MIDDLE EAST TECHNICAL UNIVERSITY

Residental Fueling with Hydrogen

Design Proposal

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EXECUTIVE SUMMARY

Increasing energy demand in all fields is one of the most important issue for the world of 21st century, when increasing world population and technological growth are considered. In order to match this demand, it is clear that the fossil fuels such as coal, oil, natural gas which are being depleted rapidly and polluting nature in all aspects could not be thought as permanent solution. Renewable energy sources offer sustainable and clean energy in massive amount. As one of the most abundant and achievable one, solar energy is expected to be used in numerous fields in the near future. Hydrogen is the key energy carrier in nature. Energy requirement of the world is supplied by the combustion of hydrocarbons; however, air pollution and global warming are mainly caused by this process. If the pure hydrogen could be obtained somehow and is used for fuelling purposes, energy problem of humankind can be solved in an easier and cleaner way. Therefore, producing hydrogen for fueling purposes by using solar power is very promising. There are different alternatives for producing pure hydrogen such as steam methane reforming of natural gas, utilizing biogas or water electrolysis.

We are students of Middle East Technical University from Turkey, mainly from Chemical Engineering background. In our approach, water electrolysis is combined with solar panels to provide the necessary energy for the electrolysis reaction in a renewable and green manner for a single home. Therefore, the ultimate aim is to design a system that will provide the necessary fuel for a hydrogen fuelled car at home. Capacity of the system is approximately 0.8 kg H_2/day which will be enough for the daily operation of our hydrogen fuelled car. There are no greenhouse gas emissions or any other products that may be harmful for the environment. System will utilize the tap water and create pure hydrogen as the product. In addition to these, this approach will provide a saving of approximately 3300 $/year for annual product cost of hydrogen when compared with the conventional cars fuelled with gasoline. Unit production cost of hydrogen is calculated as 1.09 $/kg due to low operation costs. On the average, for a 25 years of system life, our design can achieve a unit hydrogen price of 29.8 $/kg under the specified conditions.

It can be clearly seen that high capital investments are the main drawback for this system. Therefore, it is vital to provide funds for the establishment of the project. In years, the project refunds this investment in an increasing rate when increasing gasoline prices and soaring demand on green technologies are considered.

Table of Contents

LIST OF TABLES AND FIGURES

1. FUELING SYSTEM TECHNICAL DESIGN

1.1. Site Plan Selection

This project is proposed for several locations in Turkey. Turkey has a great potential with its young population. This young generation is highly sensitive about nature and has desire to build a cleaner planet for future. Their attitude towards renewable energy technologies is so positive that it is expected to increase number of projects on this field in near future. In addition, Turkey is a country negotiating European Union Membership. Government has a policy that encourages people to change their way of living into much sensitive to surrounding. There would be some government founds and tax reductions for renewable energy technologies; and also some legal regulations would be done on this subject during negotiations period. Therefore, Turkey is one of the best countries that are proper for such kind of project.

One other key advantage of Turkey is geopolitical position. When the solar radiation maps of Turkey are analyzed and compared to other European Countries, it can be seen that Turkey is far from many countries with number of sunny days and solar radiation values. Figure 1.1 below shows solar radiation range of different regions in Turkey.

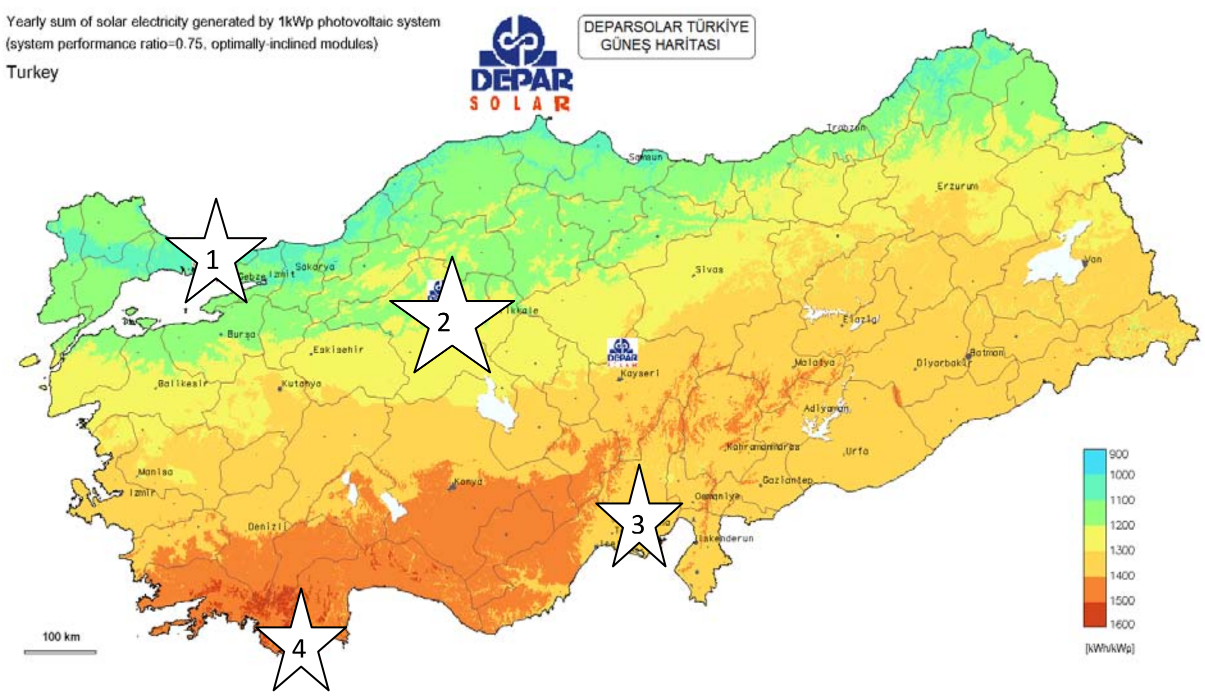

Figure 1.1: Annual solar radiation map of Turkey [1]

Four different cities in four different regions are chosen as proposal locations after this map is examined. Istanbul from green zone (Region 1), Ankara from yellow zone (Region 2), Adana from light brown zone (Region 3) and Antalya from orange zone (Region 4) are selected. It is aimed to compare performances of solar panels in different regions. It is also wanted to be shown how number of panels, required area and costs change with different locations.

Cities picked up from each region are not chosen randomly. When the project is taken into consideration with all aspects, an average customer profile has been determined. Potential users of this system in their resident should be able to afford not only this system but also a hydrogen car and have a certain economical status. They should have a proper education level so they can easily use and control process. In addition, they must have an intellectual point of view to prefer clean and renewable energy instead of conventional ones. Therefore, by considering all these parameters, the biggest metropolis in each region has been selected to reach the highest number of customers for proposed project.

1.2. Hydrogen Production

Hydrogen is one of the most promising energy carrier for future energy crisis and environmental problems; however, due to high cost of production of hydrogen compared to conventional energy carriers such as gasoline, natural gas and diesel, the way of H_2 production becomes critical since it directly determines the hydrogen economy. In this project, electrolyzer which use on-site solar system for generation electricity is chosen for hydrogen production instead of natural gas reforming due to simplicity, low-temperature and pressure application. In addition, we consider people that have no access to natural gas which contributes to global warming to produce hydrogen for their cars by only consuming water and using solar energy.

In this project, firstly, alkaline and PEM type electrolyzer are chosen for hydrogen production. Then, these electrolyzers are modeled for optimization by selecting # of cell, # of stacks, current, voltage, temperature, pressure and cell area as input variables after literature survey. For alkaline type electrolyzer, studies done by Karim [2] et. al., Ulleberg [3] whereas for PEM type electrolyzer, Gorgun [4] and Laoun [5] are selected and remodeled for 1 kg hydrogen/daily by using Matlab Simulink®, Mathcad®, Fortran77® programs. Results of these simulations are combined with on-site solar application. Then, by considering the cost item, final results are analyzed by Microsoft Excel® and JMP® softwares; and optimum design parameters are found and tabulated in table 1.1 and 1.2.

Table 1.1: Optimum design results for PEM type electrolyzer at different operating hours.

Daily operating hours	Production Rate (Nm^3/h)	# of stacks	# of cell	Current (A)	Power (Wh/Nm^3)
12.2	0.92	2	10	100	3390
10.2	1.1	2	30	40	3865
8.1	1.38	3	50	20	4800
6.8	1.65	2	90	20	5875
5.1	2.2	2	30	80	7845

*Region 1 only as an illustration.

Table 1.2: Optimum design results for alkaline type electrolyzer at different operating hours.

Daily operating hours	Production Rate (Nm^3/h)	# of stacks	# of cell	Current (A)	Power (Wh/Nm^3)
13.7	0.82	1	21	100	3570
6.2	1.82	1	21	220	4620
4.1	2.72	1	21	340	7140

*Region 1 only as an illustration.

From tables above, one easily says that alkaline type electrolyzer more profitable than PEM type electrolyzer. This is actually true in one way; however, alkaline type electrolyzers contain caustic KOH solution and asbestos [6], they are threatened the environment whereas PEM type electrolyzers are environmentally friendly. In addition, energy efficiencies of alkaline type electrolyzers are very low when compared with PEM type electrolyzers. Therefore, as a team we prefer PEM electrolyzer for hydrogen production since we are given more importance to environment and energy efficiency although it is more expensive than alkaline type electrolyzer. After choosing the type of electrolyzer, the hydrogen generator capacity is determined as 1.05 Nm^3/h capacity by considering average sunny hours in average sunny in Turkey as 10 hours. Thereafter, HOGEN® S40 (App. 1 for technical specifications) is selected from our market analysis. (Figure 1.2)

Figure 1.2: Representative picture for HOGEN® S40 [7]

1.3. On-site Solar System

The purpose of this work is to produce hydrogen with using a renewable energy source. There are many ways to do this commonly based on depletable fossil fuels. Increasing hydrogen experiments and usage as energy source pushes us to investigate more relevant methods. Sunlight is one of the most abundant source of energy that mankind can use. It is easy to achieve, free, endless, clean. It does not contribute any kind of pollution of sources on earth. The limit of solar power is the limit of technology we use to capture and store it. This is a great deal for human and many people work on this issue for long time worldwide. Solar panel technology achieved today gives us a chance to think sun as not only biological but also technological energy source. A simplified energy cycle with photovoltaic cells can be seen in figure 1.3.

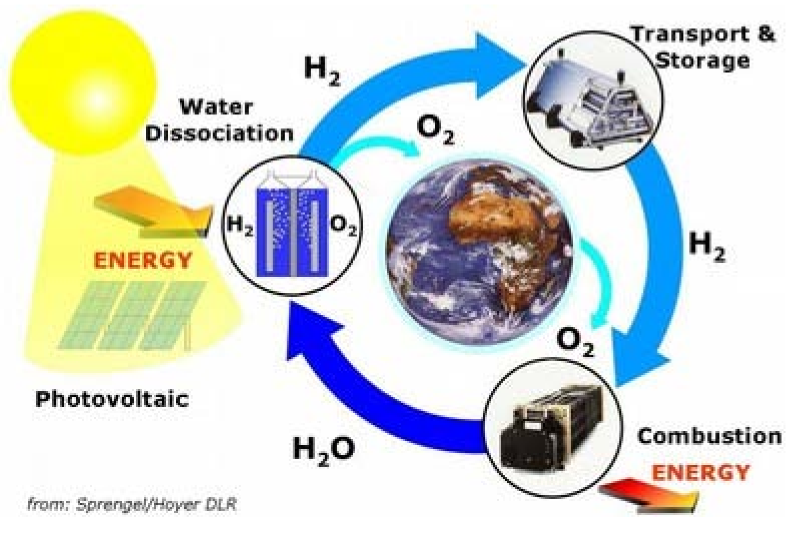

Figure 1.3: Energy cycle with photovoltaic cells and hydrogen production[8]

In this project, photovoltaic solar panels are chosen to supply required energy to produce hydrogen. They are specially designed plates capturing sunlight by converting solar radiation to electricity. The working mechanism is extremely simple. When sunlight reaches to plate surface at certain level, material is induced and an electrical current is created due to potential gradient. There are different materials used for this purpose in solar panels but silicon is the most proper one. Many companies in this sector manufactures silicon based solar panels with high efficiency and lifetime. Configuration of materials at surface is key point to absorb sunlight. Therefore, two silicon solar panel types are decided to compare to be able to achieve stronger design process. Polycrystalline silicon panels and thin film silicon panels are progressed with respect to their performances and costs. There are also some new panels developing like CIGS. These panels include some additive materials such as cadmium to improve sorption capacity. They are also considered as alternative of others. These three panel type are examined according to some design parameters such as current, voltage, power obtained; required panel area for different conditions and costs of system corresponding. Figure 1.4 shows an example of polycrystalline solar modules in residential usage.

Figure 1.4: Polycrystalline solar panels for residential usage [9]

Polycrystalline materials obtained from highly purified polysilicon are placed graphite crucible and melted. Many layers are formed on each other to increase rate of production.

These types of panels are widely used not only to deliver energy for high energy demand but also for some simple operation with low energy requirement. Their efficiency and power capacity increase day by day. Thin film silicon panels have thickness in a few micrometers. This property allows them to change optical movement mechanism of light in cells so that path of light is shortened during time which light stays in cell is increased. Therefore this configuration offers more efficient operation under some conditions. CIGS panels are produced in ternary forms by addition of Cu, In and Ga. However, these panels are not manufactured and used in large scales widely. Therefore, they left out of consideration for now.

After two different types of photovoltaic panel are chosen, approximate capacity requirement is estimated. According to this power requirement solar panel market is investigated. A proper solar module of each type for project purposes is selected as unit module. Unit module of design is a module having certain numbers of photovoltaic cell, supplying certain current and voltage; delivering certain level of power to system. During the comparison period of various panels in market, numerous parameters are taken into consideration. One critical point is the technical stability. The less fluctuations occur in operation, the more accurate design can be achieved. Next thing has to be considered is the module efficiency. Although solar cells have high efficiencies individually, they have to be combined such carefully that they reach high efficiency as one unit. Another parameter is the operational safety. This system is designed for residential purpose; that's why; there will be no operator or engineer on site, so it must offer safe operation. Warranty of material is also checked and the best option for long life performance is preferred. During all these examination, cost is the factor that it has never been forgotten. The lowest possible price for desired specifications is always looked for.

Each module for polycrystalline silicon and thin film silicon has a peak power value. Peak power is the power of module under standard conditions. Each photovoltaic cell performs different under different conditions such as sun radiation and temperature. Therefore, it is needed to find the average current, voltage and power production of each unit module under specified conditions. Project is prepared to commercialize in Turkey. Four different regions and four major cities in these regions are chosen according to their annual sunlight radiations. The first city is Istanbul in region having the lowest solar radiation. The second city is Ankara capital of Turkey. The third one is Adana placed in southern part and the last one is Antalya with the highest annual solar radiation level. Each unit module is modeled to place in each city at four different regions and their performances at those locations are calculated. Maps prepared for annual solar electricity generated by photovoltaic panels at Turkey are used for this purpose.

Unit modules are considered that they supply constant current, voltage and power. These values are calculated with the lowest efficiency and the worst conditions so that they always operate more than minimum and match the requirements of system all the times. Electrolyzer is also designed by variation current and voltage. The desired current and voltage are estimated for electrolyzer performance. To be able to supply desired current to electrolyzer, a certain number of unit modules are linked in series so that current coming from each one is sum up. In order to achieve the voltage, unit modules are linked in parallel with same analogy. Therefore, number of modules is not found alone by using power supply; configuration of these modules in series and parallel is also defined.

Next step is the alignment of these panels on roof. There are two possible way to do this. If the roof is flat, modules have to be inclined with the proper angle so that sunlight could reach surface as perpendicular as possible. Locations are in Northern Hemisphere, so panels must be placed to look south. The proper angle depends on the latitude of the location of system. For the cities proposed, this angle is in between 36-42^{o}. If the roof is inclined, another inclination of panels is not necessary; they be installed smooth on surface.

The area covered by modules on roof is key parameter for design. If there is no enough space for panels, this is not possible to match power supply. The more power system needs, the more panel we have to use, the more space has to be required. Each unit module chosen for polysilicon and thin film have certain areas. These areas and number of modules are used to find roof space required.

Cost of modules in total is estimated by using price of each unit module. Numbers of modules vary with different operation conditions, so lots of different costs are achieved with different power supplies. These costs are added to others for further optimizations.

Simultaneous technical design of electrolyzer and solar modules and cost optimization give us results for polycrystalline and thin film silicon modules located in four different cities in Turkey. (Table 1.3) There will be 101, 85, 79, 73 polysilicon solar modules; they occupy 166, 140, 129, 120 m^2 space for Istanbul, Ankara, Adana and Antalya correspondingly to provide required energy for HOGEN® S40. There will be 179, 150, 139, 130 thin film silicon modules; they occupy 276, 231, 215, 200 m^2 space for Istanbul, Ankara, Adana and Antalya correspondingly

Table 1.3: Required polycrystalline solar panel area for PEM type electrolyzer

Daily operating hours	Production Rate (Nm^3/h)	Reg. 1 Panel Area (m^2/Nm^3)	Reg. 2 Panel Area (m^2/Nm^3)	Reg. 3 Panel Area (m^2/Nm^3)	Reg. 4 Panel Area (m^2/Nm^3)
12.2	0.92	8	7	7	6
10.2	1.1	10	8	7	7
8.1	1.38	12	10	9	9
6.8	1.65	15	12	11	11
5.1	2.2	19	16	15	14

1.4. Hydrogen Compression

In this project, hydrogen is produced at 440 psi from HOGEN® S40 and it is compressed to 3600 psi for storage considerations. The volumetric flow rate of hydrogen is 1.05 Nm^3/hour. To deliver high-pressure hydrogen, 3-5 stages of compression are required because water-cooled positivedisplacement compressors could only achieve 3 compression ratios per stage. Compression requirements depend on the hydrogen production technology and the delivery requirements. Therefore, in this project, hydrogen compressor is designed by considering minimum thermic losses, automatic gas inlet and gas outlet, use of thermic fluid to initiate the heating, use of electric resistance heating when the thermic fluid temperature is not sufficient, security system, automatic operation control, and electric components separated from mechanical components. [10] After considering this parameters, power requirement for compressor is calculated as 0.09kW. [11]

1.5. Hydrogen Storage

One of the most technically challenging bariers to the widespread use of hydrogen as a form of energy is that developing safe, reliable, compact and cost effective hydrogen storage technologies. Hydrogen is difficult to store in large quantities without occupy a significant amount of space due to its physical characteristics. Hydrogen has a very high energy content by weight (about three times more than gasoline), but it has a very low energy content by volume (about four times less than gasoline). This makes hydrogen a challenge to store, particularly within the size and weight constraints of a vehicle. In table 1.4, it is seen that comparison of main hydrogen storage techniques.

In this design project, it is decided to store hydrogen is as compressed gas and the capacity of the storage tank is selected as 5 kg for considering extreme cases such as breakdown in the system for a long time etc. Storage pressure of hydrogen is determined as 3600 psi which is service pressure of hydrogen to the vehicles.

Table 1.4: Comparison of main hydrogen storage techniques [12]

	Advantages	**Disadvantages**
Compressed Hydrogen	• Small weight • Some already present infrastructure • Easy interfacing with fuel cells	• Big volume • Energy loss due to compressibility factor at high pressures • Hydrogen permeation through walls • Hydrogen embrittlement in the wall • High cost of materials
Liquid Hydrogen	• Small weight • Small volume • Low operating pressure	• Boil-off losses • Hydrogen embrittlement in the wall • Very low operating temperature • Hydrogen permeation through walls • High liquefaction energy • Little infrastructure • Harder interfacing with fuel cells • High cost of materials
Hydrides	• Very small volume • Low operating pressure	• Required factor of safety more than 2.25 • Big weight • High operating temperatures • Hysteresis • Slow charging/decharging • Volume changes upon charging/decharging

1.6. Hydrogen Dispensing

Hydrogen dispensing involves the transfer of hydrogen fuel from storage containers to hydrogen-fueled vehicles. Stations are equipped with elegant designed hydrogen dispensers for fast, safe and easy refuelling of hydrogen to vehicles. Two different versions are offered, a stand-alone version with an intuitive design in sheeted stainless steel and a compact wall-mounted version. Both versions include easy user interface with operation buttons & indicators and optional payment module.

In this system, hydrogen is served at 3600 psi from the storage tank to the vehicle. A stand-alone version of dispenser which is shown in figure 1.5. is chosen for the system. (App 2. for technical specification)

Figure 1.5: Stand-alone version dispenser with intuitive design in sheeted stainless steel[13]

1.7. Safety Equipment

Compressed hydrogen gas has the uniqe characteristic and it has the potential hazards associated with it. So, safety measures considered for compressed hydrogen gas system. Hydrogen is undetectable to human sense because it is colorless, odorless and tasteless. Detection sensors can be used as a safety measure. Hydrogen has a low viscosity and small atoms that can be absorbed into materials, so leaks and embrittlement of certain materials are possible, which can result in structural failure. Leak-detection systems, ventilation, and material selection can be used as safety measures. Hydrogen also has low volumetric energy density, so it is potentially hazardous when stored at high pressures. Storage container design and pressure-relief devices can be used as safety measures. Hydrogen is not breathable, so it can accumulate in confined spaces and act as an asphyxiant like any other gas that displaces oxygen. Ventilation and leak-detection systems can be used as safety measures. Hydrogen has a wide flammability range of 4 percent to 75 percent, so leaks of all sizes are a concern. Ventilation and leak-detection systems can be used as safety measures. Hydrogen burns with a pale blue flame that is nearly invisible in daylight, produces no smoke, and emits little heat, so there is potential for undetected flames. Flame detectors and leak-detection systems can be used as safety measures.

In the dispenser system, the nozzle-receptacle compatibility is important, because 3600-psi vehicle can be refueled only from 3600-psi dispenser while 5000 psi vehicle can be refueled from 5000-psi or 3600-psi dispenser due to preventing over-pressuring vehicle fuel tank. When the break-away coupling event, which a vehicle being refueled drives away with the nozzle connected, is occurred, a device that connects the hose to the dispenser separates and valves close to preclude hydrogen flow from the hose or dispenser. There may be a card lock system, a key lock system, PIN access, or similar means for accessing to a hydrogen dispenser due to safety concerns. Emergency shutdown device (ESD) is needed so that fuel flow to the dispenser(s) can be immediately terminated in case of an emergency. Isolation valves are a normal closed valve that opens when activated and closes due to deactivation, power loss or ESD activation. Excess flow valves can be used as terminating filling when there are excessively high flow rates due to a hose rupture. Dispenser has hose integrity protection which includes filling sequencing and algorithms, which detects leaks and terminate filling. During refueling, ground cables are used to maintain a grounding connection with the vehicle. Temperature-compensated fill control is a good safety feature which stops gas flow when fuel tanks reach the temperature-corrected fill pressure to prevent tank over-pressure if vehicle is filled in cold environment and subsequently warms up. [14]

At the end of the technical design, proposed flow sheet for hydrogen production is drawn by using TRNSYS 17® (figure 1.6.) whereas application of this process to residential areas is sketched by using Google SketchUp 8®. (Figure 1.7 and figure 1.8)

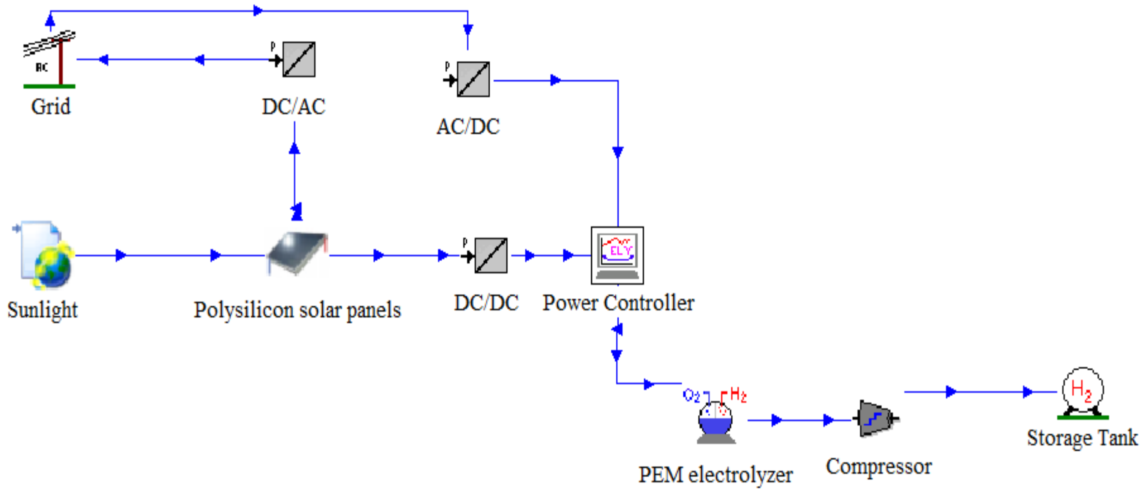

Figure 1.6: Representative flow sheet for proposed solar hydrogen production.

Figure 1.7: Typical residential home for solar hydrogen production

Figure 1.8: Hydrogen production unit for residential home. (Basic components are shown such as dispenser, electrolyzer, and compressor)

2. SAFETY ANALYSIS

Safety is one of the main considerations when designing hydrogen production unit for residential use. Even though, light and buoyant properties of hydrogen make it difficult to create high enough concentrations for combustion, the slightest safety hazard can strengthen the public prejudices about hydrogen fueling safety in contrast to gasoline usage. Therefore, compliance with codes and standards and analyzing failure modes to take preventive actions are vital for the design.

2.1. Code Compliance

First step in safety design is the code compliance. Current codes and standards for hydrogen production, piping, transportation and fire protection and maintenance are evaluated. Codes relevant to the hydrogen and standards for fire protection are shown on the Table 2.1 and 2.2. ([1],[2],[3])

Table 2.1: Complied codes and standards for H_2 production, transportation and storage

Association	Code	Description
CGA	G-5	Properties, manufacturing, transportation, storage and use of gaseous H2.
CGA	G-5.5	Hydrogen Vent Systems
NFPA	54	Fuel gas piping installation (Fuel gas code).
SAE	J2600	Compressed H2 vehicle fueling connection devices
ICC	International Fire Code	National standards in fire safety for new and existing buildings.
BSR/CSA	HV4.3	Temperature compensation devices for H2 dispensing systems.
	HV 4.4	Breakaway devices for H2 dispensing systems.
	HV 4.5	Priority and sequencing for H2 dispensing systems
	HV 4.6	High pressure manually operated valves for H2 dispensing systems
	HV 4.7	Automatic high pressure operated valves for H2 dispensing systems.
ISO	14687	Quality characteristics of H2 fuel
ISO/DIS	11119	Composite tanks for storing H2 at pressures up to 600bar.
	15916	Basic considerations for the safety of hydrogen systems
ASME	B31.1	Requirements for power and auxiliary service piping

	B31.3	Requirements for process piping
	B31.8	Gas Transmission & Distribution Piping Systems
	B31.9	Requirements for building services piping
NFPA	55	Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks

Table 2.2: Standards applied for fire protection

Standard	**System**
NFPA 10	Portable fire extinguishers
NFPA 11	Low, medium and high expansion foam systems
NFPA 25	Water based fire protection systems
NFPA 72	Fire alarm systems

2.2. Failure Mode Analysis

A Failure Mode and Effect Analysis is done on the system to identify most probable and hazardous failure risks involving hydrogen production storage and loading to vehicle. As a result following 3 failure modes are selected as having highest risk and mitigation procedures are selected.

2.2.1. Fire or combustion

H_2 burns in air with a pale blue, almost invisible flame while its flammability range of is around 4-74% by volume in air. Therefore, it poses a great risk in case of introduction of a flame. Preventive measures include hindering flame in production area and vehicle as much as possible. For instance, nozzles valves are opened only for fueling and kept closed for other times. To prevent ignition, smoking in the room should be prohibited as well as using any kind of lighter or match. In the equipment, infrared sensors can detect flame and close safety control valves. Also start-up and shut down automatic leak check is performed. In addition to those, spark- resistant coating on equipment is used in technical and storage equipment. External fire is also reduced by a pre-planned and exercised execution strategy with automatic inclusion of the fire department.

2.2.2. Failure in Equipment

Failures in equipment are highly frequent within the system components. They can be unexpected and highly hazardous, damaging both the equipment and furniture in the house as well as human health. To mitigate equipment failure risks, maintenance checks should be conducted regularly, reducing control sensors and certified emergency procedures should be acquired. In hydrogen exposed surfaces, stress-crackings which result in failures are highly frequent therefore, any cracks or scratchs should be closely monitored. Another possible equipment failure is power outrage as it can result in a loss of instrumentation and system control. In case of an electrical power outrage, gas release can take place. To prevent this, pressure relief valves should be designed to be fail closed type and without power requirement, so that an critical pressure variation can be controlled.

2.2.3. Natural Disasters

The most unexpected and difficult to prevent failure mode is the case of natural disasters. Even though the selected site is not a region of frequent earthquakes, still, regulations for earthquake resistant buildings should be applied. Safety procedures in case of an earthquake should be well learned. Also the control system should be designed in a manner such that, in case of an earthquake system should shut off without any hydrogen release to the surroundings.

3. ECONOMIC/BUSINESS PLAN ANALYSIS

Costs for all equipments (capital and installed) are listed below. These costs are calculated for 4 different regions which have different solar energy potentials, therefore different solar cell stack equipment necessities. Calculations were done by considering certain assumptions such as installment costs are taken as 35% of the capital cost and maintenance cost as 4% of fixed capital cost. [1]

Table 3.1: Capital and Installed Cost Analysis

	Capital Cost ($)				Installed Cost ($)			
Equipments	**Reg 1**	**Reg 2**	**Reg3**	**Reg 4**	**Reg 1**	**Reg 2**	**Reg 3**	**Reg 4**
Solar Cell Stack	61700	52000	48000	45000	83300	70200	64800	60700
Water Purifier	2000				2700			
Electrolyzer	75000				101000			
Gas Compressor	700				950			
Storage Tank	2750				3720			
Dispenser	25000				33750			
SUB-TOTAL	167150	157500	153450	150450	225400	212300	206900	202800
Marketing ($/unit)	1000[1]							
Maintenance (4% of Cap.Cost)					6686	6300	6138	6018
TOTAL COST					233000	220000	214000	209000

As utility, our system only requires electricity and water. Electricity is consumed by gas compressor and water purifier only. Water is the feed material for the system. Unit costs for water are obtained for 4 different regions again. Electricity cost is taken as the unit cost in Turkey. Table 3.2 shows annual and unit costs for utilities.

Table 3.2: Utility Costs for Residential Fuelling System

Utilities	**Price per Unit**				**Price per 1kg H_2 ($/kg H_2)**				**Annual price ($/yr)**			
Type	**R.1**	**R.2**	**R.3**	**R.4**	**R.1**	**R.2**	**R.3**	**R.4**	**R.1**	**R.2**	**R.3**	**R.4**
Water ($/m^3)	2.42	1.75	2.34	1.55	0.018	0.009	0.013	0.008	4.9	3.4	4.7	3.1
Electricity ($/kWh)	0.12				0.17				60			
TOTAL:					0.19	0.18	0.18	0.18	65	63	65	63

[1] This is the predicted value for marketing per one unit system sales.

Cost per kg of hydrogen is calculated using the necessary expenditures annually for the operation of the electrolyzer system. It can be clearly seen that annual operation costs are really low compared to the value of the product.

Table 3.3: Unit Product Cost in terms of Operating Costs

Region	**Electricity Cost ($/yr)**	**Water Cost ($/yr)**	**Maintenance Cost ($/yr)**	**H_2 production rate (kg/yr)**	**Product Unit Cost ($/kg)**
1	60	4.9	270	292	**1.15**
2	60	3.4	250	292	**1.07**
3	60	4.7	250	292	**1.08**
4	60	3.1	240	292	**1.04**

When comparing the hydrogen vehicle with the conventional gasoline one, it is assumed that they both have the same annual mileage of 12000 miles/year. Unit gasoline price is taken as 4 TL[2]/lt which is equivalent of 9.8 $/gal.

Table 3.4: Specifications of Gasoline and Hydrogen Cars

Parameter	**Value**
Annual Mileage	12000 miles
Daily Commute	35 miles total
Fuel Economy (for H_2 vehicle)	**44 miles / kg**
Fuel Economy (for gasoline car)	**32.6 miles / gallon**

According to table 3.4 which gives parameters of the hydrogen and gasoline cars, annual fuel costs are shown in the table 3.5.

Table 3.5 shows that annually 3300 $ (average for 4 regions) can be saved by using a hydrogen fuelled car instead of using conventional car. The drawback is that the capital costs are much more higher; therefore it requires unrealistic time periods to make the hydrogen fuelling system investment feasible.

[2] TL*: Turkish Lira

Table 3.5: Comparison between Gasoline and Hydrogen Vehicle

Fuel Type	Amount Needed	Unit Price	Annual Fuel Cost ($/yr)	Difference ($/yr)
Gasoline	1393 L	2.58 $/L [3]	3594	
Hydrogen	273 kg	1.15 $/kg	315	3280
		1.07 $/kg	290	3305
		1.08 $/kg	295	3300
		1.04 $/kg	285	3310

Table 3.6 shows the results for two different regions which have the highest (Region 1) and lowest (Region 4) capital investments. System life can be considered as the maximum time that hydrogen fueling system could operate in a continuous manner. It can be clearly seen that as system life increases, hydrogen cost per kg is decreasing down to 29,8 $/kg. These selected regions differ from each other in terms of their solar energy potential. Region 1 requires more area for solar panels and that increases the capital investment, therefore the hydrogen price per kg produced.

Table 3.6: Hydrogen Price Analysis for different system life estimations

System Life (years)		Fixed Capital Investment ($)	Annual Costs ($)	Total Cost ($)	Total Hydrogen Production (kg)	Hydrogen Price ($/kg)
Region 1	25	233000	8375	241400	7300	**33.1**
	15	233000	5025	238000	4380	54.3
	10	233000	3350	236300	2920	80.9
	5	233000	1675	234700	1460	160.7
Region 4	25	209000	8375	217400	7300	**29.8**
	15	209000	5025	214000	4380	48.9
	10	209000	3350	212400	2920	72.7
	5	209000	1675	210700	1460	144.3

We planned to put 8% of a profit rate for the sales of the system. Setting up such a low profit rate is has several reasons. Firstly, it is an expensive system compared to the conventional fueling, however it is more environmental-friendly and cost effective when the future petroleum

[3] Unit price of gasoline in Turkey

prices and system life is considered. Also, unit product costs are very low since the solar energy provides necessary electricity for the system. Secondly, this system is a new technology and does not have a considerable demand in the market. Therefore, it is wiser to choose lower profit rates in order to increase the public awareness about the benefits of the system (Table 3.8). When this awareness combined with technological advances is provided, it could be a good alternative to increase profit rate considering increasing sales number.

Table 3.7: Final marketing prices for residential hydrogen fueling system

Regions	**Sales Price ($)**
Istanbul (1)	250000
Ankara (2)	235000
Adana (3)	230000
Antalya (4)	225000

Table 3.8: Advertisement cost that will be spent for raising public awareness

	Numbers	**Cost ($)**
Posters	1000	1000 x .5 = 500
Brochures	10000	10000 x 0.05 = 500
Commercial (TV, Radio, Bilboards, etc.)		5000
Rental Mobile Led Truck	1 Truck for 30 days	30 x 100 = 3000
Mobile Open House	1	12000
Educative Seminars	5	5 x 500 = 2500
TOTAL		23500

3.1. Projections for market growth for residential fueling system in Turkey

Hydrogen as energy carrier is new technology for Turkey. Since supports by government and private sector to hydrogen technologies are limited, this future technology is progressing under politic, social and industrial restrictions. Nevertheless, projections done in International Energy Outlook 2010 shows that world marketed energy use increases in near future. This expectation brings that future energy diversification will become more important since oil prices affect the daily life of Turkish people directly.

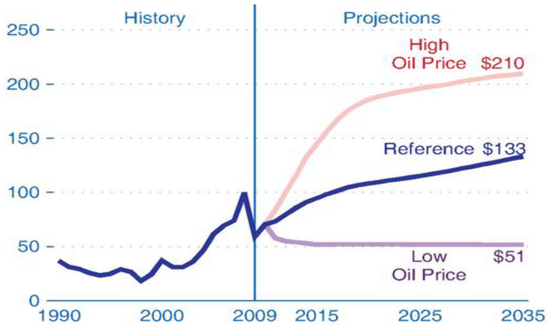

Figure 3.1: 3 future scenario for oil prices up to 2035 [2]

Cases shown in figure 3 suggest that high oil prices are more expected than low ones. Therefore, especially countries like Turkey which is the world most expensive fuel consumer will be deeply affected from high costs and people will start to look another way to consume energy. Residential hydrogen fueling system offers new solution for diversifying energy intensity. Although Turkish people don't even hear this system now, expected high oil prices and the idea that producing your own fuel for your own car will be encourage the people to buy hydrogen fueling systems for their home; that is, in near future Turkey will be a potential market for hydrogen fueled cars and their fueling system applications. In figure 3.2, gasoline price increase in Turkey is easily seen with their trendlines which suggest that gasoline prices will be continuously increase to 10.9$/gal[4] gasoline in 2012. In 2035, gasoline prices is predicted as 14.6$/gal[3] for reference case and 23$/gal[3] for high oil price case those of which strengths the idea of applications of hydrogen fueling system for residential buildings in Turkey.

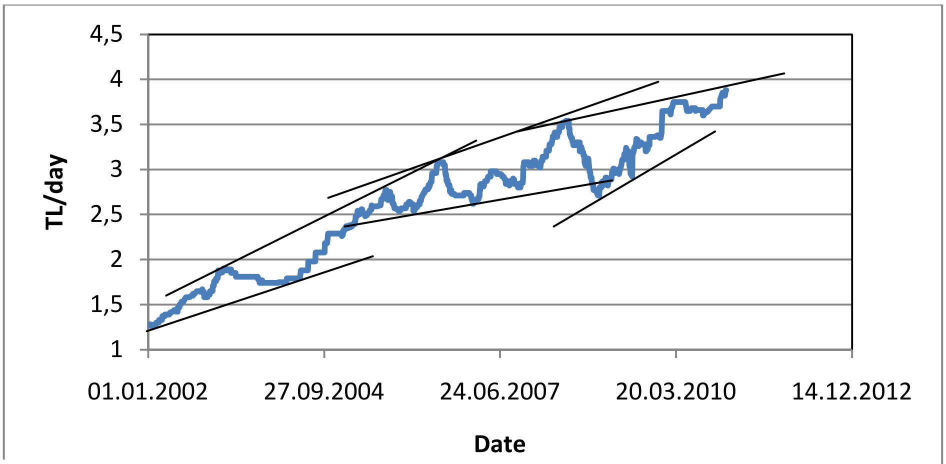

Figure 3.2: Gasoline prices sold in Turkey up to Dec 12,2010. [3]

[4] Exchange rate for dollar is taken as 1$=1.5TL.

4. ENVIRONMENTAL ANALYSIS

All kinds of design processes in all fields require a detailed environmental examination in today's world. No matter how profitable your process, if it does not involve environmental concerns it could not proceed in long term. Producing hydrogen by using solar power in a residence and using it for transportation purposes are examined with environmental point of view.

There will be four parts of system directly placed on/in or next to the resident. First part is the solar panels converting energy coming from sun to electricity. These panels are made of inorganic materials and metals. They do not contain any material which is harmful for human, animal or plant. During the process, they do not release any gas, liquid or solid waste to the surrounding. Furthermore, they are %99 recycling material. Second part is the production of hydrogen in electrolyzer. This process takes pure water and electricity as input and gives oxygen and hydrogen as output. There is no combustion and there is no CO_2, CO, NOx or SOx release during production. Catalysts used in electrolyzer have no negative effect on the health of people living in that house. Third part is the storage of produced hydrogen and there will be a tank which is made of a special material for this purpose. This tank connected to a compressor which may create little noise but when the scale is considered this seems much less than dangerous levels. Last part is the loading station of hydrogen to vehicles. This part is just transition and has no impact on surrounding. If there is any failure at any point of process, system will still be safe for nature. The only possible release can be hydrogen because of a leakage. Hydrogen is the lightest gas in nature and it rapidly rises in atmosphere and forms water vapor. Therefore, no air pollution can be foreseen accordingly.

When whole system is considered in unity, process takes sunlight, water and electricity; gives oxygen and hydrogen. There are many alternatives of producing hydrogen by using fossil fuels; however, they are all based on combustion of hydrocarbons so that CO_2, CO, NOx, SOx release to nature is inevitable. Steam methane reformers are commonly used to produce hydrogen. They have moderate level of greenhouse gas emissions when compared other fossil fuels such as coal and gasoline. Vehicles using gasoline and diesel also have same disadvantage. When hydrogen is started to use as energy source, not only the air pollution will decrease in great extent but also efficiency of cars will increase extremely since combustion engines lost most of the energy due to combustion and heats atmosphere. Some methods like electrolysis using electricity instead of fossil fuels to produce hydrogen are also contributes

CO_2 release indirectly. The electricity taken from city lines may cause some dangerous gas formation during production.

Figure 4: Proposed process is 100% environmentally friendly [1]

Designed process is %100 greenhouse gases free, and has no contribution to global warming. (Figure 4) There is no direct or indirect contamination of air, water or soil neither during production nor using hydrogen as fuel. The system proposed is ‘planet friendly’ with all steps and offers a clean energy alternative for future.

5. MARKETING AND EDUCATION PLAN

5.1. Marketing Objective

As having a comprehensive, sophisticated and difficult essence the target group of this hydrogen technology will definitely experience difficulty in understanding the nature and advantages of using this system. Thus, one of the major considerations of this project should be to stress upon the ways to communicate, in other words market, this technology as plainly and understandably as possible so that the target group can acknowledge the features of this technology, see the advantages of its use and as a result of these become persuaded to take action and use this system at their houses to produce their own fuels. Also, hydrogen technology is generally considered as being unsafe, which will certainly make the consumers reluctant to purchase this system. With an effective marketing plan, this fear can also be overcome and the reliability of the system can be emphasized. Thus, the marketing plan of this project is an essential step for the acceptance of this hydrogen technology by the target group.

5.2. Target Group

Since this hydrogen technology is a system that will be installed to apartments, houses, and similar residential areas, and the households will benefit from this technology as a whole, the target group of this technology can be considered as the typical, moderate, Turkish core family, that will have little or no knowledge about such a system and thus, will approach to it suspiciously.

5.3. Marketing Approaches & Plans

With such a target group we believe that an experiential and educative approach (figure 5), meaning both letting them experience the system with their senses and receiving detailed information about the system prior to purchase. To actualize this aim, first, we decided to determine a pilot family that possesses the characteristics of our target household group and that is willing to purchase this system. In order to demonstrate the advantages of having this system at their home, this family will also have an automobile that runs by hydrogen fuel. The experiences that the family will have with this system will be observed, recorded and used as a marketing tool. For instance, the reasons why they decided to purchase this system, the advantages that they see in this system (like; its cleanness, how it protects the environment, how it leaves a clean world to the future generations, why it is safe to have such a technology at their houses, etc.) will be asked to the family members and their answers will be recorded in the presence of a notary public, so that it will be reliable and trustable in the eyes of the target group. It is important to stress the reliability of marketing tools when the product at hand is such complicated.

Figure 5.1: One example of clean energy education kit. [1]

In addition to this, for the people to come and see the system with their own eyes, mobile open houses and mobile trucks with this system installed will be used. The dates and locations of these will be announced to public via mass media tools like televisions, radios, billboards, etc. By this, the potential buyers of this system will have the chance to see the structure of the system personally, and also ask any question about the system that comes to their mind to the informed people that will be present at these points which can be considered as a much better way to persuade potential customers than the mass media tools.

The spread of the use of automobiles that run by hydrogen fuel is essential for the success of this technology. Therefore, an experiential activity with this kind of automobiles can also be beneficial for the marketing of this technology. For that, free test drives with these automobiles where the people interested can also be briefed about the benefits of using hydrogen fuel can be organized.

In order to stress one of the most important advantages of this technology; the fact that it does not harm the nature and thus leaves the future generations a clean environment, it will be beneficial to support this project with a social responsibility campaign which will definitely serve as a marketing tool as well. For that, we decided to determine a region to start foresting and plant one sapling for each family who purchases this technology. With this, the families that purchased this system will contribute to the protection of nature not only by using clean technology as fuel but also contributing to the forestation of a region.

As stated earlier, the informative aspect of the used marketing approaches is crucial for the acceptance of this system, especially for overcoming the fear in the minds of people about having such a system at their houses. Thus, we believe, organizing educative seminars given by experts of this technology will definitely contribute positively for creating a safety notion in the minds of potential consumers. In order to reach as much people as possible, we consider the shopping malls as the perfect locations to organize these seminars. By that, not only the people that will consciously come to listen to the seminar, but also the people passing by just to wander in the malls will be educated about this technology.

Finally, we are also planning to use the mass media tools; TV ads, billboard ads, newspaper ads, and etc. Even though we believe the marketing plans that we explained earlier will definitely be more effective in creating acceptance and persuading the potential customers, they are generally directed to people who are willing to participate in such activities. For the consumers who are reluctant to take action, the use of media tools that “reach” them in their houses becomes crucial. Thus, efficient and effective use of these tools will certainly contribute to our marketing aims.

Figure 5.2: One of advertisement options for hydrogen production from solar systems

Figure 5.3: One of billboard options for hydrogen production from solar systems

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APPENDIX 1:

Technical Specification of HOGEN® S40 [1]

Hydrogen Production	
Nm^3/h at 0°C, 1 bar	1.05 Nm^3/h
kg per 24 hours	4.31/24 hours
Delivery Pressure	14 barg (30 bar option)
Power consumed per volume of H_2 Gas Produced	6.7 kWh/Nm^3
Purity	99.9995 %
DI Water Requirement	
Rate at Max Consumption Rate	0.94 L/h
Temperature	5 to 35°C
Pressure	1.5 to 4 barg
Enclosure Characteristics	
Dimensions (W x D x H)	97 cm x 114 cm x 132 cm
Heat Load and Coolant Requirement	
Cooling	Air-cooled
Heat Load from System	4.3kW Max.
Coolant	Ambient Air, 5°C to 40°C
Electrical Specification	
Recommended Breaker Rating	12 kVA
Electrical Specification	105 to 240 VAC, single phase, 50 or 60 Hz

APPENDIX 2:

Technical specifications of a stand-alone version dispenser from H2 Logic company. [2]

Maximum Design Pressure	350bar / 450bar or 875bar
Filling Pressure	250bar / 350bar or 700bar
Dimensions (Width X Depth X Height)	800mm x 550mm x 1850mm
Media operation temperature:	-40ºC to +85ºC
Ambient temperature Range:	-20ºC to +65ºC
Minimum- maximum flow meter rate	0.1kg /min – 3kg/min
Ex-identification	For hazard installation Zone 1+2 (ATEX)
Directives and Standards	CE marked, ATEX, PED, EMC
Refuelling Nozzle options	Tk4 / Tk16 / TK17 (optional communication)
Materials	Stainless steel, white paint, corrosion class 4H
Refuelling control system	Integrated
Weight:	95 kg
IP class:	IP 66
Hose length:	Approx. 2m
Safety features:	Break away and H2 detector
Other/options	Optional precise flow measurement of refuelled hydrogen with Coriolis mass flow metering principle
	Optional temperature compensated refuelling ensuring complete fill of vehicle
	Optional hydrogen priority sequencing panel for controlling flow to/from high pressure storage
	Optional high pressure storage (200-1000 bar) with flexible storage capacity
	Optional online monitoring & surveillance control system: HMI display interface (Onsite/Remote) / Webscada Customized program interface. Remote administration support available
	Exterior packaging & design: White or grey painting with customer specified graphics. Uniquely designed roofing available for outside placement of stand-alone dispenser.
	Optional handling of installation & authority approval process
	Optional full service contract