Exercise 1: wood pyrolysis energy balance

Input:

- 1 kg dry wood with LHV 17 MJ/kg
- heat supply for the pyrolysis (endothermal): 2.4 MJ (=delivered from burning the liberated pyrolysis gases)

Products:

- 200 L gas (with LHV equal to 1/3rd of that of NG (36 MJ/m^3))
- 0.45 kg liquids (with LHV equal to 1/3rd of oil (42 MJ/kg))
- 0.3 kg charcoal (with LHV equal to that of coal (24 MJ/kg)

Compute the total energy balance of the pyrolysis process.
Compute the energy balance only for the solid output (charcoal).

Solution:
Products:

- 200 L gas (LHV 1/3rd of NG (36 MJ/m^3) = 12 MJ/m^3) => 2.4 MJ
- 0.45 kg liquids (LHV 1/3rd of oil (42 MJ/kg) = 14 MJ/kg) => 6.3 MJ
- 0.3 kg charcoal (LHV of coal (24 MJ/kg)) => 7.2 MJ

Total: 15.9 MJ
Balance: (15.9-2.4) / 17 = 79% (total)
7.2 / 17 = 42% (carbon basis only)

Exercise 2: wood gasification energy balance (downdraft gasifier, air)

Input:
1 kg 15% humid wood (with LHV of wood with 0% H_2O = 17.8 MJ/kg)
⇨ compute the LHV of the humid wood

Products:
2 m^3 'producer gas' of :
18% CO / 16 % H_2 / 2 % CH_4 / 14% CO_2 / 50% N_2
(LHV (CO): 305 kJ/mole; LHV (H_2) : 241 kJ/mole; LHV (CH_4) : 800 kJ/mole)

Compute the energy balance of this gasification process ('cold gas efficiency').

Indication:

Producer gas type	**Main compounds**	**Process**
Poor : ≤ 5 MJ / m^3	N_2, CO, H_2	pulsed **air**
Medium : 10 MJ / m^3	CO, H_2	pulsed **oxygen**; mixed air/steam reforming
Rich : ≥ 15 MJ / m^3	CH_4	**steam** reforming, hydrogenation

Input: 1 kg 15% humid wood (17.8 MJ/kg 0% H_2O), see the course formula for humid wood:

=> LHV(15% water) = 17.8*(1 – 1.14*15%) = 14.75 MJ/kg

2 m^3 producer gas of :
18% CO / 16 % H_2 / 2 % CH_4 / 14% CO_2 / 50% N_2
= 360 L CO / 320 L H_2 / 40 L CH_4
= 16 moles CO / 14.3 moles H_2 / 1.8 moles CH_4 (22.4 L/Nm^3)
(LHV (CO): 305 kJ/mole; LHV (H_2) : 241 kJ/mole; LHV (CH_4) : 800 kJ/mole)

=> 4.88 MJ CO + 3.45 MJ H_2 + 1.44 MJ CH_4 = 9.77 MJ
(= 4.9 MJ/m^3) = 'poor' gas (air-pulsed) – see the above table

Balance: 9.77 MJ out / 14.75 MJ in = 66% ('cold gas efficiency')

Exercise 3: 25 MWe straw biomass power plant

Data:

- 8000 h per year, producing 200 GWh_el
- 160'000 tonnes / yr of straw
- assume a typical yield of 3 tonnes straw per ha

Questions:

- what is the electrical efficiency of the plant?
  (use the LHV for straw from the course slides)
- what would be the straw collection area needed for the plant?

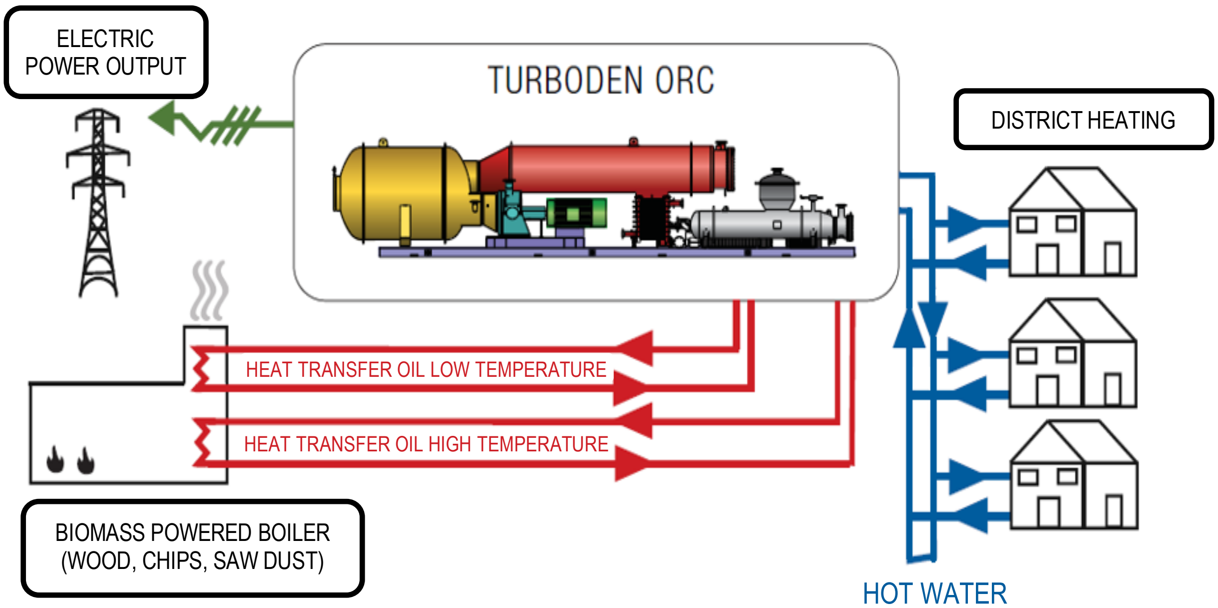
→ What is the electrical efficiency of the plant?
use the LHV for straw from the course slides => 13 MJ/kg
(this straw is 20% wet)
input : 160'000'000 kg straw * 13 MJ/kg = 2.08 PJ

Electricity produced : 200 GWh_el = 0.72 PJ
⇨ efficiency = 0.72/2.08 = 34.6%. This is a particularly efficient (optimised) plant, due to the fairly large steam turbine size (25 MWe)

→ What would be the straw collection area needed for the plant?
With 3 tonnes/ha straw, we need 160'000 tonnes/3 = 53333 hectare = 533.3 km^2, or a square of 23 x 23 km. This is a huge area, for a comparatively small power plant.

Exercise 4: ORC with biomass combustion

The Organic Rankine Cycle (ORC) is a technology used with biomass applications. The systems are flexible and can be used in e.g. district heating, pellet production factories, sawmills and tri-generation systems with absorption chillers. A possible application is reported in the scheme below:



Considering the following data:
Input of wood biomass = 5.254 ton/h
Wood biomass LHV = 2.6 kWh/kg
Heat transfer oil properties :

	Temperature	Enthalpy
Inlet Low Temp cycle	132°C	200 kJ/kg
Outlet Low Temp cycle/ Inlet High Temp cycle	252°C	443 kJ/kg
Outlet High Temp cycle	312°C	578 kJ/kg

Oil Mass flow Low Temp cycle = 4.3 kg/s
Oil Mass flow High Temp cycle = 81.3 kg/s

Hot water outlet temperature from ORC system = 90°C
District heating water return = 60°C
Water properties :

Temperature	Enthalpy
60°C	251 kJ/kg
90°C	377 kJ/kg

District heating water flow = 76.43 kg/s
Electric net power output = 2.175 MWe

Calculate

1) <u>The boiler efficiency</u>

Thermal oil total power = 4.3 kg/s *(443-200) kJ/kg + 81.3 kg/s *(578-443) kJ/kg = 12.02 MW
Wood Biomass input = 5254 kg/3600s * 9.36 MJ/kg = 13.66 MW
Efficiency of boiler = 12.02 MW / 13.66 MW = 88%

2) <u>The electrical efficiency of the ORC</u>

Efficiency = output (electric power)/ input (thermal oil power)
Efficiency = 2175 kW / 12020 kW = 18%

3) <u>The cogeneration efficiency of the ORC</u>

District heating power = 76.43 kg/s * (377-251) kJ/kg = 9630 kW
Cogeneration efficiency on recovered heat = (2175+9630)/12020 = 98.2%
Cogeneration efficiency on woody biomass = (2175+9630)/13660 = 86.4%