



# Technical and economic viability of hydrogen road vehicles in Valencia, Spain

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## Abstract

Decarbonising the automotive industry is important in improving air quality by reducing emissions. As one of the main promising alternatives to achieve this, hydrogen technologies are emerging. This paper will analyse the hydrogen automotive market, studying the economic and functional feasibility of implementing a plan to introduce hydrogen vehicles in society. The necessary supply is estimated, as well as the green production of the required hydrogen through the investigation of a plant to produce this gas using solar energy. This way, a vision of the future of hydrogen technologies applied to automation and its possible introduction to society will be obtained.

## Keywords

hydrogen vehicles, electrolysis, fuel cell, FCEV, solar energy.

## 1. Introduction

The decrease in the impact of automotive pollution on our planet by reducing vehicle emissions (*Zalacko et al., 2021*) is unquestionable. Decarbonisation will be key to achieving this (*Torok et al., 2014*). In this sense, one of the most promising and increasingly viable solutions is the implementation of hydrogen cars (*Zöldy, 2009*). These vehicles use fuel cells that convert hydrogen into electricity, emitting no polluting gases. Moreover, hydrogen is a renewable and abundant resource on our planet, which makes it a sustainable option in the long term (*Szendrő, Csete, Török, 2012*). However, despite the advantages of hydrogen cars, their implementation presents significant challenges, such as the need for infrastructure for hydrogen production, storage, and distribution or willingness to use (*Andrejszki et al., 2015*) or safety-related questions (*Ágoston and Madleňák, 2021*). Therefore, this paper will analyse the hydrogen automotive market, studying the economic and functional feasibility of implementing a plan to introduce hydrogen vehicles. The necessary supply and the green production of the required hydrogen will be explored by investigating a plant to produce this gas using solar energy in Valencia, Spain. This way, a vision of the future of hydrogen technologies applied to automation and its possible introduction to society will be obtained.

## 2. Data and methods

### 2.1. Plans description

This paper focuses on the Spanish city of Valencia, where the data show that there will be 1.3 million vehicles in 2021 and an average of 32,000 new registrations annually (*Statistical Portal of the Valenciana, 2021*). An introduction plan is devised to analyse the implementation of the hydrogen vehicle in this location. A certain percentage of the new vehicles registered annually will be assumed to be hydrogen vehicles, starting with 1 % during the first year and contemplating three different levels according to the plan's acceptance (*Szabó et al., 2021*). The medium-rate plan with an increase of 1.5 % per year, the high-rate plan, where the percentage of new vehicles registered each year will be assumed to be hydrogen-fuelled. Moreover, the very high-rate plan, where the same will be done by 2 %. With these plans, more than 16 000 hydrogen-powered vehicles would be obtained in the case of the average acceptance of the plan, and more than 41 000 vehicles in the most favourable case, with a very high rate. In the next *Table 1*, the plan numbers are shown.



Table 1. Introduction plan description

|                                 |         |  |  |  |  |  |  |  |  |
|---------------------------------|---------|--|--|--|--|--|--|--|--|
| Total cars at Valencia          | 1293340 |  |  |  |  |  |  |  |  |
| New registered cars at valencia | 32386   |  |  |  |  |  |  |  |  |

| YEAR 1 | YEAR 2 | YEAR 3 | YEAR 4 | YEAR 5 | YEAR 6 | YEAR 7 | YEAR 8 | YEAR 9 | YEAR 10 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|
| 0,5%   | 1,5%   | 2,5%   | 3,5%   | 4,5%   | 5,5%   | 6,5%   | 7,5%   | 8,5%   | 9,5%    |
| 0,5%   | 2,0%   | 3,5%   | 5,0%   | 6,5%   | 8,0%   | 9,5%   | 11,0%  | 12,5%  | 14,0%   |
| 0,5%   | 2,5%   | 4,5%   | 6,5%   | 8,5%   | 10,5%  | 12,5%  | 14,5%  | 16,5%  | 18,5%   |

| New H <sub>2</sub> cars |     |      |      |      |      |      |      |      |      |
|-------------------------|-----|------|------|------|------|------|------|------|------|
| 162                     | 486 | 810  | 1134 | 1457 | 1781 | 2105 | 2429 | 2753 | 3077 |
| 162                     | 648 | 1134 | 1619 | 2105 | 2591 | 3077 | 3562 | 4048 | 4534 |
| 162                     | 810 | 1457 | 2105 | 2753 | 3401 | 4048 | 4696 | 5344 | 5991 |

| Total H <sub>2</sub> cars |     |      |      |      |       |       |       |       |       |
|---------------------------|-----|------|------|------|-------|-------|-------|-------|-------|
| 162                       | 648 | 1457 | 2591 | 4048 | 5829  | 7935  | 10364 | 13116 | 16193 |
| 162                       | 810 | 1943 | 3562 | 5668 | 8258  | 11335 | 14898 | 18946 | 23480 |
| 162                       | 988 | 2544 | 4903 | 8147 | 12362 | 17646 | 24107 | 31861 | 41039 |

## 2.2. Hydrogen supply calculation

The necessary supply of hydrogen for implementing the plan in the society must be calculated, for which two parallel calculations have been performed so that the result has been obtained following two different procedures.

First, the starting point was a database for the consumption of traditional fuels for the fleet of private vehicles in the different provinces of Spain (*Statistical Portal of the Valenciana, 2021*). Thus, knowing the diesel and gasoline consumption for a year based on 2021 consumption, the total supply needed to provide autonomy to all vehicles in Valencia was calculated. From this, the "hydrogen energy equivalent" could be estimated, calculating the necessary hydrogen supply for vehicles in Valencia. Then, the necessary quantities for the different plans can be obtained.

Secondly, it is calculated by estimating the average distance travelled and the number of vehicles in Valencia. It is known that the average distance travelled by a private vehicle in Spain is 12562.9 km/year, and there are a total of 1 293 340 vehicles in the province of Valencia (*Statistical Portal of the Valenciana, 2021*). Thus, the quantities of traditional fuels needed to supply the entire fleet of Valencian vehicles could be calculated.

To transform the equivalent energetic quantity between traditional fuels and hydrogen, the consumptions and densities of both fuels for a given distance were calculated (*Eq 1*), obtaining a ratio of 5.6913 kg of traditional fuel for each kilogram of hydrogen. So, the required supply of hydrogen for each plan and each year can be calculated. In *Table 2*, this process is described, and following the equation, the equivalence of both fuels is calculated.

Table 2. Energetic equivalence between conventional fuels and hydrogen.

|                | Consumption<br>(l/100km) | Density<br>(kg/l) | Consumption<br>(kg/100km) |
|----------------|--------------------------|-------------------|---------------------------|
| gasoline       | 6                        | 0.832             | 4.992                     |
| diesel         | 4.50                     | 0.75              | 3.375                     |
| HC             | 5.0649                   | 0.78              | 3.98                      |
| H <sub>2</sub> | -                        | -                 | 0.7                       |

$$\text{Consumption ratio} = \frac{\text{HC consumption}}{\text{H}_2 \text{ consumption}} = \frac{3,98}{0,7} = 5,6913 \quad (1)$$

In this way, the quantities needed to supply 100% of the vehicles in the province of Valencia if they were hydrogen cars are obtained in both ways, getting very similar results and with a deviation of 2.19 %, being these 111 302 t of H<sub>2</sub> with the CORES data analysis calculation and 113 625 t with the other calculation method. Given the closeness between the two methods, from now on, the author proceeded with the calculations considering the values obtained from the CORES data.



After this, from these values, the supply for each plan and each year will be calculated following Eq (2), and the results are shown in *Table 3*:

$$\text{Annual } H_2 \text{ consumption} = \text{Consumption } 100\% H_2 \text{ cars} * \frac{\text{Total } H_2 \text{ cars}}{\text{Total cars Valencia}} \quad (2)$$

Table 3. Hydrogen demand in Valencia, Spain

| YEAR    | Total H <sub>2</sub> Cars | H <sub>2</sub> amount(kg) | H <sub>2</sub> amount/day |
|---------|---------------------------|---------------------------|---------------------------|
| YEAR 1  |                           |                           |                           |
| 0.5%    | 162                       | 13935                     | 38                        |
| 0.5%    | 162                       | 13935                     | 38                        |
| 0.5%    | 162                       | 13935                     | 38                        |
| YEAR 2  |                           |                           |                           |
| 1.5%    | 648                       | 55741                     | 153                       |
| 2.0%    | 810                       | 69677                     | 191                       |
| 2.5%    | 972                       | 83612                     | 229                       |
| YEAR 3  |                           |                           |                           |
| 2.5%    | 1457                      | 125418                    | 344                       |
| 3.5%    | 1943                      | 167224                    | 458                       |
| 4.5%    | 2429                      | 209030                    | 573                       |
| YEAR 4  |                           |                           |                           |
| 3.5%    | 2591                      | 222965                    | 611                       |
| 5.0%    | 3562                      | 306578                    | 840                       |
| 6.5%    | 4534                      | 390190                    | 1069                      |
| YEAR 5  |                           |                           |                           |
| 4.5%    | 4048                      | 348384                    | 954                       |
| 6.5%    | 5668                      | 487737                    | 1336                      |
| 8.5%    | 7287                      | 627090                    | 1718                      |
| YEAR 6  |                           |                           |                           |
| 5.5%    | 5829                      | 501672                    | 1374                      |
| 8.0%    | 8258                      | 710703                    | 1947                      |
| 10.5%   | 10687                     | 919733                    | 2520                      |
| YEAR 7  |                           |                           |                           |
| 6.5%    | 7935                      | 682832                    | 1871                      |
| 9.5%    | 11335                     | 975474                    | 2673                      |
| 12.5%   | 14736                     | 1268116                   | 3474                      |
| YEAR 8  |                           |                           |                           |
| 7.5%    | 10364                     | 891862                    | 2443                      |
| 11.0%   | 14898                     | 1282052                   | 3512                      |
| 14.5%   | 20905                     | 1799053                   | 4929                      |
| YEAR 9  |                           |                           |                           |
| 8.5%    | 13116                     | 1128763                   | 3093                      |
| 12.5%   | 18946                     | 1630435                   | 4467                      |
| 16.5%   | 28339                     | 2438824                   | 6682                      |
| YEAR 10 |                           |                           |                           |
| 9.5%    | 16193                     | 1393534                   | 3818                      |
| 14.0%   | 23480                     | 2020625                   | 5536                      |
| 18.5%   | 37165                     | 3198315                   | 8763                      |

### 2.3. Hydrogen supply production

Once the needed hydrogen for implementing each plan has been calculated (*Table 3*), the problem of how to produce this hydrogen was investigated. To produce it, electrolysis has been selected as the most optimal process for this investigation due to its green and sustainable character. In addition, it is necessary to analyse which method best suits the project's requirements to produce the energy needed for the electrolysis process. For this, the production of the energy necessary for the hydrogen production process from solar energy was chosen, given the favourable characteristics of the Valencia location and the sustainable nature of this process. The best way to combine this is in a solar hydrogen production plant, so knowing the production needed to supply the hydrogen demanded by the FCEV (Fuel Cell Electric Vehicle - FCEVs are a type of vehicle that uses compressed hydrogen gas as fuel to generate electric power via a highly efficient energy converter, a fuel cell. The fuel cell directly transforms hydrogen into electricity to power an electric engine.) introduction plans can start with the sizing of the plant to know its approximate size. For this, the energy needed to produce one kilogram of hydrogen is known, which is 50 kWh, and knowing the efficiency ( $\epsilon$ ) of the solar panels, which is 0.21, and the average irradiance in Valencia of 5.23 kWh/m<sup>2</sup>, we can calculate approximately the size of solar panels and power needed to supply the hydrogen supply. The calculations needed are given in the 3,4,5 and 6 equations:



$$\text{Electrolysis energy}(kWh) = \frac{\text{Electrolysis energy}}{kgH_2} * H_2 \text{ amount} = 50 * H_2 \text{ amount} \tag{3}$$

$$\text{Solar energy}(kWh) = \frac{\text{Electrolysis energy}}{\epsilon} = \frac{\text{Electrolysis energy}}{0,21} \tag{4}$$

$$\text{Area}(m^2) = \frac{\text{Solar energy}}{\text{solarradiation vlc}} = \frac{\text{Solar energy}}{5,73} \tag{5}$$

$$\text{Instalated power}(kW) = \text{Solar radiation} \left(\frac{kW}{m^2}\right) * \epsilon * \text{size of solar panel} = 5.23 * 0,21 * \text{size of solar panel} \tag{6}$$

Following these steps, *Table 4* shows the results of the estimated plant size and power:

Table 4. Size and power estimation for the plant.

| YEAR    | kWh(electrolysis) | kWh(sun) | area(m2) | powinst/MW |
|---------|-------------------|----------|----------|------------|
| YEAR 1  |                   |          |          |            |
| 0.5%    | 1909              | 9090     | 1738     | 0.37       |
| 0.5%    | 1909              | 9090     | 1738     | 0.37       |
| 0.5%    | 1909              | 9090     | 1738     | 0.37       |
| YEAR 2  |                   |          |          |            |
| 1.5%    | 7636              | 36361    | 6952     | 1.5        |
| 2.0%    | 9545              | 45451    | 8690     | 1.8        |
| 2.5%    | 11454             | 54541    | 10429    | 2.2        |
| YEAR 3  |                   |          |          |            |
| 2.5%    | 17181             | 81812    | 15643    | 3.3        |
| 3.5%    | 22907             | 109083   | 20857    | 4.4        |
| 4.5%    | 28634             | 136354   | 26071    | 5.5        |
| YEAR 4  |                   |          |          |            |
| 3.5%    | 30543             | 145444   | 27810    | 5.8        |
| 5.0%    | 41997             | 199985   | 38238    | 8.0        |
| 6.5%    | 53451             | 254527   | 48667    | 10.2       |
| YEAR 5  |                   |          |          |            |
| 4.5%    | 47724             | 227256   | 43452    | 9.1        |
| 6.5%    | 66813             | 318159   | 60833    | 12.8       |
| 8.5%    | 85903             | 409061   | 78214    | 16.4       |
| YEAR 6  |                   |          |          |            |
| 5.5%    | 68722             | 327249   | 62571    | 13.1       |
| 8.0%    | 97357             | 463602   | 88643    | 18.6       |
| 10.5%   | 125991            | 599956   | 114714   | 24.1       |
| YEAR 7  |                   |          |          |            |
| 6.5%    | 93539             | 445422   | 85167    | 17.9       |
| 9.5%    | 133627            | 636317   | 121667   | 25.6       |
| 12.5%   | 173715            | 827212   | 158167   | 33.2       |
| YEAR 8  |                   |          |          |            |
| 7.5%    | 122173            | 581776   | 111238   | 23.4       |
| 11.0%   | 175624            | 836302   | 159905   | 33.6       |
| 14.5%   | 246446            | 1173550  | 224388   | 47.1       |
| YEAR 9  |                   |          |          |            |
| 8.5%    | 154625            | 736310   | 140786   | 29.6       |
| 12.5%   | 223347            | 1063558  | 203357   | 42.7       |
| 16.5%   | 334086            | 1590884  | 304184   | 63.9       |
| YEAR 10 |                   |          |          |            |
| 9.5%    | 190895            | 909024   | 173810   | 36.5       |
| 14.0%   | 276798            | 1318085  | 252024   | 52.9       |
| 18.5%   | 438125            | 2086311  | 398912   | 83.8       |

After obtaining the power required for the plans to introduce the hydrogen vehicle in Valencia, this research was continued by designing a hydrogen production plant using solar energy with a power of 10 MW, which, as shown in *Table 4*, will be possible to supply the hydrogen required for the plan during the first five years in the case of the medium rate plan or four years in the other two cases.

#### 2.4. Solar plant design for hydrogen production

The following points of the paper will analyse the technical and economic feasibility of a plant of this power to cover the designed plan. First, an analysis of the plant's annual production is carried out in a fictive location, in La Pobra de Vallobona, a small town in Valencia with a largely rural area. The following values are extracted on the solar irradiance measured as a monthly average (*Figure 1*):



### 5.23 peak sun hours per day

Your monthly averages:

- January: 4.19
- February: 4.72
- March: 5.28
- April: 5.44
- May: 5.77
- June: 5.91
- July: 6.33
- August: 6.11
- September: 5.75
- October: 4.99
- November: 4.35
- December: 3.93

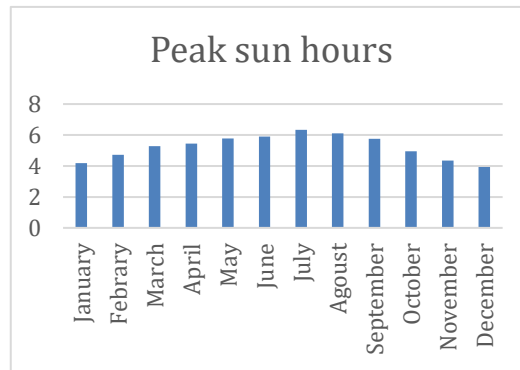


Figure 1. Monthly solar irradiation study.

Based on these data and having an installed capacity of 10 MW, the plant's maximum possible hydrogen production can be calculated. This will occur during July, with the maximum length of irradiation (Eq. 7):

$$Kg \text{ of } H_2 = \frac{6,33 \cdot 10000}{50} = 1266 \text{ kg/day} \tag{7}$$

To know the productive capacity of the planned hydrogen plant, the monthly production is calculated in the same way as in the previous section, analysing each month separately because the average monthly irradiation is variable. Thus, there will be months like winter in which the production will be lower. The next figures represent these calculations (Figure 2):

|           | Peak sun hrs | H <sub>2</sub> kg |
|-----------|--------------|-------------------|
| January   | 4.19         | 25978             |
| February  | 4.72         | 26432             |
| March     | 5.28         | 32736             |
| April     | 5.44         | 32640             |
| May       | 5.77         | 35774             |
| June      | 5.91         | 35460             |
| July      | 6.33         | 39246             |
| August    | 6.11         | 37882             |
| September | 5.75         | 34500             |
| October   | 4.95         | 30690             |
| November  | 4.35         | 26100             |
| December  | 3.93         | 24366             |
| Average   | 5.23         | 31817             |
| Total     | 62.73        | 381804            |

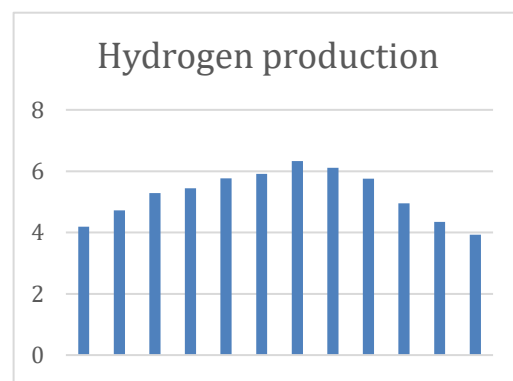


Figure 2. Hydrogen production estimation of the plant in Valencia, Spain

Therefore, with a 10 MW plant, approximately 381 t H<sub>2</sub> will be produced yearly.

### 2.5. Installation components

Thus, we already know certain technical requirements about the plant's production that will be important for further design. Further on, the most important and necessary components for the implementation of the plant will be described, and through the analysis of their cost, the author can approximate the economic viability of the implementation of this plant to supply the plan.



First, to cover the selected power, solar modules must be installed, for which the 545 W JA Solar Mono PERC model has been selected, as it is most commonly used in Spain nowadays. To reach 10 MW power, 18 349 solar panels should be installed. Thus, the total area of solar panels will be 47 500 m<sup>2</sup>. Secondly, to produce hydrogen, an electrolyser is required. This is the device with which we can carry out the electrolysis process, which consists of separating the hydrogen and oxygen molecules in water using electricity. Different electrolysers exist, such as alkaline electrolysers, proton exchange membrane electrolysers (PEM) or solid oxide electrolysers (SOEC). For this plant, the PEM electrolysers have been selected because of their benefits, which include the production of high-purity hydrogen and ease of cooling, and better performance with renewable energies due to their variable nature. To suit the size of our plant, the EL600N electrolyser from H2B2 has been selected with the following technical specifications:

#### **Hydrogen gas production:**

Max. nominal hydrogen flow: 600 Nm<sup>3</sup>/h (1,290 kg/day)

Hydrogen flow range: 10–100 %

Operating pressure: 15–40 bar (217–580 psig)

Hydrogen purity (before gas purification): > 99.9 %; < 25 ppm O<sub>2</sub>; H<sub>2</sub>O saturated

Hydrogen purity (after gas purification): 99.999 %; < 5 ppm O<sub>2</sub>; < 5 ppm H<sub>2</sub>O

#### **Electrical requirements:**

Power (BoP + Stacks): 3,100 kW

Stack consumption: 4.7 kWh/Nm<sup>3</sup> H<sub>2</sub>

AC power consumption (BoP + stack): 5.1 kWh/Nm<sup>3</sup> H<sub>2</sub>

#### **Feed water requirements:**

Consumption: < 1 L/Nm<sup>3</sup> H<sub>2</sub>

Temperature: +5 °C to + 40 °C (+41 °F to +104 °F)

The compressor is another vital element for the installation because it transports the hydrogen at high pressures, higher than 700 bar, the pressure required in the hydrogen stations for vehicles. Two compressors, one low-pressure and one high-pressure, will be applied to achieve this. This way, the low-pressure compressor will raise the pressure to 160 bar and the high-pressure compressor to 900 bar. Therefore, the path that the hydrogen will follow in its compression process will start at the beginning of the electrolyser, from where it will be conducted to the low-pressure compressor, and after the compression process, it will be stored in the low-pressure tank at 60 bar. After this, the hydrogen will pass to the high-pressure compressor and will be stored in the high-pressure tanks, from where it can be distributed to the different hydro line plants in the province of Valencia. Thus, the equipment applied must have the above pressure requirements. In addition, the compressor must be able to work with a hydrogen flow higher than the maximum flow provided by the electrolyser, so we must look for a compressor that operates correctly with the flow required. The Hyperbaric brand was selected for this: model 1KS 50 for the first stage of compression and model 1KS 95 for the second stage, as it is widely used in Spain. Thus, two compressors will be needed for the low-pressure stage due to the high hydrogen flows and one for the high-pressure stage. Another main installation component is the low-pressure tank, where the hydrogen is stored after the first compression stage. To calculate its capacity, the daily hydrogen production must be estimated. Assuming production at 100% of the electrolyser capacity to obtain an upward estimate, which will not occur because the solar energy obtained in the most favourable month is not enough for that production level, a value of 1290 kg of H<sub>2</sub> per day is obtained. Since the pressure at the outlet of the first compression stage will be 160 atmospheres, the required tank volume can be obtained by following Eq. 8:



$$V = \frac{n \cdot R \cdot T}{P} = \frac{m \cdot R \cdot T}{M \cdot P} = \frac{1290 \cdot 0.082 \cdot 298}{0.002 \cdot 160} = 98507.6 \text{ l} \quad (8)$$

where

- $V$  is the volume [l];
- $m$  is the hydrogen mass [kg];
- $R$  is the ideal gas constant [atm-l/k-mol];
- $T$  is the temperature of hydrogen [K];
- $M$  is the molecular mass of H<sub>2</sub> [kg/mol];
- $P$  is the hydrogen pressure [atm].

For this volume, the LH 100H tank manufactured by LAPESA SL will be installed with the following technical specifications:

- Nominal volume [m<sup>3</sup>] =100
- Outer diameter D [mm]=3 000
- Overall length L [mm]=15 350
- Unladen weight [ton]=34.7

Finally, the last component that will be considered for the economic estimation of the project will be the high-pressure tank, where the hydrogen will be stored and ready for distribution. For this purpose, the required dimensions of the tank are calculated in the same way as in Eq. 7, obtaining a value of 17 512.5 l.

After that, the LH 25H model is selected with the following technical data:

- Nominal volume [m<sup>3</sup>] =25
- Outer diameter D [mm]=2 200
- Overall length L [mm]=7 850
- Unladen weight [ton]=10.1

Now, the main components of the solar hydrogen production plant are known, and the economic analysis can be performed.

### 3. Results and discussion

#### 3.1. Economic viability analysis.

In order to be able to make the feasibility study of this project, the different types of costs that the implementation of the hydrogen production plant would carry and the income generated by the sale of the hydrogen at the different points of distribution and sale to the public must be analysed.

Firstly, the different fixed costs will be collected, mainly the investment in the equipment necessary to construct the hydrogen production plants. In addition, other fixed costs will be the purchase of the building and the land. These costs are represented in Table 5:



Table 5. Fixed costs.

| Fixed costs                          |              |                   |               |
|--------------------------------------|--------------|-------------------|---------------|
| Equipment<br>[€]                     | Units<br>[€] | Unit price<br>[€] | Amount<br>[€] |
| Solar panels 545W JA Solar Mono PERC | 18349        | 216.24            | 3967788       |
| Electrolyzer EL600N H2B2             | 1            | 10000000          | 10000000      |
| Compressor 1KS50                     | 2            | 500000            | 1000000       |
| Compressor 1KS95                     | 1            | 600000            | 600000        |
| Low-pressure tank                    | 1            | 98900             | 98900         |
| High-pressure tank                   | 1            | 253100            | 253100        |
| Land and warehouse purchase          | 1            | 300000            | 300000        |
| Total                                |              |                   | 16219788      |

In addition, the different variable costs of the installation must also be considered. These include the costs for the water supply of the electrolyser, and an average water price of 1.97 €/m<sup>3</sup> will amount to 15,000 €. A small percentage of the project's direct costs must be established destined to the complementary direct costs, which include concepts that are difficult to quantify. Thus, we will establish 1% of direct costs. Also, indirect costs are execution costs not attributable to specific work units but to the whole or part of the project. For these, we establish 4% of the direct costs. An example of these costs would be plant maintenance. The Budget for Material Execution and the Investment Budget can be calculated by applying the different standardised rates (Table 6):

Table 6. Investment budget.

| Equipment<br>[€]                      | Units<br>[€] | Unit price<br>[€] | Amount<br>[€] |
|---------------------------------------|--------------|-------------------|---------------|
| Solar panels 545W JA Solar Mono PERC  | 18 349       | 216               | 3 967 788     |
| Electrolyzer EL600N H2B2              | 1            | 10 000 000        | 10 000 000    |
| Compressor 1KS50                      | 2            | 500 000           | 1 000 000     |
| Compressor 1KS95                      | 1            | 600 000           | 600 000       |
| Low-pressure tank                     | 1            | 98 900            | 98 900        |
| High-pressure tank                    | 1            | 253 100           | 253 100       |
| Land and warehouse purchase           | 1            | 300 000           | 300 000       |
| Water yearly supply                   | 20           | 750               | 15 000        |
| Equipment and material budget         |              |                   | 16 234 788    |
| Complementary direct costs (1%)       |              |                   | 162 348       |
| Indirect costs (4%)                   |              |                   | 649 392       |
| (1) Budget for Material Execution (1) |              |                   | 17 046 527    |
| (2) Overhead Expenses (0,13*1)        |              |                   | 2 216 049     |
| (3) Industrial Profit (0,06*1)        |              |                   | 1 022 792     |
| (4) Contract execution budget (1+2+3) |              |                   | 20 285 367    |
| (5) Value added tax (0,21*4)          |              |                   | 4 259 927     |
| (6) Investment Budget (4+5)           |              |                   | 24 545 294    |

The hydrogen plant's income will come from selling hydrogen to the different hydrogen sales points. Thus the selling price of a kilogram of hydrogen must be known. Due to the current uncertainty about the price of hydrogen, to investigate the feasibility, instead of setting a specific price, it was calculated from what price our project starts to be profitable. Graphically this can be understood as the intersection between the cost and benefit curve, and the point of the intersection is called the break-even point. We must draw both curves from the data to translate this to the present case. First, the cost curve can be approximated to the fixed costs since the variable costs only include the water supply, and their cost is insignificant to the investment budget. So the cost will be represented by a straight line with the value of the investment cost. In addition, due to the lack of data on the residual value of the installation components, we will be in the most unfavourable situation to avoid failing the feasibility study, and we will take the residual values of the acquired equipment as 0. Second, the income curve is studied. This has a higher complexity since the selling price of hydrogen, as mentioned above, is very uncertain for the coming years. It is expected that with economies of scale, it will be reduced considerably. Therefore, we cannot determine the slope of the income curve and plot the situation to find the break-even point.

Due to this, the minimum average selling price of hydrogen will be calculated so that the investment is recovered in the 20 years of the project's useful life. It will be studied if it fits with the predictions that exist or, on the contrary, it is an unreal price, and therefore the project of the construction of the plant to supply green hydrogen for the plan of introducing vehicles would not be viable.



After these calculations, we obtain an average selling price of hydrogen of 3.21 €, from which the investment will be recovered in 20 years. The following graphs represent the break-even points for a price of 3.21 €/kg H<sub>2</sub> and 5 €/kg H<sub>2</sub>, with the amount in € on the y-axis and the years since start-up on the x-axis. 100% production capacity of the plant is assumed, so 381 t H<sub>2</sub> are produced each year (Figure 3):

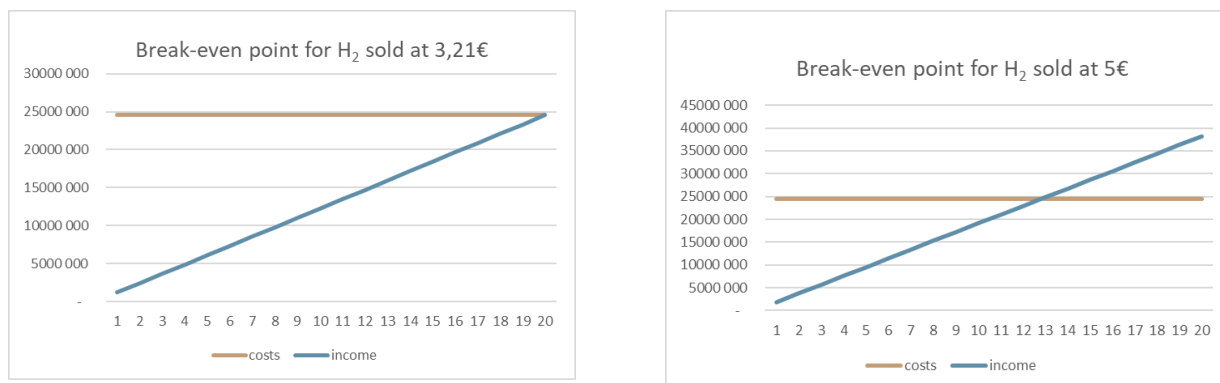


Figure 3. Break-even point graph for H<sub>2</sub> price of 3.21 and 5€.

As can be seen in the first graph, if the plant operates at 100 % and the average selling price of hydrogen during the investigation period is 3.21 €, the investment will be recovered in year 20, while if the price of H<sub>2</sub> is increased to 5 €, the investment will be recovered in year 12, and the useful life of the plant will end with an approximate profit of 15 million €. Considering the hydrogen market and the predictions we found about its price in the future, we can see that currently, its selling price is 8 to 10 €. However, due to economies of scale, there will be a considerable reduction in the prices of fuel cells and storage tanks, which will bring about a 70 % reduction in the cost of hydrogen production over the next ten years. A comparative analysis between hydrogen and other conventional fuels can be analysed to get a different perspective on the selling price of hydrogen and whether it would be attractive to the market. For this, the costs of the equivalent amount of energy in terms of autonomy in both cases and the percentage difference between the two prices will be the energetic equivalent in terms of the autonomy of 1 kg of H<sub>2</sub> is 7.2965 litres of traditional fuels and setting an average price of 1.795 €/l, the total price for this amount of energy is 13.1 €, a value much higher than that obtained for hydrogen in the study, which put its selling price of that amount of energy between 3.21 and 5 €. In percentage terms, hydrogen would give us a 62 % cheaper energy to power vehicles. This saving can be observed more clearly when the price is analysed as a function of the kilometres travelled. Acting in this way, the price for travelling 100 km with an H<sub>2</sub> vehicle and considering a high consumption value for hydrogen vehicles, would oscillate between 3.21 and 5 € due to the range of sales prices with which we have been working in this study while using conventional fuel would be 9.1 €/100 km.

### 3.2. Environmental viability analysis.

The benefits of implementing the studied plan can also be addressed from an environmental point of view. For this, when analysing the reduction of pollutant emissions, only the previous emissions of vehicles with conventional fuels should be calculated since the saving will be 100%. The analysis of environmental data on vehicle emissions during the year 2021 proves that vehicles emit an average of 2.45 kg of CO<sub>2</sub> per litre of fuel, so knowing the litres of fuel that will be saved with the implementation of the plan can be known the savings of CO<sub>2</sub> emissions into the atmosphere. After these simple calculations, we obtain values of a reduction of CO<sub>2</sub> emissions close to 200 000 megagrams after the 10-year duration of the plan. Lastly, the economic value of these emissions can be determined. The price of CO<sub>2</sub> emission allowances during 2021 reached an annual average of 53.55 €/t, so we multiplied this value by the calculated emissions to obtain the economic value of 10 710 000 €.

### 4. Conclusion

In conclusion, after studying the sustainable plan for introducing hydrogen vehicles in the province of Valencia, it has been possible to show the strong advantages that the implementation of hydrogen technologies can bring to the automotive industry, and the barriers are to be dealt with. A proposed plan covers the sale of hydrogen vehicles and the calculation of the required hydrogen fuel supply for the sustainable production of hydrogen fuel, showing the necessity of the progressive electrification of the automotive market and the consequent evolution of hydrogen production systems to supply this change in the market. After this study, the feasibility of this project has become clear after analysing the approximate investment cost of a fully green hydrogen production plant, the implementation of which will be a key point in the course towards sustainable hydrogen. Also, the economic and environmental benefits of this change in the vehicle market have been discussed, and the beneficial character of introducing the studied plan has been evidenced. In addition, it must be emphasised the stage of development of the hydrogen market and how economies of scale will make hydrogen prices even more competitive. This is a technology whose future will undoubtedly be very promising.



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