Renewable Energy: Hydrogen solution

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

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

   (a) $P_{\text{wind}} = 0.5\rho_{air}c_p A u^3 = 343.5 \text{ kW}_{\text{AC}}$, where $\rho_{\text{air}} = 1.2 \text{ kg m}^{-3}$
   $P_e^- = P_{\text{wind}} \cdot \eta_{\text{AC/DC}} = 326.3 \text{ kW}_{\text{DC}}$
   $E_e^- = P_e^- \cdot 12\,\text{h} = 3.916 \text{ MWh}_{\text{DC}}$ at most
   $E_e^- = P_e^- \cdot 8.2\,\text{h} = 2.676 \text{ MWh}_{\text{DC}}$ on average, with $3000\,\text{h}$ of average annual load divided by $365.25\,\text{d}$ providing roughly $8.2\,\text{h}$ of operation per day.

   Energy balance in the system:
   $$E_e = E_{\text{EL}} + m_{H_2} \cdot e_{\text{comp}} = m_{H_2} \cdot \frac{\text{HHV}_{H_2}}{\eta_{\text{EL}}} + m_{H_2} \cdot e_{\text{comp}}$$

   $$\Rightarrow \quad m_{H_2} = \frac{E_e^-}{\frac{\text{HHV}_{H_2}}{\eta_{\text{EL}}} + e_{\text{comp}}} \quad \text{with } e_{\text{comp}} = \frac{1}{\gamma - 1}p_1 v_1\left[\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \text{ for a closed system}$$

   (small tank), with $p_1 = 101\,325 \text{ Pa}$, $v_1 = 12.1 \text{ m}^3\,\text{kg}^{-1} (= \text{specific volume at } 25\,^\circ\text{C})$, $p_2 = 400 \cdot 10^5 \text{ Pa}$, $\gamma = 1.41$, $\text{HHV}_{H_2} = 39.41 \text{ kWh kg}^{-1}$. Here, we assumed a small tank like a gas bottle (closed system).
   $\Rightarrow e_{\text{comp}} = 14.019 \text{ MJ kg}^{-1} = 3.89 \text{ kWh kg}^{-1}$
   $\Rightarrow m_{H_2} = 65.1 \text{ kg}$ at most and $m_{H_2} = 44.5 \text{ kg}$ on average

   At most, $\frac{65.1\,\text{kg}}{3\,\text{kg car}^{-1}} = 21$ cars can be tanked daily, and on average $\frac{44.5\,\text{kg}}{3\,\text{kg car}^{-1}} = 14$ cars/day.
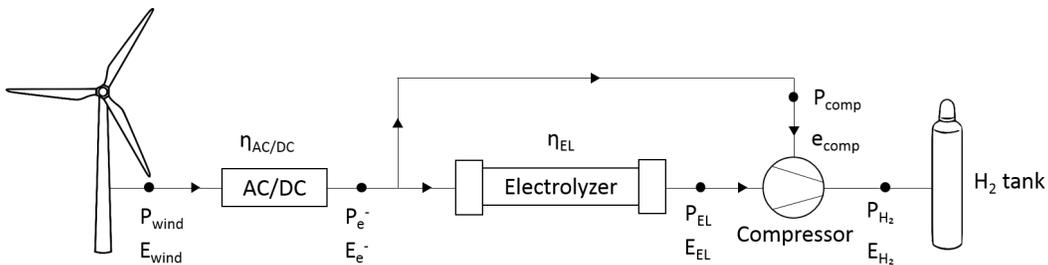
Figure 1: Schematic of the wind energy converted to hydrogen energy with all the losses

(b) In this case: $E_{PV} = Irr \cdot A \cdot t \cdot \eta_{PV} = 700 \cdot 2000 \cdot 10 \cdot 0.15 = 2.1\,\text{MWh}_{\text{DC}}$ at most or $0.86\,\text{MWh}_{\text{DC}}$ on average

$\Rightarrow m_{H_2} = \dfrac{E_e^-}{\frac{\text{HHV}_{H_2}}{\eta_{\text{EL}}} + e_{\text{comp}}} = 34\,\text{kg}$ at most or $14\,\text{kg}$ on average

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

(c) Wind turbine: $C = \dfrac{P_{\text{wind}}[\text{W}] \cdot 12[\text{h}]}{300[km/car] \cdot 21[car]} = 0.654\,\text{kWh}\,\text{km}^{-1}$

PV panels: $C = \dfrac{P_{\text{PV}}[\text{W}] \cdot 10[\text{h}]}{300[km/car] \cdot 21[car]} = 0.636\,\text{kWh/km}$

Gasoline car: $C = \dfrac{33[\text{MJ}\,\text{L}^{-1}] \cdot 7.5[L]}{3600[\text{s}\,\text{h}^{-1}] \cdot 100[\text{km}]} = 0.69\,\text{kWh}\,\text{km}^{-1}$

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