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Deliverable D2.1

Novel energy storage systems for increasing buildings flexibility potential

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EXECUTIVE SUMMARY

This deliverable, titled "Novel Energy Storage Systems for Increasing Buildings Flexibility Potential" and classified under Task 2.1 of Work Package 2 (EVELIXIA's Intelligent Technological Repository as Flexibility Enablers), presents a preliminary framework for three innovative energy storage solutions. These solutions aim to enhance the flexibility potential of buildings by integrating hydrogen storage systems and vehicle-to-grid technologies. Each proposed solution addresses distinct storage needs and is configured for practical, replicable deployment within industrial, residential and commercial buildings.

Objectives and Scope

The main objective of this deliverable is to design and evaluate energy storage solutions that enable buildings to better manage and adapt their energy consumption patterns. The methodology includes technical studies, simulation modelling, and risk assessments across the following solutions:

Solution 1: H2 Demonstrator (Power-to-Power) for Stationary Application (IS 28)

This solution focuses on a hydrogen-based power-to-power setup for stationary use, with an integrated system consisting of hydrogen production, storage, and conversion modules. It includes a PEM electrolyser for onsite hydrogen generation, storage tanks, and fuel cells, housed in a 20-foot container with designated zones for each subsystem to optimize safety and operability.

Results and Key Findings

- Energy Efficiency: Initial studies suggest a strong potential to reduce grid dependency, particularly during peak hours, by storing surplus local renewable energy generation as hydrogen.
- Safety and Monitoring: The system integrates advanced safety measures, including real-time monitoring, leakage detection, and emergency shutdown protocols, ensuring safe operation and compliance with regulatory standards.

- Resilience: The solution enhances energy resilience by providing backup power capabilities and mitigating risks associated with grid outages.

Replication Potential

This solution demonstrates a high replication potential for buildings with energy-intensive profiles, such as:

- Hospitals and student hostels, which demand uninterrupted energy supply.
- Manufacturing facilities with variable energy consumption patterns.
- Commercial buildings with high peak demand.

The design considers both case-specific characteristics (e.g., local regulatory compliance) and replicable elements (e.g., modular containerized setup, standardized safety protocols). Its scalability makes it adaptable for broader applications across Europe and beyond.

Open Points and Barriers

Key challenges and barriers identified include:

- Cost Constraints: The high initial investment required for hydrogen production and storage components.
- Regulatory Hurdles: Navigating permitting and compliance processes, particularly for hydrogen storage on-site.
- Technical Optimization: Ensuring seamless integration with building energy systems, requiring iterative testing and tuning.

Requirements for Implementation

Implementation of Solution 1 involves:

- Time: An estimated timeline of 12–18 months, including permitting, procurement, and installation.
- Cost: Moderate to high initial capital expenditure, offset by long-term operational savings.
- Complexity: High complexity due to the integration of multiple subsystems and compliance requirements.

- User-Friendliness: The containerized setup is designed to minimize operational demands on users, with automated monitoring and maintenance alerts.

Promotion Channels

To promote this solution effectively:

- Stakeholder Engagement: Industry expoevents, conferences, and stakeholder workshops to showcase the solution's benefits.
- Case Studies: Demonstrating real-world applications to highlight its impact and replication potential.
- Policy Advocacy: Collaboration with policymakers to emphasize the role of hydrogen-based solutions in achieving energy transition goals.

Future Directions

Next steps include:

- Completing regulatory compliance checks and securing permits.
- Conducting on-site trials to validate performance.
- Gathering stakeholder feedback to refine scalability and improve cost-effectiveness.

Through these efforts, the hydrogen Solution aligns with EVELIXIA's broader objectives, contributing to Europe's commitment to sustainable energy solutions.

Solutions 2 (IS 27: Hydrogen Power to Power)

The proposed solution for the Greek pilot project focuses on the advanced utilization of green energy, specifically energy generated by photovoltaic (PV) systems. This energy is stored in the form of hydrogen using a proton exchange membrane (PEM) electrolyzer and later converted back into electrical energy through a fuel cell. To implement and test this solution, a power-to-power system will be installed, consisting of a PEM electrolyzer (7 kW), a hydrogen storage system (Metal Hydride rack), and a fuel cell (10 kW).

Results and Key Findings

- Energy Efficiency: Enhances the amount of energy generated by photovoltaic (PV) systems that is effectively utilized.
- Energy Flexibility: Enables the use of green energy on-demand, ensuring a continuous supply whenever there is a need.
- Security and Monitoring: The system is equipped with a comprehensive monitoring framework to ensure its reliable, safe, and efficient operation at all times.
- Resilience: The solution improves energy resilience by offering backup power capabilities and reducing the risks associated with grid outages.

Replication Potential

The proposed solution is designed for small-scale applications and is best suited for pilot projects. However, a similar compact green hydrogen unit could also be effectively utilized in small hotels and catering establishments.

Open Points and Barriers

The use of hydrogen technologies for harnessing green energy is an area currently under research and development. From a technological perspective, it is crucial to examine various types of electrolytes and hydrogen storage systems to identify the most efficient solutions. Economically, since hydrogen technologies are still in the developmental phase, their costs remain relatively high; however, these costs are expected to decrease as technology advances. In terms of the legislative and regulatory framework, there is no clear or comprehensive structure within Greek legislation to govern such technologies. On a smaller scale, such as the technology being implemented at the CERTH facilities, there are no significant legislative or licensing barriers.

Future Directions

All licences have been secured and preparations have been conducted for the installation of the system. Therefore, next steps include:

- The installation of the system at the CERTH's facilities
- The connection to the energy production source (PV) and to the consumption network
- The operation, testing and monitoring of the system

Solution 3 (IS 26: Vehicle-to-Grid Charger)

Energy storage solutions play a crucial role in ensuring grid stability, reducing energy costs, and improving overall system efficiency.
Among emerging storage technologies, Vehicle-to-Grid (V2G) systems have gained significant attention due to their dual functionality - enables bidirectional power flow, allowing electric vehicles (EVs) to store excess renewable energy and discharge it back to the grid or directly to buildings when needed.

By leveraging V2G, buildings can improve their energy flexibility potential, reducing reliance on centralized power systems while enhancing demand response capabilities.

Results and Key Findings

In this deliverable, both regulation at the national and European level for the V2G systems are described. Also, TUCN explores the role of V2G technology as a novel energy storage system for increasing buildings' flexibility potential. It examines, through simulations, the technical feasibility, economic benefits, and challenges associated with V2G integration.

Open Points and Barriers

While Vehicle-to-Grid (V2G) technology offers promising benefits for enhancing building energy flexibility and grid stability, its widespread adoption faces several challenges, including battery degradation, regulatory barriers, infrastructure requirements, high initial investments, and user participation incentives.
Besides this, the dynamic pricing mechanisms should be implemented to encourage participation while maintaining grid stability.

For V2G to reach its full potential as a novel energy storage solution for building flexibility, stakeholders—including policymakers, utilities, automakers, and consumers—must collaborate to overcome these barriers.

Future Directions

Next steps include:

- Preparation of the necessary documents for the purchase and the actual purchase
- Completing licensing and getting the approvals for the installation
- Installation and conducting on-site trials to validate performance.
- Operation training
- Gathering stakeholder feedback and improve cost-effectiveness.
- Evaluate the impact on demand-side management, grid stability, and energy optimization.

Through these efforts, the V2G Solution aligns with EVELIXIA's objectives to design and evaluate the energy storage solutions that enable buildings to better manage and adapt their energy consumption patterns, thus contributing to Europe's commitment to sustainable energy solutions.

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1.1 Scope and objectives

1.1.1 Background and Context of the Task

The deliverable 2.1 is the result of the work done in the task 2.1 which is a part of the **WP2 EVELIXIA's Intelligent Technological Repository as flexibility enablers.** It focuses on the development of novel energy storage systems for self-consumption and community use alongside the corresponding micro-control tools.

1.1.2 Overview of the Three Solutions

1.1.2.1 HYDROGEN-BASED LONG-TERM STORAGE SYSTEM (IS28)

The French pilot site, led by ENTECH, will design and integrate an optimized hybrid storage system, incorporating an innovation hydrogen storage system with a BESS. On top of that a new system-dedicated controller, incorporated in a new cloud hypervisor solution, will be developed.

1.1.2.2 POWER-TO-HYDROGEN-TO-POWER COMPACT SYSTEM (IS 27)

The Greek pilot site, led by BER, will develop a building-scale power-to-hydrogen-to-power system with internal micro-control and self-observation devices for remote operation.

1.1.2.3 VEHICLE-TO-GRID EV CHARGER (IS 26)

The Romanian pilot site, led by TUCN, will investigate a dedicated micro-regulation strategy for V2G chargers, leveraging local building observations for cost-effective operation.

1.2 Structure

This report is divided into several key sections. It begins with an introduction outlining the scope, objectives, and background of the task, followed by a detailed overview and technical studies for each solution (French, Greek, and Romanian pilot systems). Each system's section includes analysis on system sizing, supplier selection, permitting, and installation processes, along with results and comparisons with simulations. The final sections provide conclusions, lessons learned, and future action plans. The annexes contain detailed technical specifications, calculations, and regulatory documents for each solution.

1.3 Remarks

1.3.1.1 HYDROGEN-BASED LONG-TERM STORAGE SYSTEM (IS28)

Due to budget limitations the initial declared capacities of the H2 system were decreased as presented in *Table 1*:

Table 1 Comparison between system initial and final capacities

Initial	Final
100 kW Electrolyzer	30 kW Electrolyzer
90 kg of hydrogen storage	10 kg of hydrogen storage
30 kW FC	10 kW FC

1.3.1.2 POWER-TO-HYDROGEN-TO-POWER COMPACT SYSTEM (IS 27)

Table 2 present a comparison between system initial and final capacities.

Table 2 Comparison between system initial and final capacities

Initial	Final
7 kW Electrolyzer	7 kW Electrolyzer
20 kg of compressed hydrogen storage	3 kg of metal hydride hydrogen storage
5 kW FC	10 kW FC

1.3.1.3 VEHICLE-TO-GRID EV CHARGER (IS 26)

Table 3 present a comparison between system initial and final capacities.

Table 3 Comparison between system initial and final capacities

Initial	Final
V2G EV charging systems 2x22 kW – 32 A	V2G EV charging systems 2x22KW – 32 A

2 HYDROGEN-BASED LONG-TERM STORAGE SYSTEM (IS28)

2.1 Overview of the Solution

While renewable solar powered production plants, EV chargers, battery electricity storage systems and energy management solution are already installed, further developments, aiming to integrate a long-term storage system using hydrogen technologies aiming at increasing optimum self-consumption.

An optimized hybrid storage system will be designed and integrated into the E-factory pilot site (French PS). Innovative components will comprise a 30 kWe electrolyser combined with a 10 kg of stored hydrogen at 300 bar and a 10 kWe fuel cell as showed in Figure 1.

The excess energy generated by the photovoltaic (PV) system will be directed to the electrolyzer, which will operate at a low pressure of 30 bar to produce hydrogen. This hydrogen will subsequently be compressed to 300 bar using a compressor, using as well excess green electricity, thereby reducing the required storage volume. When demand arises, the fuel cell (FC) will utilize the stored hydrogen to generate electricity, effectively meeting the energy requirements [1].

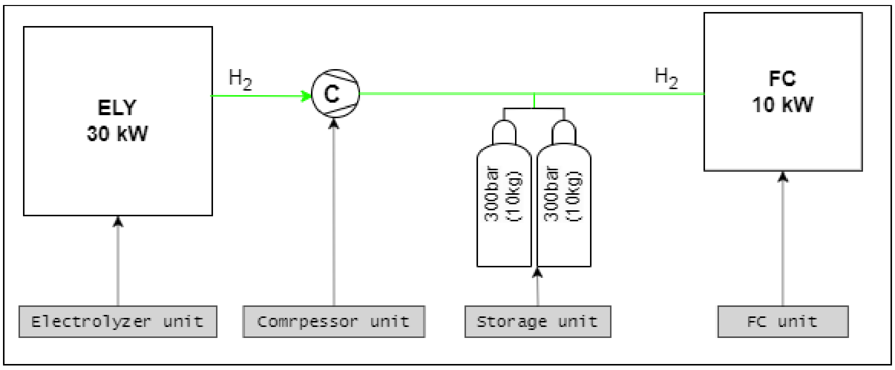


Figure 1. Hydrogen system architecture

Innovative bidirectional AC/DC converters designed for EV charging station application will be used to fit the electrolysers and fuel cell low levels of voltage, to reduce the cost and increase stability and efficiency by up to 5%.

A system-dedicated controller will ensure interoperability between all components of the system and optimal system control.

The demonstrator aims to optimize the use of flexibilities and storage systems on-site to maximize the self-consumption of photovoltaic energy production at both the building and neighbourhood scales. The expected monthly energy productions and consumptions on the site remain the same as the existing balance, while the self-consumption rate should increase significantly, with a target of 70% compared to the current 40%.

Additionally, Entech will upgrade existing ESEsoft software to develop a new hypervisor solution in a secure cloud computing environment for managing and overseeing the entire operation of the whole system.

ESEsoft platform will include ESEdiag (the diagnostic and prognostic module and ESEmanage (the Energy Management System module). ESEdiag will supervise the operation of the hybrid system, providing the necessary control inputs to operate the system safely and efficiently. While, SEmanage will consider both day-ahead and seasonal scheduling to maximize the annual self-consumption ratio. Optimal energy dispatch will be calculated every 10' based on PV production and consumption forecast.

2.2 Sizing and Technical Studies

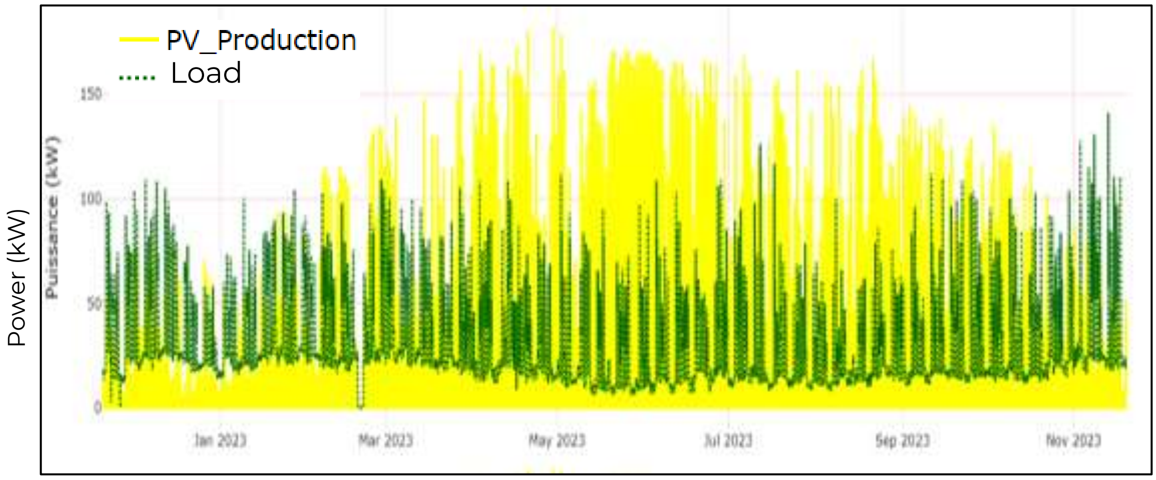
2.2.1 System Sizing and Design

The hydrogen system design has been based on engineering considerations, taking into account the eventual budget limitations. In this section, the technical part of the sizing will be presented, which have been determined through modeling and simulation of the different hydrogen equipment [2][3]. The budget respect will be defined in the section 2.3.

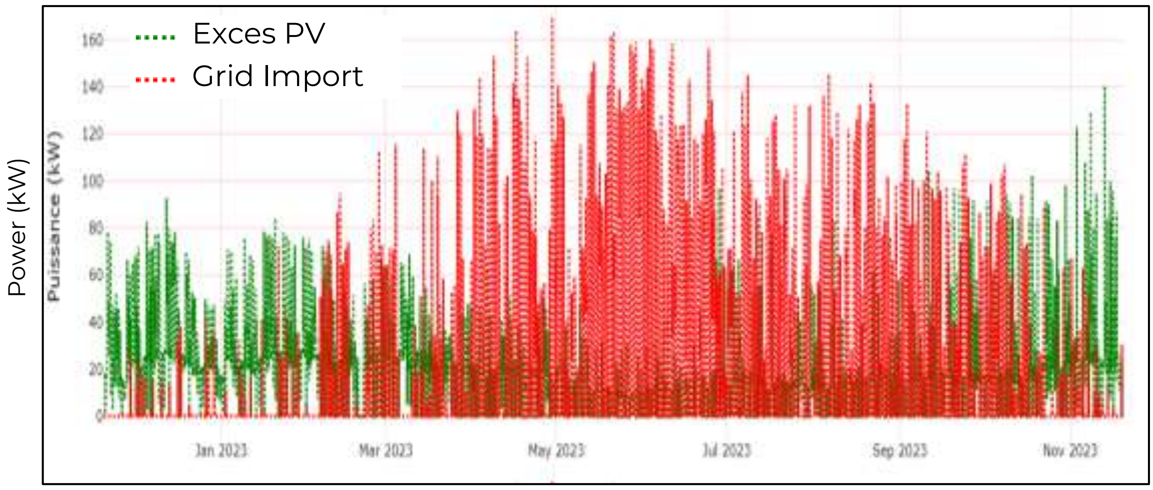
The H2 system will help increasing the global site PV self_consumption. Therefore, the onsite PV production and the total building consumption were used to size the H2 system.

On total, there are 1257 photovoltaic panels installed with a peak power of 394 kWp with 44 kWp PV parking canopies and 350 kWp PV roofing systems. 244 kW is used for the individual self-consumption operation and 150 kWp is destined for use in the collective self-consumption operation under development. For the experimental demonstrator application, only the 244 kW PV will be used. The hourly profiles for one year of the PV production and the site consumption are presented in Figure 2-a. The PV produced power attained a maximum of 210 kW within a yearly average of 26 kW, while the building consumption varied between 10 kW and 140 kW within a yearly average power of 28 kW.

After supplying the building's consumption with PV-generated electricity, the surplus PV and the necessary grid-imported electricity were calculated, as shown in Figure 2-b. The excess PV ranged from 0 to 160 kW, with an annual average of 15 kW, while the grid-imported electricity varied from 0 to 140 kW, averaging 17 kW per year. These profiles were used to size the hydrogen system. The excess PV powers the electrolyzer to produce hydrogen, which is then stored and used by the fuel cell to regenerate electricity based on a setpoint. This setpoint matches the grid-imported electricity profile to compensate for shortages and enhance self-consumption.



(a) PV total production and building consumption



(b) PV exces and grid import profiles.

Figure 2. Annual Building Energy Profile

Storage Sizing:

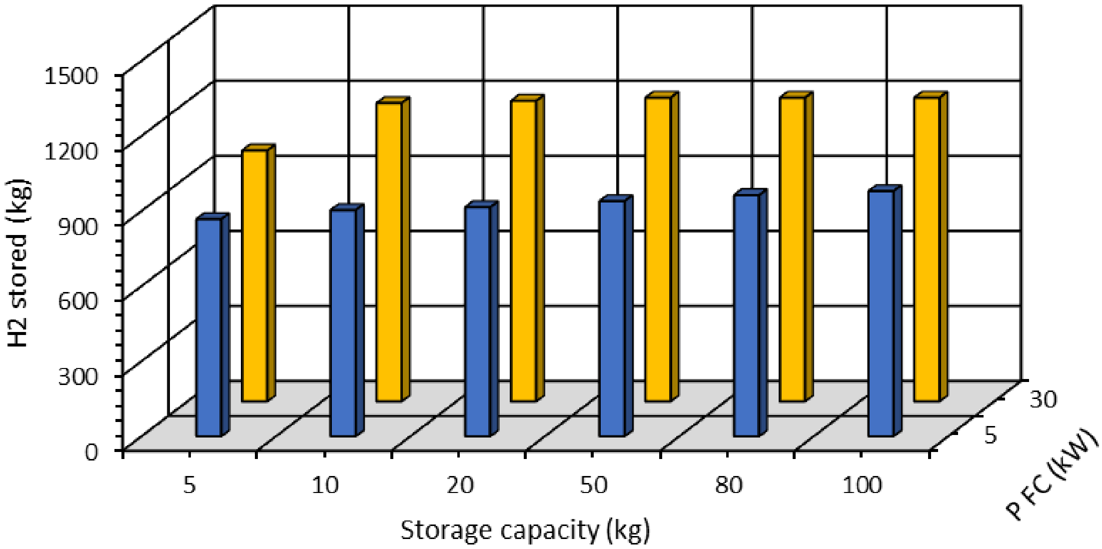
Figure 3 (a and b) illustrates the variation in yearly stored hydrogen and PV self-production rate as a function of storage capacity and fuel cell (FC) power, for an electrolyzer capacity of 30 kW.

Different electrolyzer capacities (ranging from 10 kW to 100 kW) were simulated. In this section, we present the results for the 30 kW electrolyzer, which, based on supplier consultations (section 2.3), was identified as the optimal choice to remain within the budget, taking into account the results of the simulations conducted.Consequently, this 30 kW electrolyzer is used to size the other components of the system.

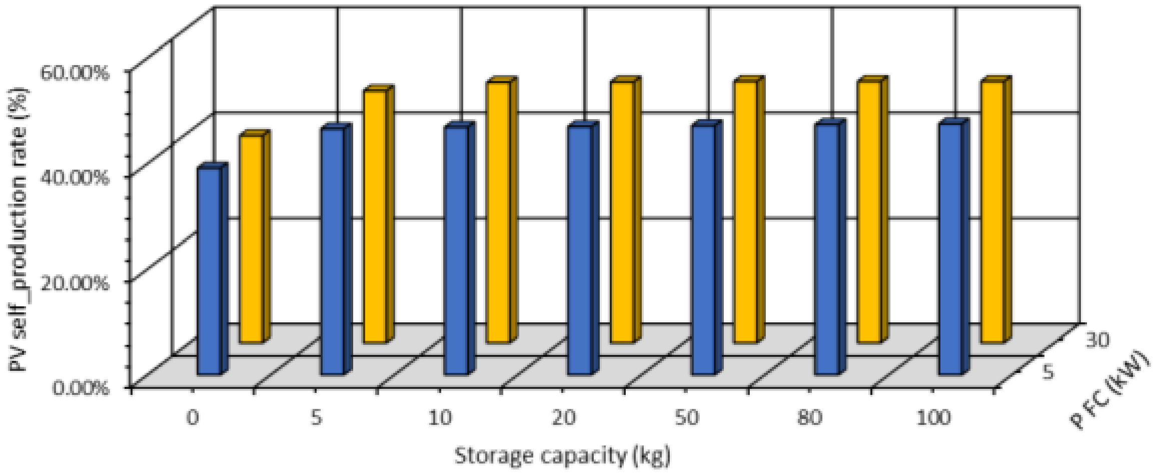
The hydrogen storage capacity ranges from 5 kg to 100 kg, while the FC power varies between 5 kW and 30 kW. The results show a significant increase in stored hydrogen (from 1000 kg to 1191 kg at 30 kW FC power) when increasing the storage capacity from 5 kg to 10 kg. However, beyond a storage capacity of 10 kg, the variation in stored hydrogen becomes much less important across different FC power levels.

The variation in the PV self-production rate shows similar trends, where adding 10 kg of storage capacity results in a 7 to 8% increase in the self-production rate compared to the initial scenario without a hydrogen system. However, beyond 10 kg, the increase is limited due to system constraints.

In conclusion, considering the simulation results and the budget constraints, it has been determined that the onsite hydrogen storage capacity will be set at 10 kg of gaseous hydrogen. This decision aligns with our objectives to optimize system performance while remaining within financial limits.



(a) Variation of the stored hydrogen with respect to the storage capacity and the FC power

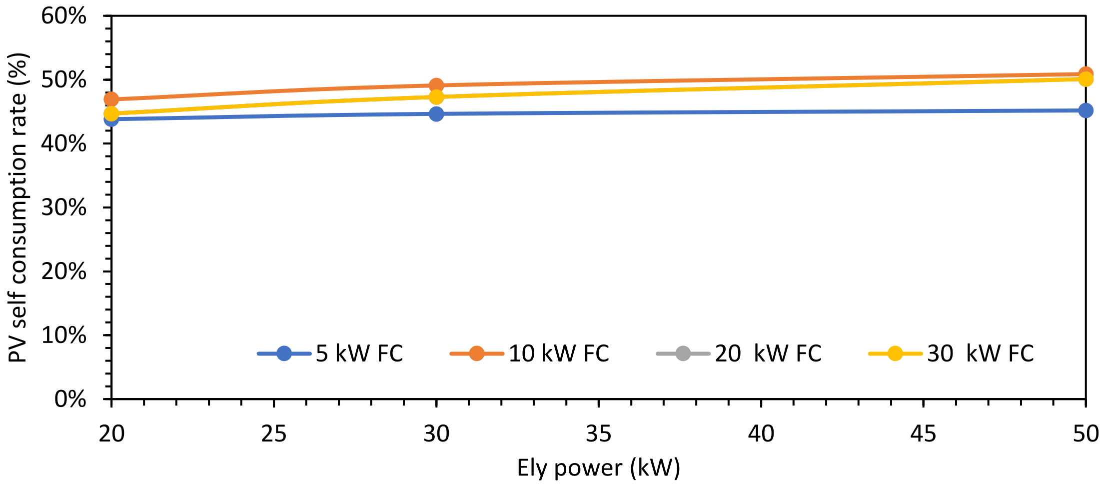


(b) Variation of the PV self-production rate with respect to the storage capacity and the FC power

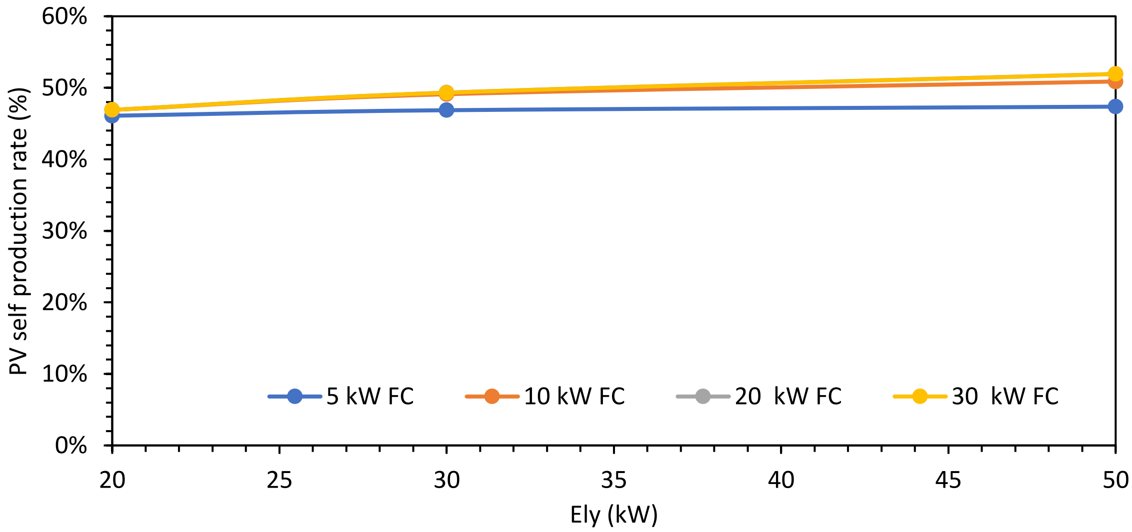
Figure 3. Variation of the hydrogen storage system KPIs

FC Sizing:

Figure 4 illustrates the variation in simulated PV self-consumption and self-production rates relative to the power of the fuel cell (FC) and electrolyzer (ELY). The results indicate that the highest rates of PV self-consumption and self-production 49.1% and 49.3%, respectively are achieved with a 10 kW FC for the case of a 30 kW electrolyzer. Consequently, the recommended FC power for installation in the onsite hydrogen system is 10 kW, as it also aligns with the budgetary constraints.



(a) variation of the PV self consumption rate with respect to the FC and ELY powers



(b) variation of the PV self production rate with respect to the FC and ELY powers

Figure 4. PV KPIs variation

The Figure 5 illustrates the overall P&ID (Piping and Instrumentation Diagram) of the hydrogen system. The system's instrumentation has been meticulously defined to ensure both safety and optimal operation. Sensors required for monitoring and control have been specified for each fluid in the system (water, oxygen, and hydrogen) to guarantee accurate measurement and regulation [4].

This system consists of four primary units: the electrolyzer unit, compressor unit, storage unit, and fuel cell (FC) unit:

- The electrolyzer unit includes a water treatment system that delivers high-purity water at the required flow rate to the electrolyzer. This system is equipped with pressure and thermal treatment components to enhance electrolyzer efficiency. The electrolyzer itself separates the water into hydrogen and oxygen. Additionally, a gas purification unit is used to remove impurities from the hydrogen produced at a pressure of 30 bar.

- The compressor unit, fitted with essential sensors (PSV, vent, security valve, pressure and temperature sensors) and monitoring equipment for enhanced safety, will compress hydrogen from 30 bar to 300 bar.

- The storage unit consists of Type 1 hydrogen vessels, designed to store hydrogen at a pressure of 300 bar with a total capacity of 10 kg. This unit is equipped with essential safety features, including a pressure safety valve (PSV), pressure regulator, and security valves, along with pressure and temperature sensors to ensure safe and effective monitoring and control.

- The fuel cell (FC) unit will utilize the stored hydrogen to generate electricity, operating according to a set power output. This process is controlled by a control unit and monitored through various installed sensors, including pressure and temperature sensors, ensuring precise regulation and optimal performance of the system.

The necessary safety equipment, monitoring sensors, control valves, and instrumentation were specified based on detailed calculations considering the fluid characteristics at each stage, including density, flow rate, pressure, and temperature. Additionally, pipe dimensions and materials were selected following the same criteria to ensure proper system function and safety across all operational conditions.

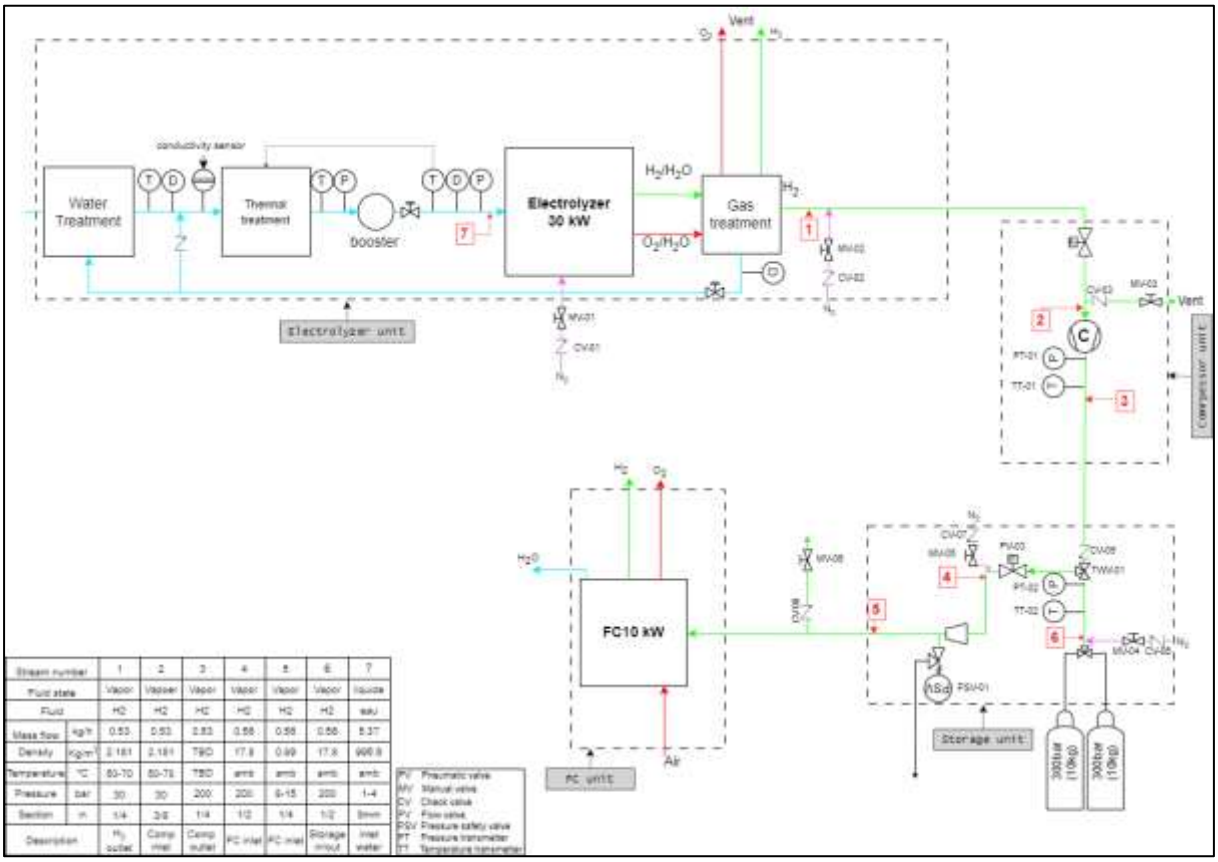


Figure 5. Hydrogen system general P&ID

2.2.2 Safety Study

Given the high flammability of hydrogen, a comprehensive safety study for the installation of the hydrogen system was conducted, addressing various safety aspects to mitigate risks. One of the critical considerations is compliance with ATEX (Atmosphères Explosibles) regulations, which aim to prevent the formation of explosive atmospheres [5][6]. ATEX defines the safety requirements for equipment used in potentially explosive environments, such as those involving hydrogen. To avoid the occurrence of such hazardous conditions, the hydrogen system is designed to minimize gas leaks, ensure proper ventilation, and incorporate explosion-proof components. These measures help prevent the accumulation of hydrogen in confined spaces, thus reducing the risk of ignition.

The hydrogen system will be housed in a 20-foot container, divided into three distinct zones for better risk management and isolation of hydrogen-related hazards. Zone A will accommodate the hydrogen storage and compressor, Zone B will house the electrolyzer, and Zone C will contain the fuel cell (FC) and the electrical conversion and control systems. This compartmentalization is crucial for safety, as it helps to clearly define areas with varying levels of hydrogen risk. Table 4 provides the ATEX classification for each zone within the container. Furthermore, each zone is equipped with essential safety devices such as hydrogen detectors, flame detectors, pressure relief valves, and emergency shutoff systems to ensure the detection and prevention of potential hazards. The detailed safety aspect will be presented in the section 2.4.

Table 4. ATEX specifications

	Release source				Flammable substance		Ventilation			Dangerous location		
	Description	Location	Release level	Release rate (kg/s)	T and P °(C)	(MPa)	Type	Ventilation level	Disponibility	Zone Type	Zone size (m) Vertical	Horizontal
Zone A	High pressure H2 storage	Container	2 nd	0.0001383	ambient	30	A et N	Medium	Good	Zone 2	1.5	2.238
Zone A	High pressure H2 storage	Container	2 nd	0.0001383	30-75	3	A et N	Medium	Good	Zone 2	1.5	2.238
Zone A	H2 comrpessor	Container	2 nd	0.0001383	ambient	3-30	A et N	Medium	Good	Zone 2	1.5	2.238
Zone A	H2 Busbar	Container	2 nd	0.0001383	ambient	30-1.6	A et N	Medium	Good	Zone 2	1.5	2.238
Zone B	Electrolyzer	Container	2 nd	0.0001383	30-75	0-3	A et N	Medium	Good	Zone 2	1.9	2.238
Zone C	FC	Container	2 nd	0.000157407	ambient	0.8-1.6	A et N	Medium	Good	/	2.5	2.238

The placement of the container onsite was carefully selected to ensure adherence to safety distance requirements from surrounding buildings, main roads, electrical sources, and chemical sources. As shown in the Figure 6, the designated location is in the rear corner of the parking area, approximately 26 meters from the building wall and 18 meters from the main road. These distances are critical for minimizing risks and ensuring compliance with safety standards regarding hydrogen storage and equipment. Additionally, an ATEX zone extending 3 meters around the container is mandated, with restricted access controlled by safety barriers to further enhance security.

Figure 6. Hydrogen system location

2.2.3 Simulation Study

The simulation section of the deliverable provides a detailed analysis of the integrated hybrid system's behavior, focusing on preliminary simulations to predict and optimize its performance under defined capacities. This hybrid system combines hydrogen technologies such as electrolyzer (ELY), compressor, storage, and fuel cell (FC) with renewable energy sources (onsite PV) and real historical energy demand data from the building. The primary objective is to assess the system's efficiency in meeting building energy needs sustainably across various seasonal conditions.

For these simulations, distinct models were developed for each hydrogen subsystem. The electrolyzer model simulates hydrogen production based on available excess power, the compressor model manages hydrogen pressurization, the storage model tracks inventory over time, and the fuel cell model simulates power generation based on hydrogen consumption to meet demand. Together, these models reflect the performance and constraints of each component, allowing for a comprehensive understanding of the system’s operation.

The simulations were conducted over a one-year period with an hourly time step, ensuring both resolution and granularity in capturing daily and seasonal variations. By using real historical data for both PV production and building load, we can simulate how the hybrid system interacts with varying energy supply and demand patterns. Results will focus on typical days in winter and summer to illustrate seasonal impacts on the system, showing how it adapts to lower solar availability in winter and higher production potential in summer. The seasonal comparison will also highlight system flexibility, storage sufficiency, and overall resilience, offering insights into potential improvements and scaling opportunities.

Summer Day:

The hydrogen system's behavior on a typical summer day is illustrated in Figure 7. It shows the hourly profiles for PV production, building load, grid imports and exports, as well as the power levels for the electrolyzer (ELY) and fuel cell (FC). The building's load on a regular operational day ranged between 15 kW and 100 kW, while PV production peaked at 160 kW, yielding 860 kWh of daily demand against 1440 kWh produced.

During low or non-sunny hours, the FC operated at a maximum power of 10 kW to help meet the building's energy requirements, with any remaining demand covered by the grid. At the start of the day, hydrogen storage held a full 9.7 kg of H_2 (see Figure 8). The 10 kW power production of the FC corresponded to a hydrogen consumption rate of 0.54 kg/h.

When surplus PV production began, the electrolyzer activated at its maximum power (30 kW) for about 9 hours, producing hydrogen at a rate of 0.52 kg/h and yielding approximately 4.7 kg by day’s end. This outcome highlights the hydrogen system’s benefit in shifting power use by converting excess energy into stored hydrogen, which can then be utilized as needed by the FC. Currently, the system provides short-term daily storage due to the limited capacity, with potential for future expansion to support long-term storage applications.

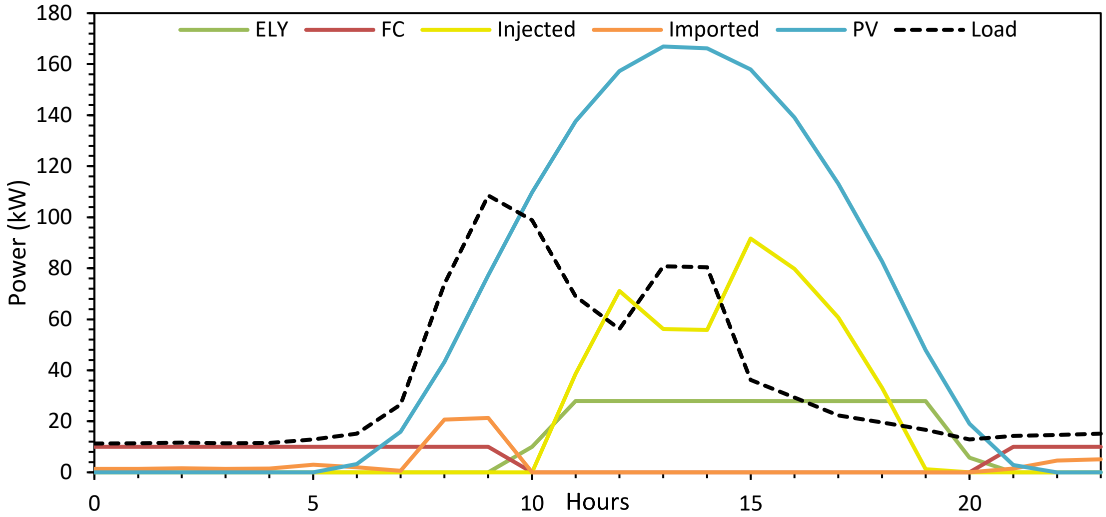


Figure 7. Hybrid PV, Grid, H2 system powers for a summer day

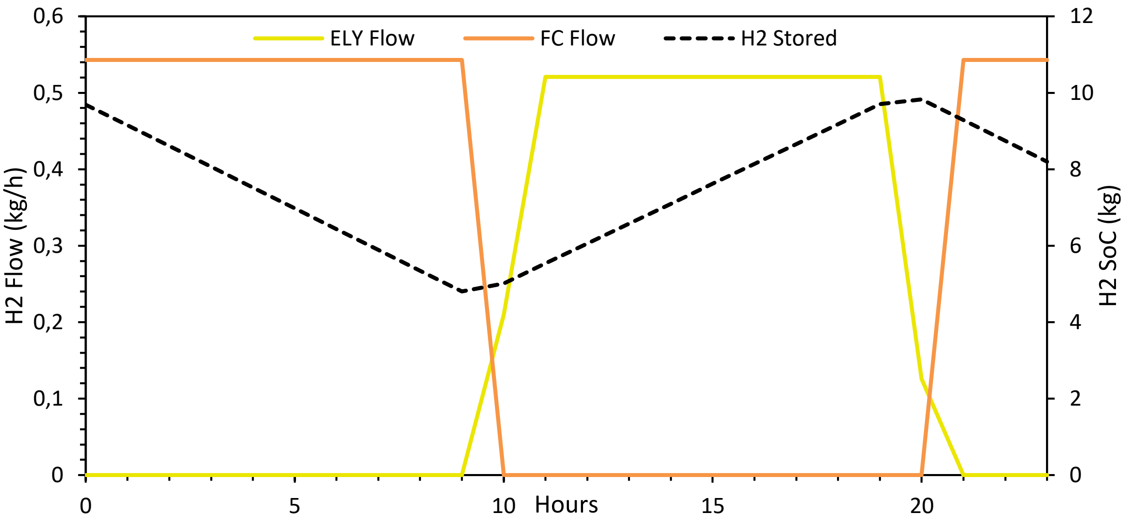


Figure 8. Hydrogen storage SoC for a summer day

<u>Winter Day:</u>

On a typical winter day, the hydrogen system's operation was limited due to reduced PV production. As illustrated in Figure 9, the building's load ranged between 22 kW at night and up to 100 kW during peak demand hours. In comparison, PV production was significantly lower, peaking at only 70 kW, which resulted in a daily demand of 900 kWh against 346 kWh of PV energy produced.

At the start of the day, hydrogen storage was empty (Figure 10), which restricted the FC's operation, leaving the grid as the sole power source for the building's needs. During midday, the electrolyzer activated intermittently for around three hours at varying power levels, storing 0.9 kg of hydrogen when excess PV was available. Subsequently, the FC could operate briefly when demand increased again, but due to limited hydrogen reserves, it was only able to run for two hours before depletion. Thereafter, building demand was fully covered by the grid. This limited winter performance underscores the current system's capacity constraints and highlights the need for storage expansion to better leverage hydrogen power in low-sunlight conditions.

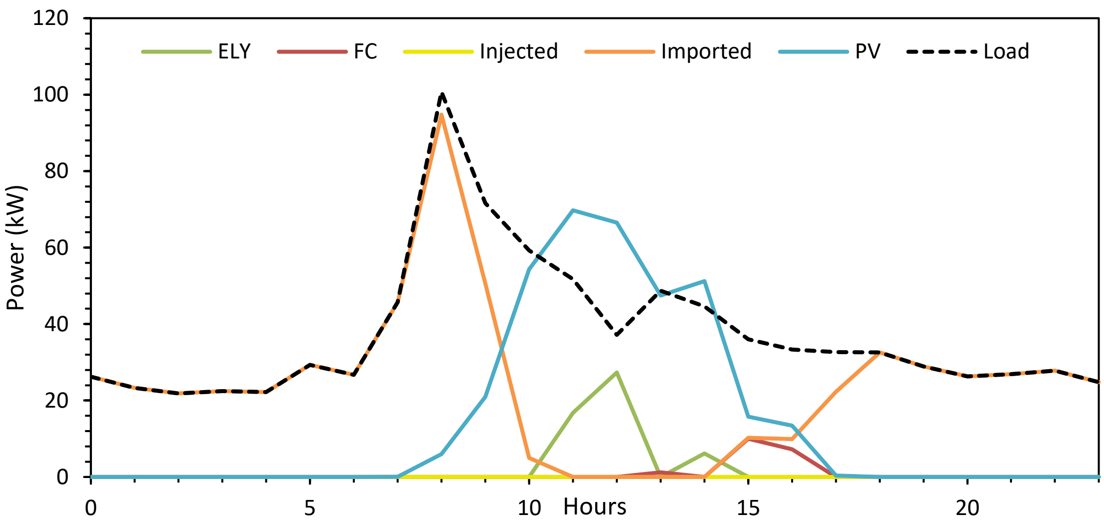


Figure 9. Hybrid PV, Grid, H2 system powers for a winter day.

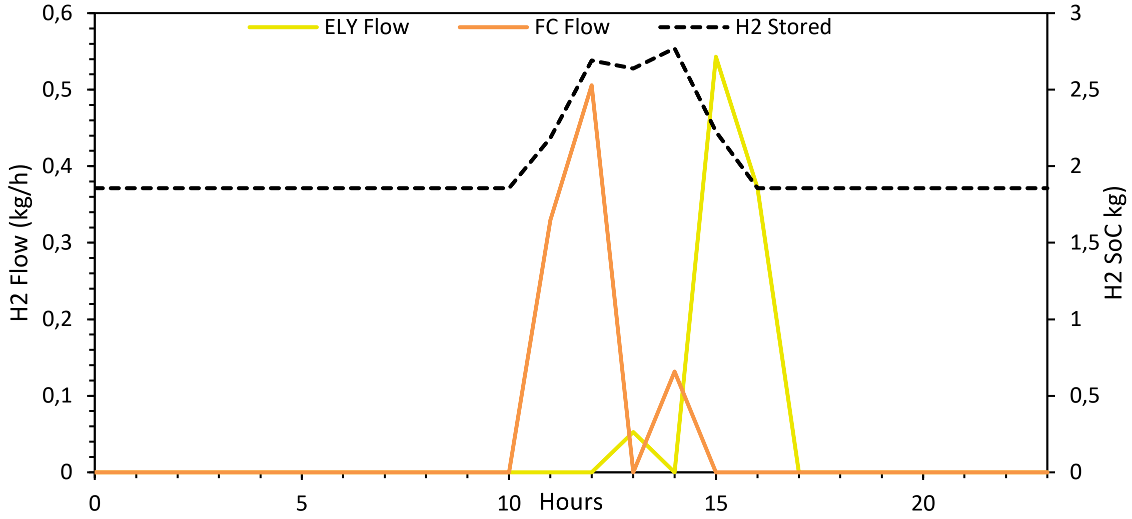


Figure 10. Hydrogen storage SoC for a winter day

Technical KPI's:

In this section, Table 5 presents key performance indicators (KPIs) of both the hydrogen system and the overall hybrid system, derived from a year-long simulation. These KPIs serve as critical metrics to evaluate the system's functionality and overall performance [7]. They help reveal the system's strengths and weaknesses, assess the operational advantages, and highlight areas for potential improvement. By analyzing these KPIs, stakeholders can gain insights into efficiency, reliability, storage capacity, and energy conversion rates, providing a robust basis for optimizing future designs and expanding the system's capabilities.

Table 5. Technical KPIs obtained by the annual hourly simulation

KPI Type	KPI	Value
Environmental	Electrolyzer water usage (m3)	8.97
Energy balance	Electrical consumption ELY (MWh)	50.42
	Electrical consumption COMP (MWh)	1.25
	Electrical production FC (MWh)	18.3
	Total demand (MWh)	147.27
	Total_PV_prod (MWh)	228.31
Production and Capacity	P max FC (kW)	10
	H2 prod max (kg/h)	0.525
	ELY Capacity Factor (%)	19.18
	H2 Produced (kg)	996.87
Operational Performance	FC operating hours	2080
	ELY operating hours	2270
	on/off FC cycles	325
	on/off ELY cycles	336
System efficiency	Electrolyzer Efficiency (%)	65.9
	FC Efficiency (%)	54.5
	Round-Trip Efficiency (%)	36.3
	PV Self-Production Rate (%)	80.29
	PV Self-consumption Rate (%)	51.79

The KPIs for the hydrogen system are divided into the following categories: Environmental, Energy Balance, Production, Performance, and Efficiency. Over a year, the electrolyzer consumed around 9 m^3 of water and approximately 50.4 MWh of electricity, yielding 997 kg of hydrogen. The compressor's annual consumption was 1.25 MWh, or about 2.5% of the electrolyzer's usage. In terms of output, the fuel cell (FC) generated 18.3 MWh, resulting in average annual efficiencies of 65.9% for the electrolyzer and 54.5% for the FC. The overall efficiency of the hydrogen system (from electricity-to-hydrogen conversion and back to electricity) reaches 36.3%, which can be considered satisfactory.

The yearly operating hours for the electrolyzer and FC are 2,270 and 2,080 hours, respectively, each undergoing around 330 on/off cycles, equivalent to roughly six hours of daily operation and one cycle per day. This steady operation reduces equipment wear, contributing to longer equipment life.

For the entire hybrid system, the PV installation achieved an annual self-production rate of 80.29% and a self-consumption rate of 51.79%. The high self-production rate indicates substantial grid autonomy, while a 52% self-consumption rate shows efficient PV utilization. Comparing these metrics with and without the hydrogen system reveals increases of 12.5% in self-production and 8% in self-consumption, underscoring the added value of hydrogen storage.

One drawback noted is the electrolyzer's low capacity factor (CF), defined as the ratio of actual output to potential maximum output over a period, averaging 19% annually. This low CF is largely due to the system being a demonstrator, only connected to PV and not the grid, thus limiting the electrolyzer's operational hours. This limits the potential for hydrogen production to a fraction of the system's maximum capability. This reflects a mismatch between the PV energy production and the electrolyzer's available operating time, resulting in underutilization of the equipment. With a CF this low, the system may face longer payback periods, as the cost of the electrolyzer—typically a substantial investment—is not fully offset by hydrogen production. Additionally, low-capacity utilization can contribute to inefficiencies, as the fixed costs of system maintenance, operations, and energy storage assets are distributed over fewer output hours.

These preliminary simulation results provide an initial view of the anticipated behavior of the hydrogen system post-installation. These findings will later be compared with real KPIs gathered from the system's actual operation, allowing us to identify any discrepancies that might indicate system issues or limitations. Additionally, this comparison will help pinpoint the system's operational constraints.

Moreover, an Energy Management System (EMS) will generate forecasts for various components of the site, including the hydrogen system, to optimize its operation and maximize self-consumption rates. This topic will be further explored in Deliverable D2.5, where the EMS strategy and its impact on system performance will be detailed.

2.3 Supplier Selection and Procurement Planning

To ensure the highest standards and cost-effectiveness for the project, a comprehensive supplier evaluation process was conducted for each key piece of equipment. Multiple suppliers were consulted to compare offers based on technical specifications, delivery times, and pricing. Table 6 provides an overview of the suppliers evaluated for each equipment type, along with brief comments. This transparent approach underscores the project’s commitment to due diligence and informed decision-making.

Table 6- Suppliers Consulted for Each Equipment

Equipment	Suppliers consulted	Comments
Electrolyzer	• IMI Remoza • Fusion fuel • Pure energy center • Pure energy • Center • Huadehytech • HeleTitanium	All suppliers met the minimum technical requirements. There were significant variations in pricing and efficiency levels, reflecting differences in design and technology.
H2 Compressor	• Haskel • Rejool • Sauer • Eifhytec • Sera hdyrogen • Pure energy center	The proposed solutions demonstrated diverse technological approaches. All suppliers complied with the required specifications, but cost and energy efficiency varied.
H2 Storage	• PLASTIC OMNIUM • Steel head • Glacier energy • Roth2 • Calvera • Tenaris • Pure energy center	Suppliers provided a range of capacities and configurations. All options were compliant with safety standards, but delivery timelines and costs differed.
Fuel cell	• Nuvera • Proton motor • Omnium • Genevos, Hy move • Ballard • Huadehyteh • Hydroxcell	All suppliers proposed solutions that met the basic technical and safety requirements. Differences were observed in system efficiency, stack lifespan, and maintenance needs. Pricing varied significantly based on power output and additional features.

Following the supplier evaluation process, the most suitable supplier was selected for each piece of equipment based on a combination of technical performance, compatibility with the project requirements, and cost considerations. Table 7 presents a detailed summary of the selected equipment, including the supplier's name, the technology type, key technical characteristics, and the rationale for their selection. This table ensures clarity in documenting the procurement process and provides a comprehensive reference for the equipment's role and expected performance within the project.

Once the suppliers were selected, the hydrogen system components were ordered by the end of December 2024. The system is expected to be delivered in June-July.

Table 7. Details of Chosen Equipment

Equip	Supplier	Technology Type	Usage	Key Characteristics	Selection Criteria
Electrolyzer	Huadehytech	PEM	Hydrogen production	• 6 Nm^3/h output capacity • 99.9995% H2 purity • < 4.5 kWh/Nm3H2	• containerized solution • energy efficiency
Compressor	Rejool	Electric Piston	Hydrogen compression	• High efficiency • compact design • robust safety features	• Best balance of cost • Efficiency • safety features
Storage	Huadehytech	Type 1	Hydrogen storage	• 10 kg capacity • 50 L volume per bottle • 16 bottles	• containerized solution • Durability • compliance with safety standards
Fuel cell	Huadehytech	PEM	Electricity production	• 10 kW power • Efficiency > 50% • 109 NL/min of H2 consumption	• containirized solution • Efficiency • integration compatibility • operational stability

2.4 Demonstrator system description

The scope of supply for this system includes a 6 Nm³/h electrolysis hydrogen production module, a 10 kW hydrogen fuel cell system, a 10 kg hydrogen storage system, and the corresponding supporting equipment. The entire system consists of a hydrogen production module, a hydrogen storage module, a fuel cell module, and associated control and power electronics modules. The system's principle is illustrated in Figure 11 and the design specification are shown in Figure 11.

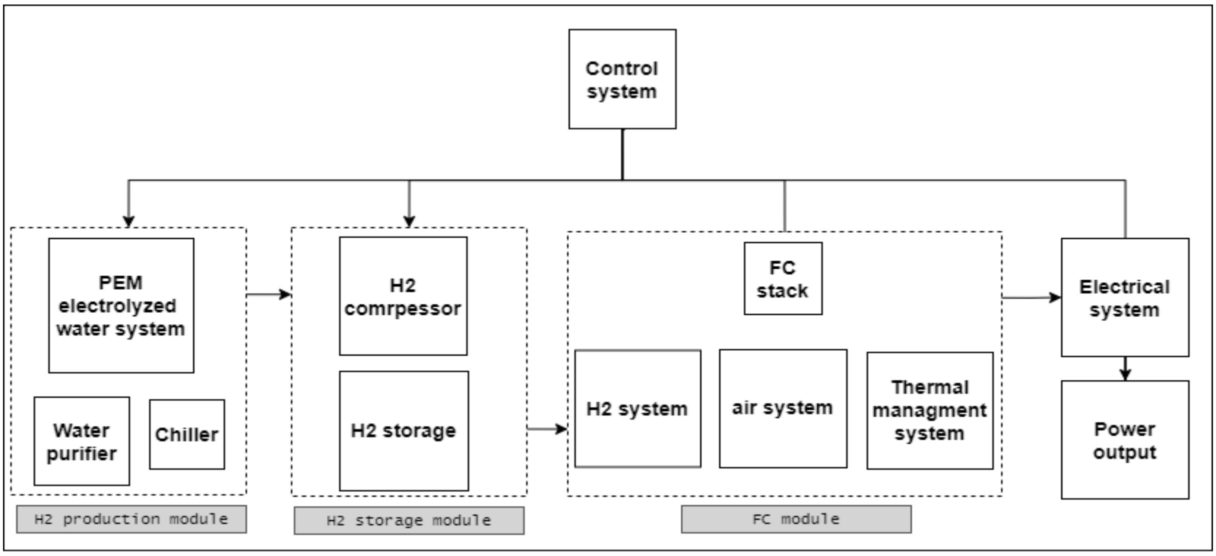


Figure 11. Demonstrator system architecture

Table 8. System design specifications

project	parameter
Project location	France
Installation conditions	outdoor
Expected use	Hydrogen production, hydrogen storage, fuel cell integrated equipment
How to use electricity	On-grid
Electrical power and voltage levels	Electric power: 10 kW; voltage: 380V / AC
Hydrogen source	PEM water electrolysis for hydrogen production
Hydrogen production flow rate	6 Nm^3/h
Fuel cell H2 consumption rate	109 L/min
Hydrogen storage capacity	10 kg
Hydrogen storage pressure	30 MPa

2.4.1 Electrolyzer unit

The PEM electrolysis water hydrogen production equipment utilized in this project serves as the hydrogen production module. It provides energy to the module and breaks down deionized water into oxygen and hydrogen through an electrochemical reaction. The hydrogen is then separated from gas and water, followed by dehydration using Pressure Swing Adsorption (PSA).

This apparatus has the capability to produce high-purity hydrogen, which is ultimately stored directly in the hydrogen container. The hydrogen production equipment in this project employs PEM water electrolysis technology, capable of producing up to 6 cubic meters of hydrogen per hour with a purity of 99.999% and a maximum gas production pressure of 3 MPa. It is designed for continuous operation with power and deionized water.

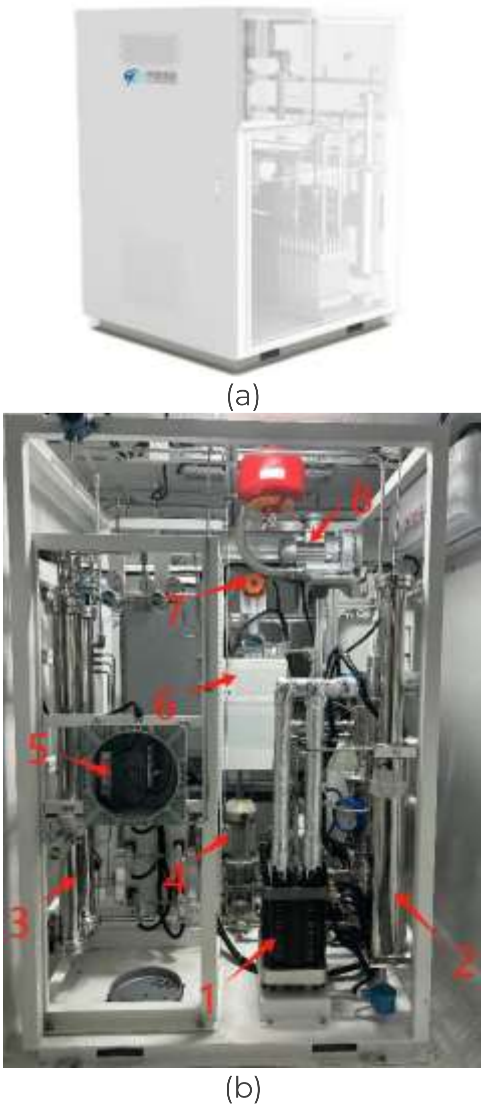
The equipment consists of four modules: electrolyzer, thermal management, purification, and control. The system features an anode normal pressure and cathode high voltage design, ensuring safety, stability, long lifespan, resistance to alkali corrosion, and unmanned operation. The specifications are presented in *Table 9*.

Table 9. Electrolyzer Unit Characteristics

parameter	Unit	Values
Rated hydrogen production	Nm3/h	6
H2 purity	%	> 99,999
H2 pressure	Mpa	0-3
Rated DC power consumption	kWh/Nm3 H2	<4,5
Cell voltage	V	<2,5
H2 dew point	°C	<-65
Working temperature	°C	mai-70
Water consumption	L/h	2,7
pure water requirement	MΩ.cm	>10
Cold strat time	min	<5
Water port size	in	0,5
Drain outlet size	mm	12
Colling water inlet size	in	1
Cooling water outlet size	in	1
O2 outlet size	in	1 1/4
H2 outlet size	in	0,25
Dissipation port size	in	0,5
Equipment size	mm	1200*1300*2000

2.4.1.1 System Appearance

Explosion-resistant components have been carefully chosen for the water electrolytic hydrogen production apparatus, which combines water circulation, hydrogen purification, and additional modules. The equipment's dimensions are 1200 * 1300 * 2000mm, with its external design depicted in Figure 12.



1- PEM electrolyzer
2- Gas-water separator & condenser
3- PSA desiccator
4- Circulator water pump
5- Dew point sampling module
6- Water tank
7- H2 sensor in O2
8-O2 suction fan

Figure 12. Electrolyzer unit appearance

2.4.1.2 Functional description of the electrolysis subsystem

The PEM water electrolysis system typically consists of an electrolysis module, a water management module, a purification module, and a control module. The following sections provide an introduction to each specific subsystem and their respective functions.

2.4.1.2.1 Electrolyzer module

The electrolysis module features a PEM electrolyzer with a capacity of 6 Nm^3/h (at 20°C and 1 atm), an input power of 30 kW, and a hydrogen side pressure resistance of 3 MPa.

2.4.1.2.2 Water management module

The primary function of the water management module is to ensure that the electrolyzer receives circulating water with the appropriate temperature and quality. Chilled water from the chiller is utilized to effectively dissipate the heat produced by the electrolyzer through a plate heat exchanger. Additionally, a deionized water circulation module is incorporated to maintain the quality of the circulating water at a level greater than 10 MΩ·cm, thereby extending the lifespan of the electrolyzer.

2.4.1.2.3 Hydrogen Purification module

The hydrogen pressure on the cathode side is regulated by adjusting the back-pressure valve. After passing through the gas-water separator, the hydrogen is drained from the cathode side, while the liquid water is returned to the water tank. Subsequently, a condenser is employed to cool the gas and remove a small quantity of condensed water. To eliminate oxygen and moisture, the hydrogen undergoes purification using a palladium catalyst and a pressure swing adsorption (PSA) dryer.

2.4.1.2.4 Control module

The PEM electrolyzed water system is remotely controlled by a PLC-based control system, ensuring both simplicity and safety. The system's operational data is efficiently recorded by an internal microcomputer, facilitating easy access and maintenance. With its intelligent design, the system features a one-key start and shutdown function. An intelligent display screen shows the operational parameters, including temperature and pressure curves, as well as electrolyzer voltage, providing real-time monitoring capabilities.

2.4.2 Hydrogen storage module

The hydrogen storage capacity is 10 kg, with a storage pressure of 30 MPa. The initial setup includes a set of hydrogen tanks rated for 30 MPa, providing approximately 11 kg of hydrogen capacity, along with a 30 MPa hydrogen compressor and two 50 L hydrogen buffer tanks.

2.4.2.1 Hydrogen storage process flow

The hydrogen produced from the PEM electrolysis system is initially introduced into a 100 L buffer container at a pressure of approximately 3 MPa. It is then pressurized using a 30 MPa compressor and directed into a 30 MPa assembly. Before entering the fuel cell system, the hydrogen is depressurized to a pressure range of 8-12 bar. Nitrogen is used to purge the compressor and associated instruments, while excess hydrogen is released through the discharge pipe. Additionally, a flame arrestor mechanism is incorporated.

2.4.2.2 Control logic

Initially, the hydrogen produced by the hydrogen generation system fills the buffer tank to a pressure of 3 MPa. The pressurization process is illustrated in Figure 13. From the buffer tank, hydrogen flows into the compressor, which charges the gas storage tank to a pressure of 30 MPa. This is monitored by a pressure sensor located at the outlet of the gas storage tank, which controls the activation and deactivation of the compressor.
The control system also manages the closure of specific valves to ensure that hydrogen gas is pressurized and directed into the predetermined pipeline. The secondary pressure reduction is directed to the fuel cell system. By operating the valve switch, the gas from the high-pressure hydrogen container is permitted to flow into the stack via a designated pathway.

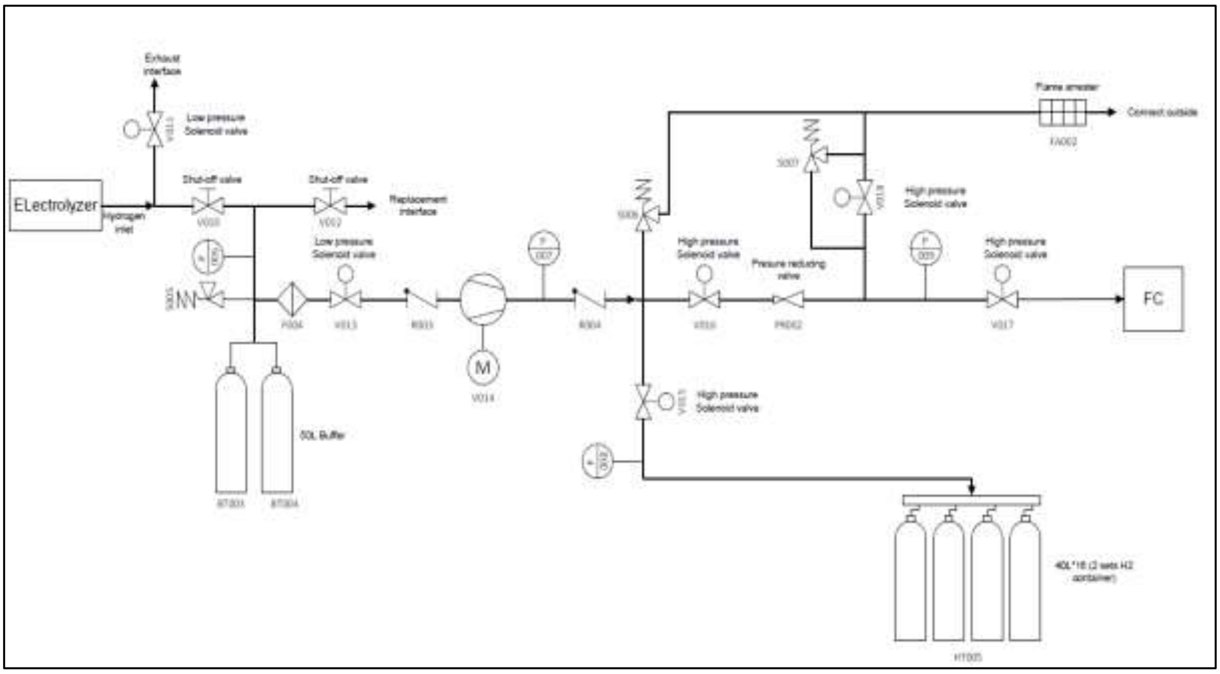


Figure 13. Hydrogen system P&ID

2.4.2.3 Description of the hydrogen storage subsystem

2.4.2.3.1 Hydrogen assembly

The hydrogen storage bottle assembly serves both storage and buffering functions, continuously monitoring safety conditions through various sensors, including pressure and temperature monitors. The design and production of the hydrogen storage bottles comply with TSG 21 Safety Technical Supervision Regulations for Fixed Pressure Vessels, JB 4732 Steel Pressure Vessel - Analysis and Design Standard, and T/CATSI 05003--2020 Special Technical Requirements for Hydrogen Storage Pressure Vessels in Hydrogenation Stations.

Notably, the manufacturing process of the hydrogen storage bottles avoids welding, resulting in a seamless, unified cylinder. This approach significantly reduces the risk of defects such as cracks, air pockets, and slag commonly associated with welding. To accommodate customer requirements, this project includes two sets of 10 MPa hydrogen storage bottles, with their specifications provided in

Table 10

Table 10. Hydrogen bottles specification

parameter	Unit	Value
working pressure	MPa	30
designed pressure	MPa	30
Working temperature	°C	-40 to 60
Single bottle volume	L	50
Single bottle diameter	mm	219
Number of hydrogen bottles in a single group	/	10
Number of required sets	group	1
size	mm	1040*1065*2050

Appearance of the equipment is shown in Figure 14.

Figure 14 Appearance of the hydrogen storage system

2.4.2.3.2 Busbar system

The hydrogen busbar system functions as a centralized pipeline network designed for the transportation and management of hydrogen. It comprises a series of pipes, valves, pressure sensors, pressure regulators, and other associated equipment to facilitate the safe and efficient delivery of hydrogen. The design of the hydrogen busbar system is illustrated in Figure 15.

Figure 15. Hydrogen busbar system

2.4.2.3.3 Hydrogen Compressor

The type of hydrogen compressor used in this project is Hermetically gastight, oilless, dry-running, vertical, inline piston compressor with wear-free magnetic coupling. The electric piston-type booster pump offers several notable characteristics:

- High Efficiency and Energy Saving: The piston pump operates with high efficiency, effectively converting motor energy into gas pressure energy with minimal loss.
- Stability and Reliability: Its working principle ensures stable hydrogen delivery, with precise control over flow rate and pressure.
- Versatility: The pump is adaptable to a variety of operating conditions, including varying temperatures, hydrogen purity levels, and humidity.
- Compact Design: Its compact structure requires minimal space, making it easy to install and maintain.

- Material Durability: Designed specifically for hydrogen applications, the pump materials are chosen to resist corrosion and hydrogen embrittlement, ensuring long-term, reliable operation.

Figure 16 presents the physical diagram of the hydrogen compressor, while Table 11 provides its parameter specifications.

Figure 16. Apperance of the hydrogen compressor solution

Table 11. Hydrogen compressor characteristics

parameter	Unit	Values
No. of cylinders	-	2
No. of stages	-	2
Type of construction	-	Inline
Pressure resistance of case	bar	PN40
Type of gas	V	Hydrogen
H2 dew point	°C	-50
max. particle size	µm	15
Inlet pressure	bar	20 to 40
Outlet pressure	bar	max. 300
Flow rate	Nm3	1 to 5
Length	mm	575
Height	mm	410
Width	mm	395
Type of cooling	-	Active air cooling
Power	kW	1.1

2.4.3 Fuel cell unit

Hydrogen and ambient air are combined in the fuel cell to produce direct current, which is then converted into 380VAC AC power through a DCDC boost converter and a DCAC inverter. The characteristics of the fuel cell system are detailed in Table 12.

Table 12. Fuel cell system charcateristics

Parameter	Value
Installation conditions	Inside the container
Expected use	On-grid
Electrical power and voltage levels	10 kW ; AC380V
Thermal power	7.6 kW
Electrical efficiency	≥50 %
Cold start time	≤1 min
Low temperature start time	≤15 min
Delayed power-off time	≤6 min
H2 gas inlet air pressure range	800-1600 kPa
H2 utilization rate	≥97 %
hydrogen purity	99.97%
H2 source	PEM electrolyzer
H2 flow	＞109 NL/min
Cooling	Liquid cooling
Opereating temperature	64-68 °C
Storage temperature	(-) 30 45 °C
Altitude	≤3000m
System insulation resistance	≥500 Ω/V
Relative humidity	≤95 %
Noise	≤85 dB
Overall running time	≥40000 h
Single maintenance running time	≥10000 h

The hydrogen fuel cell system is the CarNeu-10, a power generation device that converts the chemical energy of hydrogen and oxygen directly into electricity. The fundamental principle is based on the reverse reaction of water electrolysis, where hydrogen is supplied to the anode and oxygen to the cathode. As hydrogen diffuses through the anode and interacts with the electrolyte, it transfers electrons to the cathode via an external load. The complete system consists of a fuel cell module, a control module, a power electronics module, and a heating module.

2.4.3.1 System Appearance

The entire system features an integrated box design, where all modules are housed within the enclosure. This highly integrated configuration ensures not only an aesthetically pleasing appearance but also enhanced safety. The overall appearance of the system is illustrated in Figure 17.

Figure 17. FC system appearance

2.4.3.2 Material balance of the fuel cell system

In grid-connected mode, the hydrogen consumption is set at a rated operational flow of 109 N L/min. The output power generated by the reactor module is approximately 11.1 kW, yielding a net output power of around 10 kW, with a heating output estimated at about 7.6 W. The balance of plant (BOP) consumes power sourced from the grid, and the boost inverter incurs an estimated loss of about 1.1 kW.

2.4.3.3 Functional description of the fuel cell subsystem

2.4.3.3.1 Gas supply module

Once the high-pressure hydrogen reaches the anode side, it is introduced into the system and enters the reaction loop within the reactor. Concurrently, the air on the cathode side is pretreated using an air compressor and humidifier before it reacts with the hydrogen as it flows into the reactor.

2.4.3.3.2 Thermal management module

The heat generated by the fuel cells is collected in the main heat pipe and then dissipated by the cooling fan.

2.4.3.3.3 Control module

The primary controller collects and analyzes real-time data from the module, which is compiled by the switch. This data is then monitored and visualized on the host computer and saved in the database. Customers have the option to view this information via their mobile devices.

2.4.4 Overall system

The overall layout of the equipment is depicted in this section for a comprehensive view. Figure 18 provides a 3D front view, while the rear view is displayed in Figure 19. These visuals offer a complete representation of the equipment from multiple angles, facilitating a clear understanding of its design and configuration.

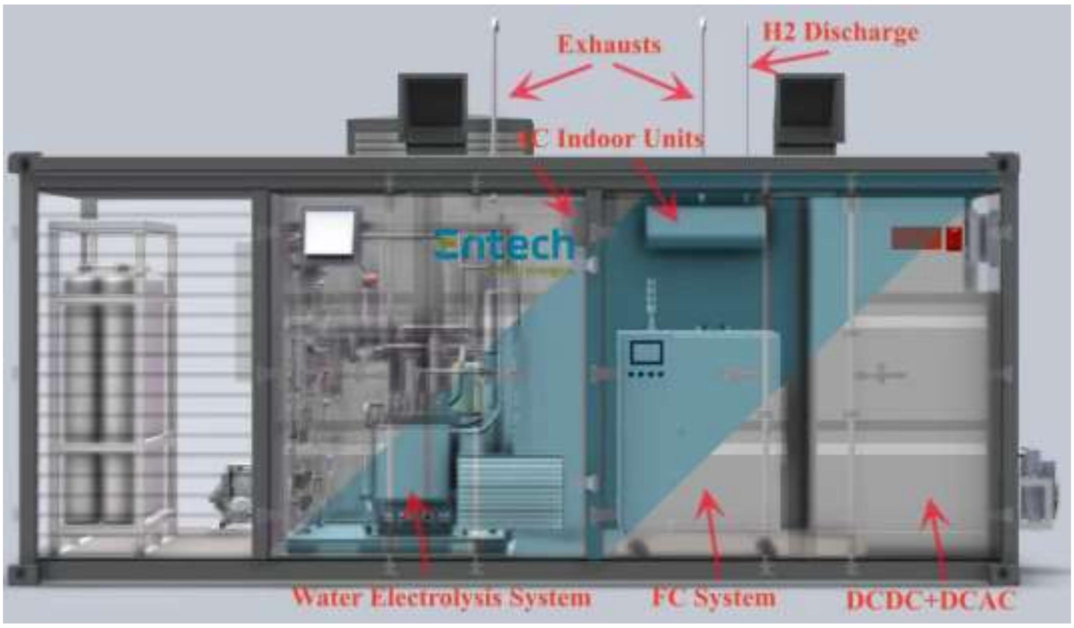


Figure 18. Front view of the system

Figure 19. Rear view of the system

The integrated equipment layout is illustrated in Figure 20 The setup is housed within a standard 20-foot container, measuring approximately 5996 mm in length and 2238 mm in width. In the layout, Zone A represents the hydrogen storage area, which includes a 10-container group (50L each), a buffer tank, compressor, manifold, and a nitrogen cylinder. Zone B encompasses the hydrogen production system—a 6 Nm^3/h PEM electrolysis setup equipped with chiller and explosion-proof air conditioning to maintain optimal temperature. Zone C is designated as the non-hydrogen production area, containing a 10 kW hydrogen fuel cell system, pure water system, electrolyzer power supply (DCDC), and junction box.

Both Zones A and B are hydrogen-associated areas and are fitted with safety measures, including hydrogen concentration alarms, smoke detectors, and fire suppression equipment (details provided in Section 2.4.5). This careful layout helps ensure safe operation by isolating the hydrogen-related equipment and maintaining temperature control with explosion-proof air conditioning across critical areas.

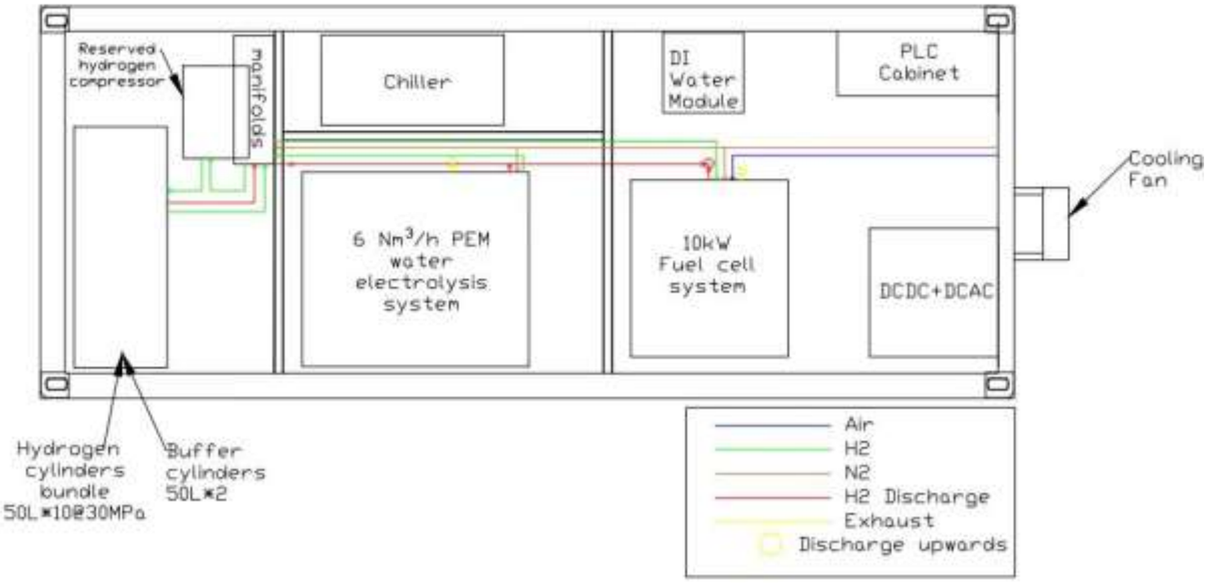


Figure 20. General Layout drawing of the integrated equipment

2.4.5 System Safety

Figure 21 illustrates the layout of the hydrogen safety systems within each designated area (Zones A, B, and C):

Zone A: This area contains the high-pressure hydrogen storage at 300 bar, buffer tank, nitrogen cylinder, and hydrogen compressor. It is equipped with safety measures to monitor hydrogen levels and prevent hazards. The system includes explosion-proof components, hydrogen concentration detectors, and alarms to respond promptly to gas leaks or safety issues.

Zone B: The PEM hydrogen production equipment here uses explosion-proof components (e.g., Exd II CT4) designed to meet safety requirements for hydrogen environments. The hydrogen-related area is separated from the non-hydrogen areas within the container. The system is fitted with both oxygen-hydrogen sensors and hydrogen concentration sensors, along with smoke detectors, to monitor operational conditions continuously, minimizing the risk of incidents.

Zone C: Divided into stack, system, and electronic control areas, the fuel cell system is safeguarded by isolated enclosures for each section. Safety equipment includes hydrogen concentration sensors, smoke alarms, a regular and an emergency exhaust fan, automatic hydrogen cut-off valves, an emergency shut-off valve, fire sprinklers, and dry powder extinguishers. Additionally, monitoring and alarm systems are in place to detect and respond to any dangerous conditions. Should the hydrogen concentration reach 0.08%, the system triggers an alarm; at 0.2%, the strong exhaust fan automatically activates. In case of fire, the system shuts down to ensure safety through a comprehensive safety chain design, supporting stable and secure operation of the power station.

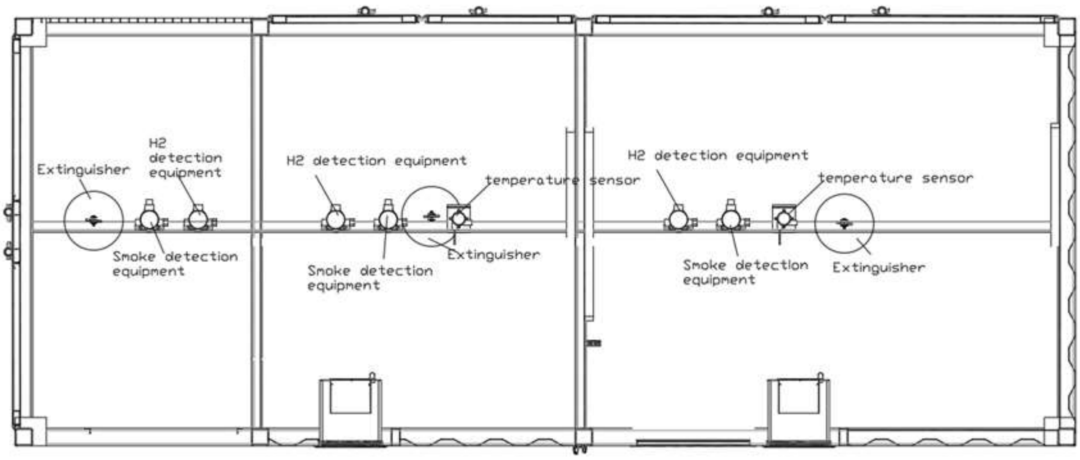


Figure 21. Hydrogen system safety system layout

2.5 Permitting and Regulatory Status

We have successfully completed all necessary regulatory and permitting processes for the hydrogen system installation at our industrial site. This includes obtaining approvals from the building owner and securing the appropriate certifications from the building's insurance provider to ensure all risk management aspects are adequately covered. In addition, we have submitted the required documentation to the municipality and received official municipal authorization, affirming that the hydrogen system installation meets all local safety and environmental regulations. This comprehensive permitting process ensures compliance with industry standards, building codes, and local regulations, providing a foundation for a safe and operational hydrogen system on-site.

2.6 Future Steps and Planned Timeline

The next steps are:

- System reception
- Fire and explosion risk management
- Finalize the PID/PFD and electrical scheme
- Finalize the necessary VRD
- System commissioning
- System operation and testing

2.7 Installation

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

2.8 Results and tests

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

2.9 Comparison with simulations

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

3 POWER-TO-HYDROGEN-TO-POWER COMPACT SYSTEM (IS 27)

3.1 Overview of the Solution

The EVELIXIA Energy Pack (EP) is a complete, containerized, turnkey, power to hydrogen to power system. Table 13 shows the system specifications.

It stores electrical power by generating hydrogen, storing it, and generating electrical power on demand as presented in Figure 22.

Table 13 Specifications

Parameter	Value
Power input	400 VAC 3-phase + N + PE @ 10 kW (peak)
Power output	48 VDC @ 10 kW (peak) (220A)
Electrolyser production rate	1600 NL/h @ 7kW
Fuel cell consumption rate	7600 NL/h @ 10kW
Power storage	40 kWh (2.6 kg H2 / 29000 NL H2)
Operating temperature	5°C - 45°C
Storage temperature	-10°C - 45°C

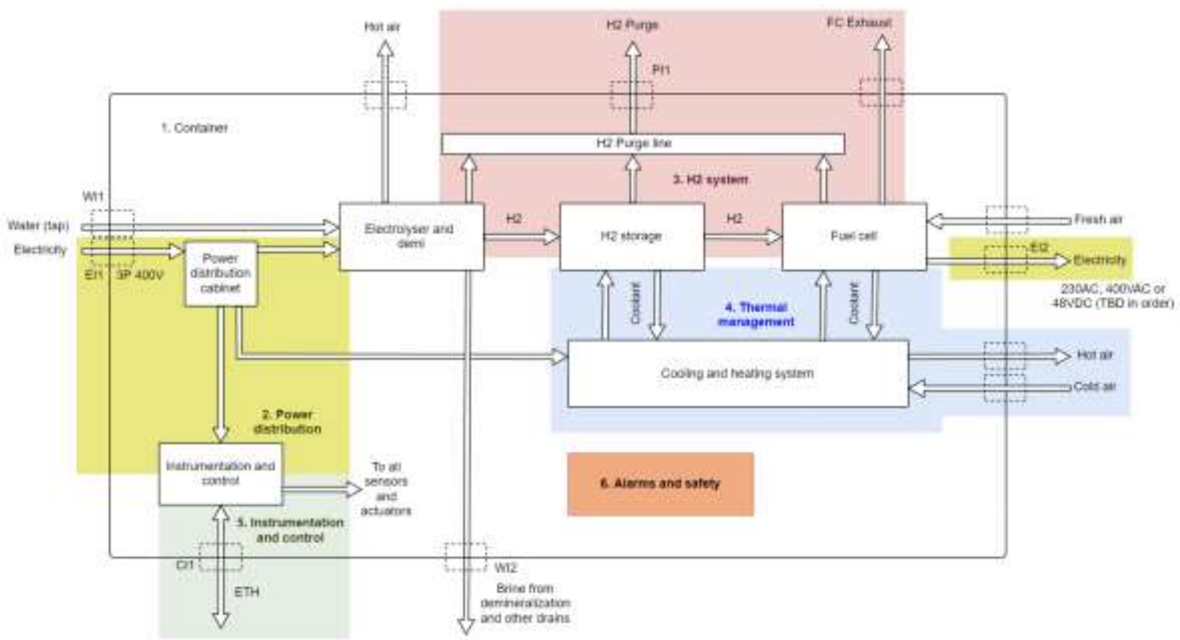


Figure 22. Hydrogen system operational diagram

3.1.1 Container

The system is assembled within a standard 10-foot container (Figure 23), in such a way that it continues to be standard and is able to be transported using multimodal shipping. This philosophy also facilitates the placement of the system by third parties, as no specific civil works will be necessary other than the general ones for the placement of stationary containers, and the system will be weatherproof on installation.

The system has a temperature rating of 5°C-45°C. In case the customer requires a wider temperature range, the system can be adapted on request.

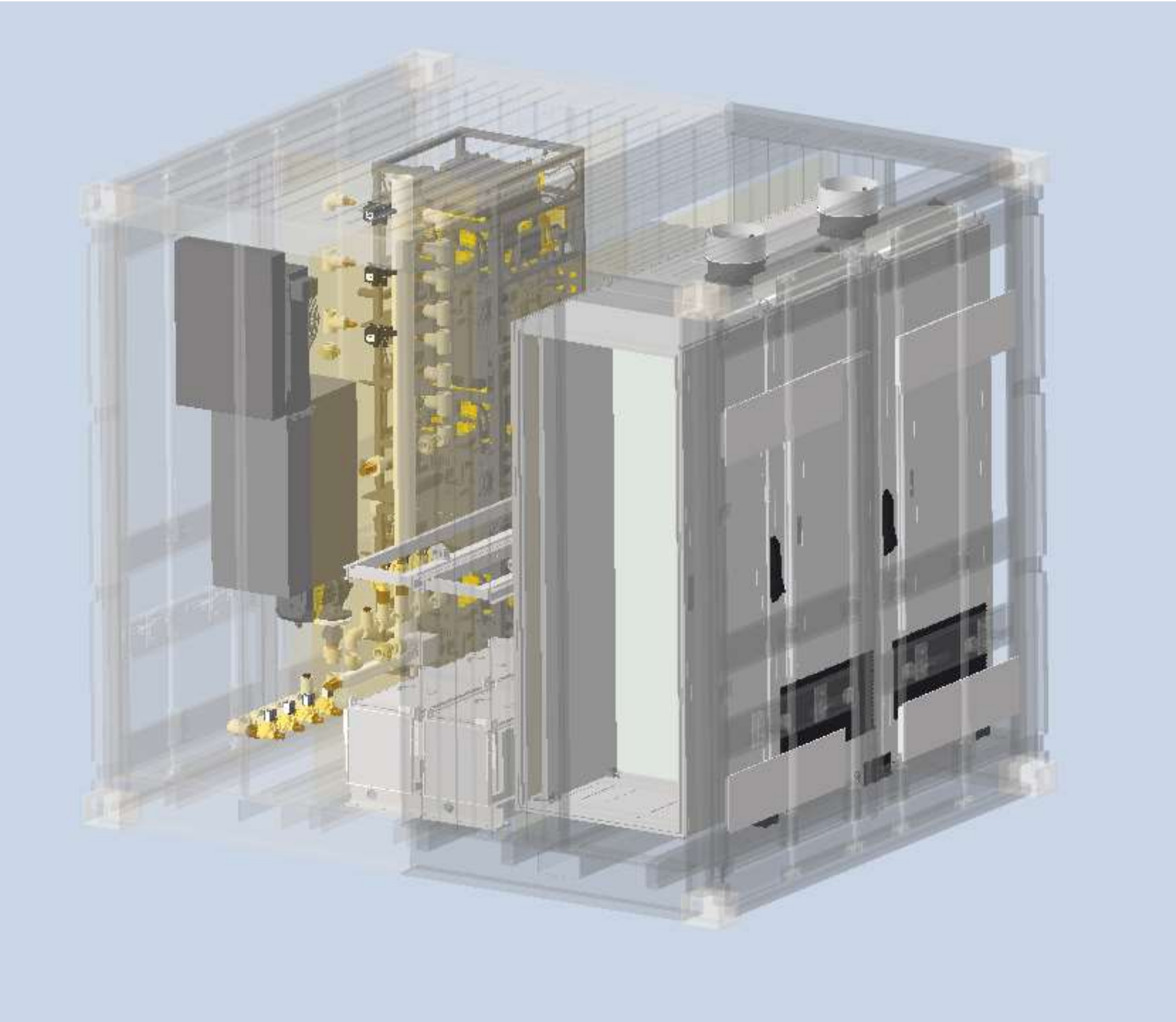


Figure 23. Container view

3.1.2 Power distribution

The Energy Pack, being a power-to-power system, has an electrical input and an electrical output. When the user decides, the system will consume electricity from the input and store it in the form of hydrogen or alternatively, consume the hydrogen to produce electricity.

The system absorbs three-phase mains supply at 400V at a power of 7kW. Additional power demand might rise to a peak of 2-3kW in rare cases and as such the supply should be able to provide a minimum of 10kW.

On the other side, a fuel cell converts the hydrogen to direct current, converted to 48VDC by a DC/DC. This voltage is common in battery systems, and as such, the voltage setpoint can be adjusted programmatically in order to follow the batteries' charge curve.

3.1.3 H2 system

The H2 system is the heart of the Energy Pack. It produces H2 at a rate of 0.3kg/hr, storing it into a Metal Hydride rack (MH) able to contain 1.7kg, by converting the gaseous hydrogen to a solid state. Finally, the hydrogen is brought to the fuel cell when required in order to generate electrical power.

The electrolyser and the fuel cell need to vent some hydrogen during normal operation. This hydrogen is released to atmosphere via the purging system. The metal hydrides have a separate, higher diameter line that allows them to discharge at a much higher rate in order to guarantee controlled depressurization in case of a sudden rise in pressure, such as due to a fire.

It is important to consult with local authorities before installation of the Energy Pack. There are legal requirements for the placement of systems storing flammable gases near occupied buildings, etc. and they must be complied with. BER gives its availability to provide all required information necessary for this part of the integration process.

3.1.4 Thermal management

The MH absorbs the hydrogen in an exothermic reaction, and as such it must be cooled in order to continue absorbing H2. On the other hand, when the MH releases hydrogen, it experiences an endothermic reaction and it must be heated in order to maintain its pressure. This heat comes from the inefficiency of the FC and as such no extra energy must be added to the system for this purpose. The excess heat from the system is released to the outside via a radiator. A resistive heater is also added to the system in order to provide heating or increase the MH gas pressure during cold weather. If required, BER can provide a hot water source to use the waste heat from the container.

3.1.5 Instrumentation and control

The system contains dozens of sensors and actuators which are managed by a central industrial PLC. This PLC autonomously manages the functioning of the system and provides the user with a simplified high-level interface that allows them to control the system in an easy and safe manner, minimizing the risk of human error during operation. To control the unit, the user can either connect to a secure GUI hosted on a separate device from the PLC, or use a direct Modbus connection using an Ethernet cable. The industrial PLC which manages the safety and operation of the system has no direct connection with the Internet, which renders it secure against cyberattacks.

3.1.6 Alarms and safety

Since hydrogen is a dangerous substance, the development of this system is fundamentally structured around the safety and integrity of the device. During development and before commissioning, risk assessments are done internally and with external consultants, which ensure that all adequate procedures are followed and the system complies with a standard higher than the current state of the art.

The system has multiple risks, which include, but are not limited to:

3.1.6.1 Overpressure

Since the system contains gas at around 35 bar, there is a risk of overpressure. This risk is managed using the following layered approach:

The system is constructed using stainless steel pipes and fittings capable of withstanding pressures up to the hundreds of bar, which no part of this system is capable of producing;
The system contains certifies pressure transmitters which bring the system to alarm if a certain pressure is surpassed for any reason;
The system contains pressure switches which trigger the SIL 2 emergency loop, opening the multiple hydrogen venting electrovalves, removing the loads and supply to all systems and locking the system;
There are multiple mechanical safety relief valves which open at a specified pressure;
All eligible pressure vessels are certified as compliant with the Pressure Equipment Directive and are tested at 1.2 times the rated pressure of the relief valves.

3.1.6.2 Explosive gases

Hydrogen is explosive and a leak, combined with a source of ignition, can cause an explosion. This risk is managed in the following way:

The MOSE system is compliant with ATEX since it has enough ventilation to be considered Zone II NE. The ventilation is redundant and checked with an air flow meter connected to the SIL 2 emergency loop of the system. Additionally, it has an H2 presence sensor which is also connected to the SIL 2 emergency loop;
The Fuel Cell cabinet is heavily ventilated in a similar way and also contains a hydrogen sensor connected to the emergency loop;
The Metal Hydride cabinet is an ATEX Zone II and as such all components contained within it are certified ATEX IIC and are integrated in a compliant manner, using barriers when required;
When the system goes into emergency mode, all hydrogen in the FC and MOSE cabinets is vented and the only hydrogen which remains is in the Metal Hydride ATEX zone II;

The control and cooling cabinets are monitored using differential pressure sensors to be at a higher pressure than the cabinets containing hydrogen, ensuring no leaks can go from one to the other;
The outside vents are positioned in such a way to avoid the exchange of possibly contaminated air from one to the other.

3.1.6.3 Electrical

The electrical system contains multiple sensors and safety elements in order to secure the system in case of any unexpected behavior. The system also has grounding of all steel parts and piping, in order to minimize the risk posed by static electricity, and redirect lightning that could land on the container.

3.1.6.4 Other

There are flood sensors in the necessary areas. Temperature sensors are also included to ensure the system only operates in adequate environments.

3.1.7 VISUAL INDICATORS

The machine communicates state visually in accordance to IEC 60073 by means of a stack light positioned on top of it, with the following color code:

CONTINUOUS GREEN: Power to H2
FLASHING GREEN: H2 to power
WHITE: Idle
YELLOW: Warning
RED: Alarm (is accompanied by siren until it is reset)

3.2 Sizing and Technical Studies

3.2.1 Safety Study

When dealing with flammable or explosive gases the ATEX Directive must be followed. This directive defines a system of zone classification according to possible leaks and ventilation systems. This system produces a specific class for each zone of the system, and all components and systems within those zones must be certified to be used in that specific class. For the system we have defined 5 zones.

The zones containing hydrogen are FC, MH, and EL. CO and EC are considered safe (non ATEX) areas since they are physically separated from the other ATEX zones. In order to maintain this separation, care must be taken to avoid all possible flows of hydrogen from the ATEX areas to the safe areas using effective sealing techniques and adequate engineering practice to keep differential pressures or air inlets/outlets from carrying contaminated gas between vanes. The EL system has its own CE certification (and thus, is compliant with the ATEX Directive) and independently monitors its own airflow so only the FC and MH compartments will be analyzed.

Zones 0 and 1 require very stringent measures and the items certified to be placed within them are very costly. Furthermore, they require very exhaustive certification which also adds significant cost to the system. For this reason, we will aim to classify all zones as Zone II or NE Zones (negligible extent). To achieve this we aim to have the smallest grade of release and the highest and most available ventilation.

The grades of release are defined on IEC 60079-10-1 as

- **continuous grade of release:** release which is continuous or is expected to occur frequently or for long periods
- **primary grade of release:** release which can be expected to occur periodically or occasionally during normal operation
- **Secondary grade of release:** release which is not expected to occur in normal operation and, if it does occur, is likely to do

so only infrequently and for short periods

In all relevant zones the grade of release is defined as SECONDARY. This is because there are no items that release hydrogen to the outside in normal operation modes, and such a release can only happen due to a fault.

In order to evaluate the degree of ventilation for each ATEX zone and ensure they fall into the desired classification; we use a calculation sheet that includes the area of the compartment and the airflow. The following plots show the result of the preliminary calculations. The full definitive calculations will be provided in the Technical Book.

3.2.1.1 FC COMPARTMENT

Table 14 shows the specifications of the FC.

Table 14. Specifications of the FC

VARIABLE	VALUE
OPERATING PRESSURE	45 bar
DISCHARGE COEFFICIENT	0.9
CROSS-SECTION OF OPENING	2.50E-7
TEMPERATURE	45 °C
CROSS-SECTION OF VOLUME	2 m2
VOLUME	4.8 m3
VENTILATION FLOWRATE AFTER P LOSSES	2000 m3/h

Secondary release + high dilution + good availability = NON-HAZARDOUS (ZONE 2 NE)

In order to guarantee that the non ATEX certified components in the fuel cell compartment function only when there is no explosive atmosphere, a safety function is created which uses a timed safety relay to monitor the air flow. When the user attempts to turn on the fuel cell, the fan is turned on immediately; this flow is monitored by an air flow switch, which is itself monitored by the safety relay; if airflow is sensed for a specified period of time, hydrogen is allowed in the compartment, and the fuel cell is connected to the external electrical loads. Furthermore, if the emergency stop circuit is opened the system also is stopped via multiple pathways. Finally, if the system detects that the fan is not on when it should be, it will throw a fatal error via software and the system will be locked until it is inspected. This is not a safety function since it does not create a dangerous situation as the FC is never turned on if there is no flow regardless.

3.3 Future Steps and Planned Timeline

3.4 Installation

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

3.5 Results and tests

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

3.6 Comapraison with simulations

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

4 VEHICLE-TO-GRID EV CHARGER (IS 26)

4.1 Overview of the Solution

Vehicle-to-grid (V2G) technology has gained significant attention due to the increasing number of electric vehicles (EVs) entering the market. EVs can function either as energy sources or specific electrical loads, providing support for load-balancing grid services. These services include regulating active and reactive power while enhancing grid stability and reliability.

TUCN will showcase the cost-efficiency of the V2G system under vehicle-to-building (V2B) conditions. This approach leverages the energy stored in EV batteries during peak electricity demand periods to reduce power costs for facility operators, who face high consumption charges during these times. Additionally, the V2G EV charger software will integrate with TUCN's local Building Energy Management System (BEMS) to demonstrate an effective demand response V2G solution.

4.2 V2G Legislation at the European level and in Romania

In Europe, the specific V2G regulations are still under development, although, there are a lot of initiatives at the European level that reflect the EU's commitment to create an enable environment for V2G technology, aiming to enhance grid flexibility, support renewable energy integration, and promote the widespread adoption of electric vehicles.

- The Agency for the Cooperation of Energy Regulators (ACER) proposed Grid Code Amendments: These amendments aim to establish uniform grid connection requirements for electric vehicles (EVs) and electric vehicle supply equipment (EVSE), facilitating the integration of V2G technology across Europe. The proposed changes are expected to be implemented by the end of the decade, enhancing grid stability and enabling EVs to provide ancillary services such as frequency regulation and reactive power compensation.
- The EU Regulation 2023/1804 mandates that member states assess options for integrating EVs with the power grid using V2G technology. This

assessment is a critical step toward creating a cohesive strategy for V2G deployment across the EU.

V2G adoption is still in its early stages in many European countries. Denmark has been a pioneer in V2G technology, many projects have demonstrated V2G capabilities in real-world settings, contributing to Denmark's leadership in this field. In UK, the programs to support EV adoption and V2G integration were adopted since 2011, but the lack of cars on the market that support this technology has led to a small number of V2G stations on the UK. In late 2024, Nissan announced plans to introduce affordable on-board bi-directional charging in selected electric vehicles (EVs) starting from 2026. This initiative aims to make V2G technology more accessible to consumers, allowing EVs to feed electricity back into the grid and support energy sustainability efforts. In Europe, France is at the forefront of V2G adoption, supported by favourable regulations and active projects. Germany is actively pursuing V2G integration and Italy is preparing for V2G technology with significant trials, such as the Fiat-Chrysler V2G Project and with the upcoming TIDE Act in 2025, V2G will be allowed to provide flexibility services.

Romania has not yet implemented specific legislation governing Vehicle-to-Grid (V2G) technology. However, the country is actively advancing its renewable energy infrastructure and electric vehicle (EV) ecosystem, laying the groundwork for potential future V2G integration. Romania plans to install at least 30,000 recharging points for electric vehicles by mid-2026, as outlined in the National Recovery and Resilience Plan. This initiative aims to consolidate the national infrastructure for alternative fuels in road vehicles.

In July 2024, Romania enacted Law 255/2024, requiring prosumers with photovoltaic (PV) systems ranging from 10.8 kW to 400 kW to install energy storage systems. Existing prosumers with installations between 3 kW and 400 kW must comply by December 31, 2027, or face limitations on electricity exports to the grid. The mandated storage capacity is at least 30% of the PV system's capacity for installations between 3 kW and 200 kW, and at least 50% for those between 200 kW and 400 kW. In May 2024, the Romanian Ministry of Energy initiated efforts to develop legislation supporting energy communities. This move aims to empower citizens to access renewable energy, either through personal production or as part of local energy communities, thereby reducing costs and dependence on traditional energy sources.

While V2G-specific regulations are not yet in place, these initiatives reflect Romania's commitment to enhancing its renewable energy framework and EV infrastructure. However, there are unique local policies and procedures in Romania that encourage the incorporation of V2G technology into the national grid. These efforts may facilitate the future adoption and regulation of V2G technologies.

A list of legal rules is provided below:

- **1. EU Directive 2018/2001 (Renewable Energy Directive)**
  - Encourages the use of renewable energy sources, which is key for the growth of EVs and the development of V2G technology.
  - Supports the integration of energy storage technologies, like electric vehicle batteries, into the power grid.
  - Establishes a common framework for the promotion of renewable energy in the EU and set a binding target of 32% for the overall share of renewable energy in the EU's gross final energy consumption in 2030.
- **2. EU Regulation 2024/1747 (Electricity Regulation)**
  - Focuses on creating a more integrated and competitive electricity market within the EU.
  - Encourages the use of distributed energy resources, such as V2G, to support grid stability.
- **3. Romanian Energy Law (Law 123/2012)**
  - The main framework for the energy sector in Romania.
  - Provides rules for electricity generation, distribution, and supply, which would be important for the integration of V2G systems in Romania.
  - Specific terms are defined, and projects are encouraged to improve the efficiency of electricity consumption and sustainability in Romania.
- **4.** Romania has recently updated its **National Energy Strategy,** replacing the 2019-2030 framework with a new strategy **covering 2025 to 2035, with projections extending to 2050.** This marks the first comprehensive energy strategy adopted by the Romanian government in 17 years.
  - Emphasizes Romania’s commitment to reducing carbon emissions and increasing renewable energy sources, aiming for a 41.1% share in gross final energy consumption by 2035 and an impressive 86.1% by 2050..

- Supports the development of green energy solutions like V2G chargers to help balance supply and demand in the electricity market.

This updated strategy reflects Romania's commitment to transitioning towards a sustainable, secure, and competitive energy system, aligning with broader European Union climate and energy objectives.

- **5. EU Regulation 2016/1447 (Regulations on the Connection of Distributed Generation)**
  - The directive establishes standards for connecting dispersed generating systems, including V2G technologies, to an integrated electrical grid and outlines energy distribution measures throughout EU Member States.
  - Defines technical requirements for the safety and reliability of such systems.
  - They are updated annually and are based on EC 714/2009.
- **6. Romanian Grid Code ANRE-MV480 Romania MV**
  - Shapes the technical standards for connecting to the national grid, including new technologies like V2G.
  - Includes technical rules for the operation of the national electricity system.
- **7. EU Green Deal and Fit for 55 Package**
  - The package updates EU climate and energy legislation to meet the objective of reducing greenhouse gas emissions by 55% by 2030 and implementing the Green Deal. The Package follows the EU's Climate Law, which aims to achieve climate neutrality by 2050 and a 55% decrease in emissions by 2030.
  - Romania is committed to these EU-wide targets, which could further support the development of V2G systems.
- **8. Romanian Public Procurement Law (Law 98/2016)**
  - The legislation oversees the procurement of public sector projects, including those for installing electric car charging infrastructure.
  - Municipalities are encouraged to implement energy-efficient initiatives, such as PV panels and EV charging.
- **Overview of V2G Regulation Landscape in Romania:**
  - **Incentives for EVs**: Romania offers financial incentives and subsidies for purchasing electric vehicles.

- **Grid Integration**: Technical guidelines and standards are being developed to guarantee that V2G chargers work with Romania's electrical infrastructure.
- **European Union Alignment**: Romania complies with EU regulations promoting energy storage, decentralized electricity production, and green energy technology as a member of the EU.
- **Energy Strategy:** By prioritizing green technology and renewable energy, Romania's energy strategy fosters an atmosphere that is conducive to the deployment of V2G systems.

Currently, there are few vehicles on the market that offer V2G capabilities allowing them to discharge electricity back to the grid. Notable models are Nissan Leaf, Ford F-150 Lightning, Hyundai Genesis, Kia Models, Mitsubishi Outlander, Renault 5 E-Tech and Alpine A290. V2G functionality requires compatible bidirectional charging equipment and may depend on local grid infrastructure and regulations. As the technology evolves, more EV models are expected to incorporate V2G capabilities, contributing to grid stability and energy efficiency.

4.3 Sizing and Technical Studies

Giving the fact that there is no specific secondary regulation at Romanian level for the V2G technology and also there are not so many car models that support V2G capabilities, it was very difficult to find on the market a V2G system. So, first TUCN decided to create its own prototype and to use it together with a battery in one of the laboratories of the university, thus demonstrating the cost-efficiency of the V2G system under vehicle-to-building (V2B) real conditions.

4.3.1 Design of the Charger System

In order to simulate the initial capability that the project wanted to achieve; we proposed the following solution presented in Figure 24:

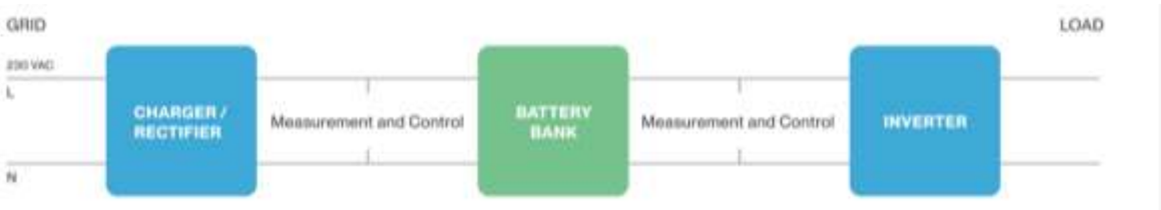


Figure 24. The block scheme for the V2G system prototype

The block diagram represents a battery energy storage system (BESS) with power conversion components for managing energy flow between the grid, a battery bank, and the load. The Charger/Rectifier, with an installed power of 6.2kW, converts AC power from the grid (230 V AC) into DC power to charge the Battery Bank, this includes measurement and control functions to regulate charging conditions. The Battery Bank of a capacity of 5kWh and a voltage of 200 V DC stores energy in DC form for later use and interfaces with control and measurement systems to monitor charge levels and energy flow. The block also includes the inverter.

Taking into account that we intended to build our own prototype, we decided to decrease the power from 22 kW to 6.2 kW. The proposed system acts as a backup power system, storing excess electricity for later, converts AC to DC for charging and DC to AC for load usage, interacts with the grid like a renewable energy system, stores energy and supplies it when needed. Also, the system has the bidirectional flow possibility, this system can be used for Vehicle-to-Grid (V2G) or Grid-to-Vehicle (G2V) applications.

We have done the preliminary simulations for analysing the electrical system performance (Figure 25).

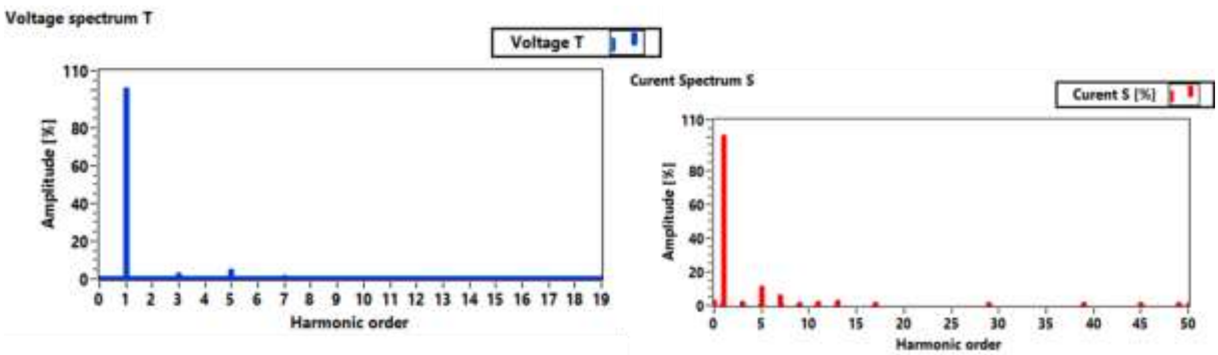


Figure 25. Recorded signal’s voltage and current harmonic spectrum

Funded by the European Union

In the following step we intended to build this V2G prototype, but using this idea, the full capability of a V2G system could not be demonstrated, so we come back to the original idea of the project, to test a real V2G system of 22kW. The charger, according to the specifications of the Grant Agreement, has a power of 22 kW connected to 3-phase supply system (Figure 26).

Figure 26. V2G electric charger – Twin5 Plus Model

The chosen charger is a premier electric vehicle (EV) charging station designed to meet the demands of both business and public environments. This model introduces advanced features and enhanced capabilities to set a new standard in EV charging infrastructure.

Equipped with a full-color 7-inch HD LED display, it provides clear and accessible information to users. The station supports direct payment through dynamic QR codes, enabling users to initiate and pay for charging sessions seamlessly. Transparent, upfront pricing is displayed prominently, ensuring clarity and trust in the transaction process. The Twin 5 Plus offers triple-phase charging with options for 11kW or 22kW speeds, catering to various vehicle requirements. It is fully compliant with the Alternative Fuels Infrastructure Regulation (AFIR), ensuring it meets current European standards for EV charging stations. The station is also prepared for bidirectional power transfer, supporting vehicle-to-grid (V2G) technology, which allows energy to flow from the vehicle back to the grid, promoting energy efficiency and sustainability.

Figure 27 presents the main technical specifications of the charging system.

Energy meter, per socket	MID certified 4 quadrant meter
Supported power systems	TN-S, TN-C-S, TT, IT * 3 x 230 V / 400 V +N 3 x 230 V w/o N
Nominal output voltage (+/- 10%)	400 V (3 x 230 V)
Maximum design current per socket	32 A per phase
Maximum design power	1-phase: 7.4 kW 3-phase: 22 kW

Figure 27. Technical specifications of the charging system Twin 5Plus

Futureproofing is also a key aspect of Twin 5 Plus. It comes equipped with ISO 15118 communication capabilities, facilitating advanced features such as Plug & Charge, where the vehicle and charger communicate seamlessly to authenticate and authorize charging sessions without user intervention. The station's hardware is designed to be compatible with emerging technologies.

Figure 28presents the communications protocols compatible with the V2G system.

Communication and Protocols

Controller board	Alfen Hardware Platform v1
Vehicle communication	Mode 3 in accordance with IEC 61851-1 ed 3 (2017) ISO 15118 communication (optional)
RFID reader	ISO/IEC 14443A/B, 13.56 MHz MIFARE Classic 1K/4K, MIFARE Ultralight, DESFire (EV1/EV2) Maximum length: 7 bytes
Internet/networking possibilities	GPRS 2G LTE Cat M1 4G Ethernet/LAN

Figure 28. Twin 5Plus's Communication protocols

4.3.2 Energy Flow Simulations and Grid Integration

For simulations, an earlier developed custom energy management algorithm was used to simulate the controlled charge and discharge rates and times of the EV to provide energy flexibility for the building.

The simulations have been run under the following conditions: The state of charge of the present EV to not fall under 10% of total capacity and at time of departure, the EV to have been charged at least 30% over the initial charge. In terms of initial conditions, the following parameters were considered: In all cases, the EV arrives at the charging station with an initial charge of 40% of its total capacity of 60 kWh.

In the simulations cases, 1 to 3, the EV arrives at the charging station at 7 AM and departs at 4 PM. In the last scenario the arrival time is considered 2 PM and departure time is considered 10 PM. The charging and discharging limits are considered 22 kW as per the technical requirements mentioned in the Grant Agreement.

Table 15 and Table 17 show the cost, general consumption and optimized consumption values for cases 1 and 2.

All simulations have been done with real consumption data, recorded from the pilot site, and the simulate output of the PV pannels which are to be installed at the student building through the EVELIXIA project (17kWp). For the simulations the following days were arbitrary chosen: 20th September 2024, 15 October 2024 and 23rd of November 2024 with their respective day ahead prices per hour for energy.

Table 15 CASE I

Results 23.11.2024 (Case 1)			
Hour	Cost [EUR/kWh]	General consumption [kWh]	Optimized consumption [kWh]
1	0.094002	71.979	71.979
2	0.085776	72.96	72.96
3	0.08	68.724	68.724
4	0.081966	73.07	73.07
5	0.08	58.934	58.934
6	0.087432	62.445	62.445
7	0.102528	61.229	61.229
8	0.109926	94.565	71.065
9	0.107294	66.596	55.596
10	0.08522	70.723	76.223
11	0.07957	67.231	71.531
12	0.075864	67.394	86.074
13	0.07379	74.574	84.274
14	0.086596	76.331	86.031
15	0.106896	94.075	88.575
16	0.134802	83.681	75.801
17	0.17016	97.068	97.068
18	0.178048	106.044	106.044
19	0.178048	106.484	106.484
20	0.178044	115.208	115.208
21	0.15063	110.38	110.38
22	0.124634	93.511	93.511
23	0.10855	87.635	87.635
24	0.095896	78.136	78.136

The graph from Figure 29, represents the optimized EV Charging/Discharging on the November, 23, 2024, showing the State of Charge (SOC) percentage of an electric vehicle over a 24-hour period.

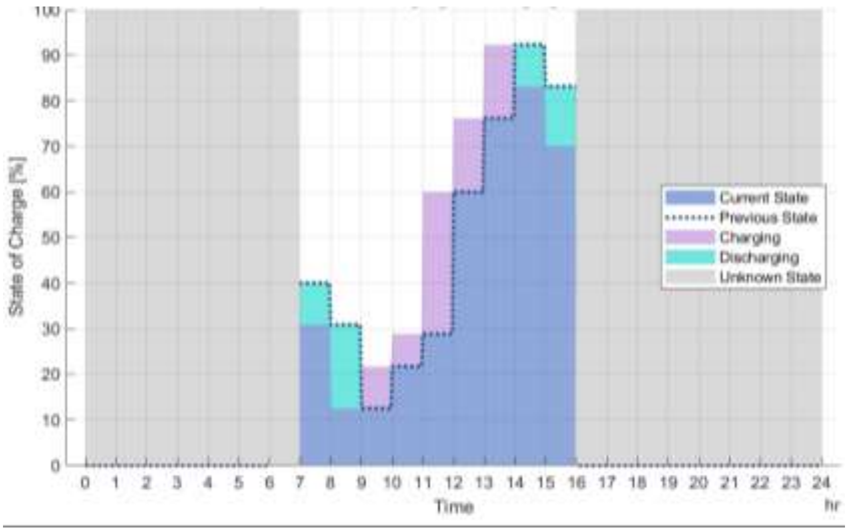


Figure 29. Optimized EV Charging/Discharging on 23/11/2024

Analyzing the graphs one can see that, early in the morning (0-6 AM), there is no activity (gray area), indicating that the vehicle is off grid. Between 6-10 AM, a discharging event occurs (green): The battery SOC drops from around 40% to 20% between 6:30 and 9:00 AM. Possible use case: The EV is supplying power to the grid or being driven. In the interval 10 AM-2PM, there is a charging event (purple): SOC increases significantly, reaching around 85% by 2 PM.

This suggests an optimized charging strategy, likely using solar energy or lower-cost electricity. In the afternoon (2-4PM), a small discharging event (green) occurs, reducing SOC slightly before stabilizing. In the evening and night, no significant changes (gray area again), indicating that the vehicle is idle.

Figure 30 shows the energy demand, grid imports, EV charging/discharging, and solar power utilization over 24 hours for November 23.

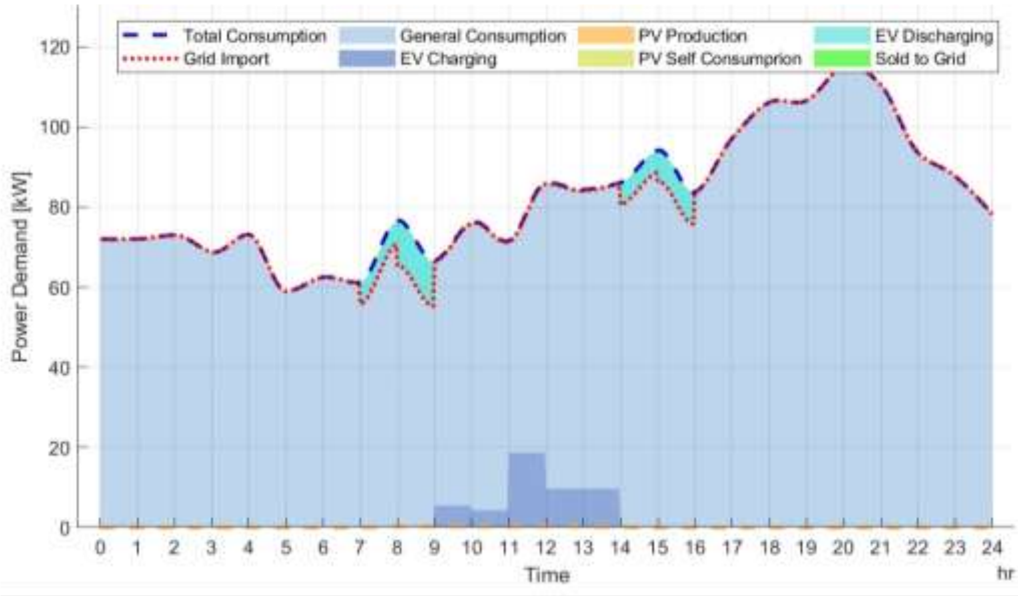


Figure 30. Power flow optimization

The blue dashed line represents total consumption, while the red dotted line shows grid imports. EV charging (blue shading) occurs between 10 AM - 4 PM, likely utilizing solar power, and EV discharging (light green) happens around 8 AM and 3 PM to reduce grid dependency. Solar PV production (yellow) peaks midday, with some energy self-consumed and excess sold to the grid (bright green).

This optimization strategy helps balance energy costs, grid stability, and renewable energy use efficiently.

PV production for the respective day clearly shows that, the EV is charging from the solar power (Figure 31).

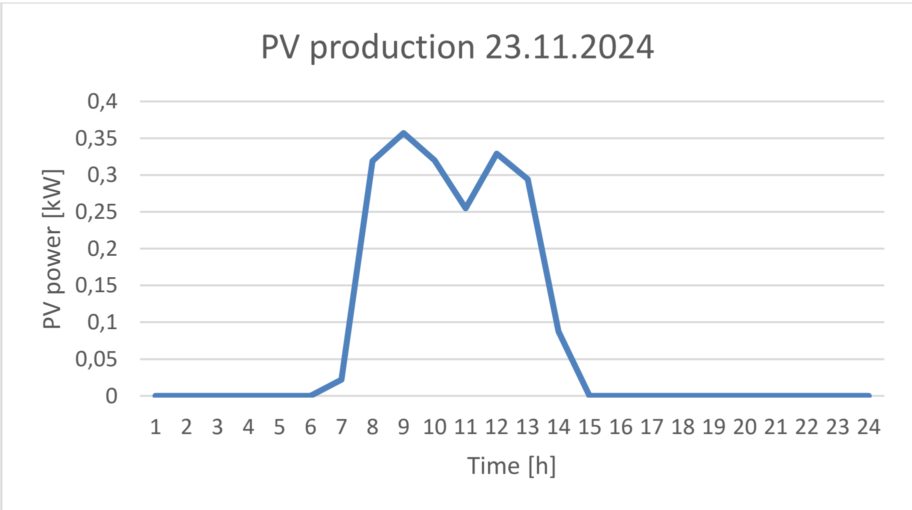


Figure 31. PV generation in November 23, 2024

Table 16 shows the energy savings for CASE I.

***Table 16* Energy savings for CASE I**

Cost EV [EUR]	228.5992
Cost EV optimized [EUR]	226.9693
Cost saving [EUR]	1.6299

***Table 17* CASE II**

Results 15.11.2024 (Case 2)			
Hour	Cost [EUR/kWh]	General consumption [kWh]	Optimized consumption [kWh]
1	0.089152	63.804	63.804
2	0.08511	50.664	50.664
3	0.084778	54.435	54.435
4	0.081092	47.715	47.715
5	0.077214	61.724	61.724
6	0.08607	90.697	90.697
7	0.114852	76.038	76.038
8	0.18958	117.468	84.208
9	0.174342	92.106	90.646
10	0.109986	104.23	104.4
11	0.09	103.061	110.041
12	0.08264	95.499	89.999
13	0.078084	113.215	118.285
14	0.071674	123.097	145.097
15	0.077142	111.638	127.808
16	0.089726	111.786	101.616
17	0.116318	112.475	112.475
18	0.160124	126.985	126.985
19	0.190052	134.475	134.475
20	0.199008	140.064	140.064
21	0.13426	137.067	137.067
22	0.105222	126.343	126.343
23	0.087998	136.49	136.49
24	0.071948	95.489	95.489

In this case, a day from October is considered. In this day, from the optimization EV charging/discharging graph (Figure 32) we can conclude that at the start of the day, the state of charge is stable and relatively low, around 30%. The charging events are around 7:00 AM, and around 3:00 PM, bringing the SoC close to 100%. The discharging events occur between 8:00 AM and 10:00 AM, the battery discharges, reducing the SoC significantly and a smaller discharging period occurs around 1:00 PM. The current optimized schedule differs from the previous state, as shown by the dashed line, indicating adjustments in charging/discharging timing or rates.

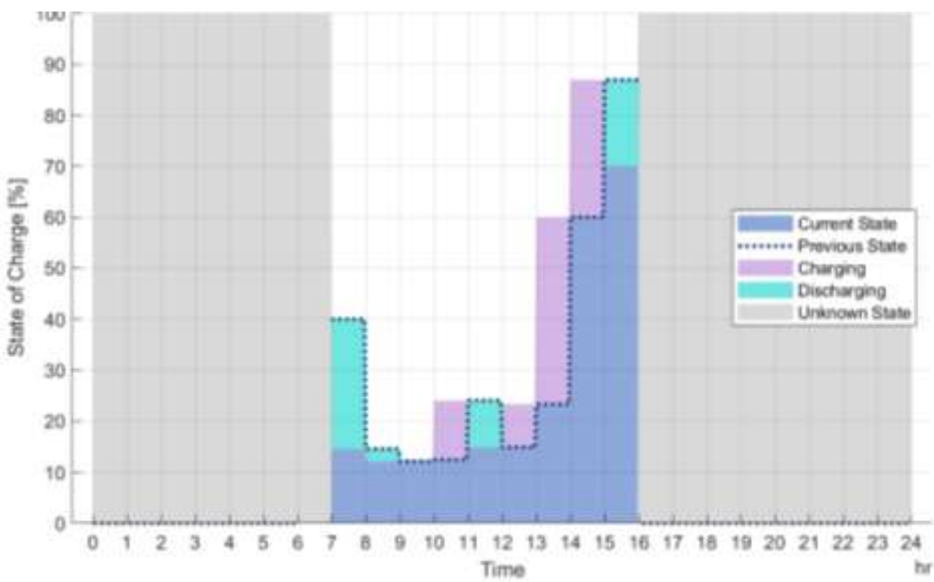


Figure 32. Optimized EV Charging/Discharging on 15/10/2024

The optimized energy flow is shown in Figure 33 below.

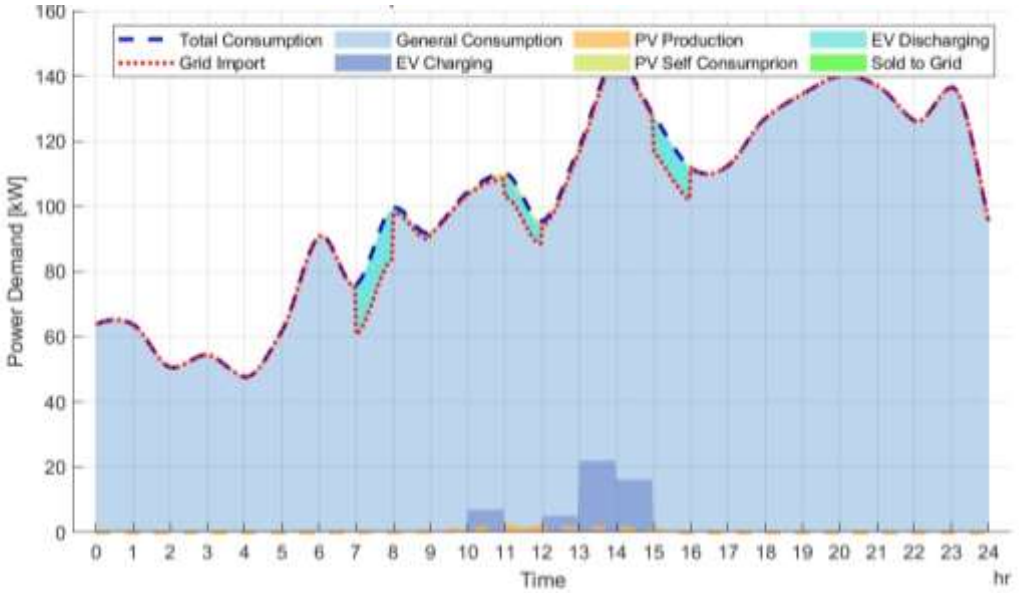


Figure 33. Optimized power flow, October 15, 2024

This graph shows optimized power flow on 15.10.2024, balancing energy demand and sources: The cost saving for this case is about 4,0600 EUR/day.

The third day chosen is September 20, 2024. In this case we considered two scenarios: first the EV arrives at the charging station at 7 AM and departs at 4 PM. In the second scenario the arrival time is considered 2 PM and departure time is considered 10 PM.

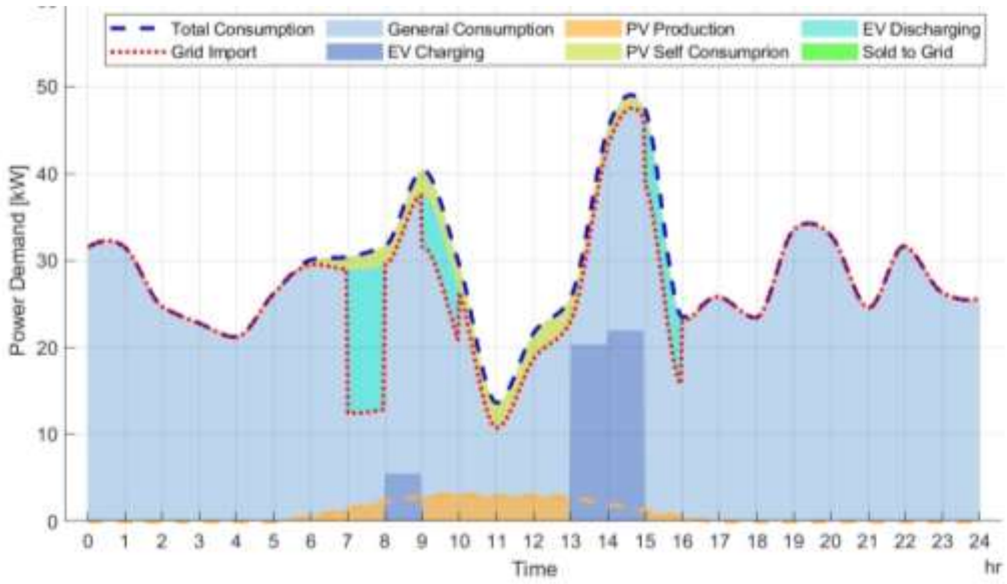


Figure 34. Optimized Power flow – first scenario

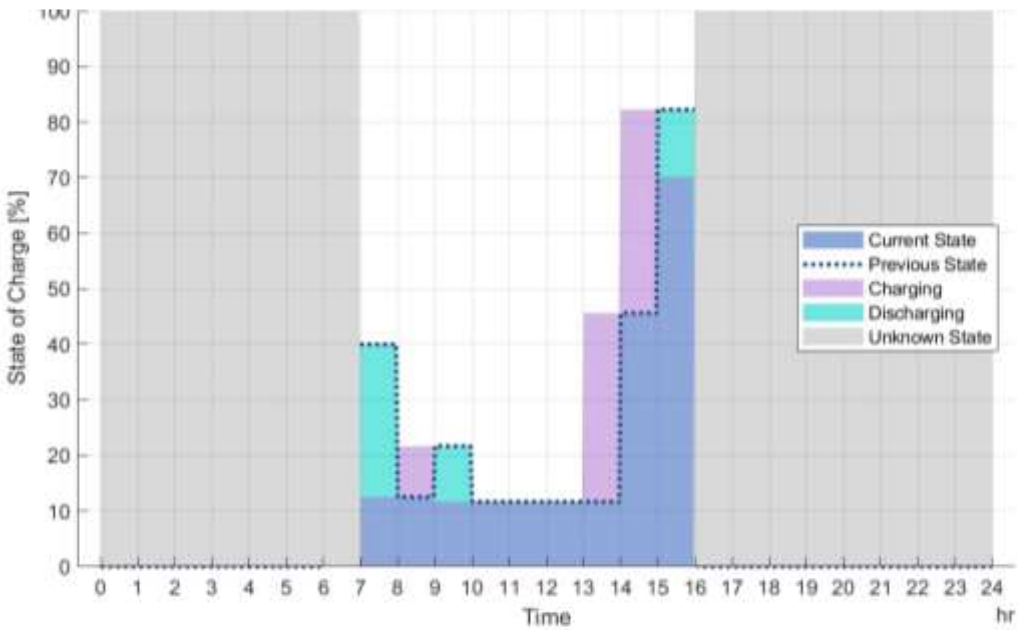
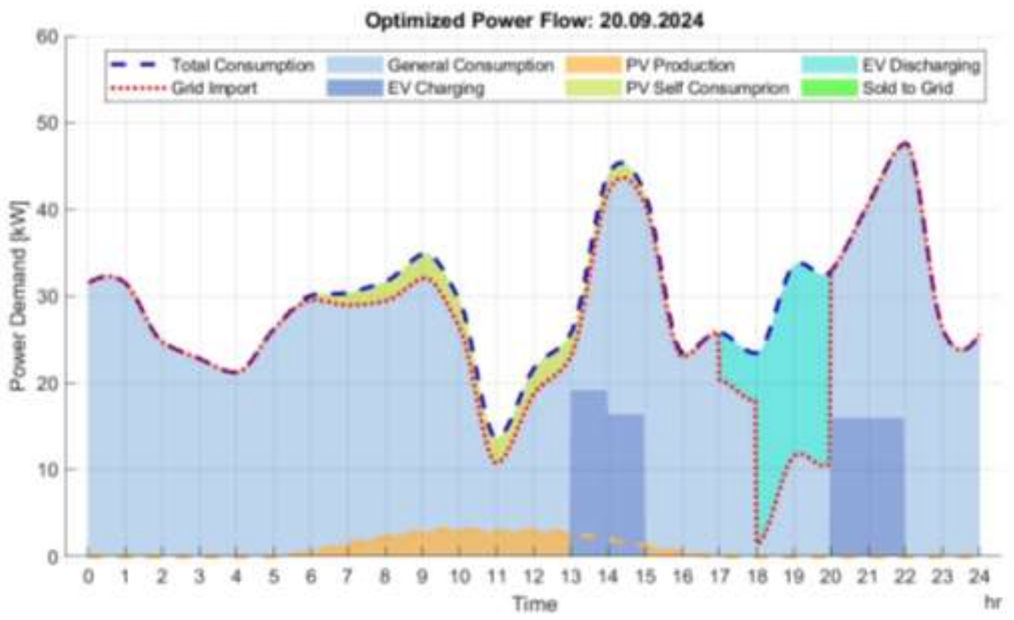
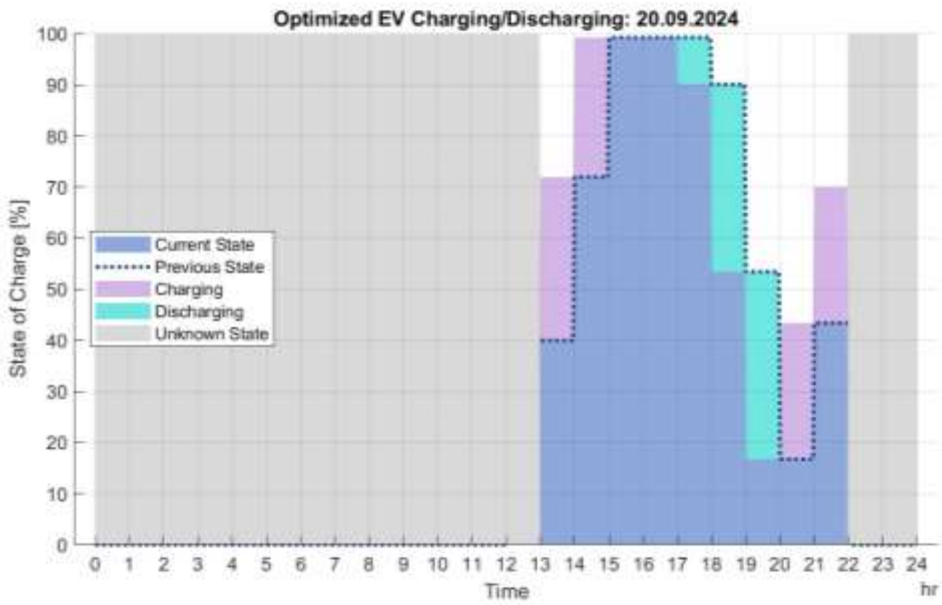


Figure 35. Optimized EV charging/discharging – first scenario

For the second scenario below is the power optimization flow and EV charging/discharging (Figure 36).



(a) Optimized Power Flow,



b) EV Charging/Discharging

Figure 36. EV Charging Profile (September 20, 2024)

In this case, the solar PV energy significantly reduces reliance on the grid during daylight hours. The EVs play a dual role:

Charging during low-demand periods.

Discharging during high-demand periods to optimize power flow.

The system balances demand and supply through a combination of PV production, grid imports, and EV energy management. This graph highlights an optimized strategy for integrating renewable energy (PV) and electric vehicles into the grid to reduce dependency on external power sources and enhance efficiency.

In this scenario, the saving cost is about 6,72 EUR/day.

In terms of results, over the four cases of the simulations, TUCN would have achieved a total saving of 17,54 EUR or an average of 3,51 EUR per day just by using the discharge flexibility that the V2G system provides.

4.4 Supplier Selection and Procurement Planning

In the context of acquiring a charging station capable of bi-directional energy transfer and capable of running at the quoted power, TUCN has made efforts for over 10 months asking for quote from at least 5 different equipment providers including local as well as international. Until recently, TUCN has not been able secure such a quote due to the fact that V2G chargers as well as electric vehicles that can work in such a regime are not widespread on the market. Because of this lack of demand, naturally, suppliers did not have stocks or relations with manufacturers that produced these chargers for niche application.

At the beginning of this year, we got an offer from a company, the V2G system described above, and we are about to purchase this station, so we will begin the first tests as soon as possible.

4.5 Permitting and Regulatory Status

In terms of regulatory status in Romania, V2G regime is not covered by any regulation on a national level directly, as it was mentioned above. This section will be filled after the station will be purchased and then and then we will begin the installation steps, regarding the necessary permits, approvals, both at the local level and at the TUCN administration level. In this endeavour, our local DSO will have a crucial role.

4.6 Future Steps and Planned Timeline

The paperwork for a suitable EV charger has already been submitted, the Alfen Twin 5 Plus model, and it is on the procurement process. Planned installation and start of tests are slated to begin in Summer.

Implementation schedule for V2G system is depicted in Figure 37 below:

Figure 37. Time schedule for the V2G implementation for this year

4.7 Installation

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

4.8 Results and tests

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

4.9 Compraison with simulations

This section will be completed once the solution is installed at the pilot site and incorporated into the updated version of this document

5 CONCLUSIONS

5.1 General conclusion

This section will be updated once the solution is installed at the pilot site and incorporated into the updated version of this document

5.2 HYDROGEN-BASED LONG-TERM STORAGE SYSTEM (IS28)

5.2.1 Summary of Completed Work

This project aims to install a hydrogen power system for the French PS. A preliminary study was conducted to size the system and select the necessary equipment. This was followed by a consultation phase to choose the supplier. Once the system was selected and verified, the purchase order was issued after the initial acceptance regarding permitting. In parallel, internal work began on-site to prepare for the reception and installation of the system, which includes VRD work to prepare the foundation for the container, as well as electrical and water connections.

5.2.2 Key Challenges and Lessons Learned

During this phase of the project, we encountered several challenges, including:

- **Permitting:** The approval process took longer than expected, leading to a delay of several months compared to the initial schedule.
- **Acceptance:** It was quite challenging to convince the people on-site that hydrogen is not dangerous when handled in compliance with regulations and standards.
- **Budget Constraints:** As previously explained, we had to reduce the initial system capacity to fit within the budget. This was due to a significant shift in the hydrogen market, where most suppliers shifted towards large-scale (Mega and Giga) production, causing a substantial increase in the cost of low-capacity equipment.

5.3 POWER-TO-HYDROGEN-TO-POWER COMPACT SYSTEM (IS 27)

5.3.1 Summary of Completed Work

Initially, the system was dimensioned, according to the necessities of the project. The PFD, P&ID and component list were developed and validated. Lastly, a complete mechanical CAD design was created. In the first months of 2025 the components were purchased and assembled.

The construction of the containerized system has been finalized. In the coming weeks, the system will be brought to different fairs in order to provide dissemination opportunities for the EVELIXIA project and communicate H2 technology to the general public.

Next, the system will be transported to BER's facilities in Genoa, Italy to undergo an intensive FAT, after which it will be installed at CERTH's facilities in the Greek pilot site.

5.3.2 Key Challenges and Lessons Learned

The main challenge from BER's side was that this was a completely new project, integrating for the first time electrolyser, metal hydride storage and fuel cell, so a lot of resources were dedicated to research and development of the system. Our main challenges were adapting our tooling and material resources in order to build a machine of this size, and some delays were experienced due to this issue. For example, due to the size of the workshop, the delivery of the container had to be delayed for a few weeks because space wasn't available due to other projects. Furthermore, one of the electrolyser stacks had to be replaced because it leaked, which stopped testing of the electrolyser system for some weeks.

Another challenge will be the integration of the system, because since H2 solutions are rather new, a lot of documentation is lacking regarding electrical integration into existing systems. This will require close collaboration with the pilot site in order to achieve a safe and reliable final installation.

5.4 VEHICLE-TO-GRID EV CHARGER (IS 26)

5.4.1 Summary of Completed Work

While there isn't a dedicated regulatory framework exclusively for V2G in Romania, several strategic documents and regulatory measures indicate the country's commitment to integrating such technologies into its energy system.

TUCN, which is the main responsible for the V2G implementation in the Romanian pilot site, explore innovative approaches to develop a specialized micro-regulation strategy for V2G chargers,

Utilizing insights from local building observations gathered through its advanced building monitoring system, the optimization of the operational cost-effectiveness of the V2G system in both Vehicle-to-Grid (V2G) and Vehicle-to-Building (V2B) application will be investigated. By leveraging stored energy in electric vehicle (EV) batteries during peak electricity demand periods—when energy prices are high—the strategy will help reduce overall costs.

TUCN explores, though simulations, Vehicle-to-Grid (V2G) technologies, which enable electric vehicles (EVs) to feed electricity back into the grid, thereby enhancing grid flexibility and supporting renewable energy integration. All simulations have been done with real consumption data, recorded from the pilot site, and the simulate output of the PV panels which are to be installed at the student building through the EVELIXIA project (17kWp). For the simulations we chose 3 arbitrary days with their respective day ahead prices per hour for energy.

5.4.2 Key Challenges and Lessons Learned

TUCN will demonstrate through simulations, the cost-saving potential of the V2G system under V2B conditions, highlighting its ability to support facility operators by mitigating high electricity costs during peak hours. Electric vehicles (EVs) serve a dual function:

- Charging during periods of low electricity demand.
- Discharging during peak demand to optimize power distribution.

The simulated system efficiently manages energy flow by integrating PV generation, grid imports, and EV energy storage.

The simulations show an energy savings of about 17.54 EUR, within the fourths case scenarios, solely by leveraging the V2G system's discharge flexibility.

The V2G EV charger software will integrate with TUCN's local Building Energy Management System (BEMS) to showcase a fully functional demand response V2G solution.

Even if it was very difficult to find on the market a V2G system, TUCN will purchase the Alfen Twin 5 Plus V2G model. If there are no issues in the procurement process and the installation permits from the University administration are obtained on time, then the system could be implanted and tested on time schedule.
The simulations performed until now could be compared with the real results obtained from site.

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