Technical and Economic Feasibility of a Small-Scale Hydrogen-Based Energy Production Plant

**OVERALL PLANT DESIGN**

**PEC Fuel Cell**
- The conversion of hydrogen in the fuel cell is conducted in two main reactions:
  - Anode: \( H_2 \rightarrow 2H^+ + 2e^- \)
  - Cathode: \( O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \)
- For the PEMFC performance, we based our computations on a net electrical efficiency \( \eta_e \) of 39% and a thermal efficiency \( \eta_t \) of 56%, resulting in an overall efficiency of 65%. We assume 8 hours of production per day:
  - Electric power supplied by the fuel cell:
    \[ P_e = \eta_e \cdot \eta_t \cdot LHV_t = \frac{J_{\text{design1}}}{3.15} \hspace{1cm} \text{[kW]} \]
    \[ P_e = \eta_e \cdot \eta_t \cdot LHV_t = \frac{J_{\text{design2}}}{3.15} \hspace{1cm} \text{[kW]} \]
  - Thermal power supplied by the fuel cell:
    \[ P_t = \eta_t \cdot LHV_t = \frac{\eta_t \cdot J_{\text{design1}}}{3.15} \hspace{1cm} \text{[kW]} \]
    \[ P_t = \eta_t \cdot LHV_t = \frac{\eta_t \cdot J_{\text{design2}}}{3.15} \hspace{1cm} \text{[kW]} \]

**Cogeneration and Energy Consumption Coverage**
- The average Swiss household consumes per year:
  - Coverage ratio of electrical energy:
    \( C = \frac{E_e}{E_{\text{SW}}} = \frac{3500}{4700} = 0.748 \)
  - Coverage ratio of thermal sanitary water energy:
    \( C = \frac{E_t}{E_{\text{SW}}} = \frac{1207}{7556} = 0.160 \)

**SUMMARY OF THE COSTS [CHF]**

<table>
<thead>
<tr>
<th></th>
<th>PEM Panels Costs</th>
<th>PEMFC Costs</th>
<th>Pumps and Pipes Costs</th>
<th>Deionised Water Costs</th>
<th>Control Systems Costs</th>
<th>Total Costs</th>
<th>Final Cost of produced Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design 1</strong></td>
<td>16'630</td>
<td>23'080</td>
<td>760</td>
<td>8'290</td>
<td>7'900</td>
<td>33'690</td>
<td>11'02 CHF/kg</td>
</tr>
<tr>
<td><strong>Design 2</strong></td>
<td>9'632</td>
<td>23'080</td>
<td>760</td>
<td>5'220</td>
<td>7'900</td>
<td>34'441</td>
<td>12.35 CHF/kg</td>
</tr>
</tbody>
</table>

**PEC DESIGNS AND SIMULATIONS**
- The electrolysis of water is conducted in two main reactions as shown below:
  \[
  2H_2O \rightarrow 2H_2 + O_2 + 2e^- \\
  2H_2 + 2O_2 \rightarrow 2H_2O + 2e^- 
  \]
- **Design 1**: Tandem GaP\textsubscript{2}/GaAs photovoltaic cell that lies on a GaAs substrate, coated with two platinum catalysts that drives the HER and OER.
- **Design 2**: Four n-i-n\textsubscript{2} PV cells connected in series with a NiB catalyst-layer for the HER and a NiMoZn catalyst-layer for the OER.
- The graphs give the current density (\( j \)) versus potential (\( V \)) curves of the cells:
  - blue curve expresses the photocurrent density by the diode equation:
    \[ j = j_0 \cdot \exp \left( \frac{qV}{n_1 kT} \right) - 1 \]
  - red curve are computed with the following equation:
    \[ \Phi_f = \Phi_0 + \eta + \frac{\Phi_0}{2.303} \]
- The crossing of the red and the blue curve gives us the operating point, from which we can compute the STH efficiency:
  \[ \eta_{\text{th}} = \frac{\Phi_f \cdot \eta}{\Phi_0} \]
- The production of hydrogen in a PEC cell, based on the solar irradiance of Lausanne (\( S = 3.42 \text{[kW/} \text{day} \cdot \text{m}^2] \)) is given by the equation:
  \[ M_{H_2} = \frac{S \cdot \eta_{\text{PEC}} \cdot \eta_{\text{eff}}}{LHVT} \]
  \[ M_{H_2,\text{day}} = 0.816 \text{[kg/day]} \]
  \[ M_{H_2,\text{day}} = 0.513 \text{[kg/day]} \]

**CONCLUSIONS**
- Based on our calculations, it is possible to cover the energy consumption per year for electricity and sanitary water heating of a Swiss household with the Design 1, whereas the Design 2 only covers ~70% of the mentioned consumptions.
- In order to be cost competitive with more traditional energy resources, the hydrogen should be produced at a price between 2.00 [CHF/kg] and 4.00 [CHF/kg]. The main drawbacks are the short life time of the PEC cells (10 years), and their still low efficiencies. Moreover, regions with more solar irradiance would produce more hydrogen.

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