Design concept of a hydrogen filling system

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Abstract— *The rising costs of fossil fuels, particularly oil and declining reserves point to a growing need to find alternative possibilities for public and private transport. Currently, hydrogen appears to be a promising fuel. Production of hydrogen by electrolysis of water guarantees ecological purity and a positive impact on the environment. The mass application of hydrogen as a transport fuel is prevented by the lack of infrastructure, the construction of which requires a large initial investment. Despite this, there is growing pressure on car manufacturers that must respond to market demand if they want to be able to compete. The present article discusses the design of a hydrogen pump system based on the production of hydrogen by electrolysis of water, using photovoltaic panels as a primary source of electrical energy.*

Keywords— hydrogen, hydrogen technology, design, filling station.

I. INTRODUCTION

The dependence of mankind on fossil fuels today is enormous and has the effect of drastically reducing the reserves of them. In the next few decades, society may reach the point where the volume of these sources reaches a critical point and demand greatly exceeds production. It is therefore necessary to seek possible alternatives that would be able to fully replace fuel which we cannot rely upon in the future will not be counted. Another reason to consider new sources is the significant negative impact of fossil fuels on the environment.

One possibility, which might possibly act as a substitute for oil and natural gas is the use of hydrogen. Hydrogen as a fuel has enormous potential. As regards relative calorific value per unit of mass, hydrogen exceeds oil in the ratio of 3:1, which gives it very good properties for application in a wide range of economic sectors such as energy or transport.

The use of hydrogen to power cars is not new. A large number of car manufacturers have experimented with such types of power for many years. During that time, the technology has crystallized at such a level that they can, in terms of range, fully compete with the internal combustion engine but despite this, the technology is used only very rarely. What prevents it becoming widespread is very poor infrastructure. If there was at least partial replacement of conventional fuels with hydrogen, there would be a need to perfect existing technology to a level able to meet the overall demand that could theoretically arise from a reduction in the production of fuels from conventional sources. It will also be necessary to build an extensive network of filling stations, which are capable of continuously supplying hydrogen to vehicles along their entire route, as is the case today at filling stations for petrol or diesel.

II. FILLING STATION FOR GASEOUS HYDROGEN

The hydrogen system must be designed, manufactured and tested in accordance with national guidelines for pressure tanks and piping systems, as well as in accordance with relevant legislation. Equipment and systems, where necessary, be earthed and secured so as to provide protection against the danger of stray electric currents and static electricity.

Hydrogen systems can be installed either outdoors or inside buildings, but they must be located so as to be readily available for distribution vehicles, fire-fighting equipment, and to ensure the means for personnel to escape in an emergency. They must not be placed under high voltage lines. The distance must be considered to other technologies or buildings that include production facilities which could potentially cause fire or explosion. Adequate measures in this case may increase the safety margin. It is necessary to take protective measures, such as security barriers and fences, so that the facility is permanently protected against tampering.

A hydrogen filling station is a device in which hydrogen in gaseous form and under pressure from the compressor system moves to various cylinders, or lines connected to arrays of them, and is then selectively transported from the container to an automobile. The filling system includes storage tanks, connecting pipes, filling manifolds, hoses, valves, control systems, analytical equipment, vacuum pumps and a fuel dispenser.

The system of storing gaseous hydrogen contains fixed tanks (pressure vessels or arrays of pressure vessels), pressure regulators, safety (pressurized) devices, distributors and interconnecting piping and controls. Commonly used pressure vessels are primarily high pressure, but it is possible through multistage compression to select a combination of low and high-pressure tanks.

Hydrogen stations are considered particularly risky in terms of fire and explosion hazard. The degree of risk is also affected by the type of wiring. Electrical installations must be such that during operation there is no sparking, formation of arcs or increase in temperature. Electrical equipment should be earthed and placed in the lower parts of the facility. It is necessary is to install lightning rods on the roof of facility. All of the power supply shall be continuously and effectively earthed to provide protection against the danger of stray electric currents or static electricity. If the electrical equipment is located outside the danger zone it is possible to use standard electrical equipment.

Before starting the operation of the station it is necessary to perform a series of tests in accordance with the REGULATION OF THE EUROPEAN PARLIAMENT AND COUNCIL (EC) no. 79/2009 dated 14 January 2009 on the type-approval of motor vehicles using hydrogen, amending Council Directive 2007/46/EC, which establishes requirements for the type-approval of hydrogen powered vehicles, the type-approval of hydrogen components and hydrogen systems.

After the tests it is necessary to suck out the oxygen from the system. This can be done by vacuuming, if the rigidity of the system permits, or by flushing the system with an inert gas (e.g. N2). There follows a check, which must verify that the oxygen content is below 1%.

After performing tests checking control elements and safety devices, the system is ready to run hydrogen operations in accordance with operating instructions. After running further tests for leaks should be carried out in order to ensure the tightness of components in the operating mode. Each system must contain detailed operating instructions including relevant technical information in a comprehensible form.

III. PROPOSED DESIGN OF A HYDROGEN FILLING STATION

At the present time, most hydrogen filling stations currently operate on the principle of continuous replenishment of large-scale store of hydrogen in the vicinity of the station meaning that the station is totally dependent on external supply of hydrogen.

The proposed design is based on integration of a hydrogen-manufacturing unit with a filling station. In this way the station gains a certain independence from external sources. Electricity required for the electrolysis will also be acquired from renewable technologies through photovoltaic panels.

The filling station consists of 2 main sections:

Electrical section:
- operational part
- production of electrical energy

Technological section:
- low pressure part
- high pressure part

1 – METAL-HYBRID VESSEL, 2 – COMPRESSOR, 3- HIGH PRESSURE VESSEL, 4 – HEAT EXCHANGER, 5- FUEL DISPENSER

FIG. 1 SIMPLIFIED SCHEMA OF A FILLING SYSTEM

Each of the sections has an irreplaceable role of the overall system. Figure 16 shows a simple schematic illustration of the process. For hydrogen to achieve its required characteristics that are essential for fuelling the vehicle it must pass through a system of technological equipment (cleaning, cooling, compression).

Since hydrogen is highly reactive gas, it is necessary to design such a facility to include safety features that reduce the risks to a minimum. All electrical equipment installed in the technology section must comply with the ATEX Directive (hazardous areas). With regard to the materials used, they must be sufficiently resistant and meet strict standards so that they do not degrade during service.

The most suitable choice for such a facility is known as “container design”, due to its compactness. The components that have the most substantial impact on the performance of the entire station must allow sufficient space for the modular solution. This means that if, for example, the electrolyser is swapped for a model twice as big, there should be enough space around it to do it. The design therefore considers space reserves for possible exchanges for other equipment. The design of the metal hydride storage tanks and compressors is such that when it is required to increase capacity with other components they can be stacked to a height. The vessel design is also advantageous for the reason that for much larger performance the container units can be combined into a larger whole. An essential part of the operation is to use detonation walls or a ceiling anchored so that in the event of explosion the explosion energy is released through them.

An integral part of the electrolyser and also gas analyser is the HVAC. The outlet leads through the left wall of the container. Each ventilated device has a separate outlet, i.e. the ventilation air is collected back into one line. The electrolyser ventilation outlet must be sufficiently far away because it creates Ex zone within a radius of 1 meter (ball) from the link. The air intake (located on the bottom right side of the container) contains controllable louver to aid in cooling air cell. This is so that in winter the cold air from outside has the possibility to be mixed with the air within the container before it enters the cell. This is done as far away as possible from it so that the airflow does not freeze sensitive components. The exhaust of air is provided by ATEX fans with an external aperture to protect against rain. It is envisaged to automatically trigger it if there is an observed increase in the hydrogen content in the container or if the internal temperature exceeds 40 °C. Since hydrogen is light and rises up, the most appropriate place to install it is in the upper part of the container.

At outside temperatures below 0 °C, or during the decommissioning of the whole technology, it is necessary to heat the entire container to stop it freezing. Heating in the form of an electric radiator is considered. This is a device in ATEX version. It is located on the ceiling of the technological part of the container.

Lighting various parts of the container (if necessary) is proposed with a trio of LED lights in ATEX version, which are switching at the operational part of the container by the electrical switchboard.

The floor of the container is made of a conductive material. It is unacceptable to have anything that would isolate the operator from the ground (floor mats, carpets, etc.) because of the risk of electrostatic charges, which can lead to an explosion in the greater concentration of hydrogen.

Between the operational and technological parts are explosion proof fire doors. The main entrance is designed with massive double doors. The entrance and internal doors in ATEX environments always open in the direction out of the room.

In any such facility it is necessary to take account of the potential imposition of routes of pipelines. It is necessary to know what, with what and how it should be linked. Interconnection is realized through pipes made of stainless steel. The oxygen outlet of the devices is also in the form of stainless steel pipe and the outlet is implemented at an approx distance of 1 m from the wall of the container. Pipelines lead along the ceiling and inner walls of the container. The pipes are fitted so as to keep to the minimum possible distance from cable routes (distance min. 5 cm).

Major cable channels leading through the ceiling of the container and around the inner walls of the devices have (electrical connection, connection of sensors). Another option is the installation of cable harnesses in underground gutters that are covered with grates. If desired, the tray may be lifted to provide direct access to the harness. Linking individual rooms of the container (electrical and technology parts) is implemented using reducers that are intended for ATEX environments. The power cable from the distribution network is fed into the container at the inlet (in the ground). The ideal would be to cable the container before installing individual components. This solution is advantageous in that the components are connected in place only by linking the connectors.

3.1 Production of electrical energy

The electrical and operating parts of the station are located in the front part of the container. From the technological part they are separated by a partition with fire doors, so that the risk of ignition as low as possible.

The station is capable of a certain proportion of electricity consumption from own resources. In our case, solar panels mounted on the roof of the container ideally cover the total consumption of the electrolyser. Other electrical components (compressors, lighting, cooling, heating, etc.) Are supplied from the distribution network. If we desire total independence from external sources of electrical energy it would be necessary to install photovoltaic panels also in the area around the filling station.

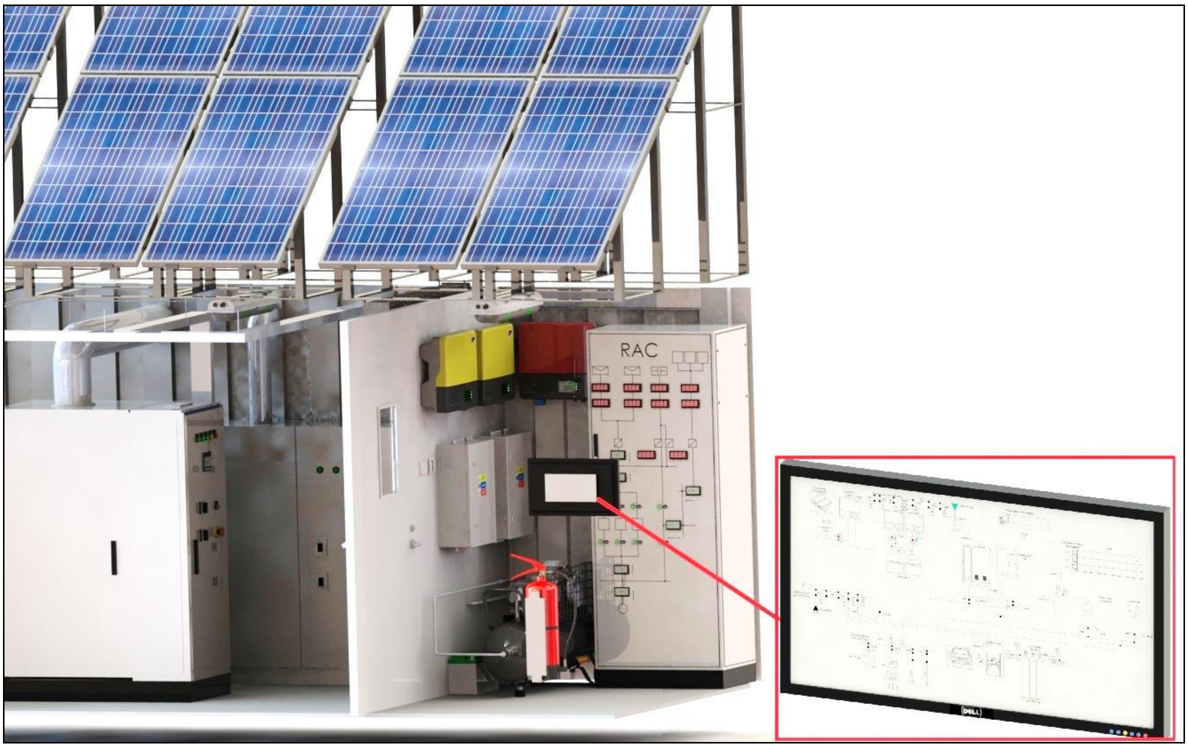


FIG. 2 ELECTRICAL PART OF THE HYDROGEN FILLING SYSTEM

3.2 Low pressure part of the hydrogen filling system

The basic part of a technological section is the electrolyser. In it, demineralised water is split into two-atom molecules of hydrogen (H2) and oxygen (O2). The actual device is located in the central portion of the container. This is an alkaline electrolyser. Water supplied to the device must be adjusted to the required quality, so the system includes a deioniser. During its operation the cell generates heat, so cooling is required. The water cooler for the electrolytic cell is fitted within the container. The operating time of the cooler will be approximately half the running time for the electrolyser, considering that the cooler is turned off when the desired temperature is reached. The system then works without cooling, but after regaining critical temperature (approx. 82 °C) the cooler is again put into operation. At higher power and therefore demand for cooling it will be necessary to install an additional air cooler on the roof of the container.

The hydrogen outlet from the electrolyser is in the form of two stainless steel pipes. One goes in goes to the gas analyser and the second to the metal hydride tanks. The gas analyser is a device that examines whether the hydrogen produced is sufficient quality.

Before entering the high pressure part the manufactured hydrogen is stored in metal hydride tanks. They are stored along the side wall of the container. Two connection possibilities are considered. The first option allows synchronous operation as an electrolytic cell as well as a booster because the individual vessels are separated such that one container can supply the booster and the other can take hydrogen from the electrolytic cell. The disadvantage is the difficulty of control and thermal management. The second option is much simpler compared to the first. It does not offer the option of dual running of both key components, but given that the containers are filled evenly it is not (for us) necessary to have an additional cooler.

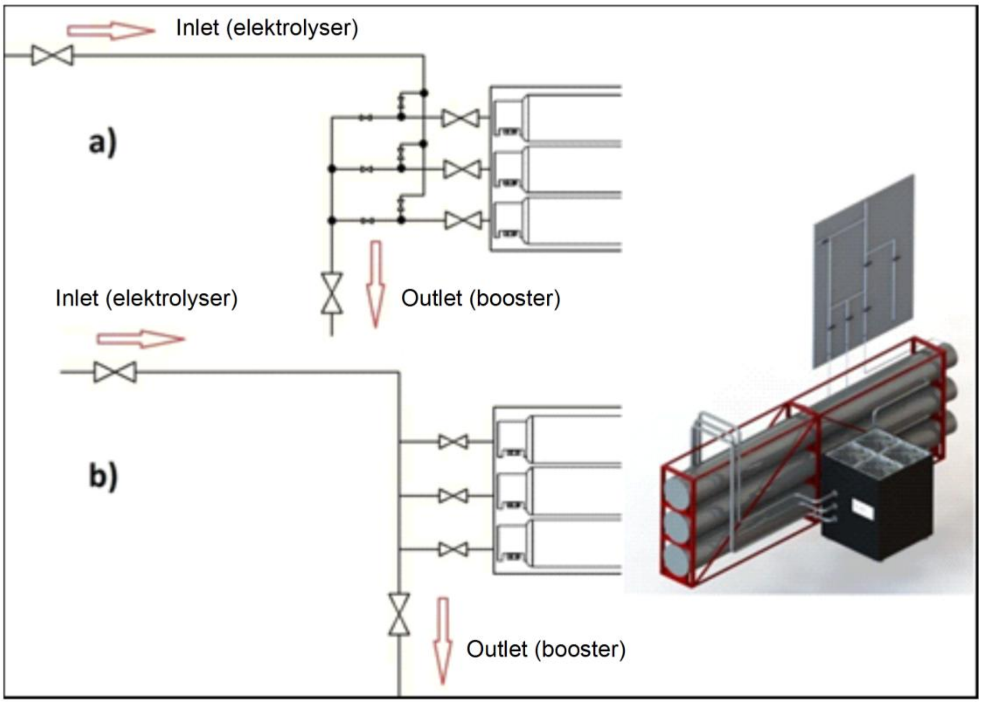
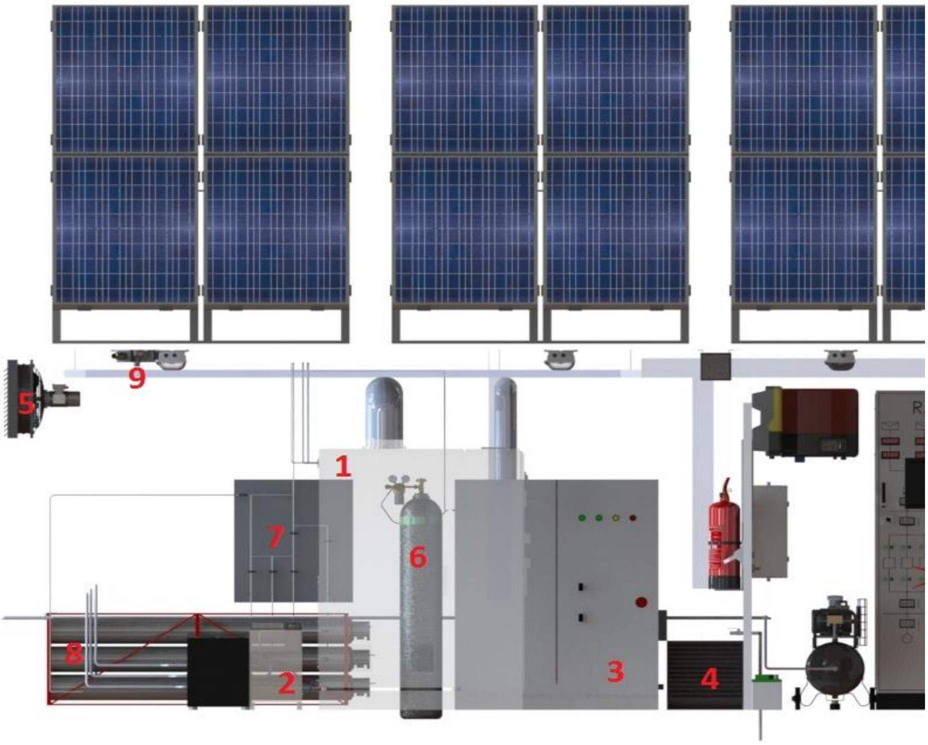


FIG. 3 POSSIBILITY OF CONNECTING A METAL-HYDRIDE VESSEL

Hydrogen stored in this way is ready for the next technological section. When emptying the metal hydride, in contrast to when it is filled, there is a fall in temperature in the vessel. This fall can be used e.g. to cool recently filled vessels. The coolant is the water circulating in the jacket of the MH container.



1 – ELECTROLYSER, 2 – COOLANT, 3 – ANALYSER, 4 – AIR INLET, 5 – VENTILATION, 6 – NITROGEN CYLINDER, 7 –DISTRIBUTION PIPING, 8 – METAL-HYDRIDE VESSEL, 9 – HYDROGEN DETECTOR

FIG. 4 ARRANGEMENT OF LOW-PRESSURE PARTS OF THE HYDROGEN FILLING SYSTEM

3.3 High pressure part of the hydrogen filling system

This is the most critical section of the whole filling station, because it's here that hydrogen is compressed to extremely high pressures. The operating pressure in the cars of today is in the range 350-700 bar, but the filling pressure has to be even slightly higher (e.g. if the design pressure is 700 bar to fill a volume of 1 m3 of storage it must be at least 800 bars). When compressing to such a high value, considering our performance the most optimal solution pair of two-stage boosters connected in series. In this way, it is possible effectively to correct the temperature rise during compression.

Hydrogen from the metal hydride vessel is sucked into the inlet chamber of the first boosters, which leads to the first level of compression. Then, the compressed medium leaves the chamber, and passes through an intercooler to the next step. The compressors are connected to each other directly. The drive of the booster is provided by an electrical compressor with air tank, located in the electrical part of the container. Heated air is withdrawn from the system via a short pipe, the mouth of which is outside the container. The air compressor must be powerful enough to provide sufficient airflow to drive the hydrogen compressor. At a pressure of 800 bar, the outlet of the flow of the booster is 150 l/min. To achieve these parameters requires an air compressor with a flow of 1200 l/min.

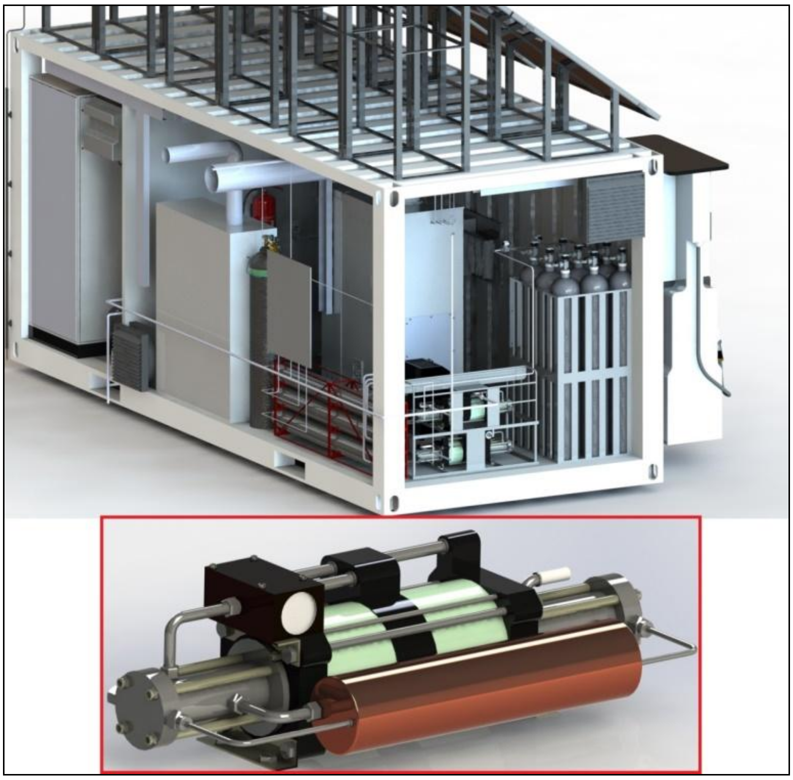


FIG. 5 FURTHER COMPRESSION - BOOSTER

With such high pressures we can consider only storage in a pressurized container with a composite layer. The bottles are combined into a single unit (volume) and mounted in a safety cage. Filling is through the dispenser (fuel dispenser) and performed by the pressure difference between the source container and container in the car. Therefore, the source container requires a slightly higher pressure. Refuelling takes place through an expansion valve. If there were a requirement to shortening the charge time, it would be necessary to radically supercool the hydrogen to cause a change in density and thus increase the flow rate of gas (e.g. the supercooling from 85 °C to 10 °C would accelerate the flow by 30%). In such a case, the system compressor would require a cooling device.

3.4 Fuel dispenser

The dispenser is a device that is an essential part of every filling station. It creates a stable connection between the pressure tank and the car. It allows one to safely refuel hydrogen vehicles a speeds of up to 60 g/s. It is protected from rain and weather by a roof, the length of which is large enough to protect both the dispenser and car when refuelling. It is protected from mechanical damage by its steel structure (preventive measure against the potential impact of a car).

FIG. 6 FUEL DISPENSER

3.5 Visualization of a hydrogen filling system

The following part shows the individual parts of a hydrogen filling system in several versions.

FIG. 7 VIEW OF THE TECHNOLOGICAL PART OF A HYDROGEN FILLING SYSTEM

FIG. 8 SINGLE CONTAINER VERSION OF A HYDROGEN FILLING SYSTEM

FIG. 9 MULTI-CONTAINER VERSION OF A HYDROGEN FILLING SYSTEM

IV. CONCLUSION

The design concept consists of three main parts. The first part includes facilities for generating electricity using photovoltaic panels. The concept was included on the grounds that it means the hydrogen can be fully classified as a clean energy source. Given the dimensions of the panel the ideal solution was to mount them on the roof of the container.

The uniqueness of the station lies in the fact that it is able to produce the required amount of hydrogen. This happens in the second part. The low-pressure section contains, in addition to the electrolytic cell and other components, for example the analyser, the H2 detector, and the deioniser etc., necessary for effective and especially safe operation. The produced hydrogen is gradually stored in MH vessels and after the required amount is ready it is sent to a section in which it is the compressed to the desired pressure. This happens in the third, high-pressure zone. The central components are the two hydrogen boosters connected in series and high-pressure vessels, which allow storage of hydrogen under extreme pressure.

The base for the technology has been chosen as a 20ft cargo container that due to its compactness and high levels of mobility is ideal for housing the entire system. The container, unlike a standard version, has several modifications, such as openings for ventilation, cable trays, a bulkhead dividing the electrical part from the other technology as well as a lightning rod and a safety design protecting the fuel dispenser from the weather and mechanical damage.

Part of the concept is setting out suitable routes for hydrogen and air ducts, electrical wiring and water supply, the design of the general arrangement of key components within the container design, as well as a basic wiring diagram of the operation of the station, starting with the production of electricity up to the filling of the automobile.

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