



Hymantovalley

RENHIVE

D2.1 Energy Accumulator

Feasibility study of the accumulator between PV plant and electrolyzer with barriers and study for different solutions

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Executive Summary

A two-year analytical and design journey through a green hydrogen ecosystem that did not reach physical implementation, but generated a substantial body of technical, financial and territorial work that retains full validity and value for replication.

This Report constitutes Deliverable D2.1 of the HyMantoValley project, funded by the European Commission through the Interregional Innovation Investments (I3) instrument managed by EISMEA under call I3-2021-INV1 GREEN. The document, of a public nature, provides a complete account of the contribution made by Partner Renhive Srl to Work Package 2 Production and Storage, tracks its evolution over the course of the project, and underscores the analytical and design assets that it generated.

Renhive's contribution was originally designed around a lithium electrochemical storage system supporting the integration of a photovoltaic field with the electrolyser intended for green hydrogen production at the Mantova Industrial Hub. The Italian financial and regulatory environment evolved in the months following the project's start, and made the physical execution of that investment unfeasible within the planned timeframe and conditions. The consortium therefore activated the Grant Agreement amendment procedure, which the European Commission formally approved. The amendment redefined the technical perimeter of the Partner's contribution towards an alternative configuration based on the integration of a 350 kW mobile hydrogen genset with APA atmospheric abatement technology, in partnership with BluDrive Ltd and Iscleanair Srl.

The physical execution of the alternative solution likewise did not materialise within the project's time horizon. Three factors converged to make it unfeasible: a green hydrogen price trajectory that has not yet reached competitiveness for stand-alone investments, limited availability of renewable hydrogen on the Italian market, and the standard duration of national permitting procedures for newly installed energy assets, which exceeds the project's remaining timeframe.

Against this backdrop, Renhive developed a substantial body of technical studies, system simulations, financial models and market analyses, all of which feed into this Deliverable. The work includes: full technical characterisation of a 2,752 kWh LFP BESS; specification of the 350 kW Genset H2 + APA solution; an hourly PVSYST simulation of the photovoltaic and electrolyser system with four sizing iterations; an eighteen-year financial model under [omissis] scenarios; TAM/SAM/SOM market analysis and a mapping of the Italian regulatory landscape; a socio-economic business case for APA technology in the Province of Mantova; a four-category strategic risk matrix; and the activation of an international technical partnership for the execution of the alternative solution.

Taken together, these outputs form an analytical and design corpus that retains full technical validity and lends itself to replication on three levels. It can serve as a project reference immediately usable for future Hydrogen Valley initiatives in comparable contexts. It can function as a methodological framework transferable to feasibility assessments of other supply-chain initiatives. And it can be activated as an industrial capacity through the network of specialist partners consolidated during the project.

What did not become a physical installation became a body of structured knowledge: technical, methodological, industrial. None of it is lost. All of it is transferable.

The Report is organised in four sections. Section 1 frames the project, the Partner's role and the scope of the Deliverable. Section 2 describes, across ten thematic subsections, the activities actually carried out by Renhive. Section 3 documents the reasons why the activities did not translate into a physical investment, the Commission-approved amendment, and the conditions that affected the feasibility of the alternative solution as well. Section 4 summarises the value generated, the prospects for replication and the alignment with European priorities. The annexes list the technical documents underpinning the Report.

1. Framing

In this section the project, the Partner, and the perimeter are defined. We set out the HyMantoValley initiative and its EU funding logic, qualify Renhive's role in the consortium, and frame the scope and the editorial conventions of this public Deliverable.

1.1 The HyMantoValley project and the EISMEA I3-2021-INV1 GREEN call

HyMantoValley is an interregional project for the development of an integrated green hydrogen ecosystem in the Mantova area, funded by the European Commission through the Interregional Innovation Investments (I3) instrument managed by the European Innovation Council and SMEs Executive Agency (EISMEA) under call I3-2021-INV1 GREEN — Green Transition. The I3 instrument is part of Cohesion Policy 2021-2027 and is financed by the European Regional Development Fund. It aims to strengthen the capacity of European regions to join forces around shared innovation investment priorities through Smart Specialisation Strategies, supporting interregional innovation projects in their scale-up and commercialisation phase. The GREEN strand specifically seeks to turn climate and environmental challenges into opportunities by supporting innovative supply-chain investments in green technologies that contribute to climate neutrality by 2050.

The project was conceived to demonstrate the feasibility of a replicable green hydrogen ecosystem at regional scale, in the Po Valley, one of the most pollution-affected areas in Europe. The original design covered the full hydrogen value chain: production via renewable-powered electrolysis, storage, transport by pipeline and high-pressure trailer, and end uses across mobility (maritime, rail, road and public transport), industrial process heat and the heating of public buildings. The project also envisaged the creation of a Centre for Applied Research and Advanced Training on hydrogen, run by the consortium's university partners, focused on the technological optimisation of the supply chain and on training the sector's human capital.

The project formally started on 1 September 2023, with a total duration of thirty-six months and an end date of 31 August 2026. The partnership brings together sixteen entities, including full partners and affiliated entities, distributed across four EU Member States (Italy, Austria, Netherlands and Belgium) and across several regions: Lombardy, the Autonomous Province of Trento, Veneto, Emilia-Romagna, Lazio and Campania in Italy, South Holland in the Netherlands and the Bruxelles Region in Belgium. The project is co-funded at seventy per cent by the European contribution, with the remaining share borne by the participants under the mechanisms set out by the I3 instrument, which requires at least seventy per cent of the contribution to be allocated to investments carried out by partner companies.

The operational structure of the project is articulated across eight Work Packages, coordinated by the Provincia di Mantova as Lead Beneficiary, with AGIRE Srl acting as operational Project Coordinator. Work Package 2, dedicated to hydrogen production and storage, brings together the activities relating to the electrolyser, the supply of green electricity, the storage and pressurisation systems, and the management of the storage infrastructure. The remaining Work Packages cover project management (WP1), distribution and end uses (WP3), business models and commercialisation (WP4), the applied research hub (WP5), performance and impact assessment (WP6), communication and dissemination (WP7) and financial support to third parties (WP8).

1.2 Renhive's role in the partnership

Renhive Srl participates in the HyMantoValley project as Partner of the consortium, with a role specifically focused on supplying the green electricity needed to power the electrolyser, and on delivering the storage system that ensures its operational stability. Renhive is an Italian company headquartered in Rome, set up as a joint venture of four complementary specialist entities: Hive Energy Ltd, an international renewable energy developer headquartered in the United Kingdom with over 1.97 GW of installed renewable capacity worldwide and a 24 GW development pipeline; SunLeonard Energy Ltd, a renewable energy developer active in Italy with over 700 MW under development; Proter Srl, a financial advisory firm specialised in public-private partnerships and public support instruments; and Renovo SpA, an Italian player

active in applied research, development, construction and operation of innovative industrial plants for renewable energy generation.

The joint venture structure enables Renhive to combine, within a single operating entity, expertise in the development of utility-scale renewable plants, the financial structuring of energy supply-chain initiatives, and applied research in the bioeconomy and renewable energy. That combination is particularly suited to the type of contribution required by the HyMantoValley project, which calls for integrating a technical view of generation and storage with a financial view of investment bankability and with a strategic view of how the project sits within the broader green hydrogen trajectory at regional and national level.

Renhive is Lead Beneficiary of a specific project Deliverable, identified as D2.1 within Work Package 2 Production and Storage. D2.1 was originally framed as a Public Demonstrator and is now delivered through the present Report as a documentary synthesis of the contribution produced. Renhive's total project budget, as defined in the Grant Agreement with EISMEA and subsequently amended with the Commission's approval, amounts to EUR 1,166,300, broken down across technical staff costs, specialist engineering subcontracting, equipment and indirect costs.

1.3 Scope and perimeter of this public Deliverable

The Report provides an organised and complete picture of the contribution that Renhive produced over the course of the project. That picture covers the technical studies and analytical models developed, the coordination, networking and governance activities carried out, and the reasons that led to the non-execution of the physical investment originally envisaged.

The Report provides material evidence of how the financial resources allocated to the Partner under the project Grant Agreement were used, in line with the general guidance, to highlight the work carried out, particularly where activities have not translated into physical investments for reasons outside the Partner control and despite of the effective value of each Partner contribution.

The Report contributes to the project dissemination and knowledge transfer activity: it is classified as a deliverable of level PU — Public, under the rules of the I3 instrument and the conventions of HyMantoValley consortium and will be published on the project website (<https://hymantovalley.agirenet.it>). That classification means the document is accessible for the community of stakeholders involved in the development of the European green hydrogen economy and is therefore suited to be used as a project and methodological reference by industrial operators, public-private consortia, policy bodies and research institutions, facing comparable challenges in other contexts. In keeping with this classification, the Report has been drafted by omitting any data or information that may qualify as confidential, commercially sensitive or covered by confidentiality agreements between consortium parties.

1.4 Methodology and document structure

The Report has been developed through a process of synthesis and documentary reorganisation of the corpus of outputs produced by Renhive during the project, supplemented by an explicit account of coordination and governance activities that, although they did not generate dedicated technical documentation, represent a substantive part of the Partner's contribution. The drafting process followed the conventions set out in the Project Handbook of the HyMantoValley consortium, including the Quality Review rule which requires each Report to be reviewed by a person other than the author before formal submission for acceptance by the Grant Authority.

The document is structured into four main sections, preceded by an Executive Summary and followed by annexes and references. Section 1 (the present section) frames the project, the Partner and the Deliverable. Section 2 describes, in ten thematic subsections, the activities concretely carried out by Renhive, organised by functional logic and supported by references to the underlying technical documents. Section 3 documents the reasons why the activities studied did not result in physical investment, the project's reformulation as approved by the European Commission, and the conditions that affected the feasibility of the alternative solution. Section 4 summarises the contribution produced, characterises its residual value and replication prospects, and confirms its alignment with the call's objectives and with broader European priorities. The Annexes section lists the base technical documents that fed the drafting of the Report, available for consultation upon request from the project archives. The References section lists the institutional documents and external sources cited.

2. Activities carried out

In this section ten thematic strands of work, from initial scope framing to development pathway and risk management. Across the strands: technical studies for three alternative energy solutions, hourly system simulations, financial modelling under long-horizon scenarios, market and regulatory mapping, territorial impact assessment, and the activation of an international technical partnership network.

The activities described in this section constitute the effective content of Renhive's contribution to Work Package 2 of the HyMantoValley project. They are presented in ten thematic subsections, each of which groups activities of a homogeneous nature. The sequence follows a logic of progressive development, moving from the initial framing of the scope to technical studies of alternative solutions, integration simulations, market analyses, financial models and impact assessments at territorial and consortium level. All activities described produced technical documentation, quantitative models or design outputs that are now held in the project archives.

2.1 Initial framing of Renhive's contribution

At the Grant Agreement stage, Renhive defined the technical perimeter of its contribution to Work Package 2 Production and Storage, identifying the object of Deliverable D2.1 as the implementation of a storage system supporting green hydrogen production. The target site selected is the Mantova Industrial Hub in the municipality of Gonzaga, chosen for its proximity to the Sapio plant dedicated to H₂ production and for the availability of suitable surfaces for installing a utility-scale photovoltaic field.

On the commercial side, Renhive carried out the preliminary negotiation of a Power Purchase Agreement with Sapio, for an expected annual production of approximately 1500 tonnes of hydrogen in the Phase 1 configuration of the partnership.

On the financial side, the participant's budget structure was defined, with a total investment of EUR 1,166,300 split across technical personnel, specialist engineering subcontracting, equipment and indirect costs.

2.2 Study of the lithium-ion BESS solution

The first design strand developed by Renhive concerned the sizing and technical characterisation of a lithium electrochemical storage system aimed at stabilising the renewable energy fed to the electrolyser. Lithium Iron Phosphate (LFP) chemistry was selected as the technological reference, driven by its market dominance (over 85% of utility-scale installations in Europe), its intrinsically superior safety profile, the stability of raw material prices and its high cycle life (6,000-8,000 full cycles).

The storage unit was specified at a capacity of 2,752 kWh, with maximum discharge power of 1,000 kW and nominal operating voltage between 1,160 and 1,500 V DC. The expected round-trip efficiency is above 95%, with the dispatch window configurable between 2 and 8 hours depending on the electrolyser's demand profile. The architecture relies on active liquid cooling for cell temperature management, an outdoor cabinet with IP54 ingress protection and Type 3R classification, and an optional C5 anti-corrosion coating for harsh environments. The incident safety system includes sprinklers with fusible links for fire suppression and ventilation compliant with NFPA 69 and IDLH gas protocols, in line with UL 9540, UL 9540A and NFPA 855 standards. The communication interfaces include RS485 and Ethernet, with Modbus RTU and Modbus TCP protocols for integration with plant control systems.

On the economic side, an industrial cost breakdown was developed by item: LFP battery procurement EUR 580,000; specialised transport EUR 10,000; specialised installation EUR 55,000; materials for the connection to the electrolyser (cables, conduits, protections) EUR 15,000; execution of the connection works EUR 20,000; testing and commissioning activities EUR 5,000; first-year maintenance EUR 2,500. The total estimated investment for the deployment of the solution amounted to EUR 687,500.

The technical analysis specifically addressed the three operational constraints that characterise the integration between variable renewables and PEM electrolyzers: intermittent renewable generation, grid limitations on the export of overproduction, and variable hydrogen demand from downstream users. For each constraint, the functional response offered by the proposed BESS was documented: storage of surplus energy during photovoltaic generation peaks, support for grid stability through synchronised absorption and release, and supply of energy to the electrolyser even in the absence of concurrent renewable generation.

2.3 Study of the Genset H2 + APA alternative solution

In parallel with the electrochemical storage study, Renhive developed a second design strand built around a hydrogen power generation system integrated with emissions abatement and CO₂ capture technology. The solution was conceived as a complementary option able to operate either in stand-alone mode or in integration with the main photovoltaic and electrolyser system, and to extend its use across the project's value chain through a mobile configuration.

The strategic rationale was set out in the positioning paper "Hydrogen Valley: Bridging the Gap to a Sustainable Future". The hydrogen genset was positioned as a bridging technology in the transition towards a full green hydrogen economy, leveraging the consolidated infrastructure of internal combustion engines, their track record of reliability and the availability of mature service chains, while fuel cell technology continues to mature towards cost competitiveness. Three macro application areas were identified: transitional energy supply during project construction and ramp-up; emergency backup against grid outages or adverse events; and off-grid power for unserved or remote areas.

For the technical execution of the solution, Renhive activated a partnership with two specialist partners. BluDrive Ltd, a UK engineering company with a consolidated track record in retrofitting internal combustion engines for hydrogen and ammonia operation since 2019, was selected for the engine side. The designated project team brings together senior engineers with long-standing experience in the design of large-bore engines in collaboration with major powertrain industry partners, and in the management of academic engineering research. Iscleair Srl, an Italian SME founded in 2016 and specialised in air purification through its proprietary APA technology, was selected for the emissions abatement and CO₂ capture side.

The Genset specifications were defined around a nominal power of 350 kW, based on the conversion of a spark-ignition internal combustion engine. The planned technical modifications include adapting the fuel injection system to handle hydrogen, modifying ignition timing and replacing spark plugs to suit hydrogen combustion characteristics, selecting compatible materials to prevent hydrogen embrittlement, and implementing safety protocols specific to a highly flammable gas. Engine calibration follows an ultra-lean combustion

approach aimed at zero emissions: lean combustion at low temperature prevents the formation of NO_x, the main category of pollutants associated with conventional combustion.

The APA technology proposed by Iscleanair is a patented atmospheric abatement solution that uses water, including seawater, in a mechanical process that simultaneously captures particulate matter (PM₁₀, PM_{2.5}, PM₁ and nanoparticles down to 20 nanometres), nitrogen oxides, sulphur oxides, carbon monoxide, ozone, light and heavy hydrocarbons, heavy metals, pollen and spores, alongside CO₂. The system is qualified as a Best Available Technology under IPCC Directive 2008/1/EC, obtained Class 1 Medical Device (CE) certification in June 2020 thanks to its ability to remove nanoparticles, received the Solar Impulse award in 2019 (renewed in 2023) and is covered by 20 patents granted in Italy and worldwide. The declared Technology Readiness Level is 7-9, with operational installations validated in Italy, Israel, Spain and the United Kingdom across urban, rail, airport and school settings.

The APA Panel model selected for the project's configuration takes up 0.6 square metres of urban surface and treats up to 70,000 cubic metres of air per day, with water consumption below 5 litres per day and electricity consumption of 0.85 kWh. The design integration foresees powering the APA module through a battery pack recharged directly by the energy generated by the Genset, configuring a self-sufficient mobile solution.

The joint BluDrive plus Iscleanair technical-commercial proposal, formalised in May 2024, set a total cost of EUR 912,000 excluding VAT over a thirteen-month duration, articulated across five operational phases: retrofit design and component procurement; integration and initial testing; baseline pollutant monitoring at the installation site for six to eight weeks; APA system adaptation and testing; and the operations and data collection phase with iterative calibration of the Genset-APA integration.

The operational parameters of the system were quantified as follows: hydrogen consumption of 15 kilograms per operating hour; annual operating hours estimated at 7,300 against 80% technical availability over the theoretical 8,760 hours; CO₂ reduction efficiency of the APA modules at 90%; and integrated hydrogen tank capacity of 360 kilograms corresponding to a volume of 15.18 cubic metres at 350 bar pressure.

2.4 Study of the hybrid solution

To complement the two main alternative solutions, Renhive developed a third configuration of a hybrid nature, designed to combine the distinctive advantages of the two technologies in a single integrated architecture. The solution was sized around an electrochemical storage capacity of 500 kWh, paired with a smaller hydrogen genset of 150 kW and integrated with the same APA module used in solution 2.

The rationale for the hybrid option is the simultaneous availability of the three functions that the two stand-alone solutions deliver separately: storage of

surplus energy for time-shifting between high-generation and high-demand hours; on-demand power generation in the absence of concurrent renewable sources; and active removal of pollutants and CO₂ from the surrounding environment. The smaller size of the two energy components (compared with the 1 MWh battery-only and 350 kW genset-only configurations) was calibrated to optimise the upfront investment while maintaining full functional coverage.

A comparison matrix of options A, B and C was developed across technical (size, autonomy, modularity, integration level), economic (CAPEX, OPEX, payback, expected IRR), environmental (emissions avoided, active abatement capacity, installation footprint) and operational (set-up time, required expertise, mobility, scalability) criteria. The matrix provides decision-making support for identifying the preferred configuration depending on the specific application context.

2.5 PV-electrolyser system integration study

Renhive carried out, in-house, an hourly system simulation of the photovoltaic field in integration with the Sapio electrolyser, using PVSYST software version 7.2.12 with PVGIS API TMY meteorological data referenced to the specific site of the Mantova Industrial Hub. The simulation covers the full typical year at hourly resolution, for a total of 8,760 hours.

Four photovoltaic field configurations were explored in successive sizing iterations aimed at finding the optimal scale: an initial configuration of 14.7 MW DC, an intermediate configuration of 13.4 MW with storage, a reduced configuration of 8.2 MW, and a final proposed configuration of 8 MW. For each configuration, the simulation returns the expected annual production, monthly distribution, average hourly curve, distribution of operating hours by power band, and the energy not absorbed by the electrolyser as a function of its acceptance thresholds.

The main quantitative results for the two most relevant configurations are as follows. The 13.4 MW DC Renovo configuration with storage produces 24,137 MWh per year, of which 23,497 MWh from photovoltaic alone and 639 MWh from storage integration, distributed with monthly peaks in the summer months (3,230 MWh in July) and minima in the winter months (537 MWh in December). The final proposed 8 MW configuration produces 13,413 MWh per year, with 894 MWh of energy not absorbed by the electrolyser and an economic valuation of the surplus energy estimated at EUR 53,679 per year at the reference price of EUR 60/MWh.

The analysis distributed across time bands F1 (daytime peak hours), F2 (intermediate hours) and F3 (night-time and holiday hours) makes it possible to characterise the expected behaviour of the system with respect to the national tariff regime, and to identify the hours in which photovoltaic generation exceeds the electrolyser's absorption capacity (overflow conditions) and those in which it falls short.

2.6 Market study and regulatory context

Renhive's design work was accompanied by a systematic analysis of the Italian and European market and regulatory context within which the solutions studied would have operated. The analysis was developed along two distinct but converging axes: the Battery Energy Storage Systems market in Northern Italy for the electrochemical storage solution, and the market for hydrogen generators with abatement technology for the Genset plus APA solution.

On the BESS side, the structure of electricity demand in Northern Italy was characterised. The area absorbs more than 56% of national consumption while concentrating, on less than a third of the territory, a particularly high industrial and civilian density. The structural rigidity of the system with respect to local renewable generation, mostly hydro and photovoltaic, was documented, along with the resulting chronic congestion on the transmission corridors that carry renewable energy from the South to the North. That congestion generates gas dispatching costs of around EUR 2 billion per year and renewable curtailment that is projected to grow from 0.3 TWh in 2024 to 5 TWh by 2030 in the absence of intervention. The role of BESS in the system was characterised through two complementary strategic functions: absorbing the renewable surplus as an "energy sponge" to prevent curtailment, and providing fast frequency regulation as a "grid shock absorber" replacing traditional thermal machines.

On the regulatory side, the Italian framework that defines BESS opportunities and remuneration mechanisms was mapped: the PNIEC target of 71 GWh of storage capacity by 2031, the MACSE mechanism introduced from the first auction in September 2025 with 15-year inflation-indexed capacity contracts, and the Capacity Market and ancillary services as complementary revenue sources. The mapping of the main Italian BESS operators identified six leading players (Enel Green Power with 2.6 GW of pipeline, ACL Energy plus BW ESS with 2.9 GW, Altea Green Power with 1.1 GW, GreenGo with 1.73 GW, ContourGlobal with 1.6 GW, and Bright Storage), classified by category (incumbent utilities, international investment funds, agile Independent Power Producers) and by business model (stand-alone units connected directly to the transmission grid, and co-located units paired with renewable assets).

On the Genset plus APA side, a market analysis was developed along the TAM/SAM/SOM framework. The global Total Addressable Market for portable generators was sized at USD 2.54 billion in 2021, with a projection of USD 3.75 billion by 2029 and a CAGR of 5.1%, with a European market of USD 640 million in 2020 projected to reach USD 1.1 billion by 2027 at a CAGR of 7.8%. The European Serviceable Available Market for industrial, construction, events and public administration applications was sized at approximately EUR 625 million per year. The initial Serviceable Obtainable Market was estimated at EUR 20 million per year, with a target of capturing 10% of the SAM within five years.

The competitive analysis developed a full SWOT of the Genset plus APA solution, identifying strengths (zero local emissions, active air purification with

up to 90% CO₂ abatement in the surrounding area, low noise levels, operational flexibility, available subsidies), weaknesses (relatively high cost of hydrogen, limited refuelling infrastructure, high upfront investment, evolving technological maturity), opportunities (growing demand for clean solutions, development of hydrogen infrastructure, continuous technological innovation, supportive policies, new markets linked to air purification) and threats (competition from alternative technologies, hydrogen price volatility, evolving regulatory framework, residual technological scepticism).

A techno-economic comparison among Genset H₂ plus APA, lithium-ion batteries and fuel cells showed an upfront investment cost for the Genset 35% lower than that of a fuel cell of equivalent size, a payback period of 4 years versus 5 for the fuel cell, competitive long-term operating costs thanks to the downward trajectory of hydrogen prices, and distinctive environmental advantages thanks to the active removal of 90% of CO₂ emissions from the surrounding area.

2.7 Financial modelling

To support the assessment of the economic sustainability of the Genset H₂ plus APA solution, Renhive developed a financial model with an eighteen-year time horizon, covering 2026 to 2043. The model is fed by the projections of the [omissis] Q4 2023 scenario for the Italian electricity market, the standard industry reference for long-term financial planning of energy assets.

Two distinct revenue flows were modelled. The first stems from arbitrage operations on electricity markets, developed over a 70% share of the Genset's availability, and stands at EUR 171,528 in the first year of operation, with a gradual evolution reaching EUR 164,950 in year eighteen. The second flow comes from leasing the Genset to third parties over a 30% share of availability at a daily rate of EUR 267 per hour, starting at EUR 572,746 in year one and growing to EUR 801,983 in year eighteen on the back of tariff indexation. Total revenues start at EUR 744,275 in the first year and grow to EUR 966,934 by year eighteen.

On the operating cost side, the main driver is the cost of hydrogen fuel. The model incorporates a decreasing price trajectory consistent with scenario projections for the Italian market: EUR 12/kg in 2026, EUR 10 in 2027, EUR 7 in 2028, EUR 4 in 2029, EUR 3 in 2030, and EUR 1.50 from 2031 onwards. At a constant hourly consumption of 15 kg of hydrogen over 7,008 annual operating hours, the annual hydrogen cost starts at EUR 1,286,669 in year one and progressively reduces to EUR 225,206 in year eighteen. Maintenance was modelled starting from EUR 20,000 per year with 2% inflationary growth, insurance on a base of EUR 4,500 per year, and contingencies were provided at EUR 107,000 on the initial investment plus an additional EUR 214,000 in year ten for the refresh of critical components.

The resulting EBITDA is negative in the first three years of operation (EUR -563,219 in year one due to the high cost of hydrogen at the outset), reaches break-

even between years three and four, rises to EUR 588,254 in year six, and stabilises around EUR 650,000 to 700,000 per year from year seven onwards. Cumulative EBITDA reaches break-even between years eight and nine of operation, and stands at EUR +6,704,394 at the end of the projection horizon.

A sensitivity analysis was developed on the model to test the robustness of the results against the most critical variables. A 15% increase in CAPEX reduces the IRR by 2.3 percentage points; a 20% reduction in MSD revenues reduces it by 1.7 points; a 50% increase in network charges reduces it by only 0.4 points. The analysis confirms CAPEX as the primary critical variable and the stability of long-term contracts as the main risk mitigation factor.

For the BESS solution, a parallel financial characterisation was developed based on industry benchmarks for the Italian market: CAPEX in the EUR 300-400/kWh installed range (battery pack EUR 150-200/kWh, power conversion system EUR 50-70/kW, balance of system EUR 30-50/kW, connection hardware EUR 20-30/kW, civil works EUR 15-25/kW, soft costs EUR 40-60/kW), annual OPEX of EUR 25-35/kW (maintenance EUR 10-15, insurance EUR 3-5, network charges EUR 5-8, asset management EUR 4-6), variable energy costs of EUR 20-30/MWh, LCOS of EUR 150-180/MWh, round-trip efficiency of 85-90% and annual degradation of 2-3%. Two archetype business cases were built on this basis: a stand-alone case at 100 MW / 400 MWh with EUR 140 million CAPEX and a 10.5% target IRR, and a co-located case at 20 MW / 80 MWh with EUR 25 million CAPEX and a 9.5% target IRR.

2.8 Study of the cross-cutting value for the consortium and for the territory

A significant portion of Renhive's analytical work was devoted to characterising the value that the Genset H2 plus APA solution, in its mobile and multifunctional configuration, can generate for the HyMantoValley consortium as a whole and for the Province of Mantova. This activity produced a systematic positioning document titled "Closing the Loop", which mapped the application areas of the Genset for each project partner.

For the Provincia di Mantova as Project Coordinator, the Genset was proposed as a clean and reliable energy source for outreach events, conferences, workshops and mobile offices. For Sapio, the Genset can supply energy to the electrolyzers and to the compressors of hydrogen refuelling stations for hydrogen vehicles. For Wolf tank Group, the Genset powers compressors and cooling systems of hydrogen storage facilities and supports their maintenance activities. For VENA, Future Proof Shipping and IPE Locomotori 2000, the Genset powers the direct recharging of hydrogen vehicles and the mobile and fixed refuelling infrastructure for maritime, rail and road mobility. For STRESS, the Genset powers sensors, monitoring units, mobile laboratories and analytical instruments for the environmental monitoring of the territory. For EFIP and for the universities involved, the Genset powers laboratories, pilot plants, teaching workshops and training activities dedicated to hydrogen technologies.

The impact of APA technology on the Province of Mantova was quantified through a dedicated socio-economic business case. The provincial population of 400,000 inhabitants and the 50,000 students attending the territory's schools are exposed to PM2.5 levels that exceed World Health Organization guidelines. The installation of APA modules in public buildings, schools and high-density workplaces is estimated to be capable of reducing respiratory illnesses by 20% and of generating direct and indirect healthcare cost savings of around EUR 10 million per year, for a PM2.5 reduction of just 10%, according to estimates developed by the University of Brescia.

The impact on workforce productivity was quantified at an overall economic benefit of more than EUR 27 million per year, calculated by applying a 5% productivity gain (documented in the scientific literature on indoor air quality) to the provincial average salary of EUR 30,000. The impact on school absenteeism was estimated at savings of around EUR 2 million per year for a 10% reduction in absences, based on estimates developed by Politecnico di Milano. The impact on the tourism sector was qualitatively characterised against the 2 million annual visitors that the territory attracts, identifying Mantova's positioning as an air-quality conscious destination as a differentiating factor for eco-aware tourism.

A further axis of value lies in carbon credit mechanisms: the active CO2 removal capacity offered by APA technology, under European credit prices ranging between EUR 50 and EUR 100 per tonne of CO2 equivalent, can generate an additional revenue stream for the operators of the installation, with a potential impact on investment bankability.

2.9 Development of the technical partner network and governance of the contribution

The execution of Renhive's contribution required the development of an articulated network of technical, contractual and governance relationships, much of which is not directly reflected in the technical documents produced, yet was essential to the conduct of the work. This activity covers Renhive's participation in the consortium's coordination bodies, the activation and management of specialist technical partnerships, and the dialogue with the industrial Partner Sapio for the definition of the system interfaces.

In terms of the internal governance of the consortium, Renhive took part in the Project Assembly composed of representatives from all project Partners, with semi-annual meetings starting from the kick-off of 1 September 2023. The Assembly is the supreme decision-making body of the project, chaired by the Coordinator and responsible for approving amendments to the Grant Agreement, for the assignment and review of Project Management Board appointments, for the resolution of strategic-level conflicts, and for the approval of plan deviations and high-impact scope changes. Renhive's participation in the Assembly entailed preparing and reviewing meeting documentation, representing the Partner's interests in the qualified-majority

decisions provided for by the Consortium Agreement, and contributing to the definition of the project's risk mitigation strategies.

In terms of operational coordination, Renhive maintained ongoing dialogue with AGIRE Srl, in its capacity as operational coordination support to the Lead Beneficiary, and with the Provincia di Mantova as Project Coordinator. The dialogue covered the monitoring of Renhive's contribution against the Project Work Plan, alignment on the scope changes introduced during the Budget amendment phase, the sharing of intermediate deliverables for the Quality Review procedures set out in the Project Handbook (which require each Report to be reviewed by a person other than the author), and coordination on financial and reporting deadlines.

In terms of technical and industrial coordination, Renhive developed a structured dialogue with Sapio, responsible for green hydrogen production on site. The dialogue covered the sizing of the electrolyser based on the simulated photovoltaic generation profile, the definition of the technical interfaces between the PV-storage system and the electrolyser, the negotiation of the ten-year Power Purchase Agreement for the supply of green energy at a reference tariff of EUR 60/MWh, and the convergence on the final photovoltaic field size (8 MW) following the four sizing iterations.

In terms of specialist technical partnerships, Renhive carried out a scouting, evaluation and selection process for two international partners for the execution of the Genset H2 plus APA solution: BluDrive Ltd in the United Kingdom for the engine side, identified on the basis of its track record of hydrogen and ammonia engine retrofits since 2019 and the qualifications of its key personnel; and Iscleanair Srl in Italy for the emissions abatement side, identified on the basis of its TRL 7-9 technological maturity, the international certifications obtained, and the portfolio of documented operational installations. The formalisation of the partnerships was structured through the joint drafting of the technical-commercial proposal of May 2024.

2.10 Study of the development pathway and risk management

To complete the analytical work, Renhive developed a study of the development pathways and of the risks inherent to the physical implementation of the proposed solutions, with a specific focus on the Italian context for utility-scale BESS projects. The aim of the study was to provide the consortium with a realistic understanding of the timeframes, regulatory constraints and main risk drivers that characterise the realisation of storage assets within the Italian institutional framework, and, in symmetrical fashion, in the case of the Genset.

The typical greenfield-to-ready-to-build pathway for BESS projects in Italy was defined, articulated in three main phases over a total duration of 18 to 30 months. Phase one, lasting 0-3 months, covers site identification and screening through GIS analysis, verification of urban planning and environmental constraints, verification of land rights and logistical requirements, and the

acquisition of exclusive options on selected sites to de-risk the initial investment. Phase two, lasting 6-9 months, covers the submission of the connection request to Terna, the execution of the technical load-flow studies for the identification of the General Minimum Technical Solution for the connection, the acceptance of the STMG within 60 days with the payment of a 30% advance, and the transformation of the project from concept to contracted interconnection, with a significant increase in commercial value. Phase three, lasting 9-18 months, covers the unified authorisation process involving multiple national and local administrations, the environmental impact assessments, and the obtaining of the Single Authorisation decree that enables the construction phase.

A strategic risk matrix was developed across four main categories. Market risks include price cannibalisation following the growth of installed capacity and the volatility of arbitrage revenues, mitigated through long-term contracts (MACSE at 15 years, Capacity Market at 5 years), the adoption of alternative contractual structures (hybrid Power Purchase Agreements for co-located assets, tolling arrangements for stand-alone assets) and the deployment of Energy Management Systems with advanced predictive algorithms. Technology risks include technological lock-in on LFP chemistry should competitive alternative chemistries emerge (such as sodium-ion), supply-chain constraints for critical components, and end-of-life costs and management burden; they are mitigated through modular design for repowering, supplier diversification, the setting up of decommissioning funds, and take-back programmes negotiated with vendors. Regulatory and political risks include uncertainty on the post-2030 market framework and interim policy interventions, mitigated through the maximisation of contract duration, investment in flexible EMS software, and proactive engagement with regulatory authorities. Operational and black swan risks include the everyday risks of equipment failure and safety and the rare risks of cyber attacks and natural disasters, mitigated through the selection of Tier 1 suppliers, performance-based Operation and Maintenance contracts, advanced fire suppression systems, cyber-secure-by-design IT architectures and specialist insurance coverage.

Key takeaways - Section 2

Three alternative energy solutions studied at preliminary design depth, complemented by a hybrid configuration that combines storage and generation in a single architecture.

An hourly system simulation of the photovoltaic field in integration with the electrolyser, developed across four sizing iterations, completes the technical work with a quantitative reference base for the integration architecture.

A long-horizon financial model and a market analysis under the TAM/SAM/SOM framework provide the techno-economic basis for the assessment of the alternative solution.

A strategic risk matrix structured across four categories, alongside the activation of an international specialist partnership network, complete the analytical and design corpus produced.

3. Reasons why physical implementation did not occur

Context shifted, the project was reformulated with European Commission approval, and the alternative solution did not reach physical execution either. We document the financial and regulatory evolution that drove the change, the formal reformulation process, the Partner's strategic response, and the conditions that affected feasibility.

Three converging factors, none of them under the Partner's control: a green hydrogen price trajectory still above competitiveness thresholds, limited renewable hydrogen availability on the Italian market, and permitting timeframes that exceeded the project's remaining window.

The activities described in the previous section, developed by Renhive over the course of the project, produced an articulated body of technical studies, simulations, financial models, market and territorial impact analyses. Despite the substance of the analytical and design work done, and the concrete availability of technologies ready for deployment, the activities did not translate into a physical investment on site within the project's timeframe. This section documents the reasons for that outcome, describing the evolution of the context within which design decisions were taken, the project's reformulation as formally approved by the European Commission, the strategic path that Renhive followed in responding to those changes, and the conditions that made the alternative solution unfeasible as well.

3.1 The evolution of the reference financial and regulatory landscape

The HyMantoValley project was conceived and submitted to the EISMEA I3-2021-INV1 GREEN call in 2021-2022, a period marked by strong political and institutional momentum behind the development of green hydrogen as a strategic energy vector for the decarbonisation of industrial areas with a high environmental footprint. The project's application sat squarely within that context, envisaging a significant physical investment in the Mantova area and an integrated value chain spanning production, distribution and end use. The underlying design assumption was the availability of complementary national co-funding to the European contribution, sufficient to cover the share of investment not eligible under the I3 instrument's rules and to secure the overall bankability of the planned initiatives.

In the months after the formal start of the project on 1 September 2023, the national financial and regulatory framework within which the consortium's partners expected to develop the physical investments evolved significantly. The national public support mechanisms that were assumed available

alongside European funding, and that underpinned the economic feasibility of the project's capital-intensive components, saw substantial changes in their modalities, timing and effective beneficiaries. In parallel, the green hydrogen market followed a slower development trajectory than initially projected. The cost of one kilogram of green hydrogen produced via electrolysis remained well above commercial competitiveness thresholds, and the European regulatory framework on the taxonomy of sustainable investments and on the definition of renewable hydrogen was still consolidating.

To these factors must be added the reshaping of the industrial outlook of some of the main Italian partners, with consequent adjustments to the perimeter of their own investments in green hydrogen production, distribution and end-use infrastructure at the reference site. The combined effect of these factors made the physical realisation of the originally planned assets unfeasible within the project's timeframe and prevailing economic conditions, including the electrochemical storage unit that was the object of Deliverable D2.1 assigned to Renhive.

3.2 Project reformulation and European Commission approval

Faced with the evolution of the context, the HyMantoValley consortium activated the Project Change Management process provided for in the Project Handbook and codified in the Grant Agreement with EISMEA, with the aim of realigning the perimeter of project activities to the new feasibility landscape. The process followed the formal procedure, which envisages the submission of structured Change Requests, the assessment of the impact of the proposed amendments on the project's scope, time, cost, quality and risk parameters, the approval of amendments by the governance levels competent in proportion to their magnitude (Work Package Leader for low-impact changes, Project Management Board for medium-impact changes, Project Steering Group for high or very high impact changes), and the formalisation of the amendments through updates to the Decision Log and to the planning artefacts.

The amendments of greater scope were submitted to the European Commission through the Grant Agreement amendment procedures provided for by the I3 instrument's rules. The Commission, through EISMEA as granting authority, accepted and approved the amendment of the Budget and of the technical perimeter of the project, taking note of the soundness of the new project design and the consistency of the new activities with the policy objectives of the I3-2021-INV1 GREEN call. The formal acceptance of the amendment is an institutional element of significance, as it confirms the funding authority's recognition of the legitimacy of the project's repositioning relative to its original configuration at submission stage.

In the specific case of Deliverable D2.1 assigned to Renhive, the amendment entailed the replacement, within the Equipment line items of Work Package 2, of the originally planned configuration (a 1 MWh buffer battery between photovoltaic and electrolyser, integrated with a hydrogen engine for a total

equipment investment of approximately EUR 1 million) with an alternative configuration based on the integration of a hydrogen storage system, the Iscleanair APA atmospheric abatement modules, and a 350 kW mobile hydrogen genset, for a total equipment investment slightly above EUR 1 million. The overall structure of Renhive's Budget, articulated across personnel, subcontracting, equipment and indirect costs, was kept substantially unchanged in its totals, while the technical content of the activities was redefined.

3.3 Renhive's strategic path in responding to the change of context

Renhive responded to the change in the project context through a strategic path in three successive stages, each documented by the analytical outputs described in the previous section.

The first stage, developed in the early months of the project, consisted of completing the design strand originally envisaged, that is, the detailed study of the lithium electrochemical storage solution for stabilising the photovoltaic input to the electrolyser. That strand produced the full technical characterisation of a 2,752 kWh LFP system, the industrial cost breakdown at EUR 687,500, and the analysis of operating conditions and applicative constraints. The depth of this strand provided the consortium with a solid technical basis for assessing the feasibility of the original configuration, while at the same time organising the documentation of a technology solution that retains full design validity for future replication initiatives in comparable contexts.

The second stage, developed as the context matured, consisted of identifying an alternative solution that could remain consistent with the project's original objectives while adapting to the new feasibility conditions. The analysis pointed to the Genset H2 plus APA solution as the strategically preferable option, for three converging reasons. Technologically, the Genset benefits from being built on a widely consolidated base technology (internal combustion engines) supported by mature service chains, with a retrofit path to hydrogen operation that avoids the TRL uncertainties associated with fuel cells of comparable size. Economically, the Genset's upfront investment is 35% lower than that of a fuel cell of equivalent power, with an estimated payback period of 4 years against the 5 years of the fuel cell, and with the possibility of generating revenue from third-party leasing that diversifies the asset's revenue base. In terms of value extension to the consortium, the Genset's mobile configuration makes it possible to serve multiple project partners and to function as a multipurpose demonstration platform, capable of powering events, training activities, laboratory support and integration with hydrogen vehicle refuelling systems.

Integrating the Genset with Iscleanair's APA technology added a further dimension of value, in the form of the active removal of atmospheric pollutants and CO₂ from the environment surrounding the installation. That capability is particularly relevant in the Po Valley, one of the European areas most affected

by air pollution, and lends itself to positioning the project as a tangible demonstration of an integrated decarbonisation and depollution model applicable to urban and industrial areas with a high emissions density.

The third stage, developed in continuity with the second, consisted of a systematic deepening of the market, regulatory, financial and risk conditions within which the alternative solution would have operated. That deepening produced the 2026 BESS/Storage strategic study, the hourly PVSYST simulations of the photovoltaic system, the eighteen-year financial model under [omissis] price scenarios, the Iscleanair business case for the Province of Mantova, and the four-category strategic risk matrix. Together, these outputs gave the consortium a complete analytical basis for assessing the feasibility of the alternative solution, while at the same time generating a body of structured knowledge of intrinsic value, independent of the completion of any physical implementation.

3.4 Conditions that prevented the implementation of the alternative solution

Despite the technical quality of the alternative solution, the substance of the supporting studies and the strategic alignment with the project's objectives, the realisation of the Genset H2 plus APA solution did not materialise within the project's timeframe either. The reasons relate to a set of factors that operate on the economic feasibility of stand-alone investment, on the conditions of the green hydrogen market, and on the development timeframes required by the Italian permitting framework for newly installed energy assets.

In terms of economic feasibility, the financial model developed by Renhive showed that the sustainability of the Genset H2 plus APA business case is strictly dependent on the cost reduction trajectory of green hydrogen. In the scenario modelled, hydrogen cost starts at EUR 12/kg in 2026 and would need to fall progressively to EUR 1.5/kg from 2031 onwards for an equilibrium positive EBITDA to be reached. The model shows a negative EBITDA in the first three operating years and a cumulative break-even no earlier than year nine. That return profile, in the absence of public support mechanisms for the cost of hydrogen or of long-term offtake contracts at prices above market levels, makes stand-alone investment unprofitable for a private entity that must bear the full price risk.

In terms of the green hydrogen market, the effective availability of renewable hydrogen at competitive prices in Italy turned out, over the project's development period, to be significantly lower than initially projected. National green hydrogen production remains concentrated in a small number of limited-scale pilot initiatives, and the transport and storage infrastructure is still at an early stage of development. This translates into uncertainty about continuity of supply for end users and into difficulty in structuring supply contracts of duration and price suitable to support downstream investment bankability.

In terms of development timeframes, the study carried out by Renhive on the permitting pathway for newly installed energy assets in Italy showed a typical total duration of 18 to 30 months, articulated in three phases (site feasibility analysis, obtaining the General Minimum Technical Solution for the connection from Terna, and obtaining the Single Authorisation with the involvement of multiple administrations). Applied to the residual project window from the moment the alternative solution was developed, these timeframes made it unrealistic to complete the permitting procedure, the construction phase and the start of operations within the project's end date, even assuming the immediate availability of all financial and contractual preconditions.

A further consideration adds to these three factors. The planned investment, in its multifunctional mobile configuration, would have required the alignment of usage plans across multiple consortium partners within the same time window, with each contributing to the generation of the estimated 7,300 annual operating hours through the integration of the Genset into its own activities. The progressive reshaping of the individual partners' operational perimeters, as a consequence of the context evolution described above, created uncertainty about the effective demand base for the Genset's services and weakened the continuous-use assumptions underlying the financial model.

The combined effect of these factors led, through Renhive's internal evaluation process and through dialogue with the project coordination, to the decision not to proceed to the construction phase of the physical investment within the project's timeframe. The integrity of the output produced was instead preserved in documentary and analytical form, as a permanent contribution to consortium knowledge and to public dissemination. That decision was taken in line with the guidance from the project coordination and with the recognition, by the competent bodies, of the validity of repositioning Renhive's contribution towards a deliverable of a study, research and preliminary design nature.

4. Conclusions

In this section The contribution produced, its residual value, the alignment with European priorities, and the development prospects beyond the project's perimeter. A reading that closes the Deliverable while opening the conditions for the work to be picked up again, in the same territory or elsewhere.

Renhive's contribution to the HyMantoValley project, developed within the perimeter of Work Package 2 Production and Storage and formalised in Deliverable D2.1, unfolded as a path of study, analysis and preliminary design that moved through three successive phases in response to the evolution of the project context. This Report has documented in an organised way the set of activities carried out, the outputs produced, the reasons that led to the non-execution of the physical solutions studied, and the elements of residual value

that the work done leaves available to the consortium, to the European Commission and to the wider community of stakeholders involved in the development of the European green hydrogen economy.

4.1 Summary of the contribution produced

Renhive's contribution translates into an analytical and design corpus articulated across five distinct yet convergent dimensions. On the technology side, sizing, specification and integration studies were developed for three alternative solutions for stabilising renewable energy and generating clean power: a 2,752 kWh lithium electrochemical storage system, a 350 kW hydrogen generation system integrated with APA atmospheric abatement technology, and a hybrid configuration that combines both solutions at a reduced scale. On the system modelling side, an hourly PVSYST simulation was developed for the photovoltaic and electrolyser system at the reference site, with four photovoltaic field sizing iterations and an analysis of the electrolyser's absorption and overflow dynamics. On the economic and market side, an eighteen-year financial model under [omissis] price scenarios was developed, alongside a TAM/SAM/SOM market analysis, a mapping of the Italian regulatory framework for storage, and a full characterisation of the competitive landscape. On the territorial value side, a quantitative socio-economic business case was developed for the impact of APA technology on the Province of Mantova, with estimates of the effects on healthcare costs, workforce productivity, school absenteeism and the territory's tourism attractiveness. On the industrial network side, a structured technical partnership was activated with two international specialist entities, BluDrive Ltd in the United Kingdom for the engine side and Iscleanair Srl in Italy for the abatement technology, formalised in a joint operationally-actionable technical-commercial proposal.

Taken together, these outputs form a documentary and analytical corpus that exceeds, in breadth and depth, what was strictly needed for the mere characterisation of the storage unit originally envisaged as the object of Deliverable D2.1. That breadth reflects the strategic choice to respond to the project's evolving context not by narrowing the scope of work, but by extending and deepening the underlying analytical and design base, with the aim of preserving the substance of the Partner's contribution and of generating a body of knowledge useful to the consortium and to the wider community of stakeholders.

4.2 Residual value and replicability of the solutions studied

Three layers of replicable value: project references usable as is, a methodological framework transferable across contexts, and an industrial network ready to be re-engaged.

The technology solutions studied by Renhive over the course of the project retain full technical validity and design applicability, regardless of the fact that

their physical implementation did not materialise within the project's timeframe. That validity translates into replicability value at three distinct levels.

At the first level, the solutions provide project references that are immediately usable for future Hydrogen Valley development initiatives in contexts comparable to that of Mantova. The technical specifications, cost breakdowns, integration architectures and operational models have been documented at the level of detail required for the preliminary design phase, and can be picked up by industrial operators, public-private consortia or policy initiatives facing comparable challenges in other European areas. The fact that the Report is classified as a public deliverable and is made available on the HyMantoValley project website ensures that this design corpus is accessible to the interested community.

At the second level, the analytical methodologies developed represent a replicable framework for the feasibility assessment of comparable initiatives. The structure of the comparison among alternative solutions on technical, economic, environmental and operational criteria; the modelling approach for the integrated PV-electrolyser simulation; the structure of the long-horizon financial model under institutional reference price scenarios; and the four-category strategic risk matrix are all methodological elements transferable to other application contexts. That methodological dimension of the value produced is particularly consistent with the nature of the HyMantoValley project, conceived from its submission as a replicable initiative, in line with the dissemination and knowledge transfer objectives of the EISMEA I3-2021-INV1 GREEN call.

At the third level, the industrial network built by Renhive over the course of the project, in particular the partnership formalised with BluDrive Ltd and Iscleanair Srl, represents a design capability that can be activated for future implementation of the solutions studied. That network, consolidated through the joint work of the project, is available to be re-engaged in future realisation contexts, should the feasibility conditions that prevented implementation within the project's perimeter turn more favourable.

4.3 Alignment with the call's objectives and with European priorities

Renhive's contribution to the project, in the form in which it was developed and documented, aligns coherently with the objectives of the EISMEA I3-2021-INV1 GREEN call under which the project was funded, and with the broader priorities of the European Union's climate and energy action.

At the call level, the Interregional Innovation Investments instrument aims to strengthen the capacity of European regions to join forces around shared Smart Specialisation investment priorities, by supporting interregional innovation projects in their scale-up and commercialisation phase. The GREEN strand specifically seeks to turn climate and environmental challenges into opportunities by supporting innovative supply-chain investments through green technologies. Renhive's contribution developed three technology

solutions fully consistent with those objectives: a lithium electrochemical storage solution based on LFP chemistry, a green hydrogen power generation solution with active abatement of atmospheric pollutants, and a hybrid configuration that combines the two technologies. The solutions were characterised both in terms of technological maturity and in terms of business model and replicability in comparable European contexts.

At the level of broader European priorities, the contribution fits within the framework of the European Green Deal and of the trajectory towards climate neutrality by 2050. The technologies studied contribute to three of the main objectives of that framework: the decarbonisation of the energy sector through the integration of green hydrogen in power generation and storage; the improvement of air quality through the active reduction of atmospheric pollutants in urban and industrial areas with a high emissions density; and the strengthening of the European value chain for clean technologies through the development and integration of components and industrial know-how of European origin.

4.4 Development prospects beyond the project's perimeter

The conclusion of the HyMantoValley project within its time horizon does not exhaust the development prospects of the work carried out by Renhive. The analytical and design corpus produced, the industrial network activated, the methodologies developed, all remain available as bases for future implementation initiatives, both within the Mantova territory and in other European contexts.

In terms of the reference territory, the evolution of the market and regulatory conditions that prevented implementation within the project's perimeter is subject to continuous change. The downward trajectory of the cost of green hydrogen, the operational rollout of storage capacity support mechanisms (in particular the MACSE mechanism, with its first auction in September 2025 and subsequent auctions), the maturation of green hydrogen production and distribution infrastructure in Italy, and the evolution of the tariff framework for flexibility services, are all factors that may shift, over time, the feasibility conditions of investments. The study produced by Renhive provides a reference base that can be readily reactivated to reconsider the opportunity for implementing the solutions studied as more favourable context conditions emerge.

In terms of extension to other European contexts, the solutions studied and the methodologies developed are transferable to comparable Hydrogen Valley initiatives in other regions of the European Union, in particular in areas characterised by a combination of industrial green hydrogen demand, availability of renewable resources (photovoltaic or wind) and the need to stabilise intermittent generation. The fact that the HyMantoValley consortium brings together partners from Italy, Austria, Netherlands and Belgium is itself a natural dissemination channel for the design corpus produced, through the professional and institutional networks of the individual partners.

In terms of contribution to European green hydrogen policy, the experience accumulated in the HyMantoValley project, including the documentation of the reasons that prevented the transition from study to realisation, represents a relevant input for the calibration of future public support instruments, for the identification of bottlenecks that require policy intervention, and for the definition of the framework conditions needed to make supply-chain investments in green hydrogen bankable. This Report, in its public form and in its availability on the project's website, is also intended as a contribution to that collective learning process, in line with the dissemination and knowledge transfer mission that the I3-2021-INV1 GREEN call has set as a defining objective.

5. Reference framework and technological-regulatory context

In this section The European and Italian policy coordinates, the state of the art for the technology families considered, and observations from the broader European Hydrogen Valley landscape. The reference context in which the analytical work of the previous sections takes its full meaning.

This section frames the broader reference context within which the activities described in Section 2 were developed and against which their content acquires its full meaning. The aim is twofold. On the one hand, to make explicit the institutional, regulatory and technological coordinates that shaped the analytical work, so that the choices documented in the previous sections can be read in continuity with the strategies set out at European and Italian level. On the other hand, to provide the reader with a synthetic but organised characterisation of the state of the art for the technology families considered, of the policy framework that supports them, and of the comparable initiatives that, at the European scale, have addressed analogous challenges.

The section does not aim at exhaustiveness in either dimension. It selects the reference documents, technology developments and comparable initiatives that have a direct bearing on the perimeter of the work documented in this Report, and offers a synthesis that allows the analytical corpus produced by the Partner to be situated within the broader trajectory of European green hydrogen policy and of the storage and clean-power generation industries.

5.1 European hydrogen strategy: key reference documents

The European policy framework for hydrogen has consolidated, over the past decade, through a sequence of strategic documents and legislative acts that have progressively defined the role of renewable and low-carbon hydrogen in the European Union's energy and climate trajectory. The conceptual core was set out in the European Hydrogen Strategy adopted by the European Commission in July 2020, which identified hydrogen as a strategic vector for the decarbonisation of energy-intensive industries, of heavy and long-distance transport, and of integrated energy systems based on a high share of intermittent renewable generation. The Strategy laid down quantitative targets

for electrolyser deployment over the decade and identified the conditions for the development of a European hydrogen market, in terms of infrastructure, regulation, demand stimulation and international cooperation.

The Strategy was subsequently complemented by the REPowerEU Plan, presented by the European Commission in May 2022 in response to the security-of-supply and energy-pricing dynamics that emerged following the Russian invasion of Ukraine. REPowerEU strengthened the level of ambition on the deployment of renewable hydrogen, raised the domestic production targets and introduced explicit objectives for the import of renewable hydrogen from third countries, supported by the activation of dedicated financial instruments such as the European Hydrogen Bank and the auctions managed by the Innovation Fund.

On the regulatory side, the Renewable Energy Directive in its third revision (commonly referred to as RED III) and the delegated acts on the definition of Renewable Fuels of Non-Biological Origin (RFNBO) have provided the legal definition of renewable hydrogen, fixing the requirements for additionality, temporal correlation and geographical correlation between renewable electricity used in electrolysis and the resulting hydrogen output. That regulatory framework constitutes the binding reference for any project that intends to qualify its output as renewable hydrogen for the purposes of the targets set out in sectoral directives, including the Renewable Energy Directive for transport and the Industrial Emissions Directive for industry.

The Hydrogen and Decarbonised Gas Markets Package, adopted in 2024, completes the regulatory framework on the infrastructure side, defining rules for access to hydrogen transport and storage networks, principles of unbundling and tariff arrangements, with the aim of supporting the development of an integrated European hydrogen market. The package is part of the broader integration of energy markets envisaged by the European Green Deal and operationally supports the implementation of the European Hydrogen Backbone vision developed by gas Transmission System Operators.

The activities carried out by the Partner in the framework of HyMantoValley sit consistently within this set of reference documents. The integrated PV-electrolyser sizing logic, the qualification of hydrogen output, the structuring of the Power Purchase Agreement, and the modelling of long-term price trajectories were all developed taking into account the requirements and conditions of these reference frameworks.

5.2 Italian hydrogen strategy and PNIEC alignment

The Italian national framework for hydrogen takes shape through the convergence of two complementary lines of policy. On the one hand, the National Integrated Energy and Climate Plan (PNIEC), submitted by Italy in its updated version to the European Commission in 2024, which sets out the national trajectory for the achievement of the climate and energy targets to 2030, in line with the Fit for 55 package. The updated PNIEC integrates the

hydrogen dimension across three main axes: renewable hydrogen production, the use of hydrogen in industrial sectors that are hard to electrify (refining, steel, chemicals, cement, glass), and the use of hydrogen in heavy and long-distance transport applications.

On the other hand, the National Hydrogen Strategy, framed around the lines of action identified at European level and adapted to the structural specificities of the Italian energy system. The Strategy identifies as strategic the development of dedicated electrolysis production capacity, the activation of demonstration projects at industrial cluster scale (Hydrogen Valleys), the development of the infrastructure required for the transport and storage of hydrogen, the qualification of supply chains for components and balance of plant, and the creation of conditions for the participation of national industrial players in the European hydrogen market.

In terms of operational support instruments, the framework is articulated through measures funded by the National Recovery and Resilience Plan, dedicated to the development of renewable hydrogen production projects through electrolysis, with prioritisation criteria that favour location in disused industrial areas, the integration with co-located renewable generation, and the demonstration value at supply-chain scale. To these instruments are added the regional regulatory frameworks, with specific reference to the Lombardy Region for projects in the Po Valley, which provide complementary incentive measures and offer simplified authorisation pathways for hydrogen technology demonstration projects.

The activities carried out by the Partner in the framework of HyMantoValley fall within this national framework on multiple dimensions. The geographical positioning in the Mantova area is consistent with the PNIEC's territorial priorities for the development of demonstration Hydrogen Valleys in industrial areas with significant decarbonisation pressure. The configuration of the system, organised around a dedicated electrolyser fed by co-located photovoltaic generation, is consistent with the additionality and temporal correlation requirements set out at European and national level. The analysis of the regulatory landscape for storage and the financial structuring of the alternative solution were developed in line with the support mechanisms made available by the national policy framework.

5.3 Battery Energy Storage System technology landscape: state of the art

The technological landscape of utility-scale electrochemical storage systems has undergone, over the second half of the past decade and in the first half of the current decade, a process of rapid maturation that has consolidated lithium iron phosphate (LFP) chemistry as the de facto market standard for stationary applications integrated with renewable generation and for grid services. That standardisation reflects the convergence of three factors: the intrinsic safety profile of LFP chemistry, which dispenses with the active management constraints required by lithium nickel manganese cobalt (NMC) chemistries; the stability of the raw materials supply chain, which is no longer

exposed to cobalt price volatility; and the high cycle life, which makes LFP particularly suitable for applications requiring intensive daily cycling.

The architecture of utility-scale BESS units has consolidated around a containerised modular configuration, organised by battery rack with internal Battery Management System, power conversion system based on bidirectional inverters, active liquid cooling system, integrated fire suppression and control system, and Energy Management System with predictive optimisation algorithms based on price signals, ancillary service requests and renewable generation forecasts. The integration with co-located renewable generation has progressively shifted from purely physical configurations (with shared point of interconnection) towards integrated control configurations, which jointly optimise renewable generation, storage charging and discharging, and grid interaction across multiple market timeframes.

In terms of business models, the European storage market has progressively articulated itself across four main archetypes. Stand-alone units connected directly to the transmission grid, remunerated through capacity contracts, ancillary services and arbitrage on the day-ahead and intraday markets. Co-located units paired with renewable assets, remunerated through Power Purchase Agreements of integrated structure, capacity contracts for the storage component and ancillary services. Behind-the-meter units serving energy-intensive consumers, remunerated through avoided network charges, peak shaving on time-of-use tariffs and ancillary services to the meter operator. Aggregated units in Virtual Power Plant configuration, remunerated through participation in demand response markets and ancillary services through the aggregator.

The trajectory of unit installation costs has shown, over the past five years, a marked downward trend, with parallel improvements in the energy density of batteries, the modularity of installations and the efficiency of conversion systems. The Italian context, in particular, is going through a phase of intense growth, driven by the operational rollout of the MACSE mechanism, by the expansion of the Capacity Market to include storage as an eligible technology, and by the development of a Power Purchase Agreement market for renewable assets that increasingly includes storage components.

The analytical work developed by the Partner sits squarely within this trajectory, and the technical specifications, design choices and business models considered are consistent with the configurations that the market has progressively recognised as references for the segment of utility-scale storage integrated with green hydrogen production.

5.4 Hydrogen internal combustion technology: state of the art

Power generation through hydrogen combustion in modified internal combustion engines represents a technological development pathway that complements, with distinct characteristics, the more widely covered pathway of low-temperature fuel cells (PEMFC) and high-temperature fuel cells (SOFC).

The hydrogen combustion engine builds on a base technology consolidated over a century of development for transport, marine and power generation applications, supported by mature service chains, supply chains for spare parts and operational know-how distributed across the European industrial fabric.

The retrofit of an internal combustion engine to hydrogen operation requires a focused set of interventions on the fuel injection system (substitution of injectors and adjustment of injection timing for hydrogen's much faster combustion characteristics), on ignition (adjustment of ignition timing and substitution of spark plugs suited to hydrogen's combustion thermodynamics), on materials (selection of components qualified against hydrogen embrittlement), on combustion control (calibration on ultra-lean cycle to minimise NOx formation), and on safety systems (leak detection in the fuel circuit, gas detection in the engine compartment, automated emergency shutdown sequences). The combustion thermodynamics of hydrogen, characterised by extended flammability limits and very fast flame velocity, make it possible to operate engines under lean combustion conditions that, properly calibrated, allow the formation of nitrogen oxides to be brought to very low levels.

The application landscape of hydrogen internal combustion generation is positioned in clearly distinct niches with respect to fuel cells. In comparison with fuel cells of equivalent installed power, hydrogen combustion engines are more competitive in terms of upfront investment, benefit from a more readily available service chain, offer greater operational flexibility against rapid load variations and ambient conditions, and admit a degree of fuel quality flexibility that fuel cells cannot tolerate. Conversely, hydrogen combustion engines display lower electrical conversion efficiency than fuel cells (typical engine efficiencies are in the order of forty per cent against PEMFC efficiencies in the order of fifty to sixty per cent), and require active emissions management (whereas fuel cells produce zero emissions at the stack), although the integration with atmospheric abatement technology can compensate for that limitation.

In the European context, the market for hydrogen internal combustion generation has consolidated, over the past five years, around a small number of specialist players who have developed dedicated retrofit and design capabilities, often emerging from engineering services to the marine and stationary generation industries. The application sectors include the powering of mobile demonstration units, the supply of energy to off-grid sites in transition, peak shaving and the integration with renewable generation at industrial cluster scale. The technological maturity of the solution, measured against the Technology Readiness Level scale, sits in the seven-to-nine range for retrofit configurations on consolidated engines, and at the upper edge of the range for dedicated configurations qualified for industrial use.

The activities carried out by the Partner in the framework of HyMantoValley fit consistently within this technological landscape, with the choice of the retrofit path on a spark ignition engine of mid-range size, the activation of a specialist

partnership with operators of consolidated track record in the segment, and the integration with atmospheric abatement technology of dual-use (combustion emissions plus ambient air pollutants).

5.5 PV-coupled electrolysis: integration patterns observed in Europe

The integration between dedicated photovoltaic generation and electrolyser for renewable hydrogen production constitutes the configuration most widely covered by European policy documents on renewable hydrogen, and is the configuration that most directly fulfils the additionality and temporal correlation requirements set out by the RED III delegated acts on RFNBO. The European industrial landscape has, over the past five years, developed a body of comparable experiences at demonstration and early commercial scale, from which it is possible to extract a set of integration patterns that the activities carried out by the Partner in the framework of HyMantoValley draw upon, with adaptations to the specificities of the Mantova area.

A first pattern concerns the sizing logic of the photovoltaic field with respect to the rated power of the electrolyser. The most widely observed configurations adopt a moderate oversizing of the photovoltaic field with respect to the electrolyser, typically in the order of one and a half to two times the rated power of the electrolyser, with the aim of maximising the electrolyser's annual operating hours under partial-load conditions and of limiting the share of photovoltaic generation not absorbed by the electrolyser. The optimal sizing depends on the local solar resource profile, on the electrolyser's response characteristics under low load, and on the relative cost of photovoltaic generation against the value of hydrogen produced.

A second pattern concerns the coupling architecture between photovoltaic generation and electrolyser. Three main configurations are documented in the European landscape. Direct DC-DC coupling, in which the photovoltaic field is connected to the electrolyser through a dedicated DC-DC converter without an intermediate inverter stage, with maximum simplicity and conversion efficiency but reduced operational flexibility. AC-AC coupling through a shared interconnection point, in which the photovoltaic field is connected to the local grid through an inverter and the electrolyser draws energy from the same connection point, allowing the export of surplus energy to the grid and the import of integration energy when photovoltaic generation falls short. Grid-interactive coupling with managed import or export, in which the system is configured to optimise the participation in spot and balancing markets in addition to renewable hydrogen production.

A third pattern concerns the management of curtailment and minimum-load constraints. PEM electrolysers, which are the most widely deployed in the demonstration landscape, admit a minimum operating load in the order of ten to twenty per cent of rated power, below which they switch to standby mode. The integration with the photovoltaic field must therefore manage the share of photovoltaic generation below the minimum load (typically used for the local consumption of the plant, for the charging of small accumulation systems, or

curtailed) and the share of generation above the rated power of the electrolyser (typically exported to the grid or curtailed depending on the contractual configuration).

A fourth pattern concerns the integration of storage as a flexibility element. The introduction of an electrochemical storage component between the photovoltaic field and the electrolyser allows a smoother operating profile for the electrolyser, reduces the frequency of switches to standby mode, allows the electrolyser to operate beyond the photovoltaic generation hours for a fraction of the day, and provides operational flexibility for the management of imbalances and ancillary service offers to the grid. The sizing of the storage component varies significantly across observed configurations, depending on the strategic value attached to the operational continuity of the electrolyser and the relative cost of storage capacity.

The simulation work developed by the Partner falls within this set of integration patterns. The hourly simulation of the photovoltaic field at the reference site, the analysis of the energy not absorbed by the electrolyser as a function of its acceptance thresholds, the consideration of grid coupling configurations and the analysis of storage integration are all elements consistent with the methodological framework that has consolidated at European level.

5.6 Hydrogen valleys in Europe: comparative observations

The Hydrogen Valley concept refers to a set of integrated initiatives at regional or sub-regional scale that combine renewable hydrogen production, dedicated transport and storage infrastructure, and end-use applications across multiple sectors, with the objective of building an articulated and replicable local hydrogen ecosystem. The European Commission, through Clean Hydrogen Partnership and through the Mission Innovation Hydrogen Valley Platform, has promoted, monitored and supported, over the past five years, a set of demonstration initiatives across multiple European Member States, gradually consolidating the conceptual framework, the indicators for performance measurement and the lessons learned in terms of replication.

The European Hydrogen Valley landscape includes initiatives at very different scales and stages of development. Mature initiatives that have moved from the design phase to the implementation phase with the construction of dedicated production assets and the activation of multi-sector end uses. Initiatives at the demonstration phase, with limited installed capacity and pilot end uses, designed to test the integration architectures and the regulatory conditions before scale-up. Initiatives at the design phase, supported by feasibility studies and preliminary engineering, aimed at maturing the financial and contractual conditions required for the transition to implementation. The HyMantoValley project finds itself, in light of the trajectory documented in this Report, in a position that combines elements of the second and third categories, with substantial analytical work and design specification developed at consortium scale and with the physical implementation

deferred to feasibility conditions that the project's timeframe did not see materialise.

A set of cross-cutting observations emerges from comparison with the broader European landscape. The first observation concerns the absolute centrality, for the maturation of an investment from study to implementation, of the alignment between European funding, national co-funding and private investment, with national co-funding emerging as the most volatile component of the alignment and the one most subject to discretionary policy changes during the lifecycle of the initiative. The second observation concerns the role of long-term hydrogen offtake contracts, which the European landscape is gradually developing through dedicated public support mechanisms (such as the European Hydrogen Bank auctions) and through the maturation of demand from energy-intensive industrial sectors. The third observation concerns the strategic value of the demonstration component, regardless of the achievement of full physical implementation: the analytical, methodological and design corpus produced by Hydrogen Valley initiatives that have completed only part of the planned implementation retains documentary, methodological and replication value of significant relevance for the wider community.

The activities documented in this Report, and the way in which they have been organised and disseminated through the present Deliverable, are intended as a contribution to that body of European Hydrogen Valley experiences, with a specific focus on the lessons learned in terms of context evolution, project reformulation, and preservation of the value generated by the analytical work in the face of difficulties in the transition from study to physical implementation.

Key takeaways - Section 5

The analytical work sits coherently within the European hydrogen policy framework, from the European Hydrogen Strategy to REPowerEU, RED III and the Hydrogen and Decarbonised Gas Markets Package, and within the Italian national framework articulated through PNIEC and the National Hydrogen Strategy.

The technology choices reflect consolidated state-of-the-art positions across the three families considered: utility-scale lithium electrochemical storage, hydrogen retrofit of internal combustion engines, and PV-electrolyser integration patterns.

The trajectory of the project, including the deferral of physical implementation, fits within a recognisable pattern of European Hydrogen Valley initiatives in which demonstration value is preserved through the analytical and design corpus produced.

Annexes

Annex A — Base technical documents produced by Renhive

This Annex provides a structured synthesis of the analytical, technical, modelling and design documents produced by the Partner over the course of the project, which together constitute the documentary corpus underpinning this Report. For each item, the Annex sets out the format and the production context, an executive summary of the content, the key elements documented, and the cross-reference to the sections of the Report where the content is used. Where the original document is available in a graphical format, a representative figure has been extracted from the source document and is reproduced here for documentary purposes. Numerical values appearing in the reproduced figures refer to the assumptions of the studies as developed in 2024 and are documented as historical references to the analytical work carried out, in line with the institutional practice for archive documents.

A.1 Renhive Energy Storage Solution for Electrolyzers

Format: technical document, 12 pages, issued 2 June 2024

Executive summary. The document constitutes the technical reference characterisation of the electrochemical storage solution developed by the Partner for the integration with the electrolyser dedicated to renewable hydrogen production at the Mantova industrial site. The document opens with a framing of the operational challenges that characterise the integration between variable renewable generation and PEM electrolysis: the intermittence of the renewable resource on multiple time scales, the limitations of the electrical grid on the absorption of generation peaks, and the variability of hydrogen demand from downstream users. For each operational constraint, the document characterises the functional response offered by the lithium electrochemical storage solution, in the form of surplus energy storage, support to grid stability, and supply of energy to the electrolyser even in the absence of concurrent renewable generation.

Key elements documented. The document covers the full technical characterisation of the proposed system, including the architecture of the modular battery rack, the design of the active liquid cooling circuit, the configuration of the safety system in compliance with applicable international standards, the communication interfaces for integration with the plant control system, the level of integration achieved through pre-assembled modules for rapid installation, and the techno-economic profile of the solution articulated by cost item. The document also includes a synthesis of the distinctive advantages of the Renhive solution against the typical benchmarks of the utility-scale storage market.



Figure A.1: Technical characterisation page of the Renhive Lithium Energy Storage Solution for Electrolyzers (Renhive, 2024)

Referenced in sections: 2.2, 4.1, 5.3.

A.2 I3 BESS/Storage Study for HyMantoValley

Format: strategic technical presentation, issued in the second half of 2024

Executive summary. The document is the most articulated strategic deliverable on the storage component developed by the Partner in the framework of the HyMantoValley project. It sits at the intersection between the technological analysis of the BESS solution, the market analysis of the storage sector in Northern Italy, the analysis of the Italian regulatory framework, and the financial structuring of representative business cases at scale. The document was developed in support of the strategic decision-making activity of the Partner and of dialogue with the consortium on the perimeter of the contribution to Work Package 2.

Key elements documented. The document includes the analysis of the structure of electricity demand in Northern Italy and of the structural rigidities that justify the strategic value of stationary storage, the characterisation of two complementary functional roles for BESS (renewable surplus absorption and fast frequency regulation), the mapping of the Italian regulatory framework with reference to the support mechanisms for storage capacity, the qualification of the main operators active on the Italian market, the comparison of the three design options considered by the Partner (lithium electrochemical, hydrogen genset with atmospheric abatement, hybrid configuration), the construction of archetype business cases for stand-alone and co-located configurations, the development of a sensitivity analysis on the main critical variables, and the structuring of a strategic risk matrix articulated across four categories.

Referenced in sections: 2.3, 2.4, 2.6, 2.7, 2.10, 5.3.

A.3 Hourly PVSYST simulation of the PV-electrolyser system

Format: PVSYST model version 7.2.12 with companion analysis spreadsheet, finalised in July 2024

Executive summary. The document constitutes the most quantitatively detailed simulation work developed by the Partner on the dynamic integration between dedicated photovoltaic generation and the electrolyser dedicated to renewable hydrogen production. The simulation covers the full typical year at hourly resolution, exploring four photovoltaic field sizing configurations in successive iterations aimed at finding the most appropriate scale with respect to the absorption profile of the electrolyser and to the constraints of the reference site. The work was carried out in-house by the Partner, using a software platform recognised as an industry standard for the simulation of photovoltaic generation at hourly resolution.

Key elements documented. The simulation produces, for each configuration considered, the expected annual production, the monthly distribution, the average hourly curve, the distribution of operating hours by power band, the energy not absorbed by the electrolyser as a function of its acceptance thresholds, and the analysis of the system's behaviour across the time bands of the Italian tariff regime. The analysis qualifies the conditions under which photovoltaic generation exceeds the absorption capacity of the electrolyser, and those under which it falls short, providing the necessary operational information for the design of the system's coupling architecture and for the evaluation of the integration of a storage component as a flexibility element.

Referenced in sections: 2.1, 2.5, 5.5.

A.4 Joint Proposal for H2 Genset and APA Technology Demonstrator

Format: joint technical-commercial proposal, drafted in May 2024

Executive summary. The document is the formal proposal jointly drafted by BluDrive Ltd and Iscleanair Srl for the execution of the alternative Genset H2 plus APA solution developed in response to the reformulation of the project. The document defines the technical perimeter of the intervention, the operational plan articulated across distinct phases, the breakdown of activities between the two specialist partners, and the timeline for the execution of the work. It constitutes the contractual reference for the specialist technical partnership activated by the Partner for the execution of the alternative solution.

Key elements documented. The proposal includes the technical rationale for the retrofit of a spark ignition internal combustion engine to operation on hydrogen as the sole fuel, the description of the modifications required on the fuel injection system, on ignition, on the materials of the components in contact with hydrogen, and on the calibration of the combustion cycle. It

includes the description of the atmospheric abatement technology proposed by Iscleanair, the integration scheme between the Genset and the abatement module, the operational plan articulated in five phases (retrofit design and component procurement, integration and initial testing, baseline pollutant monitoring at the installation site, abatement system adaptation and testing, and operations and iterative data collection), and the technical appendix on the qualifications of the partners.

Referenced in sections: 2.3, 3.2, 4.1, 5.4.

A.5 Closing the Loop — A Hydrogen Generator for a Sustainable and Resilient HyMantoValley

Format: positioning document, drafted in the central months of 2024

Executive summary. The document characterises the cross-cutting value of the Genset H2 plus APA solution for the HyMantoValley consortium as a whole, mapping the application areas across the different project partners and identifying the distinctive value dimensions of the proposed solution. The document was developed in support of the dialogue with the consortium on the strategic value of the alternative solution and on its capacity to serve the multiple stakeholders involved in the project.

Key elements documented. The document maps the application areas of the Genset for each project partner, identifying for each entity the specific operational contexts in which the solution can provide value: support to outreach events and mobile offices for the Project Coordinator, energy supply to electrolyzers and refuelling station compressors for the industrial hydrogen producer, support to storage facility operations for the storage infrastructure operator, direct vehicle recharging and mobile refuelling infrastructure support for mobility partners across maritime, rail and road, support to environmental monitoring activities and laboratory operations for the research partners, support to teaching workshops and pilot plant operations for the university partners. The document identifies the three distinctive value dimensions of the solution: rapid deployment, multiple application capability, and active air purification.

Referenced in sections: 2.3, 2.8, 4.1.

A.6 Hydrogen Valley: Bridging the Gap to a Sustainable Future

Format: strategic positioning document, 15 pages, issued 2 June 2024

Executive summary. The document develops the strategic positioning of hydrogen internal combustion power generation technology as a bridging technology in the transition towards a fully integrated green hydrogen economy. The document was conceived to support the rationale of the choice of the alternative solution within the broader narrative of European Hydrogen Valley initiatives, and to qualify the role of hydrogen combustion

technology as complementary, and not alternative, to the development of fuel cell technology.

Key elements documented. The document identifies three macro application areas in which hydrogen power generation finds its most natural deployment: transitional power supply during the construction and ramp-up phases of integrated hydrogen systems, emergency backup against grid outages or adverse events, and off-grid power for unserved or remote areas. For each application area, the document characterises the value of the solution against incumbent alternatives and the conditions under which the integration with hydrogen production assets can be operationally activated. The document also addresses the integration with atmospheric abatement technology and the real-world deployment cases that have validated the maturity of the technology in industrial and demonstration contexts.



Figure A.6: Decarbonising use cases of hydrogen gensets across power generation, transportation and industrial processes (Renhive, 2024)

Referenced in sections: 2.3, 4.1, 5.4.

A.7 Economic Analysis — Diesel Engine Retrofit to Hydrogen with APA Modules

Format: economic analysis document, 9 pages, issued 2 June 2024

Executive summary. The document develops a multi-year economic projection of the retrofit of a spark ignition engine to operation on hydrogen as the sole fuel, integrated with atmospheric abatement modules. The analysis was developed under a set of assumptions framed within the price and operational landscape observable in the months of preparation of the study, with the explicit purpose of providing the consortium with an operational economic reference for the assessment of the feasibility of the alternative solution. The values that appear in the analysis are to be understood as

documented elements of the analytical work and not as projections that retain validity beyond the period in which they were developed.

Key elements documented. The document articulates the analysis around five blocks: the description of the project's objectives, the structure of the basic assumptions on operating parameters, the breakdown of investment costs into the capital items required for the realisation, the structure of annual operating costs articulated across fuel, maintenance and insurance, and the projection of revenue streams articulated across direct electricity sales and revenue from carbon credit mechanisms. The cash flow projection is developed over the operational lifetime of the asset, with the calculation of the payback period and of the synthetic financial indicators used for the investment evaluation. The analysis closes with a comparative section against the conventional diesel generator that would constitute the natural alternative in a non-decarbonised supply chain.

Cash Flow Projection (10 years)				
Year	OPEX (€)	Revenues (€)	Cash Flow (€)	Cumulative Cash Flow (€)
0	0	0	-1,070,000	-1,070,000
1	353,000	560,620	207,620	-862,380
2	353,000	560,620	207,620	-654,760
3	353,000	560,620	207,620	-447,140
4	298,250	560,620	262,370	-184,770
5	298,250	560,620	262,370	77,900
6	298,250	560,620	262,370	340,270
7	298,250	560,620	262,370	602,640
8	298,250	560,620	262,370	865,010
9	298,250	560,620	262,370	1,127,380
10	298,250	560,620	262,370	1,389,750

Figure A.7: Cash flow projection table from the Economic Analysis of the hydrogen retrofit project (Renhive, 2024)

Referenced in sections: 2.3, 2.7, 4.1.

A.8 Market Analysis — Hydrogen Genset with APA Modules

Format: market analysis document, 14 pages, issued 2 June 2024

Executive summary. The document develops a structured analysis of the market in which the Genset H2 plus APA solution would have operated, organised around the standard analytical framework of Total Addressable Market, Serviceable Available Market and Serviceable Obtainable Market.

The analysis integrates the quantitative sizing of the market segments with a qualitative characterisation of the structural drivers of demand, of the regulatory enablers, of the technological barriers and of the competitive landscape, with the aim of providing the consortium with a robust strategic basis for assessing the commercial viability of the solution.

Key elements documented. The document articulates the market analysis on multiple dimensions: the sizing of the global and European Total Addressable Market for portable power generation, with reference to recognised market research sources; the segmentation of the Serviceable Available Market across the four main application sectors (industrial, construction, events and entertainment, cities and municipalities), with quantification of the value of each segment; the qualitative profiling of the Serviceable Obtainable Market and of the entry strategy; the full SWOT analysis of the solution along strengths, weaknesses, opportunities and threats; the identification of the target customer segments with characterisation of the buying profile; the analysis of market trends in terms of demand growth, technology cost decline, regulatory framework evolution and infrastructure development; the construction of the unique value proposition; and the competitor analysis with mapping of market leaders and emerging players. The document closes with a comparative section that positions the Genset H2 plus APA solution against alternative technologies including lithium battery storage and fuel cells.



Figure A.8: SWOT analysis structure for the Hydrogen Genset with APA Modules solution (Renhive, 2024)

Referenced in sections: 2.6, 4.1, 5.4.

A.9 Iscleanair — The Solution to Combat the Deadly Impact of Air Pollution

Format: socio-economic business case, 12 pages, issued 4 June 2024

Executive summary. The document develops a multi-dimensional characterisation of the socio-economic impact of atmospheric abatement technology on the reference territory of the Province of Mantova. The analysis goes beyond the strictly industrial dimension and embraces the wider implications of improved air quality on public health, workforce productivity, school performance, tourism attractiveness and the territory's strategic positioning. The document is positioned at the intersection between the technological dimension of the abatement solution and the territorial dimension of the project, providing the consortium with elements of valuation that contribute to the qualification of the cross-cutting value of the contribution.

Key elements documented. The document organises the analysis across five blocks. The first block characterises the impact on direct and indirect healthcare costs, drawing on independent studies developed by academic institutions of the reference territory, with reference to documented reductions in respiratory illnesses, savings on absenteeism costs and savings on chronic care costs. The second block characterises the impact on workforce productivity, drawing on the scientific literature on the relationship between indoor air quality, cognitive function and worker performance. The third block characterises the impact on school absenteeism and on academic performance, with reference to estimates developed by Italian polytechnic institutions. The fourth block characterises the impact on the tourism sector, qualifying the positioning of the territory as an air-quality-conscious destination as a differentiating factor against comparable destinations. The fifth block characterises the carbon credit dimension, identifying the active CO₂ removal capability of the abatement technology as a potential additional revenue stream.

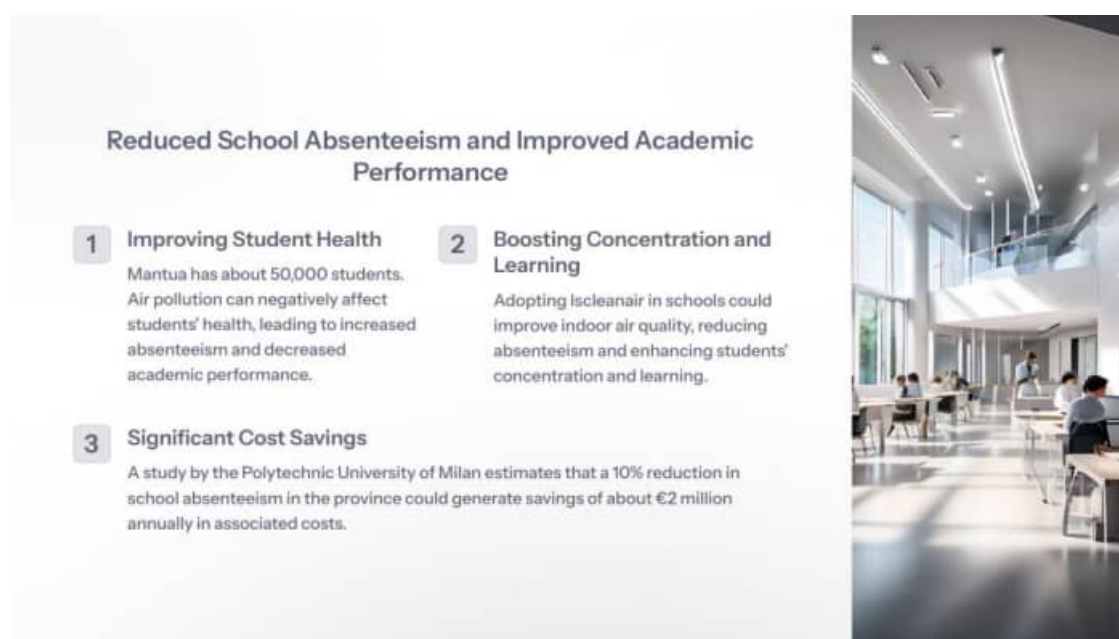


Figure A.9: Economic and social benefits of Iscleanair APA technology in the Province of Mantova (Renhive, 2024)

Referenced in sections: 2.8, 5.4.

A.10 Genset H2 plus APA financial model over a multi-year horizon

Format: structured spreadsheet financial model, finalised in 2024, multi-year coverage

Executive summary. The document constitutes the most articulated financial deliverable developed by the Partner for the assessment of the long-term sustainability of the Genset H2 plus APA solution. The model integrates the revenue projection across multiple business lines, the operating cost trajectory across multiple input drivers, the time profile of investment and maintenance costs, and the calculation of synthetic financial indicators across the full operational horizon. The model is fed by long-term price scenarios developed by an internationally recognised energy market analysis provider, used as the industry reference for long-term financial planning of energy assets in the Italian market.

Key elements documented. The model articulates the projection of revenues across two distinct streams, corresponding to the two business modes considered for the asset. The first stream is fed by arbitrage operations on electricity markets across day-ahead and balancing time frames, sized in proportion to a fraction of the asset's annual availability. The second stream is fed by third-party leasing of the asset over the residual share of availability, with daily rates subject to inflation indexation over the operational horizon. On the operating cost side, the model integrates the cost of hydrogen fuel with a trajectory consistent with long-term scenario projections, alongside maintenance costs with inflationary growth, insurance costs and contingency provisions for component refresh activities at mid-life of the asset. The model returns the annual and cumulative profile of operating profitability and of the synthetic financial indicators, alongside a sensitivity analysis on the most critical variables of the configuration.

Referenced in sections: 2.7, 4.1, 5.3.

Annex B — List of technical and contractual partners activated

Entity	Location	Role in Renhive's contribution
BluDrive Ltd	United Kingdom	Technical partner for the engine retrofit of the H2 Genset
Iscleanair Srl	Italy	Technical partner for the APA atmospheric abatement technology
Sapio Spa	Italy (Partner #3 of the consortium)	Industrial counterpart for hydrogen production and for the Power Purchase Agreement negotiation
Hive Energy Ltd	United Kingdom	Co-founder of the Renhive joint venture, lead sponsor
SunLeonard Energy Ltd	United Kingdom	Co-founder of the Renhive joint venture
Proter Srl	Italy	Co-founder of the Renhive joint venture, financial advisor
Renovo SpA	Italy	Co-founder of the Renhive joint venture, lead photovoltaic developer

Annex C — Chronological reconstruction of Renhive's activities in the project

This Annex reconstructs the chronology of the activities carried out under the perimeter of Renhive's contribution to Work Package 2, with the granularity of the half-year. The reconstruction is anchored to the documentary sources available in the project archives and listed in the table at the end of this Annex. Dates have not been assigned to individual events where these are not supported by a specific document; the periods are expressed in the form of half-years or quarters to reflect the documentary granularity available.

The Partner's contribution to Work Package 2 Production and Storage unfolded along a temporal arc that spanned the formative and early development phase of the HyMantoValley project. The reference framing dates back to the EISMEA call I3-2021-INV1 GREEN, with the contractual framework formalised over the course of 2023 and the Project Handbook approved at the end of December of that year. The first half of 2024 saw the production of the principal nucleus of technical studies: in the month of May, the joint Proposal on the H2 Genset plus APA solution was drafted, while in the

month of June, the studies on economic analysis, market, strategic positioning in the context of European Hydrogen Valleys and on the electrochemical storage solution were issued. In the same period, the simplified Business Plan model for the Genset solution was finalised, alongside the allocation of the Work Package 2 budget at the level of the Grant Agreement. In the month of July 2024, the hourly PVSYS simulation of the PV-electrolyser integration at the reference industrial site was completed. In the second half of 2024, the i3 strategic study on the BESS was deepened at system level. Between 2024 and the start of 2026, the evolution of the financial and regulatory framework that led to the reformulation of the project at consortium level took shape. The drafting of the present Deliverable, in its public version, was carried out in May 2026.

The reconstruction summarised in narrative form above is supported by the following documentary anchor points.

Period	Documented event	Supporting source
2021	Opening of the EISMEA I3-2021-INV1 GREEN call within the framework of the Interregional Innovation Investments instrument	Call fiche I3-2021-INV1
First half of 2023	Project identifier registered with the European Commission (project number 210902154)	Grant Agreement, internal reference 2023-05-19
7 July 2023	Grant Agreement associated with document reference Ares(2023)4743092	Grant Agreement, recurring page reference
29 December 2023	Approval of Project Handbook version 1.1 by the Project Manager (Provincia di Mantova), drafted by AGIRE Srl in its capacity as operational coordination support	D1.1 Project Handbook
May 2024	Drafting of the joint Proposal for H2 Genset and APA Technology Demonstrator	Document filename: Proposal for H2 Genset-APA 9 May 2024
Early June 2024	Issuance of the set of technical studies on the Genset H2 plus APA	File timestamps 02/06/2024 and 06/06/2024

Period	Documented event	Supporting source
	solution (Economic Analysis, Market Analysis, Hydrogen Valley Bridging the Gap, Lithium Energy Storage) and of the BASE Renhive presentation	
June 2024	Finalisation of the simplified Business Plan Genset model, revision 3	Document filename: 2024_06_09_Simplified_BP_Genset_rev3
June 2024	Issuance of the Grant Agreement model RENHIVE v2 with the allocation of the Work Package 2 Production and Storage budget	Document timestamp 12/06/2024
July 2024	Finalisation of the hourly PVSYS simulation of the PV-electrolyser system for the Sapio industrial site	Document filename: 2024_07_24_Italy_Industrial_Sapio_VC0_HourlyResults
Second half of 2024	Deepening of the i3 BESS study for HyMantoValley at system level	Document filename: RenHive_HyMantovalley_i3_BESS_Study
2024 to 2026	Period of evolution of the financial and regulatory framework leading to the consortium-level reformulation of the project	Cross-reference to Section 3 of the present Report
May 2026	Drafting of Deliverable D2.1 in its public English version	Document metadata of the present Report

Annex D — Glossary and acronyms

This Annex collects the technical and institutional terminology used in the Report, with neutral definitions and without taking position on disputed technical or policy aspects. The aim is to support the reading of the Report by stakeholders who may not be familiar with all the specialist categories used.

APA — Atmospheric Pollution Abatement. A patented technology developed by Iscleanair Srl that uses water in a mechanical process to capture particulate matter, nitrogen oxides, sulphur oxides, carbon monoxide, hydrocarbons, heavy metals, pollen, spores and CO₂ from the surrounding air.

Ares — Reference identifier of the document registration system of the European Commission, used to track formal communications between the Commission and project beneficiaries.

BESS — Battery Energy Storage System. Electrochemical storage system based on batteries, used for utility-scale stationary applications and for the integration with renewable generation and electricity markets.

Bridging technology — Technological solution that fulfils a transitional role in the path between an existing energy paradigm and a future paradigm, allowing the activation of clean operating practices on the basis of consolidated infrastructure.

CACM — Capacity Allocation and Congestion Management. European regulation governing the allocation of cross-border transmission capacity and the management of congestion on interconnected electricity grids.

CAPEX — Capital Expenditure. Investment in capital assets, typically associated with the initial phase of installation of an energy asset.

CER — Configurazioni per l'Autoconsumo. Italian regulatory category referring to collective self-consumption configurations of electricity from renewable sources, in particular through Renewable Energy Communities.

Clean Hydrogen Partnership — European public-private partnership in the form of a Joint Undertaking, which manages part of the funds allocated to hydrogen research and innovation in the Horizon Europe programme.

EBITDA — Earnings Before Interest, Taxes, Depreciation and Amortisation. Operating economic indicator that measures profitability before financial, fiscal and depreciation effects.

EISMEA — European Innovation Council and SMEs Executive Agency. European executive agency that manages, among other programmes, the I3 instrument under which the HyMantoValley project is funded.

Electrolyser — Equipment that produces hydrogen and oxygen through the electrolysis of water using electricity, in particular renewable electricity for renewable hydrogen production.

EMS — Energy Management System. Software platform that optimises the operation of an integrated energy system across multiple market timeframes and balancing services.

ERDF — European Regional Development Fund. European fund within Cohesion Policy, which co-finances regional development and innovation actions.

EU Taxonomy — European regulatory framework for the classification of economic activities that are considered environmentally sustainable, used to direct private investment flows.

Genset — Generator set. Power generation system based on an internal combustion engine coupled to an alternator, used for stationary or mobile generation applications.

Grant Agreement — Funding agreement signed between the European Commission and the beneficiaries of a research and innovation programme, which defines the perimeter of activities, the budget, the reporting rules and the obligations of the parties.

Hydrogen Valley — Integrated initiative at regional or sub-regional scale that combines renewable hydrogen production, dedicated infrastructure and multi-sector end uses, with the objective of building an articulated local hydrogen ecosystem.

Hydrogen Bank — European financial instrument managed by the European Commission, which supports the development of the renewable hydrogen market through dedicated auction mechanisms.

I3 — Interregional Innovation Investments Instrument. European instrument managed by EISMEA, which supports interregional innovation projects in the scale-up and commercialisation phase.

IRR — Internal Rate of Return. Financial indicator that measures the rate of return of an investment over its life, expressed as a discount rate that brings the net present value to zero.

LB — Lead Beneficiary. Role assigned to a project partner that is responsible for the delivery of a specific Deliverable, distinct from the Project Coordinator role.

LCOH — Levelised Cost of Hydrogen. Indicator that expresses the average production cost of one kilogram of hydrogen over the operating lifetime of the production asset.

LFP — Lithium Iron Phosphate. Lithium battery chemistry based on iron phosphate cathode, characterised by high intrinsic safety, long cycle life and a stable raw materials supply chain.

MACSE — Mechanism for the Electricity Storage Capacity in Italy. Italian capacity support mechanism for stationary storage assets, introduced in 2025 with the first auction.

MSD — Mercato dei Servizi di Dispacciamento. Italian market for ancillary services and balancing services managed by Terna, in which storage assets can participate.

NMC — Nickel Manganese Cobalt. Lithium battery chemistry based on nickel, manganese and cobalt cathode, alternative to LFP, characterised by higher energy density and different cost and supply chain profile.

NPV — Net Present Value. Financial indicator that measures the value of an investment as the sum of expected cash flows discounted at a defined discount rate.

OPEX — Operating Expenditure. Recurring expenditure for the operation of an energy asset.

PEM — Proton Exchange Membrane. Electrolyser technology based on a proton exchange membrane, characterised by quick response to load variations and intermittent operation.

PMB — Project Management Board. Project governance body provided for by the Project Handbook of the HyMantoValley project, with responsibilities for medium-impact change approval and operational coordination across Work Packages.

PNIEC — National Integrated Energy and Climate Plan. Strategic Italian document that defines the national trajectory for the achievement of European climate and energy targets.

PPA — Power Purchase Agreement. Long-term contract for the purchase of electricity, typically signed between a renewable generator and an industrial offtaker, which defines the price and conditions for the supply.

RED III — Renewable Energy Directive, in its third revision. European directive that defines the rules for renewable energy in the European Union, including the requirements for the qualification of renewable hydrogen.

REPowerEU — European plan presented by the European Commission in May 2022, which strengthens the level of ambition on the deployment of renewable energy and on energy security.

RFNBO — Renewable Fuels of Non-Biological Origin. European regulatory category that includes renewable hydrogen produced through electrolysis fed by qualified renewable electricity, with requirements for additionality and temporal correlation.

SAM — Serviceable Available Market. Market segment that the offer of a specific product or service can serve, in light of geographical, regulatory and technological constraints.

SOM — Serviceable Obtainable Market. Market segment that a specific operator can realistically aim to capture, in light of competitive position, distribution capacity and marketing strategies.

TAM — Total Addressable Market. Total potential market for a category of products or services, in the absence of competitive or geographical constraints.

TEN-T — Trans-European Transport Network. European transport network identified by European policy for the integration and development of the transport infrastructure of the European Union.

TRL — Technology Readiness Level. Scale developed by NASA and adopted by the European Commission to qualify the level of maturity of a technology, ranging from level 1 (basic principles observed) to level 9 (technology proven in operational environment).

Virtual Power Plant — Aggregation of distributed energy resources (renewable generation, storage, flexible demand) which, through a control platform, is managed and remunerated as a single entity on energy and ancillary services markets.

WP — Work Package. Project organisation unit that groups homogeneous activities under the responsibility of a Work Package Leader.

WPL — Work Package Leader. Project partner responsible for the coordination and delivery of a specific Work Package.

References

The references that follow list the institutional documents, regulatory acts, technical analyses and information resources cited or used as a base reference for the drafting of this Deliverable. The list is organised by category and within each category by chronological order.

Project documents (HyMantoValley consortium)

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- Grant Agreement between the European Commission and the HyMantoValley consortium, document reference Ares(2023)4743092, 7 July 2023
- HyMantoValley project website, <https://hymantovalley.agirenet.it/>

European Commission and EISMEA documents

- Call fiche I3-2021-INV1 GREEN, European Commission, November 2021
- European Hydrogen Strategy, COM(2020) 301 final, European Commission, 8 July 2020

- REPowerEU Plan, COM(2022) 230 final, European Commission, 18 May 2022
- Renewable Energy Directive (recast), Directive (EU) 2023/2413 (commonly referred to as RED III), Official Journal of the European Union, 31 October 2023
- Delegated acts on Renewable Fuels of Non-Biological Origin (RFNBO), Commission Delegated Regulations (EU) 2023/1184 and 2023/1185
- Hydrogen and Decarbonised Gas Markets Package, European Commission, 2024
- European Green Deal, COM(2019) 640 final, European Commission, 11 December 2019
- EISMEA Communication Toolkit for I3 beneficiaries, EISMEA

Italian national framework

- Italian National Integrated Energy and Climate Plan (PNIEC), updated version, 2024
- National Hydrogen Strategy, Ministry of the Environment and Energy Security
- National Recovery and Resilience Plan (PNRR), measures for renewable hydrogen production
- MACSE Decree on the Electricity Storage Capacity Mechanism, Ministry of the Environment and Energy Security
- Capacity Market Decree, Ministry of Economic Development

Technical and scenario references

- [omissis] Q4 2023 release
- Solar Impulse Foundation Efficient Solutions database, entry on APA technology by Iscleanair Srl
- IPCC Directive 2008/1/EC on Integrated Pollution Prevention and Control
- World Health Organization Air Quality Guidelines

Standards cited

- UL 9540, Standard for Energy Storage Systems and Equipment
- UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
- NFPA 855, Standard for the Installation of Stationary Energy Storage Systems
- NFPA 69, Standard on Explosion Prevention Systems
- Modbus RTU and Modbus TCP communication protocol specification



RENHIVE



13 BESS/Storage Study

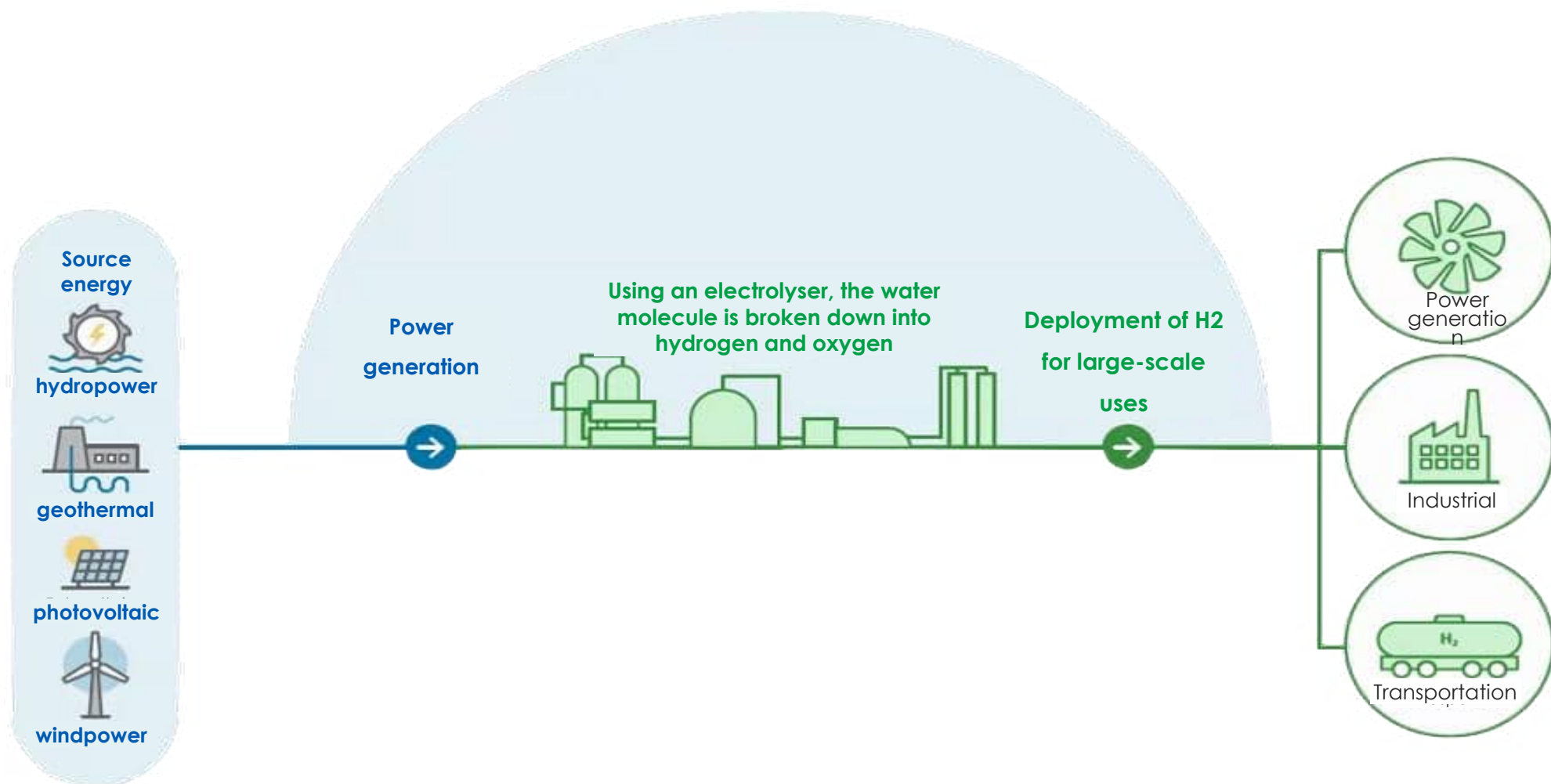


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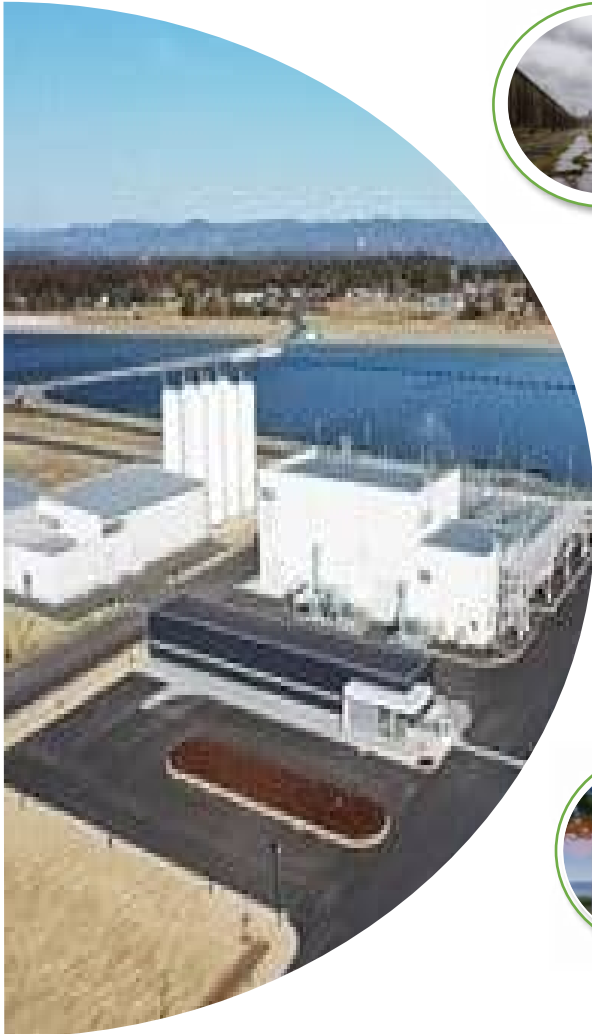


The green hydrogen opportunity

Green' hydrogen is produced through the electrolysis of water using electricity from renewable sources. Its use could accelerate over the next decade as new needs and opportunities arise.



"Europe prioritizes the development of 'Hydrogen Valleys'—local hubs for the production, storage, and use of hydrogen—and the Italian government has since launched a 'National Hydrogen Strategy'.



Conversion of disused infrastructure

Production costs are expected to decrease by 12% per year by 2030



Decarbonisation of industry sectors

Making a contribution to CO2 abatement in sectors with a high level of emissions, when produced from renewable energy



Reducing the carbon footprint of the mobility sector

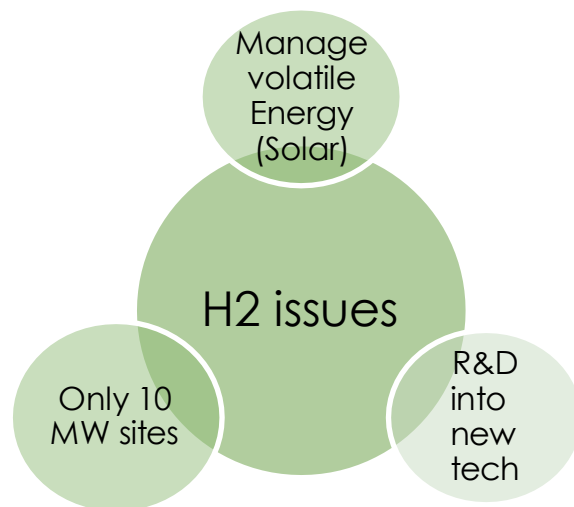
Hydrogen is a 'green' fuel par excellence and large-scale applications in transport and residential heating are expected



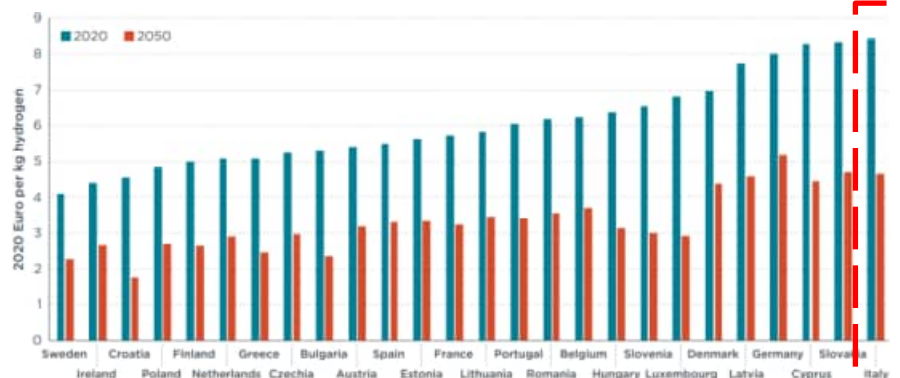
Renewable redundancy valorisation

Making use of surplus renewable energy production that is difficult to be received by the grid in the short to medium term

3 challenges in Italy



Worst H2 Cost pricing: LCOE highest



Lack of presence:

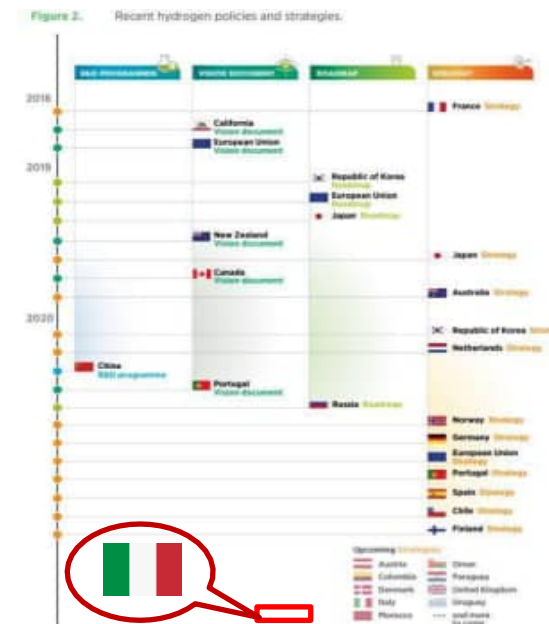


Solution: Subsidies



1st Pilot:
€ 0.5Bn
 Project Electrolyzer
10 MW
 Capex Costs Deduction
40 %

Lack of policies/strategies :



Pre-requisites:

1. Industrial Destination
2. No Contamination
3. Grid Access
4. Gas Access
5. Water Access
6. Road Access
7. Next to Industrial area

RenHive is the result of a joint venture between Hive Energy Ltd, SunLeonard Energy Ltd, Proter S.r.l. and Renovo S.p.A aiming to develop Hydrogen Valley in Italy through the use of a renewable energy generator.

Actors involved in the JV:

1. Hive Energy Ltd*

- Hive Energy Ltd is a leading international developer of renewable energy plants. To date, Hive Energy has built 1.97 GW of renewable capacity worldwide and intends to develop a total development pipeline of 24 GW in the coming years.
- Hive Energy Ltd is the main sponsor of the JV and the major Shareholder

2. SunLeonard Energy Ltd*

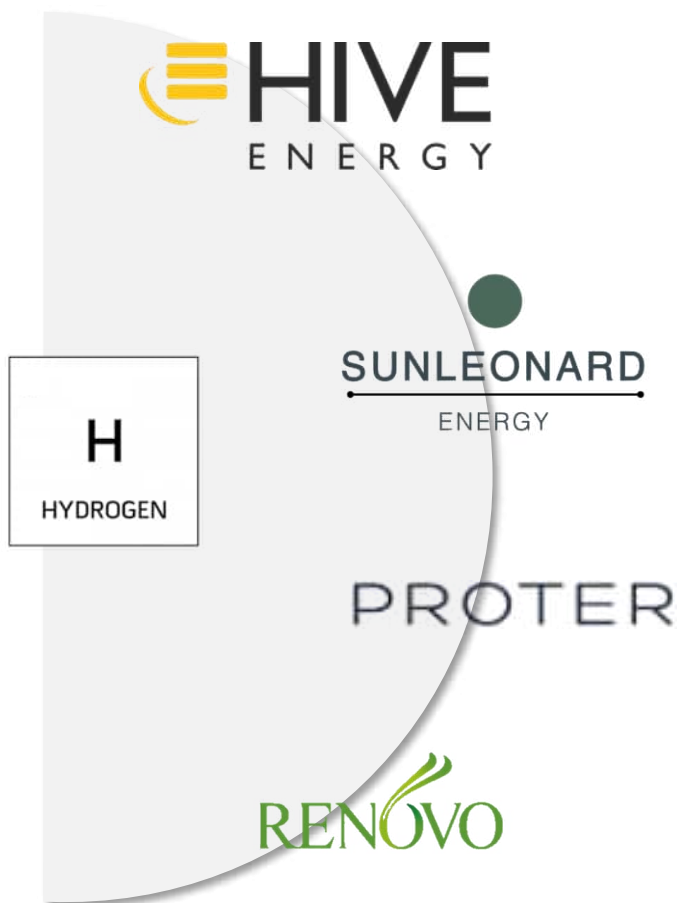
- SunLeonard Energy Ltd is developing, alongside with Hive, over 700 MW in Italy
- Part of this pipeline, has been allocated to GreenIT Spa, the JV between CDP and Eni and KKR via Encavis platform.

3. Proter S.r.l.

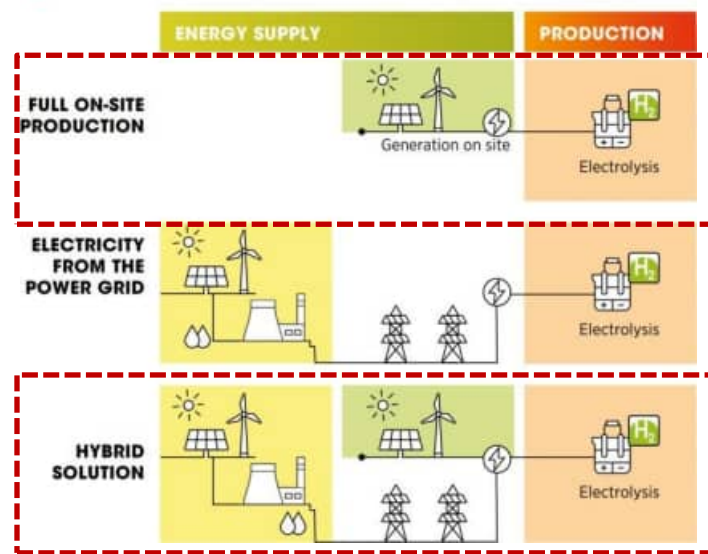
- Proter is the financial advisor of the JV and expert onf PPP and public Grant leading the financial and prefeasibility studies

4. Renovo S.p.A.

- Renovo is engaged in applied research, project development, construction and operation of innovative industrial plants for the production of energy from renewable sources and for the transformation of agro-industrial by-products and special waste into bio-based products
- Renovo is the main project originator & lead developer on the PV



* <https://www.reuters.com/business/energy/enis-jv-greenit-signs-deal-start-up-four-solar-projects-italy-2023-07-10/>



➔ **24 month (33 Ha)**

Feeding all the electricity to the Electrolyser and finding new land in addition

15 month (14 Ha)

Hybrid Solution: Renhive acting as Energy Supplier through a Private Wire and a PPA



PPA 10 yrs*



Revenues pa Investment Employees

> 100 Years in the Industry leader O2 and H2

Dossi Family - Italian President H2

49% Shareholder an American Company (Air Product)



1. Site RTB in 10-15 Months
2. Special agreement with Region and Municipality ("Accordi di Programma")
3. Municipality hired a team of professionals to follow this project and get it consented on record timing ("Agire")
4. PPA: subject to simulation at least 60 €/MWh - we have leverage
5. Circa 320 Ton/H2/Y



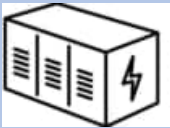
*Currently Under Negotiation to be closed EOQ (Q2-24). Price 10 yrs PPA in the market at 60€/MWh

The I3 Task for Renhive



1 MWh Lithium Battery “traditional”

1



Provides a comprehensive energy storage system for time-shifting, outage backup, and excess energy storage.

The 1MWh battery solution provides a comprehensive energy storage system that includes the procurement, transportation, installation, and operation and maintenance (O&M) of a lithium-ion battery.

Applications:

•**Time shifting:** Allows excess energy to be stored during periods of low demand (e.g., during the day or in summer) and used during peak times (e.g., in the evening) to flatten the demand curve and optimize grid utilization.

•**Outage:** Provides emergency backup in case of a power grid outage, ensuring the continued operation of the electrolyzer despite being minimal (1M).

•**Energy recovery:** Recapture excess grid electricity during electrolyzer downtime, preventing to not utilize it – this might be useful during planned maintenance

Advantages:

- Simplicity and plug-and-play operation:** The solution is ready to use, requiring no additional infrastructure and simplifying implementation.
- Reliability and proven performance:** Lithium-ion technology is well-established and offers high performance in terms of lifespan and stability.
- No additional infrastructure:** The system is self-contained and does not require significant modifications to the existing plant.

Disadvantages:

- High cost:** The initial investment for battery purchase is still considerable.
- Non-compliance with ESG standards:** The production and disposal of lithium-ion batteries can have environmental and social impacts that need to be considered.
- Risk of overheating:** Lithium-ion batteries can overheat under certain conditions, requiring adequate cooling systems.
- Limited lifespan:** Lithium-ion batteries have a limited lifespan, necessitating planning for periodic replacement.

Introduction:

As we strive to make HIMANTOVALLEY a beacon of sustainability, we have partnered with industry leaders to explore innovative solutions for our energy storage and environmental needs. Through a rigorous evaluation process, we identified three promising approaches that address the unique requirements of the project and contribute to the development of a robust hydrogen sector.

1 MWh Lithium Battery “traditional”

1



Provides a comprehensive energy storage system for time-shifting, outage backup, and excess energy storage.

250kW up to 8000 hrs per year - 100% Hydrogen Genset with CO2 and Pollution Removal including other pollutant (e.g. NOX, SOX)

2



Offers clean energy generation and environmental remediation, with zero CO2 emissions and high-efficacy pollution removal.

500kWh Lithium Battery + 150kW 100% Hydrogen Genset with CO2 and Pollution Removal hrs. including other pollutant (e.g. NOX, SOX):

3



Combines the benefits of both solutions, providing energy storage, clean power generation, and environmental protection.

General Considerations:

•**Selection depends on specific needs and priorities:** Each solution offers unique advantages and may be better suited for different applications:

- 1) Ideal for time-shifting, outage backup, and excess energy storage in applications when weather conditions are not stable.
- 2) Includes all the considerations in 1 plus suitable for off-grid applications, remote locations, or areas with unreliable grid access but also can be used for several scopes
- 3) Provides a hybrid approach, combining energy storage, clean power generation, and environmental protection.

250kW up to 8000 hrs per year - 100% Hydrogen Genset with CO2 and Pollution Removal including other pollutant (e.g. NOX, SOX)

2



Offers clean energy generation and environmental remediation, with zero CO2 emissions and high-efficacy pollution removal.

The innovative integration of a 100% Hydrogen Genset and APA's pollution & CO2 removal technology offers a comprehensive solution for sustainable energy generation and environmental remediation.

Applications:

•Decarbonizing Power Generation :

Retrofitting existing internal combustion engines to utilize clean hydrogen, paving the way for wider fuel cell adoption

•Sustainable Industrial

Applications: Combating pollution and carbon emissions in industrial settings, including manufacturing plants and power generation facilities.

•Urban Pollution Mitigation:

Addressing air pollution challenges in urban environments, improving air quality and public health

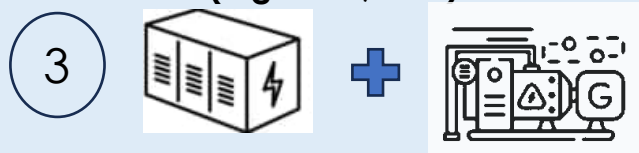
Advantages:

- Clean Energy Generation:** Achieves zero CO2 emissions from power generation, reducing the environmental impact of energy production.
- Environmental Remediation:** Effectively removes pollutants and CO2, creating a cleaner and healthier environment.
- Scalability and Modularity:** Adaptable to various scales and applications, allowing for customized solutions across different sectors.
- Cost-Effectiveness:** Offers a relatively economical approach to clean energy and environmental protection compared to traditional methods
- Flexible and transportable:** can be used as a normal Generator and used for other necessity (e.g. event, concert).

Disadvantages:

- Setup Time:** Requires slightly a more setup time and customization compared to plug-and-play lithium storage solutions.
- Technical Expertise:** Requires technical expertise for installation, operation, and maintenance.

500kWh Lithium Battery + 150kW 100% Hydrogen Genset with CO2 and Pollution Removal Lithium including other pollutant (e.g. NOX, SOX):



Combines the benefits of both solutions, providing energy storage, clean power generation, and environmental protection.

The **combination** of the **100% H2 Genset** and **APA Pollution and CO2** removal technology represents an **innovative solution** for sustainable **energy generation** and **environmental remediation** balanced with a more plan vanilla traditional Lithium battery.

Applications:

•Decarbonizing Power Generation in addition to the usual Lithium Battery features :

Retrofitting existing internal combustion engines to utilize clean hydrogen, paving the way for wider fuel cell adoption, using the storage, Time Shifting

•Sustainable Industrial Applications: Combating pollution and carbon emissions in industrial settings, including manufacturing plants and power generation facilities.

•Urban Pollution Mitigation: Addressing air pollution challenges in urban environments, improving air quality and public health

The **hydrogen genset**, through **retrofitting** existing **internal combustion engines**, offers a practical pathway to **decarbonize** power generation, leveraging proven technology and paving the way for **a future** where **fuel cell technology** becomes more **competitive**. With its rugged design and ability to operate in **various environments**, the genset ensures **zero CO2 emissions**, accelerating the **adoption of hydrogen** as a **clean fuel**. Integrated modifications enable seamless compatibility with hydrogen fuel injection and safety requirements.

Paired with the **APA pollution and CO2 removal technology**, this system provides a comprehensive approach to combating **pollution** and **carbon emissions**. **APA technology**, with its **high TRL** and demonstrated efficacy, **utilizes water** to achieve **pollution reduction** equivalent to **thousands of trees**, making it suitable for **industrial sites** and **urban** applications. Its **low energy consumption** and ability to integrate with battery packs ensure **continuous operation**, complemented by **recharging capabilities** from the **hydrogen genset**.

Together, this **innovative pairing** addresses both **power generation** and **environmental challenges**, offering **scalable solutions** for a sustainable, net - **zero carbon future** across various **sectors** and **applications**.



BLUDRIVE LTD is a UK-based company with a proven track record in Hydrogen and ammonia engine design and operation.

Since 2019, they have successfully overseen **numerous engine retrofit and testing projects**, collaborating with global powertrain industry partners.

Their experience spans from single-cylinder research engines to multi-cylinder production engines. They have a demonstrated history of adhering to stringent **UK health and safety regulations** for alternative fuel projects.

Their team boasts **highly qualified research engineers** with direct experience in engine design and testing.

Key Personnel:

- Prof. Nino La Rocca:** Over 15 years of experience leading large engine design projects with major industry partners. He will serve as Chief Project Engineer, overseeing technical objectives and progress.

- Prof. Alasdair Cairns:** Over 25 years of experience in engineering research management, providing strategic direction for future projects.



ISCLEANAIR is an innovative Italian SME founded in 2016 that operates in the field of **ambient air purification**, both **indoor** and **outdoor**.

Its proprietary technology, called **APA - Air Pollution Abatement**, represents a true **revolution** in the industry landscape. Unlike traditional filter-based systems, APA harnesses the power of **water** to effectively and sustainably abate a wide range of pollutants, including:

- Particulate matter (PM10 and PM2.5), Volatile organic compounds (VOCs), Harmful gases (NOx, SOx, CO)**

ISCLEANAIR offers:

Innovative filterless technology: APA does not use filters that clog and require frequent maintenance, ensuring **greater efficiency** and **lower management costs**.

High efficiency: APA technology can abate up to **99%** of pollutants in the air, guaranteeing **excellent air quality**.

Modular and intelligent solutions: ISCLEANAIR systems are **customizable** and **adaptable** to any need, both in terms of size and capacity. They are also equipped with **IoT sensors** for continuous air quality monitoring and remote performance control.

Sustainability: APA technology is **eco-friendly** and does not produce any harmful waste for the environment.

Intro BESS Market in Italy



Demand concentration, limited renewables, and grid stress create critical storage needs

Northern Italy consumes **over 56% of Italy's electricity** while covering less than a third of its territory, concentrating heavy industrial and civil demand.

Local renewable generation is structurally limited: hydropower is mature and climate-dependent, solar is intermittent, and wind potential is minimal due to geography.

National transmission grid faces chronic congestion transporting **abundant Southern renewables northward**, causing bottlenecks and costly dispatch of gas plants.

Renewable curtailment is rising, with 0.3 TWh wasted in 2024 and projections up to **5 TWh by 2030** without intervention.

Battery Energy Storage Systems (BESS) address structural deficits by reducing congestion, storing surplus energy, and providing rapid grid stability services.

Strategically placed **BESS improve system security, alleviate transmission bottlenecks**, and enable higher renewable integration in the North.



Electricity Demand Concentration

- Northern Italy accounts for 56% of Italy's total electricity demand, driven by industrial hubs **like Lombardy and Emilia-Romagna**.
- This intense demand reflects the region's role as Italy's economic powerhouse despite covering less than one-third of the national territory.



Structural Energy Deficit and Imports

- **Local renewable generation is insufficient to meet demand**, causing Northern Italy to import electricity from southern regions and neighboring countries (France, Switzerland).
- This persistent imbalance creates a structural energy deficit reinforcing reliance on external sources.



Local Renewable Energy Production

- Photovoltaic capacity: **Northern Italy hosts about 48% of national PV capacity**; solar output peaks midday but cannot meet evening or nighttime demand due to intermittency.
- Hydroelectric power: Historically vital but mature and constrained by climate variability, limiting additional growth.
- Wind power: Minimal in the North due to geographic and anemometric limitations, with over 96% of Italian wind capacity located in Central-South and islands.



Role of Battery Energy Storage Systems (BESS)

- **BESS mitigate structural deficits** by storing cheap surplus solar energy (midday excess) or imported energy during low demand periods.
- Stored energy is released during peak evening and nighttime hours, enhancing grid stability and reducing reliance on costly gas plants.

Industrial-driven 56% electricity demand vs. intermittent local renewables create a structural energy deficit

Overcoming Italy's transmission bottlenecks with flexible storage solutions



Italian grid built for unidirectional flow from thermal plants to consumers; **now faces bidirectional flows from southern renewables to northern demand** causing congestion.



Congestion bottlenecks force Terna to dispatch expensive gas plants, incurring **€2 billion/year in uplift costs and causing renewable curtailment.**



Renewable curtailment **wastes clean energy: 0.3 TWh in 2024, projected to rise to 5 TWh by 2030 without interventions.**



BESS act as 'energy sponges' by absorbing surplus renewable energy, preventing curtailment and freeing grid capacity.



BESS serve as 'grid shock absorbers' providing fast frequency regulation, critical as traditional thermal plants retire.



BESS are modular, flexible solutions rewarded increasingly by market mechanisms, essential for grid stability and renewable integration.

PNIEC's 71 GWh Target, MACSE Contracts, and Complementary Mechanisms Secure Investor Confidence



PNIEC mandates 71 GWh of storage by 2031, ensuring long-term political and market stability.



MACSE offers 15-year capacity contracts via competitive auctions, delivering stable, inflation-indexed revenue floors.



MACSE significantly reduces market risk, enhancing project bankability for investors and financiers.



Existing mechanisms like Capacity Market and ancillary services diversify revenue streams for BESS projects.



First MACSE auction in September 2025 provides a concrete, immediate investment opportunity.



The combined regulatory framework creates a supportive, predictable environment that attracts strategic capital.

Italy's 'exceptionally competitive' first
MACSE energy storage auction
concludes, procuring 10GWh

By Cameron Murray

October 2, 2025

Europe Grid Scale Policy, Business

[LinkedIn](#) [Twitter](#) [Reddit](#) [Facebook](#) [Email](#)



Key Player Types and Dominant Business Models Shaping Strategic Investment



Three main player categories: **Incumbent Utilities** with large capital and integrated portfolios; **International Investment Funds** partnering locally to scale pipelines; and **Agile Independent Power Producers (IPPs)** leveraging local expertise and speed.



Two dominant business models shape the sector: **Stand-alone BESS assets** connected directly to the transmission grid, focusing on market flexibility and arbitrage.



Co-located BESS paired with renewable generation assets (solar/wind) to optimize overall asset value and reduce curtailment risks.



Stand-alone models offer **maximum market flexibility** and strategic geographic positioning near congestion points but face **higher exposure to price volatility** and connection costs.



Co-located models provide **stable cash flows via PPAs**, share infrastructure costs, and mitigate curtailment risk but have **limited operational flexibility** tied to renewable output.



Understanding these player types and business models is **crucial for strategic positioning** and tailoring investment approaches in the evolving Italian BESS market.

Profiling Utilities, Investment Funds, and Agile IPPs by Pipeline, Geography, and Business Model

Player	Pipeline Size (GW)	Geographic Focus	Business Model & Strategy
Enel Green Power	2.6	Nationwide (37 plants)	Hybrid model: Stand-alone & co-located projects; leader in scale and integration
ACL Energy & BW ESS	2.9	North (Lombardy, Piedmont) & South (Puglia)	Joint venture aggregating large-scale pipeline across regions
Altea Green Power	1.1	Primarily South Italy (90%)	Investment fund partnership focusing on southern renewables
GreenGo	1.73	Northern Italy (Bologna HQ)	Agile IPP with 75 fragmented projects; 693 MW authorized; rapid permitting expertise
ContourGlobal	1.6	Italy-wide	Portfolio acquisition strategy targeting near-ready projects ahead of MACSE auctions
Bright Storage	N/A	Italy	Specialized developer focused exclusively on Italian BESS market

Comparing BESS Business Models: Stand-Alone vs Co-Located

Evaluate strategic, operational, and financial trade-offs for optimal project positioning

Stand-Alone BESS: Flexible Grid Player

- 1. Represents 73% of Italian connection requests (54.4 GW)
- 2. Operates independently on transmission grid, enabling full market participation 24/7
- 3. Maximizes geographic positioning near congested nodes for highest service value
- 4. Offers maximum market flexibility—arbitrage, capacity, and ancillary services
- 5. Faces full exposure to volatile market prices without stable PPA revenue
- 6. Bears high connection costs and full infrastructure investment
- 7. Simpler project design focused on a single technology
- 8. Higher risk profile with potential IRR 10.5% but sensitive to CAPEX and market fluctuations

Co-Located BESS: Renewable Asset Optimizer

- 1. Growing model, especially paired with PV solar (20–30% of new projects)
- 2. Integrated behind-the-meter with renewable plants to enhance asset value
- 3. Enables energy shifting and mitigates curtailment losses
- 4. Provides revenue stability through long-term PPAs (10-15 years)
- 5. Shares connection, land, and infrastructure costs, reducing CAPEX by 15%
- 6. Limited operational flexibility tied to renewable production profile
- 7. Geographically constrained to renewable resource locations, often South Italy
- 8. Lower risk profile with IRR 9.5%, supported by stable cash flows

Dominant LFP advantages, sodium-ion and flow alternatives, plus evolving recycling regulations shape investment strategies.

	Technology	Key Characteristics	Typical Applications
 Lithium Iron Phosphate (LFP) batteries dominate with over 85% market share due to low cost, supply stability, superior safety, and long cycle life (6,000-8,000 cycles)	Lithium-Ion BESS	High energy density, compact footprint, and fast response times.	Frequency regulation, peak shaving, and short-duration storage.
 Sodium-ion batteries offer a promising low-cost alternative using abundant materials but have lower energy density , requiring more space for equivalent capacity	Sodium-Ion Batteries	Uses abundant materials, lower cost than lithium, and performs well in extreme temperatures.	Emerging as a sustainable alternative for stationary grid storage.
 Flow batteries excel in long-duration storage (8+ hours) with near unlimited cycle life and high safety but involve higher costs for short-cycle applications	Flow Batteries	Decouples power (stack size) from energy (tank size), allowing for long-duration discharge.	Long-duration energy storage (multi-hour/day) and renewable integration.

 End-of-life management faces challenges: LFP recycling is complex and less lucrative compared to cobalt-containing batteries, pushing innovation in **hydrometallurgical recycling processes**

 Regulatory pressures enforce recycling targets, making **lifecycle cost and compliance planning essential** for investor risk management and project viability

 Investors must integrate evolving technology trends and recycling regulations into strategic planning to ensure sustainable, cost-effective BESS deployment in the evolving energy market



18–30-month stage-gate process with critical milestones to de-risk any BESS project in Italy’s complex permitting landscape.



Site Feasibility Validation (0-3 months)

Identify and screen sites via GIS analysis, urban and environmental constraints, verify ownership and logistics, then secure exclusive options to de-risk initial investment.

Grid Connection with Terna (6-9 months)

Submit formal connection request to Terna, undergo technical studies, receive and accept the STMG with a financial commitment, securing grid interconnection rights.

Obtaining Single Authorization (AU) (9-18 months)

Complete the unified permitting process involving multiple authorities, environmental assessments, and obtain the AU decree, enabling project readiness for construction.

Phase 1: Site Screening & Preliminary Feasibility (0-3 months)

Identify optimal sites and secure early land options for BESS development





GIS Mapping Layers: electrical substations, urban planning constraints, environmental protections to shortlist 5-10 industrial-zoned candidate sites



Desktop Feasibility: cadastral verification, estimating connection distance and logistics via satellite imagery



Early Landowner Engagement: negotiate and sign option agreements or exclusivity contracts (18-36 months) on top candidate sites

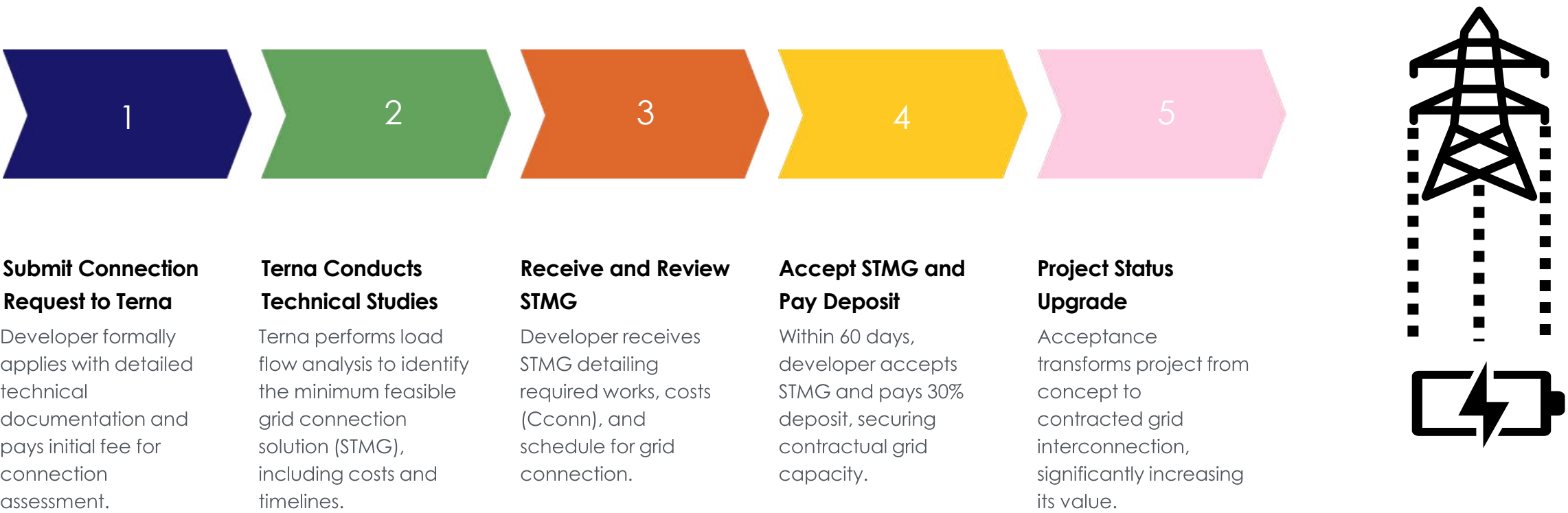


Milestone Deliverables: preliminary feasibility report plus signed option agreements forming the basis for grid connection requests



Phase 2: Secure Grid Connection & Obtain STMG

From formal application to contractual grid interconnection, ensuring project value uplift



Phase 3: Streamline Project Approval with Single Authorization

Coordinate key agencies to secure the AU decree, enabling construction and operation within 9–18 months

Initiate AU Process

Developers submit comprehensive technical and environmental documentation based on land options and accepted STMG.

Multi-Agency Review

Key stakeholders including MASE, regional authorities, municipalities, and heritage bodies review and provide binding opinions.

Conference of Services

Centralized coordination consolidates approvals and addresses all agency requirements asynchronously.

Issue AU Decree

Final decree authorizes construction and operation, grants public utility status, and confers urban planning variances.

Project Ready-to-Build

With AU decree, the project achieves full permitting status, enabling financing, sale, or immediate construction.



Navigating Development Challenges in BESS Projects

Identify and mitigate key technical, administrative, and social risks to ensure project success

Technical Risks: Network saturation limits new connections despite speculative demand, causing potential refusals or costly, complex solutions; volatile STMG costs and extended infrastructure timelines can delay project start.



Administrative Risks: Soprintendenza's critical opinions may impose costly prescriptions; procedural delays in Conferenza dei Servizi can extend permitting beyond planned 180 days; legal appeals post-authorization risk 1–2-year project freezes.



Social Risks: Local opposition (NIMBY syndrome) can stall or block approvals, complicating construction phases; volatile CAPEX due to material cost fluctuations during 18–30-month development threatens margins.

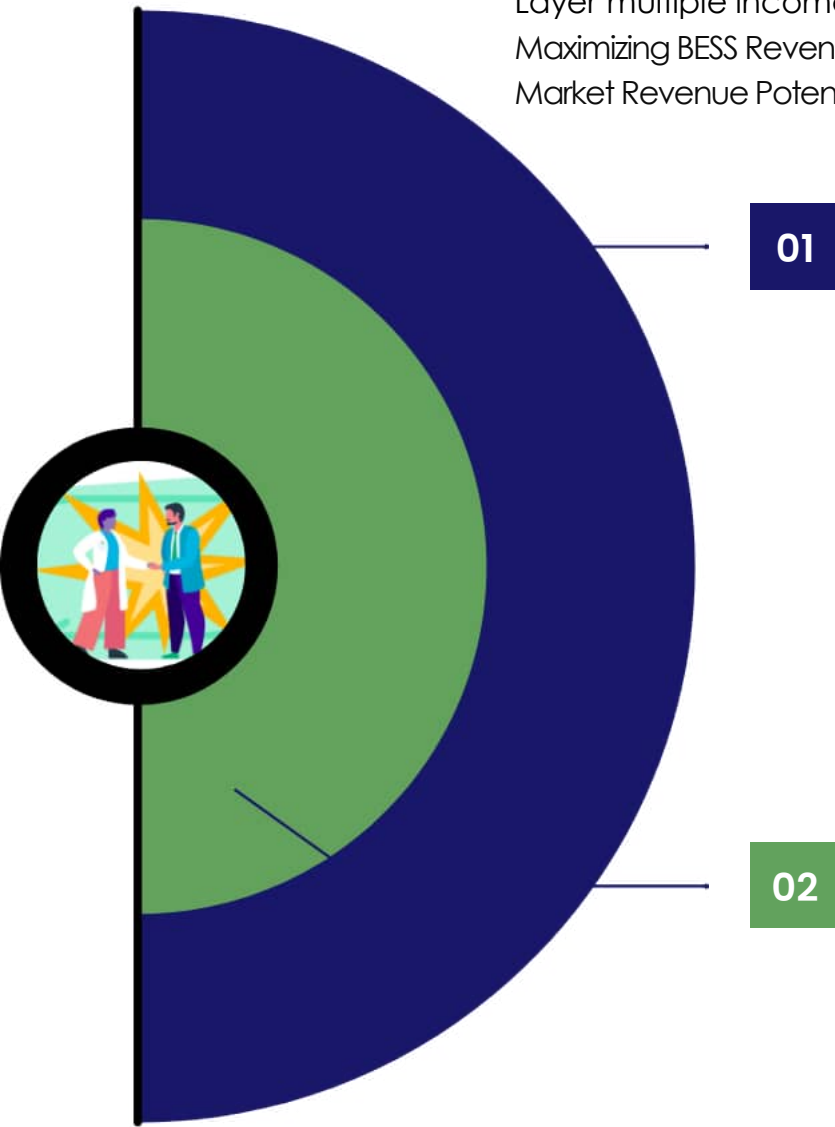


MITIGANT

Successful development requires combined expertise in technical planning, specialized administrative legal support, political navigation, and proactive community engagement to overcome these bottlenecks.



Layer multiple income streams
Maximizing BESS Revenue:
Market Revenue Potential & Trends



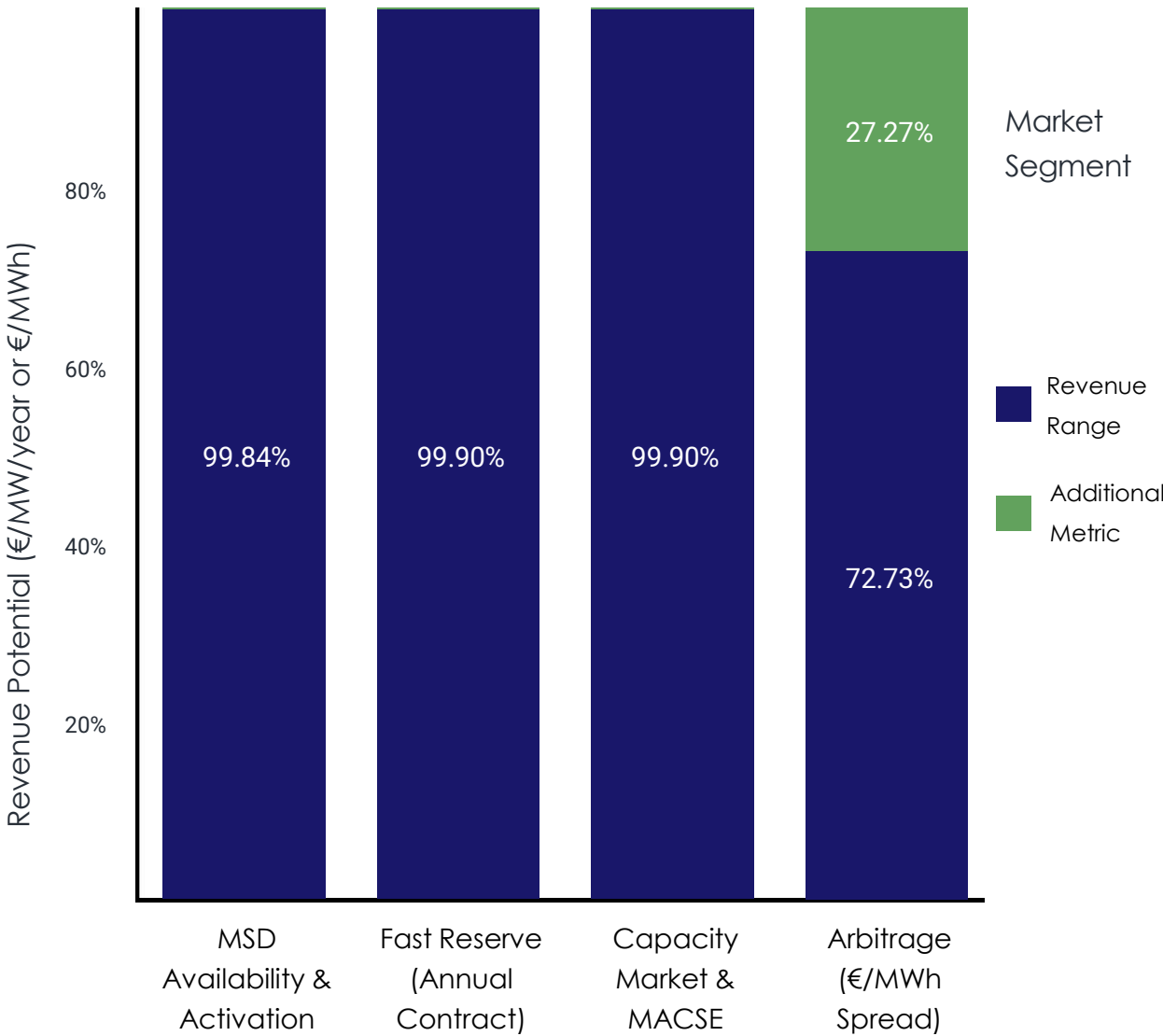
Layered Revenue Ladder

Like renting out floors of a building separately, BESS stack income streams—capacity payments, ancillary services, and arbitrage—to maximize overall returns efficiently.

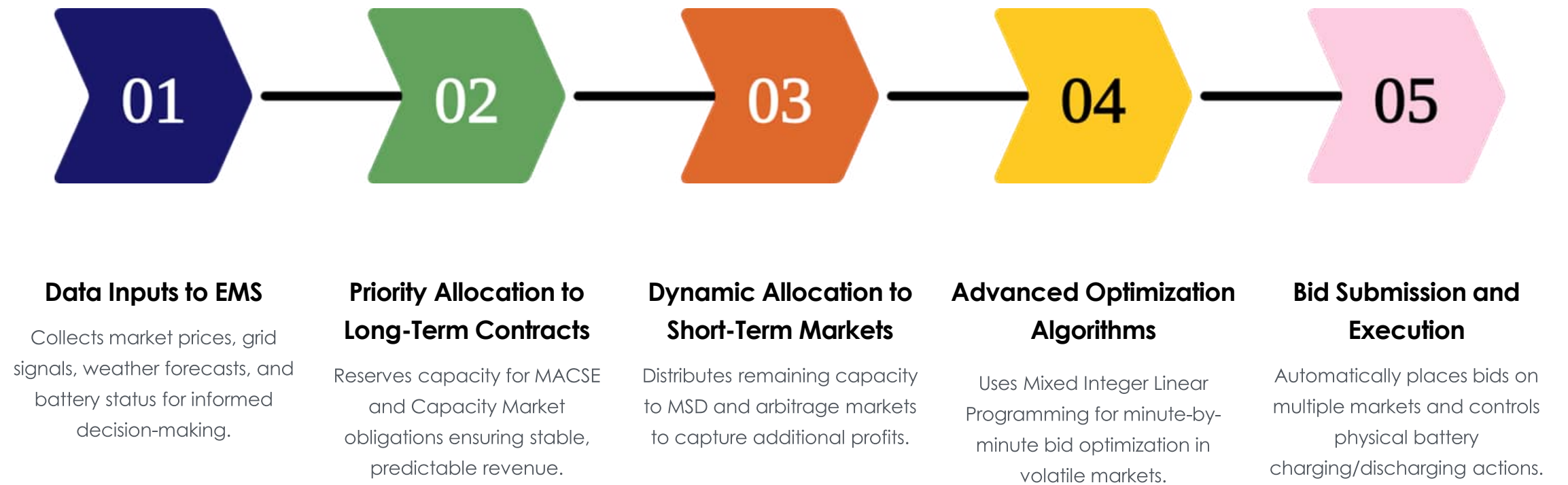
Diversified Income Streams

Each income layer supports the next, creating a stable, resilient revenue structure that requires precise operational optimization across markets.

Comparing MSD, Fast Reserve, Capacity Market, and Arbitrage in Northern Italy



How EMS balances long-term contracts with dynamic market opportunities to maximize profitability



Hybrid PPAs vs Tolling Agreements: Contract Structures for BESS

Compare risk allocation, revenue stability, and investment profiles of leading contractual models.



Hybrid Power Purchase Agreements (PPAs)

- Pair BESS with renewables to convert intermittent energy into programmable supply.
- Secure premium prices via long-term energy delivery commitments (10-15 years).
- Provide revenue stability through fixed-price contracts, enhancing project bankability.
- Increase asset value by enabling energy dispatch during high-value hours.
- Mitigate market volatility by shifting reliance from spot markets to contract revenue.
- Ideal for investors seeking balanced risk with predictable cash flows.

Vs



Tolling Agreements

- Lease BESS assets to third-party operators who assume full market risk.
- Owner receives fixed fees akin to infrastructure-like stable cash flows.
- Third party manages market participation and optimization, capturing upside and downside.
- Transforms BESS into a low-risk, bond-like investment vehicle for risk-averse capital.
- Reduces exposure to price volatility but limits upside potential for owners.
- Suitable for investors prioritizing steady income and minimal market exposure.

Key financial drivers shaping project viability and profitability



Capital Expenditure (CAPEX) dominates initial investment, averaging 300–400 €/kWh, including battery packs (150–200 €/kWh), power conversion (50–70 €/kW), balance of system, connection, civil works, and soft costs.



Operational Expenditure (OPEX) averages 25–35 €/kW/year, covering maintenance, insurance, network charges, and asset management; energy costs vary with market prices.



Levelized Cost of Storage (LCOS) ranges 150–180 €/MWh, reflecting total lifecycle costs divided by lifetime energy delivered, setting the breakeven price for storage services.



Round-Trip Efficiency (RTE) of 85–90% measures energy retained after charge-discharge cycles, directly impacting operational cost and revenue potential.



Degradation rates of 2–3% annually reduce battery capacity over time, influencing asset longevity and requiring effective thermal management to maintain performance.



Combined, these cost components and performance metrics form the foundation for robust financial modeling and bankability assessment of BESS projects.

Detailed cost structure and projected declines enhancing project economics by 2030

Component	Cost Range (€/kWh or €/kW)	Cost Driver
Battery Pack	€150 - €200/kWh	Energy capacity (MWh)
Power Conversion System (PCS)	€50 - €70/kW	Power capacity (MW)
Balance of System (BOS)	€30 - €50/kW	Power capacity (MW)
Connection Hardware & Transformers	€20 - €30/kW	Power capacity (MW)
Civil Works	€15 - €25/kW	Power capacity (MW)
Soft Costs	€40 - €60/kW	Engineering, permitting, project management

Precise OPEX Breakdown for BESS Assets

Fixed and variable costs define annual operational expenditure from **€25 to €35/kW**

Annual OPEX averages €25-35/kW, covering essential fixed costs ensuring asset reliability and compliance.

- **Maintenance (10-15 €/kW/year):** Includes scheduled inspections, software updates, and corrective repairs to maximize uptime.
- **Insurance (3-5 €/kW/year):** Covers civil liability, physical damage, and business interruption risks for financial security.
- **Network Charges (5-8 €/kW/year):** Fixed fees for grid connection and transmission services mandated by Terna and ARERA.
- **Asset Management (4-6 €/kW/year):** Operational supervision, contract management, and performance optimization.
- **Variable Costs (20-30 €/MWh):** Energy procurement costs for charging batteries, fluctuating with market prices and operational strategy.
- **Effective OPEX** control combined with maximizing asset availability is crucial to optimize net returns and ensure long-term profitability.

Quantify core battery metrics to optimize profitability and asset lifecycle

Energy storage cost calculation

$$LCOS = \frac{I \left(C_E + \frac{C_P}{d} \right) + \left(C_E + \frac{C_P}{d} \right) \sum_{t=1}^T \frac{O\&M(t)}{(1+r)^t} + \frac{P_C}{\eta} \sum_{t=1}^T \frac{n(t)}{(1+r)^t}}{\eta \sum_{t=1}^T \frac{n(t)}{(1+r)^t}}$$

LCOS (Levelized Cost of Storage): Total lifetime cost per MWh, currently €150-180/MWh for LFP BESS in Italy, sets the break-even revenue target.

Round-Trip Efficiency (RTE): Energy retained after charge/discharge cycles, averaging 85-90%, impacts operational profitability directly.

Degradation Rate: Annual capacity loss of 2-3%, accelerating with higher temperatures, shortens asset lifespan and affects replacement timing.

These metrics critically influence revenue potential and **financial modeling accuracy**, guiding investment and operational strategies.

Degradation Calculation

$$\eta = \frac{\int_{t=0}^{t=T} P_{discharge} dt}{\int_{t=0}^{t=T} P_{charge} dt}$$

Financial Modeling and Sensitivity Analysis in BESS Investments

Integrate revenue drivers and cost parameters into DCF models; test resilience through sensitivity to key inputs



Financial modeling consolidates revenue drivers, costs, and performance into discounted cash flow (DCF) analyses to calculate key investment metrics: Internal Rate of Return (IRR), Net Present Value (NPV), and payback period. Sensitivity analysis evaluates project robustness by simulating impacts of variations in critical inputs like CAPEX, market prices, and network charges. This approach equips investors with a clear risk-reward profile, enabling informed strategic decisions and optimized portfolio allocation in the dynamic BESS market.

Compare technical specs and financial profiles of two key investment models in Northern Italy's energy storage market.

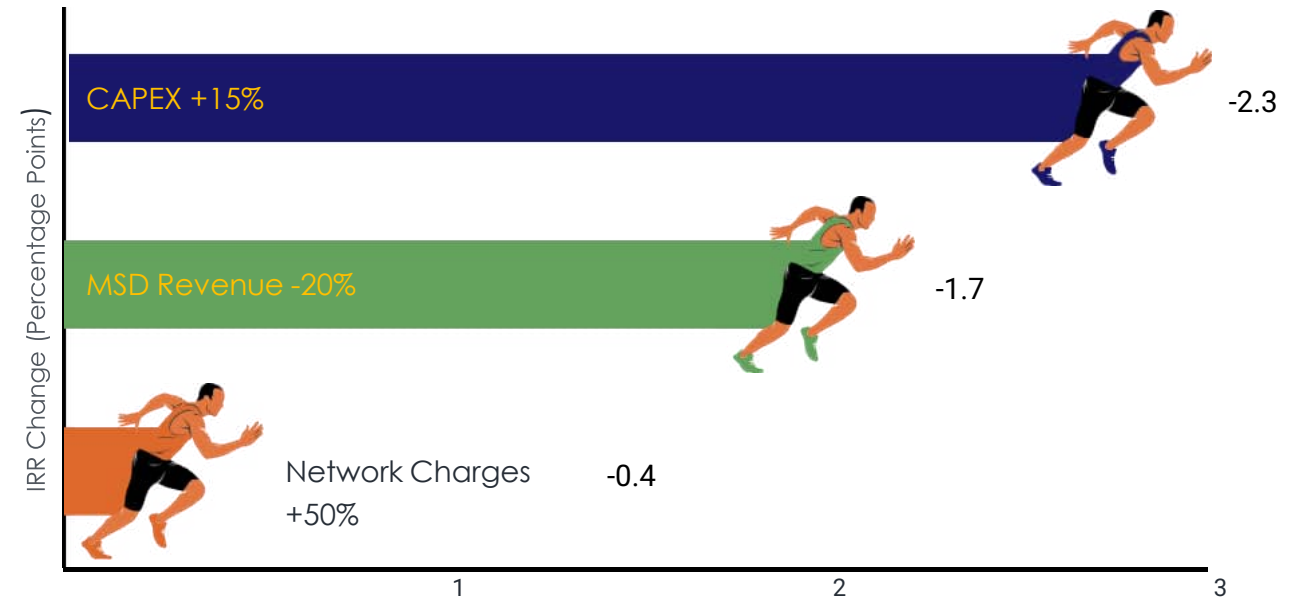
Parameter	Stand-Alone BESS	Co-Located BESS
Capacity	100 MW / 400 MWh (4-hour duration)	20 MW / 80 MWh (4-hour duration)
Technology	LFP (Lithium Iron Phosphate)	LFP
CAPEX	€140 Million (€350/kWh average)	€25 Million (15% cost reduction on shared components)
OPEX (Fixed)	€3 Million/year (€30/kW/year)	€0.6 Million/year (€30/kW/year)
Revenue Focus	Optimized for grid services and arbitrage	Integrated with PV; stable revenues via PPAs
Revenue Allocation	40% to MSD services, 25% to Fast Reserve/Capacity Market, 35% to arbitrage	60% to PV asset optimization and PPA-backed sales, 40% opportunistic MSD participation
IRR Target	10.5%	9.5%
Risk Profile	Higher market risk, volatile revenues	Lower risk, stabilized by long-term contracts

Comparing Stand-Alone and Co-Located BESS Models on IRR, NPV, EBITDA, and Payback

€16.5M Annual EBITDA Target (Stand-Alone) Required EBITDA range €15-18M to achieve IRR 10.5%	10.5 % IRR (Stand-Alone) Target Internal Rate of Return for stand-alone projects	€15M NPV (Stand-Alone) Positive Net Present Value confirms viability	8.5 years Payback Period (Stand-Alone) Estimated payback between 8 and 9 years
€2.75M Annual EBITDA Target (Co-Located) Required EBITDA range €2.5-3M supported by stable PPA revenues	9.5 % IRR (Co-Located) Target Internal Rate of Return for co-located projects	€1M NPV (Co-Located) Positive NPV confirms economic feasibility	9.5 years Payback Period (Co-Located) Estimated payback between 9 and 10 years

Sensitivity Analysis: Impact of CAPEX, MSD Prices, and Network Charges on IRR

Sensitivity testing shows IRR drops by 2.3 points with CAPEX +15%, 1.7 points with MSD revenue -20%, and a minor 0.4-point impact from a 50% rise in network charges for Stand-Alone BESS. Co-Located projects are less sensitive, losing only 0.5 points IRR from MSD decline due to PPA stability. These results highlight CAPEX control as critical and underscore PPAs' role in risk mitigation and investment resilience.



Stress Scenario

Transforming BESS Investment Risks into Managed Opportunities in Northern Italy



Market Risks

Includes price cannibalization and revenue volatility. Mitigate by securing long-term contracts like MACSE, adopting hybrid PPAs or tolling agreements, and deploying advanced EMS bidding algorithms to optimize market participation.



Technological Risks

Risks of technology lock-in, supply chain constraints, and end-of-life management. Mitigation involves modular design for repowering, diversifying suppliers, establishing decommissioning funds, and partnering with vendors offering battery take-back programs.



Regulatory & Political Risks

Uncertainty in post-2030 market frameworks and political interventions. Mitigate by maximizing contract durations (e.g., MACSE 15-year), investing in flexible EMS software, proactive regulatory engagement, and structuring investments with European partners.



Operational & Black Swan Risks

Day-to-day risks like equipment failure and safety, plus rare catastrophic events including cyber-attacks and natural disasters. Mitigate via Tier 1 suppliers, performance-based O&M, advanced fire suppression, cybersecurity by design, and specialized insurance coverage.

Market Risks: Managing
Cannibalization and Revenue
Volatility

Key risks include price cannibalization from rising BESS capacity and revenue swings in arbitrage; mitigation hinges on stable contracts and advanced bidding strategies.

RISK 1



Price Cannibalization Risk: Growing BESS capacity depresses service prices, eroding margins especially in MSD and Fast Reserve markets.



Mitigation: Prioritize Long-Term Contracts such as 15-year MACSE and 5-year Capacity Market agreements to secure stable, inflation-indexed revenue floors.



Adopt Alternative Contract Structures: Use hybrid PPAs for co-located assets and tolling agreements for stand-alone BESS to shift market risk and stabilize cash flows.

RISK 2



Revenue Volatility in Arbitrage: Profits depend on fluctuating price spreads, which are inherently unpredictable and subject to market dynamics.



Mitigation: Treat Arbitrage as Upside Potential and ensure base revenues from contracts cover fixed costs and debt service.



Invest in Advanced EMS: Deploy sophisticated Energy Management Systems with predictive algorithms to optimize bidding and capture maximum value amid tighter margins.



Comprehensive risk management combines **contractual stability, strategic bidding, and prudent financial modeling** to safeguard project viability.

Addressing lock-in, supply chain dependencies, and end-of-life costs with proactive lifecycle strategies

Technology lock-in risk: Dominance of LFP batteries exposes projects to obsolescence as new chemistries (e.g., sodium-ion) emerge; plan modular designs enabling future repowering.

Supply chain vulnerability: Heavy reliance on China-based suppliers risks price spikes and delivery delays; mitigate through supplier diversification and long-term framework contracts.

End-of-life recycling costs: EU regulations impose significant recycling and disposal expenses; incorporate recycling funds and contractual take-back programs from suppliers.

Lifecycle planning strategies: Amortize investments within contract periods (e.g., 15-year MACSE), ensuring payback before technology obsolescence or regulatory changes.

Extend asset value: Explore second-life battery applications to delay recycling, creating residual revenue streams and reducing upfront disposal costs.

Schedule buffers: Include timeline contingencies in project plans to absorb possible supply chain delays and regulatory compliance requirements.

Securing long-term revenue stability amid evolving market rules and political dynamics

Regulatory risk stems from potential shifts in market frameworks post-2030 that could disrupt revenue streams.



Political risk includes government actions such as windfall taxes and 'Golden Power' controls over strategic energy assets.



Mitigate risks by securing **long-term contracts** like MACSE (up to 15 years) that ensure stable, inflation-indexed payments.



Deploy **flexible EMS software** adaptable to future market products and regulatory changes, preserving operational agility.



Engage in **active advocacy** through industry associations (e.g., Elettricità Futura) to influence policy and gain early regulatory



Structure investments via **European or Italian entities** to align with national interests and reduce political exposure.



Ensure **portfolio diversification** across geographies to spread and mitigate country-specific political risks.



Mitigating Operational & Black Swan Risks in BESS

Protect infrastructure from equipment failure, fire, cyber threats, and rare catastrophic events



Mitigate equipment failures with **Tier 1 suppliers**, performance-linked O&M contracts, and **predictive maintenance** to maximize uptime and revenue.



Reduce fire risk via inherently safer **LFP battery chemistry**, strict safety standards, and advanced **fire suppression systems**.



Address cybersecurity threats through **secure IT architectures**, continuous monitoring, specialized insurance, and robust disaster recovery protocols.



Prepare for black swan events like natural disasters with **specialized insurance coverage** and comprehensive **contingency planning** to protect assets and investments.

01 Northern Italy offers a compelling BESS opportunity driven by **urgent grid balancing needs**, regulatory support (MACSE), and proven financial viability.

02 Key challenges include **intense competition**, complex permitting (18-30 months), and sensitivity to CAPEX fluctuations and market revenue volatility.

03 Success depends on flawless execution: securing **MACSE contracts**, adopting flexible business models (stand-alone or co-located), and engaging specialized legal expertise.

04 Early negotiation of **supply agreements** with Tier 1 battery and PCS vendors is critical to control CAPEX and protect project economics.

05 Investing in advanced **Energy Management Systems (EMS)** ensures optimal revenue stacking and operational efficiency amid evolving market dynamics.

06 This strategic, risk-balanced approach enables institutional investors to capitalize effectively on Italy's energy transition and the accelerating demand for flexibility.

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