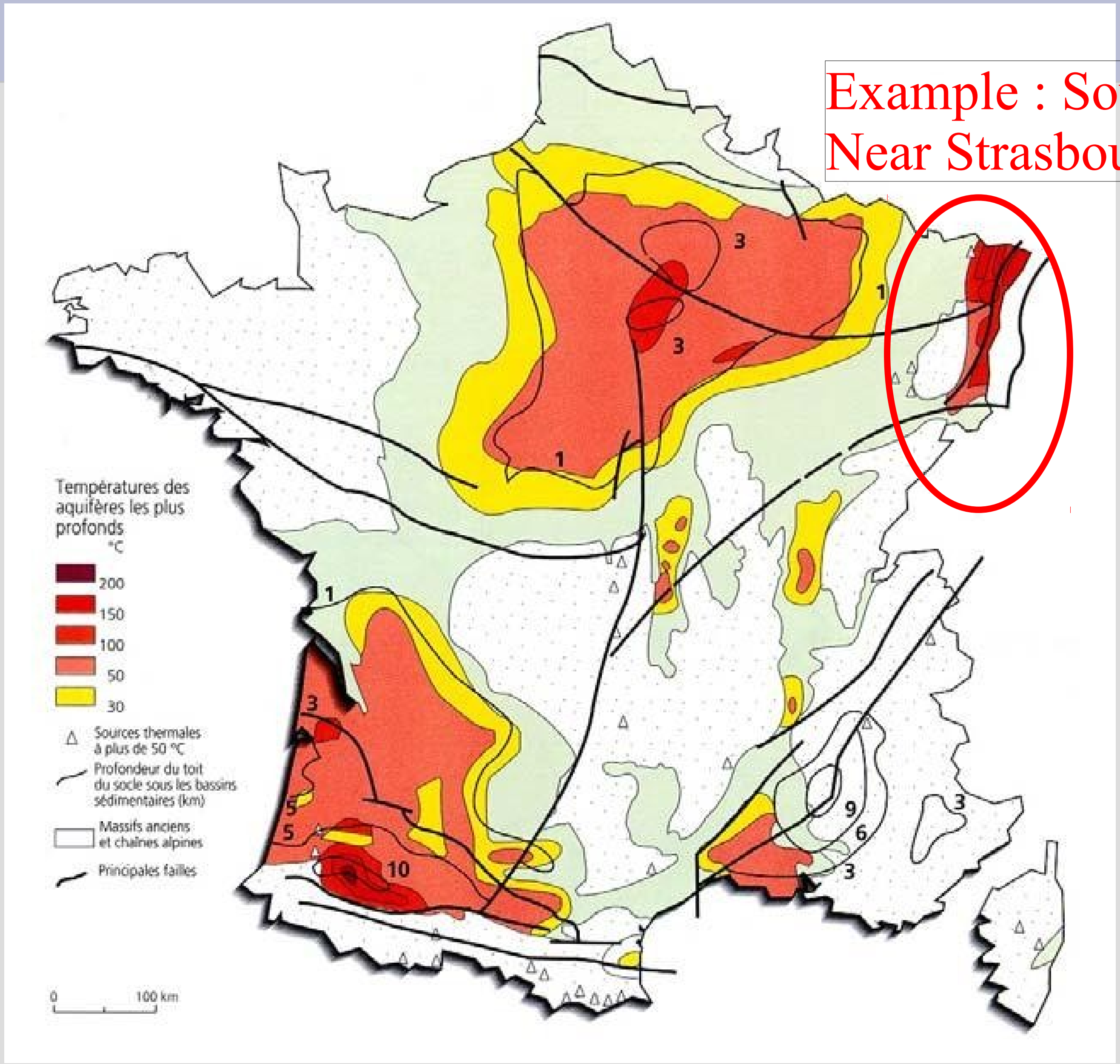


Animation
geo_anim_01.html

Geyser (Islande)

Géothermie en France

Example : Soultz sous forêt
Near Strasbourg



The main project steps

1987 – 1991

Exploration phase

- Drilling GPK1 at - 2000 m
- Coring EPS1 at - 2227 m

1991 – 1998

Creation of the 2 wells system GPK1/GPK2 at - 3600 m

- Deepening of GPK1 at - 3600 m and stimulation
- Drilling of GPK2 at - 3880 m and stimulation
- Circulation test between the 2 wells (4 months)

1999 – 2007

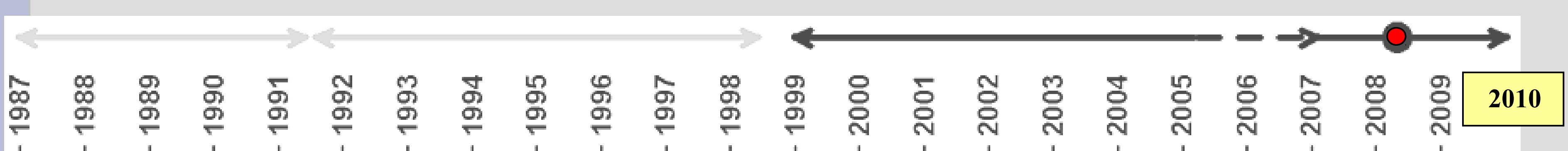
Creation of the 3 wells system GPK2/GPK3/GPK4 at - 5000 m

- Deepening of GPK2 at - 5080 m and stimulation
- Drilling of GPK3 at - 5100 m and stimulation
- Drilling of GPK4 at - 5270 m and stimulation
- Circulation test between the 3 wells (5 months)
- Complementary stimulations (chemical)

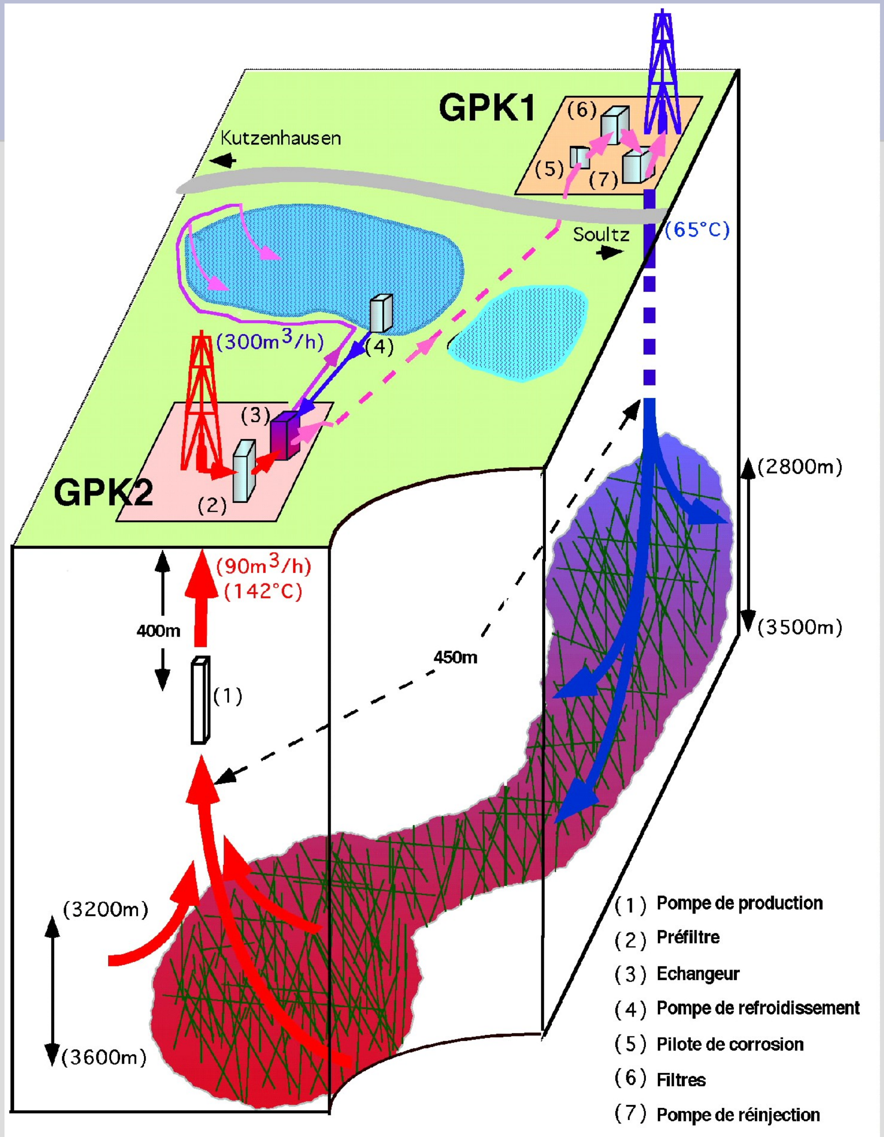
2007 – 2009

Construction of the first production unit ORC - 1.5 MWe

- **Installation of surface equipment (turbine and generator, heat exchangers, cooling systems …)**
- **Installation of the LSP in GPK2 at - 350 m**
- **Inauguration of the power plant 13.06.2008**
- **Installation of the ESP in GPK4 at - 500m**



Circulation test in 1997



Upper reservoir: 2800-3600 m

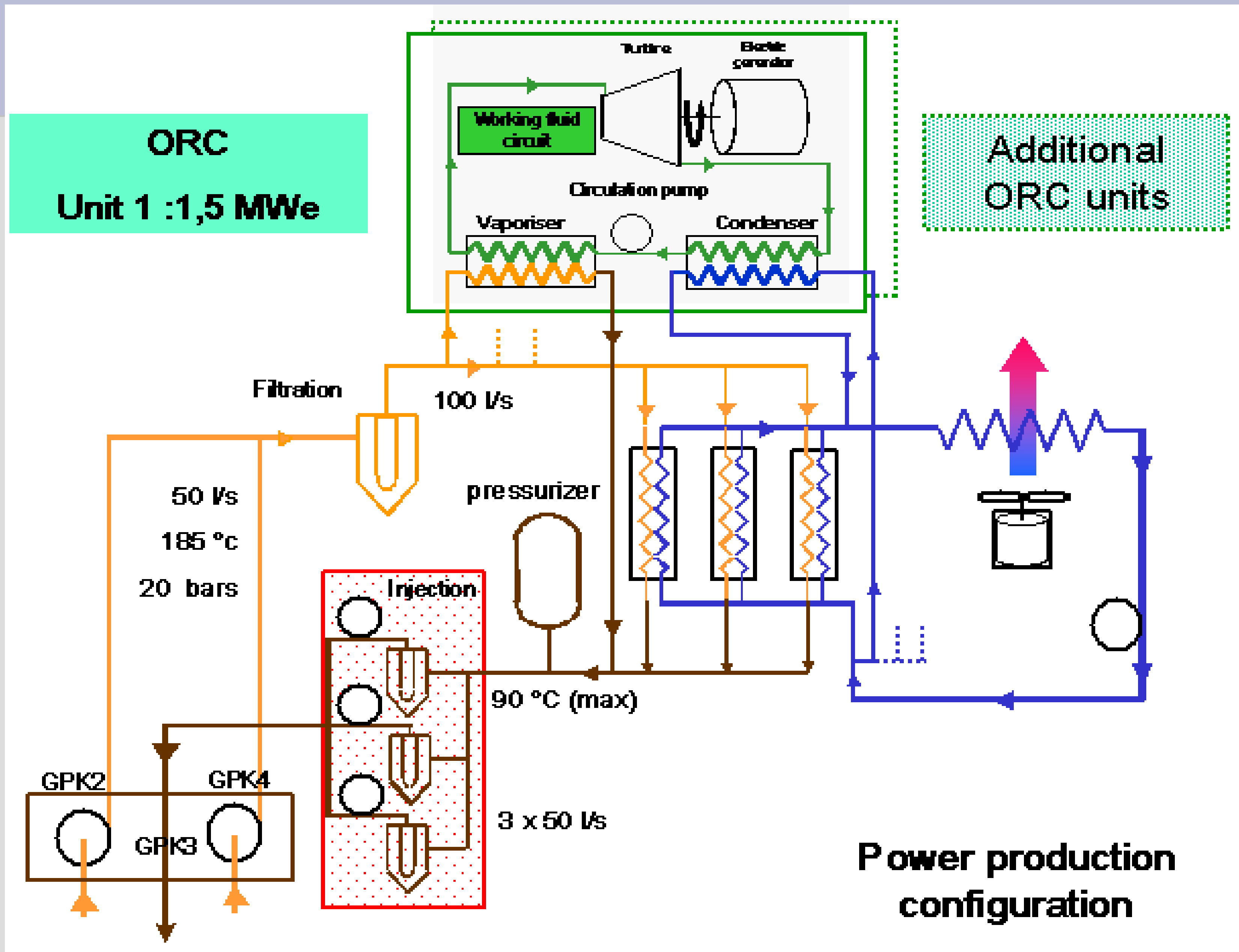
Test duration: 4 months

Production temperature: 140°C

Thermal output: 10 MWth

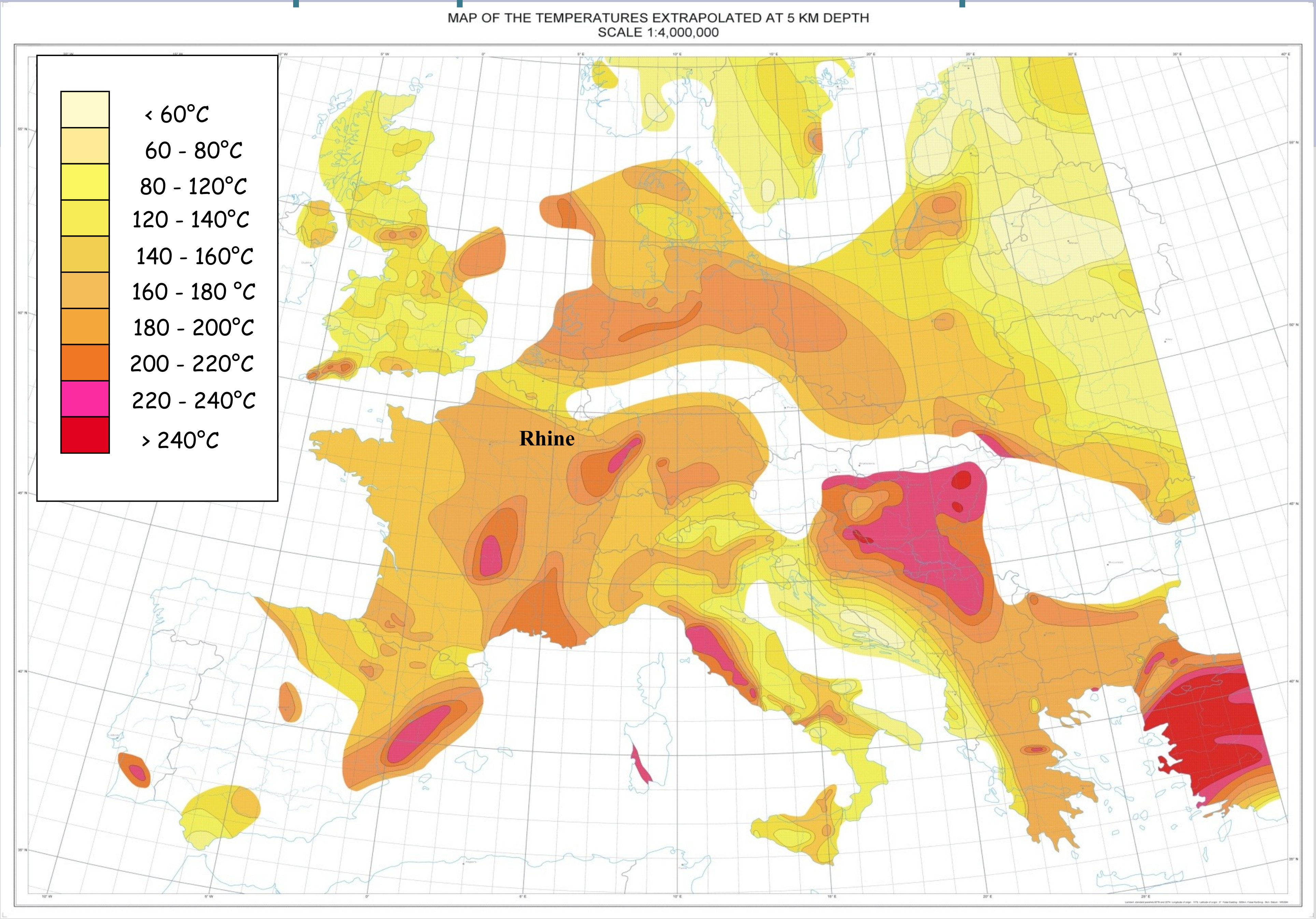
No fluid losses

Binary Cycle: RANKINE



The Soultz power plant

Deep temperatures in Europe



That's all Folks