SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE - Laboratory of Renewable Energy Sciences and Engineering

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Renewable Energy: Exercise 10 solution

In this exercise, you will calculate the capacity of a renewable power driven hydrogen filing station.

---

1. Hydrogen from renewable electricity for mobility applications (see figure 1)

   (a) $P_{\text{wind}} = 0.5\rho_{air}c_pAu^3 = 343.5\ \text{kW}_{\text{AC}}$ where $\rho_{air} = 1.2\ \text{kg/m}^3$
   $P_e^- = \text{P}_{\text{wind}} \cdot \eta_{\text{AC/DC}} = 326.3\ \text{kW}_{\text{DC}}$
   $E_e^- = \text{P}_e^- \cdot 12\text{h} = 3.916\ \text{MWh}_{\text{DC}}$ at most
   $E_e^- = \text{P}_e^- \cdot 8.2\text{h} = 2.676\ \text{MWh}_{\text{DC}}$ in average

   Energy balance in the system:

   $E_e^- = E_{\text{EL}} + m_{H_2} \cdot \text{e}_{\text{comp}} = \frac{m_{H_2} \cdot \text{HHV}_{H_2}}{\eta_{\text{EL}}} + m_{H_2} \cdot e_{\text{comp}}$
   $\Longrightarrow \quad m_{H_2} = E_e^- \cdot \left(\frac{1}{\frac{\text{HHV}_{H_2}}{\eta_{\text{EL}}} + e_{\text{comp}}} \right)$ with $e_{\text{comp}} = \frac{1}{\gamma-1} \cdot p_1 v_1 \cdot \left(\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1 \right)$ for an closed system (small tank) otherwise for a open system (large tank such as a cavern) use $e_{\text{comp}} = \frac{\gamma}{\gamma-1} \cdot p_1 v_1 \cdot \left(\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1 \right)$ with $p_1 = 101325$ Pa, $v_1 = 12.1\ \text{m}^3/\text{kg}$, $p_2 = 400 \cdot 10^5$ Pa, $\gamma = 1.41$, $\text{HHV}_{H_2} = 39.41\ \text{kWh kg}^{-1}$. Here, we assumed a small tank like a gas bottle (closed system).
   $\Longrightarrow\ e_{\text{comp}} = 14.019\ \text{MJ/kg} = 3.89\ \text{kWh/kg}$
   $\Longrightarrow\ m_{H_2} = 65.1$ kg at most and $m_{H_2} = 44.5$ kg in average

   At most, (65.1 kg)/(3 kg/car)= 21 cars can be tanked daily, and on average (44.5 kg)/(3 kg/car) = 14 cars/day.

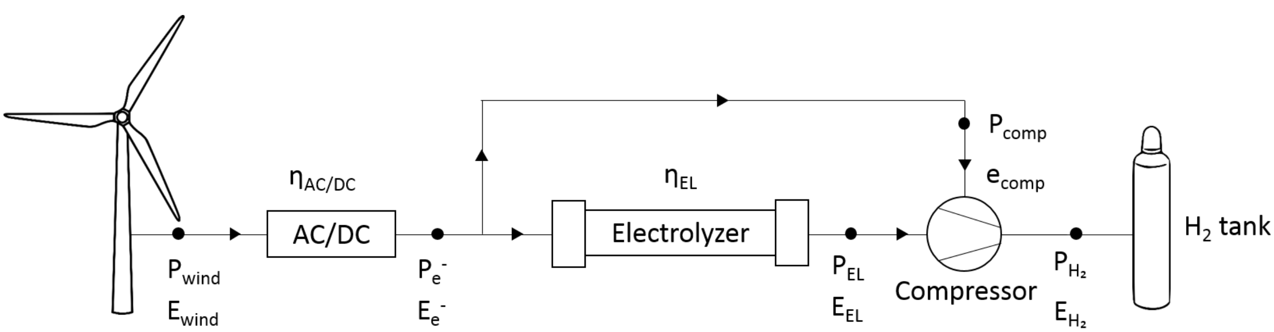

Figure 1: Schematic of the wind energy converted to hydrogen energy with all the losses

(b) In this case: $E_{\text{PV}} = Irr \cdot A \cdot t \cdot \eta_{\text{PV}} = 700 \cdot 2000 \cdot 10 \cdot 15 = 2.1\ \text{MWh}_{\text{DC}}$ at most or 0.86 MWh_{DC} in average

$\implies m_{H_2} = E_e^- \cdot \left(\frac{1}{\frac{\text{HHV}_{H_2}}{\eta_{\text{EL}}} + m_{H_2} \cdot e_{\text{comp}}} \right) = 34$ kg at most or 14 kg in average

Thus, at most 11 cars can be tanked daily and 4 cars in average.

(c) Wind turbine: $C = \frac{P_{\text{wind}}[\text{W}] \cdot 12[\text{h}]}{100[\text{km/kg}] \cdot 63.4[\text{kg}]} = 0.65$ kWh/km

PV pannels: $C = \frac{P_{\text{PV}}[\text{W}] \cdot 10[\text{h}]}{100[\text{km/kg}] \cdot 34[\text{kg}]} = 0.61$ kWh/km

Gasoline car: $C = \frac{33[\text{MJ/L}] \cdot 7.5[\text{L}]}{3600[\text{s/h}] \cdot 100[\text{km}]} = 0.69$ kWh/km

The overall consumption remains very similar. Nevertheless, the hydrogen-car is pollution free, both in operation and in fuel generation.