2011 Hydrogen Student Design Contest: Residential Fueling with Hydrogen

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EXECUTIVE SUMMARY

From the point of view of road transport, hydrogen is a clean energy source that is more efficient than other fossil fuels used to date. However, its use in this field is still limited, not only because of technical and economic reasons of the vehicle itself but also because the need for large H2-refueling stations. One solution being analyzed for this latter problem is the use of "Residential Fueling with Hydrogen", the object of this contest.

Water electrolysis using renewable energy and electricity from the grid (if necessary) has been chosen as option for hydrogen production. Besides, considering the alternatives of renewable resources, we have chosen the option of wind power, taking into account the favorable characteristics of efficiency, reliability, cost and safety of this resource.

Thus, the hydrogen supply system proposed consists mainly of: three vertical axis wind turbines, water collector system, a deionizer, an electrolyzer, a hydrogen compressor, a chiller, a hydrogen storage tank, a hydrogen dispenser, the interconnection with the electrical grid, electronic devices for electrical signal conditioning, safety devices to ensure system security, etc. For all those devices, different aspects have been covered. First of all, calculations about energy required, pressure level in hydrogen and dimensions needed for tanks have been developed. Following, using those numerical values, a market analysis has been developed to find the devices that are more suitable for those parameters. So, it has been possible to do a justified selection of the devices, which have been identified and characterized. It can be said that all the devices used in this prototype are well-tested technologies that can be found in the market, with the idea of an easy implementation.

Furthermore, in this proposal the following aspects can also be pointed out:

- The use of wind and rainwater, as main energy sources to obtain the hydrogen, which can substitute the traditional fuels in road transport.
- A detailed analysis about wind and rain conditions in the city of the USA where this proposal would be installed.
- An analysis of electricity costs and possible revenues, in case the owner of the installation could sell the excess of energy from the wind turbines to the grid.
- The use of a vehicle based on a PEM fuel cell.
- The possibility of recovering oxygen, to sell it as by-product.

Finally, this proposal has also covered the following aspects:

- An analysis of capital, operation and maintenance costs, market price for the system and market growth forecast.
- An analysis to ensure a proper ratio of security and compliance with codes and standards.
- The most important features of environmental impact, marketing and education plan.

CONTENTS

1. INTRODUCTION

Concern about the limited fossil resources and global climate change is leading to the pursuit of clean energy sources to meet growing energy demand [1-2]. In this context, hydrogen can optimally replace the fossil fuels, particularly in the transport sector, which represents the worldwide biggest oil consumer [3].

Hydrogen can be used for automotive applications, either in a combustion engine which uses hydrogen as a fuel or in a fuel cell installed on the vehicle. The latter option is what is contemplated in this proposal.

In this scenario, the Department of Energy of United States has specified the long-term objectives for the development of fuel cell vehicles. In 2015, it is expected that fuel cells achieve an efficiency of 60% and a cost of $ 30/kW. Moreover, it is expected that fuel cells have a rated life of at least 5,000 hours, which is equivalent to a distance of 150,000 miles, traveling at 30 mph. In addition, the Energy Law of 2005, in the United States, includes an authorization of $ 3.7 billion for research and development of hydrogen and fuel cells, for ten years. One of the objectives of this project is to encourage the commitment of manufacturers to offer safe fuel cell vehicles, affordable and technically feasible, no later than 2015. Previous goals are also envisaged by the international research community [4].

One of the main obstacles for the implementation of fuel cell vehicles is the lack of hydrogen distribution infrastructure [5]. Within this aspect, one possibility currently addressed is the residential production of hydrogen, which can be obtained from:

1) Catalytic cracking of natural gas.
2) Catalytic cracking of biogas, residentially generated.
3) Electrolysis of water using power from the electrical grid.
4) Electrolysis of water using electricity generated by renewable energy sources.

From an environmental point of view, the production of hydrogen for use as fuel makes sense if it is obtained using renewable energy sources, or whether the method used to recover the energy content is efficient enough to compensate the energy used in its production.

Thus, although the first method seems to be the most practical, a source of primary energy is needed, which is not considered as renewable. The second method requires a residential plant of biogas production, which may consist of a biogas digester, biogas storage system and a catalytic cracking biogas system. But this is an unlikely option. Biogas is a source of poor hydrogen and requires complicated chemical processes such as catalytic steam reforming process for conversion [6]. The third method may be feasible, however, the electric power, in general, is obtained from non-renewable energy sources. Finally, the latter method, using wind power or solar radiation, combines the two requirements for a residential application: (a) the power source is usually available where it is needed (b) they are sufficiently developed technologies.

In this context, this proposal focuses on the design of a Residential Fueling Station with Hydrogen to feed fuel cell based vehicles. This station will run on with electricity obtained from three vertical axis wind turbines of 4 kW (5.43 HP) each one. Besides, if necessary, the Residential Fueling Station could take electricity supplied from the grid. This combination of resources ensures the supply of hydrogen to the vehicle during periods of low wind activity and contributes to the hydrogen generation from renewable resources. The choice of wind turbines, instead of photovoltaic modules, is based on aspects related to the efficiency of both technologies [7].

For the implementation of this residential fueling system, based on electricity from wind turbines, a map of wind speed distribution in the USA has been analyzed [8]. Thus, the city of Amarillo, Texas, has been chosen as the more favorable location. This election has been based on available data on wind energy potential and the characteristics of the installation to implement. Specifically, wind speed data for 61 years have been obtained in that city [9]. As the amount of data obtained is really huge, historical data of year 2009 have been used for the analysis and design of the Residential Fueling system [10]. Additionally, the power company that operates in that area has been identified. It is the South Western Public Service Company. Details of that company have been used in cost, amortization and revenue estimations [11].

Electricity will be used in an electrolyzer to split water into hydrogen and oxygen [12-13]. The strategy for the Residential Fueling Station with Hydrogen design is based on three operation modes:

a) The wind turbines, in normal operation, will provide the electricity needed to power the hydrogen generator system.
b) In a prolonged absence of wind, the electricity needed to power the hydrogen generator system will be obtained from the electrical grid.
c) If the hydrogen storage tank is full, the power of the wind turbines will be sold to the electrical grid.

The hydrogen generated and stored is used to refuel the tank of a fuel cell vehicle. Regarding the fuel cell technology used in the vehicle, the PEM fuel cell seems to be the most appropriate [12-14]. This technology can easily start up at ambient temperature and can operate at relatively low temperatures, below 100ºC. Besides, this technology has relatively high energy density and, consequently, its size is smaller. Additionally, compared to other fuel cell types, its maintenance is simpler, it has better withstand to shocks and vibrations and adapts quickly to changes in energy demand. Moreover, the hydrogen obtained by electrolysis of water is free of carbon monoxide, a circumstance particularly favorable for the use of PEM fuel cell [15].

2. TECHNICAL DESIGN

In this section, issues related to the location of the Residential Fueling Station with Hydrogen and analyses of the components comprising the system are described. Also, specifications for the choice of components are justified. These components cover the stages of production, compression, storage and supply of hydrogen, as well as safety equipment.

2.1. SITE PLAN

The Residential Fueling Station with Hydrogen of this proposal is located in the city of Amarillo, Texas. As it has been said before, a map of wind speed distribution in the USA has been reviewed for choosing the location [8]. This site presents some historical data of wind speed that are appropriate for the operation of the wind turbines selected. From the historical data referred to 61 years, it can be concluded that the average wind speed in that city is 6 m/s (13.5 mph), [9]. Figure 1 shows the geographic location of Amarillo city. Figures 2 and 3 show a typical residence, capable of accommodating a Residential Fueling Station, such as the one designed in this proposal. Finally, the distribution of devices in the Residential Fueling Station is shown in Figures 4 and 5. These figures include the devices that make up the whole residential hydrogen generator system, which is located in the garage.

(a) (b)

Figure 1: City of Amarillo: (a) USA (b) Texas

Figure 2: Possible residence for installing the *Residential Fueling Station* with Hydrogen

Figure 3: View of the residence's garage

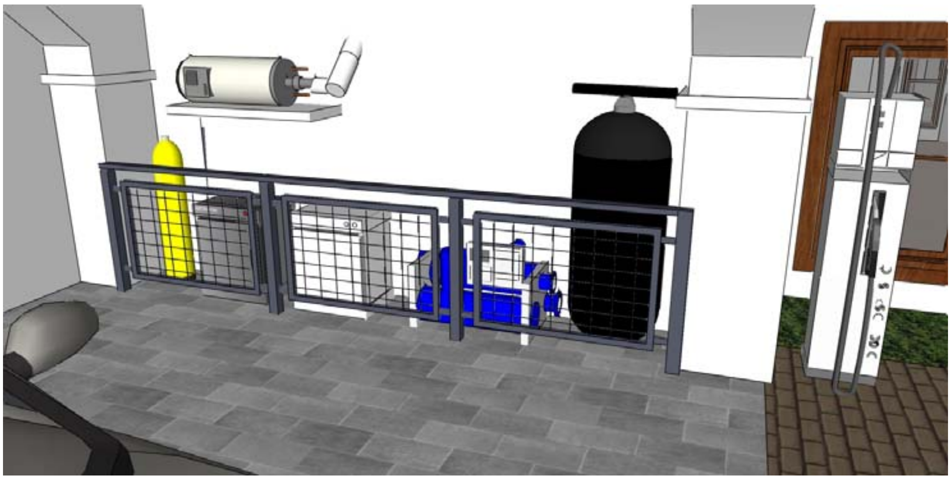


Figure 4: VIEW A - Distribution of devices of *Residential Fueling Station* in the garage

Figure 5: VIEW B - Distribution of devices of *Residential Fueling Station* in the garage

In the following section, the technical characteristics of all the components involved are described.

2.2. DESCRIPTION OF MAJOR COMPONENTS

In the guidelines of this contest, natural gas reforming and electrolysis of water are proposed for hydrogen production. As example, in 2005, 48% of hydrogen global demand was produced by steam reforming of natural gas, about 30% by oil/naphtha reforming from refinery/chemical industrial off-gases, 18% from coal gasification, 3.9% from water electrolysis and 0.1% from other sources [16].

In this proposal, hydrogen generation by electrolysis of water using electricity from wind turbines has been chosen. This choice will reduce harmful emissions and contribute to a cleaner transport. The modus operandi of this hydrogen generating system is the following:

1) Electricity is provided from three vertical axis wind turbines and, if necessary, from the grid.

2) Water for electrolysis is provided from a storage tank. In this way, we can ensure that the process will not be interrupted due to lack of water. Additionally, water used for electrolysis will be subjected to a process of deionization. Furthermore, with the idea of optimizing the system, most of the water is expected to come mainly from the rain.

3) The hydrogen produced in the electrolyzer is compressed by a compressor, operating at pressure of 420 bar (6,000 psi). Oxygen obtained can be used for other purposes, as a by-product.

4) The hydrogen generated is stored in a tank, at pressure of 420 bar (6,000 psi).

5) The hydrogen from the storage tank is conducted to the hydrogen dispenser to refuel the vehicle.

Figure 6 shows the block diagram of the proposed Residential Fueling Station operation.

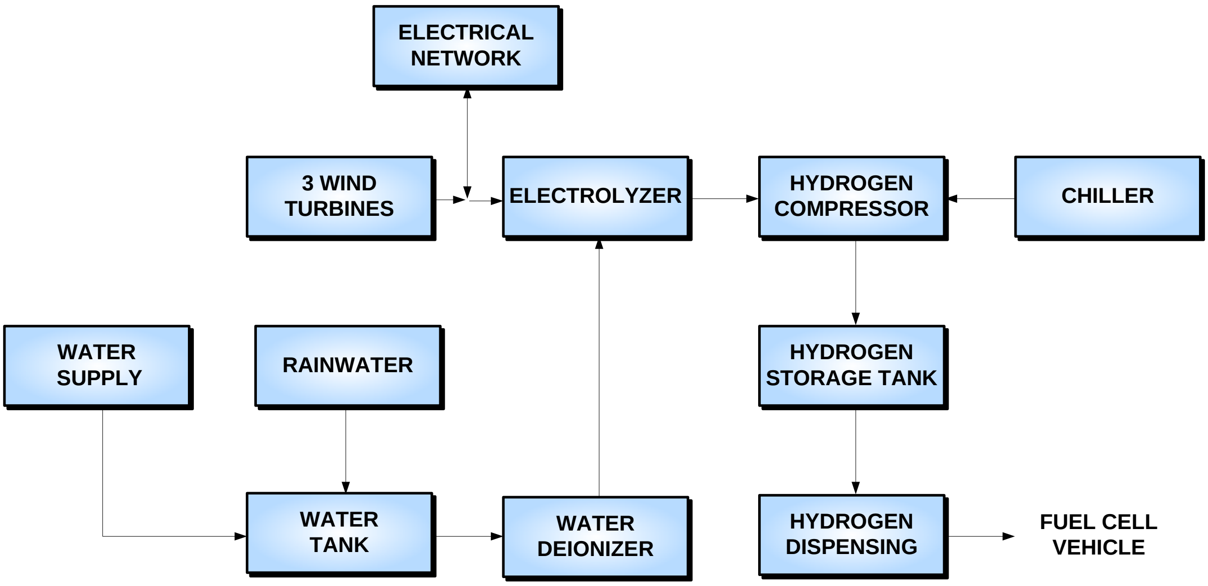


Figure 6: Diagram of the Residential Fueling Station operation

2.2.1. Electrolyzer

There are two main types of electrolyzers, built with alkaline electrolyte or polymer electrolyte (PEM). For the latter, the cost is higher due to the use of fluorinated membranes and noble metal electrodes. However, they are more versatile and have a higher efficiency. They can also work with different temperatures, pressures and power densities, with a good compromise between different factors. Thus, they work with values around 80°C, 0.1 MPa, Jo = 15 kA/m^2 and a Nafion membrane of 50 microns [17]. This PEM electrolyzer has the reverse operation process of a PEM fuel cell.

Following, the amount of hydrogen needed is calculated using the vehicle requirements. These requirements are:

12,000 miles/year
35 miles/day
44 miles/kg hydrogen

Amount of hydrogen needed each day: $\frac{35 miles}{44 miles / kg} = 0.795454 kg$

Thus, considering the amount of hydrogen needed to fill the tank of the vehicle, the PEM electrolyzer HOGEN ® S20 has been chosen [18]. Table 1 shows the most relevant characteristics of that electrolyzer. Following, the energy consumed by the electrolyzer is calculated using data from the selected electrolyzer (Table 1), as shown below.

It is necessary 0.795454 kg hydrogen per day. Knowing that 1kg of hydrogen is equivalent to a 33.33 kWh [19], the energy consumed by the car in one day is:

$$0.795454 kg \cdot 33.33 \frac{kWh}{kg} = 26.512 kWh$$

According to the manufacturer, the electrolyzer consumes 6.7 kWh per Nm^3 of hydrogen [20]. Moreover, it is known that 1 Nm^3 of hydrogen is equivalent to 3 kWh [19]. From these data, the efficiency of the electrolyzer can be calculated:

$$\eta = \frac{3 kWh / Nm^3}{6.7 kWh / Nm^3} \cdot 100\% = 44.77\%$$

Once we know the efficiency of the electrolyzer, the amount of electricity to be supplied to the electrolyser, daily, can be determined.

$$\frac{26.512 kWh}{0.4477} = 59.2182 kWh$$

According to specifications of the electrolyzer [20], the maximum production of hydrogen per day is 1.14 kg. Thus, the electrolyzer needs to be running during 16h 45min, at nominal power, to be able to produce 0.795454 kg.

Therefore, the annual energy required to feed the vehicle with hydrogen is 9,677 kWh and 21,615 kWh for the electrolyzer.

Table 1: PEM HOGEN® S20 Electrolyzer Specifications

Electrolyte	Proton Exchange Membrane (PEM) - caustic-free
Hydrogen Net Production Rate	0.53 Nm^3/hr - 20 SCF/hr - 9.4 slpm - 1.14 kg/24hr
Delivery Pressure – Nominal	13.8 barg (200 psig)
Power Consumed	6.7 kWh/ Nm^3
Volume of H_2 Gas Produced	17.6 kWh/100 ft^3
Purity (Concentration of Impurities)	(99.9995%) Water Vapor < 5 ppm, -65°C (-85°F) Dewpoint, N2 < 2 ppm, O2 < 1 ppm, All Others Undetectable
Turndown Range	0 to 100% net product delivery
Upgradeability	N/A
Input Water Quality	ASTM Type II Deionized Water required, < 1 µSiemen/cm (>1 MΩ-cm) ASTM Type I Deionized Water preferred, < 0.1 µSiemen/cm (>10 MΩ-cm)
Rate at Max. Water Consumption Rate	0.47 L/hr (0.13 gal/hr)
Temperature	5°C to 35°C (41°F to 95°F)
Pressure	1.5 to 4 barg (21.8 to 58.0 psig)

Finally, it can be added in this section that oxygen could be stored and sold, as by-product, to improve the economical efficiency of the whole system.

2.2.2. Deionizer

The electrolyzer requires deionized water for operation. Deionization reduces the amount of dissolved minerals in water. The efficiency of deionization equipment is determined by measuring conductivity, resistivity or concentration of dissolved minerals. The removal of ions produces an increase in the water resistivity, providing an accurate method to determine the degree of deionization.

As already indicated in electrolyzer data (Table 1), water consumption is 0.47 l/hr (0.13 gal/hr) and 16.75 work hours are required. Therefore, for daily production, 7.87 liters (2.08 gallons) of deionized water, with conductivity less than 1 uS/cm, will be required. With this water flow, the demand of 0.795454 kg of hydrogen can be met.

From these numerical values, the deionizer OTG2-SDIL of On the Go®, from PORTABLE WATER DEIONIZERS has been chosen [21]. Table 2 shows the most relevant characteristics of the selected deionizer.

Table 2: Technical Specifications of OTG2-SDIL deionizer

SIZE	48" x 6.75
WEIGHT	52 lbs
CAPACITY	0.90 cubic feet
TANK	Single
RINSES	Approximate of rinses before refilling, assuming TDS of 250 ppm
METER	Portable TDS Hand-held Meter
FLOW RATE	Less than 5-6 gallons/min for best performance & effectiveness

2.2.3. Water supply

The electrolyzer receives water, through the deionizer, from a water storage tank. This tank is filled in two ways: rainwater and/or domestic pipe water. The tank will supply the water, by gravity, to operate the deionizer and electrolyzer. Also, the tank has detectors of minimum and maximum level to ensure adequate water flow to the electrolyzer and to cut the water supply to the tank, respectively.

In order to choose the water tank dimensions, data from rainfall in the Amarillo area have been previously collected. Average annual precipitation is 505.2 mm (19.9 inch) [22]. The floor space occupied by the garage roof, where the hydrogen generation system is located, is 30 m^2 (322.92 Sq Ft). Thus, 30 m^2 x 0.5052 = 15.156 m^3 = 15,156 liters per year, are available. This is, an average value of 41.52 liters/day. Because the daily amount of water needed for hydrogen generation is 7.87 liters (2.08 gallons), the water supply can be ensured with rainwater.

Considering the previous numerical values, we have chosen the water tank of 300 liters (80 gallons), from Water Tanks Norwesco [23]. This tank is oversized so it is possible to fill it, in a single day that precipitate 10 mm. With the water tank full, it is possible to produce hydrogen during 40 days, without rain. However, if there is not enough rainwater, water from the domestic pipe can be used.

The deposit is located under the garage roof. It is cylindrical in shape, with the following dimensions: 0.5 m diameter x 1.5 m length (1.64 ft diameter x 4.92 ft length).

2.2.4. Compressor

In order to supply hydrogen to the vehicle, there must be a pressure difference between the electrolyzer and dispenser. Electrolyzer supplies hydrogen at a pressure of 13.8 bar (200 psi) and the vehicle needs hydrogen at a pressure around 350 bar (5.000 psi) to fill the vehicle tank. Therefore, a compressor is needed to raise the pressure of the hydrogen from the electrolyzer output to store it in a tank.

The hydrogen compressor selected is model C06-03-140/300LX, from HYDRO-PAC, Inc. [24]. The most relevant technical specifications of the compressor are shown in Table 3.

Table 3: C06-03-140/300LX Compressor Specifications

Discharge pressure	420 bar (6,000 psi)
Range of inlet pressure	9.6-20.7 bar (140-300 psi)
Capacity at minimum inlet	92.6 Nm^3/h (1.7 scpm)
Capacity at maximum inlet	5.4 Nm^3/h (3.5 scpm)
Motor power	2.3 kW (3 HP)
Length	1,270 mm (50 in)
Width	762 mm (30 in)
Height	915 mm (36 in)

The average consumption to compress 1kg of hydrogen to 350bar (5,000psi) is taken as 3.1kWh [25]. Then, the energy required per year is:

$$0.795454\frac{kg}{day}\cdot\frac{3.1kWh}{1kg}\cdot\frac{365days}{1year}=900kWh/year$$

2.2.5. Chiller

The heat generated during hydrogen compression has to be released for proper operation of the compressor. Compressor manufacturer, in its technical specifications, states that a cooling rate of about 8,000 BTU/hour is required. For this application, it is used a refrigerator comprising: a cooling system, a cooling circuit and electronic control devices. Considering the needs, we have chosen the model Recirculating chiller RC022, from Kodiak [26]. Table 4 shows the most relevant technical specifications of the chiller. Finally, as it has not been possible to have actual data, the energy required per year has been estimated in 338 kWh.

Table 4: Kodiak Recirculating RC022 Chiller Specifications

Cooling capacity	8200 BTU/hr (2400 W)
Compressor capacity	3/4 HP
Fluid connections	½'' FNPT
Reservoir capacity	2 gallons (8 liters)
Ambient temperature range	50ºF – 90ºF (10ºC – 35ºC)
Dimensions (W x D x H)	14.8 x 24.5 x 26.5 inches (376 x 623 x 673 mm)
Weight	166 dry lbs (75 kg)
Electrical configuration	208/230V, 60Hz, 1ph, 10A @ Full Load

2.2.6. Hydrogen Storage Tank

One of the main problems for the development of hydrogen technology is the need for safe and cost effective ways of storing it. There are various possibilities for hydrogen storage, among which the following can be pointed out [27-30]: compressed hydrogen, liquid hydrogen, metal hydrides and carbon-based material (fullerenes, carbon, nanotubes, activated carbons). The option chosen in this proposal has been compressed hydrogen.

Specifically, the model W076 DyneCell Hydrogen Cylinders, from Dynetek Industries Ltd. has been selected [31]. Table 5 shows the most relevant technical characteristics of the chosen hydrogen storage tank.

Table 5: W076 Hydrogen DyneCell Cylinder Specifications

Pressure	450 bar (6527 psi)
Internal volume	76 liters w.c. (4.638 cu.in.)
Diameter	428 mm (16.9 in)
Length	954 mm (37.6 in)
Weigth	53.6 kg (118 lb)
Capacity	2.17 kg H_2
Maximum fill pressure	563 bar (8158 psi)

2.2.7. Hydrogen Dispensing

The fuel gas dispenser is a "stand-alone" unit, which provides the mechanical interface between the hydrogen fuel station storage tank and the vehicle, together with safety features and metering equipment. The dispenser consists of a small enclosure where regulation and control valves are located.

The hydrogen dispenser chosen for this proposal is the model TK17H_2 70MPa [32]. Its characteristics are shown in Table 6.

Table 6: TK17H_2 70 MPa Hydrogen Dispenser Specifications

Nominal pressure	10,000psi (700 bar)
Temperature range	-40ºF up to 185ºF
Inlet port	UNF 9/16''-18 external thread
Standards	SAE J2600

2.2.8. Wind Turbine

The wind turbine has to supply the energy consumed by the electrolizer, the deionizer, the compressor, the chiller and the dispenser. The following outlines the criteria for selecting the most suitable wind turbine for the chosen site.

Figure 7 shows the average direction of winds in the city of Amarillo. The data have been measured at a height of 50 m (164.04 ft) above the 1074 m (3,523.6 ft) of altitude of the site. The GPS coordinates of the sensor location are: 35°10' Latitude and 101°32' Longitude [33]

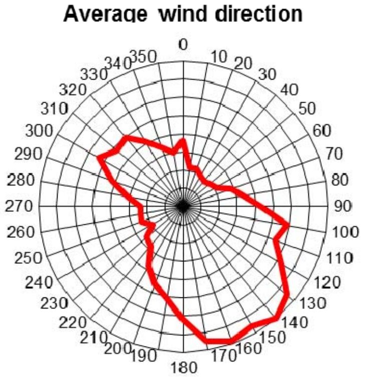


Figure 7: Wind rose of Amarillo (Texas)

Using the following expression, wind speed data has been translated to a height of 10 m (32.81 ft), the height of the wind turbine [34].

$$\frac{V_1}{V_2} = \left(\frac{h_1}{h_2}\right)^{3\cdot\alpha}$$

Where *α* is a parameter called roughness coefficient that depends on topography and weather conditions. A value of 0.14 has been chosen, which corresponds to a flat and unobstructed terrain [34].

Next, the annual wind speed data histogram has been approximated by a continuous curve using a two parameter Weibull probability density function. The Weibull function is defined as follows [34]:

$$f(v) = \frac{\beta}{\alpha}\left(\frac{v}{\alpha}\right)^{\beta-1} e^{\left[-\left(\frac{v}{\alpha}\right)^{\beta}\right]}$$

Where *v* is the wind speed, *α* is the scale parameter and *β* is the shape parameter. The optimal values of α and *β* that adjust the Weibull function to the wind speed data histogram are:

α = 2.62527647069198
β = 7.07632929347926

The wind speed data histogram and the Weibull function that fits the data are shown in Figure 8.

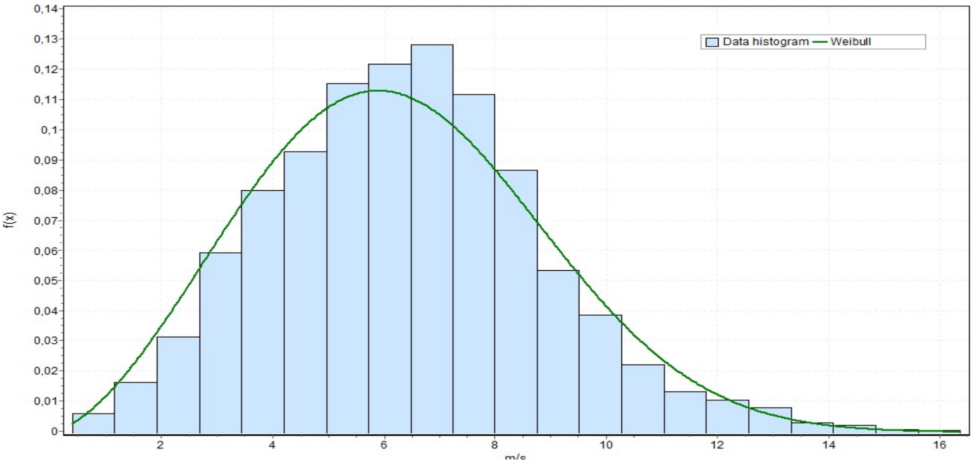


Figure 8: Wind speed data histogram and Weibull distribution

Taking into account the energy requirement and the wind distribution in the site area, a UGE-4K wind turbine, from Urban Green Energy, has been chosen [35]. UGE-4K is a vertical axis wind turbine and has been chosen because it has the following advantages:

- No need for a large tower.
- No need for an orientation mechanism. The turbine works even when wind changes direction quickly.

- It can be located close to the ground, making maintenance easier.
- It can take advantage of irregularities of the terrain.
- It needs a lower wind speed to start generating.
- Less likely to break in strong winds.
- Lower environmental impact and easily avoided by birds.

The main characteristics of the UGE-4K wind turbine are shown in Table 7 and the power curve in Figure 9.

Table 7: EGenX- UGE 4KW Specifications

PERFORMANCE	
Rated Power	4 kW
Peek Power Wind Speed	28 mph
Operating Range	6 - 65 mph
Maximum Wind Speed	125 mph
Noise Level at 3 m Distance	@ <7 m/s - < 27 dB @ 7 - 10 m/s - < 32 dB @ 10 - 13 m/s - < 37 dB
PHYSICAL PARAMETERS	
Mill Size	4.2m x 2.75m (165” x 108”)
Tower Height	5.5m (18’)
Gross Weight w/o Tower	200 kg (440 lbs)
GENERATOR	
Type	Permanent magnet direct drive generator
Temperature range	- 40 ºC to 115 ºC
WInd Interface Box	(Power-One Aurora PVI-7200) Output: 0-600Vdc
Grid-TIe Inverter	(Power-One Aurora PVI-6000) Input: 50 - 580Vdc

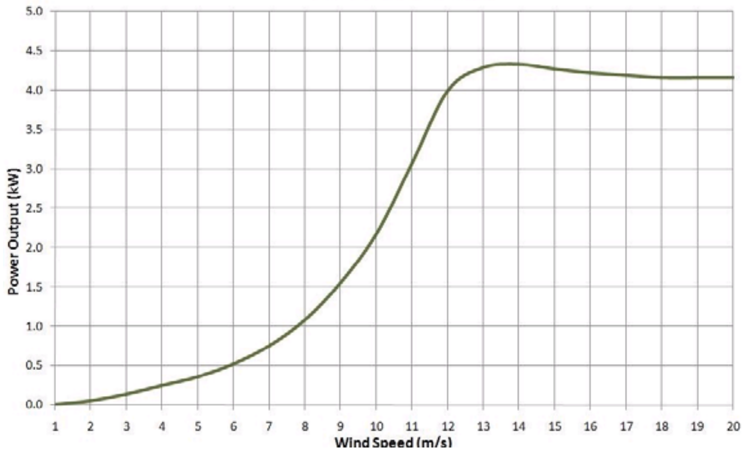


Figure 9: UGE-4K wind turbine power curve

Multiplying the power curve by the wind speed distribution, it gives the energy curve shown in Figure 10. This curve gives the energy produced by the wind turbine for every wind speed value. The area below the curve gives the energy produced by the wind turbine for a year, which corresponds to a value of 7,755.42 kWh per year.

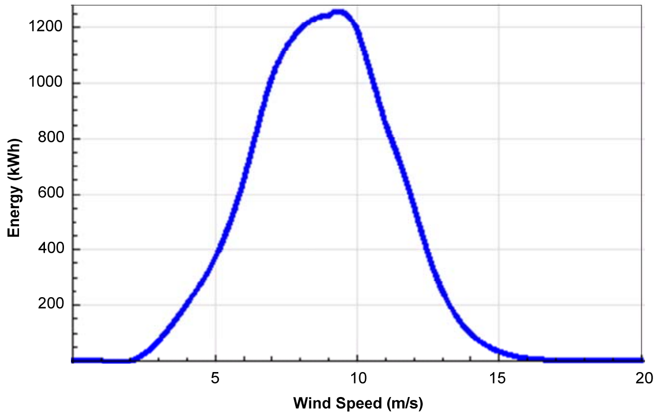


Figure 10: Electricity produced as a function of wind speed

Therefore, 3 wind turbines will be used to supply the power needed by the proposed design. With this number of wind turbines, the energy produced per year equals 23,266 kWh, enough to supply the energy needs of all the components:

$$23{,}266 \text{ kWh} > 21{,}615 + 900 + 338 = 22{,}853 \text{ kWh}$$

2.2.9. Electricity supply

The electricity needed for the operation of the Residential Fueling Station will be supplied, mainly, by three vertical axis wind turbine generators located in the residence, close to the main building. Each wind turbine tower will also contain one street light (see Figure 2).

If the hydrogen generation needs are covered with the wind turbines, the excess energy will be sold to the utility company. On the other hand, in times of low or no wind, the energy needed for the electrolyzer and the other equipments will be purchased from the electrical grid. The utility responsible for the electricity supply in Amarillo is the Southwestern Public Service Company [11]. The tariffs for buying and selling electricity for a residential service are summarized in Table 8.

Table 8: Information of electrical tariffs

Residential Service Tariff		
Service availability charge	$5.65 per month	
Energy charge	$0.05355 per kWh	Summer month (Jun-Sept)
	$0.04393 per kWh	Winter month (Oct-May)
Fuel cost recovery & adjustments	$0.024964 per kWh	
Energy purchase from a qualifying facility of aggregate generating capacity, 100 kW or less		
Service charge	$20 per month	
Energy credit	$0.024964 per kWh	

Additionally, under present law, a federal-level investment tax credit (ITC) is available to help consumers purchase small wind turbines for home, farm or business use. Owners of small wind systems with 100 kW of capacity or less can receive a credit for 30% of the total installed cost of the system [36].

2.2.10. Connection between devices

For the interconnection of the system components, it is necessary to use different valves, piping, pressure relief valves, gauges and adapters. Figure 11 shows the diagram of the connections (of fluids) between different devices.

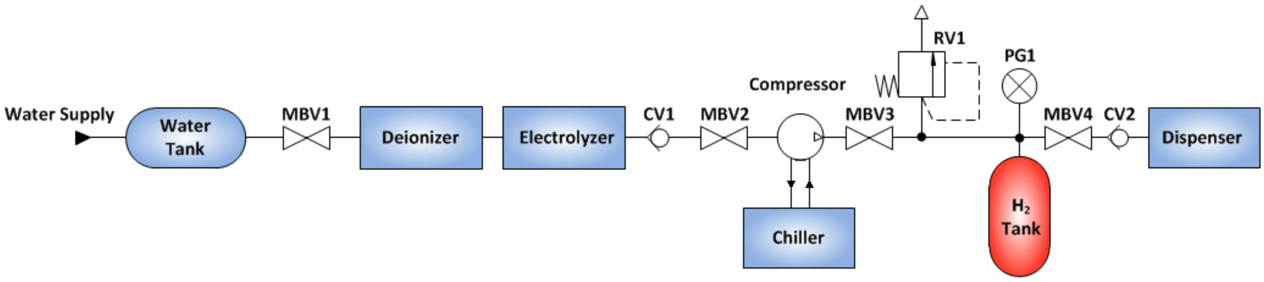


Figure 11. General diagram for fluids interconnections

Table 9 presents the corresponding devices, with different input and output connectors, and their characteristics.

Table 9: Input and output connectors

Water tank	H2O outlet	3/4'' OD (Outer Diameter)
Deionizer	H2O inlet	3/4'' OD
	H2O outlet	3/4'' OD
Electrolyzer	H2O inlet	1/4'' Push to lock
	H2 outlet	1/4'' CPI™
	H2O outlet	1/4'' OD
	O2 vent outlet	1/4'' Push to lock
	H2 & H2O vent outlet	3/8'' OD
Compressor	H2 inlet	1/2'' FNPT
	H2 outlet	1/2'' Ferrule Type
	Cooling inlet/outlet	3/4'' FNPT
Chiller	Cooling inlet/outlet	1/2'' FNPT
H2 Tank	H2 inlet/outlet	CGA 350
Dispenser	H2 inlet	UNF 9/16''-18 external thread
	H2 outlet	DN 4mm

For connecting the different devices, pipes and adapters listed in [37] are used. Besides, Table 10 specifies data of control and safety devices used in the system.

Table 10: Control and safety devices

	Figure ref.	Device ref.
Manual Ball Valve	MBV1	Swagelok SS-45S12
	MBV2	Swagelok SS-43GS4 (2500psi)
	MBV3	Swagelok SS-H83PS8 (6700psi)
	MBV4	Swagelok SS-H83PS8 (6700psi)
Check Valve	CV1	Swagelok SS-CHS4-5 (6000psi)
	CV2	Swagelok SS-CHS8-5 (6000psi)
Relief Valve	RV1	Bauer Compressor Valve-0154 (6500psi)
Pressure Gauge	PG	Swagelok PGI-100B-PG10K-LAQ1 (0 to 10,000psi)

Manual valves are used for maintenance and repair operations in the system. Additionally, electrolysis by-products are disposed of properly to meet the standards of NFPA (National Fire Protection Association).

After defining connections for fluids, electrical connections of the system are described (Figure 12).

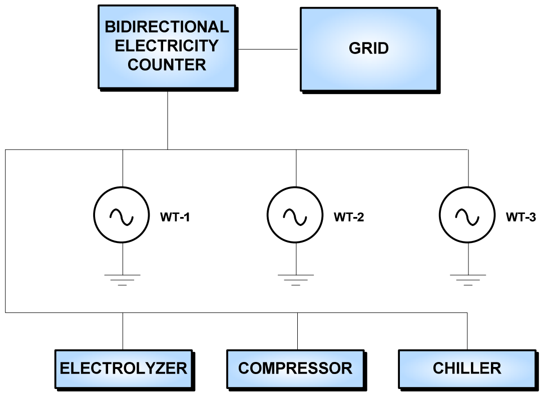


Figure 12. Electrical connections squeme

The output voltage and frequency that provide the three wind turbines are variable, according to the specifications, required by the client, to meet the needs of the local electrical network where the wind turbines are to be connected. For this case, a generation voltage of 230V between phases, frequency of 60 Hz, has been selected. These voltage and frequency levels correspond to the values of domestic electrical network for which the design has been developed. So, the system does not require any additional conditioning device for connecting components.

Table 11 shows the electrical specifications and connections for the different components of the Residential Fueling System designed that require power for their operation

Table 11: Electrical specifications and connections

Device	Electrical specification	Established connection
Electrolyzer	205 to 240 Vac, 1ph, 50 or 60 Hz.	Phase-phase connection (240 Vac, 60 Hz)
Compressor	230/460 Vac, 3ph, 60 Hz	3-phase connection (240 Vac, 60 Hz)
Chiller	208/230 Vac, 1ph, 60 Hz	Phase-phase connection (240 Vac, 60 Hz)

2.2.11. Safety equipment

A safety system will be installed with the objective of reducing the risks associated with the Residential Fueling Station. The safety system comprises the following elements:

a) Hydrogen leakage and flame detection systems.
b) Venting system.
c) Relief pressure system.
d) Emergency stop switch.
e) Other safety systems such as: fire extinguisher, fire hose, safety signaling, lock, etc.

3. SAFETY ANALYSIS

Taking into account the safety standards listed in Appendix A, the following safety measures are proposed.

3.1. Safety requirements

Like with other fuels, hydrogen must be carefully managed. Since it is a very light gas, hydrogen is dispersed in the air at high speed, therefore, all components must be reviewed frequently to detect any leak. Furthermore, hydrogen does not produce smoke when burned and the flame, light blue, is difficult to observe with the naked eye, for that reason, leak detectors should be installed. Moreover, the ventilation of hydrogen in an emergency or for cleaning should be done under the rules.

The flammability of hydrogen makes it difficult to manage and, therefore, special measures must be taken when handling to prevent contact with ignition sources. Thus, before introducing hydrogen into any container, the container must be vented to prevent formation of flammable hydrogen. Also, all electrical appliances must be grounded to prevent static discharges. For the proposed design, the maximum length of dispenser hose has been taken into account to prevent the user can get close with the dispenser to the electrical equipment, such as defined by the NESC standard.

In case of fire, the best way to extinguish it is to prevent the spread of the hydrogen and allow it to burn until the hydrogen supply is cut gradually. Water and a fire extinguisher must be at hand to extinguish the fire immediately.

3.2. Safety Measures of Components

3.2.1. Safety measures for the Electrolyzer

Before filling the electrolyzer with water, proceed to the detection of leaks. All inlet and outlet pipes must be fully threaded. The body cladding of the electrolyzer must be of a corrosion resistant material such as titanium, which presents no problems when in contact with hydrogen.

3.2.2. Safety Measures for the Compressor

The greatest dangers with the compressor are associated with the flow of hydrogen and the high pressure. To minimize the risks, there is a monitoring system, which controls both the flow and pressure of hydrogen. Likewise, the compressor is equipped with the appropriate switches to control the suction, pressures and temperatures. Also a safety valve is installed to release excess pressure in case of emergency. The released hydrogen will be conducted to the garage roof, through a pipe, to avoid dangerous concentrations.

3.2.3. Safety Measures for the Storage Tank

Pressure inside the hydrogen storage tank must be continuously monitored to detected excessive pressure. The tank body has to be made of an explosion-proof material capable of withstanding excessive gas pressure and strong enough to act as a barrier to protect the gas from external temperatures and pressures. Thus, joints and valves must be made of materials capable of withstanding the pressure of the gas.

Moreover, the tank must be kept under continuous surveillance to detect leak. For this reason, the storage system is installed above ground. Furthermore, it should be noted that the storage system cannot be installed under power lines. Finally, an area of 15 feet around the hydrogen storage tank must be kept dry and free of vegetation and combustible material.

3.2.4. Safety for Hydrogen Dispensing

The hydrogen dispensing system must meet the codes and standards for hydrogen distribution, addressing the needs of the equipment, leak detection system, fire fighting and pressure and temperature limitations.

In thunderstorm weather conditions the supply of hydrogen should not be done. Nor will take place at other times of greatest risk, such as extreme winds (tornadoes) or earthquakes. The dispenser shall have a system of gas purging, which can be initiated automatically or manually. It will be an important ancillary part of the filling station. Inert gas purging system must be used during start up and shutdown and in emergency situations.

3.3. Major Failure Modes

3.3.1. Leakage of Hydrogen

The main cause of leakage is the misalignment of valves and seals, deformation of joints and faulty construction of the components. Therefore, the components used in the system must be of superior quality in their construction materials and features, in case of emergency.

All components must be tested before putting them into use. Also, periodic inspections are required. A control system must be employed to verify the correct alignment of valves, seals, gaskets, etc. If the control system indicates a malfunction of any component, it must be replaced immediately.

In addition, the dispenser should be fitted with an emergency gas flow. To dilute gas filtration is necessary to use fans and vents in the walls.

3.3.2. Excessive pressure inside the components

Pressure inside the components should be monitored and constantly checked. Control systems will be used to check the pressure and gas flow. Tanks are installed outdoors to reduce the risk from storage, where the dissolution of gas in the atmosphere reduces the risk of detonation.

To prevent the risk from high pressure, the electrolyzer must be equipped with pressure gauges to check the gas produced in its interior. If the pressure exceeds the limits, the gas is released through vents installed on the walls of the electrolyzer. Ingress of air in suction side of compressor implies risk for internal fire or explosion and significant material damages. Special design for hydrogen compressor to prevent ingress of air (coupled to temperature and pressure indicators) will reduce the risk.

3.3.3. Flammability of Hydrogen

Before starting the supply of hydrogen the first check is to verify that the vehicle engine is off. In addition, there may be problems with the hose nozzle and static electricity due to friction. To reduce these risks the following measures have to be followed:

- Periodic inspection and preventive maintenance.
- Grounding of electrical equipment, including fuel station.
- As the supply of hydrogen is performed at high pressure, a fast control system must be installed using temperature sensors at regular intervals, automatic valves in the supply unit to reduce the likelihood of operator error, etc.

3.3.4. Detonation of Hydrogen

If a flame is detected at any point, it must be extinguished before a blast is produced. Since hydrogen burns rapidly, the time to cut the gas supply must be very short. Therefore, a high-speed (3-4 ms) invisible flame detector must be installed to detect high energy UV radiation emitted by hydrogen, at the time of ignition. Automatic ventilation and sprinklers should also be used to avoid any delays.

Finally, hydrogen must be released into the atmosphere in case of emergency when the pressure exceeds safe limits.

3.3.5. Natural Disasters

This proposal of Residential Fueling with Hydrogen is designed with materials that can withstand natural disasters such as earthquakes, tornadoes, etc. and fire accidents.

4. ECONOMIC/BUSINESS PLAN ANALYSIS

In relation with the economical analysis, in some cases, it has been difficult to obtain actual costs of the devices, mainly due to confidential reasons expressed by manufactures. For this reason, it has been necessary to make estimations in those cases.

4.1. Capital Cost

In this section, costs associated with initial investment capital are described. The obtained capital cost of the installation is $165,806, as shown in Table 12. However, the Investment Tax Credit (ITC) has also to be considered. This ITC is available to help consumers purchase small wind systems for home, farm, with 100 kW of capacity or less, with a credit for 30% of the total installed cost of the system [36].

Taking this option into account, the ITC for our Residential Fueling Station is $49,742. So, new figures are obtained, bringing the total capital of the system, including the cost of the Marketing Plan, as $126,064. Analyzing the total amount of capital, we would highlight the costs of: wind turbine system (50.7%), electrolyzer (24.1%) and compressor (15.7%).

Table 12: Capital Cost

ITEM	PRODUCT DESCRIPTION	QUANTITY	COST PER UNIT($/u)	COST ($)
WATER TANK	NORWESCO WATER 80 GALLON LEG TANK	1	316	**$316**
DEIONIZER	OTG2-SDIL	1	660	**$660**
ELECTROLYZER	PEM HOGEN S20	1	40,000	**$40,000**
WIND TURBINE SYSTEM				
WIND TURBINE	GENX-UGE-4KW	3	18,250	$54,750
TOWER	18 ft X-UGE-4K-T550	3	2,590	$7,770
PO WIND INTERFACE BOX	PVI-7200	3	2,250	$6,750
PO GRID-TIE INVERTER	PVI-4200	3	4,200	$12,600
INSTALLATION		3	750	$2,250
SUBTOTAL WIND TURBINE SYSTEM				**$84,120**
COMPRESSOR	HYDRO-PAC C06-03-140/300LX	1	26,050	**$26,050**
CHILLER	KODIAK RECIRCULATING RC022	1	3,000	**$3,000**
STORAGE TANK	W076 HYDROGEN DYNECELL	1	8,560	**$8,560**
DISPENSER	TK17H2 70MPA	1	1,500	**$1,500**
SAFETY EQUIPMENT		1	1,600	**$1,600**
SUBTOTAL				**$165,806**
INVESTMENT TAX CREDIT (30% of the total installed cost of the system)				**$49,742**
TOTAL INVESTMENT				**$116,064**
MARKETING				**$10,000**
TOTAL CAPITAL COST				**$126,064**

Finally, we think that the total capital cost of Table 12 would correspond to the worst case. Perhaps, it could be reduced if some additional public investment aids might be obtained from governments and public institutions (however, we have not a clear idea of those options in the USA).

4.2. Maintenance and Operating Cost

The expected lifetime of the designed system, as indicated in paragraph 4.5, is 20 years. To make the system operational during that period of time, a number of costs (expenses) have been taken into account related to the maintenance of the facility (labor costs and maintenance of equipment), as detailed in Table 13.

Table 13: Expenses of maintenance and operation

EXPENSES	
DESCRIPTION	COST PER YEAR
LABOR MAINTENANCE	$2,000
EQUIPMENT MAINTENANCE	$500
TOTAL	$2,500

4.3. Revenues

In this section, fuel savings and costs of CO_2 emissions have been considered as sources of revenue. Fuel economy has been evaluated considering the avoided cost of fuel consumption [38-39]:

$$35\frac{miles}{day}\cdot\frac{365days}{1year}\cdot\frac{0.03gallons}{1mile}\cdot\frac{3\$}{1gallon}=\$1{,}154/year$$

In relation with the CO_2 emission costs, it can be mentioned that the social cost of carbon (SCC) is highly uncertain. The wide range of estimations is explained mostly by underlying uncertainties in the science of climate change, different choices of discount rate, different valuations of economic and non-economic impacts and how potential catastrophic impacts are estimated. Other estimations of the SCC spanned at least three orders of magnitude, from less than $1/t$CO_2$ to over $1,500/t$CO_2$. The true SCC is expected to increase over time. The rate of increase will very likely be 2 to 4% per year [40-42]. Given that the current rate of emissions is priced at $20/t$CO_2$, the cost avoided of CO_2 emissions has been calculated:

$$35\frac{miles}{day}\cdot\frac{365days}{1year}\cdot\frac{0.415kgCO_2}{1mile}\cdot\frac{0.02\$}{kgCO_2}=\$106/year$$

Table 14: Incomings

REVENUES	
DESCRIPTION	INCOMES PER YEAR
FUEL SAVE	$1,154
CO_2 EMISSIONS	$106
TOTAL	$1,260

Therefore, the income during the first year is $1,260.

4.4. Business Plan

Considering the revenue and expenses during the first year, it seems that there is a deficit of $1,240. However, additional considerations must be taken into account:

- On the one hand, other sources of income have not been taken into account, such as sale of: power to the grid, hydrogen, oxygen. Also, water saving could be considered. These extra byproducts could avoid the losses indicated above.
- Additionally, fuel and emissions prices used in our calculations are current values and may change up under different scenarios. Thus, in a future scenario of light growth, these prices are estimated to increase by 4%. However, there are other assumptions such as a moderate growth (increase by 10%) and/or a dramatic growth (an increase by 30% may happen)

4.5. Hydrogen Cost

This section calculates the cost of hydrogen production, given that the investment is estimated at 20 years.

$$\frac{\$126.064}{0.795454\frac{kg}{day}\cdot\frac{365days}{1year}\cdot 20years}=\$21.7/kg$$

However, it must be pointed out that this price has been calculated based on current costs, which are still very high. Although there are other less expensive methods to obtain hydrogen, as derived from steam reformation of natural gas, the research team has wanted to select this solution (electrolysis and wind turbines), as it is more environmentally friendly.

In a future scenario in the short term, it is estimated that the price of $21.7/kg can be reduced to about $8/kg. Even, in the most optimistic forecasts it may be around $3/kg, as indicated in a report by Khosla Ventures. A company of this group, Electrochemical Research Laboratory GridShift, has developed a way to produce hydrogen, using water electrolysis, more cheaply than petroleum, a breakthrough that, if replicable on a commercial scale, could revolutionize the use of hydrogen as a means of energy storage.

The company has developed a 3D electrode coated with powders exhibiting nanoscale qualities as a means of increasing the surface area available to interact with the water passing over it. This could make hydrogen a more affordable alternative to gasoline, which currently sells at an equivalent cost of $2.70 [43].

5. ENVIRONMENTAL ANALYSIS

The Intergovernmental Panel on Climate Change (IPCC) has indicated that the average global temperature has increased from 0.3 to 0.6°C and sea level has risen 0.1-0.25 m during the twentieth century. The ten warmest years of the century have taken place over the past 15 years. If this trend continues during the present century, the IPCC predicts a temperature increase of 1.4 to 5.8°C, a sea level rise of 0.9 m and a likely increase in rainfall intensity. Changes in climate could adversely affect human health, agriculture, water resources and ecosystems. Most national and international agencies have concluded that the uses of carbon-rich fuels are responsible for global warming through greenhouse [44].

This proposal focuses on hydrogen production, using mainly electricity supplied by three wind turbines. In this scenario, regarding the environmental impact of renewable energy, we can say that it is minimal, except hydropower, whose capture requires the construction of large reservoirs. Therefore, in the assessment of impacts, only those derived from the manufacturing, conversion devices and transport of these energies can be included. Obviously, these impacts also exist in the exploitation of non-renewable energy.

5.1 Relevant environmental aspects

The hydrogen generation option for this proposal has focused on water electrolysis. In order to make a better use of local renewable resources, rain water that falls on the roof of the Residential Fueling Station is used mainly. Moreover, regarding the use of wind turbines, it must be said that they include positive and negative impacts. Some key indicators for sustainability, reflecting the main justification for the choice of this electric generation technology, are the following [45]:

1. Price per unit of electricity generated.
2. Emissions of greenhouse gases.
3. Availability and limitations of each technology.
4. Efficiency of energy transformation.
5. Land Requirements.
6. Water consumption, which is especially relevant in arid climates.
7. Social impact.

Figures 13, 14 and Tables 15, 16 and 17, show those indicators for comparative analysis of wind turbine technology with other renewable and non-renewable technologies.

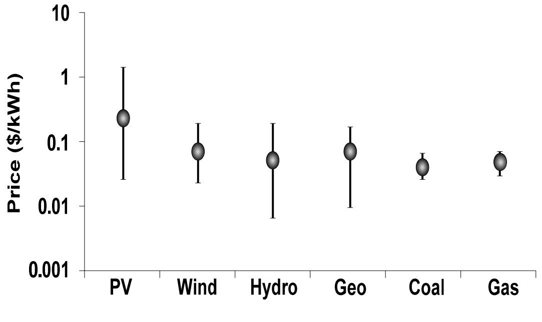


Figure 13: Cost of electricity generation per kWh

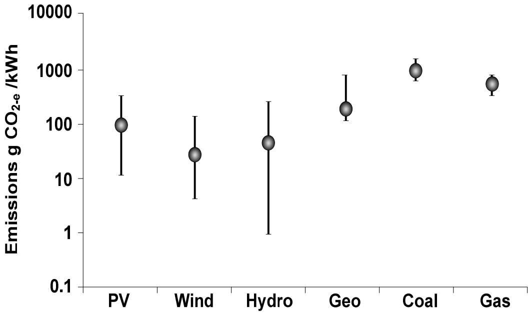


Figure 14: Carbon dioxide equivalent emissions during electricity generation

Table 15 shows the mean price of electricity and average greenhouse gas emissions expressed as CO_2 equivalent for individual energy generation technologies.

Table 15. Mean Price of electricity and average greenhouse gas emissions

	$/kWh	gCO_{2-e}/kWh
Photovoltaic	$0.24	90
Wind	$0.07	25
Hydro	$0.05	41
Geothermal	$0.07	170
Coal	$0.042	1004
Gas	$0.048	543

Table 16. Efficiency and water consumption - electricity generation

Technology	Efficiency of electricity generation	Water consumption in kg per kWh of electricity generation
Photovoltaic	4-22%	10
Wind	24-54%	1
Hydro	>90%	36
Geothermal	10-20%	12-300
Coal	32-45%	78
Gas	45-53%	78

Table 17. Qualitative social impact assessment

Technology	Impact	Magnitude
Photovoltaic	Toxins	Minor-major
	Visual	Minor
Wind	Bird strike	Minor
	Noise	Minor
	Visual	Minor
Hydro	Displacement	Minor-major
	Agricultural	Minor-major
	River damage	Minor-major
Geothermal	Seismic activity	Minor
	Odour	Minor
	Pollution	Minor-major
	Noise	Minor

In relation with CO_2 emissions of wind turbines, most of these emissions are the result of energy used during the manufacturing process of this technology. In this case, emissions are typically calculated using an average value of the electricity production mix in the region.

Thus, considering that for this Residential Fueling Station proposal the amount of annual energy needed is 23,266.26 kWh and emissions, due mainly to the manufacturing process of this technology, are 25 gr CO_2, this option gives an overall annual emissions of 0.59 tons CO_2. If gas were used as fuel, the results would be approximately 12.7 tons of CO_2.

Consequently, the proposed Residential Fueling Station shows a positive environmental impact on aspects related to CO_2 emissions and water consumption, compared to other technologies.

Regarding the visual impact, the choice of vertical axis wind turbines and the layout used in wind turbine tower as a support for street lighting lamps (see Figure 2), minimize that visual impact.

Finally, in relation to noise emissions, the model chosen has good performance and it is in accordance to the IEC-61400-11 (approximately a maximum value below 50 dB, at ten feet distance of the wind turbine). Considering the locations of the three wind turbines in the urban layout, the noise impact is considerably reduced.

5.2 Energy flow analysis

Figure 15 shows a Sankey Diagram, concerning the flow of energy that responds to operating mode of the proposed Residential Fueling Station with Hydrogen.

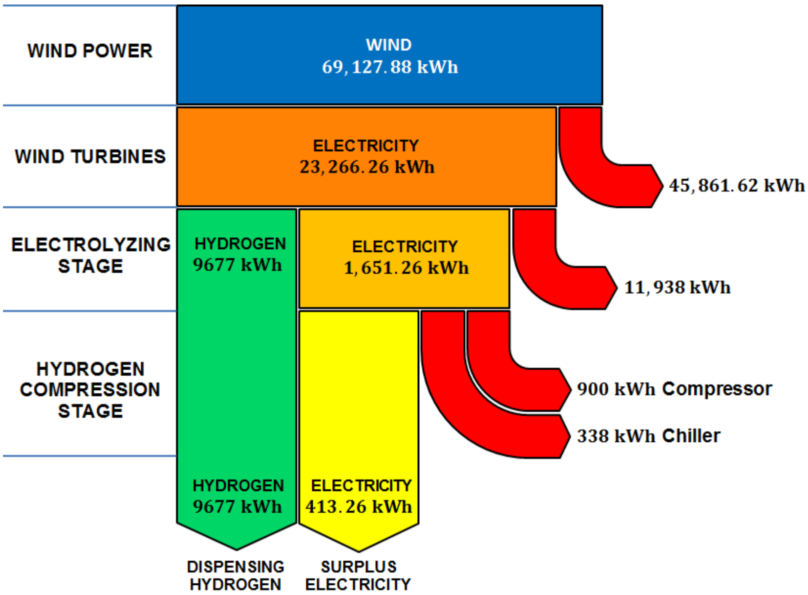


Figure 15: Energy flow Sankey Diagram of the proposed Residential Fueling Station

6. MARKETING AND EDUCATION PLAN

Hydrogen is an attractive alternative to fossil fuels. However, although it is a renewable and non-polluting resource, there is strong resistance to adopting hydrogen as a new energy vector. This is motivated by the cost of the technology compared with the traditional ones and the natural tendency to reject any change.

To change this dynamic, an extensive promotion campaign to disseminate the advantages of the hydrogen economy is needed. This campaign must be focused on key issues aimed at all audiences, reporting on issues such as safety, pollution reduction and energy independence, arising from the use of hydrogen as a fuel. By focusing on these issues, providing information and advertising to a large numbers of citizens, it is possible to influence public opinion towards the use of hydrogen technology.

To achieve these objectives a marketing campaign and an educational program to popularize the concept of hydrogen and its applications to all citizens has been planned. The following are initiatives that can be developed to achieve these objectives.

6.1. MARKETING PLAN

The design carried out of the Residential Fueling Station with Hydrogen located in Amarillo, Texas, must be environmentally sustainable and economically viable in the short to medium term, using public investment aids.

Today, many people have heard of hydrogen as a fuel for the future, but do not understand it. For them it is an utopic vision, and in the best case, distant. The objective to be achieved is to convince the public of the viability of hydrogen nowadays and of the benefits associated with the proposed change.

To achieve this goal, the first step is to create a flow of information highlighting the advantages of this new energy source, reaching hydrogen producers and distributors, vehicle manufacturers and customers, making them see the importance and possibilities arising from the use of hydrogen technologies

The means used will be brochures, posters, and press, radio and television advertisements, and video advertisements on the internet. This would help getting the awareness among the general public, promoting the idea of hydrogen as a sustainable energy source.

The cost estimated for the marketing campaign, for the completion and distribution of brochures, posters and advertisements in various media, amounts to $10.000.

6.2. EDUCATION PLAN

Within the informative strategy needed around the use of hydrogen-based technologies, special mention must be made to education. This action will promote an awareness campaign among young people, which will be, in the near future, customers who use the hydrogen. Indirectly, this action also serves to bring this information to parents of students. Thus a more informative impact is achieved.

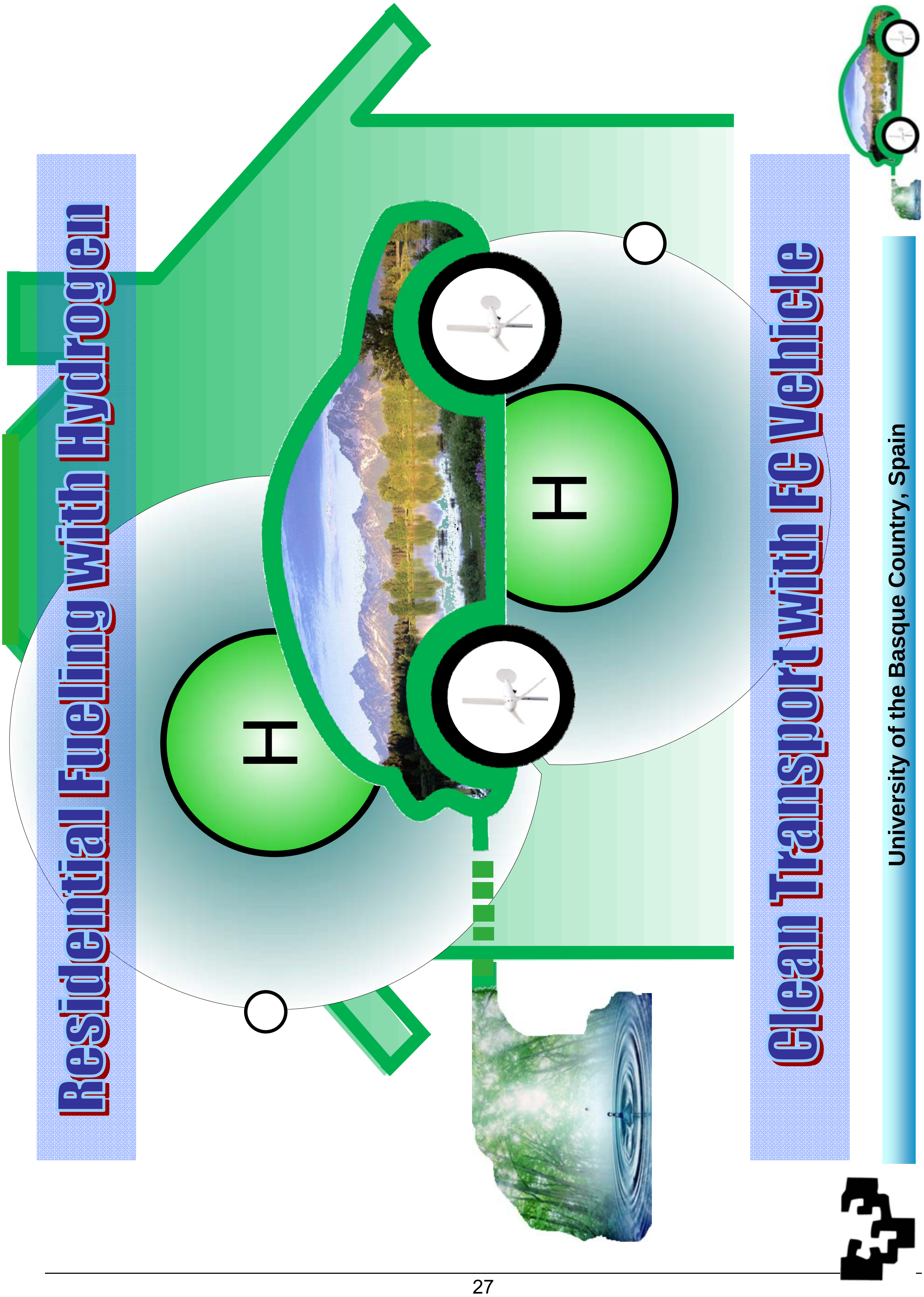
The educational campaign will be done in schools and on university campus, informing all students. The following are the main aspects of the campaign:

- Creation of posters and brochures featuring new technologies displayed in common areas like corridors and halls.
- Organizing workshops, highlighting the benefits of a hydrogen economy.
- Organizing conferences about the characteristics of hydrogen-based technologies and the challenges to be overcome for possible implementation.
- Organizing expositions and science fairs, presenting applications and demonstrations
- Introduction of the concept of hydrogen as fuel and fuel cells technology within the curriculum of the university.
- Delivery of seminars and workshops on topics related to alternative energy, in general, and hydrogen from renewable energy and fuel cells, in particular.

All these actions are designed to create a climate of awareness in society, by knowing, learning and doing, to understand the benefits of the use of new technologies related to hydrogen.

Finally, it is considered of the highest interest to prepare and organize courses about operation and maintenance of the Residential Refueling Station, in order that the users can learn to operate it safely. For the development of these courses, economical support could be asked for to government, public institutions and private enterprises, with the aim of implanting a pilot installation, with a small fuel cell vehicle. This way, general public could learn to use this technology and be less afraid about the use of hydrogen and fuel cell vehicles, before having something similar installed in their own homes.

6.3. ADVERTISEMENT



7. APPENDIX

APPENDIX A: CODES AND STANDARDS

The codes and standards referenced are the following:

NFPA 55. Standard for Gaseous Hydrogen Systems at Consumer Sites
NFPA 70. National Electric Code
NFPA 496. Standard for Purged and Pressurized Enclosures for Electrical Equipment
ASME Boiler and Pressure Vessel Code, Sect. VIII, Div. 1 (storage container)
ASME Boiler and Pressure Vessel Code, Sect. VIII, Div. 2 (relief devices)
ASME B31.12 – 2008. Hydrogen Piping and Pipelines
ASME BPVC II – 2010. Materials Properties
ASME PTC 25 – 2008. Pressure Relief Devices
ASME PTC 42 – 1988. Wind Turbines
ASME PTC 50 – 2002. Fuel Cell Power Systems Performance
CGA G-5.4. Standard for Hydrogen Piping at Consumer Locations
CGA G-5.5. Hydrogen Vent Systems
CGA C-17. Methods to Avoid and Detect Internal Gas Cylinder Corrosion
CGA H-5. Installation Standards for Bulk Hydrogen Supply Systems
CGA P19. Recommended Hazard Ratings for Compressed Gases
ICC. International Fuel Gas Code
ISO/DIS 15869. Compressed Hydrogen Storage
ISO/CD 22734-1. Hydrogen Generators Using Water Electrolysis Process
OSHA 1910.103. Hydrogen
UL 2264. Gaseous Hydrogen Generating Appliances
ISO/TR 15916. Technical Report: Basic Considerations for the Safety of Hydrogen Systems

Internationals Standards Associations abbreviations

NFPA: National Fire Protection Association
ASME: American Society of Mechanical Engineers
CGA: Compressed Gas Association
ICC: International Code Council
OSHA: Occupational Safety and Health Administration
UL: Underwriters Laboratories
ISO: International Organization for Standardization
NESC: National Electrical Safety Code®

APPENDIX B: DRAWINGS

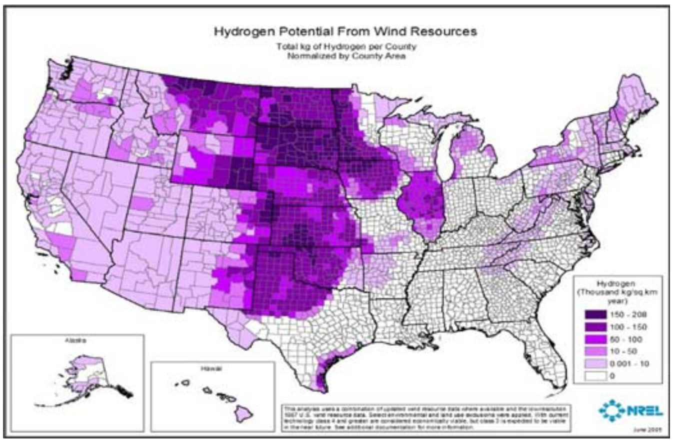


Figure B1. Hydrogen potential from wind [46]

Figure B2. EGenX- UGE 4 kW Wind Turbine [35]

Figure B3. Distribution of the three wind turbines in the residence

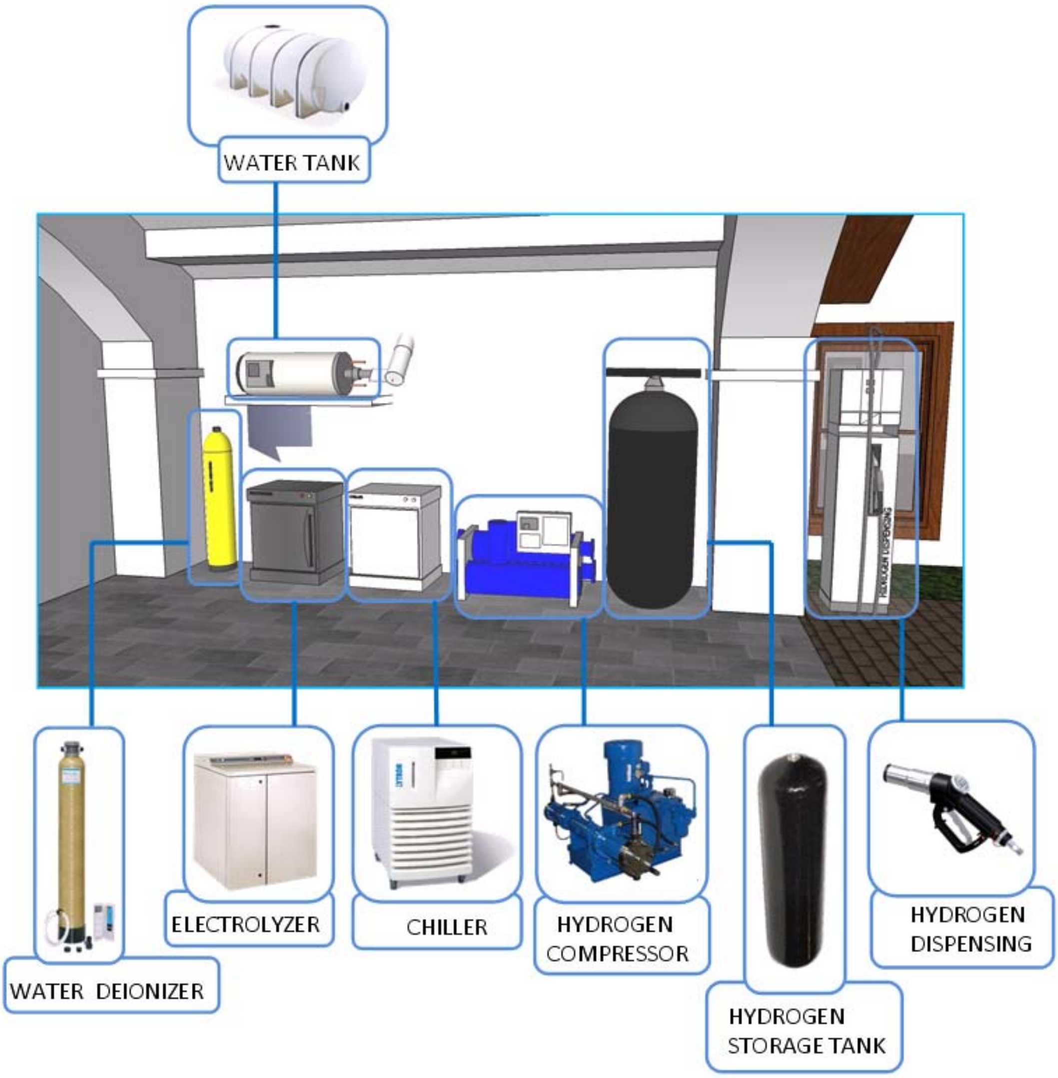


Figure B4 - Distribution of devices, inside the garage

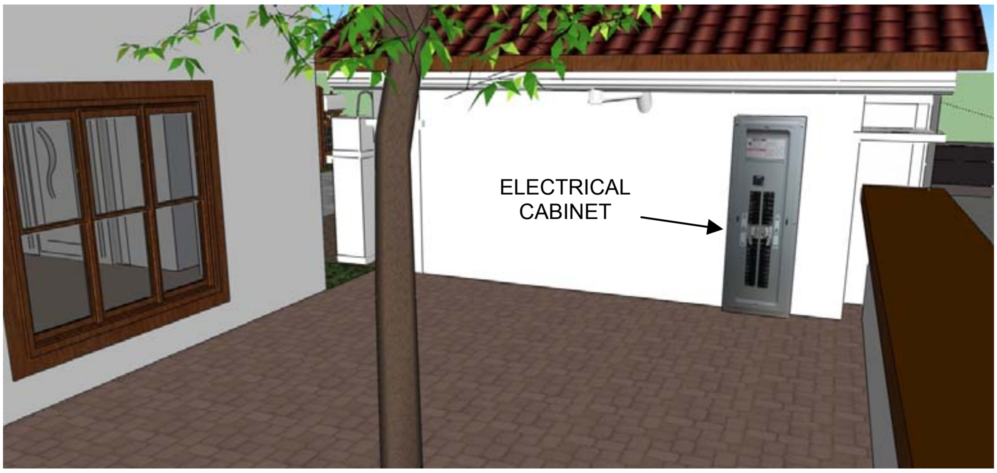


Figure B5 – Location of electrical cabinet, outside the garage

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