SAFETY STRATEGY FOR THE FIRST DEPLOYMENT OF A HYDROGEN-BASED GREEN PUBLIC BUILDING IN FRANCE

Verbecke F.[1], Vesy B[2].
[1] Quality, Health, Environment and Safety Department, HELION - AREVA Group, Domaine du Petit Arbois - BP71, 13545 AIX EN PROVENCE CEDEX 04, franck.verbecke@areva.com
[2] Quality, Health, Environment and Safety Department, HELION - AREVA Group, Domaine du Petit Arbois - BP71, 13545 AIX EN PROVENCE CEDEX 04, benoit.vesy@areva.com

ABSTRACT

In the context of the project JANUS, HELION, a subsidiary of AREVA and in charge of the business unit Hydrogen and energy storage, is deploying for the first time in a French public building, a hydrogen-based energy storage system i.e. the Greenergy Box™. The 50 kWe system is coupled with a photovoltaic farm to ensure not only up to 45% electrical autonomy but also power backup solution to the building. The safety strategy and sitting measures of the complete hydrogen chain are described in the paper. The work realized with the Fire Authorities and Public to gain the acceptance of the project is highlighted in the paper.

1.0 INTRODUCTION

The future belongs to Renewable Energy Sources (RES), and satisfying the energy growing demand for sustainable energy sources must be one of the highest priorities for research in the energy field. Four main electricity storage applications can be distinguished for RES management:

- Load leveling – to allow to smooth the RES power plant output (Figure 1 left).
- Time shifting – to store electricity during low demand periods and feed in the grid when demand is high and/or electricity prices high.
- Forecast optimization uses the storage system as a buffer enabling a real-time RES production as scheduled – for example in PV or wind 24 hours' forecasts (Figure 1 right).
- Grid stabilization and system services: storage systems based on hydrogen can act as secondary and tertiary reserves for grid frequency and voltage regulation

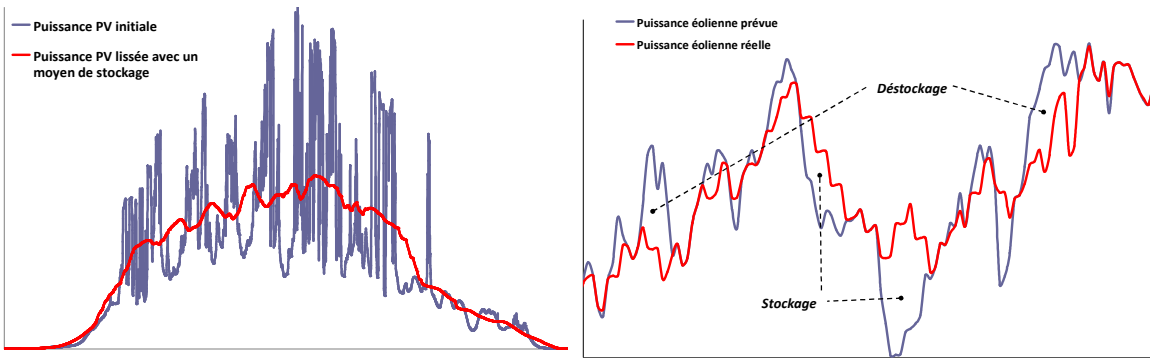

Figure 1: Storage system allows to smooth the RES power plant output (Left); Forecast optimization uses the storage system as a buffer enabling a real-time RES production as scheduled – for example in 24 hours forecasts (Right).

Hydrogen presents many advantages for storage of the RES, in particular:

- PEM electrolyser are suitable for high dynamics from RES e.g. wind and photovoltaic;
- High pressure electrolysis i.e. 35 to 50 bar allows the production of gaseous hydrogen and oxygen without further compression stage which implies lower investment costs and higher simplicity of the system;
- H2 and O2 are both stored and used to produce electricity back in an H2/O2 fuel cell;
- O2/H2 fuel cells are air independent system and present a better output compared to Air/H2 fuel cells
- Carbon free electricity production without toxic compounds ;
- Noise free;
- High efficiency when combined with power and heat production;
- No self-discharge over time;
- Independent optimization of the system delivered power (fuel cell power: kW) and of the available stored energy (gases storage: kWh).

2.0 JANUS PROJECT AND THE DEPLOYMENT OF THE GREENERGY BOX™

2.1 Energy context of the city of La Croix Valmer

The city of La Croix Valmer, located in the Golf of Saint Tropez, faces a significant electricity demand in summer on account of a population multiplied by a factor 10. Therefore, the city is often exposed to repeated power cut during this period. In this context, the city of La Croix Valmer targets to be more autonomous from the electricity network.

2.2 The project JANUS: an innovative concept

The project JANUS [1] aims at developing hydrogen-based energy storage solution coupled with photovoltaic panels in order to:

- Insure the green production of electrical and thermal energy of for five buildings of the city
- Ensure partial energy autonomy of these buildings while guarantying backup solution in case of power cut
- Decrease the energy bill of the city while contributing to sustainable development
- Develop a reliable and safe solution for the new generations

The project is partially self-financed thanks to the fact that a part of the electricity produced by the photovoltaic panels is sold back to the French electricity provider EDF.

The project JANUS was labelled in October by the Capenergies cluster, dedicated to the CO2-free polluting energies of the Regions Provence-Alpes-Côte d'Azur, Corsica, Guadeloupe, Réunion and Monaco.

The Greenergy Box™ [2], developed by HELION-AREVA [3], is a hydrogen-based energy storage system that has been chosen to be coupled with photovoltaic panels to answer to the energy requirements of the city of La Croix Valmer. The first Greenergy Box™ is going to be installed in a Kid Leisure Centre of the City.

2.3 The GREENERGY BOX™: the solution for JANUS project

The Greenergy Box™ is a containerized hydrogen chain comprising an electrolyser, a fuel cell, a water , heat, electricity management systems coupled with a hydrogen and oxygen storages installed aside of the container. The Greenergy Box™ is an integrated modular product that can offer a power from 50 to 500 kW with a storage capacity from 0.2 to 2 MWh. Several systems can be coupled to increase the power and the energy capacity. Coupled with RES, such solution allows not only to ensure a building autonomy from 45 to 85 % but also to provide the function of backup system for few hours at high power.

The photovoltaic panels provide electricity to the electrical network and the surplus is used by the electrolyser to produce gaseous hydrogen and oxygen. Once stored, hydrogen and oxygen can be used to generate electricity thanks to the fuel cell system. Heat which is also produced by the system during both electrolysis and hydrolysis processes is also managed and valorized for adjacent buildings.

The water-proof and wind-resistant Greenergy Box™ is segregated into three different compartments, including in particular an electrical, a fuel cell and an electrolyser compartment as shown in Figure 2 below.

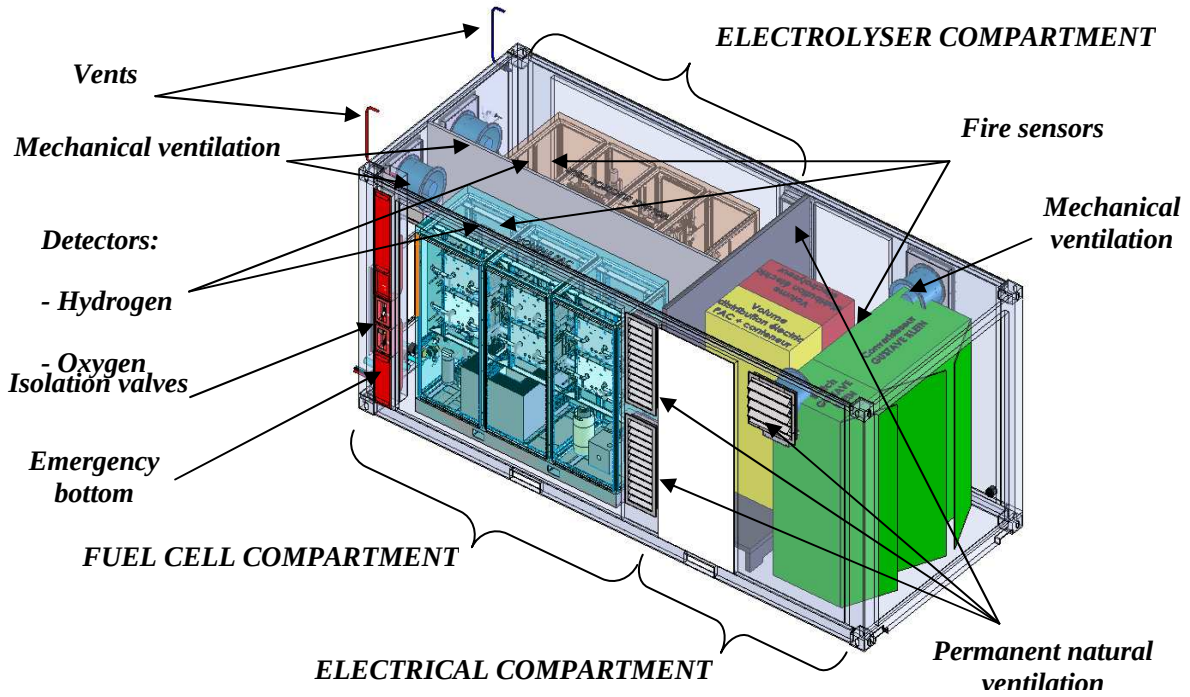

Figure 2: Segregation of the Greenergy Box™.

The Greenergy Box™ system is currently being tested on HELION's site as shown in the Figure 3 below. The development of such solution enables HELION to offset the remaining barrier to the full deployment of renewable energies: their intermittency.

Figure 3: Greenergy Box™ settlement on HELION's site.

2.4 Sizing for the Kid Leisure Centre

The Kid Leisure Centre is going to be equipped with a 200 m^2 photovoltaic panel farm delivering 29 kWc power and coupled with a complete hydrogen chain. The different sized components of the hydrogen chain are presented in Figure 4. In particular, the Greenergy Box™ is able to deliver a 50 kWe power. The gaseous hydrogen and oxygen tanks were sized to achieve 45 % of the electrical and thermal building autonomy i.e. about 200 Nm^3 of hydrogen and about 100 Nm^3 of oxygen. The back-up solution offers an electrical autonomy of 4 hours at 50 kW or 10 hours at 20 kW.

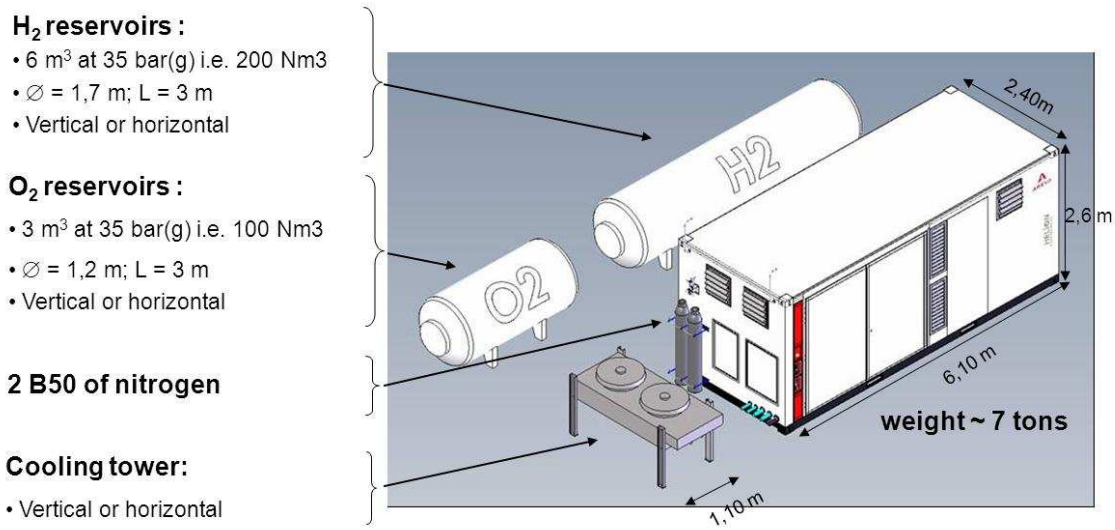

Figure 4: Hydrogen chain to be installed in the Kid Leisure Centre.

3.0 SAFETY STRATEGY OF THE HYDROGEN CHAIN

HELION is designing and building hydrogen systems for more than 10 years. Safety of system and installation is always a key consideration. A good knowledge of hydrogen behavior and a conception in accordance with European and French codes, standards and best practices allows to maintain a high safety performance.

The Greenergy Box™ is certified CE by following the Low Voltage Directive, LVD 73/23/EEC, the Electromagnetic Compatibility Directive, EMC 89/336/EEC, Machinery Directive, MD 98/37/EC, Pressure Equipment Directive, PED 97/23/EC.

The risk assessment of the complete hydrogen chain is realized in three steps. First, a document "Basic safety considerations" that describes the main safety requirements for the conception stages of the hydrogen chain is defined. Once the conception of the system is sufficiently detailed, a HAZOP revue of each subsystem (HAZard and OPerability Study) is performed to identify potential causes of process deviation, their associated consequences and assess the efficiency of the existing barriers. As a third stage, a fault tree analysis completes the HAZOP revue so as to highlight the conception failure, inappropriate system configuration and external sources of danger for identified unwanted events. All the safety study is centralized in a same document "Synthesis of the safety studies of the Greenergy Box™" [4].

The overall safety strategy of the hydrogen chain is detailed below.

3.1 Leak suppression and control

Equipment and piping materials are chosen to be compatible with hydrogen and oxygen use to prevent hydrogen embrittlement and oxygen corrosion. Materials could be selected from the IGC15/06, ISO/TR 15916 and ISO 11114-4. Pressurized hydrogen and oxygen are commonly stored in steel cylinders. The maximum carbon equivalent (CE) required for hydrogen material is 0.43 as described in the IGC 121/04, § 3.

Welded connections are preferred and are used wherever practical to minimize potential leak sources. The number of joints and fitted connexions are minimized.

Both electrolyser and fuel cell compartments of the Greenergy Box™ are equipped with two hydrogen sensors and one oxygen detector. A security shutoff is triggered when hydrogen is detected in concentration greater than 10 % of the Lower Flammability Level (0.4 % H2 in air) in the compartment. An emergency shut-off occurs if the hydrogen concentration is above 25 % of the Lower Flammability limits (1 %). Oxygen detection triggers whenever the oxygen concentration reaches more than 23 % in volume air.

Furthermore, hydrogen and oxygen leaks are also detected by pressure difference during standby phases. An alarm is triggered if there is a minor loss of pressure during the standby stage, and if the pressure loss is too significant the system will not be able to restart.

Before commissioning, hydraulic and leak tests are performed as required by the Pressure Equipment Directive, PED 97/23/EC.

Regular inspections and preventive maintenance programs are organized to ensure the maximum safety level. In particular, leak tests on pressure regulators, valves, pipes, joints and connections etc. are regularly realized. Frequent visual inspections are organized to check the level of corrosion. Information regarding inspection and maintenance frequencies can be found in the Appendices F of the IGC 121/04 and IGC 13/02.

3.2 Prevention of formation of flammable or over-oxygenated atmospheres

The three compartments of the Greenergy Box™ are naturally ventilated thanks to lateral vents located on both sides of the container as shown in Figure 2.

The fuel cell and electrolyser compartments are both equipped with an ATEX protected ventilation that triggers when the hydrogen concentration is above 0.4 % by air volume or when the oxygen concentration reaches 23 %. The maximum flow rate that the fan is capable to deliver is sized for the thermal dissipation in the compartments i.e. 2500 m3/h for the Fuel Cell compartment and 2700 m^3/h for the electrolyser compartment.

Modelling of an catastrophic hydrogen leak of 750 Nl/min flow rate using the LES (Large Eddy Simulation) approach developed at the University of Ulster [5, 6] highlights that it takes about 10 s for the hydrogen sensor to detect a hydrogen in concentration higher than 0.4 % in the naturally ventilated electrolyser compartment. Considering the conservative hypothesis of 30 s for a response time of the hydrogen sensor, it can be observed that after 40 s of continuous constant release the hydrogen-air concentration formed under the ceiling is still below the Lower Flammable Limit (LFL) of hydrogen in air i.e. 4 % by air volume. At this moment, the hydrogen sensor sends a signal to the control command that activates the air intake fan to its maximal speed. It can be observed that the hydrogen air cloud is entirely diluted in less than 2 s.

3.3 Suppression/reduction of ignition sources

The inside of the Greenergy Box™ where hydrogen may leak or diffuse is not classified as ATEX zone since it can be demonstrated the safety barriers prevent the formation of ATEX zone by accumulation. Nonetheless, all the equipment installed just under the ceiling and susceptible to ignite a flammable hydrogen-air mixture is certified for ATEX zone 2. It concerns in particular the fire sensors, hydrogen detectors, oxygen sensors and the ventilation system.

The Greenergy Box™ and reservoirs are earthed and bonded to give protection against the hazards of stray electrical currents and static electricity.

3.4 Protection against overpressures

Each reservoir and piping lines from the Greenergy Box™ to the storage tanks are equipped with a pressure relief valve. The tare pressure of the pressure relief valve is set so that the PRV actuates when the tank pressure reaches 1.15 of the maximal operating pressure.

The storage tank vents are mounted vertically at a minimum height of 3 m and are bended at 90° to avoid the introduction of water within the vent.

The hydrogen and oxygen vents are located at a minimum height of 1 m above the roof the container and are well separated to avoid oxygen-enriched hydrogen-air mixture. Each venting line is common to the electrolyser and the fuel cell and allows the depressurization of the system in less than 2 minutes in case of emergency shut-down.

3.5 Emergency and safety shutdown

The control command is also used to trigger the safety functions. About 70 safety functions are recorded into the control command to detect any process deviation, gaseous leak or fire within the system. Depending on the amplitude of the process deviation in comparison with the safety threshold, an emergency or a security shutdown is triggered and may be followed by a power cut, a depressurization, an inerting stage and/or ventilation activation (except for fires).

The main safety functions i.e. H_2, O_2 and fire detections, emergency shutdown bottom and watch dog of the control command respect the Safety Integrity Level 1 (SIL).

3.6 Security of the installation

The Greenergy Box™ and storage tanks are installed outside within a controlled area surrounded by fences, walls or safety barriers and only accessible to authorized persons.

Authorized staff is trained and are trained to relevant emergency procedures. Any work other than that directly connected with operating or maintenance of the system is realized under the control of a Safety Work Permit.

4.0 KID LEISURE CENTRE: THE FIRST GREENERGY BOX™ IMPLEMENTATION IN A PUBLIC BUILDING

4.1 The challenges

Lack of hydrogen-related regulation

The first installation of the Greenergy Box™ in the frame of the JANUS project is foreseen to be in the new Kid Leisure Center building of the city. Regarding the French regulation, this type of building occupation is considered as a public housing that has to follow precisely the building codes requirements. In France, such regulation is not adapted to the installation of hydrogen-energy installations since the word 'hydrogen' is even not mentioned anywhere in the texts. Therefore, one major challenge was to define the rules for the first installation of a hydrogen-energy storage system in adequacy to the existing safety strategy in public housing regulations.

Late stage agreement to install the Greenergy Box™ within the building

In a perfect world, the installation location of the hydrogen chain would have been defined with the architects during the conception stage of the building. In reality, the agreement to install the Greenergy Box™ was obtained whereas the architecture plans of the building were almost finalized. At this stage there was no chance to modify significantly the building structure. On account of this late involvement, the space attributed for the settlement of the Greenergy Box™ system and the hydrogen and oxygen reservoirs was quite narrow and located in the proximity of the reception area of the building, close to the building access road and a garage entrance, as shown in Figure 3 below. Above the garage is found a multi-purpose hall and its terrace that gets a direct view of the hydrogen chain settlement.

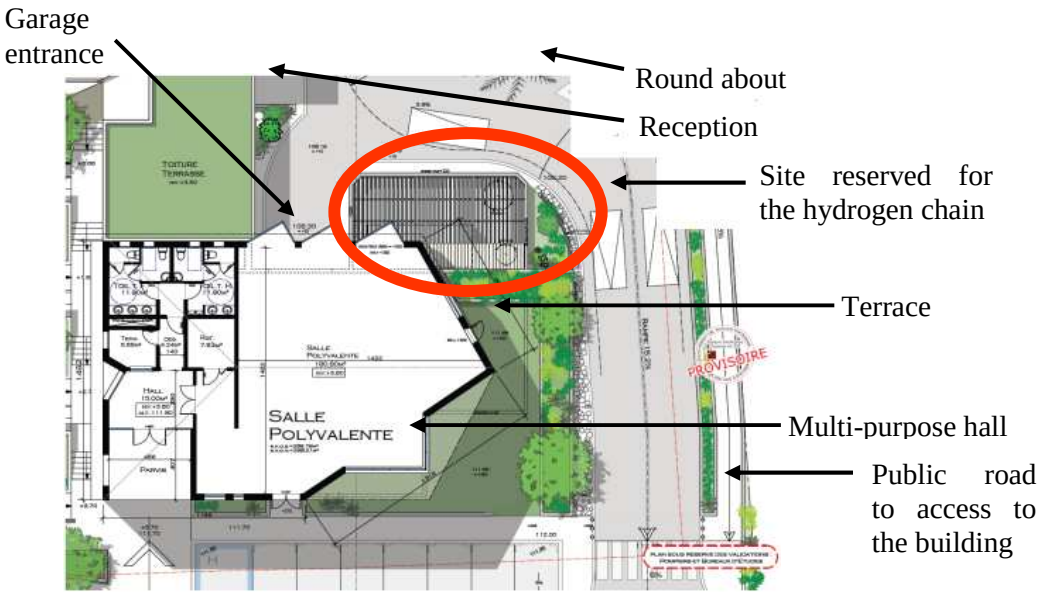

Figure 4: Top view of the Kid Leisure Centre and the installation site reserved for the hydrogen chain.

Public acceptance of hydrogen technology and safety

In addition to the challenges related to the first installation of the hydrogen chain in the environment described above, public perception and acceptance regarding hydrogen represent a crucial factor for the successful implementation of the hydrogen-based energy storage chain in the city. A communication strategy was therefore necessary not only to convince the population of the benefits of such projects but also to demonstrate them that the installation of the hydrogen chain is safe.

4.2 Solution of the hydrogen chain implantation

Analogy with cogeneration system installation in public buildings

As it has been previously described, the public housing regulation is not adapted in France for the installation of hydrogen systems. Nonetheless, looking closely to the texts, some similarities can be found for the installation of cogeneration systems. According to the regulation, a cogeneration system consists of producing simultaneously electricity and heat with the help of a thermal motor or a turbine using liquid or gaseous combustible. Looking at this definition, a Greenergy Box^{TM} can also be considered as a cogeneration system since it produces electricity and heat, the only difference being that the electricity and heat are produced thanks to an electrochemical process using hydrogen, oxygen and water.

Considering that a Greenergy Box^{TM} is a compact and containerized system, it can be assimilated to a "cogeneration module" according to the regulation. The installation guidelines have therefore to follow the requirements defined for combustion heating systems, which are defined according to two parameters, namely the total power and the location of installation i.e. inside, outside or on a terrace. The parameter "power" is described as representing the total electrical and thermal power delivered by the system and is classified into three categories: "below 30 kW", "between 30 and 70 kW" and "over 70 kW". The total power delivered by the Greenergy Box^{TM} corresponds to 100 kW i.e. 50 kW for the electrical power and 50 kW for the thermal power, thereby falling into the third category "over 70 kW". For an outside installation, the text requires in particular that:

- The envelop of the system must be constructed as a M0 material (not flammable)
- The system has to be installed in an area not accessible to the public or made inaccessible by the use of a wall or a fence of at least 2 m high
- The system has to be installed at a minimum distance of 10 m from the public highway, private property limit or other buildings. If this distance cannot be respected, a protective wall of fire resistance of 2 hours and of minimum height of 2 m must be erected
- A display must indicate that the installation is conceived to work outside and the access must be forbidden to the public

Hydrogen and oxygen storage tank installations

Regarding the hydrogen and oxygen reservoir installation requirements, it has been proposed to install the storage tanks in the same Greenergy Box^{TM} zone inaccessible to public. In addition to that, it has been recommended to physically separate both storage tanks by a protective wall of fire resistance of 2 hours. It has been preconized to install a one hour flame guard canopy on the top of the tanks to protect them from the risk from thermal flux in the case of a fire in multi-purpose hall.

Solution of implantation

The solution of implantation of the complete hydrogen-based energy storage solution, including the Greenergy Box^{TM} and associated hydrogen and oxygen tanks, is presented in the Figure 5. The dimension of the zone respects area reserved by the architects shown in the Figure 4.

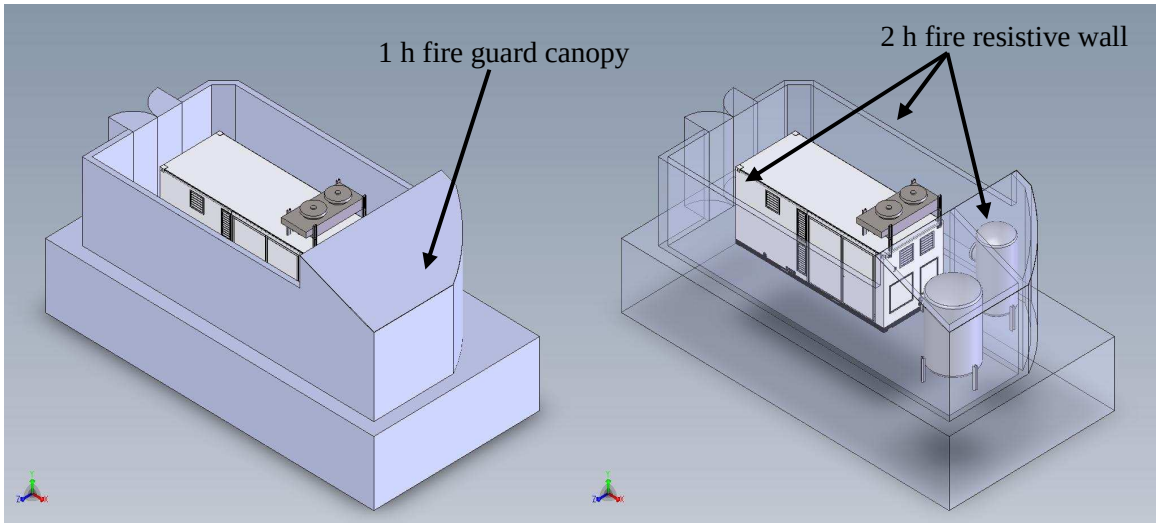

Figure 5: Solution of implantation of the Greenergy Box™ and associated hydrogen and oxygen tanks.

4.3 Strong collaboration with fire authorities

Organization of a meeting with local and National Fire Prevention Officers

In France, a local Public Housing Safety Commission composed of a representative of the Fire Prevention Department, the Mayer of the town, a policeman, a public representative of the Equipment Department, is in charge of examining the compliance of architectural plans with the Public Housing Safety regulation. The commission also realizes inspections at the openings or after modifications of buildings. Fire Prevention Service plays a key role in this commission since they check the conformity to the fire safety regulations.

On account of the lack of official safety requirements defined for the installation of a hydrogen-based energy storage system in a public building, the local safety commission is not competent to authorize the installation of such systems in the Kid Leisure Centre of La Croix Valmer. The safety document has to be presented for authorization to the National Public Building Safety Commission that takes place every month in Paris.

Thanks to the MYRTE project [7] and the good relationship established with the Fire Authorities of Corsica, it has been possible to get the contact of a member of the National Public Housing Safety Commission. We invited this Firefighter Officer but also the local Firefighter officers under the jurisdiction of the City of La Croix Valmer. The presentation included in particular:

- HELION's activities and hydrogen products that are developed in HELION. A visit was organized at the end of the meeting to show the FC and electrolyser test platforms, the didactic product BAHIA [7], the Autonomous Underwater Vehicle PAC-SM [7], the 70 kW backup system called "MISTRAL" [7], the energy storage system "Greenergy Box™" [7]

- The key hydrogen-energy associations, platforms and partnerships at the International, European and National levels to give an understanding of the global context regarding hydrogen as an energy carrier

- Few key demonstration projects such as MYRTE project [7] or deployment projects of hydrogen stations and vehicles in California or North of Europe

- A comparison of hydrogen properties with those of more conventional fuels such methane, propane and gasoline with the message behind that a good understanding of hydrogen physical properties allows the safe design and handling of hydrogen systems

- JANUS objectives, calendar and realization planning

- The safety treatment of the Greenergy Box™ and associated storage tanks as described in the present paper

- The description of the solution of installation as described above.

The conclusions of the meeting were very satisfactory. The Firefighter Officers highlighted that they were pleased to be approached at an early stage for the installation of such new system. They underlined that their knowledge regarding these new hydrogen technologies was low and that Fire Departments will need educational and practical hydrogen safety training in the future to know how to handle potential incidents.

They gave a pre-agreement for the installation of the hydrogen-based energy storage system within the Kid Leisure Centre. They highlighted that the analogy with cogeneration system installation in accordance to Public Housing Regulation was the right approach to follow. They also confirmed that the final safety document will have to be presented to the National Public Building Safety Commission to get a definitive authorization.

Bearing in mind that the project JANUS aims at installing other hydrogen-based storage systems in four additional buildings of La Croix Valmer, they also advised us to start the process of modifying the French Public Housing Regulation.

Further collaboration with the French National Fire Association

Following this positive meeting with the Fire Authorities, it has been offered to the Officer who belongs to the National Public Housing Safety Commission to participate to the review of the on-going French standard ISO/TC 197 "Installation of hydrogen system". This standard that is being prepared by an ad-hoc group led by AIR LIQUIDE and composed by HELION, CEA, INERIS, SOPRANO, McPHY, N-GHY and BENSI, aims at defining installation rules of hydrogen systems.

A meeting, gathering several Firefighter Officers including the President of the National Fire Association and the members of the ad-hoc group was then organized in Paris to present a draft of the standard. The National Fire Association found a real interest to continue this collaborative work and decided to organize other meetings with the ad-hoc group before the publication of the standard.

4.4 Social acceptance of hydrogen

Public acceptance regarding hydrogen is a strategic factor for the successful implementation of the hydrogen project. A conference and a press publication were organized for the Science Day of the City of La Croix Valmer. A whole afternoon was dedicated to present and discuss about hydrogen as a future energy, hydrogen technologies, the JANUS project and the safety aspects of the hydrogen chain. A small model of a hydrogen energy storage system and a remote controlled hydrogen powered car were displayed to familiarize people with hydrogen technologies.

Safety treatment of the hydrogen chain and the implementation of the Greenergy Box™ within the Kid Leisure Centre were also presented. From a safety point of view, the key messages delivered during the presentation were that:

- Hydrogen behavior is well known and perfectly handled in the industry,

- The Greenergy Box™ is a certified CE product that follows the European Regulations and state-of-the-art related standards,

- The integration of the Greenergy Box™ within the Kid Leisure Centre is realized in close cooperation with the Fire Authorities

- A pre-agreement was given by the Fire Authorities for the implementation of the hydrogen chain within the Kid Leisure Centre. The final agreement will be delivered by the National Public Housing Safety Commission

The audience seemed to be interested by the presentations and we did not notice severe opposition to the project. From a safety perspective, it was central in our talk to highlight our close collaboration with Fire Authorities. Indeed, it gives more confidence to people regarding the safety of the hydrogen installation, therefore facilitating the acceptance of the project. Fire Authorities are essential partners that have to be included as early as possible for installations of hydrogen systems, especially when they are not very familiarized with these new technologies.

5.0 CONCLUSION

For the first time in France, a hydrogen-based energy storage system, the Greenergy Box™ developed by HELION-AREVA, is being deployed in five French Public Buildings in the frame of the project JANUS. The Greenergy Box™ is an integrated modular system that can offer a power from 50 to 500 kW with a storage capacity from 0.2 to 2 MWh. Coupled with Renewable Energy Source, such solution allows not only to ensure a partial building autonomy from 45 to 85 % but also to provide the function of backup system for few hours at high power.

The Greenergy Box™ is a certified CE system that respects European Regulations and state-of-the-art related standards. The safety measures of the complete hydrogen chain is recapitulated into several parts i.e. leak suppression and control, prevention of formation of flammable or over-oxygenated atmospheres, suppression/reduction of ignition sources, protection against overpressures, emergency and safety shutdown and security of the installation.

In the frame of the JANUS project, the first Greenergy Box™ is going to be installed in a Kid Leisure Centre of the City of La Croix Valmer. Despite the lack of regulation related to the installation of hydrogen system in Public Housing Regulation, the implementation requirements were defined by analogy to cogeneration system. A pre-agreement was given by Local and National Fire Authorities before the final presentation to the National Public Housing Safety Commission.

The involvement of the Fire Authorities has been a key element not only for the pre-validation of the Greenergy Box™ installation within the Kid Leisure Centre but also to develop further collaboration on the on-going French standard ISO/TC 197 “Installation of hydrogen system”.

Communication related to the project was realized during a conference and through a press report. No strict opposition was observed for the installation of a hydrogen system in the Kid Leisure Centre. The collaboration with Fire Authorities gave more credibility and reassurance to the public. The role of Fire Authorities is then central not only for the permitting process of hydrogen projects but also for hydrogen public acceptance.

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