

STRATEGIC RESEARCH & INNOVATION AGENDA

June 2025

HYBRID ENERGY STORAGE





DISCLAIMER

This Strategic Research and Innovation Agenda has been developed through expert contributions coordinated by the StoRIES project, with the support of the EERA Joint Programme on Energy Storage, and EASE. While it draws upon input from various stakeholders and aligns with European policy goals, the sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the views of the European Union. The European Commission is not responsible for any use that may be made of the information contained therein.

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Their collaboration reflects the cross-sectoral nature of hybrid energy storage and reinforces the importance of coordinated action in advancing Europe's clean energy goals.



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SUMMARY

This Strategic Research and Innovation Agenda (SRIA) on Hybrid Energy Storage (HES) presents a comprehensive strategic framework to support Europe's transition toward a climate-neutral, secure, and competitive energy system. HES, which combines the strengths of diverse storage technologies, offers a flexible and cost-effective solution to support renewable energy integration, grid stability, sector coupling, and the decarbonisation of industry and transport. The SRIA aligns with overarching European objectives outlined in the European Green Deal, REPowerEU, the Clean Industrial Deal, and other strategic frameworks. It responds directly to the needs for technological resilience, strategic autonomy, and sustainable innovation by identifying concrete pathways for research, demonstration, and market integration of HES solutions.

The document opens with a shared vision and mission, followed by a focused overview of the policy landscape, regulatory environment, and funding mechanisms shaping hybrid storage development in Europe. Special attention is given to the evolving skills landscape, with clear recommendations to close existing gaps in education, training, and workforce development.

Four Strategic Research Areas (SRAs) form the core of the SRIA:

- SRA 1 focuses on enhancing system resiliency through long-duration and seasonal hybrid storage solutions.
- SRA 2 addresses the integration of multi-vector energy storage and conversion systems, enabling flexibility across electricity, heat, cooling, and fuels.
- SRA 3 highlights the importance of digitalisation and advanced energy management systems to ensure real-time, optimised operation of complex hybrid systems.
- SRA 4 lays the foundation for a European HES ecosystem by advancing standardisation, regulation, strategic coordination, and workforce excellence.

The SRIA concludes with policy recommendations at both the EU and national levels, supported by an assessment of current challenges and barriers to deployment. These insights are intended to guide coordinated action across public and private stakeholders, aligning industrial, regulatory, and research efforts toward the large-scale deployment of HESS. This agenda serves not only as a strategic framework for future Research and Innovation (R&I) investments, but as an instrument to position hybrid energy storage as a cornerstone of Europe's energy, industrial, and climate strategy.

1. Introduction

The European Union is undergoing a profound transformation to address the dual imperatives of climate neutrality and energy resilience. This shift demands systemic changes across energy production, consumption, and infrastructure. At the heart of this green transition lies energy storage and, specifically, hybrid energy storage systems (HESs) which offer the flexibility and reliability necessary to accommodate the growing share of intermittent renewable energy sources like solar and wind.

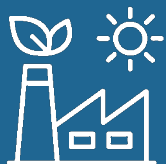
HESs combine two or more complementary storage technologies within a single architecture. This allows them to overcome the limitations of any individual solution, providing tailored performance across different timeframes, applications, and energy vectors. In a landscape where no single technology can meet all flexibility, duration, cost, or resilience requirements, HESs represent a systems-level response to the evolving demands of a secure, reliable, and decarbonized energy infrastructure.

This Strategic Research and Innovation Agenda (SRIA) outlines how hybrid energy storage systems can support the EU's sustainability objectives, particularly under landmark frameworks such as the European Green Deal, REPowerEU, and the Clean Industrial Deal. It maps out regulatory and funding mechanisms, industry-relevant acts, and policy instruments aimed at accelerating the deployment of HESs and promoting European technological sovereignty.

To maximise the impact of hybrid energy storage across Europe, this SRIA aligns its priorities with broader European policy goals and long-term strategic frameworks. In doing so, it recognises that the value of HESs extends beyond technical performance, but it also contributes to climate neutrality, energy security, digitalisation, and industrial leadership.

The following section outlines the key **EU-level objectives** that guide this agenda, followed by a shared **Vision** for how hybrid energy storage can support Europe's transition to a secure, clean, and competitive energy future.

1.1 EU Objectives



Decarbonisation
and Zero Emissions

The EU's path to net-zero emissions is anchored in its climate legislation, which establishes ambitious decarbonisation targets across key sectors. HESSs are central to achieving these goals by enabling deeper penetration of renewables, improving energy efficiency, and supporting the electrification of transport and heating. Regulations such as the Renewable Energy Directive III (REDIII) set higher targets for renewable energy—42.5% by 2030—and introduce requirements for grid operators to incorporate energy storage in their planning strategies. Moreover, the Energy Efficiency Directive (EED) enhances final energy savings, indirectly fostering the development of HESS technologies that support smart demand-side energy solutions. Together, these acts help reduce greenhouse gas emissions, promote green hydrogen integration, and ensure system-wide flexibility.



European Resilience
and Fade-Out
of fossil Fuels

Geopolitical disruptions, particularly the war in Ukraine, have underscored the importance of reducing dependence on fossil fuel imports. The REPowerEU Plan was developed in response, focusing on accelerating renewable deployment, improving energy security, and facilitating energy independence. REPowerEU includes critical support for long-duration storage and removes regulatory bottlenecks for storage projects, offering faster permitting and clearer investment signals. HESS, by enabling flexibility and reliability in national grids, plays a pivotal role in the EU's strategic autonomy. In tandem, the Batteries Regulation and the Net-Zero Industrial Act support secure and sustainable supply chains, including recycled and domestically sourced materials essential for hybrid storage technologies.



Industrial
Competitiveness
and Strategic Autonomy

The Clean Industrial Deal, launched in 2025, represents a major evolution of the European Green Deal, shifting the focus toward industrial decarbonisation and economic sovereignty. HESS technologies are identified as strategic assets within this vision. With provisions like the €100 billion Industrial Decarbonisation Bank and the Clean Industrial State Aid Framework (CISAF), the EU aims to build a domestic clean-tech industry capable of meeting at least 40% of deployment needs by 2030. Through streamlined permitting, digitalisation of project approval, and strong financial incentives, the EU is setting the foundation for a resilient industrial base that aligns with both climate and economic priorities.

The digital transformation of Europe's energy landscape is a cornerstone of grid modernization. Through regulations like the Electricity Market Design (EMD), the EU is driving the integration of digital tools in managing flexibility resources. EMD mandates the use of Contracts for Difference (CfDs), Renewable PPAs, and flexibility support schemes that provide revenue certainty for HESS developers. Moreover, digital battery passports introduced under the Batteries Regulation ensure transparency and performance tracking across the lifecycle. These developments enhance the role of digitalisation in managing complex hybrid systems, increasing interoperability, system forecasting, and grid balancing capabilities.



The EU's push for a circular economy is evident in policies such as the Circular Economy Act and the Critical Raw Materials Act (CRMA). Energy storage technologies often rely on materials like lithium, cobalt, aluminium, and nickel—resources that are both strategically important and environmentally taxing. Through CRMA, the EU incentivizes domestic sourcing, recycling, and ethical procurement of critical raw materials. The Batteries Regulation furthers these efforts by enforcing minimum recycled content thresholds and establishing standards for performance and safety. These initiatives ensure that the lifecycle of HESS is aligned with circularity principles, reducing environmental impacts and strengthening material resilience.



The EU's funding architecture for clean technology innovation is robust and multi-layered. Programmes such as Horizon Europe, the Innovation Fund, and the European Innovation Council (EIC) directly support R&D for hybrid energy storage systems. At the same time, nationally administered funds—especially through State Aid and Recovery & Resilience Plans—offer significantly larger capital pools for industrial-scale deployment. The synergy between EU-level instruments and Member State initiatives provides the financial backbone for HESS development, bridging the valley of death from prototype to commercialisation. As State Aid alone reached €384 billion in 2022, nearly half of which was allocated to energy and environment, the potential for scaling HESS is unprecedented.



1.2 Vision

The European Union stands at a decisive moment in its transformation toward climate neutrality, industrial leadership, and strategic autonomy. In this era of energy transition and geopolitical rebalancing, the integration of innovative, scalable, and sustainable technologies will determine the future of Europe's competitiveness and resilience. Among these, **Hybrid Energy Storage Systems** emerge as crucial enablers that bridges sectors, connects markets, and unlocks the full potential of renewable energy.

Our vision is for a **net-zero Europe powered by flexible, intelligent, and domestic anchored energy infrastructure** where energy storage is no longer a bottleneck, but a strategic advantage. We envision an ecosystem in which HESS technologies are integrated into every layer of the energy system: from industrial applications and decentralized prosumer solutions to national grids and cross-border electricity markets.

This vision is one of technological sovereignty, where Europe leads global value chains in the design, manufacturing, and deployment of hybrid storage technologies. These systems will be rooted in circular economy principles, digital innovation, and strategic raw material sourcing, ensuring both environmental and economic sustainability. They will empower industries to decarbonise, support the electrification of transport, and enable citizens to participate in a distributed and democratized energy market.

Our goal is for hybrid energy storage to evolve from a supporting role into a strategic pillar of the European energy transition—recognized for its value not only in stabilizing the grid, but in fostering resilience, accelerating innovation, and safeguarding European autonomy.

This Strategic Research and Innovation Agenda sets the course for achieving that future. It outlines the pathways, policy frameworks, and investment mechanisms necessary to scale HESS solutions across Europe, aligning technological advancement with climate objectives and market realities. With collective commitment and coordinated action, we can ensure that energy storage becomes one of Europe's strongest assets in building a carbon-neutral, economically vibrant, and geopolitically resilient union.

2. Context

2.1 Policy Agenda

In pursuit of ambitious sustainability goals, the European Union instituted a comprehensive regulatory framework and embarked on strategic initiatives to address environmental challenges, promote renewable energy adoption, and ensure energy security. These efforts are aligned with key objectives, including the decarbonization of the transport and power supply sectors, enhancing energy resilience, and fostering innovation in critical industries.

The EU's sustainability agenda, first driven by the European Green Deal and now emboldened by the Clean Industrial Deal, emphasizes the transformation of the transport sector towards climate neutrality. Regulations such as those within the European Green Deal Industrial Strategy focus on fostering clean technologies and improving resource efficiency, crucial for reducing emissions in transportation. The REPowerEU Plan, a response to Russia's invasion of Ukraine and consequent energy supply disruptions, aimed to accelerate the transition to renewable energy, thereby reducing the transport sector's reliance on fossil fuels and enhancing both its energy security and carbon intensity.

The backbone of the recent changes in policy focus on promoting clean & affordable energy production and reduce bills for European citizens were built on delivering the encompassing policy package of the Clean Energy for All Europeans Package (2019). Due to rising energy costs and emerging geopolitical tensions, the last years saw a reinforcement in policy priority along with this package.

- REPowerEU Plan & key implementing acts Renewable Energy Directive III (2023) and Energy Efficiency Directive (2022)
- Publishing the Net-Zero Industrial Act & Critical Raw Materials Act (2023)
- The introduction of Phase I of the Carbon Border Adjustment Mechanism (2023)
- Publishing of the Batteries Regulation (2023)
- Reforming the EU's Electricity Market Design (2024)
- Embracing the new EU Commission with a Clean Industrial Deal (2025)
- Announcing an Affordable Energy Action Plan (2025)

These initiatives prioritised the expansion of renewable energy capacity and aligning policy signals to account for the value that clean technologies including hybrid energy storage solutions have in mitigating climate change impacts.

Simultaneously, the EU's policy agenda also saw key updates to funding instruments designed at enabling both clean tech and renewables research, development & innovation. This includes a focus on accelerating 'made-in-EU' technology & projects in achieving industrial deployment. Funding instruments as part of the policy agenda that provided support to renewables are:

- Introduction of the European Innovation Council (EIC)
- Bolstering Horizon Europe's Pillar II
- Promoting CEF Energy
- The European Investment Bank's (EIB) expansion including Invest EU
- The release and growth of the EU ETS Innovation Fund
- The introduction of the European Defence Fund
- Re-orientation of the LIFE Programme

Beyond these funding programmes administered & managed at EU level, there are a series of Member State administered EU funds that will have a significant impact on HESS project development across the EU. These funding avenues are the ETS Modernisation Fund, Recovery & Resilience Plans (part of the post-COVID recovery) and State-Aid.

Whilst EU funding programmes are considerably large & present unique opportunities to promote the EU's leading clean technologies, these nationally administered instruments are proportionally much bigger. In 2022, State-Aid alone reached total spending of **€384 billion** (~2.7% of EU GDP) with almost 50% being allocated to energy & environment sectors. According to the recently unveiled Clean Industrial Deal, State Aid will be enhanced and simplified through the form of the Clean Industrial Deal State Aid Framework (CISAF).

In the following sub chapters 2.2 & 2.3, more detail will be provided concerning the regulatory & funding signals that promote Hybrid Energy Storage Systems. This SRIA will elucidate what are the opportunities and likely avenues of development for the offering of HESS innovations in contributing to a cleaner and resilient EU energy system.

2.2 EU Regulations

As mentioned in the previous section dedicated to the EU's Policy Agenda, there are many relevant EU regulations that provide important signals to the public and private sector in adopting a wide variety of clean technologies. The following subchapter will focus on understanding the direct and indirect contributions of recent regulatory packages to HESS & energy storage solutions as a whole:

- REPowerEU Plan & key implementing acts Renewable Energy Directive III and Energy Efficiency Directive (2022)
- Publishing the Net-Zero Industrial Act & Critical Raw Materials Act (2023)
- The introduction of Phase I of the Carbon Border Adjustment Mechanism (2023)
- Publishing of the Batteries Regulation (2023)
- Reforming the EU's Electricity Market Design (2024)
- Embracing the new EU Commission with a Clean Industrial Deal (2025)
- Announcing an Affordable Energy Action Plan (2025)

The REPowerEU Plan, launched in **May 2022** to reduce reliance on Russian fossil fuels and accelerating EU renewable energy adoption. The REPowerEU plan contained significant changes to the storage systems such as REPowerEU removes regulatory barriers for energy storage including quicker permitting (≤ 12 months for renewable projects paired with energy storage in designated **renewable acceleration areas**)¹ and influenced funding for thermal storage batteries, pumped hydro, hydrogen storage. **The REPowerEU plan also introduced** incentives for **long-duration energy storage (LDES)** to handle seasonal energy fluctuations. At its time, this policy package was a turning point in geopolitical relations on the EU continent and further because it harnessed the idea of more aggressively supporting industries & sectors that were of key strategic importance to **the EU and its autonomy**.

More specifically, two implementing acts under the Plan were **REDIII & EED**. Adopted in **2023**, the REDIII increased **EU-wide renewable energy target to 42.5% by 2030**, up from REDII's promise of 32%. REDIII placed a lot of importance on facilitating flexibility and had called for **Stakeholder Committee for Flexibility and Energy Shifting Scenarios, a key avenue for HESS considerations**. Furthermore, Article 15e mandates that Transmission System Operators (TSOs) assess the potential for energy storage solutions and integrate these findings into their grid investment strategies. REDIII also establishes green hydrogen targets for

¹ https://www.consilium.europa.eu/en/press/press-releases/2022/12/19/repowereu-council-agrees-on-accelerated-permitting-rules-for-renewables/?utm_source=chatgpt.com

industry (60% by 2035) and for transport (1.2% supplied to shipping and 1% to aviation). Despite the lack of direct HESS applications in these sectors, technological overlap and spillover should bolster HESS innovation.

The second key implementing act: the **Energy Efficiency Directive** (EED). Released in 2022, the act strengthens the EU's energy-saving goals, with a target to reduce final energy consumption by 11.7% by 2030. Although not as influential as REDIII, the EED still has notable indirect impact at fostering heating & cooling technologies that can support these goals for energy efficiency.

Following REPowerEU, a landmark package for clean technologies needed to reach net-zero was adopted; the Net-Zero Industrial Act (NZIA). The NZIA built on prior implementing acts, particularly in removing regulatory barriers and helping accelerate uptake. Most notably, the NZIA introduced Single Points of Contact for project developers. This is to say that each Member State (MS) is required to establish a single point of contact to facilitate and coordinate the approval process for net-zero technology manufacturing projects, thereby reducing administrative burdens and enhancing efficiency. Further digitalisation of permitting procedures was also largely encouraged by the act and the NZIA establishes a group to oversee the reduction of administrative burdens on manufacturers, ensuring that permitting procedures are both streamlined and accelerated via Net-Zero Regulatory Burden Scientific Advisory Group. A key provision of the NZIA is benchmark for European manufacturing capacity to meet at least 40% of the EU's annual deployment needs for net zero technologies by 2030, which directly promotes innovation in HESS technologies made in EU.

Simultaneous to the release of the NZIA, was the release of the Critical Raw Materials Act. While hybrid storage technologies do not directly deal with industrial refining activities, many have critical raw materials in their supply chains. The CRMA brought in the idea of strategic refining and mining projects and supporting their development, but it also brought in key provisions on recycling & sourcing from EU supply chains. This regulatory signal may have indirectly fostered innovation in HESS technologies.

A widely discussed and debated regulatory system, the Carbon Border Adjustment Mechanism (CBAM) also entered into force in 2023. The objectives of CBAM primarily consist of discouraging carbon leakage, a phenomenon portrayed by key EU industries leaving Europe due to business opportunities arising from less stringent environmental burden in other territories. CBAM aims to achieve this by effectively introducing a green levy for products coming into the EU. In this sense, the mechanism protects EU industries investing in cleaner and environmentally conscious practices, raising revenue for clean investments and incentivising adoption of cleaner practices for exporters aiming to enter EU markets. In this

stage, CBAM is in a transition phase, trying to map the embedded emissions in EU products and full implementation is scheduled to enter vigour in 2026 but may be subject to postponement. CBAM may prove to be a key disruption to many EU value chains presenting a credible threat and opportunity for many cleantech manufacturers in the short term. In this sense, it is likely that CBAM will provide positive signals for made-in-EU hybrid storage project development.

In July 2023, the Batteries Regulation was adopted to replace the previous Batteries Directive (2006/66/EC) and introduces comprehensive measures to govern the entire lifecycle of batteries, aiming to enhance sustainability, safety, and circularity within the EU market. The regulation provides Performance and Durability Standards and Recycled Content and Material Recovery including minimum shares of recycled materials: 6% for lithium and nickel, and 16% for cobalt by 2031. Moreover, the regulation foresees the implementation of a digital battery passport to account for the lifespan of each battery and optimises the battery circular economy. The impact for HESS technologies already considering wider sustainability impact of battery technologies will be positive.

Soon thereafter, the EU adopted the long-debated Electricity Market Design (EMD). This policy package could prove to be very relevant for HESS focusing on energy systems and grid support. EMD specifically provided key regulatory signals to HESS innovators by enhancing capacity markets, a key avenue for long-term revenue certainty of stationary storage asset managers. Added to this, EMD introduced provisions to flexibility support schemes that include non-fossil support; MS are empowered to implement support schemes that provide payments for the available capacity of non-fossil flexibility resources. EMD mandates the establishment of national objectives for flexibility, tailored to address needs across various timeframes—short-term, monthly, and seasonal—and considering locational criteria. This strategic planning ensures that flexibility resources are developed in alignment with the specific requirements of each Member State's energy system.

Both these provisions encourage the deployment of Hybrid energy storage solutions, which are well-positioned to provide ancillary services and stability to the grid. Moreover, EMD promotes long-term contractual instruments like Contracts for Difference (CfDs) or Renewable Power Purchase Agreements (RPPAs), the market design provides stable revenue streams. This financial predictability makes investments in hybrid energy storage projects more attractive. Furthermore, EMD aims at reducing the risk of high and volatile prices and promotes a stable investment environment. Overall, EMD provides clear investment signals for storage technologies as EU grids and energy markets transition.

These notable packages were passed during Von Der Leyen's first term as President of the EU Commission. Following 2024's EU elections and negotiations to form a governing coalition, a second successive term for Von Der Leyen and the

European People's Party (EPP)-led coalition was announced. This time, aligned with the much-anticipated Draghi Report, the new Commission aimed at providing more focus on EU industrial competitiveness and strategic autonomy, raising key signals for hybrid storage technologies.

In February 2025, the EU launched the successor of the European Green Deal, the Clean Industrial Deal. The objective of this overarching strategy is to transform Europe's industrial landscape to achieve climate neutrality while enhancing competitiveness. Key pillars of this strategy include the establishment of an Industrial Decarbonisation Bank with €100 billion in public funds, aiming to leverage €400 billion from the private sector. On top of that, there will be the previously mentioned CISA. On a higher level, the deal will support renewable energy and electrification with emphasis on driving renewables, electrification, grids, and storage to support energy-intensive industries and clean tech manufacturing. It will also continue to promote the goals of the European Green Deal in pushing for circular economy and resource efficiency via the Circular Economy Act which will be adopted to lower feedstock costs and promote recycling on an industrial scale. The deal also includes measures to reform trade regulations and establish international partnerships, ensuring that European industries remain competitive in the global market. Collectively, these packages aim to reduce emissions by 90% by 2040, revitalize heavy industries, and make energy cheaper, cleaner, and more secure.

One of the first key packages to be unveiled was the Affordable Energy Action Plan. While the plan does not directly foster support for HESS, one of the primary objectives is to encourage Member States to drastically or totally cut taxation for electricity generation as well as provide clearer framework for renewable Power Purchase Agreements. Furthermore, the action plan has guidance on anticipatory investments for electricity grids to assist system operators, regulatory authorities, and Member States in planning and outlines an investment of approximately EUR 584 billion in the electricity grid by 2030. Of this, around EUR 400 billion is allocated for distribution grids. Furthermore, the plan emphasizes the need to scale up investments in grid infrastructure and flexibility solutions, such as energy storage and demand response systems. These goals provide signals for investment in HESS technologies, particularly those that are linked to the large projects of long provision.

2.3 Funding Opportunities

Investment is now at the heart of the EU and many core Member States priorities. As previously discussed, both funding instruments administered at the EU level & Member State will play important roles in accelerating the development of tomorrow's clean technologies. This section will focus on the various funding instruments available at EU level and how they specifically complement HESS.

- Introduction of the European Innovation Council (EIC)
- Bolstering Horizon Europe's Pillar II
- Promoting CEF Energy
- The European Investment Bank's (EIB) expansion including Invest EU
- The release and growth of the EU ETS Innovation Fund
- The introduction of the European Defence Fund and there-orientation of the LIFE Programme.

Given the variation of rules predicated on individual Member State organisations, State Aid and similar frameworks will not be elaborated in this section.

At the start of the last Multi-annual Financial Framework (MFF) in 2021, the European Innovation Council was introduced. Europe excels in research but lacks in turning scientific breakthroughs into global businesses, which gives EIC the mission to support high-risk, high-impact innovations by bridging the gap between research, deep tech startups, and market-scale ventures. The EIC can be broken down into the 3 funds and a cross-cutting EIC Challenges framework:

- **EIC Pathfinder** funds early-stage, high-risk research-oriented consortia projects exploring disruptive technologies, typically at **Technology Readiness Level (TRL) 1-4**, with grants of up to **€3 million**. In many ways, these projects look like Horizon Europe projects.
- **EIC Transition** helps bridge the gap between research and commercialization, supporting the validation and prototyping of promising technologies at **TRL 4-6**, offering up to **€2.5 million** in grants.
- **EIC Accelerator** targets deep-tech startups and SMEs, providing a mix of **grants (up to €2.5 million)** and **equity investments (up to €15 million)** to help scale innovations and bring them to the market at **TRL 6-9**.

The European Innovation Council supports high-impact, deep-tech innovations through both **Open** and **Challenge**-specific calls, designed to address specific global and technological issues by focusing on strategic priority areas set by the European Commission. A series of strategic challenges are issued annually under the European Innovation Council through two flagship programmes: **EIC**

Pathfinder and EIC Accelerator. While the 2025 challenges are broader in scope, several are directly pertinent to hybrid energy storage systems or may offer indirect benefits to their development and deployment. Below is a curated selection of the most relevant topics under each programme.

EIC Pathfinder Challenges (Early-Stage Research)²

- **Waste-to-Value Devices: Circular Production of Renewable Fuels, Chemicals, and Materials.** This challenge supports technologies that transform problematic waste streams—such as mixed plastics, flue gases, or wastewater—into valuable inputs. Innovations in this area may contribute to sustainable materials for HESS components and support circularity in hybrid energy systems.
- **Towards Autonomous Robot Collectives Delivering Collaborative Tasks in Dynamic Unstructured Construction Environments** Focuses on advanced robotic collaboration for complex construction tasks. While not storage-specific, progress in autonomous systems could enhance the deployment, assembly, or maintenance of HESS infrastructure.

EIC Accelerator Challenges (Scaling Startups and SMEs³)⁴

- **Acceleration of Advanced Materials Development and Upscaling Along the Value Chain:** targets innovations in advanced materials across key sectors including energy. This challenge is directly relevant to SMEs developing scalable components for hybrid energy storage technologies.
- **Breakthrough Innovations for Future Mobility** supports deep-tech solutions for sustainable, low-emission transport. HESS can play a key role in electrification and the development of integrated charging, fueling, and storage systems for mobility applications.
- **GenAI4EU: Creating European Champions in Generative AI.** While not focused on energy, this challenge supports AI-driven innovations that can strongly benefit HESS through smart energy management, predictive control, and digital twin development.

EIC winners also access EIC Business Acceleration Services. These services include corporate partnerships, connecting startups with industry leaders, and facilitating public procurement opportunities. To support fundraising, EIC provides investor matchmaking, ePitching sessions, and access to venture capitalists. Startups also benefit from one-on-one coaching, leadership training, and

² https://eic.ec.europa.eu/eic-funding-opportunities/eic-pathfinder/eic-pathfinder-challenges-2025_en#biotech-for-climate-resilient-crops-and-plant-based-biomanufacturing

³ *Small and Medium-sized Enterprises*

⁴ https://eic.ec.europa.eu/eic-funding-opportunities/eic-accelerator/eic-accelerator-challenges-2025_en#list-of-eic-accelerator-challenges

mentoring to refine their business strategies. For international expansion, EIC offers trade missions, soft-landing programs, and regulatory guidance, helping companies establish operations in new markets. Visibility is enhanced through participation in major trade shows (CES, Web Summit) and EIC summits, while dedicated IP advisory services assist with patent strategies. Additionally, EIC provides fast-track access to Horizon Europe funding and partnerships with initiatives like EIT InnoEnergy and EIT Digital.

EIC is a proven avenue to promote the individual key innovations driving hybrid energy storage solutions. Previous long duration energy storage innovations funded by EIC are **Ore Energy** and **Energy Dome**. Ore Energy developed the F-AIR BAT, a scalable and cost-effective long-duration energy storage solution that leverages iron, water, and air. Similarly, **Energy Dome**, which specializes in CO₂ battery technology, received €17.5 million in grant and equity financing from the EIC to expand its innovative energy storage solutions.

In parallel to the boosting European startups, the Commission has directed a lot of resources in bolstering its flagship R&D programme Horizon Europe and its Pillar II on global challenges and industrial competitiveness. The Horizon Europe initiative has provided a lot of support to emerging energy & storage technologies by consolidating large and diverse consortia to provide innovation by responding to the very specific calls found in the biannual programmes. In May 2024, the European Commission allocated €241.6 million to 43 projects under Horizon Europe's Cluster 5, focusing on sustainable, secure, and competitive energy supply topics and ranging from Research & Innovation Action projects (TRL3-5) with a reimbursement rate of 100% for all partners and Innovation Actions (TRL6-7) with a reimbursement rate capped at 70% for the for-profit partners.

Along with StoRIES, Horizon Europe, and its predecessor Horizon 2020, has provided funding for the development of pivotal hybrid energy storage solutions in the four projects: **SMHyLES**, **HAVEN**, **HYBRIS**, and **HYFLOW**. **SMHyLES** develops innovative hydrogen-based energy storage systems, aiming to improve the integration of renewable energy sources by creating more efficient and scalable storage solutions. **HAVEN** focuses on integrating hydrogen into ports and maritime sectors by developing a hydrogen supply chain that enables cleaner and more sustainable operations in shipping. The **HYBRIS** project is centred on optimizing hydrogen production, storage, and utilization through the development of advanced electrolysis technologies, while **HYFLOW** seeks to enhance the efficiency of hydrogen fuel cells in transport applications, aiming to reduce greenhouse gas emissions and support the decarbonization of the transport sector. These projects collectively contribute to the scaling & improving key metrics (cost, performance, reliability) of hybrid energy storage technologies.

The EU also promoted Connecting Europe Facility for Energy (CEF Energy) with over **€5.84 billion** for the period 2021-2027 to provide critical support for infrastructure projects. It is a financial instrument established by the European Union to support the development of cross-border energy infrastructure projects that enhance the EU's energy security, sustainability, and integration of renewable energy sources. The program provides funding for **key energy infrastructure** projects, including the construction and upgrade of energy transmission networks, storage systems, and cross-border interconnections. By prioritizing projects that foster the integration of energy markets, reduce energy isolation, and support the decarbonization goals of the EU, CEF Energy plays a critical role in creating a more resilient and efficient European energy system. It supports a range of initiatives, from **hybrid energy storage solutions** to **smart grids**, contributing to the overall goal of achieving a **low-carbon, secure, and competitive energy union**.

Arguably, the largest grant instrument for industrial & hybrid energy storage projects is the EU ETS Innovation Fund (IF). Launched in 2020, the fund uses the revenues generated by the EU ETS to finance breakthrough innovation aimed at decarbonising key sectors, processes and products of European economies. During the period of 2020-2030, a foreseen total of 40 billion EUR should be disbursed to decarbonising projects. This substantial amount enables the fund to provide up to **60%** of net extra project costs making it an essential source of financing for cutting-edge clean technologies. The fund is primarily aimed at projects of an industrial scale specialising in industry decarbonisation, manufacturing components for cleantech (storage, renewables, electrolyzers, heat pumps, etc.), piloting deep decarbonising projects and scaling up green hydrogen & battery projects. This breakdown can be seen in the visual representing the different calls under IF 2024's call, as shown in Figure 1.

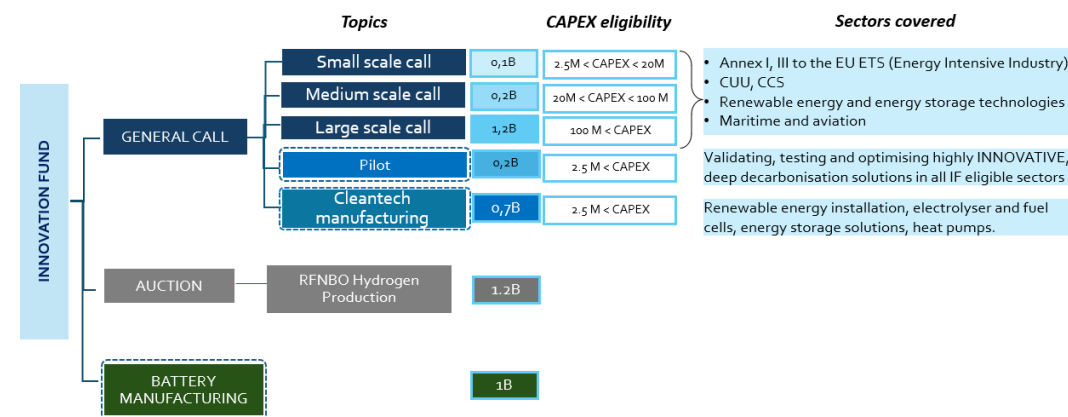


Figure 1. Innovation Fund's multiple calls, associated budgets, CAPEX ranges, etc. Circled in dotted lines are the projects most relevant to hybrid energy storage innovation. Source: CLERENS.

As of early 2025, the fund boasts a portfolio of around 10B EUR and just under 200 projects⁵. Key HESS projects include **TRUCK2WIND Project** integrating first and second-life batteries, into a renewable energy plant in Spain. The project aims to demonstrate the advantages of combining various battery types by evaluating the feasibility and performance of the hybrid solution and its potential for participation in different grid services. Another project is the **SOVALIS Project** featuring a hybrid energy storage system that combines lithium-ion and vanadium flow batteries, directly linked to a large-scale solar photovoltaic farm.

Wider than grant instruments, The **European Investment Bank (EIB)** and the **InvestEU** program significantly contribute to funding clean technology initiatives through debt and equity-based instruments. In 2024, the EIB committed €500 million in counter-guarantees to support clean-tech companies, aiming to bolster Europe's competitiveness in this sector. Additionally, the EIB's **Cleantech Co-Investment Facility**, launched in January 2024, is a €200 million equity co-investment instrument targeting companies that contribute to the EU's climate neutrality objectives by 2050. InvestEU, backed by an EU budget guarantee of €26.2 billion, aims to mobilize over €372 billion in public and private investments across various sectors, including sustainable infrastructure and innovation. One key way the EIB has supported cleantech startups like Verkor is through venture debt. This financing instrument provides **low-cost, flexible loans** with longer repayment periods, offering companies a pathway to secure funding without giving up significant equity. Venture debt is especially beneficial for **clean technology** and **energy storage** firms, which often require substantial upfront investment but may not yet generate steady revenue to qualify for traditional financing. Beyond this financial support, the InvestEU Advisory Hub offers technical assistance and advisory support to project promoters, helping them navigate the complexities of project preparation, structuring, and implementation. Through a network of experts and advisors, the Advisory Hub provides customized advice and expertise to ensure the viability and success of InvestEU-supported projects.

This expansion of support mechanisms based on loans, equity and other debt instruments have opened a positive channel for Hybrid Energy Storage solutions looking to access larger pools of capital. The EIB also supports projects that aim to integrate renewable energy, stabilize power grids, and contribute to the EU's goal of achieving climate neutrality by 2050.

There is also the realignment of the LIFE programme and European Defence Fund to include projects with energy storage. The LIFE Programme and the European Defence Fund (EDF) are two key EU funding mechanisms supporting innovation

⁵ https://dashboard.tech.ec.europa.eu/gs_digit_dashboard_mt/public/sense/app/6e4815c8-1f4c-4664-b9ca-8454f77d758d/sheet/bac47ac8-b5c7-4cd1-87ad-9f8d6d238eae/state/analysis

and sustainability in different sectors. The LIFE Programme focuses on environmental and climate action, providing grants (€997 million for 'Clean Energy Transition' topics until 2027) for projects that contribute to clean energy transition, climate resilience, and decarbonization, making it an attractive option for energy storage initiatives. On the other hand, the EDF has a €7 billion budget dedicated to strengthening Europe's defence capabilities by supporting research and development of advanced technologies, including energy resilience and security solutions for military applications. Energy storage projects can apply for funding under both programs by responding to calls for proposals. To be eligible, LIFE applications should focus on sustainability and emission reductions, while EDF projects should demonstrate a clear contribution to energy security and operational efficiency in defence. In both funds, successful applications typically require a consortium of partners, a strong innovation component, and a plan for scaling and deployment within the EU's strategic priorities.

While it is more challenging for hybrid energy storage projects to directly align with the primary scopes of LIFE or EDF, tailored proposals can still fit within their funding frameworks—particularly when they support decarbonised military operations, dual-use technologies, or large-scale energy flexibility. This alignment becomes especially relevant in the context of the **European Commission's 2025 White Paper on Defence** and the **ReArm Europe / Readiness 2030 Plan**⁶ which reinforce the need for energy autonomy, resilience, and innovation in both civilian and defence contexts.

2.4 Education, training, and required skills for future workforce in Hybrid Energy Storage in Europe

The Role of Skilled Workers in HES. The deployment of HESSs depends not only on technology and regulation but also on a skilled and adaptive workforce. As the energy system becomes more decentralised, digitised, and hybridised, Europe will need professionals capable of designing, managing, and integrating diverse storage technologies across sectors and applications. This workforce must span a broad range of fields, from science and engineering to IT, policy, operations, and market design.

Workforce Projections and Skills Gap. The scale-up of energy storage capacity across Europe, from 60 GW in 2022 to a projected 600 GW by 2050⁷, will require

⁶ https://ec.europa.eu/commission/presscorner/detail/en/ip_25_793

⁷ https://energy.ec.europa.eu/topics/research-and-technology/energy-storage/recommendations-energy-storage_en

significant workforce expansion. Existing projections for adjacent sectors underscore this need and predict that:

1. Establishing a circular battery value chain is expected to generate 10 million safe, fair, and high-quality jobs worldwide by 2030⁸.
2. Hydrogen energy could contribute 24% of Europe's final energy demand (equivalent to 2,250 TWH of energy) by 2050 and create an estimated 1 million highly skilled workers by 2030 and 5.4 million jobs across the sector by 2050⁹.

While dedicated figures for HES are not yet available, these trends indicate that system-level integration skills, digitalisation expertise, and hybrid configuration know-how will be increasingly in demand. There is currently a mismatch between the complexity of hybrid energy solutions and the readiness of education systems to deliver qualified professionals.

Key Competences for the future HES Workforce. The development of a highly skilled workforce is essential for the advancement of HES in Europe. This requires a structured approach to technical expertise, digital competencies, regulatory knowledge, and soft skills, ensuring that professionals are qualified to effectively design, develop, integrate, and manage hybrid storage systems.

A HES workforce must be equipped with a multidisciplinary skill set that includes:

- **Core technical knowledge:** fundamentals of electrochemical, thermal, mechanical, and chemical energy storage systems, including manufacturing of their components.
- **Manufacturing and industrialisation skills:** Knowledge of component production, device assembly, and sustainable manufacturing processes, including critical raw materials (CRM) substitution, circular design, and quality assurance, supporting Europe's strategic resilience goals under the Critical Raw Materials Act.
- **Practical and operational skills:** installation, commissioning, maintenance, and safe operation of integrated hybrid systems.
- **Digital and smart systems expertise:** data analytics, AI, EMS, IoT, and real-time system diagnostics.
- **Regulatory and market literacy:** understanding of EU policies, permitting procedures, and commercialisation models.
- **Cross-cutting and soft skills:** communication, project management, interdisciplinary collaboration, and continuous learning.

⁸ https://link.springer.com/chapter/10.1007/978-3-031-48359-2_16

⁹ <https://op.europa.eu/en/publication-detail/-/publication/0817d60d-332f-11e9-8d04-01aa75ed71a1/language-en>

Current Education and Training Programmes in HES. Developing a skilled workforce for HES requires structured education and training programmes that address the complexity of integrating multiple energy storage technologies. Although fully dedicated HES courses remain limited, relevant training is emerging through:

- Courses on energy storage and smart energy systems at the university level.
- Vocational training initiatives with components on multi-vector integration.
- EU-funded projects like **StoRIES**¹⁰, **SkillBill**¹¹, **GreenVOCnet**¹², **European Battery Academy**¹³ via InnoEnergy Skills Institute programme, whose offer workshops, summer schools, and online training.
- Programmes under **Erasmus+**, **Marie Skłodowska-Curie Actions**, and **national innovation agencies**, which support interdisciplinary curricula and mobility.

Strategic Priorities for Skills Development. Addressing the skills challenge in hybrid energy storage requires a coordinated focus on several priority areas. First, academic curricula must integrate HES-related content into engineering, IT, and energy policy programmes to reflect current market demands. Simultaneously, vocational excellence should be reinforced through apprenticeships and technical training for system-level installation, operation, and maintenance. Digital learning platforms, including online modules, virtual simulations, and AR/VR tools, must be expanded to reach learners across different regions. These efforts will benefit from strong industry-academia collaboration, ensuring that course design, internships, and applied research projects align with real-world challenges. Finally, ensuring diversity and inclusion must be a cross-cutting priority, creating opportunities for underrepresented groups to access and thrive in the HES workforce.

Recommendations for Workforce Development. To accelerate HES workforce readiness, a number of strategic actions are recommended.

- The EU should support the development of certification frameworks to ensure standardised skills recognition across member states, especially for technicians and engineers working on multi-technology systems.
- Establishing Centres of Vocational Excellence with a focus on hybrid and multi-vector integration would enable hands-on learning in close collaboration with industry.
- Building joint high-technological centres in collaboration with strategic industrial partners across the renewable energy sector, the broader

¹⁰ <https://www.storiesproject.eu/training-education>

¹¹ <https://skillbill-project.eu/>

¹² <https://fiap-ev.org/en/greenvocnet/>

¹³ <https://innoenergy.com/skillsinstitute/community-programmes/european-battery-academy/>

transport domain – including road, heavy-duty, maritime, rail, and aviation – as well as the stationary energy sector.

- Dual-degree and interdisciplinary programmes should be promoted to merge energy science with data analytics, policy, and business, reflecting the systemic nature of HES deployment.
- At the research level, targeted funding through MSCA, Horizon Europe, and European University Networks (EUN)¹⁴ should support structured PhD networks and postdoctoral training across HES topics.
- Finally, dedicated public awareness campaigns are needed to improve the visibility and attractiveness of careers in energy storage, especially for younger generations and non-traditional learners.

The future competitiveness and scalability of hybrid energy storage technologies depend on the availability of skilled professionals. As outlined later in **Section 4. Strategic Research Areas**, the establishment of a dedicated Coordination and Support Action (CSA) will be crucial to align education, research, and industrial strategies, ensuring that workforce readiness is embedded into Europe's energy storage innovation ecosystem.

¹⁴ <https://education.ec.europa.eu/european-universities-factsheets/>

3. Mission & Objectives

The mission of this Strategic Research and Innovation Agenda (SRIA) is to position **Hybrid Energy Storage Systems (HESSs)** as a **strategic pillar of Europe's clean energy transition**, accelerating the deployment of scalable, interoperable, and sustainable storage solutions across all sectors of the energy system. HESS will enable Europe to bridge temporal and sectoral energy needs, unlocking the full potential of renewable energy sources and supporting a flexible, resilient, and integrated energy infrastructure.

At a time of climate urgency, increasing electrification, and energy system decentralisation, hybrid energy storage offers a transformative approach to address the growing complexity of energy supply and demand. By combining the unique strengths of different storage technologies (electrochemical, thermal, chemical, mechanical) HESSs can provide tailored, cost-effective, and high-performance solutions that no single technology alone can achieve.

This SRIA aims to develop **technological, regulatory, and economic conditions** that will allow HESSs to move from niche applications to mainstream deployment, contributing to Europe's goals of climate neutrality, energy sovereignty, industrial competitiveness, and strategic autonomy.

We envision a **net-zero Europe** powered by intelligent, hybridised energy systems where **storage is not a constraint but a competitive advantage**. In this future, hybrid energy storage is seamlessly integrated at every level of the energy system—from industrial sites and renewable energy hubs to decentralised energy communities and cross-border grid operations.

Hybrid systems will deliver **multi-service flexibility**, support the **electrification of transport**, enable **decarbonised heat** in industry, and secure **energy supply in remote or critical environments**. Grounded in circular economy principles, digital innovation, and material resilience, Europe will lead the global value chain in the design, manufacturing, deployment, and lifecycle management of HESS technologies.

This SRIA sets out the pathway to realise this vision by articulating clear research, innovation, and deployment priorities that respond to Europe's evolving energy needs.

Objectives

To fulfil its mission and in alignment with the strategic EU objectives introduced in this agenda, the SRIA on HESS is guided by the following core objectives:

1. **Deliver flexibility and resilience through hybrid storage integration.** Accelerate the deployment of hybrid systems that enable dispatchable, stable, and sector-bridging energy services across different timeframes and use cases.
2. **Accelerate TRL progression and innovation uptake.** Bridge gaps between low and high TRLs, ensuring material and system innovations can be validated and demonstrated in practical hybrid configurations.
3. **Establish a harmonised framework for integration and interoperability.** Contribute to the development of European standards, regulatory guidelines, and interface protocols that support safe, interoperable, and efficient hybrid systems.
4. **Integrate hybrid storage within sector coupling and decarbonisation pathways.** Position HESS as an enabler for cross-vector energy use, contributing to industrial decarbonisation, transport electrification, and energy system flexibility.
5. **Advance skills, education, and workforce transformation.** Ensure that the European workforce is equipped with the skills and knowledge necessary to design, operate, and maintain hybrid systems, through dedicated education, training, and reskilling programmes.
6. **Strengthen Europe's innovation capacity and strategic autonomy.** Align policy, funding, and industrial ecosystems to support a competitive European HESS value chain and secure leadership in the global energy storage landscape. Foster synergies between Horizon Europe, the SET-Plan, national programmes, and public-private partnerships to ensure coordinated investment and policy support for HESS R&I and deployment.

Through these objectives, the SRIA provides a unified and forward-looking framework to guide research, policy, and investment actions across Europe, ensuring hybrid energy storage plays a decisive role in meeting Europe's climate, energy, and industrial ambitions.

3.1 Review of R&I activities

To ensure that the proposed SRIA for Hybrid Energy Storage is built on a comprehensive and evidence-based foundation, a review of **past and current Research and Innovation (R&I) activities** has been undertaken. This review covers initiatives funded at both the **European and national levels**, including EU Framework Programmes, Joint Undertakings, Public-Private Partnerships, and nationally funded projects.

The analysis provides a clear snapshot of **ongoing research trends across Europe**, identifying key players, dominant technologies, and emerging hybridisation concepts. Critically, it also offers insight into the **Technology Readiness Levels (TRLs)** associated with specific HESS configurations and components, enabling a more targeted understanding of where the EU stands in terms of innovation maturity.

This mapping exercise has been essential in identifying not only **existing strengths and gaps**, but also in framing a forward-looking strategy that responds to the challenges and opportunities outlined by the six EU objectives presented at the beginning of this document.

Horizon 2020 Projects

(EU research & innovation programme running 2014–2020)

H2020-LC-GD-2020

LC-GD-9-1-2020 – European Research Infrastructures capacities and services to address European Green Deal challenges



Research / Industry	StoRIES	Access to 64 pan-European labs across 5 storage tech domains; infrastructure support for hybrid system R&D	2021-2025
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H2020-JTI-FCH-2017-1

FCH-02-12-2017 – Demonstration of fuel cell-based energy storage solutions for isolated micro-grid or off-grid remote areas



Stationary / Off-grid	REMOTE	Remote area Energy supply with Multiple Options for integrated hydrogen-based TEchnologies	2018-2023
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H2020-LC-BAT-2019-2020

LC-BAT-9-2020: Hybridisation of battery systems for stationary energy storage



Grid & Offgrid	HYBRIS	LTO + aqueous redox flow battery, EMS, digital twin	2021-2024
Grid	iSTORMY	1st- & 2nd-life Li-ion, SiC converters, smart hybrid EMS	2020-2024
Grid (municipal/industrial)	HyFlow	VRFB + supercapacitor, hybrid converter	2020-2024
Transport – EV Charging	HEROES	Li-ion + Li-capacitors, wide-voltage DC/DC, EMS	2021-2024

H2020-LC-BAT-2020

LC-BAT-10-2020: Next generation and realisation of battery packs for BEV and PHEV



Transport – Automotive	HELIOS	LFP + NMC hybrid packs, modular, AI BMS, PCM cooling	2021-2025
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H2020-LC-BAT-2020

LC-BAT-11-2020: Reducing the cost of large batteries for waterborne transport



Transport – Waterborne	SEABAT	Modular HE + HP Li-ion, marine BESS, DC/DC	2021-2025
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Horizon Europe Projects

(Current EU R&I Framework Programme, 2021–2027)

HORIZON-EIC-2021-PATHFINDERCHALLENGES-01-01

Novel routes to green hydrogen production



Grid, Industry	DualFlow	Redox flow + H ₂ electrolysis & chemical synthesis	2022-2026
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HORIZON-CL5-2022-D3-01-10

Interoperable solutions for flexibility services using distributed energy storage



Buildings, Energy Communities	PARMENIDES	Ontology-based plug-and-play EMS	2023-2025
Grid, Industry, Buildings	INTERSTORE	Middleware, virtualisation, open-source EMS	2023-2025

HORIZON-CL5-2022-D3-01-11

Demonstration of innovative forms of storage and their successful operation and integration into innovative energy systems and grid architectures



Grid, District Heating	2LIPP	Li-ion + salt + flywheel hybrid, EMS	2023-2026
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HORIZON-CL5-2022-D3-01-14

Thermal energy storage solutions



Stationary, Buildings	HYSTORE	Hybrid Services from Advanced Thermal Energy Storage Systems	2023-2026
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HORIZON-CL5-2022-D5-01-01

Exploiting electrical energy storage systems and better optimising large battery electric power within fully battery electric and hybrid ships (ZEWT Partnership)



Transport – Waterborne	NEMOSHIP	Hybrid Li-ion (HP + HE), modular BMS, digital twin	2023-2026
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HORIZON-CL5-2022-D5-01-02

Innovative energy storage systems on-board vessels (ZEWT Partnership)



Transport – Waterborne	AENEAS	Solid-state + supercaps, hybrid marine storage	2023-2026
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HORIZON-CL5-2023-D2-01-05

Hybrid electric energy storage solutions for grid support and charging infrastructure (Batt4EU Partnership)



Grid & Offgrid	SMHYLES	Supercapacitors + salt batteries + redox flow; modular hybrid design	2024-2027
Grid, EV Charging	HAVEN	HESS: high-energy and high-power modules, cognitive converters, digital twin	2024-2027

LIFE Programme Projects

EU funding instrument for climate action and environment

LIFE20 CCM/GR/001642

LIFE Programme



Offgrid	CO₂toCH₄	Water electrolysis + methanation (CH ₄), mobile unit	2021-2025
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Nationally Funded Projects

(Funded by national ministries, innovation agencies, or research councils)

FFG Vorzeigeregion Energie

Austria's Showcase Region Energy R&D Programme



Grid & Off-grid	SEKOHS Theiß	Sector-coupling hybrid system: BESS + thermal long-duration storage + AI/ML	2021-2024
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Denmark – Innovation Fund

Grand Solutions



Grid	HYBRIDize	Designing and operating large-scale, grid-connected hybrid power plants	2019-2022
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Germany – BMWK / BMDV

National hybrid storage and mobility innovation calls



Transport & Industry	SuKoBa	Hybrid Li-ion battery + supercapacitor toolbox & modelling	2021-2023
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Grid	HYBAT	1500 V Li-ion system with advanced thermal management	2020-2022
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Transport – EV Charging	OMEI	2nd-life EV batteries + redox flow in V2G/V2H context	2022-2025
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Buildings – Residential	BiFlow	Hybrid VRFB + Li-ion system with heat integration	2020-2024
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Spain – National R&D

Integration of Renewable Energy and Storage in the Grid



Grid	ALMAGRID	Lab-scale battery + supercapacitor hybrid integration testbed	2020-2023
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United Kingdom – UKRI

UK Industrial Strategy Challenge Fund



Transport Automotive	– HBO	Li-ion + supercapacitor, cell-to-vehicle holistic modelling	2019-2021
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3.2 United for Innovation: ETIPs, Industry Associations, and Research Alliances Driving Europe's Clean Energy Future

The advancement and large-scale deployment of HESSs is not only a matter of technological development: it requires robust collaboration across research, industry, and policy ecosystems. Within this landscape, the European Union's Public-Private Partnerships (PPPs), Joint Undertakings (JUs), and European Technology and Innovation Platforms (ETIPs) play a crucial role in aligning strategic agendas, fostering innovation, and supporting cross-sectoral synergies. Industry associations and research alliances further contribute by providing critical sectoral expertise and helping to align innovation efforts with both industrial needs and scientific priorities.

This work has been developed in close collaboration with the **European Association for Storage of Energy (EASE)**, whose endorsement underscores the critical importance of HESS integration from both **regulatory and standardisation perspectives**. EASE's active involvement highlights the need for harmonised regulatory frameworks and common technical standards to support the interoperability and scalability of hybrid systems across Member States. In parallel, the **European Energy Research Alliance (EERA)** has been a key strategic partner in shaping this research and innovation agenda. In particular, the work has been supported by the **EERA Joint Programme on Energy Storage**, leveraging the expertise of its full network of **Sub-Programmes (SPs)**. This includes:

- Sub-programme 1: Electrochemical ES (EES)
- Sub-programme 2: Chemical ES (CES)
- Sub-programme 3: Thermal ES (TES)
- Sub-programme 4: Mechanical ES (MES)
- Sub-programme 5: Superconducting Magnetic ES (SMES)
- Sub-programme 6: Energy Storage: Techno-economics and Sustainability (ES-TES)

each contributing domain-specific insights to ensure that hybridisation pathways reflect a systems-level approach and address the full spectrum of energy vectors and applications.

One of the cornerstone contributions to the hybrid energy storage agenda has come through the **Task Force on Hybridisation** under **Batteries Europe**, in

cooperation with **BEPA (Batteries European Partnership Association)**. Experts from the **StoRIES project** have actively contributed to the preparation of the foundational **Position Paper on Hybridisation**¹⁵. This paper consolidates knowledge and best practices from multiple domains, providing both a conceptual and practical framework for hybridisation strategies that can meet future energy system needs.

This collaborative structure has created a strong foundation for policy alignment, industrial guidance, and research-driven innovation. It also reflects the growing consensus among stakeholders that **integrated, multi-technology storage solutions** are essential to achieving the EU's climate, energy, and industrial policy objectives. By building on the collective knowledge and strategic coordination provided by these networks, the deployment of HESS can be accelerated, made more efficient, and grounded in a shared European vision.

Finally, the Strategic Research Areas presented in the next section have been reviewed, enriched with constructive input, and endorsed by the following European Technology and Innovation Platforms (ETIPs), Industry associations, and Research Alliances:

- **Batteries Europe**
- **EASE** - European Association for Storage of Energy
- **EERA JP ES** – Joint Programme on Energy Storage
- **EERA JP CSP** – Joint Programme on Concentrated Solar Power
- **EERA JP ESI** – Joint Programme on Energy Systems Integration
- **EERA JP Smart Grids**
- **ESTELA** – European Solar Thermal Electricity Association
- **Hydrogen Europe Research**
- **RHC-ETIP** – Renewable Heating and Cooling

¹⁵ https://batterieseurope.eu/wp-content/uploads/2024/06/Task-Force-Hybridisation_062024.pdf

4. Strategic Research Areas

The identification of Strategic Research Areas (SRAs) in this agenda is the outcome of extensive collaboration between experts from StoRIES, the EERA Joint Programme on Energy Storage, and the European Association for Storage of Energy (EASE). It also draws on a targeted review of relevant activities from Public-Private Partnerships (PPPs), Joint Undertakings (JUs), and European Technology and Innovation Platforms (ETIPs).

As a result of the R&I landscape review and the extensive collaborations, **four Strategic Research Areas** have been defined. These areas are intended to structure and guide R&I efforts in a way that addresses the identified gaps and accelerates the development and deployment of hybrid energy storage solutions in the **short, medium, and long term**.

In the sections that follow, each Strategic Research Area is presented along with:

- A detailed **list of R&I needs** across different TRL stages, from fundamental research (TRL 1–4), to pilot-scale demonstration (TRL 5–6), to pre-commercial and industrial-scale solutions (TRL 7–9).
- A set of **policy and technical recommendations**, presented in Section 5, aimed at supporting stakeholders, policymakers, and funding bodies guide investments and implementation strategies in line with overarching EU objectives.

SRA 1. System Resiliency and Long Duration Storage Solutions

The growing complexity of modern energy systems requires robust, flexible, and cost-effective energy storage solutions capable of balancing supply and demand across multiple time scales and operating conditions. As renewable energy penetration increases, energy storage becomes critical for mitigating supply-demand imbalances, supporting grid services, and ensuring energy autonomy in both interconnected (grid-dependent) and remote (grid-independent) systems.

In the context of **system resiliency**—defined as the ability of the energy system to withstand, adapt to, and recover from disruptions, such as extreme weather events or grid disturbances, a combination of storage technologies with different discharge durations (short-, medium-, and long-duration) and energy retention is essential. These can be hybridised within system architectures to enhance flexibility, redundancy, and stability. While short-duration storage plays a role in absorbing fast fluctuations, hybrid configurations involving longer-duration and seasonal storage options are increasingly needed to ensure dispatchability and backup across hours, days, or even months. For example, TES – by integrating coupling points such as heat pumps – supports smart, cost-effective off-peak electricity use, helping to reduce electricity peaks and enable seasonal balancing. These hybridisation challenges and integration needs are addressed particularly in this SRIA at **higher TRL levels (TRL 5–9)**.

At the same time, **technical challenges at lower TRLs (TRL 1–4)** remain for the development of individual long-duration and long-term storage technologies. Although these are not hybrid systems per se, they affect the maturity and performance of the underlying technologies (particularly at the material, component, and cell levels) and therefore directly influence the feasibility of future hybrid configurations.

Energy storage technologies in this Strategic Research Area are broadly classified into **Long-Duration Energy Storage (LDES)** and **Long-Term Energy Storage (LTES)**, based on their discharge duration and energy retention characteristics. While this classification is useful for structuring research and innovation (R&I) efforts, it is important to note that definitions and thresholds can vary depending on the specific storage technology, be it electrochemical (EES), chemical (CES), thermal (TES), or mechanical (MES).

LDES refers to storage systems that can discharge energy continuously at their **rated power** for an extended period, **typically ranging from several hours to multiple days**. These technologies are essential for grid balancing, renewable

energy integration, and maintaining power system stability during periods of low generation or grid disturbances. Electrochemical systems such as flow batteries, sodium molten salt batteries, and certain types of anode-less batteries (e.g., lithium or sodium metal-based), chemical solutions like power-to-X (P2X), mechanical storage (e.g. pumped hydro, compressed air), and thermal energy storage systems that convert heat into electricity are commonly used in this category. Large-scale underground hydrogen storage – in depleted gas reservoirs, salt caverns, or artificial caverns – is emerging as a promising solution for seasonal energy storage. Ongoing pilot and demonstration projects across Europe are validating its technical feasibility and strategic value for energy system resiliency. However, what qualifies as “long-duration” may vary depending on the technology class, its efficiency, and application context.

LTES, on the other hand, focuses on **retaining stored energy efficiently over long periods—weeks, months, or even entire seasons—before discharge**. Unlike LDES, which emphasizes power output over time, LTES prioritizes energy retention with minimal self-discharge. This category includes high-capacity thermal storage using solid or molten materials, UTES (Underground Thermal Energy Storage) technologies like Borehole Thermal Energy Storage (BTES), Aquifer Thermal Energy Storage (ATES), and Cave Thermal Energy Storage (CTES). In parallel, chemical energy carriers, such as hydrogen and synthetic fuel, in addition to other CES solutions offer capabilities of long-term storage and delayed conversion. These systems are particularly relevant for seasonal balancing, industrial heat applications, or energy security in isolated or weather-variable environments.

This classification enables a clearer mapping of R&I needs across the storage landscape. While challenges related to LDES and LTES technologies often emerge at low TRL levels (1–4)—especially regarding materials, components, and design—their integration into **HESSs** becomes critical at higher TRLs (5+), where combinations of short-, medium-, and long-duration technologies are developed to deliver greater system resiliency, flexibility, and cost-effectiveness.

Strategic Research Area 1 is dedicated to enhancing the resiliency of modern energy infrastructures by advancing R&I activities in LDES and LTES, and supporting their integration with complementary technologies within hybrid energy storage systems.

Key Research and Innovation Needs

TRL 1 – 4: Fundamental research on emerging energy storage technologies.

Focus: Core scientific and technological challenges primarily at the material and component level. R&D activities in this phase are not yet focusing on hybrid systems, but rather on the individual challenges across different storage types (electrochemical, thermal, mechanical, chemical).

- **Development of high-efficiency, long-cycle-life materials for LDES and LTES**, emphasizing low-cost, sustainable, recyclable and scalable solutions, including alternatives to critical raw materials (CRM-free chemistries) and to raw materials that are scarce globally or not produced in Europe.
- **Laboratory-scale validation** & demonstration at TRL 4 of novel materials for EES, CES, TES, MES technologies tailored to long-duration discharge and seasonal retention. Lab-scale experiments exploring LDES–LTES hybridization for off-grid use cases, assessing potential synergies and preliminary control strategies.
- Key material-level challenges for LDES and LTES, categorized by storage type:
 - **EES**: Degradation under high cycling, thermal instability, and high material costs in Li-ion and flow batteries; need for scalable, CRM-free alternatives for long-duration discharge; reduction of operating temperature in molten salt batteries.
 - **CES**: Efficiency losses in hydrogen fuel cells and electrolysis systems, safety concerns (e.g., high-pressure H₂), development of low-loading platinum group metals (PGMs) and PGM-free electrocatalysts, and challenges in solid hydrogen storage technologies. In addition to hydrogen-based routes (e.g., P2H2X), alternative chemical carriers such as liquid organic hydrogen carriers (LOHCs), reactive metals, ammonia, or other direct chemical storage pathways. Materials for safe, efficient, and reversible storage remain a core R&I focus.
 - **TES**: Lack of durable phase change materials for high-temperature (>150°C) applications; materials must withstand thermal cycling with high energy density.
 - **MES**: Exploration of advanced CAES and next-gen pumped hydro as scalable long-duration options; focus on materials, seals, thermal integration, and closed-loop configurations.

TRL 5 – 6: Integration and hybridization of existing storage technologies.

Focus: HESS design, control, and demonstration using mature or advancing technologies. Research at this level targets the hybridization challenges across LDES and LTES systems, ensuring efficient, flexible, and cost-effective integration.

- **Development of integrated HESS architectures** with optimal sizing, energy/power balancing, and hybrid-compatible power electronics (e.g., bidirectional converters, high-efficiency rectifiers/inverters, thermal and chemical storage interfaces).
- **Evaluation of integration strategies for underground storage systems** (e.g. hydrogen in salt caverns or depleted gas reservoirs) within hybrid HESS architecture, addressing coupling interfaces, pressure management, and system controls for long-duration and seasonal storage.
- **Optimization of hybrid control strategies**, including thermal and energy management, degradation-aware operation, and integration with Energy Management Systems (EMS, addressed further in Strategic Area 3) to enhance system flexibility, lifecycle performance, and reduce self-discharge in long-term thermal storage applications.
- **Development of modular power electronics** tailored for HESS, including high-efficiency inverters and rectifiers for interfacing electrochemical, thermal, and chemical storage subsystems.
- **Hybridisation of short- to medium-duration energy storage technologies** (such as batteries or flywheels) with large-scale **LDES solutions** (e.g. pumped hydro and CAES) as well as **LTES options** including **chemical carriers (P2X)** and **thermal energy systems (e.g. UTES)** for seasonal or industrial applications — enabling comprehensive energy system flexibility across multiple timescales.
- **Design of modular, interoperable components and interfaces** to enable seamless hybridisation of multiple technologies in grid-connected, off-grid contexts, and microgrid, including safety, monitoring, and fault detection systems.
- **Assessment of operational logic for HESS**, including dispatch strategies that coordinate short-duration (e.g., batteries) and long-duration (e.g., TES, P2X, CAES) components under variable loads and renewable intermittency.
- **Integration of safety mechanisms**, monitoring, and fault detection systems adapted to hybrid architectures, particularly where large scale thermal or chemical components are involved.
- **Expansion of working temperature ranges** for thermal storage media (e.g., molten salts) to improve thermal-electric conversion efficiency in hybrid systems, while addressing material compatibility, corrosion, and cost, enabling more efficient coupling with high-efficiency power cycles.

TRL 7 – 8: Deployment and market integration of HESS solutions

Focus: Demonstration, scale-up, and validation of HESSs in real environments. Emphasis is on deployment of flexible, modular hybrid energy storage solutions for grid resilience, residential and industrial needs, and seasonal balancing.

- **Repurposing and retrofitting of existing storage infrastructure** to support hybrid operation and ensure interoperability between different energy storage technologies and use cases.
- **Design and deployment of solutions for new and retrofitted buildings**, which are modular, easy to install or integrated in heating/cooling system and DHW (District Hot Water) equipment.
- **Design and deployment of modular, scalable hybrid LDES–LTES systems** in microgrids, islanded grids, and remote or underserved regions to enhance energy autonomy, system stability, and reliability during peak demand or low renewable output periods.
- **Demonstration of large-scale underground chemical energy storage solutions in hybrid configurations** for seasonal balancing, including validation of operational safety, geological compatibility, and system responsiveness under real-world demand fluctuations.
- **Validation of hybrid HESS performance under real operating conditions**, demonstrating resilience to disturbances, improved energy management, and measurable system-level benefits such as curtailment reduction, grid balancing, and demand-side flexibility.
- **Implementation of safety, reliability, and resilience strategies for HESS**, particularly those integrating thermal and chemical storage technologies (e.g., molten salts, hydrogen, ammonia, LOHC, Reactive metals). Key challenges include managing high-temperature operation, thermal cycling, pressure containment, and risks related to leakage, fire, or explosion. Specific issues, such as structural failures observed in large molten salt thermal storage tanks due to thermal stress and limited operational experience at scale, highlight the need for advanced materials, monitoring, and design standards. Future R&I should address these aspects to ensure the safe, robust deployment of large-scale HESS across industrial, grid, and remote applications.

SRA 2. System integration of multi-vector energy storage and conversion

As energy systems evolve to meet the demands of decarbonization, electrification, and resilience, they are increasingly characterized by the interaction of multiple energy carriers – electricity, heat, cooling, fuels, hydrogen, and chemical products – operating across sectors and time scales. In this context, **Multi-Vector Energy Storage and Conversion** systems are emerging, in light of future energy infrastructures, with the goal of combining different technologies within a unified, flexible architecture. This Strategic Research Area addresses the system integration challenges that arise from managing these multiple forms of energy within a unified system. This area explores the coordination and optimization of different energy carriers, such as electricity, heat, and gas, to maximize efficiency and reliability across the energy network.

System integration research focuses on developing the **hardware interfaces, control systems, co-optimization strategies, and architectural design principles** necessary for hybrid storage systems that span energy carriers and sectors. Applications include power-to-heat and power-to-hydrogen systems, co-generation in industry, hybrid energy hubs in urban environments, autonomous off-grid microgrids, and complex transport platforms.

One of the most critical and complex aspects of this integration is **sector coupling**, the ability to interconnect energy systems across sectors such as electricity, heating and cooling, transport, and industry. This enables different energy carriers (electricity, heat, fuels, and chemicals) to interact efficiently, allowing for system-wide flexibility, optimized energy use, and decarbonization. For example, TES helps manage temporal imbalances in sector-coupled systems. These integrations often face mismatched time constants, physical formats, conversion losses, and system-level inertia. Realizing efficient hybrid systems demands **TRL 5–8 innovations** in cross-vector interfacing, real-world demonstration, and integration into existing infrastructures.

A closely related concept is **service stacking**, which refers to the capability of HESSs to provide **multiple services simultaneously or sequentially** across different markets or use cases. Multi-vector systems can deliver grid services (e.g., frequency regulation, peak shaving), supply industrial or urban heat, cooling, or hydrogen, charge electric vehicles, and even support black start or backup power—all from the same infrastructure. Embedding service stacking into the design of HESSs is essential for **maximizing asset utilization**, increasing return on investment, improving sustainability and enabling economic participation in **electricity markets, flexibility platforms, and local energy communities**. In **smart grid and distributed energy systems**, service stacking allows hybrid

nodes to switch roles dynamically acting as consumers, producers, storage units, or flexibility providers depending on real-time conditions. Unlocking these capabilities requires integrated control architectures, compatible market frameworks, and digital platforms capable of multi-service coordination and verification.

Transport systems, particularly aviation, maritime, and heavy-duty logistics, are strategic application areas for multi-vector energy integration. Hybrid systems that combine energy storage and energy conversion technologies enable transport platforms to switch between energy vectors such as electricity, hydrogen, ammonia, and sustainable fuels depending on operational needs and mission profiles. Importantly, **charging stations and port infrastructures** are evolving into multi-energy hubs where electricity, thermal energy, and alternative fuels converge. These hubs can support smart charging, vehicle-to-grid services, on-site hydrogen production, or shore power for ships, turning them into critical enablers of sector coupling between **mobility, power, and industry**.

Industry applications are also a key driver for system integration of multi-vector energy storage and conversion. Industrial processes often require simultaneous or sequential use of electricity, heat, and fuels, making them ideal candidates for hybrid energy systems. Multi-vector enables industries to integrate on-site renewables, shift between energy carriers based on cost or availability, recover and store waste heat, and enhance operational resilience. Moreover, the repurposing of legacy fossil-fuel infrastructure (e.g., turbines, heat exchangers, grid interconnections) into hybrid energy hubs presents a valuable opportunity to extend asset lifetimes and accelerate decarbonization. By embedding hybrid storage and conversion technologies into industrial clusters, this research area supports energy efficiency, emissions reduction, and economic revitalization of existing sites.

Key Research and Innovation Needs

Focus: Research and innovation in this area target **high-TRL system-level innovation (TRL 5–8)**, with a strong emphasis on **real-world integration, pilot demonstration, optimisation, and deployment**. The goal is to enable **interaction across multiple energy carriers** (electricity, heat, fuels) within **hybrid storage and conversion systems**, supporting **decarbonisation, energy flexibility, and interoperability with existing infrastructures**. This strategic area moves beyond early-stage material development to address the complexities of **multi-vector energy integration** at scale.

TRL 5 – 6: System Integration and Multi-Vector Control

Focus: Research and development activities at this stage focus on system-level integration and enabling technologies, including control frameworks, interfaces, and digital tools, that are essential for building scalable hybrid architectures and preparing them for deployment.

- **Design and demonstrate modular hybrid energy nodes capable of delivering multi-MW output across electricity, heat, and hydrogen**, enabling deployment in industrial clusters (e.g. high temperature thermal energy storage up to 1000°C or UTES for thermal-electric integration), energy districts, and transport-linked energy hubs. Systems should be scalable and interoperable with existing infrastructure.
- **Develop advanced control and dispatch frameworks enabling real-time energy flow optimization between two or three energy vectors**, with dynamic response to grid signals, operational conditions, and cost-efficiency constraints.
- **Innovate high-efficiency interface and power electronics for bidirectional, multi-vector conversion**, including electro-thermal interfaces, hybrid loop controllers, and hydrogen-electric switchboards with >95% conversion efficiency targets.
- **Deploy digital integration tools such as predictive EMS, digital twins, and AI-based optimizers**, enabling 24/7 monitoring, fault anticipation, and at least 20% increase in system utilization under real-world operational conditions.
- **Implement secure and interoperable communication protocols** between distributed EMS, end-user devices, and higher-level control entities (e.g., Aggregators or Distribution System Operators), to enable participation in grid flexibility services. This includes installing appropriate interface devices at end-user premises to ensure bi-directional communication, coordination, and real-time response capabilities necessary for system-wide optimization and flexibility activation.

TRL 7 – 8: Sector Coupling and Transport Applications

Focus: High-TRL demonstration of hybrid energy systems in transport-related environments, with a focus on integrating multiple energy vectors to enable fast refueling, multi-service operation, and grid-connected infrastructure.

- **Demonstrate multi-vector hybrid energy hubs at ports, airports, and logistics terminals, delivering ≥ 1 MW simultaneous capacity across electricity, hydrogen, and thermal loads**, while integrating services such as smart charging, V2G, and on-site fuel production.
- **Integrate HESS into maritime, aviation, rail, and heavy-duty mobility applications prioritizing fast refueling capabilities**, multi-fuel flexibility (e.g.,

electricity, hydrogen, e-fuels), and compatibility with onboard storage, propulsion systems, and operational requirements.

- **Demonstrate service stacking in HESS by delivering at least three concurrent services** (e.g. grid flexibility, propulsion energy, process heat, EV charging, or hydrogen refueling) from a single platform, enhancing asset utilization, infrastructure efficiency, and return on investment in transport, industrial, and energy district contexts.

TRL 7 – 8: Industrial Integration, Resilience, and Economic Performance

Focus: Large-scale pilot and near-market deployment of hybrid energy systems in hard-to-abate industrial sectors, focusing on decarbonisation, system longevity, and economic viability.

- **Deploy HESS in industrial sectors to replace $\geq 30\%$ of fossil fuel input with renewables and recovered heat**, ensuring continuous process compatibility and integration with existing infrastructure (e.g., turbines, heat exchangers).
- **Integrate hybrid multi-vector energy systems into hard-to-abate industrial sectors** (such as steel, chemicals, and cement) where simultaneous use of electricity, heat, and fuels is required. Solutions should enable deep decarbonisation through on-site renewables, waste heat recovery, load flexibility, and compatibility with existing thermal and fuel-based infrastructure.
- **Implement robust safety and reliability strategies for high-temperature and high-pressure hybrid configurations**, minimizing risk of failure and ensuring compliance with operational standards across hydrogen, molten salt, and multi-energy interfaces.
- **Optimize hybrid system lifespan by distributing operational loads across complementary technologies**, reducing degradation rates and extending component life by at least 20% through intelligent cycling and control strategies.
- **Develop techno-economic models and service-based business cases**, demonstrating positive return on investment (ROI) within typical industrial investment cycles and quantifying value from stacked services, deferred upgrades, and improved energy resilience.

SRA 3. Digitalisation and Energy Management Systems

As hybrid energy systems become more complex, digitalization and intelligent energy management systems (EMS) are critical to optimizing energy distribution, improving operational efficiency, and ensuring system resilience. The transition toward decentralized, renewable-based energy systems necessitates real-time control, predictive analytics advancements to enhance system performance across grid, off-grid, and microgrid environments.

This Strategic Research Area focuses on integrating advanced computational methods, big data analytics, artificial intelligence, and machine learning (ML) into EMS to dynamically coordinate energy resources, optimize storage dispatch, and enhance demand response capabilities. Research needs, at a higher TRL level (system integration and pilot scale deployment of the HESS), also include cybersecurity challenges in ensuring protection against potential cyber threats and enhancing system resilience.

Key Research and Innovation Needs

TRL 1 – 4: Fundamental Research on EMS Algorithms and Software

Focus: Prototyping and early-stage development of foundational software architectures, algorithms, and data frameworks to enable high-performance EMS for hybrid systems in future TRL 5–9 applications.

- **Develop modular, open-source digital twin architectures for HESS**, enabling predictive modelling, virtual testing, and adaptive control logic for future multi-vector system integration.
- **Design self-learning EMS algorithms with embedded AI/ML functionality**, capable of evolving with system performance data and adapting to new operating scenarios.
- **Establish EU-wide interoperability standards and data ontologies** for hybrid energy storage and conversion systems, ensuring long-term compatibility, collaboration, and digital infrastructure reusability. Coordinate with previously funded EU projects (e.g., BIG-MAP, PARMENIDES) to align digital infrastructure development across materials, devices, and system levels.

TRL 5–6: Advanced Sensor-Based EMS, Integration, and Testing for Hybrid Systems

Focus: Research at this level targets the integration of intelligent sensing, secure communication, and real-time analytics into hybrid EMS platforms. Emphasis is placed on developing interoperable, adaptable systems that enable accurate monitoring and dynamic control across diverse hybrid technologies.

- **Develop and implement next-generation sensor technologies**—including wireless, low-power, and high-precision sensors—for real-time state-of-charge monitoring, power flow analysis, and thermal load balancing in hybrid systems, supporting $\geq 95\%$ data accuracy and sub-second reporting rates.
- **Establish interoperability standards and secure communication protocols** for seamless data exchange between inverters, sensors, and distributed EMS components. These should ensure plug-and-play compatibility across platforms and enable the repurposing of existing storage infrastructure.
- **Deploy real-time grid-edge intelligence and autonomous decision-making algorithms** to dynamically adjust energy dispatch based on weather conditions, grid congestion, and market fluctuations, targeting a reduction of curtailment or imbalance events by $\geq 40\%$ in hybrid storage environments.

TRL 7–9: Deployment and Field Demonstrations

Focus: Activities at this level emphasize full deployment, real-world testing, and validation of intelligent EMS platforms managing complex hybrid storage and conversion systems. These efforts must demonstrate system-wide optimization, demand-side integration, and robust cybersecurity at operational scale.

- **Conduct field validation and pilot-scale deployment of fully integrated EMS platforms for large-scale hybrid energy storage applications**, such as renewable hubs, industrial parks, or islanded microgrids. Implement AI-based demand-side management strategies that incorporate consumer behaviour and dynamic pricing to improve overall system efficiency.
- **Deploy cyber-secure, cloud-based EMS platforms for multi-vector energy coordination**, enabling remote monitoring, predictive analytics integration, and real-time system control. While HESS may not introduce fundamentally new cyber risks, the combination of multiple sub-components, often from different vendors, significantly increases the attack surface, raises concerns around interoperability with legacy equipment, and may involve third-party components without fully verified supply chains. Solutions should ensure secure data exchange and $\geq 99\%$ system uptime under standard operation.
- **Demonstrate integration of EMS-enabled hybrid systems into grid flexibility markets**, including provision of ancillary services and participation in capacity or local energy markets. Target automated service stacking and $\geq 30\%$ improvement in revenue potential through hybrid-enabled flexibility.

SRA 4. Establishing a European Hybrid Energy Storage Ecosystem: advancing regulation, standardisation, strategic research, and skills excellence

Strategic Research Area 4 highlights the urgent need to establish a dedicated **Coordination and Support Action (CSA)** on Hybrid Energy Storage that brings together key actors across research, policy, education, and industry. This strategic area aims to lay the foundation for a comprehensive and coherent European HES ecosystem through the development of unified regulatory frameworks, standards, interoperability protocols, and human capital initiatives. It focuses on aligning fragmented efforts across Member States, promoting technology-neutral regulation, and addressing critical barriers to large-scale HESS deployment.

By aligning regulation, standardisation, digitalisation, education, and industrial market uptake, SRA 4 contributes to the creation of an integrated and innovation-friendly landscape where hybrid systems can thrive. This is essential for accelerating decarbonisation, grid resilience, and EU competitiveness in the global energy storage market.

Standardisation and Regulatory Development. This area is crucial as it addresses the need for cohesive regulatory policies that can accommodate the rapid advancement and integration of new technologies such as renewable energy sources, digital energy management systems, and multi-vector storage solutions. The goal is to create and refine standards that not only foster innovation but also ensure that new technologies can easily and safely integrate into the existing infrastructure. By establishing robust standards, this area aims to mitigate risks associated with the deployment of new technologies, facilitate wider adoption, and ultimately contribute to a more sustainable and secure energy future. Key aspects include aligning international standards, ensuring compliance with environmental regulations, and promoting consistency in technological implementations across borders, all of which are essential for accelerating the global transition to a more integrated and resilient energy landscape. Standardization ensures that different components of the energy sector, including grid infrastructure and digital energy systems, are compatible and able to operate steadily

Focus:

- Define technical and operational standards for HESS to ensure compatibility across diverse energy storage technologies.
- Propose certification processes for safety, efficiency, and performance, ensuring alignment with EU climate and digital policies.

- Address regulatory gaps that hinder the large-scale deployment of hybrid solutions, including interconnection and permitting barriers.
- Develop frameworks to incentivize adoption of standardised HESS solutions among stakeholders.
- Collaborate with policymakers and standardisation bodies to align HESS standards with broader energy and climate transition goals.
- Support platform-based initiatives for data standardisation and ontology development (e.g., EURAMET, BIG-MAP, PARMENIDES).

Current Regulatory Environment in Europe. This section offers a sneakpeak of the current regulatory situation for hybrid energy systems in Europe and the R&D areas that must be strengthened in order to solidify the energy storage ecosystem.

Currently, there are some regulatory frameworks and standards that are starting to take shape around hybrid energy systems, however, specific regulations for hybrid energy systems—especially those involving multiple energy storage technologies—are still under development and can vary significantly by region.

In Europe, the regulatory landscape is primarily driven by the **European Union** and the **European Electricity Grid Initiative (EEGI)**, as well as other national regulators. However, there isn't a single, unified standard across Europe specifically for HESSs that combine multiple energy storage technologies. Key regulatory and policy frameworks impacting hybrid energy systems in Europe include:

1. **European Battery Directive (2006/66/EC)**¹⁶: This provides regulations regarding the collection, recycling, and disposal of batteries, which affects energy storage systems involving batteries.
2. **Energy Efficiency Directive (2012/27/EU)**¹⁷: Aimed at promoting energy efficiency across EU member states, this directive could be relevant when hybrid storage systems are deployed to improve energy efficiency, such as in industrial or commercial settings.
3. **EU Clean Energy Package**: Includes the Electricity Directive and Regulation, which sets the framework for the electricity market, aiming for a more integrated and flexible system. As HESSs could contribute to grid flexibility, elements like market design and network access are important.

¹⁶ <https://www.iea.org/policies/15684-eu-directive-200666ec-battery-directive>

¹⁷ https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en

4. **Grid Codes and Standards**¹⁸: Countries like Germany (with its **Grid Code** and **VDE standards**) have detailed specifications for integrating energy storage systems with the grid, which could also apply to hybrid systems.

Several countries within Europe have developed guidelines or frameworks for energy storage systems, which can often be adapted or extended to hybrid energy storage systems. While the regulatory focus varies from country to country, there are common themes around **grid integration, safety, performance requirements, and communication protocols**.

A consistent regulatory framework will set the ground for new developments to thrive and for industry to invest in competitive technologies. Likewise, access to world-class research is key to foster innovation and drive competitiveness around the industry. A long-term vision, unifying political insights and scientific knowledge is required to pave the road and set the scope for a strategic European energy storage development.

Collaborative Framework and Proposed CSA: Impact on Integration & Innovation. Although the European Union actively supports the development and implementation of HESS, mainly through regulations, economic incentives and funding, there is not a single stop-shop program dedicated to coordinating the research, education, and industry efforts around these technologies. There are currently different projects under the Horizon Europe program (SMHYLES¹⁹, HAVEN²⁰, Hybris²¹, Hyflow²²) focusing specifically in the development of hybrid storage solutions that aim to maintain grid stability and efficiency. Most of these projects are focused on different battery technologies that are more sustainable, cost-effective and can be relatively easy to integrate and operate to provide ancillary services to the grid. Similarly, there are several strategic documents addressing different aspects of HESS within broader energy storage contents such as the European Energy Storage Technology Development Roadmap²³, published by EASE and EERA, the ENTSO-E Research, Development & Innovation (RDI) Roadmap 2024-2034²⁴, and Integrated SET-Plan action 7²⁵, which offer guidelines, policy recommendations and implicitly support the development. However, none of

¹⁸ <https://www.vde.com/renewables/our-divisions/grid-conformity>

¹⁹ <https://smhyles.eu/information/>

²⁰ <https://havenproject.eu/>

²¹ <https://hybris-project.eu/>

²² <https://hyflow-h2020.eu/>

²³ <https://ease-storage.eu/publication/easeeera-energy-storage-technology-development-roadmap-towards-2030/>

²⁴ https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/RDC%20publications/entso-e_RDI_roadmap_2024-2034_240710.pdf

²⁵ https://setis.ec.europa.eu/document/download/a60a2903-5948-4935-8668-b5b7c554dc87_et

these initiatives are technology agnostic and focus on developing a comprehensive European strategy for the deployment of HESS.

One example of a successful collaborative approach reuniting different value chain actors is the Battery 2030+ initiative. This project has been able to bring together industry, researchers, policy makers and the public to elaborate an integrated roadmap for the development of a competitive European battery industry.

Establishing a coordinated support action among hybrid energy storage stakeholders could underpin the creation of a long-term research agenda and provide a dedicated platform that enables knowledge sharing and alignment while enhancing standardization and large-scale adoption.

A Coordinated and Support Action should provide key focus elements from research, education, and industrial perspectives:

Research and Innovation:

- Strategic Research Agenda
 - Map existing HESS technologies and identify their main challenges.
 - Define clear metrics (KPI's) to assess the performance of the hybrid system
 - Assess the maturity level of each technology.
 - Establish hybridization priorities to determine the optimal combinations of technologies for HESS, focusing on cost-effectiveness, technical feasibility, and efficient integration strategies.
- Interoperability and Standardization
 - Collaborate closely with regulatory entities and policy makers to define common standards for technology integration.
 - Propose a standardized framework for the integration of HESS into the grid from a commercial and industrial perspective.
 - Define metrics and processes to ensure safety of operation and environmental sustainability.
- Digitalisation
 - Development of open-source models and simulation tools for materials and design optimisation.
 - Enhanced EMSs that allow for better efficiencies and lifecycle management.

Education and Skills Development:

- High education
 - Develop EU-wide curriculum for universities and technical institutes focusing on industry needs.
 - Develop joint programmes and strengthen the link between industry and academia.
 - Support research and studies focusing on HESS innovation and integration
- Training
 - Strengthen collaboration among RTO's, training centres, and universities.
 - Develop online courses and training workshops on HESS design and deployment.
 - Develop certificate programmes and/or courses around HES integration
- Public engagement
 - Engage with policymakers and funding mechanisms to foster long-term R&D investment.
 - Educate stakeholder on HESS positive impacts and benefits.
 - Promote the adoption and deployment of HESS in commercial and industrial applications.

Industrial Uptake and Ecosystem Development:

- Large-scale HESS deployment
 - Assess grid integration opportunities that allow for market participation.
 - Support pilot and demonstration projects for relevant real-world applications.
 - Develop business model methodologies and tools for investors and policymakers.
 - Collaborate closely with regulatory entities and policy makers to identify and remove potential deployment barriers and promote the participation of HESS in energy and grid services provision.
- Innovation ecosystem
 - Promote wider representation of HESS in EU funding programmes.
 - Support startups and SME's developing innovative HES solutions.
 - Incentivise collaboration between grid operators and technology providers.
 - Foster public-private partnerships to accelerate European manufacturing scale-up

Expected Outcomes from a European CSA on Hybrid Energy Storage. The implementation of such CSA would result in the following outcomes:

- **European strategic roadmap** outlining research priorities and pathways for HESS large-scale deployment.
- Definition of **common guidelines** for interoperability, energy management and optimisation of HESS.
- Advanced modelling and simulation tools to optimise HESS design and operation.
- **Long-term industry-academia collaboration** to drive innovation and commercialisation of HES technologies.
- **Workforce development programmes for upskill and reskill** of technical capabilities.
- **Regulatory and policy recommendations** that incentivise market uptake and adoption.
- Implementation of pilot and demonstration projects that allow for relevant testing environments to validate HES solutions.
- **Accelerating the deployment of HESS** through business cases and market integration strategies.
- Provide more efficient and reliable HES solutions and energy management systems.
- **Improving private sector investment confidence** and industry involvement.
- **Ensuring data accuracy** and respective quality control and safety measurements.

Main Challenges and Barriers. Coordination actions should be addressed from an integral point of view in order to cover the following foreseeable challenges:

- **Lack of unified legal framework** across EU member states for HESS deployment including certification protocols and standardised testing.
- **Regulatory uncertainty and complex permitting processes** around energy market participation for HES and expected permits delay for technology roll out.
- **Technological diversity and complexity.** HESSs combine different energy storage technologies with different operating characteristics, which makes the development of a standardized regulatory framework more challenging.
- **Integration of multi-vector energy storage systems.** Integration of different types of storage systems based on diverse operating principles is a major challenge that can be tackled through dedicated research and real-world testing environments.

- **Stakeholder coordination and regulatory variability**²⁶ require collaboration among different groups of stakeholders spanning from researchers to industry and policymakers taking into account as much as possible the different national landscapes and priorities.
- **Participation in energy market.** Lack of clear business models and strong revenue streams for HESS.
- **Supply chain for advanced materials** required by some storage technologies.
- **Securing long-term investment.** Difficulty in ensuring investment commitments for technology and infrastructure development.
- **Dedicated EU funding schemes.** Insufficient funding or incentives aiming at HESS development.

Conclusions. HESSs hold a great potential for enhancing grid stability, efficiency, and flexibility, however, the absence of a unified strategic agenda remains a significant challenge for its wide adoption and implementation. Addressing regulatory gaps, unifying international policies, and fostering collaboration among different stakeholders will be essential to unlocking the full potential of HES solutions. The benefits offered by combining different energy storage assets go beyond the capacities of any existing single energy storage technology. Nonetheless, there are numerous challenges and barriers that make the scalability and adoption of these systems very complex.

While policies and regulations around energy storage systems are increasingly gaining traction, HESSs that combine multiple storage technologies don't have yet unified standards that facilitate their integration and operation. However, it is likely that the evolving regulations, grid integration and market rules around energy storage will pave the way for a more specific HES framework in the future.

Moving forward, continued investment in research, education and policy along with the definition of clear business models will be essential to accelerate the development of HES technologies in Europe. A **European CSA on Hybrid Energy Storage** can help to accelerate the deployment of integrated multi-vector energy storage technologies, foster innovation and competitiveness, drive market and investment confidence and promote industrial competitiveness. Similarly, aligning research, education, and industry objectives will help building a resilient energy storage ecosystem in line with wider European goals.

²⁶ Reidenbach, B. et al. (2022), "Towards net-zero: Interoperability of technologies to transform the energy system", OECD Going Digital Toolkit Notes, No. 24, OECD Publishing, Paris, https://goingdigital.oecd.org/data/notes/No24_ToolkitNote_InteroperabilityEnergy.pdf

5. Policy Recommendations

5.1 EU Landscape

In recent years, the European Union has significantly expanded its legislative framework for the energy sector, aiming to increase system flexibility, support renewables integration, and foster innovation in energy storage. The most monumental pieces of energy legislation came in the form of the Clean Energy Package and, later on, the recast Electricity Market Design, which collectively laid the foundations for an improved storage environment. Key instruments include:

- The revised **Renewable Energy Directive (EU) 2023/2413**
- The **Electricity Directive (EU) 2019/944**
- The **Electricity Regulation (EU) 2019/943**

These legislative texts introduced, for the first time, a legal definition of energy storage. While HESSs are not specifically mentioned, their components may fall under this broad definition. Recent proposals under the Electricity Market Design reform also aim to reduce barriers to storage participation and enhance investment signals. Despite growing recognition of energy storage as a pillar of the green transition, **a coherent EU-level strategy for hybrid systems is still lacking**. The current legislative framework does not explicitly address the challenges and opportunities posed by the integration of multiple storage technologies within a single system.

From a technical and strategic perspective and building on the needs identified across SRAs 1–4, the following recommendation is proposed at the EU level, from a funding perspective. In the next section, two additional recommendations are introduced, targeting national-level funding action. In **Section 5.3**, EASE identifies a number of challenges hampering the overall development of hybrid energy storage, as well as storage systems more broadly, across the EU. The section concludes with a set of policy recommendations designed to address these challenges.

- **RECOMMENDATION 1:** *Align EU funding and planning instruments for system-level deployment.* A comprehensive EU funding Strategy with the inclusion of the four Strategic Research Areas among the priorities of

Horizon Europe Cluster 5, with clearer alignment to **SET-Plan Actions 4**²⁷, **6**²⁸, and **7**²⁹, and relevant roadmaps at the ETIP and PPP/JU levels. To accelerate deployment, the **Innovation Fund** should prioritize full-chain demonstrators—e.g. energy hubs in ports, industrial retrofits, or integrated mobility infrastructure.

5.2 National Landscape

The transposition and implementation of EU storage-related legislation at the national level remains fragmented and uneven. Several Member States have yet to develop comprehensive frameworks for energy storage, let alone hybrid systems. Common roadblocks include:

- Absence of legal recognition for storage as a standalone asset class
- Limited or no targets for storage deployment in national energy and climate plans
- Restrictions on participation in capacity markets and ancillary services
- Lack of financial incentives for flexibility and behind-the-meter solutions
- Unclear permitting pathways and grid interconnection rules

Furthermore, transparency is often lacking: in many countries, persistent data gaps and underreporting make it difficult to assess the effectiveness of national regulatory frameworks. National Regulatory Authorities (NRAs) may lack capacity or mandate to enforce consistent implementation.

Without structured national support, the integration of HESS remains limited to pilot projects or manufacturer-led demonstrations. National-level measures are crucial to ensure market readiness, support project pipelines, and attract investment. To strengthen the national dimension, the following recommendations are proposed:

- **RECOMMENDATION 2:** *Include hybrid system integration into NECPs³⁰ and national funding schemes.* Member States should reflect hybrid system applications in NECPs and national strategies, prioritizing relevant case studies—industrial clusters, repurposed fossil assets, urban energy hubs, or transport corridors. National R&D and innovation programmes should fund **cross-vector system integration**, not only isolated storage technologies.

²⁷SET Plan Action 4: Increase the resilience and security of the energy system

²⁸ SET Plan Action 6 on Energy Efficiency in Industry: Increasing efforts to make EU industry less energy, resource and emissions intensive and more competitive

²⁹ SET Plan Action 7 on Batteries for e-mobility: Become competitive in the global battery sector to drive e-mobility and stationary storage forward

³⁰ National energy and climate plans

- **RECOMMENDATION 3:** *Strengthen National Research and Coordination Groups (NRCGs) to bridge EU and national efforts.* NRCGs should be empowered to coordinate **multi-vector energy R&I agendas**, ensure alignment with SET-Plan and Horizon Europe priorities, and identify strategic demonstration opportunities at the national and regional level. They should also facilitate knowledge-sharing between sectors and ensure consistency between public funding, regulation, and infrastructure planning.

5.3 Barriers and Challenges

A number of barriers impeding a more rapid development of hybrid energy storage, and storage systems at large, can be identified in the current framework.

5.3.1 Lack of a clear storage strategy

While the recent energy legislation efforts of the EU have recognised energy storage as a key player in the energy transition and laid solid grounds for its development, the current regulatory landscape is still riddled with inconsistencies.

The EU lacks a comprehensive vision for different solutions and different application of energy storage. The Electricity Market Design offers an array of tools which could benefit the development of the energy storage. However, without clear instructions on how their interaction with one another, they risk remaining underutilised: at this moment, the interplay between different support schemes, capacity markets, and auctions is left ambiguous, which undermines the vision for the future of energy storage.

Looking at hybrid ESS solutions in particular, they may face additional challenges, e.g. in qualifying for certain incentives or support schemes designed for traditional energy storage systems. Besides, the criteria for funding and support might not account for the combined benefits and operational dynamics of hybrid systems.

- **RECOMMENDATION 4:** *Develop a clear storage strategy.* A comprehensive EU Storage Strategy emphasising the grid and Industry role of energy storage should be developed. It should address the complementarity, coherence, and, if necessary, prioritisation of different policy tools. Furthermore, the role of state aid, both for manufacturing and deployment, should be assessed and clarified, as it is crucial in catalysing a maturing technology such as hybrid energy storage.

5.3.2 Disproportionate economic barriers

At present, energy storage faces disproportionate costs in most Member States, thus reducing its viability as a flexibility option. Prominent barriers include double-charging of grid fees; and the double taxation on electricity from storage assets remains. Indeed, the existing taxes, fees, levies and surcharges do not reflect the actual network costs and distort the price signals, thus failing to contribute to the deployment of energy storage. This particularly affects larger consumers who tend to be more reactive to it.

These barriers greatly affect the economic competitiveness of energy storage solutions and reduces the investment attractiveness thereof. This problem is only exacerbated with hybrid storage systems, which may potentially face complex charging mechanisms due to the number of technologies involved.

- **RECOMMENDATION 5:** *Remove economic barriers.* The surcharges on energy storage should reflect the added value to the energy system. This could be achieved by moving to increasingly power-based network tariffs which correlate with capacity, unlike flat-rate charges. The taxation regimes should be transparent and coordinated to avoid double taxation and address the current legal uncertainty.

5.3.3 Manufacturing and innovation

Hybrid energy storage has been progressing towards maturity in the recent years. However, the lack of sufficient incentives continues to prevent it from reaching its full potential.

Among the unresolved challenges hampering the manufacturing of energy storage are access to raw materials, a small margin of profit, shortage of skilled labour, a rise in facility costs and operational expenses, high cost of capital, and logistic risk. The access to new technologies is limited at the manufacturing stage. The progress is also slowed down by the limited access to data of energy storage projects and technological advancements.

Furthermore, despite certain positive efforts in driving innovation across the EU, such as the Horizon Europe Programme, energy storage systems have not been sufficiently addresses. In particular, the thermal energy storage (TES) market faces an increasing need for digitalisation, which is essential to unlock its full potential as a sector coupling enabler. Enhanced digital tools and data integration can improve system efficiency, support predictive maintenance, and facilitate the large-scale deployment of TES across sectors.

- **RECOMMENDATION 6:** *Promote manufacturing and innovation.* Manufacturing of energy storage technologies should be incentivized by encouraging R&D of energy storage technologies. Data availability of projects and technologies should be improved to this end. With scaled-up R&D, the gap between novelty and accessibility will be reduced by mainstreaming new technologies and making them more available for general use. The EU Innovation Fund should introduce a dedicated call for long-duration energy storage. This would help untap the revenue streams for this cutting-edge technology and catalyse its development.

5.3.4 Congestion management and grid stability

The current congestion management framework suffers from shortcomings precluding it from reaching an optimal standard. Most measures are based on non-market-based procedures. On the national level, they are difficult to develop due to, for instance, the lack of transparent decision-making procedures. EASE has also observed an overreliance on traditional grid expansion. Many of the issues with congestion and curtailment are also connected to the incomplete implementation of the Clean Energy Package at the national level.

Moreover, currently, the stability and flexibility of the grid are not sufficient, leading to non-optimal use. This is exacerbated by the unclarity on maximum capacity during connection agreements for hybrid systems. Hopefully, the updated Regulation on network codes on requirements for grid connection of generators (RfG Regulation), to be adopted by the end of 2024, will bring more certainty.

- **RECOMMENDATION 7:** *Introduce congestion management measures.* Power grids need to be furthered. The Commission's Action Plan to support a faster rollout of more efficient energy grids is undoubtedly a promising start. The deployment of cost-efficient, smart alternatives to grid expansions should be encouraged. Notably, the EMD's total expenditure approach for the remuneration of system operators is a step in the right direction. Local flexibility markets should be established to "put a price on congestion". Clear definitions of Requirements for Generators Network Code should be introduced, alongside guidelines to Member States to support these connections.

5.3.4 Limited and unreliable flexibility assessments

Flexibility assessment methodologies developed at the EU level, such as in the context of the European Resource Adequacy Assessment (EERA) and Ten-Year Network Development Plan (TYNDP), are not satisfactory. The assessment is not

entirely holistic and does not account for crisis scenarios. The tools existing at the national level also remain inadequate. Furthermore, these methodologies underestimate flexibility contributions due to the lack of assessment of revenue stream and market failures.

Amidst the current shortcomings, the Electricity Market Design introduces the flexibility assessment – a mandatory analysis forcing Member States to look into their flexibility needs. This provision is extremely positive as many Member States do not have a clear understanding of their needs and how to deploy green flexibility solutions. The methodology is under elaboration and its full scope remains to be seen.

- **RECOMMENDATION 8:** *Develop reliable flexibility assessments.* Establishing a single, standardised approach across all Member States is essential to ensure consistency and comparability. This will also help strengthen stakeholder representation, particularly from the clean technology sector, which is currently not explicitly addressed in the Electricity Market Design (EMD). One way to ensure inclusive participation is through the creation of a **Stakeholder Reference Group** focused on the Flexibility Assessment Methodology. The methodology of the European Resource Adequacy Assessment and TYNPD needs to be reconsidered. Currently, the frameworks underestimate flexibility contributions due to the lack of assessment of revenue streams and market failures.

The EMD flexibility assessment should also not be limited to the existing methodology shortcomings and the reliability of the flexibility assessment tool needs to be ascertained. A single methodology would be key in ensuring uniformity among all the Member States which, in turn, would help address the aforementioned implementation issues.

5.3.5 Unclear rules regarding the utilisation by market actors of regulated entities-owned energy storage systems

At present, the development of regulated entity-owned energy storage systems remains constrained. The Clear Energy Package doesn't mandate storage ownership for market activities or regulated entities. Nonetheless, they are entitled to use storage systems as integrated network components. Regrettably, its potential is underutilised, as the facility cannot be contracted to market actors to access additional revenue streams.

- **RECOMMENDATION 9:** Clarify rules regarding the utilisation by market actors of regulated entities-owned energy storage systems. It should be clarified that the same facilities can be used by different actors for different services, stacking revues and obtaining the most value by the installation.

5.3.6 Lack of standards and guidelines

Hybrid storage, as an emerging area of interest, lacks developed standards and guidelines, e.g. at installation level. Different components of a hybrid system may be to different regulations and standards, ensuring compliance across the entire system can be very complex. At present, EU legislation on energy storage, which is already not entirely coherent, lacks any specific regulatory framework for hybrid storage.

- **RECOMMENDATION 10:** *Develop coherent standards and guidelines.* A tailored approach for hybrid ESS should be developed to avoid (legal) unclarity and uncertainty among developers and investors.

5.3.7 Promotion of energy storage in industry decarbonisation

(Hybrid) Energy storage, when paired with renewables, has the potential to greatly contribute to achieving the decarbonisation objectives, decreasing fossil fuel dependency by reducing global industrial greenhouse gas emissions. Importantly, it can achieve it cost-effectively.

However, currently, the regulatory landscape doesn't entirely succeed in facilitating the involvement of energy storage in the green transition. The financial support mechanism to incentivise the energy storage roll-out is weak, especially for longer durations in low-carbon systems.

- **RECOMMENDATION 11:** *Promote energy storage as a key element of industry decarbonisation.* In order to untap long-term investment and revenue streams, a financial support mechanism should be developed. Energy efficiency efforts, such as waste heat recovery, need to be incentivised. The grid connection process needs to be adapted to energy storage. This will reduce the unnecessary delays and considerably enhance the stability of the grid. The heating and cooling strategy of the EU should be reassessed, as it can play an important role in decarbonising the industry. Hybrid energy storage offers sustainable solutions at a lower price, enabling electrified industrial-grade heating and cooling solutions to capitalize on off-peak pricing to reduce production costs.

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