European Commission

SET Plan

PROGRESS REPORT 2024

Scaling up research, innovation and competitiveness in clean energy technologies

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EXECUTIVE SUMMARY

Published on the occasion of the 2024 Strategic Energy Technology Plan (SET Plan) conference in Budapest, Hungary, this report highlights the SET Plan's role in coordinating EU and national research and innovation (R&I) agendas for the development and deployment of efficient and cost-competitive clean energy technologies to drive Europe's green and digital transition.

2024 has seen a revision of the SET Plan, aligning its strategic objectives with the evolving European energy policy landscape. The SET Plan's role has been reinforced in the frame of the Net-Zero Industry Act, and its Steering Group elevated in legal status.

This new legal anchoring is expected to help the SET Plan to strengthen Europe's industrial leadership in low-carbon technologies by increasing cooperation between policymakers, industry, academia, research institutes and public and private investors.

The SET Plan's stakeholders are at its heart. Drawing extensively on their input, this report offers an overview of their recent work, their challenges, and their opportunities for growth.

FOREWORD

Europe's ability to lead the clean energy transition and achieve our climate targets depends on the unwavering commitment of our research and innovation community. The EU's capacity to conduct cutting-edge research, foster breakthrough innovation and address fragmentation in the Single Market is essential to our economic prosperity, competitiveness and success in the green and digital transitions. Enrico Letta and Mario Draghi strongly emphasized this need in their recent high-profile reports.

The Strategic Energy Technology Plan (SET Plan), which the Commission revised in 2023 to better match the policy objectives of the European Green Deal, the REPowerEU Plan and the Green Deal Industrial Plan, exemplifies these efforts. It drives progress by focusing on strategic research agendas that align public and private priorities and investments with those at EU, national and regional levels. It pools the collective strength of EU Member States and countries associated to Horizon Europe, industry, and research institutions to accelerate the development and deployment of low-carbon energy technologies.

As we take stock of what was done under the Plan during the past year, I am pleased to acknowledge the substantial progress made by the SET Plan community to advance our clean energy goals.

The scope of SET Plan has continued to grow, with the addition of Implementation Working Groups focused on clean technologies such as non-concentrated solar thermal power and hydrogen, as well as more ambitious targets for other technologies. Cross-cutting task forces have also been introduced to enhance areas such as circularity and market uptake of research and innovation results. The new legal basis of the SET Plan – following the adoption of the Net Zero Industry Act – confirms its central role in the development and deployment of clean energy technologies in the EU.

Now recognized as a structured policy under the European Research Area (ERA), the SET Plan is pivotal in advancing Europe's energy transition and strengthening our technological leadership. This structured approach not only boosts coordination among Member States but also amplifies the impact of our collective efforts in meeting the Union's energy and climate objectives. By fostering cooperation and alignment in energy research and innovation, the SET Plan enhances the resilience, efficiency and integration of the ERA, contributing to realising the 'fifth freedom' in research, innovation and education.

The SET Plan is more than a strategy – it's a vision and a roadmap for a better future. A future where the EU and its closest partners lead the clean energy transition, where our industries are competitive and resilient, and where our citizens enjoy a high quality of life.

I invite experts and non-experts alike to explore the SET Plan 2024 Progress Report, and I look forward to seeing its continued impact in the years ahead.

Iliana Ivanova
European Commissioner for Innovation, Research, Culture, Education and Youth

The global geopolitical landscape is increasingly dynamic and unstable. The occurring shifts are acutely felt in the energy sector, where the need for competitiveness has become an urgent priority for several regions of the world. The European Union, in particular, has recognised the necessity to act decisively to strengthen its long-term competitiveness, ensure its leadership on the global stage, and drive sustainable growth, while tackling the energy and climate challenges.

The achievements of the past year are a testament to Europe spearheading the deployment and uptake of clean energy technologies. In 2023, 50% of electricity generation came from renewables, with a record 96 GW of new installed solar energy capacity and a significant increase in wind capacity of an unparalleled 33 GW since 2022. Furthermore, investments in clean technologies have more than tripled over the last 5 years and the EU attracts more investments in clean hydrogen than the US and China combined.

Looking ahead, the EU is intensifying its efforts to become a global leader in clean energy technologies, decarbonised industry, and technological innovation. The European Commission's new political guidelines place competitiveness at the heart of the EU economic growth strategies. As part of the new Plan for Europe's sustainable prosperity and competitiveness, President von der Leyen has pledged to introduce a Clean Industrial Deal, to be adopted early in the next mandate. The Clean Industrial Deal will ensure that the EU delivers on the goals set out in the European Green Deal by addressing the urgent need to decarbonise and industrialise our economy at the same time, while strengthening the EU's competitive edge in the global clean technology and energy markets.

However, the clean energy manufacturing industry in the EU faces many challenges, including high energy prices, competition from third countries as well as a low market uptake of innovative solutions. In his report to the Commission, Professor Draghi highlights that innovation is a key element to overcoming these challenges and securing the EU's competitive edge.

To address these issues, innovation will be especially important in developing and manufacturing clean technologies which will shape the crucial transformation of our energy landscape and our efforts to decarbonise.

This is where the Strategic Energy Technology (SET) Plan comes into play. By aligning national energy research and innovation agendas across Europe, the SET Plan boosts innovation and supports the development of clean, efficient, and cost-competitive energy technologies. Never before has the SET Plan been so prominent in the context of the innovation and competitiveness agenda. The plan's importance is recognised in the Net-Zero Industry Act (NZIA), which provides a solid legal basis for its implementation. By working together, the SET Plan countries can accelerate the clean energy transition while enhancing the competitiveness of their net-zero industries.

This SET Plan progress report highlights the excellent progress made by clean energy technologies over the past year. At the same time, it is essential to continue pushing energy innovations towards deployment. The time has come for the SET Plan countries to work even closer together, align policies, and attract investments to create better conditions and market access for clean tech in the EU. This is a call for businesses, governments, and innovators to collaborate on sustainable clean and competitive energy solutions that secure Europe's place in the global economy.

As we move forward, it is clear that innovation and the SET Plan will be key to unlocking Europe's competitive edge in the energy sector. By embracing this challenge and working together, we can ensure a sustainable, clean, and competitive energy future for generations to come.

Kadri Simson
European Commissioner for Energy

INTRODUCTION

The SET Plan progress report offers an annual overview of SET Plan activities and achievements through the lens of those who know them best – the SET Plan community.

This year's report provides an overview of the SET Plan's relationship with the current policy landscape, and in particular, the Net-Zero Industry Act (NZIA). Recent policy developments underpin the SET Plan and guide its future work, including the establishment of its Steering Group as a high-level expert group, and the drafting of the SET Plan's first official Terms of Reference.

As in previous years, an update is provided on the status of clean energy research and innovation (R&I) investment in the EU, along with key changes to implementation plans (IPs), ongoing collaborations and more. We are delighted to note, for example, that 2024 has seen the greatest number of meetings and activities between working groups since the beginning of the SET Plan. The European Energy Research Alliance (EERA) and the European Technology & Innovation Platforms (ETIPs) FORUM, who were first invited to contribute to the report last year, are featured once again.

New to the report this year is a section on venture capital investment trends for clean energy technology start-ups. As highlighted in the recent Draghi report, this field is of key importance in achieving the EU's clean energy technology R&I priorities.

The final section presents highlights from the perspective of each of the 14 implementation working groups (IWGs), as well as the new temporary working group (TWG) on Hydrogen. These offer a concise overview of recent developments, along with future opportunities and challenges, measured against the implementation plans of each group.

This report is published on the occasion of the 18th SET Plan Conference, organised jointly by the European Commission and the Hungarian Presidency of the Council of the EU. It has been prepared by the Joint Research Centre of the European Commission in close collaboration with DG Energy, DG Research and Innovation, the 14 SET Plan working groups, the ETIPs, the TWG, EERA and the ETIPs FORUM.

A NEW POLICY FRAMEWORK FOR THE SET PLAN

POLICY DRIVERS

The European energy policy landscape is undergoing a significant transformation, driven by the imperative to achieve climate neutrality, strengthen energy security, boost industrial competitiveness and lower energy prices for consumers. Clean energy research and innovation (R&I) is crucial to meeting these objectives, and the revised SET Plan has a key role to play in facilitating its success.

The revision of the SET Plan, detailed in a 2023 Communication[1], aligned its original strategic objectives with the European Green Deal, REPowerEU, the Net-Zero Industry Act and the Critical Raw Materials Act. Alongside these policy innovations, the SET Plan continues to play a central role in implementing the research, innovation and competitiveness (RIC) dimension of the National Energy and Climate Plans (NECPs), under the Energy Union Governance Regulation.

The Commission's 2023 Strategic Foresight Report[2] highlights the need for a more coordinated approach to energy policy, both within the EU and globally, to address the challenges of climate change and energy security. In addition, the Commission's Political Guidelines[3], presented by President Ursula von der Leyen in July 2024, emphasise the need for a more strategic approach to energy policy, focusing on open strategic autonomy, economic security and climate action. The guidelines highlight the importance of further investing in clean energy technologies, promoting sustainable growth and ensuring a just transition for all.

Clean energy deployment, research, and competitiveness are inextricably linked. By bolstering Europe's scientific and technological capabilities, leveraging economies of scale, and fostering pan-continental competition, European competitiveness is expected to be further strengthened.

As Mario Draghi's report on the Future of European Competitiveness[4] highlights, R&I is crucial for driving productivity growth, economic development, and competitiveness. It also plays a vital role in creating better and more jobs, and enabling Europe to find more efficient solutions to challenges such as the green and digital transitions.

Since its inception, the SET Plan has played a pivotal role in coordinating European R&I policies in energy technologies through a shared vision and goals. Its primary objective – to accelerate the development and deployment of efficient and cost-competitive low-carbon technologies, thereby enhancing the EU's geopolitical resilience and energy security – is ever more pressing.

However, as the Draghi report outlines, Europe's R&I system is still characterised by significant disparities and fragmentation across Member States. This is particularly evident in the uneven distribution of R&I activities across the EU, while public and private investment in R&D still fall short of the target of 3% of GDP. The regulatory and business environments for clean energy innovation also vary substantially across Europe.

The SET Plan ecosystem, bringing together policymakers, industry and academia from across Europe, therefore has an essential contribution to make in the years to come.

1 COM(2023) 634 final, Communication on the revision of the SET Plan, [*link*]
2 COM(2023) 376 final, 2023 Strategic Foresight Report, [*link*]
3 Political guidelines for the next European Commission 2024–2029, [*link*]
4 Draghi, M., 2024, The future of European competitiveness, [*link*]

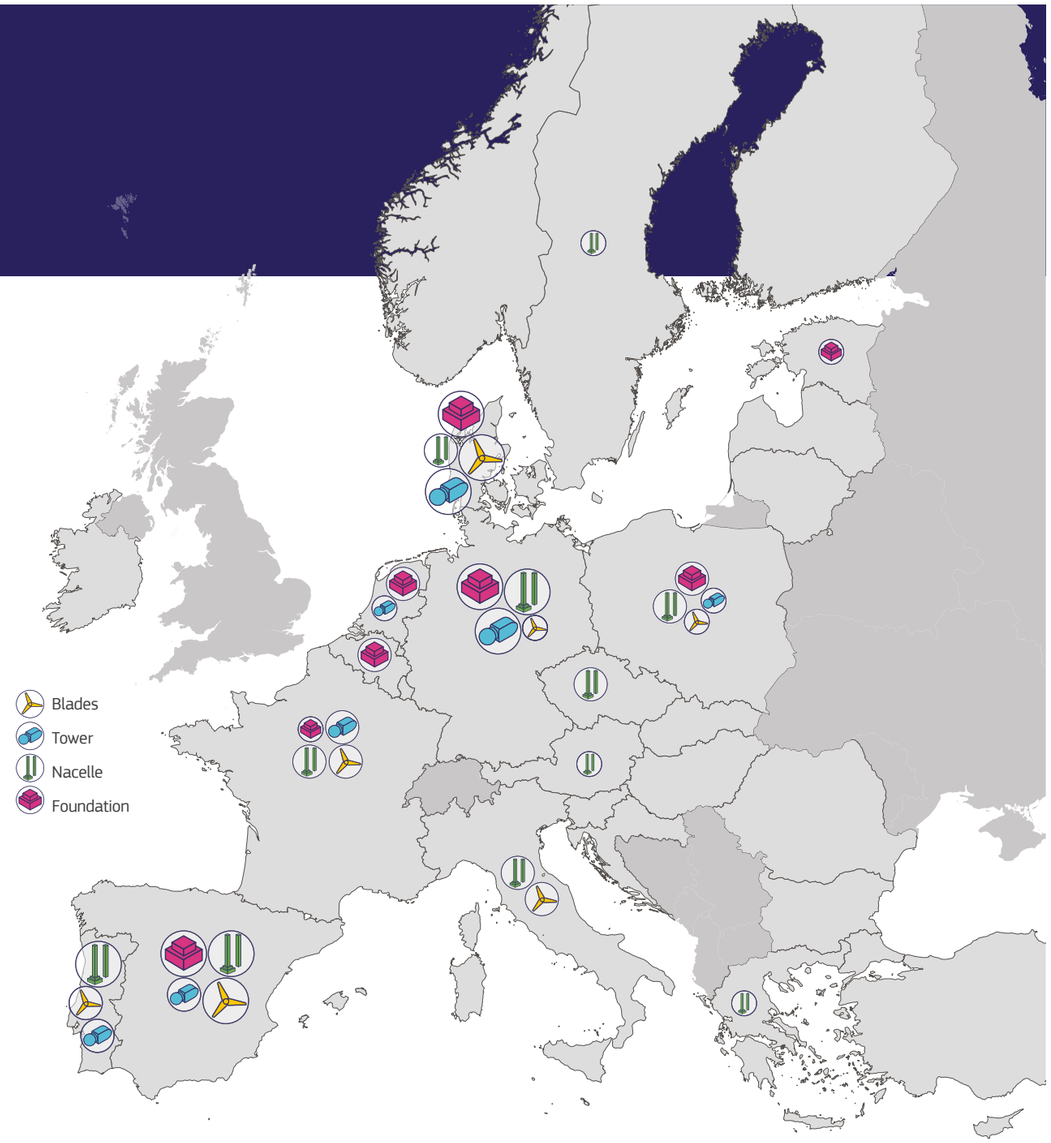


***Figure 1.** European wind energy manufacturing locations (2023)*
***Note:** The larger bubble indicates more manufacturing output.*
Source: SETIS, 2024.

THE REVISED SET PLAN UNDER THE NET-ZERO INDUSTRY ACT

The Net-Zero Industry Act (NZIA)[5], which entered into force on 29 June 2024, outlines ambitious goals to enhance the EU's capacity to manufacture clean energy technologies domestically. This presents challenges and opportunities for the energy technology sector. The focus on domestic manufacturing and securing critical raw materials for key technologies will create new opportunities for European industry.

The NZIA regulation marks a critical juncture in the SET Plan's history. For the first time, the SET Plan Steering Group is legally established as a high-level

5 Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724 (NZIA), [*link*]

expert group to the European institutions. It is to be composed of representatives of the Member States and the Commission, with the participation of European Economic Area (EEA) representatives as observers. The Steering Group will meet at regular intervals and will be assisted by an executive secretariat provided by the Commission.

The Steering Group's formal recognition is expected to give it new momentum. In terms of functions, it will continue to be responsible for ensuring alignment between energy R&I programmes at EU and national levels; advising and recommending action on the RIC dimension of the NECPs; validating the implementation plans of the SET Plan working groups; and taking decisions on the accession to working groups of new countries and entities from outside the EU and EEA.

Along with adopting its own rules of procedure, the Steering Group will now also be responsible for introducing an overarching governance document to guide the work of SET Plan stakeholders. The main objective is to define the SET Plan, its stakeholders and goals, providing an essential reference framework for all involved. This document is expected to be adopted by the new high level Steering Group in 2025.

These measures are expected to improve the governance of the SET Plan, the participation of all member countries and the political visibility of its activities. Crucially, the SET Plan legal anchoring under NZIA is expected to help boost EU industrial leadership on low-carbon technologies, and the transition towards a climate-neutral energy system, in a fast and cost-competitive way.

THE SET PLAN LANDSCAPE

R&I INVESTMENT IN THE EU

The SET Plan plays a pivotal role in coordinating R&I agendas centred around low-carbon energy solutions. It operates in alignment with an array of other EU instruments and funding mechanisms. The investment directed towards fulfilling the research and innovation priorities of the Energy Union is integral to this overarching policy context, emphasising the interconnectedness of these collective efforts.

Public spending in R&I in the Energy Union priorities[6] has been increasing. Half of the EU Member States that provide data[7] increased their public R&D spending on the respective objectives in 2022 compared to 2021, resulting to estimates for 2022 being 23% higher than in 2021[8].

In 2022, the latest year for which near-complete public data and projections for private investments are available, an estimated EUR 36.3 billion was invested in the clean energy technology R&I priorities of the Energy Union. Roughly 75% came from the private sector, while the remainder came from Member States' public funding (19%) and the EU (5%).

Over the 2020-2022 period, overall investment increased by EUR 2.4 billion or 8% on average per year. However, the share between private and public investment remains relatively stable, as does the role of EU funds. Similarly, the share of investment between the R&I priorities has remained more or less the same over the same period.

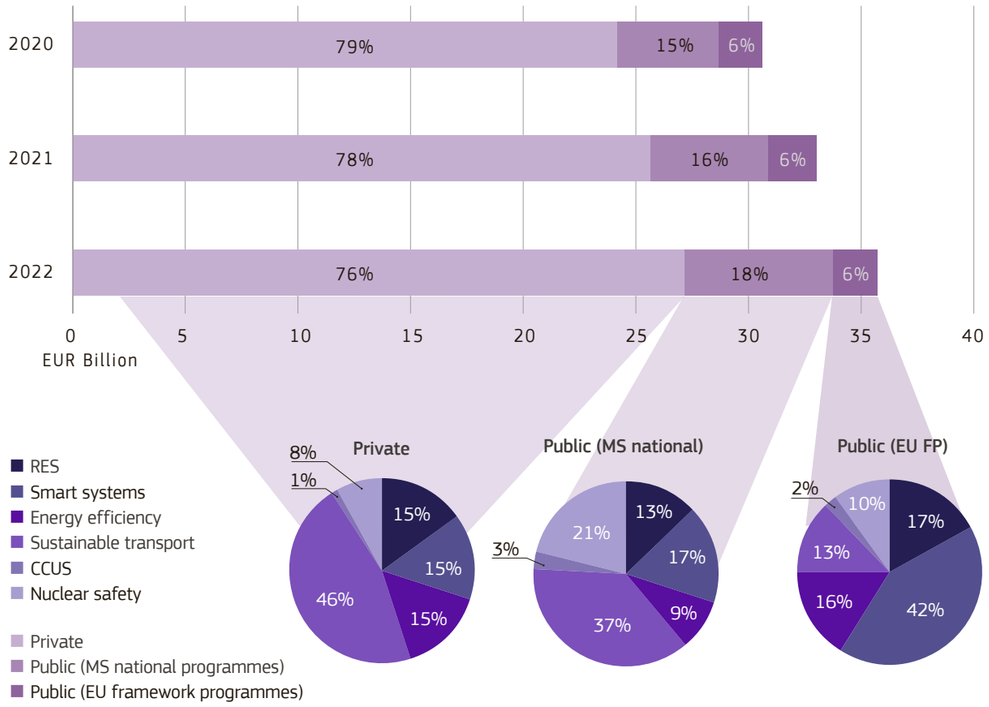
On average, the private sector contributes more than 80% of the R&I funding for sustainable transport and energy efficiency measures and over half of the funds in all other priorities. Similar to previous years, the industry with the largest R&I investment share across all priorities in 2022 was sustainable transport – attracting 42% of R&I investment overall, and nearly 46% of private investment, followed by smart systems, energy efficiency measures, and renewable generation all between 14-17% of the total.

6 The Energy Union R&I priorities are:
- Number 1 in renewable energy;
- The future smart EU energy system, with the consumer at the centre;
- Develop and strengthen energy-efficient systems;
- Diversify and strengthen energy options for sustainable transport;
- Driving ambition in carbon capture storage and use deployment; and
- Increase safety in the use of nuclear energy.

7 Member States that reported an increase to the IEA: BE, DE, EE, ES, FR, LT, IE, PL, PT, FI; IT not reported

8 A significant share of the increase in 2021 and 2022 was due to a change in reporting by Spain, and revisions by France. These two MS accounted for an additional EUR 1 billion of R&D investment in 2022. IEA, 2024. Energy Technology RD&D Budgets, May 2023 Edition, Database documentation. International Energy Agency (IEA), *Energy Technology RD&D Budgets – Database documentation,* 2024.

Figure 2. *Investment in the Energy Union R&I priorities in the EU (2020-2022) in EUR billion.*

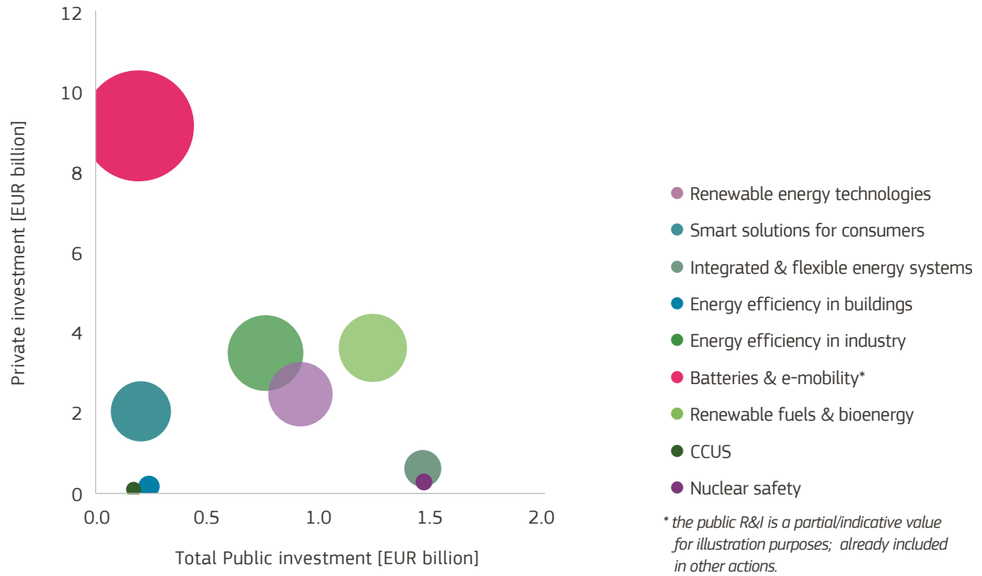


Note: *Due to a lack of sufficiently granular data and a lag in reporting, we use the following approximations: The public R&I figures for 2022 include estimates for Italy, Luxembourg and Malta equal to that reported in 2021. The private R&I for 2020 onwards is estimated based on the last 5-year trend. The sector split percentages are estimated based on the previous four years.*

Source: SETIS, 2024 (Mountraki, A., Georgakaki, A., Ince, E. and Primavera, J., 2024, SETIS R&I data https://setis.ec.europa.eu/publications/setis-research-and-innovation-data_en)

The increasing input in terms of R&I investment translates to increased research outputs, such as patent filings, in all Energy Union R&I priorities, and by extension, SET Plan actions. The areas receiving more funding – and especially funding from the private sector – also show more prominent patenting activity. The EU is a global leader in international patent filings in renewables and energy efficiency, and comes second among major economies in all other priorities except for smart systems. The specialisation index shows the share of each of the SET Plan actions in EU patent filings compared to the global average. It confirms the relative importance of sustainable transport, renewables, energy efficiency in buildings and CCUS as areas of strength, while the remaining actions are relatively less represented in the patent filings addressing the Energy Union R&I priorities.

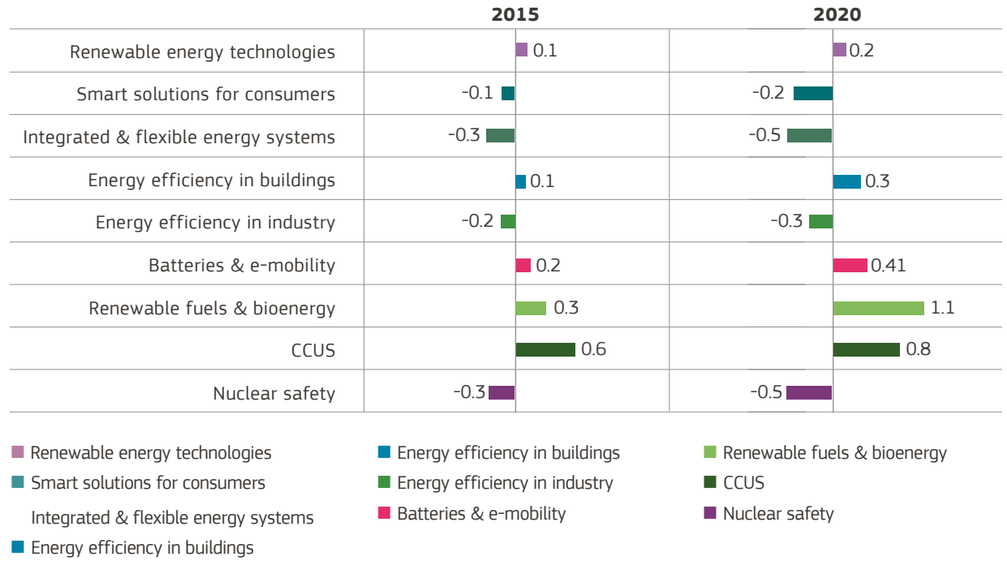
Figure 3. *Patenting activity, public (national programme) and private R&I funding per SET Plan action for 2020.*



Note: *The size of the bubble indicates the relative number of filings.*

Source: SETIS, 2024 (Mountraki, A., Georgakaki, A., Ince, E. and Primavera, J., 2024, SETIS R&I data https://setis.ec.europa.eu/publications/setis-research-and-innovation-data_en)

Figure 4. *Change in the EU specialisation index for patent filings in the SET plan actions between 2015 and 2020.*



Source: SETIS, 2024.[9]

9 Mountraki, A., Georgakaki, A., Ince, E. and Primavera, J., 2024, SETIS R&I data https://setis.ec.europa.eu/publications/setis-research-and-innovation-data_en

VENTURE CAPITAL INVESTMENT TRENDS IN CLEAN ENERGY TECHNOLOGY START-UPS

Venture capital (VC) investment in start-ups is instrumental in achieving the clean energy technology (CET) R&I priorities of the Energy Union. Start-ups are nimble compared to corporate incumbents, and can drive breakthrough or disruptive innovation, and foster the development of local innovation-driven industries. Although venture capital funding is much smaller in size than public and corporate R&I spending, it sits at the heart of the financing ecosystem for CET start-ups. It provides them with essential support for technology development, adaptation to market opportunities, and scaling up.

Following a period of rapid expansion until 2022, early-stage investment[10] in CET start-ups in the EU fell back to the level of investment seen in 2021. In 2023, the total amounted to EUR 645 million (-19% compared to 2022), still representing nearly four times as much as the average annual funding for early-stage CET deals between 2018 and 2020. This decline is accompanied by a reduction of the average deal size, as investors face unfavourable macroeconomic conditions. Over the past three years, the EU maintained a minority share of global early-stage investment in CET start-ups (14% compared to 13% between 2018 and 2020). However, its position in hydrogen and solar photovoltaics technologies is weakened by the multiplication of larger early-stage deals (above EUR 200 million) in China since 2021.

The growth of early-stage CET investment in the EU came with a shift of investment flows towards various R&I priorities. Between 2021 and 2023, renewable energy, energy systems, and hydrogen technologies only accounted for 29% of the EU early-stage CET investment total (compared to 68% over the previous three years). However, those priorities accounted for 42% of EU early-stage CET deals – a proportion that is more or less the same as that observed between 2018 and 2020.

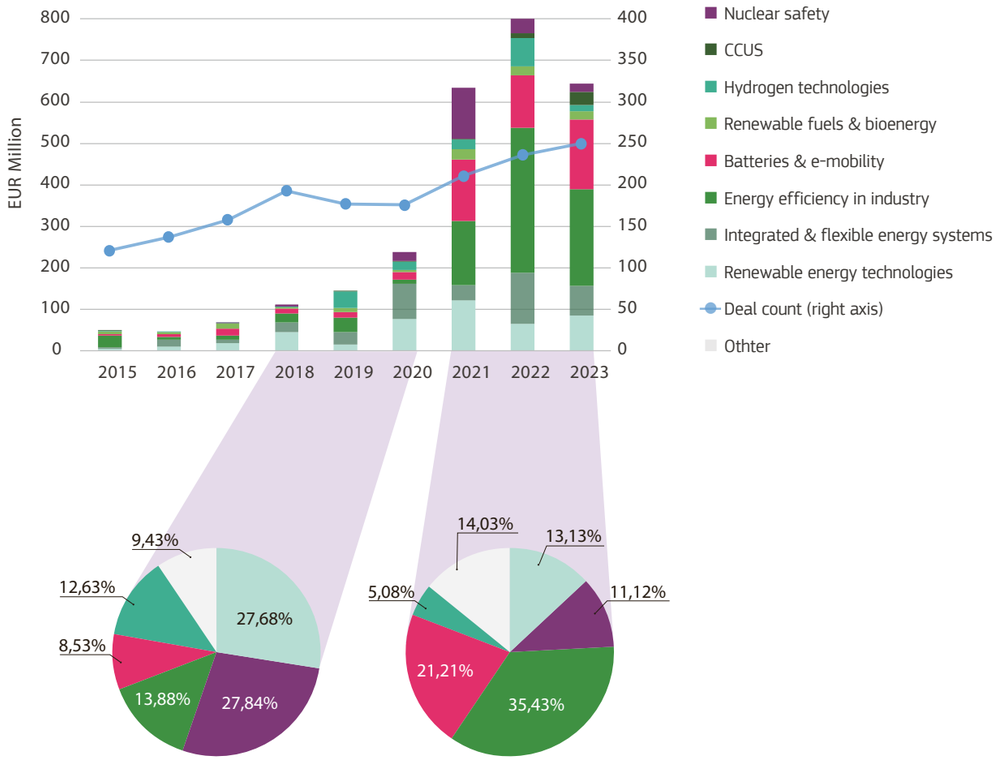
On the other hand, energy efficiency and energy storage accounted together for 56% of the total early-stage CET investment realised in the EU between 2021 and 2023 (compared to 22% over the previous three years). Since 2021, EU energy efficiency start-ups have raised higher levels of capital than their counterparts and account for 34% of global early-stage funding for this priority (against 8% between 2018 and 2020). Energy efficiency, however, only accounts for 25% of early-stage CET deals realised in the EU since 2021 and this performance is mainly due to a few single fundraising successes in battery, hydrogen-based steel production, and plastic waste recycling technologies.

Access to finance remains a barrier for CET innovators across EU Member States. EU-based CET start-ups that have raised venture capital since 2018 captured 2.5 times less early-stage investment than their US counterparts while only being 1.6 times less numerous. Moreover, while CET deals are taking place in an increasing number of EU Member States over time, seven[11] of them together host 79% of CET ventures founded since 2018 and account for 90% of early-stage investment realised in the EU since then.

10 Early-stage investment refers to accelerator/incubator, angel, seed and early-stage VC series A and B deals. Very large early-stage deals (> EUR 400 Million) are not included and re-classified as late-stage deals. For further details, see Clean Energy Technology Observatory: Overall Strategic Analysis of Clean Energy Technology in the European Union - 2024 Status Report, European Commission, 2024.

11 Namely, Germany, France, Sweden, Italy, Spain, Denmark and the Netherlands.

***Figure 5.** Venture capital investment in EU clean energy technology start-ups for early-stage deals by SET Plan Action (2015-2023).*



Source: JRC elaboration based on PitchBook data.

THE IMPLEMENTATION LANDSCAPE

2024	IWG	ETIP	CSA	EERA JOINT PROGRAMMES	INDUSTRIAL ASSOCIATION	ADDITIONAL PROJECT OR OTHER EUROPEAN COORDINATION GROUP
	Solar photovoltaics	ETIP PV	/	JP PV	SolarPower Europe	/
	Concentrated solar technologies	/	CST4All	JP CSP	ESTELA Solar	CSP ERA-NET
	Wind energy	ETIP Wind	SETIPWind	JP Wind	WindEurope	/
	Geothermal energy	ETIP Geothermal	GEOTHERM FORA	JP Geothermal	European Geothermal Energy Council	-
	Ocean energy	ETIP Ocean	-	JP Ocean Energy	Ocean Energy Europe	-
	Direct current technologies	-	DCforEU	JP Smart Grids	-	-
	Positive energy districts	ECTP	-	JP Smart Cities	-	-
	Energy systems	ETIP Smart networks for energy transition	-	JP Smart Grids JP Energy Systems Integration	-	SES ERA-NET
	Energy efficiency in buildings	Renewable Heating and Cooling Platform	IWG Buildings Secretariat	-	European Construction and sustainable built environment Technology Platform (ECTP)	-
	Sustainable and efficient energy use in industry	-	SET-IndEU	JP Energy Efficiency in Industrial Processes	A.SPIRE	-
	Batteries	Batteries Europe	-	JP Energy Storage	Batteries European Partnership Association (BEPA)	Battery2030
	Renewable fuels and bioenergy	ETIP Bioenergy	-	JP Bioenergy	-	-
	CCS – CCU	Zero Emissions Platform	CCUS Secretariat	JP CCS	Carbon Capture and Storage Association (CCSA)	-
	Nuclear safety	Sustainable Nuclear Energy Technology Platform	SNETPFORWARD	JP Nuclear Materials	nucleareurope	European Industrial Alliance on SMRs
	TWG Hydrogen	-	SET4H2	JP Fuel Cells & Hydrogen	-	-

Figure 6. *Implementation landscape (2024)*
Source: SETIS, 2024.

IMPLEMENTATION PLANS

In the reporting period 2023-2024, the working groups on Solar PV, Concentrated solar technologies, Geothermal energy, Energy systems, and Batteries updated their implementation plans. Six other plans are currently under revision.

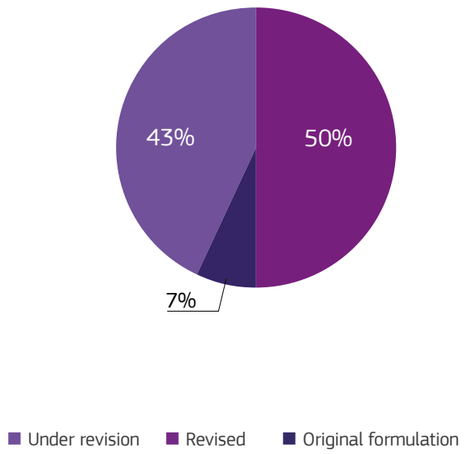
Six groups are currently working on their IPs, and the new TWG on Hydrogen is preparing its draft plan. The Nuclear group sees no need to revise its plan, which was formulated relatively recently and is still aligned with the current ambitions of the sector and of the EU. This brings the majority of implementation plans in line with today's policy and industrial goals.

***Table 1.** Status of the SET Plan implementation plans (link to the latest version in brackets).*

Under Revision	Revised	Original Formulation
Energy efficiency in buildings (2018)	Sustainable and efficient energy use in industry (2021)	Nuclear safety (2019)
Positive energy districts (2018)	Ocean energy (2022)	
Renewable fuels and bioenergy (2018)	Energy systems (2023)	
Carbon capture and storage – carbon capture and utilisation (2020)	Concentrated solar thermal technologies (2023)	
Wind energy (2022)	Solar photovoltaics (2023)	
Direct current technologies (HVDC - 2021; LVDC - 2024)	Geothermal (2023)	
Hydrogen (new under development)	Batteries (2024)	

Source: SETIS, 2024.

***Figure 7.** Status of the SET Plan implementation plans.*



Source: SETIS, 2024.

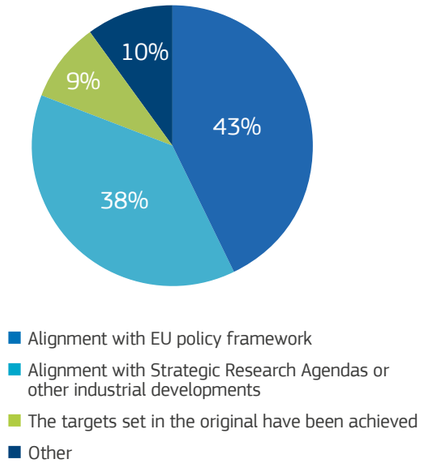
Of the 13 groups which have revised or are currently revising their implementation plans, nine have done so primarily to align their work with the current EU policy framework.

In the case of eight of these groups, a number of R&I activities also required revision to take into account updated Strategic research and innovation agendas and other key industrial developments. For a few of the groups, some of the original targets had already been met (e.g., Solar PV) or had become outdated (e.g., Wind and DC technologies).

Other reasons given by the working groups for revision include:

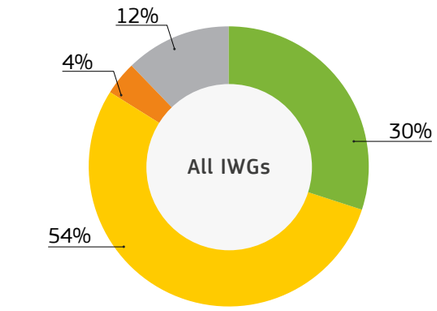
- Extension to include additional activities. In the cases of Wind, Geothermal, Concentrated solar technologies and Direct current technologies, the scope has been expanded to include additional technology areas.
- Inclusion of cross-cutting issues. Some groups have indicated that issues like skills, supply chain concerns, and advanced materials and processes have become increasingly important and will be included in the IP.
- Better identification of possible areas of collaboration and alignment of work with other IWGs.
- Defining R&I activities to be implemented at national level, which are also aligned with the ETIP's updated SRIA and the new EU ambitions.

***Figure 8.** Reasons for the changes.*



Source: SETIS, 2024.

***Figure 9.** SET Plan activities.*



Source: SETIS, 2024.

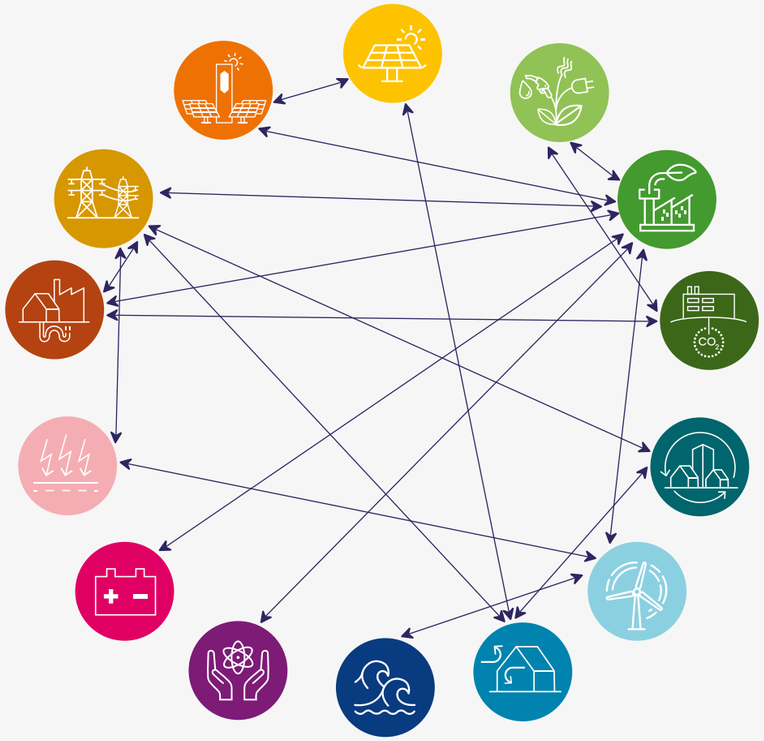
According to the latest approved implementation plans, there are 211 SET Plan activities, ranging from 4 to 30 per working group. The total number of activities has grown by 9, mainly covering the new expanded areas of some of the working groups. The IWGs classified the majority of these as ongoing (yellow), and some as already achieving results (green).

There are only 9 activities where work is delayed (orange) and 24 activities which have not yet begun (grey). The former is an improvement on last year, due to alignment of methodologies and project developments. The latter is technically a marginal step backwards, but this is mainly due to the introduction of new activities and the inclusion of some that are planned for the longer term.

COLLABORATIONS WITHIN THE SET PLAN

2024 has seen the greatest number of meetings and activities between working groups since the beginning of the SET Plan. In practice, all groups have established some contacts and collaboration with at least one other group. In addition, two of the strongest reported collaboration clusters appear around the Energy systems and Sustainable and efficient energy use in industry groups. The figure illustrates these collaborations, which were undertaken to align implementation plans and to address cross-thematic challenges.

***Figure 10.** Existing collaborations reported by the working groups.*

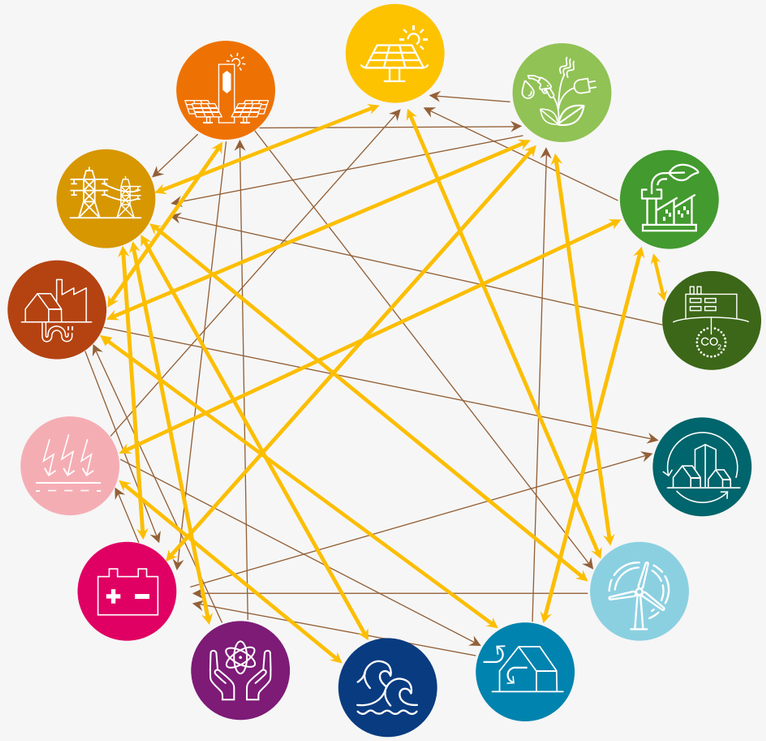


Cooperation has been established

Source: SETIS, 2024.

The working groups see the potential for yet more collaboration and integration between technologies. This confirms the trend towards establishing closer ties and breaking technological silos, a fundamental goal of the SET Plan. The task forces will work to further build upon this collaborative spirit.

***Figure 11.** Potential collaborations reported by the working groups.*



Would like to cooperate

Both would like to cooperate

Source: SETIS, 2024.

Collaboration with EERA

The collaboration between the working groups, the ETIPs and the European Energy Research Alliance (EERA) is well-established and active across various sectors. The majority of IWGs have strong ties with EERA, ensuring a harmonised approach to R&I priorities and cooperation with research stakeholders.

Some examples include:

- Close cooperation with EERA Joint Programmes (JPs) with regular exchanges of data, inputs, support on technical and technological issues, projects, and joint publications;
- The active participation of EERA representatives in IWG activities, contributing to reports and providing valuable information on sector developments; and
- Cooperation on updating R&I targets and activities, as well as coordinating R&D on innovative materials solutions. The expertise on development and qualification of materials for extreme operating conditions is important for a number of low-carbon energy technologies, which opens the way to further cross-sectorial collaboration.

While collaboration is well established in almost all areas, there are opportunities for further cooperation. This is true especially in the DC technologies and Energy efficiency in buildings groups, which report that currently, no active collaboration with EERA is in place.

Collaboration under the CETPartnership

The collaboration under the Clean Energy Transition Partnership (CETPartnership) is becoming more active and diverse across various sectors. Almost all working groups have established ties with the CETPartnership, ensuring alignment and coordination on R&I funding priorities.

Some examples include:

- Active participation in defining topics and collaborating on events and activities within CETPartnership's Transition Initiatives (TRIs);
- Strong collaboration on integrated energy systems, regional and local energy systems, and built environment integration, with a focus on digitalisation and interoperability; and
- Alignment on call topics, technological focus, and coordination of strategic priorities, as well as regular meetings to facilitate project presentations, information exchange on R&I activities, funding programme alignment, and opportunities for joint programming of R&I funding.

While the reported collaboration of many working groups is well established in many areas, there are opportunities for further growth, especially in DC technologies where there is currently limited collaboration, with no structural involvement or ongoing activities.

There are some emerging opportunities for further engagement in Wind and Energy systems. This includes a potential collaboration with the CETPartnership and Sustainable Blue Economy Partnership regarding the development of biodiversity solutions and nature-positive strategies related to the development of windfarms.

Batteries and Nuclear safety report that they currently have no active collaboration in place with the CETPartnership; this is a possibility worth exploring.

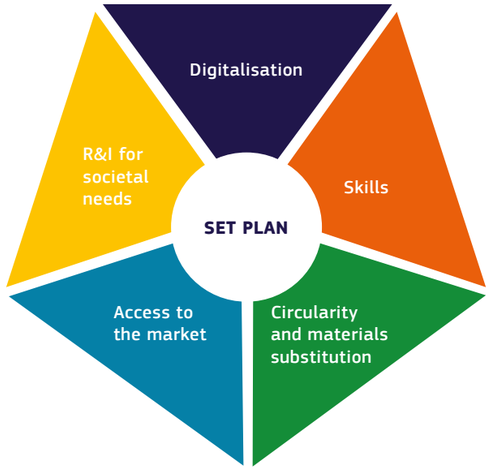
THE FIVE TASK FORCES

In line with the SET Plan revision and the 2023 SET Plan Communication, five SET Plan task forces (TFs) were officially established in 2024. They will support the work of the SET Plan IWGs and ETIPs and will play a crucial role in addressing cross-cutting challenges facing clean energy R&I at European level.

The task forces will address circularity and materials substitution, R&I for societal needs, digitalisation, skills, and access to the market. They will have clear objectives and key performance indicators (KPIs), and will deliver concrete outputs to tackle these challenges.

Each task force will be composed of representatives of key SET Plan stakeholders (i.e., the IWGs, ETIPs, EERA and CETPartnership), who will be the main driving force of the work. There will also be a number of independent Experts, as part of the contracted Support Office, and Commission representatives with observer status. The SET Plan Steering Group will oversee the work of the task forces, which will be required to report back on pre-defined milestones and contribute to SET Plan progress reporting.

Figure 12. SET Plan task forces.



Source: SET Plan Progress Report 2023.

Circularity and Materials Substitution

The production of clean energy technologies requires the use of significant quantities of materials whose supply is high risk and which may have a high environmental impact. The task force on circularity and materials substitution will focus on reducing the quantity of these materials required, and developing high-performance advanced materials as substitutes.

The task force will suggest ways to facilitate circularity by design, and identify opportunities for projects on recycling and reusing materials. It will also make recommendations regarding the development of new materials and technologies to reduce environmental impact in line with European policies and goals.

The task force will be guided by the following preliminary sub-categories:

- Promote a "circularity by design" approach;
- Improve the recyclability, reusability, and efficiency of clean energy (critical raw) materials and technologies;
- Address (advanced) material substitution to ensure the resilience of clean energy supply chains.

Related EU policy initiatives include the Critical Raw Materials Act, the 2020 Circular economy action plan, the Ecodesign for Sustainable Products Regulation, and the EC Communication on Advanced Materials for Industrial Leadership.

R&I for Societal Needs

Clean energy technologies must be aligned with the needs of consumers and can only be effective if widely adopted. The task force on R&I for societal needs will focus on integrating the requirements of citizens into technology choices, ensuring that investment is channelled towards technologies that will be widely accepted and used.

This task force will work to identify the needs and preferences of societal groups, and will develop tools and methods to ensure that these needs are taken into account in the development of strategic energy technologies. citizens It will be guided by the following preliminary sub-categories:

Address the need for increased public acceptance, engagement and participation;

- Understand and address public concerns such as energy poverty and health and safety (e.g. for workers);
- Adopt a user-centred approach that addressed accessibility and affordability (both in terms of cost and the knowledge needed for technology use).

Related EU policy initiatives include the European Citizens' Initiative and the Expert group on the economic and societal impact of research and innovation (ESIR).

Digitalisation

Digital technologies have the potential to play a major role in the transition to a low-carbon economy, and to enhance the way in which energy is produced and consumed. The task force on digitalisation will focus on driving the transition to cleaner, ever-more interconnected energy sources, and a more effective and efficient use of energy, including technological solutions for the reduction of losses necessary

The task force will be guided by the following preliminary sub-categories:

- Benefit from the application of Artificial Intelligence (AI);
- Foster the use of other digital tools to optimise operations in energy systems (balancing supply and demand, decentralised renewable energy sources, supporting electrification of energy-intensive industries, empowering consumers);
- Promote connectivity, interoperability and seamless exchange of data between different actors while respecting data security (e.g. cyber security, privacy and consumer projection).

Related EU policy initiatives include the EU Action Plan on digitalising the energy system[12], the European Strategy for data and the EU Data Act.

Skills

The transition to a low-carbon economy requires a workforce with the right skills and expertise. The task force on skills will work to identify skills gaps in strategic energy technology sectors and will develop recommendations, tools and methods to address these gaps. By identifying the necessary skillsets and priority areas for action, the task force can help to ensure that all stakeholders are prepared to efficiently support the transition to a low-carbon economy.

The task force will be guided by the following preliminary sub-categories:

- Identify the (new) skills needed to operate emerging technologies and facilitate the harmonisation and mutual recognition of skill requirements;
- Consider which job profiles require upskilling and reskilling;
- Develop and align training programs.

Related EU policy initiatives include the Pact for Skills, the Net-Zero Industry Act, and the European Net-Zero Industry Academies.

Access to the Market

The task force on access to the market will work to identify the barriers to market access for strategic energy technologies, and will develop tools and methods to address these barriers. By integrating cutting-edge industrial methods, standardisation measures, and financial needs into the R&I process of technology development, the task force can help to ensure that strategic technologies are developed to meet the needs of the market and to promote a more sustainable future.

The task force will be guided by the following preliminary sub-categories:

- Promote the development of investment projects for innovative technologies. Develop viable business models (embedding industrial needs) to attract investments and finance.
- Ensure that pioneers of technologies test manufacturability to embed industrial processes in technology development.
- Enable efficient decision making for investors and producers, including through pre-certification records and lifecycle assessment.

Related EU policy initiatives include the Net-Zero Industry Act, the Clean Industrial Deal, the EU industrial strategy, the Green Deal Industrial Plan, and the Report on the future of European competitiveness by Mario Draghi[13].

12 COM(2022) 552 final, Digitalising the energy system - EU action plan, *[link]*

13 Draghi, M., 2024, The future of European competitiveness, *[link]*

THE EUROPEAN ENERGY RESEARCH ALLIANCE

This section is an invited contribution from EERA and does not necessarily reflect the European Commission's official position.

The European Energy Research Alliance (EERA) was established in 2008 as the research pillar of the SET Plan. Through its 18 Joint Research Programmes (JPs), which bring together approximately 250 principal research institutes and universities across 31 countries, EERA actively contributes to the endeavours of the SET Plan, its IWGs and the ETIPs. EERA's mission is to catalyse European energy research, with the aim of achieving a climate-neutral society by 2050, through the delivery of best-in-class research on both technological and non-technological areas relevant to the clean energy transition.

Recent developments

The JPs are at the heart of EERA's contribution to the SET Plan, bringing together leading researchers and experts in clean energy transition and low-carbon energy technologies. As collaborative platforms, JPs facilitate knowledge exchange and idea sharing, guided by the principles of open science. This approach helps align R&I priorities across Europe and beyond, a remarkable achievement enabled by the SET Plan.

Over the years, EERA has actively contributed to the execution of the 10 SET Plan key actions, facilitating the transformation of the EU energy system, and has analysed, in depth, the cross-cutting issues within the SET Plan IWGs. It has also played a vital role in aligning funding priorities and shaping the Strategic Research & Innovation Agendas (SRIAs) of key European Partnerships. In collaboration with all JPs, EERA produced four key publications in 2023: the EERA Flagship report on Energy Demand Reduction, the EERA Critical Raw Materials Policy Analysis, the White Paper – A Just Energy Transition in the EU, and a Vision Paper on Energy System Modelling.

The launch of the RISEnergy project in early 2024 marked a significant milestone. With active participation from 10 JPs and 69 beneficiaries across 23 countries, RISEnergy aims to foster collaboration between research and industry and mobilise resources among stakeholders. Its main objective is to create a European ecosystem encompassing all areas of renewable energy technologies, advancing promising developments from the laboratory to industrial maturity. RISEnergy is the first joint research infrastructure project of this scale in Europe, covering all areas of renewable energy technologies: photovoltaics, concentrated solar power, hydrogen, biofuels, wind energy, ocean energy, integrated grids, energy storage, materials research, and information and communication technologies (ICT).

Cooperation and impact

One of EERA's most significant impacts is its crucial role in shaping the SET Plan's strategic planning and directing R&I efforts towards innovative technologies at both European and national levels. EERA members actively contribute to national R&I strategies, mobilise public and private funding, and contribute to the implementation and revision of the SET Plan's Implementation Plans (IPs). In 2024, EERA published a position paper on Framework Programme 10, advocating for a robust, competitive, and inclusive research environment that aligns seamlessly with the SET Plan's operations, ensuring coherence and effectiveness between the two initiatives.

Central to EERA's mission is fostering dialogue and collaboration among stakeholders in the clean energy sector. As concrete actions, EERA supports the National and Regional Coordination Group to enhance cooperation between Member States/Associated Countries within the IWG on Batteries (Action 7) and contributes to the secretariat of the IWG Sustainable and efficient energy use in industry (Action 6). It also plays a major role within the newly established, co-funded European Partnership, CONNECT-NM, on nuclear materials research.

Furthermore, EERA promotes collaborations across various SET Plan technology domains and facilitates alignment through the ETIPs FORUM platform. EERA has firmly established itself as a crucial link between EU policymaking and low-carbon energy research. It supports aligning the SET Plan with evolving EU policy priorities, such as the European Green Deal and Fit for 55 package, and translates these strategies into concrete R&I challenges. For instance, in 2023, EERA published its Flagship report on Energy Demand Reduction, emphasising the need to integrate energy demand reduction strategies into the clean energy transition. Additionally, the EERA Critical Raw Materials (CRM) Policy Analysis explored how vulnerabilities in the CRM supply chain could affect the EU's clean technology industry and the clean energy transition.

Challenges

The EU faces challenges in maintaining international competitiveness due to structural issues such as labour shortages, digitalisation struggles, infrastructure gaps, and the need for increased investment. Amid global shifts, the EU is increasing its efforts to ensure strategic autonomy. This requires the re-evaluation of trade, industrial, and R&I strategies in light of geopolitical tensions and economic uncertainties. The Commission has increasingly been emphasising this dimension, with policies like NZIA and CRMA. These topics are also central to the Letta report[14].

In this context, energy research is crucial for bolstering competitiveness within a clean energy transition framework. This topic is at the core of the EERA flagship report (October 2024), which examines relevant policies and legislation and uses case studies to highlight the importance of emerging low-TRL technologies for future competitiveness. It also reflects on the common challenges faced by industry and academia with more mature low-carbon energy technologies, leveraging a range of expertise across SET Plan IWGs.

According to EERA, another major challenge is integrating artificial intelligence (AI) with low-carbon energy technologies, which holds great promise to help achieve the energy and climate goals. AI can make the clean energy transition more efficient and faster, but significant challenges remain. The EERA community is currently working on a position paper addressing the most pressing issues in this domain.

Bridging the R&I gap between Member States is crucial to prevent disparities in low-carbon technology adoption, maximise R&I&D investments, and foster sustainable economic development. In this regard, the SET Plan should ensure equitable engagement from stakeholders across Europe and provide appropriate funding instruments to support the countries.

Future plans

Recognised as the research pillar of the SET Plan, EERA operates as an impartial and technology-neutral community of scientific experts. In this role, it can bolster the SET Plan within the clean energy transition by acting as a vital strategic advisor to EU policymakers. From this vantage point, EERA can enhance the SET Plan by offering informed, evidence-based input for decision-making and incorporating insights from the scientific community into the heart of the policymaking process. The SET Plan can further utilise EERA's JPs' outcomes to shape R&I funding frameworks, such as evaluating the implementation of the SET Plan. Additionally, with the newly established cross-cutting Task Forces, EERA aims to support their implementation and facilitate efficient input from its JPs.

As a concrete action in the Task Forces' workstream, under the Social Sciences and Humanities (SSH) Centre, EERA leads the analysis of all SET Plan IPs, aiming to provide SSH perspectives and insights to stakeholders and promote a transdisciplinary approach (e.g., merging SSH and STEM disciplines) across the SET Plan. The Task Force "R&I for societal needs" could capitalise on these results and integrate them into its work.

Efficient coordination between national and European R&I activities is crucial for achieving SET Plan goals. SET Plan countries should lead in aligning their R&I agendas with broader EU climate and energy policies, enabling stakeholders to access suitable funding and fostering a well-connected research and innovation ecosystem. To support this, the EERA JP Wind Energy has established the European Wind Energy Centre of Excellence (EuCoE4Wind) to foster collaboration in wind energy research across Europe. By encouraging knowledge and resource sharing, this platform will support effective wind energy research planning at all levels, ensuring alignment with the SET Plan and consideration of national specificities.

14 Letta, E., 2024, Much more than a market *[link]*

THE EUROPEAN TECHNOLOGY AND INNOVATION PLATFORMS FORUM

This section is an invited contribution from ETIPs FORUM and does not necessarily reflect the European Commission's official position.

The European Technology and Innovation Platforms (ETIPs) FORUM was created in June 2021 upon initiatives of all the ETIPs and "affiliated initiatives" (namely ESTELA and ETIP HYDROPOWER). The main goal of the ETIPs FORUM is to accelerate the execution of the SET Plan. The FORUM represents an informal platform where ETIPs' representatives and affiliated initiatives meet to discuss ETIPs' respective activities and potential common actions.

Recent developments

The ETIPs FORUM serves as a key advisory and coordination body within the SET Plan Community, providing targeted and unbiased R&I recommendations and helping to guide and facilitate the research, development and deployment of sustainable and low-carbon energy technologies in Europe. The ETIPs provide continuous support to their respective SET Plan working groups, playing a major role in their operation. In particular, they help to align national energy research agendas with EU R&I priorities, providing SET Plan country representatives with a research perspective. The ETIPs FORUM aims to share information about activities within the ETIPs and affiliated initiatives, and to identify related synergies. It also identifies, plans and carries out potential common activities and topics that can be better tackled together to create greater impact (for example, joint position papers on common challenges).

Furthermore, the FORUM defines mutually supportive communication and dissemination activities (such as joint participation in external events) and presents a united front to send joint messages (e.g., responding to Commission consultations). A key achievement of the past year has been the ETIPs FORUM, with the support of EERA, providing six joint recommendations on the draft National Energy and Climate Plans (NECPs). These recommendations focused on: setting a dedicated R&I budget in the NECPs to secure the EU's technology leadership in renewables; strengthening Europe's clean energy supply chains through the development of clean energy manufacturing; supporting the development of a skilled workforce; simplifying permitting processes to accelerate deployment and cost reduction; accelerating the deployment and optimisation of the European grid; and developing and harmonising policy measures to facilitate renewable energy data access.

Cooperation and impact

The ETIPs are open stakeholder groups driven by industry and research organisations that promote innovation, knowledge transfer and European competitiveness in the energy sector. The ETIPs represent and guide innovation funders and promoters by defining R&I priorities for different energy sectors, which are outlined in the Strategic Research and Innovation Agendas (SRIAs). These documents inform the individual SET Plan Implementation Plans (IPs) and their objectives.

Since its launch in June 2021, the ETIPs FORUM has been an effective platform to foster collaboration among all ETIPs and associated entities. It actively prevents thematic redundancy and duplication of effort, while promoting knowledge-sharing activities across the SET Plan. The FORUM provides a space for coordination in areas of common interest, ensuring that all stakeholders are part of a collective effort.

Furthermore, the ETIPs FORUM has been the banner under which ETIPs have participated in high-level panels at the annual SET Plan Conference and other relevant events, such as ENLIT Europe[15], European Sustainable Energy Week (EUSEW)[16], and SMARTER-E[17]. In these panels, the ETIPs FORUM has presented and discussed key outputs, including recommendations on the SET Plan revision and, more recently, joint recommendations on the draft National Energy and Climate Plans (NECPs), which have proved to be closely aligned with the Commission's own assessment of the draft NECPs.

In addition, the ETIPs FORUM has made a significant contribution to the organisation of ENLIT Europe 2023, the drafting of the programme of the EU project Zone, and participation in the ENLIT Impact Circle. Although ETIPs continue to work bilaterally and in small groups, the ETIPs FORUM provides a multilateral platform to bring together and consolidate the different perspectives of the various ETIPs stakeholders and to proactively address their common challenges.

Challenges

To promote inclusive and efficient collaboration, the SET Plan should undergo structural adjustments, supported by a clear governance framework. To achieve this, it is vital to clarify the roles of stakeholders and provide transparent descriptions of key actors' responsibilities. The current structure of ETIPs and SET Plan IWGs rightly focuses on technology-specific issues, which enables the development of individual technologies.

However, there are cross-cutting topics of concern to many IWGs that would be suitable for discussion in a wider group, such as the ETIPs FORUM. These topics may be non-technological in nature or relate to the energy system as a whole. Improving communication and collaboration among decision-makers and stakeholders is critical. The primary aim is to align priorities, such as the SET Plan IPs, national research and innovation agendas, roadmaps, and the specific and thematic goals of ETIPs. This alignment is essential for effective discussions and the integration of legislative proposals with research and development efforts.

In pursuit of this objective, ETIPs play a vital role through a range of value-added initiatives, including annual conferences, responses to public consultations, and material explaining their technology and its place in the energy system. The role played by ETIPs is unique and has proven to be pivotal in the functioning of the SET Plan. As the ETIPs FORUM, we believe it is imperative that they are provided with sufficient resources to enhance their effectiveness in the coming years.

Furthermore, the ETIPs FORUM has a unique capability to foster the exchange of information among its members. Its key contribution and challenge, given the rapidly evolving policy landscape, is to help align R&I cross-cutting activities for each IWG and the respective ETIPs, which will support the implementation of recent EU policy developments, including NZIA, CRMA, and the EU Green Deal.

Future plans

ETIPs play an essential role in fostering collaboration among diverse groups of stakeholders, both vertically (within the same technological domain) and horizontally (across different technological and non-technological domains). They accomplish this by effectively coordinating feedback from different stakeholders, like industry and the scientific community, thereby offering valuable input to the policymaking process.

In addition to providing recommendations to enhance the current collaboration structures of the SET Plan, ETIPs also undertake various actions within their areas of competence. The ETIPs FORUM aims to continue to amplify the voice of ETIPs and provide a platform for ETIPs to exchange ideas among themselves and with representatives of the Commission. Where relevant, ETIPs will use the FORUM to prepare joint positions or recommendations, as was the case recently when some ETIPs collaborated to define joint recommendations on the revised NECPs or wrote a joint letter to highlight the important role of ETIPs within the SET Plan and the need for continued funding of ETIPs under the Horizon Europe Framework Programme.

The ETIPs FORUM also plans to be a valuable partner in the newly established cross-cutting Task Forces of the SET Plan. In doing so, it will capitalise on the networks of individual ETIPs to identify relevant input related to technological and non-technological cross-cutting themes. Such collaboration will foster the alignment of efforts and facilitate the exchange of knowledge and expertise. Furthermore, the FORUM plans to participate in several future events to raise awareness of ETIPs' work and to bring the platforms closer to new and existing audiences. The path ahead for the SET Plan community entails harnessing the efforts and dedication of ETIPs, providing them with the opportunity to effectively articulate their pivotal role, and highlighting their notable accomplishments to fellow SET Plan stakeholders.

15 https://www.enlit-europe.com/
16 https://sustainable-energy-week.ec.europa.eu/
17 https://www.thesmartere.de/

INVOLVEMENT OF EUROPEAN STAKEHOLDERS IN THE SET PLAN PER COUNTRY

The involvement of all SET Plan countries is crucial for its success. According to the 2024 IWG reporting exercise, Germany and Italy are currently chairing or co-chairing four working groups, followed by Finland, active in managing the activities of three working groups. Austria, Belgium, France, and the Netherlands chair or Co-Chair two working groups each. Italian and Spanish organisations are in all of the SET Plan working groups, followed by Germany, France, Türkiye, Belgium, and the Netherlands.

Research, industrial, and academic organisations in all SET Plan countries demonstrate a strong commitment to collaborating on various initiatives within the SET Plan framework, contributing their expertise and resources to advance strategic energy technology development and implementation across Europe. However, as some working groups have highlighted in their reporting, the overall goal should be to increase the geographical spread to cover all SET Plan countries wherever possible.

★ Chair / ● Observer

- Solar PV
- CSTT
- Wind
- Geothemal
- Ocean
- HVDC & DC
- PED
- Energy systems
- Buildings
- Industry
- Batteries
- Renewable fuels and bioenergy
- CCUS
- Nuclear safety
- Hydrogen

Source: SETIS, 2024.[18]

18 The map is based on the working group 2024 reporting and is for visualisation purposes. The representation includes all SET Plan actors of the group from a given country (i.e., national institutions, industry, academia) and does not directly reflect the national representation and/or policy of each country.

THE WORKING GROUPS IN FOCUS

This section includes contributions from the SET Plan working groups and does not necessarily reflect the European Commission's official position.

SOLAR PHOTOVOLTAICS

In November 2017, The SET Plan Steering Group endorsed the IP for Photovoltaics (PV). Following this, the Implementation Working Group on PV (IWG PV) was established in early 2018.

One of the main topics of the IWG PV's work was the monitoring of national RD&I activities. The aim was to examine the focal points of activities within the IWG's member states and regions, and to describe the scope of these initiatives. As a first outcome, an internal report was drafted in December 2018. An updated version was published in March 2019, with a further update released in 2023.

The main achievement in 2023 was the final publication of the new Implementation Plan, as well as networking in the Clean Energy Technology Partnership (CETPartnership).

The new 2023 PV Implementation Plan is now aligned with the ETIP PV SRIA. Together, the Implementation Plan and SRIA form a comprehensive system for the European PV research community.

Recent developments

Some recent developments of the group are as follows.

- The IP has been revised and was published on SETIS and on the IWG PV website[19].
- Following the appointment of a new Chair and changes to the membership structure of ETIP PV, regular monthly exchanges have been re-established between the IWG and the ETIP.
- In May 2023, Dr. David Moser was elected as the new Co-Chair of the IWG PV, succeeding Prof. Dr. Wim Sinke, who has retired.
- The IWG PV has maintained close ties with the CETPartnership to coordinate input for future PV calls and topics, and to participate in discussions and workshops on Co-Partnerships and cross-cutting topics, such as the development of a joint solar energy research agenda.
- The IWG PV website has been updated.

Status of the implementation plan

A new topic structure has been adopted, based on the 2022 ETIP PV SRIA, with the following topics:

- Performance enhancement and cost reduction;
- Enhancing lifetime, reliability and sustainability;
- Diversified application and integration;
- Smart energy system integration; and
- Socio-economic aspects of the transition

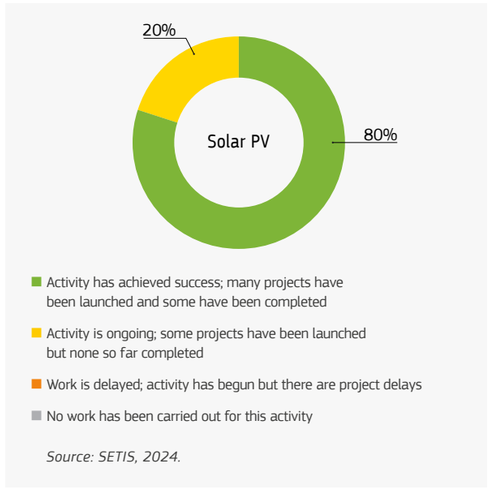
PV is a key building block in a number of overarching European energy transition challenges, including:

1. Enabling rapid and very large-scale deployment in a sustainable manner:

- Further reducing the levelised cost of electricity in a sustainable manner, to keep/make PV competitive in all parts of Europe, taking into consideration the additional costs of integrating the energy system into the living environment.
- Making PV available for a wider range of applications, with an emphasis on flexible integration (buildings, infrastructure, etc.) and dual functionality (agro-PV, etc.), as well as floating systems.
- Making PV components and systems circular.

2. (Re-)building the strategic value chain for PV by exploiting Europe's technological leadership:

- Manufacturing high-performance, circular products.
- Deploying PV on a large scale in a wide range of applications.
- Integrating PV into the energy system.



Source: SETIS, 2024.

Additionally, technical parameters have been redefined, as some targets have been partially achieved.

Status of the activities

According to the new structure of the IP, four of the five activities have projects that have already produced results while the "socio-economic aspects of the transition" activity is ongoing.

European PV research and modern manufacturing processes are still largely up to date globally. Current funding targets aim to re-establish a European PV production industry, utilising new high-efficiency technologies, and further increase and accelerate installation numbers. Plans for this re-establishment are already under development, and PV installations are increasing, in some cases, at a faster rate than ever before

Due to increasing land-use conflicts, integrated PV solutions (such as building-integrated photovoltaics (BIPV), floating PV, and agro-PV) will play a crucial role in the future. Nevertheless, there are still very few solutions available on the market. Most existing solutions are bespoke and individual, particularly for integrated PV. The sector requires significant standardisation and the development of planning tools. Current funding initiatives support these actions, but market penetration is much lower than for standard modules, resulting in delays. The production of inverters for solar PV is also receiving attention, with dedicated funding programmes being implemented, such as the one in Germany.

19 https://www.iwg-pv.eu/implementation-plan

Challenges

The main challenge is to (re-)build a complete strategic value chain for photovoltaics (PV) in order to support the climate targets and accelerate the installation numbers in the EU. In addition, this rebuilding will play a key role in achieving independence and resilience from the currently dominant Asian market. Furthermore, cross-cutting topics and energy system integration are increasingly gaining significance. Therefore, closer collaboration between the sectors (energy supply, integration, and grids) will be necessary in the future.

Future plans

Expectations remain largely unchanged from the 2023 SET Plan report. The working group on solar PV is prepared to support all measures that strengthen the role of the SET Plan and its implementation plans, particularly in relation to a more strategic orientation of EU and national research, development and innovation (RD&I) policies in the energy sector. This is especially relevant in the context of climate change mitigation targets and the current energy supply crisis.

Synergies

The integration of PV into European energy systems is of growing interest. Consequently, collaborations with other IWGs are becoming increasingly important. While contacts have already been established with the IWGs for Concentrated solar thermal technologies and Energy efficiency in buildings, further efforts to collaborate with the groups on Energy systems and possibly Wind energy could be beneficial.

CONCENTRATED SOLAR THERMAL TECHNOLOGIES

The IWG on Concentrated solar thermal (CST) technologies is chaired by Spain in close collaboration with member representatives from eight other European countries and with the active participation of the most relevant stakeholders in the sector at the European level.

The aim is to boost CST technologies as a contributor to EU energy strategies. Ambitious targets have been defined under the CST IP to maintain the EU's global leadership in CST technologies, with a particular emphasis on driving down costs and improving performance. Moreover, it is crucial that innovation, such as the development of new technologies reaching the market, takes place in Europe to maintain investors' and promoters' confidence in European CST technologies.

CST has significant potential to achieve a high level of renewable energy penetration and to facilitate the integration of variable output renewables (such as PV or wind), thereby contributing to the reliability and stability of the transmission grid. A major advantage of CST power plants is achieved by integrating large high-temperature heat storage systems, enabling the provision of dispatchable solar power around the clock at competitive prices, regardless of solar radiation. Furthermore, industrial processes can also be decarbonised through CST at costs lower than those of renewable fuels or electricity-based options.

Recent developments

CST4ALL[20], the associated Coordination and Support Action (CSA) to the working group, aims to catalyse a range of hybridisation and cooperation initiatives at the interface between CST and other renewable energy technologies, targeting the electricity, heat, and fuels sectors. CST4ALL is organising a series of parallel workshops targeting both the industrial and R&I communities to develop specific proposals at EU level from a cross-sector perspective, with the aim of fostering public/private funding for R&I and creating the necessary political and regulatory framework conditions for the execution of the updated CST Implementation Plan. The project has organised three online workshops in collaboration with ETIPs and sectors covered in the SET Plan, specifically:

- Cross-cutting materials challenges of renewable energy technologies;
- Industry workshop on the hybridisation of CST with PV; and
- R&I challenges for the hybridisation of CST with other renewable energy technologies.

CST4ALL has also delivered a project report detailing the non-technological framework conditions offered to cross-technology R&I activities and industry projects. Once approved by the Commission, the report will be shared with Member State representatives of the CST IWG, who are key actors in addressing the shortcomings in the current non-technological framework conditions described therein.

A key development for the working group is the ongoing expansion of its scope of activities to include both concentrated and non-concentrated solar thermal technologies. Following the call for expressions of interest to join the expanded IWG, relevant stakeholders will work together towards a smooth transition to an integrated Implementation Plan in the future, covering all solar thermal technologies.

Status of the implementation plan

The European CST sector is ready to contribute to the ambitious objectives of the current EU energy policy. As a mature technology, CST is well-positioned to provide bulk storage capacities at competitive costs, thanks to its large high-temperature thermal systems. This offers flexibility to the electricity system, enabling the supply of large amounts of synchronous power at any time (day and night) and dispatchable renewable electricity. New strategic targets have been agreed upon, focusing on cost reduction and efficiency, as well as other capabilities of the technology, which extend beyond power generation to include solar heat production and storage of medium and high temperatures for industrial processes and the production of solar fuels. Seven areas of R&I activities have been identified, leading to the definition of 18 R&I activities. The lessons learned from the Spanish auction and recommendations to Member States on auction design have been incorporated into the updated Implementation Plan, along with considerations on non-technological framework conditions for Concentrated Solar Power (CSP)/CST.

The IWG is now expanding its scope to include Non-Concentrated Solar Technologies (NCST). This sector is currently developing its own Implementation Plan, which will be included as an annex to the CST IP. This work is expected to be completed in 2024.

Status of the activities

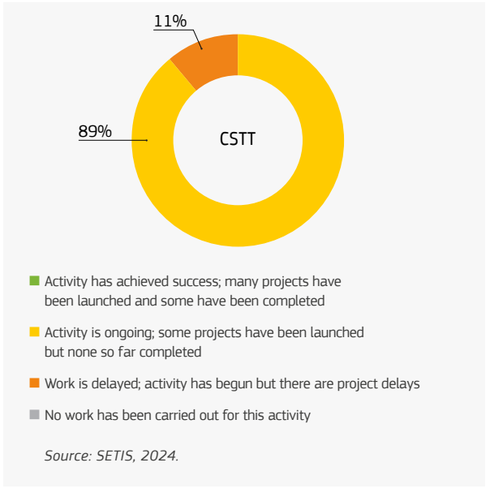
The CST group has 18 activities split into seven areas. The majority are ongoing, while two are reported as delayed/not yet begun. The seven areas are:

1. Line-focus solar power plants technology;
2. Central Receiver power plants technology;
3. Reliable and cost-effective heat transfer medium and high-temperature thermal storage systems;
4. Turbo-machinery developed for specific conditions of solar thermal power plants;
5. Medium-and high temperature systems for industrial solar heat applications;
6. Thermochemical production of solar fuels and hydrogen; and
7. Cross-cutting issues.

The activities of **Area 1** are progressing reasonably well. The most significant achievement in this area is the successful development and validation of a new silicon fluid. This fluid has the potential to bring about significant improvements in efficiency, environment, and safety in both future and existing parabolic trough power plants, replacing traditional heat transfer fluids (HTF).

Regarding Activity 1.1, the most notable step in 2023 was demonstrating the safe and efficient operation of a 3.5 MWth parabolic trough plant (684 m long, HelioTrough 2.0). This plant uses molten salt as a heat transfer and storage medium (2-tank, 3 hours capacity at ΔT = 280 K) and includes a steam generator (1.6 MWth, 140 bar steam pressure). Other notable progress in this area includes:

- Defining and validating operation and maintenance (O&M) procedures for the operational management of solar fields (e.g. filling, draining, repairing leaks, revitalising frozen parts, etc.);
- Characterising dynamic corrosion in critical components exposed to low-melting molten salt mixtures;
- Evaluating available salt mixtures for commercial plant operation;
- Gaining a better understanding of the interaction between molten salts and electrical resistances at high temperatures;
- Developing a newly synthesised molten salt with a larger operating temperature range for line-focus systems, which could help reduce operational costs; and
- Creating a fix-focus parabolic trough with an independent concentrator and fixed absorber tube using molten salt as HTF.



Source: SETIS, 2024.

Concerning Activity 1.2, one project (SING) concluded in 2023, while another (Si-CO - CSP ERANET Call) is ongoing. The main objective of this project was to accelerate the ageing of a new silicone fluid (Helisol XLP) under real solar conditions at PSA. In 2023, this silicone oil was tested for 270 hours at 440°C as part of a proof-of-concept test. Despite the project's expiration, it is expected to complete the remaining 210 hours at that temperature and conduct overheating tests at 450°C (50 hours) in 2024. Another related project, Si-CO ('High-performance parabolic trough collector and innovative silicone fluid for CSP power plants'), aimed to develop a new parabolic trough collector (PTC) designed for the higher concentration and working temperatures allowed by silicone oils. In 2023, a new ray-tracing model was developed for determining the incidence angle modifier function of the new PTC prototype, which has been erected at PSA and will be tested in 2024.

All activities in **Area 2**, with the exception of Activity 2.3, are progressing reasonably well. Notably, there is a high level of interest and activity around Activity 2.2, with many research organisations and companies working on developing innovative concepts, materials, and components for central receiver molten-salt technology. This is evident in the large number of projects and initiatives currently underway. However, Activity 2.3 has received more attention outside of Europe, particularly in the US, with European industry interest appearing to be relatively minor. As a result, only a few research organisations are currently working on this topic.

20 https://cst4all.eu/en/

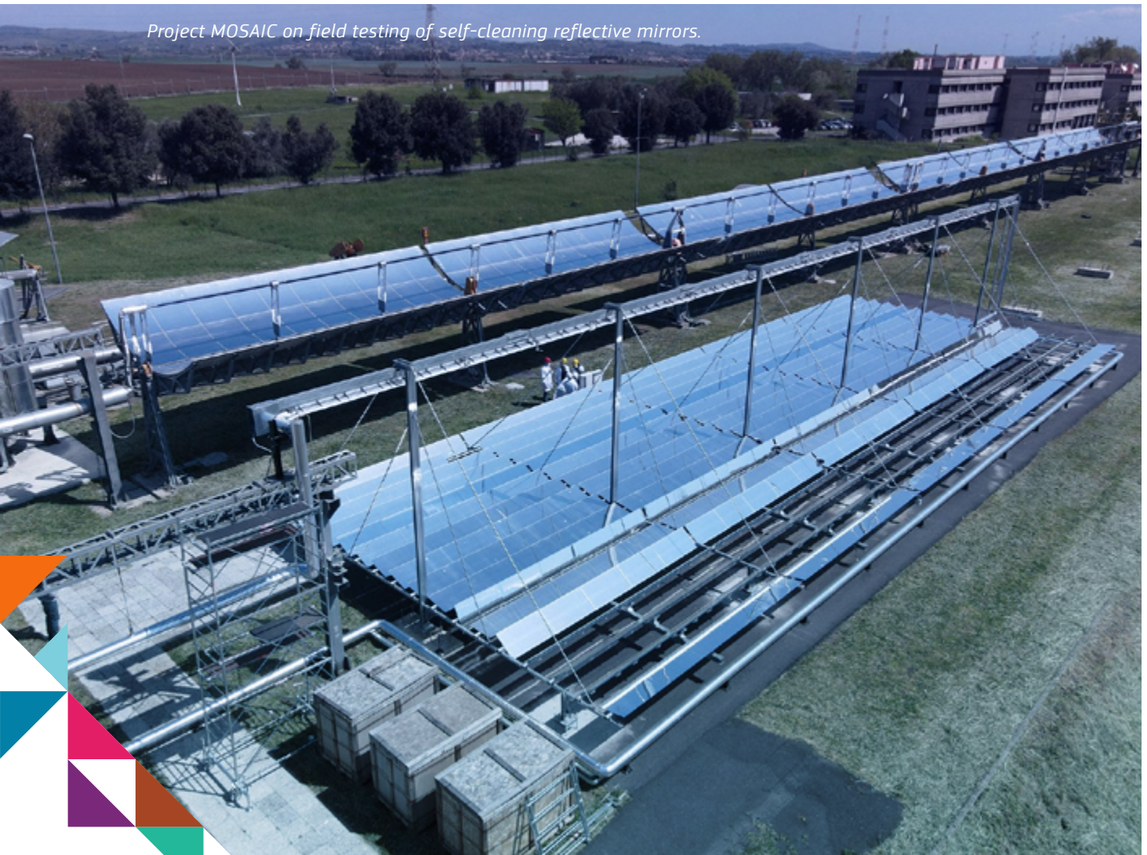
Funded by the European Union's Horizon Europe research and innovation programme under Grant Agreement No.101075408.

Key achievements in Activity 2.1 and related projects include:

- Developing selective coatings for solar tower receivers (INTECSOL project);
- Creating an advanced Computational Fluid Dynamics and Heat Transfer (CFD&HT) code for simulating central receivers for CSP. Key achievements include:
  - Consolidating an algebraic framework (HPC2) for simulating CSP plant central receivers; and
  - Conducting performance analyses on different supercomputers (MareNostrum4, Marconi, HAWK, Fugaku) using various architectures (CPU, CPU+GPU, ARM) (RETOtwin project);
- Characterising key components of tower plants using molten salts and optimising heliostat sun tracking using innovative algorithms and operation methods (SFERA III project);
- Optimising the operation and control of tower plants, including aiming strategies and flux determination, for specific receiver layouts (OPTOP project); and
- Optimising heliostat design by characterising wind loads and wind-induced responses of heliostat structures, improving availability and tracking efficiency against wind action in any orientation (HELIOPTIM project).

Key achievements in Activity 2.2 and related projects include:

- Developing the next generation of innovative, reliable, and intelligent CSP plants focused on new solutions for tower technology using molten salts (LEIA project). Core targets include:
  - Automating and improving the characterisation and calibration of large heliostat fields;
  - Developing predictive operation and maintenance tools for automated inspection of dirt distribution in large heliostat fields using drones or cameras; and
  - Integrating developed solutions and processing information in real-time to improve targeting and operation strategies.
- Developing the next generation of central receiver CSP plants with advanced high-density and high-temperature thermal energy storage (TES) systems using molten salt as HTF at 600°C (HYBRIDplus project);
- Developing and deploying a universal flux density measurement system for large-scale external and cavity receivers with high-performance image processing (TOPCSP project);



Project MOSAIC on field testing of self-cleaning reflective mirrors.

- Successfully combining thermionic energy conversion with molten salt storage for the first time (TRL3/4) (TECSAS project);
- Developing innovative concepts and systems for flux characterisation, optical characterisation of heliostats, and soiling monitoring in heliostat fields to achieve high-solar flux densities (SFERA-III, HECTOR projects);
- Developing a low-cost heliostat with adaptive optics to reduce CAPEX in central receiver power plants (SmartHelio project); and
- Improving heliostat fields for multi-tower configurations and demonstrating improved heliostat field efficiency through in-situ calibration during operation (Solbeado and HelioDEMO projects);

Key achievements in Activity 2.3 and related projects include:

- Developing and testing particles (with and without coating) for solar tower systems (COMPASsCO$_2$ project);
- Demonstrating a MW-scale fluidised particle-driven CSP prototype (Powder2Power project); and
- Developing a silicon carbide solar receiver for high-temperature gas-particle processes (SiCSun project).

All activities in **Area 3** are progressing reasonably well, with a notable number of ongoing projects, particularly in the area of next-generation thermal energy storage (TES) technologies (Activity 3.2). The most significant achievement in this area is the successful completion and full operability of the Évora Molten Salt experimental Platform (EMSP), which will significantly contribute to research advances in the near future (Activity 3.1).

Key achievements in Activity 3.1 and related projects include:

- The development and installation of a novel concrete-based thermocline TES system, compatible with molten salt and high temperatures, with a capacity of 28m3 (NEWSOL project). The system, integrated into a hydraulic loop, was installed on the Évora Molten Salt Platform, with a capacity of 2.9 MWh operating at 500°C/ΔT = 210K. The system will be hybridised, allowing charging via conventional heat process (CSP) or electricity via the Joule effect (PV field of 70 kWp to be installed).
- The development of a new structured thermocline and multi-layered phase change material (PCM) system (NEWCLINE project). Key achievements include:
  - The development of detailed simulation codes for structured thermocline systems;
  - The development of filler material based on waste products of the steel and aluminium industries;
  - Analysis of the application in commercial plants;
  - Investigating filler configurations for application in packed bed storages; a 90kWh prototype demonstrated high performance (FENOPTES project);
  - Defining a protocol to evaluate the performance of molten salt thermocline storage systems (SFERA III project); and
  - The assessment and evaluation of the impact of using different carbonate molten salt mixtures in thermocline energy storage systems, targeting corrosion protection (News4CSP project).

Key achievements in Activity 3.2 and related projects include:

- The development of a novel approach for high-temperature (>1000°C) solar heat storage with high energy density (>300 kWh/m3) and its integration into next-generation power tower CSP plants (ABraytCSPfuture project);
- The development of an innovative thermochemical battery based on a directly irradiated fluidised bed autothermal reactor (DIFBAR) for thermochemical energy storage (RETHEBES project);
- The development of macro-encapsulated thermochemical energy storage based on Ca(OH)2 and perovskite pellets for high-temperature thermochemical energy storage (ACES2030 Project);
- The integration of high-temperature (> 900°C) solar heat from particle receivers to drive a thermochemical cycle yielding solid sulphur as a high-density/low-cost storage media (SULPHURREAL project);
- The development of a phase change storage system, leveraging metal wools to enhance thermal conductivity, coupled with a PCM cascade system designed to efficiently store thermal energy from diverse heat transfer fluids (HYBRIDplus project). A 100 kWh pilot plant is currently under construction, expected to be operational in 2025;
- An innovative double-tank storage system using low-melting ternary salts for process heat, with an electric heater for integration into renewable energy-powered processes (HIBRIDA project);
- The development of an innovative heat storage

system optimised for connection to a hydrogen production process (PROMETEO project);
- The development of an innovative thermochemical cycle based on solid sulphur for integrated long-term storage of solar thermal energy (SULPHURREAL project);
- The development of a combined heat PCM storage for solar process heat at medium temperature (FRIENDSHIP Project);
- Packed bed/air storage with optimised material consumption (LuftBlock project); and
- Low-cost and high-temperature molten salt storage (LoCoMoSa project).

All activities in **Area 4** are progressing reasonably well. The most significant advancement in 2023 is the successful development of an innovative working fluid for supercritical CO_2 cycles (Activity 4.1). Although the potential impact of the activities in this area is high, the current Technology Readiness Level (TRL) development status is still low.

Key achievements in Activity 4.1 and related projects are as follows:
- The SCARABEUS project has been completed, achieving some of its main objectives. The innovative power block adopting CO_2 blends can increase thermal to mechanical conversion efficiency above pure CO_2 fluids. The adoption of this innovative fluid can reduce the Levelised Cost of Energy (LCOE) by more than 10% compared to state-of-the-art technology. Innovative heat exchangers and air-cooled condensers have been developed and tested at TRL 6, with higher heat duty per unit of volume, reducing their cost by more than 10%.
- An innovative expander screw machine has been developed to be coupled with a Scheffler receiver. A laboratory prototype has been defined for a small-scale solar power plant (10/100 kW electrical power), constructed and successfully tested.
- Improved steam cycle layouts have been developed to improve flexibility and reduce the cost of the CSP plant power block (TOPCSP project).

Key achievements in Activity 4.2 and related projects are as follows:
- A demo plant design, including the power block, has been designed and constructed. The components design is almost complete and in the process of manufacturing. The performance achieved in SCARABEUS has been confirmed in this project (DESOLINATION project).
- A 2 MW-scale integrated sCO_2 power block system has been demonstrated, coupled to the Molten Salt CSP solar field supported by fast-reactive electric heaters at the Évora Molten Salt Platform (SOLARSCO2OL project). The project addresses sCO_2 cycles as a key enabling technology to promote the deployment of CSP plants and targets demonstration at the MW scale. Specific achievements include:
  - The definition of SOLARSCO2OL Demo layout; and
  - The pre-design of the sCO_2 Turbine, the sCO_2 Compressor, the HEXs, the electric heater, and material compatibility.
- A high-performance sCO_2-air heat exchanger has been developed to couple CSP plants with a sCO_2 power cycle. The project addresses the CSP-sCO_2 power cycles using air as an operating fluid, targeting the demonstration of the techno-economic viability of air-driven/sCO_2 CSP cycles (SHARP-sCO_2 project).
- A novel PV+CSP plant concept has been developed, featuring an electrified PCM thermal energy storage system in cascade configuration coupled with a high-temperature supercritical CO_2 power cycle (HYBRIDplus project).
- A sCO_2 power cycle model has been developed to work with modified working fluids (CO_2 with additives in a limited quantity), with higher efficiency and lower cost compared to state-of-the-art solar tower technology (TOPCSP project).

Under **Area 5,** the topic of industrial process heat (Activity 5.1) is currently experiencing a high level of activity, with significant interest from industry and a notable number of projects underway. Innovative solar collectors have been developed to provide process heat to industrial processes, with the potential to lead to the construction of large commercial plants in Europe and worldwide. Activity 5.2 has a lower level of development, but the number of ongoing projects is still reasonable.

Key achievements in Activity 5.1 and related projects are as follows:
- A novel Quasi-Stationary compound parabolic collector (CPC) collector has been developed for industrial process heat applications (SHIP project). Key achievements include:
  - The successful demonstration of the optical and thermal performance of the concentrator on UEVORA's 2-axis testing platform; and
  - The successful deployment of a solar field

on the rooftop of KEMET Company in Évora, Portugal.

- Additional achievements and related projects include:
  - The application of thermal energy storage (TES) technologies for industrial heating (Newcline project);
  - The application of concentrating photovoltaic thermal (CPVT) systems for industrial medium-temperature applications (ECOSUN project);
  - The development of standardised components for modular concentrated solar thermal (CST) system configuration, reducing complexity and levelised cost of heat (LCOH) (Modulus project);
  - The optical and thermal characterisation of the new concentrating prototype collector COSMOS with pressurised water up to 160°C according to standard ISO 9806 (COSMOS project);
  - The successful design and testing of a bespoke solar concentrator for the production of solar steam, including the design of an optimum integration scheme for the balance of plant (BoP) of an solid oxide electrolyser (SOE) including CST and energy storage (projects: HUB MADRID+CIRCULAR, PROMETEO, GREENH2-CM);
  - The experimental evaluation of the rejection factor of different membranes in a nanofiltration (NF) plant for the pre-treatment of multi-effect distillation (MED) plants, aiming to improve the efficiency of the desalination process in a circular economy context, and obtaining high-quality salts (WATER-MINING Project); and
  - A thermal energy storage prototype to provide solar process heat in industrial applications (MANOEUVRE project).

Key achievements in Activity 5.2 and related projects include:
- The successful demonstration of the production of cement clinker at a solar tower (EFESTO-C Project).
- The treatement of Aluminosilicate clay kaolin in a solar reactor to produce metakaolins, which are eligible as precursors for zeolite synthesis. Results show that solar-calcined kaolin was as good and efficient as conventionally calcined kaolin in terms of supplying metakaolin for zeolite synthesis, suggesting that solar calcination is a viable alternative for mass-producing meta-forms of minerals for use in the synthesis of value-added products such as zeolites (SolarTwins Project).
- The successful use of hydrogen as a reducing reagent to obtain particular metals from their respective oxides using concentrated solar energy (Alchemist project).

The main achievement in **Area 6** has been the successful thermochemical production of hydrogen in a solar receiver with all necessary peripherals (heat exchangers/recuperators, etc.) at TRL 7 on a solar platform facility (Activity 6.2). The concept of facilitating H_2 production

HYDROSOL CRS tower during testing operation of the receiver for hydrogen production.

from water splitting using high-temperature solar heat to power the high-temperature process of the 2-step thermochemical cycle was demonstrated at 150200 kWth. However, Activity 6.3 has received more attention outside of Europe, particularly in the US, with European industry interest appearing to be relatively minor. As a result, only a few research organisations are currently working on this topic.

Key achievements and related projects of Activity 6.1 include:

- The development of new structured ceria materials for the thermal production of liquid fuels using the solar tower and heliostat field with enhanced optical performance of IMDEA (SUN-to-LIQUID II Project); and
- The development of materials based on 3D printed black zirconia with ceria coating for the characterisation of solar fuels production with concentrated solar energy (H2Green project). A successful experimental campaign was conducted with the support of the SFERA-III project.

Key achievements and related projects of Activity 6.2 include:

- The successful development and demonstration of structures from redox material to facilitate H_2 production from water splitting using high-temperature solar heat (from concentrated solar thermal power) to power the high-temperature process of the 2-step thermochemical cycle. The concept demonstrated the production of hydrogen from the dissociation of water via a redox-pair-based thermochemical cycle, at a 150-200 kWth experimental plant with a solar receiver and necessary peripherals (heat exchangers/recuperators, etc.) on the PSA solar platform (HYDROSOL-beyond Project).
- The dynamic simulation and control of a continuous gasifier for Solar Fuels production (SMARTSOL Project).

Key achievement and related project of Activity 6.3 include:

- The development of detailed simulation codes for designing thermochemical reactors with arbitrary geometry using non-structured meshes (Spanish project).

All activities in **Area 7** are progressing reasonably well. The most significant advancement in 2023 is the successful development of software tools for heliostat characterisation, heliostat calibration, and flux monitoring based on optimised algorithms and AI techniques, improving knowledge about the plant status and enhancing plant operation results and procedures (Activity 7.1).

Key achievements and related projects of Activity 7.1 include:

- The development of software tools using various prototypes and hardware implementation projects based on optimised algorithms and Artificial Intelligence techniques to improve plant performance by calculating optimal aiming point strategies (to guarantee receiver integrity) and designing components such as receivers or solar fields. Among these projects developed in 2023 are heliostat characterisation (Helioschar+ project), heliostat calibration (SHORT project), and flux monitoring (HolisticFlux project). These systems enhance plant operation, providing a more accurate knowledge of the plant state and allowing for corrective action.
- The design and development of "Intelligent" software capable of displaying a map with solar thermal power plants accurately, thanks to Artificial Intelligence. The system will be fed with Big Data information from all areas of a plant in an agile way and will obtain the relevant Key Performance Indicators (KPIs) for the industry (both automated data sources and those currently obtained manually) involved in achieving strategic objectives of the different areas that make up the comprehensive management of said facilities, facilitating control of the facilities (VISION 4.0 PLATFORM project).
- The successful development of common procedures combining virtual and physical operation of the HPS-2 loop, real-time plant monitoring system using Digital-Twins technology, and real-time long-term tracking of parabolic trough systems using molten salt as a heat transfer fluid (EuroPatMoS Project).
- Improved and more efficient heliostat fields for solar towers (HELIOSUN Project).

Key achievements and related projects of Activity 7.2 include:

- The development of nanomaterials for reduced maintenance costs in CSP plants. Several different coatings were tested for CSP mirrors, particularly for coastal locations like those in the PROTEAS Facility (Nano4CSP Project).
- The development of a new coating to boost the performance and durability of solar receivers and

mirrors based on a specifically tailored structure on the glass surface, providing key unique functionalities, such as omnidirectional Anti-Reflective (AR) coating, antifogging, anti-soiling, and improved durability (Funglass project).
- The development of anti-soiling coatings for mirrors, anti-reflective/anti-soiling coatings for PTC cover tubes, and selective coatings for Solar Tower receivers (INTECSOL project).
- Developing and testing copper-free mirrors (MIRAGE project).
- Indoor and outdoor ageing tests and characterisation of copper-free heliostat mirrors (SolarTwins Project).

Key achievements and related projects of Activity 7.3 include:
- The development of a cost-effective Concentrated Photovoltaic Thermal (CPVT) hybrid technology (ECOSUN project).
- The integration of several renewable energy power supply systems (RES) into a single Virtual Power Plant (VPP) to provide grid operators with the knowledge, models, and tools for the control and management of VPPs (POSYTYF project).

Key achievements and related projects of Activity 7.4 include:
- The development of a novel concept of a high energy density micro-thermal energy storage (μTES) dedicated to small-scale electricity production applications based on concentrated solar power (CSP) systems. The goal is to develop, test, and validate an efficient TES with a higher than ambient heat pump (HP) heat transfer fluid (HTF) inlet temperature achieved with a solar CSP. The new TES is expected to achieve a large energy storage density, minimum response time, highest roundtrip efficiency, and cost viability (INNOSOLPOWER project, "Innovative Solar Micro-TES with high power density").
- The combination of compressed air energy storage (CAES) with CSP, to increase the fraction of variable Renewable Energy (RE) in the electrical system. The concept is being investigated in the ASTERIx-CAESar project with the following main developments to be validated with a demonstration-scale prototype of 480 kWth: (i) an advanced high-efficiency solar receiver, (ii) optical sensors and AI-based solar flux control, (iii) optimised CAES with heat exchangers and compressor/expander detailed designs, and (iv) innovative integration of desalination.

Challenges

The CST industry faces numerous challenges, ranging from technological advancements and cost competitiveness to regulatory support, in order to achieve the strategic targets outlined in the updated CST Implementation Plan.

One of the key techno-economic challenges is to improve the performance and cost efficiency of CST technologies, enhance thermal energy storage solutions, and integrate with other renewable energy technologies. Recent developments in non-technological framework conditions at the EU and national level, such as the electricity market design reform, the revision of the Renewable Energy Directive (RED III), the draft updated NECPs, NZIA, and financing mechanisms, are relevant to the adoption of CST. More specifically:
- EU-wide assessment of the draft updated NECPs and country-specific recommendations by the Commission;
- Implementation of the 5% indicative target for innovative renewables in RED III and interpretation of "innovative renewable technologies" by Member States;
- Member States' flexibility in choosing technologies for their energy mix and designating strategic projects based on net-zero technologies within the NZIA framework;
- Inclusion of non-price pre-qualification and award criteria in renewable energy auctions; and
- Joint renewable energy projects between Member States using cooperation mechanisms.

Future plans

The CST4ALL project will actively seek collaboration opportunities with other renewable energy sectors. The project plans to undertake the following activities:
- Online industry-focused workshops on the hybridisation of CST with other technologies, targeting areas such as biomass, heat pumps, geothermal, and batteries.
- Online R&I-focused workshops on cross-cutting issues related to Meteorology and Future Energy Mix with a 100% Decarbonisation Level.

At the IWG level, the transition to an integrated Implementation Plan covering both concentrated and non-concentrated solar thermal technologies is a challenging process that offers a great opportunity to capitalise on their synergies. To achieve this, it is essential to track advancements in these technologies and prepare a unified IP that establishes a comprehensive and cohesive strategy for all solar thermal technologies. This requires close collaboration among stakeholders, including Member States representatives, funding agencies, research institutions, and industry players. The aim is to coordinate R&I efforts to address both common and technology-specific challenges, increase technology attractiveness, leverage synergies, and explore ways to overcome existing regulatory and financing barriers.

The CST IWG is also working closely with the Commission and the PV IWG to define the Solar Strategic Research and Innovation Agenda (SRIA). It will highlight the importance of Solar Thermal Technologies and their contribution to the decarbonisation of the energy system, particularly considering the advantages of thermal storage applications in providing flexibility and dispatchability to the electricity system.

A major initiative being analysed in the industry is the development of an innovative multi-tower CST concept that can provide power at night, complementing PV production during the day, and making large commercial plants technically possible and economically feasible.

Synergies

The CST4ALL project promoted collaboration between CST and other renewable energy sectors through a series of online workshops. Specifically:

The online workshop on cross-cutting materials challenges of renewable technologies, held on 9 November 2023, showcased recent advancements in CST, PV, wind, geothermal, and biomass technologies. The workshop explored topics related to sustainable coatings for panels and mirrors, erosion in wind turbines and similarities with PV and CST, standardised procedures for testing and qualifying new materials across sectors, material corrosion in molten salt storage tanks, and material recycling.

The online industry workshop on the hybridisation of CST with PV, held on 22 February 2024, explored the industrial potential of concepts involving PV technologies coupled with parts of the CST value chain. The event featured a policy overview from the Commission, keynote presentations on hybridisation possibilities by leading experts from the CST and PV sectors, and engaging roundtable discussions on industrial maturity of technologies, project financing considerations, and potential synergies between the two sectors in R&I, manufacturing, market development, and workforce training. The workshop highlighted that CST and PV are complementary and can be combined to create more cost-effective hybrid plants with higher capacity factors.

The online workshop on R&I challenges for the hybridisation of CST with other renewable technologies, held on 22 March 2024, discussed components and technological interfaces that enable the physical connection between different technologies. The workshop further explored tools and strategies for optimising the operation of hybrid plants, including simulations of CST hybrids integrated with PV, geothermal, and biomass technologies, considering applications for the production of electricity, heat, and hydrogen. This workshop provided valuable insights for researchers and industry professionals working on advancing hybrid CST.

WIND ENERGY

Currently, the Implementation Working Group on Wind energy brings together 10 countries[21] to establish a shared wind R&I agenda.

With the revised EU renewable energy target set at 42.5%, WindEurope estimates that the EU requires 420 GW of wind energy capacity to be installed by 2030, an increase from 220 GW today. This will necessitate a significant expansion of wind energy across Europe. R&I plays a vital role in achieving this target.

A joint secretariat supports the work of the IWG Wind and ETIPWind, ensuring collaboration and alignment between SET Plan entities, including EERA JP Wind. As a result, the ETIPWind Strategic Research & Innovation Agenda, NeWindEERA research programme, and the forthcoming IWG implementation plan for wind are aligned on common strategic R&I areas for sectoral collaboration.

Last year, the Wind group revised the SET Plan targets for wind energy, focusing R&I efforts on six key areas: national R&I budgets for wind energy, integrating wind energy into the grid, expanding wind energy manufacturing capacity, developing materials recovery and recycling technologies, creating jobs and skills, and streamlining the permitting process.

21 Belgium, France, Germany, Hungary, Ireland, Italy, Norway, Portugal, Spain, and Türkiye

Recent developments

In addition to the revised SET Plan targets for wind energy the group members were also consulted during the development of two key documents:

- A factsheet on NECPs, created by ETIPWind to assess the R&I measures in the revised NECPs of five EU Member States (Denmark, the Netherlands, Italy, Portugal, and Spain).
- ETIPWind's Strategic R&I Agenda 2025-2027, which outlines 23 priority R&I areas for the EU and national governments to address in the short term.

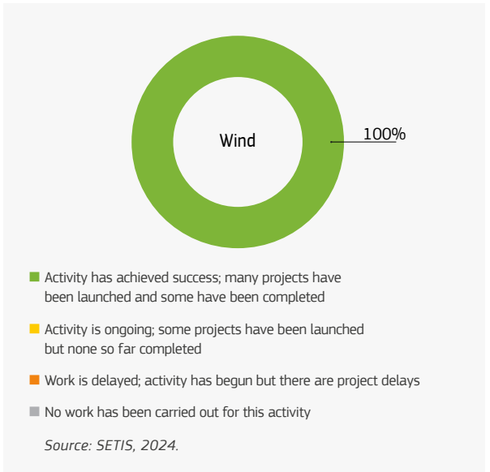
Furthermore, the group has established close collaborations with the IWGs on Direct current technologies and Ocean energy. The development of high voltage direct current (HVDC) technologies is crucial for the deployment of offshore wind in Europe, while collaboration with the working group on Ocean energy aims to identify synergies and joint R&I topics, such as quick connect/disconnect systems for mooring lines. As a next step, the IWG Wind will revise its Implementation Plan, which will include R&I actions and investments required at the national level to meet the revised SET Plan targets. The plan will also provide general recommendations for implementing these actions, as well as a reflection on the future of European collaboration on wind R&I.

Status of the implementation plan

The previous Implementation Plan was defined by the IWG Offshore Wind, only focusing on offshore wind and set up to achieve the previous SET Plan targets for offshore wind, which were outdated. The new Implementation Plan will be aligned with the new scope of the IWG Wind (also covering onshore wind technologies) and the new SET Plan targets. These will be formally adopted in the next Implementation Plan.

The new draft targets are:

TARGET 1 – Increase by at least 3% per year the national R&I funding dedicated to wind energy, starting from 2022. Most IWG Wind members seem to have increased their national R&I funding dedicated to wind energy in 2023 compared to 2022. But some IWG Wind members indicate they lack the tools and resources to monitor and report national funding.



Source: SETIS, 2024.

TARGET 2 – Achieve an annual increase of at least 0.5% in the share of wind energy in the electricity mix, thanks to R&I actions. Seven IWG Wind members reported an increased share of wind energy in their electricity mix. According to WindEurope, the share of wind energy in the EU's electricity mix increased by 2% in 2023.

TARGET 3 – Add at least 2 GW of wind manufacturing capacity per year at the European level.

TARGET 4 – Allocate research and development (R&D) budgets for materials recovery technologies in each Member State. At least five IWG Wind members provided R&D funding for materials recovery technologies[22].

TARGET 5 – Train at least 100 000 workers by 2025 at the EU level. While the IWG faces challenges in reporting on workers trained, the ETIPWind annual wind energy competitiveness report 2024 shows that the wind energy sector employed 379 000 people in Europe in 2023, a significant increase from 2022.

TARGET 6 – Launch at least one research project per year to enable faster permitting for wind energy projects. At least three IWG Wind members initiated research projects to support the acceleration of permitting for wind energy projects[23]. Several members also reported significant increases in wind projects receiving permits, including Germany, which granted permits for 7.5 GW of new wind capacity.

22 Some examples include: projects for blade recycling in Belgium, Germany, and Spain; projects for decommissioning in Belgium, as well as re-using and re-purposing in Ireland; projects dealing with rare-earth materials in Norway and new materials in Türkiye and Spain.

23 Some examples include: the German Hemm-den-Wind project on acceptability of wind energy; projects dealing with public engagement in wind energy projects like AR4WIND in Germany and ConSite Wind in Norway; the ASTRIIS project in Portugal dealing with environmental impact assessment; and the German ReNEW project that provides a decision support tool for wind energy lifetime extension and repowering.

Status of the activities

All six of the Wind group activities have projects that report finished deliverables or successful completion. The following project examples illustrate how R&I activities outlined in the previous Implementation Plan (published in March 2022) align with R&I projects launched at the national level. Please note that this list is not exhaustive, but rather provides examples of R&I projects initiated since the 2023 SET Plan progress report.

Next Generation Wind turbine technology

- **Belgium:** At least two projects were launched or successfully finished on the design optimisation of offshore wind foundations using improved soil-structure interaction models on in-situ measurements and medium-scale experiments (WindSOIL), and on the development of tools and insight to expand the Belgian offshore wind farms with airborne wind energy systems (BORNE).
- **Italy:** Three projects are ongoing on the development of vertical axis wind turbines, novel technologies, and control systems for the rotors of wind turbines, and the development of advanced floater concept with energy harvesters.
- **Germany:** One project was launched on demonstrating the next generation of Direct Drive Generators for wind energy (NextGen), as part of the CETPartnership.
- **Norway:** The Research Council of Norway funded several projects on next generation wind turbine technology. The main results of 2023 focused on: materials integrity in the drivetrain, robust welding process and high-quality welds, non-linear hydrodynamic loads, hydrodynamic experiments of floating wind turbines, next generation condition monitoring, cost-effective manufacturing, aluminium in offshore wind, etc.
- **Spain:** Five new projects have been funded. They focus on new compact power train for onshore wind turbines (POWERCOMP), new high reliability bearings through hybrid testing for offshore wind turbines above 20 MW, new advanced solutions for internal structural elements for wind superstructures, development of a technological solution for the wind sector with high technical performances and greater energy efficiency aimed at the ecological transition and development of new medium voltage (MV) power conversion system for offshore turbines up to 17 MW with advanced diagnosis and prognosis capability.

Offshore wind farms and systems integration

- **Belgium:** At least three projects were launched or successfully finished on the following activities: Belgian Offshore Wind energy parks and tools to enhance the provision of ancillary services, the stability of the grid and the lifetime of the infrastructure (BEOWIND); a North Sea energy plan for the transition to sustainable wind energy (NEPTUNE); and a Belgian electricity grid based on advanced data handling and sensor technology, including airborne systems.
- **Italy:** Two projects were launched focusing on solutions for offshore wind farms, including off-grid approaches, e.g., isolated offshore wind farms producing hydrogen, ammonia or desalt water. The other project aims to design a floating energy archipelago in the Mediterranean Sea, merging floating offshore wind, floating PV and wave energy converter (WEC) technology, for powering fishing and seaweed farms, hydrogen, ammonia and fresh-water plants.
- **Germany:** Four projects have been launched or are still ongoing. They focus mainly on controlled cluster wakes (C2-Wakes), solutions for cable damage avoidance in the vicinity of offshore foundations (CableProtect), materials and repair innovations for offshore turbine blades leading edge protection systems (MARiLEP), microbially induced corrosion of iron and possible corrosion protection measures in monopiles of offshore wind turbines (MiCorFe), and optimisation of productivity in the manufacturing of foundation structures of offshore wind turbines (LaVa-Windenergie).
- **Norway:** The Research Council of Norway funded the Green Platform Ocean Grids in 2022. It focuses on the development of cost-effective solutions for grid connection of offshore wind farms, both bottom-fixed and floating. Activities include Offshore grid development, wet design cables, subsea substation, floating HVDC platform and Ocean grid research.
- **Spain:** Six projects have been launched focusing on the development of a marine research platform in Catalonia for the R&D&I of floating wind technologies in real operating conditions in the western Mediterranean (PLEMCAT), the improvement of the infrastructures at the Port of Arinaga for applied research in marine energies such as floating solar PV, wave and offshore wind (RENMARINAS Arinaga), and the update of the electrical network to support the demonstration activities of R&D projects in the northern test bed of PLOCAN (ElectroUP). Other projects focus on the Galician offshore wind experimental platform for offshore wind turbines and floats off the coast of Arteixo, the development of wind support structure for deep-water (ENERPROFUNDA), and the development of modular and adaptable monitoring system for offshore infrastructures.
- **Türkiye:** Preliminary feasibility studies, including meteorological and oceanographic analyses, will be conducted in selected sites for the first offshore wind energy auctions. Subsequent technical, legal, and economic analyses will determine capacity levels, guiding activities for offshore wind energy installation. Following these issues, it is planned to commission offshore wind plants in the Southern Marmara Region quickly. These targets are expected to be supported through R&D and innovation projects.

Floating Offshore Wind and wind energy industrialisation

- **Belgium:** At least one project was launched to catalyse Belgian industrial expertise in floating wind through academic innovation and optimisation of offshore windfarms (BEL-Float).
- **Italy:** One new project has been launched on the development of data-driven asset management tools.
- **Norway:** The Research Council of Norway funded several projects on floating offshore wind including the development of an online park design/optimisation and annual energy prediction estimation tool for floating offshore wind farms, research for an innovative method for the installation and maintenance of floating offshore wind turbines using large offshore subsea construction vessels (SMART Wind 2025), the development of nylon ropes for mooring floating wind Turbines (NYMOOR), and improved analysis methods for safe personnel transfer to floating offshore wind turbines.
- **Portugal:** Two projects successfully ended on location optimisation for offshore platforms (LOOP Wind which consisted of artificial intelligence software seeking to optimise the location and design of offshore wind platforms), on the Twin Wind Aquaculture in Madeira (TWAM, a prototype will be developed and constructed to be tested in a tank with real climate data.).
- **Spain:** Seven projects have been launched or are still ongoing. These projects include the development of two 11 MW offshore floating wind demonstrators (ALLENDE, PRIMAVERA DEMOS), the installation of a 2 MW floating wind platform connected to the Spanish electrical grid for research and monitoring of the impact on the marine environment (FLOW2GRID), and the construction and installation of a 11 MW floating wind demonstrator at the Marine Energy R&D Platform of Catalonia (HIVEWIND). Projects also include a demonstrator prototype with 5 MW wind and wave hybrid technology (P-Demo), the development of a 6 MW floating offshore wind platform (NEXTFLOAT-CAT) and the development of an offshore environmental monitoring and electrical generation platform with a 2 MW floating offshore wind demonstrator (W1ndWachPlatform).

Wind Energy Operation, maintenance, and installation

- **Belgium:** At least 12 projects launched or successfully finished on the following activities: fatigue life extension of offshore wind foundations (FlexWind), predictions of renewables optimised for offshore using forecasting (PROOF), fleet-based artificial intelligence for fault detection and maintenance optimisation for offshore wind farms (BitWind), intelligent sensors for anomaly detection in harsh environments (ISAAC), longer lifetime of offshore wind turbine monopile structures by better understanding the fatigue corrosion mechanisms (FATCOR), maintenance, inspection and exploitation optimisation of offshore wind farms subjected to corrosion-fatigue (MAXWIND), offshore wind digitalisation of operations in the North Sea (POSEIDON), improved reliability and reduced costs of offshore wind by Blade-Leading-Edge Erosion (BLEEPID), prediction and drone-based inspection, soil ageing around offshore wind turbine foundations – from operational response to decommissioning North-C-Blade (SAGE-SAND), offshore wind decommissioning expertise centrum (OWiDEX) and leveraging model and data-driven digital twins for smart asset management and lifetime (Smartlife).
- **Italy:** Three projects have been launched on the development of dedicated methods to estimate blade erosion driven annual energy production (AEP) loss, and RUL evaluation, the improvement of AI-aided wind power forecasting tools for floating offshore farms, and the development of AI-based prescriptive maintenance and prognostic strategies for wind turbine components in onshore and offshore applications.
- **Germany:** Five new projects were launched on the following topics: damage avoidance and load reduction based control of wind turbines

(DaCoWind), wind turbine condition monitoring system for scheduling maintenance based on loads (Hybrid Wind) as part of the CETPartnership, the optimisation of a contactless optical system to measure deformation of wind turbine blades in operation (optDIC), operational strategies for economic load and lifetime optimisation for wind energy turbines (OTELLO), and the sensor data fusion for in-situ wind turbine blade structural health monitoring (SENSITU).

- **Norway:** The Research Council of Norway funded several projects on wind energy operation, maintenance, and installation. R&I activities focused on innovative heating, ventilation and cooling (HVAC) design solutions to support energy-efficient and zero-emission operation of service operation vessels (ICHzero), the optimisation of offshore wind turbine maintenance with products and services that enhance the sustainability of offshore wind by facilitating the replacement of main components at sea (Green Platform), and a decision support tool for planning the maritime logistics of the installation of large offshore wind farms (further development of COSMO).
- **Portugal:** Three projects have been continued on the damage prediction and design of scour protections in complex foundations for marine renewable energy (POSEIDON), monitoring, modelling and machine learning for managing the operating life of windfarms (M4WIND), and an all-weather offshore platform for wind blade maintenance (APLAT).
- **Spain:** Three projects were launched on the following topics: improving simultaneous testing capabilities of marine renewable demonstrators in BiMEP (OLAGARRO), a new installation and maintenance system for reducing the cost of offshore wind energy, and a new quick installation system for the latest generation wind turbines to reduce the cost of energy (COE).
- **Türkiye**: Between 2021 and 2024, six national projects focusing on R&D and innovation have been supported in this field. This support has been directed towards SMEs and universities and includes topics such as: IoT-Based performance analysis and operation management for small-scale distributed wind energy power plants; wind farm simulation coupled with weather forecasting; predictive maintenance activities in wind turbines using direct drive technology; the development of a strengthening and vibration-based structural health monitoring system for tower-foundation connection of wind turbine structures; smart maintenance period recommendation systems for early detection of lightning-induced damages in wind turbines;

and the development of a production forecasting solution with artificial intelligence for wind energy power plants.

Ecosystem, social impact & human capital agenda

- **Belgium:** At least two projects launched or successfully finished including Citizen Offshore Power 2021 (COP21) and the offshore wind beneath the wings of young researchers turning the blades of the Belgian offshore wind sector (PHAIRYWIND).
- **Germany:** One project launched on acoustic and radar sensor technology for the detection of bats and birds at wind turbines (SENSE2SAVE).
- **Norway:** The Research Council of Norway funded several projects on the ecosystem, social impact & human capital agenda. The activities focus on improved analysis methods for safe personnel transfer to floating offshore wind turbines, environmental impacts and options for environmental design, including the development of and online application for assessing life cycle impacts on avian diversity for the siting of onshore wind farms (AviSite), and public engagement, participation and controversy.
- **Portugal:** One project successfully ended on the ecosystem social impact and human capital agenda (ASTRIIS).
- **Türkiye:** A project titled "Evaluation of Mechanisms Affecting Social Acceptance of Wind Power Plants in the Framework of Energy Justice in the Context of Climate Change Mitigation Policies" has been supported to obtain a case study from the South Marmara Region, where wind energy potential is high, aiming to assess mechanisms influencing social acceptance of wind power plants within the context of energy justice and climate change mitigation policies.

Basic Wind Energy Sciences

- **Belgium:** At least two projects launched or successfully finished on next a generation climatic test lab for harsh environment R&D testing of the future 15-20 MW offshore energy systems, or on wake-effect included offshore wind power forecasting for smooth operation (BeFORE-CAST).
- **Germany:** two projects were launched on the modelling of wakes in the near field behind wind turbines (NearWake) and the improved numerical site assessment and load calculation for complex terrain (TopoPro).
- **Türkiye:** Over five national projects have been supported since 2021, focusing on basic wind energy sciences. Within the scope of these supported projects, the following topics are included: development of a univariate hybrid deep learning model for wind energy forecasting, design and prototype manufacturing of wind turbines, development of alternative materials for wind turbine blade manufacturing, development of wind turbines capable of operating at low wind speeds, and development of innovative wind turbines and blades.

Challenges

According to the Wind group, the European wind energy sector currently faces five major challenges:

1. Deploying wind power at scale: To meet its decarbonisation and renewable energy targets by 2030, Europe is expected to install at least 30 GW of wind power capacity per year. However, in 2023, the EU only installed 16.2 GW.
2. Manufacturing in Europe: The existing wind manufacturing and infrastructure capacity in Europe needs to expand its capacity further. While industry is willing to invest, it lacks clear visibility on the auction timeline, making it difficult to justify investing now.
3. Wind power in the energy system: Wind energy is expected to account for half of the EU's electricity demand by 2050. However, grids are becoming a significant bottleneck, hindering the integration of wind power into the energy system.
4. The sustainability of wind energy: Although wind energy is 85-90% recyclable, deploying it at the required scale and pace will involve potential risks to environmental sustainability and resource supply.
5. Workforce and skills: The expansion of wind energy will require 500 000 skilled workers by 2030. Attracting, educating, and training workers and researchers is crucial to maintaining Europe's position as a hub for wind energy talent.

To support the technology leadership, academic excellence, and competitiveness of the European wind energy sector, it is essential to align and increase investment in research and innovation (R&I) activities at both EU and national levels.

Regarding the working group, the IWG Wind would benefit from greater participation from SET Plan countries. Currently, the IWG Wind has 10 members, but several other EU Member States with significant wind energy interests, such as Denmark and the Netherlands, do not participate. A clearer role for the IWG at EU and national level could increase its value proposition. Specifically, the SET Plan framework should establish a connection between IWG recommendations and targets and Member State R&I activities reported in the NECPs.

Future plans

Wind energy currently accounts for 19% of the electricity consumed in Europe, and the EU aims to increase this to 35% by 2030 and over 50% by 2050. Utilising more wind power is expected to reduce the EU's reliance on energy imports. Moreover, the majority of wind turbines installed in Europe are still manufactured on the continent, making wind energy a strategic industry for the EU.

To achieve these targets, the following steps are needed:

1. Improved top-down planning and increased private finance, leveraged by the European Investment Bank.
2. Further easing the permitting process for renewables, grids, and industry, by implementing new EU rules, including tighter deadlines, a one-stop-shop, and overriding public interest, all facilitated through digital means.
3. Support for the electrification of heavy industry, including steel, cement, and chemicals, which are crucial to the economy and wind turbine manufacturing. This can be achieved through finance, flexible state aid, and an Electrification Action Plan targeting 35% electricity in the energy mix by 2030 (up from 23% today).
4. Ensuring a level playing field for Europe's clean tech manufacturing sector, by utilising all existing EU tools to promote fair competition in the wind turbine market. Additionally, establishing clear minimum standards for cyber and data security, responsible business conduct, and supply chain resilience.
5. Focusing innovation on scaling up technologies, as many new developments are struggling to be deployed. Radically simplifying and accelerating EU funding processes through targeted R&I policy actions will help them to industrialise and scale up.

The objective of the IWG Wind is to accelerate wind deployment in Europe through targeted research and innovation (R&I) efforts. The next step for the IWG is to define common R&I actions, to be implemented through projects funded at the national level, which will help to meet the new SET Plan target for wind energy. The next Implementation Plan will outline these actions, developed in close alignment with EERA JP Wind and ETIPWind research recommendations.

Synergies

Discussions and collaborations have been initiated with the following partners:

- The IWG on Direct current technologies, in particular HVDC, which is crucial for the deployment of offshore wind in Europe.
- The IWG on Ocean energy, with which the offshore wind sector shares common challenges, including technological hurdles and non-technological challenges.
- The CETPartnership, which publishes annual joint calls aimed at accelerating the energy transition. Two thematic areas of these joint calls are particularly relevant to wind energy: integrated net-zero emission energy systems and enhanced zero-emission power technologies.
- The Sustainable Blue Economy Partnership, which pools R&I investments and aligns national programmes and R&I agendas for the sea basins (Mediterranean, Black Sea, Baltic, and North Sea) and the Atlantic Ocean. It publishes annual joint calls, and several thematic areas are particularly relevant to wind energy, including: developing digital twins of the ocean at a regional sub-basin scale; creating marine multi-use infrastructures; and planning and managing sea uses at regional level.

GEOTHERMAL ENERGY

The Implementation Working Group on Geothermal energy is a forum where the geothermal energy industry, the research community, and public authorities come together to accelerate the energy transition through R&I in geothermal energy. The mission of the group is to coordinate R&I efforts to create a resilient and climate-neutral Europe that harnesses geothermal energy to its full potential. The group focuses on four key areas: (i) heating and cooling; (ii) electricity generation; (iii) underground thermal energy storage; (iv) critical raw materials.

Over the past year, there has been increasing alignment and support for geothermal energy. Notably, the Geothermal IWG and the Geothermal ETIP aligned and adopted key documents in 2023, demonstrating a shared vision for the sector. Furthermore, in early 2024, the European Parliament voted in favour of a resolution calling for a European geothermal strategy. The revised Renewable Energy Directive (REDIII) also provides a stronger policy framework to increase the use of renewable energy sources for heating and cooling, which will benefit geothermal R&I. Overall, Europe has its own geothermal industry, and expanding its use of this local heat source, that is "right under our feet", will have numerous benefits.

Recent developments

During the 2023/24 reporting period, the revised Implementation Plan of the Geothermal group was endorsed by the SET Plan Steering Group. The ETIP Geothermal also endorsed its revised Strategic Research and Innovation Agenda. These documents establish geothermal energy's promise to become a key energy sector: as a local renewable energy source supplying power and heat, minerals such as lithium, and thermal underground storage – all with little in the way of geopolitical dependencies. The role of the IWG and the ETIP is to foster research and innovation to support those goals.

To this end, the Geothermal group contributed to, and co-organised, several workshops and events in 2023-24, including a roundtable event in Slovenia focusing on the heat transition and geothermal energy opportunities; and a workshop in Ireland on low-medium temperature geothermal heating and cooling solutions.
The Geothermal group is well aligned with the collaboration in ETIP Geothermal, CETPartnership, and GEOTHERMICA.

In terms of research and innovation, several flagship projects made significant progress in 2023, including:

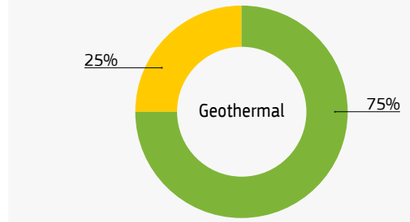
- The Eavor Geretsried project, Germany;
- The Delft thermal storage project, Netherlands;
- Mid-depth geothermal heat for district heating in Schwerin, Germany; and
- The Vulcan project for co-production of geothermal lithium.

Several important research projects are also ongoing, such as the CRM Geothermal project, which focuses on opportunities for the co-production of minerals alongside geothermal energy utilisation, innovations in seismic research, and innovations aimed at optimal energy production from geothermal sources. The Geothermal group will consider the alignment between the ambitions for geothermal energy and R&I funding, ensuring that funding supports the sector's goals.

Status of the implementation plan

In the previous Implementation Plan, the Geothermal group focused on reducing the cost of geothermal energy production. However, the revised plan[24] proposes a new vision, focussing on market share instead. Specifically, the Geothermal group aims to:

- Increase geothermal heat supply to more than 25% of Europe's demand for space heating and cooling, and a significant portion in the agricultural and industrial sectors in the low-to-medium temperature range;
- Generate 10% of power production in SET Plan countries from geothermal power;
- Use underground thermal energy storage to supply more than 10% of Europe's demand for space heating; and
- Achieve co-production of minerals and critical raw materials (CRM) for resilient mobility in at least 10 European regions.



Source: SETIS, 2024.

Furthermore, the Net-Zero Industry Act proposes that 40% of the supply chain should be European-made by 2030. This target will be incorporated into the revised Implementation Plan.

Status of the activities

Geothermal energy production technology is a complex and multifaceted field, best viewed as a development chain rather than a single product. This perspective is reflected in both the Implementation Plan and the ETIP's SRIA. The current four key priorities for R&I will guide the working group in the years to come, while also taking into account technological progress made by IWG members. Three of the priorities include projects which have either produced deliverables or reached completion.

Heating and Cooling

The vision for 2050 is that geothermal heat will supply more than 25% of Europe's demand for space heating

24 *Geothermal Implementation Plan 2023*

and cooling, as well as 25% of the demand in the agricultural sector (greenhouses) and 5% in industrial sectors. Geothermal energy is a local, dispatchable source, and its main use is in West and Central Europe. Additionally, 25% of European cities are located in regions suitable for direct use. Several R&I projects have been completed or are ongoing to facilitate the use of geothermal energy for heating and cooling.

Electricity

The vision for 2050 is that 10% of power production in SET Plan countries will come from geothermal power. Geothermal energy is a cost-effective source of baseload or dispatchable electricity production. Innovation can unlock new potential for Europe in areas such as super-hot and super-critical, magma energy, offshore geothermal, new technologies, and materials. Several R&I projects have been completed or are ongoing to facilitate the use of geothermal energy for power production.

Thermal Underground Storage (UTES)

The vision for 2050 is that UTES will supply more than 10% of Europe's demand for space heating, mainly for district heating. As around 50% of the European energy demand is for heating, bridging the winter peak for heating demand is essential. This requires a large-scale subsurface infrastructure. Using the subsurface for thermal storage is gaining momentum, with the first completed R&I projects already leading to successful operation.

Co-production of Minerals and Geothermal Energy

The vision for 2050 is that co-production of minerals and critical raw materials (CRM), such as lithium for the transportation sector and strategic autonomy, will be established in at least 10 European regions. Some geothermal fluids can be a source of significant amounts of CRMs such as lithium for car batteries. Other minerals that can be extracted from geothermal resources include silicon (in its silica compound form), used in the electronics industry, and potassium, used for the production of sustainable fertilisers. Several R&I projects are ongoing to implement this vision.

Challenges

The Geothermal group estimates that the current annual investment in R&I projects in the geothermal sector needs to be tripled from EUR 100 million to EUR 300 million by 2030 for Europe to reach its goals on transitioning to renewable energy sources. This increased investment is in line with the sector's ambitions and potential. The Implementation Plan and the SRIA both identify R&I challenges and opportunities. While the technology already exists, further improvements will enhance its application.

Some of the most important challenges for the Geothermal group include securing political priority and sufficient support, which will help address market failures due to high initial costs and large-scale investments needed.

Non-technical barriers that affect the geothermal sector include: lack of subsurface data; knowledge-transfer and training; open access to geothermal information; standardisation; risk mitigation; awareness; and public acceptance. In addition, authorisations and permitting processes need to be simplified to enable implementation of projects and further development.

Additional challenges include:

- Establishing favourable market conditions in all European countries;
- Ensuring fair competition that takes into account real costs;
- Encouraging collaboration across the continent;
- Expanding membership, particularly from Mediterranean countries;
- Building capacity through training and education in the geothermal sector; and
- Fostering favourable market conditions and increased interest in the sector.

A European-wide approach is necessary for the geothermal sector to reach its full potential.

Future plans

The future prospects of the geothermal industry are promising. Since 2022, energy security and the energy transition are in the centre of political attention, presenting opportunities for geothermal energy to play an important role. Many countries and regions can benefit by incorporating geothermal heating, cooling, power generation, thermal storage, and co-production of minerals into energy transition plans.

The Geothermal group aims to actively increase its membership following the revision of the Implementation Plan. In addition, the group plans to expand its activities on the key priority areas of thermal storage and co-production of minerals, as well as understanding the specific challenges related to low temperature geothermal heating and cooling production and its integration into the energy system.

Synergies

The Geothermal group has established close working relationships with several key partners:

- ETIP Geothermal: The IWG has a very close working relationship with ETIP Geothermal, with the ETIP Chair serving as a Co-Chair of the IWG. Both organisations share an aligned vision and R&I priorities, ensuring a strong partnership.
- CETPartnership: The Geothermal IWG Chair and secretariat are responsible for organising the CETPartnership's TRI4 'heating and cooling' thematic activity. This collaboration optimises transnational funding opportunities for geothermal R&I.
- GEOTHERMICA Initiative: Geothermal IWG Member States maintain a strong interaction on geothermal R&I through the GEOTHERMICA Initiative.
- GEOTHERM FORA / EGEC: The IWG interacts with the European Geothermal Energy Council (EGEC) through the CSA Geotherm Fora. EGEC has a deep understanding of the geothermal sector and EU policies, both of which are important for the IWG.
- Other IWGs: The Geothermal group engages with other IWGs, particularly those focused on heating and cooling in buildings and industry (IWGs on Energy efficiency in buildings and Sustainable and efficient energy use in industry), and subsurface storage (CCS/CCU). These interactions take the form of workshops and conference sessions.
- SET Plan cross-cutting topics: The Geothermal group is interested to collaborate on the advanced materials (co-production of minerals; robust materials; 'critical mineral intensity' for geothermal energy) and the acceleration of the market uptake for clean energy technologies.

ENEL San Martino geothermal power plant.

OCEAN ENERGY

The Implementation Working Group on Ocean energy is comprised of representatives from relevant government and public sector agencies of 14 European countries. The group's primary objective is to bring competitive ocean energy technology to market and contribute to the decarbonisation of the EU's energy demand.

The IWG's annual report provides an overview of progress in the sector against the implementation plan. The report offers recommendations for the next period, including tailoring national and regional funding programmes to address the implementation plan's technical theme actions and identifying mechanisms for implementing an Insurance and Warranty Fund.

The Commission recently reviewed its Offshore Renewable Energy Strategy, initially published in November 2020. The review has reset the ambition for the ocean energy sector, aiming to achieve a capacity of 100 MW by 2027 and around 1 GW by 203025. With the deployment of first-of-a-kind prototypes and the announcement of pilot farm and pre-commercial array projects, the sector appears to be on track to meet this ambition.

25 COM(2023) 668 final, Communication on delivering on the EU offshore renewable energy ambitions, *[link]*

Recent developments

The membership of the group has been expanded to include direct representation from regional bodies, in addition to national bodies, in recognition of the key role regions play in supporting the development of ocean energy.

The IWG has initiated a collaborative effort with the Wind group to explore the synergies between ocean (wave) energy technology and offshore wind technology. Studies have indicated that the collocation of wave energy and offshore wind projects can deliver benefits to both technologies through improved utilisation of space and infrastructure, in the use of common sub-systems (e.g., connection systems) and the development of common operational processes. An effective framework for collaboration is being developed.

ETIP Ocean is currently updating its Strategic Research and Innovation Agenda for ocean energy. The IWG has supported the preparatory studies, contributed to sector-wide consultations, and provided feedback on drafts.

Status of the activities

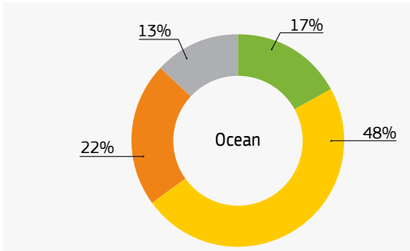
The Ocean group has 23 activities split into three areas. The majority of them are ongoing. Some have projects that report finished deliverables or successful completion, and some actions have experienced delays or not yet begun.

Technical Actions [26]

The two key technical actions for ocean energy relate to the deployment of ocean energy devices for operational experience (Action 1.1) and the establishment of pilot farms (Action 1.2). There has been notable progress in these actions.

In the tidal stream energy sector, the EURO-TIDES and Seastar pilot farm projects secured funding through the Horizon Europe programme, and the FLOWATT project was financed by the French Government.

In the wave energy sector, the Saoirse Wave Energy Project and the SEAWORTHY project received Innovation Fund financing. Additionally, the allocation of Horizon Europe funding for two more pilot farm projects is expected to be announced shortly.



- Activity has achieved success; many projects have been launched and some have been completed
- Activity is ongoing; some projects have been launched but none so far completed
- Work is delayed; activity has begun but there are project delays
- No work has been carried out for this activity

Source: SETIS, 2024.

Environmental, Policy and Socioeconomic Actions

Action 2.2: The Maritime Spatial Planning Directive requires coastal EU Member States to develop maritime spatial plans (MSP) for their marine territories. All members of the Ocean working group, except one, have adopted an approved MSP. Although no Member State has set aside zones exclusively for ocean energy (wave and tidal stream), it is common for MSPs to include areas designated for "offshore renewable energy production", which may encompass ocean energy.

Market Uptake and Financial Actions

Action 3.1: The UK's recent Contract for Difference (CfD) allocation rounds have showcased the success of dedicated single technology revenue support schemes, with ring-fenced support for tidal stream technology resulting in fifteen contracts to deliver a capacity of 93.86 MW by 2027/28. Additionally, the French Government is supporting a further 17.5 MW of tidal stream capacity. Nonetheless, technology-neutral support schemes remain dominant.

Action 3.2 concerns the creation of a Common Investment Support Fund that would provide flexible capital for ocean energy projects. The action anticipated a feasibility study to consider the viability of such a fund. The Ocean group has not found a mechanism for financing the studies needed to progress on the action.

Action 3.3: Options for creating and managing an Insurance and Warranty Fund have been developed,

26 The implementation plan's technical actions reflect the priority topics of the SRIA for ocean energy for 2021-2025. Each action is expected to encompass the completion of various projects, which may range in size from small to large. The classification of each action into categories (green, yellow, orange, and grey) is determined by evaluating projects funded by European and national programmes.

and a governance structure for the preferred form, a protected cell company, has been established. The types of coverage that could reasonably be provided have been outlined. Securing the necessary funding to establish an ocean energy insurance entity and bring this concept to fruition will require collaboration among industry stakeholders and European, national, and regional authorities.

Action 3.4: Funding at European and national levels continues to support a range of projects that tackle the actions, mainly technical, outlined in the Implementation Plan.

Action 3.5: The EuropeWave project, a collaboration between Wave Energy Scotland (UK) and the Basque Energy Agency (Spain), is demonstrating the use of precommercial procurement (PCP) to foster research and development of innovative solutions in the ocean energy sector, alongside the Basque Energy Agency's TurboWave project that is repowering the Mutriku wave power plant.

Challenges

The primary challenge facing ocean energy technology is scaling up deployment.

The tidal stream sector has made significant progress, transitioning from single full-scale device deployments to multiple device deployments in pilot farms and pre-commercial arrays. Meanwhile, the wave energy sector is consolidating deployments of large-scale prototypes and single first-of-a-kind full-scale devices in operational environments, and is beginning to take initial steps towards the first pilot farms.

However, the technical and financial risks associated with deploying prototypes, pilot farms, and pre-commercial arrays pose a significant challenge for project developers. Often, the project developer is also the technology developer, and this technology developer is typically a small to medium-sized enterprise (SME) for whom the financial risk associated with a deployment project can be an existential threat.

The creation of a proposed Insurance and Warranty Fund would significantly contribute to reducing the risk of individual deployment projects.

Future plans

The ocean energy sector is currently in a state of transition.

In the tidal stream sector, key players are gaining valuable insights from the operation of existing deployments, both single and multiple devices, while preparing for new multiple-device deployments from 2025 onwards. Notably, the UK's CfD scheme has contracted 15 tidal stream projects to deliver approximately 94 MW of capacity by 2028, and the French Government is providing capital and revenue support for the FloWatt project, which will deliver 17.5 MW of capacity by 2026.

The wave energy sector is set to witness the deployment of several prototypes in the coming year.

Securing funding for large-scale projects remains a significant challenge for small and medium-sized enterprises (SMEs) developing prototype deployments, pilot farms, and pre-commercial arrays. This challenge can pose an existential financial risk to these companies.

The proposed Insurance and Warranty Fund would be a significant step towards mitigating these financial risks. In the coming year, the working group will explore the mechanism for establishing such a fund in collaboration with industry stakeholders, European, national, and regional authorities.

The sector's SRIA is being updated by ETIP Ocean, outlining the challenge areas and priority topics for the sector up to 2030. The revised SRIA will be published in the second half of 2024, and the working group will review its implementation plan to account for the modified research and innovation requirements.

Synergies

The Ocean group continues to engage with other relevant bodies in the sector. Namely, ETIP Ocean and EERA Ocean Energy Joint Programme are stakeholders of the working group, representing the views of the industrial and research communities.

The IWG has initiated a collaboration with the IWG Wind, driven by the clear synergies between the ocean energy sector, particularly wave energy, and the offshore wind sector, including both fixed and floating technologies. The two IWGs have identified several topics of common interest, including:

- System integration requirements to support co-location of projects;
- Optimisation of port logistics;
- Quick connect/disconnect systems; and
- Innovative health monitoring systems.

Furthermore, a collaboration agreement has been established with Ocean Energy Systems, the International Energy Agency's Technology Collaboration Platform for Ocean Energy, to coordinate data collection processes in the European ocean energy sector.

The IWG continues to engage with the CETPartnership to ensure that the requirements of the ocean energy sector are reflected in the specification of the upcoming joint calls.

HydroQuest

DIRECT CURRENT TECHNOLOGIES

The Implementation Working Group on Direct current (DC) technologies is focused on developing the technology required for future renewable energy-based power systems. High Voltage Direct Current (HVDC) systems, with their high-power transmission capabilities, diverse technological options, and precise power flow controllability, are crucial for designing reliable power grids. However, HVDC technology must also be reliable, as it relies on converters using thousands of power electronic components and will largely involve underground power transmission, transferring bulk amounts of power.

This shift from traditional energy transmission requires special attention to ensure system reliability, both at the component and system levels. DC technologies can be applied across the entire electric energy sector and play a key role in seamlessly integrating renewable electricity into the European energy system. While the Implementation Plan for HVDC was published in 2021, the current focus has been on expanding its scope to include the equally important area of Low Voltage Direct Current (LVDC) technology.

The IWG was supported by a Temporary Working Group (TWG) on LVDC, which developed a separate Implementation Plan that was adopted by the Steering Group. Following the adoption of the LVDC IP, the IWG encompasses both low and high voltage direct current technologies.

Recent developments

The working group has focused on consolidating its activities, fostering connections and cooperation with other IWGs, and monitoring developments in the HVDC Research, Innovation, and Demonstration (R&I&D) landscape at both national and European levels.
More specifically, the group:

- Actively participated in the SET Plan conference in Barcelona, with both co-chairs in attendance and one Co-Chair contributing to a panel session;
- Launched the DCforEU project, a coordination and support action (CSA) designed to support the IWG's activities;
- Disseminated the IWG's HVDC Implementation Plan at various events, including the 'Power system roadmap to a net-zero 2050: Coordinate, Cooperate, Innovate' conference on 26 March 2024 in Genk, Belgium, which was attended by multiple IWG members and policy makers from the EU, Belgium, and Flanders;
- Provided support to the TWG on LVDC, which developed its Implementation Plan; and
- Prepared for the integration of the LVDC group by updating the IWG's name from 'HVDC and DC technologies' to 'Direct current technologies', to better reflect the inclusion of low voltage technologies.

Status of the implementation plan

During this reporting period there have been no changes to the HVDC Implementation Plan. However, the group has adopted a new low voltage direct current (LVDC) Implementation Plan[27].
LVDC has distinct advantages over traditional

- Direct Current on low voltages is more resource and energy efficient, reducing material and losses in wiring and converters.
- DC microgrids facilitate the integration of local renewables, demand response and storage, thereby optimising self-consumption and increasing resilience.
- DC microgrids offer advantages to the grid as they can reduce congestion and contribute to AC grid stability and voltage quality.

LVDC technologies and components are already well developed, but further R&I effort is needed to:

- demonstrate innovative LVDC microgrids in buildings or industrial plants;
- develop models, tools, strategies and guidelines for designing and using sustainable LVDC;
- systems;
- study the effects of DC stray currents on building structures and human body, as well as develop;
- protection schemes; and
- optimise power semiconductors for DC specific applications.

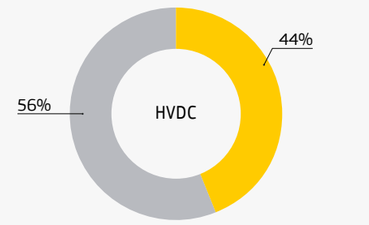
Further actions are needed beyond the scope of R&I to enable the deployment of LVDC:

- develop standards for LVDC systems characteristics and requirements (IEC, CEN-CENELEC);
- raise public awareness about the benefits and implications of LVDC systems among decision makers and the public;
- establish education and training curricula; and
- remove regulatory barriers (at national level), inhibiting use of LVDC, and harmonise the regulatory framework across the Member States.

The implementation plan was adopted by the SET Plan Steering Group on 12 September 2024.

Status of the activities

Short-term Technology Activities
The group is currently developing a monitoring system within the DCforEU CSA to track activities and their progress. This involves creating a database of projects and their outcomes. An important aspect of this activity is connecting with these projects, which is an ongoing process.
Most of the projects were initiated in 2023 or 2024, and



Source: SETIS, 2024.

27 *Implementation Plan LVDC 2024*

there are no major results achieved yet. However, it is anticipated that there will be significant developments in the upcoming reporting periods.

Short-term Operation Activities

There have been no initiatives to launch these activities yet. However, it is expected that they will be initiated in the next Horizon Europe funding rounds. The implementation plan is relatively recent, and not all aspects of it have been taken up yet.

Challenges

The grid plays a central role in several key policies, including the Net-Zero Industry Act, the Critical Raw Materials Act, and the European Green Deal/Fit-for-55 policies.

HVDC technology is crucial for achieving the renewable energy deployment targets for 2030 and beyond, particularly for offshore wind. LVDC technology is also seen as a viable option for reducing material needs and increasing efficiency.

However, like other technologies, HVDC and LVDC face several challenges, primarily related to the current volatile and uncertain situation. The three main challenges are:

- Supply chain: The current supply chain is configured for sporadic, case-tailored projects with vendor-sourced solutions, which limits the ability to achieve scale and standardisation.
- Workforce: The industry requires highly qualified personnel, but is struggling with recruitment. Education and training for HVDC engineers at all levels is lagging, and concrete actions, including the development of joint Master's programmes dedicated to HVDC, are needed to address this shortage.
- Cost reduction: While the overall cost of the technology is decreasing, further Research, Innovation, and Demonstration actions (R&I&D) are needed to drive down costs.

Future plans

In 2024-2025, the group has two primary objectives:

1. Integrate LVDC activities into the IWG.
2. Update the work plan for HVDC activities.

Operationally, the group anticipates an increase in activities, with the DCforEU CSA organising regular meetings and events. The IWG will hold four meetings per year, comprising two in-person work meetings and two online events.

Over the next year, the group aims to:

- Complete the mapping approach to better understand and track research activities, which will facilitate better yearly reporting.
- Revise the roadmap structure to enable following the innovation chain from low to high Technology Readiness Levels (TRLs) and System Readiness Levels (SRLs).

These changes will be incorporated into the new implementation plan, which is targeted for completion in the first half of 2025.

Synergies

The working group has extensively collaborated with sector organisations, including WindEurope, ENTSO-E, T&D Europe, and Europacable. These organisations play a crucial role in governing the work on HVDC technology. The IWG intends to establish similar collaborations on other voltage levels in the future.

As there is no ETIP connected to this activity, a significant part of the interactions with industry and academia are performed within the IWG.

The IWG has attended Offshore wind working group events and contributed to the Sustainable and efficient energy use in industry working group activities by speaking at their events. The IWG intends to continue this engagement in the coming years and plans to directly collaborate with other working groups on common activities.

POSITIVE ENERGY DISTRICTS

The International Working Group on Positive energy districts (PEDs), also known as the PED Programme, was launched in 2018 as a joint initiative between the SET Plan and JPI Urban Europe. Since its inception, the PED Programme has issued four calls for proposals: PED Pilot Call (2020); PED Call II (2021); DUT-PED Call (2022); and DUT-PED Call (2023), which included a cooperation with Mission Innovation.

The group has conducted a range of joint activities, including: annual joint calls for R&I projects; development of a transnational PED framework definition; mapping of PED-related projects across Europe; and stakeholder dialogues.

The PED Programme has been aligned with the Driving Urban Transitions (DUT) Partnership and has become one of the three DUT Transition Pathways.

The programme will continue to expand its activities, with the aim of initiating 100 PEDs in Europe by 2025.

Recent developments

Key achievements in 2023/24 include:

- Launching the DUT-PED Call 2023 and preparing the DUT-PED Call 2024, featuring three PED topics in each call;
- Kick-starting 13 PED projects from the DUT-PED Call 2022 and cross-project synthesis with projects from PED Call II;
- Completing four PED projects from the PED Pilot Call;
- Further developing the PED Database in cooperation with the Cost Action PED-EU-NET; and
- Updating the PED Framework Definition and PED Narrative, to be published in autumn 2024.

Some of the recent developments of the group include:

Preparation and launch of calls

- DUT launches annual calls in three thematic fields, of which one is represented by the IWG on Positive Energy Districts.
- DUT-PED Call 2023 was launched on 1 September 2023 with an overall budget of ~EUR 90 million and 28 participating countries on three PED topics: 1) Energy Resilience and Energy Poverty; 2) Urban Regeneration and Refurbishment; 3) Enabling Systems for Local Energy Transitions: Collaboration and Sustainable Investment.
- DUT-PED Call 2024 is launched in September 2024 and includes three PED topics. The scoping process included an online stakeholder survey, stakeholder workshops and specific workshops with CETPartnership, Net-Zero Cities, Global Covenant of Mayors for Climate & Energy (GCoM) and the Belmont Forum.

Cooperation with ongoing PED projects and synthetisation of project outcome

- On 11 and 12 April 2024, 13 PED projects from DUT-PED Call 2022 were kicked off and met with the eight projects from PED Call II, which proved to be an excellent opportunity to share, exchange and discuss experiences and key issues.
- The PED Expert Support Facility (PED ESF) is a panel of experts from the PED Call II projects, aiming at promoting cross-project cooperation and defining joint outcome. A "PED Landscape" has recently been finalised. Activities for 2024/25 include thematic deep-dives on specific joint challenges of PED development.

PED Database

- The online database was published in spring 2023; the collection of cases and projects is continuing. With the database in full, the PED TP will work on using and synthesising data from the different projects for developing indicators and guidelines.

Update of PED Framework Definition and Narrative

- To be published soon.

Status of the implementation plan

The update of the Implementation Plan will be finalised in spring 2025 and will include:

- Alignment with the latest European policies, including the Green Deal, Cities Mission, and New European Bauhaus;
- A revised framing of the PEDs concept to reflect the current R&I discourse and provide a more compelling narrative for urban practitioners;
- A refreshed framing of PEDs as a key tool for decentralising the energy system and driving urban transformation towards climate neutrality; and
- A revised and expanded PED mission statement for 2030.

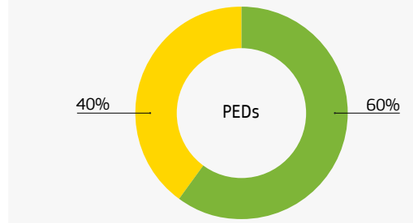
Status of the activities

Expected deliverables

Several projects have been launched, and some deliverables are expected in 2025 or 2026, such as: a toolbox for PEDs; guidelines on funding mechanisms and business models for PEDs; a solutions toolkit for climate-neutral PEDs; an energy efficiency guideline for PEDs; an administrative model for a heating cooperative; a business model for a heating cooperative; guidelines for establishing a heating cooperative; portfolio solutions; and a best practice catalogue to further progress in developing PEDs. These deliverables will be funded by the DUT Call 2022.

Additional Research

A systematic review of scientific papers on PEDs has been published[28], investigating the extent to which PED development and implementation have been supported by research and innovation programmes. The study also examines the state of the art of PED implementation and its effective penetration into the current energy systems of European cities, based on evidence from scientific literature.



Source: SETIS, 2024.

The review used open-access bibliometric software supplemented with content analysis. The results show that less than half of the analysed documents refer to actual case studies, with 80% of these being funded as part of research projects. This suggests that, despite strong encouragement from the scientific community and policy initiatives at the European level, PED implementation in cities remains limited. Moreover, an uneven distribution among countries is observed.

To overcome the existing barriers to PED diffusion and implementation, it would be useful to provide more targeted funding and, above all, facilitate accessibility to municipalities not yet well integrated into European projects, initiatives, and networks.

Challenges

The key challenges to the wider development of PEDs include:

1. Transformation of the existing building stock and enhancing refurbishment activities. Facilitating and supporting urban regeneration is a key challenge for PED development: in densely built-up urban areas a positive energy balance is near-impossible to achieve, therefore the PED concept needs to provide feasible solutions for these contexts.
2. National policies and multilevel approaches: PED development requires support from national and regional policies. While improvements have been made in recent years, there is still a need to integrate PEDs and/or elements of the PEDs concept

28 Clerici Maestosi P, Salvia M, Pietrapertosa F, Romagnoli F, Pirro M., 2024, Implementation of Positive Energy Districts in European Cities: A Systematic Literature Review to Identify the Effective Integration of the Concept into the Existing Energy Systems. Energies; 17(3):707. https://doi.org/10.3390/en17030707

into a broader policy framework, encompassing local, regional, and national levels.

3. Feasible business models for a just transition: Affordability and energy poverty remain significant challenges for the energy transition and PED development. Business models, private capital mobilisation, and public-public/public-private cooperation must be further developed in a socially responsible manner.
4. Integrating bottom-up and top-down solutions: Energy communities are growing across Europe, demonstrating the mobilising power of bottom-up initiatives. These efforts must be combined with large-scale top-down solutions, requiring new forms of stakeholder cooperation and governance models.

Future plans

The main focus of the future activities of the group includes:

1. Promoting the PED Concept: The PED concept has been established as a central element of the energy transition and the pathway to climate neutrality. The group will continue to promote the results from PED projects and support the mainstreaming of the concept in European countries and cities.
2. Developing the PED Framework: The group will further develop the PED Framework to provide a comprehensive and operational concept for the urban energy transition that is integrated into the overall goal of climate neutrality. This will better align the PED concept with other transformative actions.
3. Integrating PEDs into Energy Systems: A special focus will be on integrating PEDs into the context of energy systems and deepening cooperation with the CETPartnership.
4. Mobilising the real estate sector and utilities: The group plans to mobilise both the real estate sector and utilities to create feasible solutions and business models for the PED concept.

Synergies

The IWG is currently evaluating the opportunity to establish collaborations with other working groups, stakeholders, and external actors. In late 2023, the group explored the possibility of linking with the Urban Land Institute (ULI), which aims to shape the future of the built environment. They achieve this by connecting diverse members through a global network of interdisciplinary professionals, and by inspiring best practices for equitable and sustainable land use through content, education, convening, mentoring, and knowledge sharing.

ENERGY SYSTEMS

The Implementation Working Group on Energy systems addresses the RD&I activities to be carried out to develop and manage energy infrastructure that contributes to a reliable, resilient, affordable and efficient delivery of energy for all applications in market conditions.

The working group has successfully conducted and coordinated the discussion among Member States to build on existing initiatives (ETIP SNET, ETIP Geothermal with an industrial approach, EERA JP Smart Grids and JP Energy Systems Integration with a general research perspective, CETPartnership co-funding projects and pilots), fostering the achievement of jointly determined targets.

Specific attention has also been devoted in the revision of the Implementation Plan to the societal aspects needed to enable and facilitate the system evolution, starting from the local level, where the integration of vectors can be experienced with higher impacts. Digitalisation being a key aspect in this transformation, joint activities have been planned to foster the use of open and interoperable solutions in future energy systems.

A joint secretariat supports the work of the IWG Energy Systems and the ETIP Smart networks for the energy transition (ETIP SNET)29. This fosters close cooperation among these two entities and strong alignment of their plans.

29 https://smart-networks-energy-transition.ec.europa.eu/

Recent developments

The activities of the working group followed several parallel pathways:

- the first effort has been to revitalise members' participation: efforts have been made involving the SET Plan SG, and a very motivated (but small) group of countries has confirmed its commitment, thus ensuring the future work of the group.
- Flagship 1 (FS1) addresses the integrated energy system in its pan-European perspective: a close interaction was established and maintained with the ETIP SNET. Agreement has been reached among IWG members that reference shall be made to the Implementation Plans prepared by ETIP SNET to identify the R&I needs[30]. This has greatly facilitated the discussion, avoiding duplication of work. Attention is now dedicated to the collaboration among MSs to enable projects financing and implementation of solutions. Country reports will be drafted to reach this goal. A first version of a survey of nationally funded projects has been drafted. Very good collaboration has been created with the IWGs on Direct current technologies and Sustainable and efficient energy use in industry. Joint initiatives and workshop have been organised and will continue in the future.
- Flagship 2 (FS2) addresses regional and local systems. The IP for this FS required reshaping and very extensive efforts have been devoted to this (these aspects not being directly addressed by any ETIP, but only partly considered in different initiatives, such as ETIP Geothermal). A first version of the FS2 fiches has been agreed and related targets are being identified for inclusion.
- Overarching activities on digitalisation have also been revisited and new fiches dedicated to this subject have been proposed. A specific initiative on interoperability is planned.

The activities of the group are also in line with the work under the CETPartnership (i.e., TRI1, TRI4 and TRI5).

Status of the implementation plan

The Implementation Plan is currently under revision. Flagship 1 has remained unchanged and in line with the ETIP SNET SRIA.

Flagship 2 has been completely rewritten, considering different aspects of particular relevance for local and regional energy systems. In particular the following aspects are now considered in FS2: process chain for digitalisation in the energy system; digital services; linking the European initiatives; innovation eco-systems; heating & cooling; integration of industry systems; integration of hydrogen; and integration of batteries. The general introduction has been completely rewritten to take these changes into account. The budget part is under validation. New targets for FS2 are under advanced discussions.

The current version of the IP has been agreed with the MSs, but the text is still under revision and the targets for the FS2 have not yet been agreed upon with all IWG participants. The updated IP is therefore not yet published.

Changes to the targets

All FS1 targets are re-confirmed. However, under FS2, because of the nature of the activities considered, numerical targets are very difficult to determine. It was decided that general targets linked with GHG emissions and decarbonisation would be adopted for the time being. The activities and the domains to be considered in the IP have been agreed upon with the IWG members.

Status of the activities

Flagship 1

The activities are carried out through numerous projects financed by national, European, and private funds. Co-funded activities are carried out in ERA-NET and CETPartnership projects. The European-funded projects are grouped under the BRIDGE initiative[31] of the European Commission, where they exchange best practices and publicise their results, as well as the results of the joint work under this initiative. In parallel, the CETPartnership has established a knowledge-sharing initiative that will address developments and achievements in that specific context.

Flagship 2

The activities in the field of digitalisation are being carried out in the frame of the ERA-NET Smart energy systems (SES programme), with special reference to the call ENERdigit[32]. Several projects have been awarded and are ongoing. As far as the interoperability is concerned, concrete activities linking the ERA-NET SES and the CETPartnership are being conducted and a specific call on interoperability will be launched in CETPartnership in 2024.

Interaction with national and regional stakeholders is ongoing: several national clusters have been contacted and a roadshow has been completed in Italy. Innovation ecosystems are also ongoing in the frame of the CETPartnership initiative. Heating and cooling networks are tackled by the CETPartnership TRI4 and industrial energy systems are considered in CETPartnership TRI6. The collaboration between the Energy systems working group and the one on Sustainable and efficient energy use in industry has also outlined possibilities on joint programming in this field.

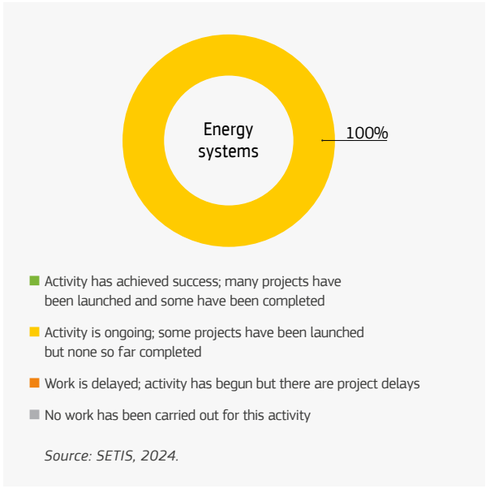
In 2024, the group has drafted and proposed two additional activity fiches under Flagship 2, as well as updated the fiches of the current ongoing activities.

Challenges

Energy infrastructure is a crucial enabler of the energy transition, yet its value and development are often underestimated. Attention tends to focus on renewable generation technologies, final use, and storage, rather than the infrastructure that underpins the entire system. However, electrification is the primary pathway to decarbonisation, and network reinforcement, digitalisation and smartening-up, integration, acceptance, and development are essential steps towards achieving this goal. The power network, as the backbone of the future energy system, will not be sufficient to integrate the required level of renewables on its own. Energy conversion to and from electricity will become increasingly important (P2X).

In this context, the activities of the Energy systems working group are vital to ensuring the success of all other IWGs. Without a strong and smart power network, adequately integrated with other energy vectors (gas, heat, cool, hydrogen, water, etc.), it will be impossible to integrate variable renewable energy sources effectively. The IWG must therefore remain at the heart of SET Plan developments, ensuring that all technologies are adequately interfaced with the respective energy network.

In addition to the technological challenges, which are the focus of R&D activities, the group needs more attention from member countries and more active participation. While the strong relationship with other SET Plan initiatives ensures that technical work is carried out effectively, policy involvement is still insufficient, particularly from Eastern European countries.



Future plans

The working group aims to:

- Strengthen its relationship with all other SET Plan initiatives dealing with power networks, digitalisation, and vector integration, including other IWGs, ETIPs, ERA-NETs, the CETPartnership, EERA, and others. The existing close cooperation with ETIP SNET and the BRIDGE initiative will be further pursued;
- Establish a permanent collaborative framework for exchanging experiences among all concerned initiatives, leveraging the knowledge communities established in the ETIPs, BRIDGE, and CETPartnership;
- Encourage member countries, also through the CETPartnership, to establish living labs and innovation hubs where they can experiment with different pathways towards local and regional energy transition;
- Conduct national surveys to identify outstanding projects that can share key exploitable results; and
- Establish and consolidate digital services, starting with the establishment and validation of testing protocols and platforms for interoperability.

Synergies

The Energy systems IWG has a central role to play in the decarbonisation of the European energy system. In this context, the group is open to collaborating with all other initiatives dealing with energy networks to avoid or limit duplication and with initiatives acting on all technologies that interact with networks, from

30 ETIP SNET R&I Implementation Plan 2025+ and ETIP SNET R&I Implementation Plan 2022-2025 (with the former being an incremental update of the latter)
31 https://bridge-smart-grid-storage-systems-digital-projects.ec.europa.eu/
32 https://www.era-learn.eu/network-information/networks/enerdigit

renewable generation to end-use technologies and storage.

Within the SET Plan framework, many working groups are of particular interest to the Energy systems group. More specifically:

- For Flagship 1, collaboration with other stakeholders can efficiently take place through active discussions within the connected ETIPs. The working group aims to reinforce its participation in the ETIP SNET governing board to ensure the governments' voice and interaction with industrial stakeholders, channelling discussions through this initiative. A direct link is established with the Direct current working group due to common technological interests.
- For Flagship 2, active collaboration can be fostered with several IWGs dealing with specific subjects of interest, such as hydrogen, heating and cooling, and industry. These are specific subjects considered in the new edition of the Implementation Plan.
- Transversal collaboration can also be established along two additional pathways: digitalisation and societal aspects of the energy transition.

ENERGY EFFICIENCY IN BUILDINGS

The Implementation Working Group on Energy efficiency in buildings aims to unlock the energy savings potential of the building sector. The group's work encompasses a range of topics, including sustainable materials, digitalisation, heating and cooling technologies, and their integration into buildings. The working group is supported by a Coordination and Support Action.

A major achievement since the last reporting period has been the strengthening of the working group's structure through a member recruitment campaign and restructuring of its management. This has resulted in the addition of 11 national representatives and 4 new stakeholders and research organisations, improving representation from Eastern European countries and stakeholders. The working group now has a more comprehensive and diverse membership.

Another key activity has been the update of the current Implementation Plan33. To support this effort, four Task Forces were established to prepare White Papers and revise targets and Activity Fiches. These Task Forces focus on sustainable materials, active façades, digitalisation, and heating and cooling technologies.

33 *Implementation Plan on Energy efficiency in buildings 2024*

The working group has established four temporary Task Forces on Active Modules, Sustainable Materials, Clean Heating, Cooling and Thermal Storage, and Digitalisation. The first three White Papers have been published, providing valuable insights into these areas[34]. Additionally, the Coordination and Support Action (CSA) of the working group has published a report analysing the draft NECPs of several EU Member States, offering recommendations to accelerate the uptake of innovative clean technologies in the construction sector. These policy recommendations have been presented to relevant networks and sent to key policymakers.

The working group also analysed the NECPs of several EU Member States, with a focus on measures concerning innovation in buildings. A report and factsheet have been published as a result of this analysis, providing valuable insights into the current state of energy efficiency in buildings across the EU[35].

The CSA has also been working on a comprehensive model of Europe's entire building stock, aiming to establish a baseline of current energy consumption and simulate various scenarios for 2030 and beyond.

The European Construction Technology Platform (ECTP) has published its Strategic Research and Innovation Agenda (SRIA) for 2024-2030[36]. The long-term vision for the built environment and related industrial sectors is to create a climate-neutral built environment that enhances the well-being of all EU citizens, supported by a circular, digitalised, and resilient construction value chain. To achieve this vision, three objectives have been set for 2030: a resilient, decarbonised, adaptable and regenerative built environment; an enriching, inclusive and health-improving built environment; and a competitive, digitalised, and circular value chain.

The Renewable Heating and Cooling European Technology and Innovation Platform (RHC-ETIP) has contributed to a report on "Skills in the Renewable Energy Sector - Visions from the European Technology and Innovation Platforms"[37] and published a recommendation paper on "How to Make Renewable Heating and Cooling Transition Socially Just?"[38]. Furthermore, RHC-ETIP has been developing an RHC Accelerator, a service that supports technology developers in transitioning from completed research projects to marketable products.

Status of the implementation plan

The group and its support action are currently updating the Implementation Plan. The new document will take into account the EU's 2030 climate and energy framework (Fit for 55), the revised Energy Performance of Buildings Directive (EPBD), the Renewable Energy and Energy Efficiency Directives, as well as the new Construction Products Regulation (CPR). Additionally, the document will incorporate input from the first White Papers on sustainable materials, active modules, digitalisation in buildings, and clean heating and cooling technologies, as well as the analysis of the NECPs.

The main changes to the Implementation Plan in the last reporting period include a shift in focus from new materials to sustainable materials in subgroup 5.1, in order to better address circularity and sustainability issues. Two of the subgroup's activities have been renamed. "New materials and technologies for energy efficient solutions for buildings" is now "Sustainable materials and technologies for energy efficient solutions", and "Digital planning and operational optimisation" is now "Digitalisation in buildings", to better cover the full digital potential of buildings.

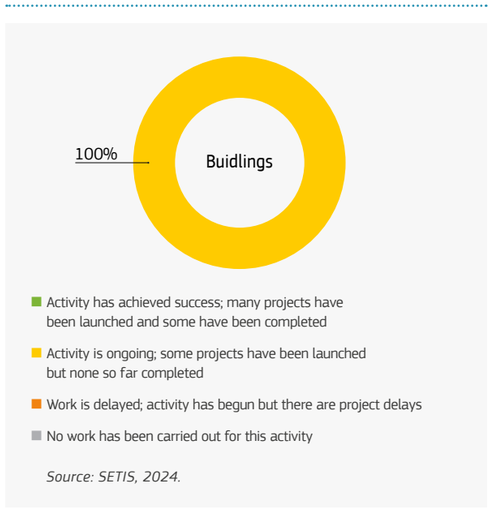
The targets of subgroup 5.1 have been updated, and two new targets have been added. The first new target focuses on developing technologies to enable energy flexibility at building and district level, helping to align energy-efficient buildings with the energy system as a whole. The second new target aims to use data-driven applications to maximise the reusability and high-value recyclability of materials and building elements at the end-of-life stage. This target integrates the requirements of the Green Industrial Plan, particularly the Circular Action Plan and the Critical Raw Materials Act, and links the energy efficiency of buildings with circularity issues.

Status of the activities

Members of the working group have initiated and carried out numerous regional, national, and EU-wide research and development projects in the building sector. The ECTP project database[39] includes 106 projects (starting in 2020 and later) related to buildings, covering topics such as advanced materials, energy performance, end of life, BIM, and smart buildings. The project database on the ETIP RHC platform[40] includes over 170 projects on district heating and cooling, heat pumps, solar thermal, hybrid systems, and thermal storage.

Several notable EU-funded projects have been completed, including:

- The Drive 0 project[41], which developed local solutions for deep renovations and fostered a circular economy for the built environment. The project designed a 'plug and play' modular solution that leveraged the local marketplace, knowledge, skills, and building materials. Pilots were conducted in seven countries, with promising results, including a complete net-zero retrofit in the Netherlands and deep renovations achieving primary energy savings, and similar reductions in the use of fossil fuels, of 55-85% in Ireland.
- The POWERSKIN PLUS project[42], which developed prefabricated, modular glazing that features solar panels and energy storage capabilities using second-life Li-ion batteries recycled from electric vehicles. The project demonstrated its innovative facade system at sites in Czechia, Germany, and Portugal, and plans to bring the system to market within three years.
- The D^2EPC project[43], which developed a BIM-based Digital Twin to enable the issuance of next-generation Energy Performance Certificates on a regular basis. The project introduced important technological advances concerning data and software quality and credibility, transparency and availability of information on actual energy performance, and smartness of buildings. The D^2EPC scheme was validated and demonstrated under real-life conditions in six buildings across Greece, Germany, and Cyprus.
- The iBRoad2EPC project[44] developed, tested and delivered a model for the Building Renovation Passport supporting single-family home-owners with personalised advice to facilitate stepwise deep renovation of their buildings. The project bridged the Building Renovation Passport with the Energy Performance Certificate to offer better and more attainable renovation information to households.
- The THERMOS tool[45], which makes district heating and cooling (DHC) planning easier, faster, and cheaper according to user-specific requirements. The tool provides advanced energy system data and map models in a user-friendly open-source software to identify optimal network solutions in almost any part of the world. Over 1 400 users have already started to develop 3 000+ maps and projects with THERMOS for professional use.
- The SunHorizon project[46], which aimed to reduce greenhouse gas emissions and energy costs for consumers in Europe by combining solar thermal panels with several types of heat pumps. The project successfully gathered data from three pilot sites in Latvia and Spain, achieving significant reductions in greenhouse gas emissions (by 40-60% for some periods) and a decrease in energy bills (by 10-30%, depending on the site). Some sites observed up to 50% savings in primary energy. The project's focus on user feedback and monitoring data led to improvements in system efficiency, and the findings are expected to inform future installations and encourage replication in other buildings across Europe.



Source: SETIS, 2024.

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46 www.sunhorizon-project.eu/

Challenges

The construction sector is currently facing multiple challenges accelerated by the geopolitical situation, including high prices, labour costs, and supply shortages for energy and construction materials, as well as slower economic growth in Europe. However, the green transition is also having the potential of creating new business opportunities.

To support the sector in addressing these challenges, cross-cutting funding programmes, investments, and support for green and digital skills are necessary. The IWG on Energy efficiency in buildings offers support by showcasing green transformation tools and pathways.

The majority of buildings in the EU were constructed before energy efficiency standards were put in place, which means they often lack proper insulation and efficient heating and cooling systems. Access to better data on buildings and their energy use is crucial for public authorities' ability to address the issue. Despite progress on collecting data through the EPCs, Building Passports and Digital Building Logbooks, the sector is still struggling with a lack of granular data on buildings and their performance.

The EU faces the challenge of addressing the whole life carbon footprint of buildings, including embodied carbon from construction materials and end-of-life processes. Article 7(2) of the EPBD require Member States to ensure that the life-cycle Global Warming Potential is disclosed in the EPC for new buildings. The shift towards reducing whole life carbon requires sustainable materials, design for longevity, and circular economy practices. This transition is necessary and will influence some of the current practices in the sector.

The revised Energy Efficiency Directive has significantly increased the EU's ambition on energy efficiency, more than doubling the annual energy savings obligation by 2028. A key element of the REPowerEU plan is the phase-out of gas boilers. Heat pumps has been identified as one key technology to replace boilers with, including a goal to install an additional 30 million units in Europe by 2030. The heat pump industry is facing a challenging period after ramping up investments in response to a sharp surge in demand. Despite these preparations, the market experienced a downturn in sales during 2023. Forecasts for 2024 anticipate a continuation of this downward trend in the sector.

The district heating and cooling (DHC) sector is facing similar challenges with declining investments. The sector needs consistent policies that are needed to enable the sector to plan ahead and invest in research, development, and innovation projects. Cooperation between partners and companies in the complete value chains is also necessary, supported by adequate funding. Grants or contributions towards pre-finance development costs could help generate future projects.

Future plans

The EU has agreed to significantly increase its climate and energy ambitions by revising key legislation for the construction sector, including the directives for buildings (EPBD), energy efficiency (EED), and renewables (RED). The war in Ukraine has provided additional impetus to move away from gas boilers. In this context, the working group aims to mainstream more innovative renewable energy and energy efficiency technologies in the construction sector.

To achieve this, a wider range of high-performance products is essential to adapt to different building types, including specificities for building renovations. Standardisation is also crucial to help reduce costs and installation time. Furthermore, the rate of digitalisation needs to increase to better manage energy systems and improve building design.

Policies should be swiftly put in place to translate into concrete funding in the short to medium term, such as the Heat Pump Action Plan, to support the deployment of new technologies. Embodied carbon and environmental impacts are key issues where advanced materials, better design, and recyclability are expected to reduce the footprint of construction and renovation. The whole-life carbon potential of buildings, which is also addressed in the new EPBD, is another important topic.

These and other technical topics are being discussed in the 2023-2024 IWG task forces and bi-monthly meetings. The topics will be included in the revised Implementation Plan, which will also include sector-specific targets for the deployment of new, efficient, and affordable technologies in buildings.

In the coming year, the working group will focus on social aspects to ensure a just transition that leaves no groups behind. A task force will investigate skills gaps in the buildings sector and strategies to address them. Another task force will examine factors that are important to increase the social acceptance of residents towards new technologies and policies, such as extending the Emissions Trading System (ETS) to buildings.

Synergies

The working group has established links with several partnerships, including:

- Built4People (B4P);
- Driving Urban Transitions (DUT); and
- Clean Energy Transition Partnership (CETPartnership), particularly with TRI4 and TRI7.

The motivation behind these collaborations is to join forces, discuss synergies, and explore joint topics and potential joint calls, especially in the context of the updated Implementation Plan. In preparation for the IP, the group has exchanged ideas with M-ERA NET and the new partnership Innovative Materials for EU (IAM4EU). Additionally, the activities and outreach of the IWG subgroup 5.1 (Activity Fiche on Sustainable Materials) are linked to the planned cross-cutting SET Plan task force on circularity and materials.

The working group also collaborates with other organisations and networks, including:

- Regular cooperation with the European Technology and Innovation Platform for Renewable Heating and Cooling (ETIP-RHC), where the group has presented twice in the past year;
- Links to other SET Plan stakeholders, including the ETIP Forum, ETIP PV, ETIP Geothermal, and IWG Industry;
- Contact with the EPBD Concerted Action on the NECPs revision; and
- Regular cooperation on data exchange and policy topics with the research organisation BPIE (Building Performance Institute Europe).

Working group on Energy efficiency in buildings, workshop.

SUSTAINABLE AND EFFICIENT ENERGY USE IN INDUSTRY

The main objective of the Implementation Working Group on Sustainable and efficient energy use in industry is to support energy-intensive industries in reducing their energy, resource, and emissions intensity while enhancing their competitiveness. Its main goals are to continue improving the performance and cost-effectiveness of industry and increase the wider use of renewables and low-carbon energy sources.

The group focuses on several key sectors, including iron & steel, chemicals, cement, pulp & paper, heating & cooling systems. The group aims to enhance performance in these sectors while reducing resource consumption and emissions.

This year, the group achieved a significant milestone by initiating a series of cross-cooperation workshops. These workshops bring together various IWGs to foster synergy, promote collaboration, and exchange knowledge, ultimately accelerating progress towards shared goals.

Recent developments

The working group has made significant progress in fostering collaboration within the framework of the SET Plan. One of the key developments has been the initiation of a series of cross-cooperation workshops aimed at promoting synergy among various IWGs.

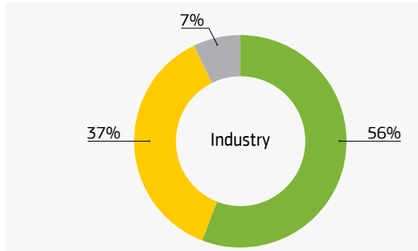
In April 2024, the group convened its second workshop with the IWG Energy systems, which featured two panel sessions. The first session examined the integration of electrical renewable energy sources and storage in more flexible industrial plants interacting with the power grid. The second session delved into the topic of nuclear and renewable heat for industry.

The working group has also expanded its collaborative efforts by building on successful models of technology cooperation. Partnering with organisations like EHPA and CEPI, the group has ventured into new sectors and technologies. This expansion includes initiatives such as integrating heat pumps in the food and drink sectors, utilising heat pumps in the manmade fibre sector, and exploring heat storage solutions in the steel sector.

Internally, the working group maintains regular meetings to facilitate the presentation of EU and national R&I projects and funding programmes, such as Horizon Europe and the CETPartnership. These meetings ensure consistency in information flow among Member States and associated countries, stimulate knowledge-sharing, and disseminate relevant EU policies and initiatives.

Furthermore, the group is actively enhancing its connections with organisations like EERA and the ETIPs FORUM to strengthen representation from the research community and the industry-led ETIPs.

Building on successful models of technology cooperation, the group has expanded its collaborative efforts into other sectors and technologies. Notable partnerships include the European Heat Pump Association (EHPA) and the European association representing the paper industry (CEPI). These partnerships aim to promote knowledge sharing, accelerate innovation, and drive progress towards a more sustainable and competitive industry.



Source: SETIS, 2024.

Status of the activities

The Industry group has 30 activities, many of which have projects that report finished deliverables or successful completion. A small number are delayed or have not yet begun.

In the coming months, an analysis will be conducted under the SET-IndEU project to assess the progress of the Implementation Plan and identify gaps and barriers impeding its full execution. These barriers can be external (such as lack of funding, technical, non-technical, regulatory, administrative) or internal (such as broadly defined actions, shifts in R&I community focus, participating countries' prioritisation). This analysis will be carried out through interviews with the IWG experts to gather further information. The results will be included in the next SETIS monitoring progress exercise.

Heat and Cold

One key ongoing project related to Activity 1.4 is the eLITHE project[47], which focuses on advancing the decarbonisation of the ceramic industry. The project aims to demonstrate innovative, sustainable, and cost-effective pathways for electrifying high-temperature thermal processes, such as melting, calcination, and firing. ELITHE seeks to showcase how polygeneration systems and hybrid plants can be effectively integrated into industrial processes to reduce carbon emissions and enhance energy efficiency.

47 www.elithe.eu/

Systems

Ongoing projects are making significant improvements in enhancing energy efficiency and sustainability across multiple sectors. For example, the REDOL project[48] valorises solid urban waste through industrial-urban symbiosis, creating robust energy-sharing networks that significantly reduce waste. Projects are also advancing the efficiency and sustainability of carbon capture and utilisation systems. The integration of cutting-edge technologies is optimising industrial processes, enhancing process control, and improving energy management. These projects emphasise the exchange of technological, economic, behavioural, and social knowledge through innovative training programmes and broader dissemination of successful case studies.

Cement

Ongoing projects in the cement sector are driving innovation to facilitate a low-carbon transition. These projects focus on resource efficiency, energy efficiency, carbon capture storage and usage, and recarbonation and mineralisation. The CAPTUS project[49] will demonstrate sustainable and cost-effective pathways to produce high-added value renewable energy carriers in energy-intensive industries by valorising industrial carbon emissions and integrating renewable electricity surplus. When it comes to cement, the project looks into electrochemical reduction of CO_2 to produce formic acid in a cement plant.

Chemicals

Ongoing projects in the chemicals sector are focused on integrating climate-neutral energy sources, utilising alternative carbon sources such as biomass, CO_2 captured from industrial effluents, and waste including plastics. These projects aim to produce low CO_2 emissions hydrogen and improve process efficiency. The FIREFLY project[50] exemplifies these efforts by supporting the sustainable electrification of the catalyst-based chemical industry, reducing dependence on metals and fossil energy.

Iron and Steel

Ongoing R&I activities in the iron and steel sector concentrate on optimising the two main steel production routes: converting iron ores into steel using coke or coal in blast furnaces, and using electric arc furnaces (EAF) to melt iron-bearing materials such as scrap steel with electricity. Efforts are aimed at enhancing the efficiency and reducing the carbon footprint of these traditional processes.

Pulp and Paper

In the pulp and paper sector, ongoing R&I projects focus on integral drying and heat recovery processes to improve energy efficiency. Innovations aim to eliminate water evaporation in papermaking, reducing energy demand. Modular electrification and process optimisation reduce reliance on fossil fuels. Mild pulping processes are being developed for lower energy consumption. Biomass is being explored as an alternative feedstock for sustainability, supporting the transition to renewable resources and cost-efficient carbon capture and storage (BECCS) for decarbonisation.

Challenges

The process industry sector is facing significant challenges in achieving decarbonisation, as the technology currently commercially available is insufficient for full decarbonisation. Meeting net-zero objectives by 2030 requires further research and investment in pilot demonstrations and largescale first-of-a-kind (FOAK) projects for proven but not yet market-ready technologies.

However, the high cost of CO_2 quotas poses economic challenges, requiring substantial investments. Despite these obstacles, improvements in energy efficiency, renewable energy uptake, and collaboration have been made, although progress remains slow.

To meet net-zero objectives by 2030, a shift from fossil fuels to renewable and low-carbon sources, enhanced energy efficiency (including recycling industrial waste heat with heat pumps), and accelerated development of near-zero-emission processes like carbon capture, utilisation, and storage (CCUS) and hydrogen are essential.

Government policies play a crucial role in reducing the risks associated with new technologies and enforcing mandatory CO_2 emission reduction measures. Cooperation between technology suppliers and industrial end-users is also vital to promote the deployment of optimised and standardised solutions across most plants.

48 www.redolproject.eu/
49 www.captusproject.eu/
50 www.firefly-project.eu/

However, slow permitting processes and bureaucratic hurdles continue to impede progress. To ensure the success of the IWG, it is essential to identify and prioritise regulatory and standardisation needs and barriers, and to adopt a standardisation process that supports current innovations.

Utilising best practices can highlight effective solutions and promote cooperation among energy-intensive industry sectors, facilitating the transfer of solutions and ensuring optimal participation in EU regulatory procedures. Creating favourable market conditions for costly innovations compared to traditional methods is also crucial. Alignment of regulations across Europe will support these efforts, ensuring a cohesive and efficient decarbonisation path.

Future plans

The prospects for the industrial energy efficiency transition are promising in the upcoming year, with concerted efforts aimed at advancing the implementation of the SET Plan strategy and the priorities outlined by the working group. The group is committed to fostering a cohesive alignment among various stakeholders involved in this transition.

One of the primary actions this year is the organisation of the SET Plan IWG Industry 2024 Annual Event, which targets a technical audience and focuses on critical industrial topics. The event covers challenges faced by the process industry, ongoing initiatives in Europe, and strategies for ensuring sustainable development in the energy-intensive industry by 2030 and 2050. To increase visibility and sectorial synergies, the event is being organised under the scope of the Belgian Presidency Semester, as a satellite event of the INDTech conference 2024 and as an EU Sustainable Energy Week (EUSEW) event.

In addition to the annual event, the group will work towards consolidating and developing synergies within the energy-intensive industry community and related networks. This will involve organising cross-cooperation IWG Workshops and replicating successful technology cooperation models across different sectors. Active participation in external events such as the EU Research and Innovation Week, ETIPs FORUM, EERA's events, A.SPIRE, and P4Planet events will also be prioritised. Furthermore, the group will continue facilitating dialogue between the European Commission, SET Plan countries, and stakeholders to identify and address necessary actions for progress outlined in the Implementation Plan. By engaging key stakeholders and fostering collaboration, the working group aims to drive significant advancements in industrial energy efficiency, contributing to the wider climate and energy objectives of the EU.

Synergies

Collaboration with other working groups and external actors is crucial for enhancing synergies and dialogue across the SET Plan. Specifically, the Industry and Energy systems IWGs jointly hosted a workshop focused on integrating electrical and thermal, renewable, and low-carbon energy sources in industry.

The workshop aimed to identify key areas of cooperation, facilitate knowledge sharing, and explore new collaboration opportunities among IWGs, setting a strategic path forward. This collaboration is highly strategic, recognising the interconnections beyond the IWGs on Industry and on Energy systems, and extending to other SET Plan working groups.

Together, these groups aim to drive the transition towards a fully climate-neutral energy system in Europe. The workshop included a section on "International Trends on Industry Energy Efficiency and Integration" and featured panel sessions on "Integration of Electrical Renewable Energy Sources and Storage in More Flexible Industrial Plants Interacting with the Power Grid(s) - Challenges and Opportunities" and "Nuclear and Renewable Heat for Industry."

Additionally, the ETIPs FORUM presented its current activities and future collaboration plans with the SET Plan IWGs. The event highlighted the importance and relevance of organising similar cooperation workshops, showcasing their contributions to strengthening the SET Plan community and addressing the urgent need for timely action.

By joining forces, the groups aim to leverage each other's expertise, share best practices, and foster innovation, thereby accelerating the development and deployment of sustainable energy solutions across Europe.

BATTERIES

The Implementation Working Group on Batteries, implemented by Batteries Europe, brings together a diverse range of stakeholders from the European battery sector, including researchers, industries, and policymakers. This collaborative approach fosters communication and cooperation across the entire battery value chain.

In line with the SET Plan's goals to support the EU's transition to clean energy and establish Europe as a leader in clean energy technologies, the IWG identifies and prioritises key research areas for battery development. The group also helps shape a roadmap to ensure Europe becomes a global leader in sustainable battery cell and pack manufacturing.

In 2023, the IWG organised the Batteries Europe Plenary Session in June and co-organised the Battery Innovation Days in November. A key milestone in 2023 was the publication of the Technology Roadmap. In the first quarter of 2024, the IWG updated its Implementation Plan/Batt4EU Strategic Research and Innovation Agenda[51], emphasising sustainability, competitiveness, and inclusiveness in the European battery industry.

51 In the case of the Batteries group, for practical reasons the Implementation Plan is integrated with the Batt4EU Strategic Research and Innovation Agenda. Therefore, currently they constitute one and the same document. *https://bepassociation.eu/our-work/sria/*

Recent developments

The working group has made significant progress in the last year, with the following key developments:

- The 6 Working Groups and 6 Task Forces, comprising over 700 experts, produced four key outcomes: R&I Roadmap; Battery Key Performance Indicators (KPIs); Batt4EU Strategic Research and Innovation Agenda (SRIA) 2024; and 6 cross-cutting position papers.
- The National and Regional Coordination Group (NRCG) and the Batteries European Partnership Association (BEPA) organised a workshop during the World Circular Economy Forum 2024, featuring representatives from the Commission, industry, and the R&I community. They also organised three thematic meetings, where each Member State/ Associated Country presented their battery R&I landscape.
- The working group facilitated the ETIPs FORUM activities, producing several outcomes (see ETIPs FORUM section).
- Two additional factsheets were published for India and Canada, complementing those produced in 2022.
- A 9-day mission was organised to Japan and South Korea, meeting with Ministries' directors, Technology Institutes, leading industry representatives, and associations, and participating in major battery events in both countries.
- The working group participated in workshops on "Cooperation across SET Plan IWGs" and "Transport Research Arena", and presented the Task Force on sustainability in a Battery2030+ meeting.
- The Batteries Europe Plenary Session was organised, and the Battery Innovation Days were co-organised, attracting over 1 400 participants.
- Battery2030+ included 13 new projects in the last year, expanding its scope to include recycling, digital twins, sustainable production, and raw materials. The exploration of interfaces deepened, as did collaboration around standards, ontology, and the development of new academic courses in the battery field.
- The European Battery Alliance (EBA) Academy continued its upskilling and reskilling efforts, developing seven new courses, translating 115 courses into various languages, and certifying over 60 000 learners.

The IWG has focused its activities on cross-cutting topics and has published six position papers outlining R&I requirements across various domains, including: education and skills; safety; sustainability; digitalisation; hybridisation; and social sciences and humanities. These position papers provide a comprehensive framework for addressing the challenges and opportunities in the European battery sector.

Status of the implementation plan

Over the past five years, Europe has embarked on a journey to establish large-scale factories, marking the beginning of a trajectory aimed at bringing production and manufacturing activities in Europe, known as onshoring supply chains, and enhancing the sustainability of the battery value chain. To achieve this, broad support for R&I is necessary, funded both publicly and privately, to foster environmental sustainability and technological leadership on the global stage.

Following the adoption of the Battery Regulation in 2023, the battery passport is a central element of the Implementation Plan[52]. The battery passport will digitally store labelling and essential information on battery components and recycled content, aiming to enhance transparency, improve market functioning, and ensure fair competition by providing easy access to safety and sustainability information.

Essential to boosting Europe's competitive, sustainable, and circular battery value chain is the establishment of flexible battery manufacturing and recycling systems, enabled by economies of scale and technological innovation, to catch up with and eventually surpass Asia.

Aligned with the imperatives of the most recent EU regulations, critical raw materials are at the heart of battery development and are key to safeguarding European strategic autonomy. The new IP signifies the needed efforts to boost European raw material processing capacity, considering also the raw materials needed for other chemistries than lithium-ion (e.g., sodium-ion). Investment in research on secondary raw materials (including waste from mining and manufacturing) will be needed to boost the use of recycled material.

Developing a qualified workforce tailored to the needs of battery manufacturing is essential, with initiatives focused on creating battery manufacturing pilot lines and digital training tools to be rapidly replicated across Europe.

52 *Batteries Europe Strategic Research and Innovation Agenda 2024*

Lastly, another new aspect in the updated IP is the emphasis on lower TRL research in the field of biomimetic materials with self-healing functionalities.

Changes to the Targets

There have been several changes to the initial 2016 targets, compared to the most recent targets set in 2023. Some have been achieved, while others have been updated or their metrics changed.

The 2016 target for 2020 volumetric energy density of automotive application batteries at cell level was 700 Wh/L, a value that as of 2023 has been achieved (currently 650-750 Wh/L) and is expected to further increase in the future.

The same applies for the charging rate, with a current value of 20min (3C) - higher than the 2020 target (i.e., 2C) – and expectations to overshoot the respective 2030 target of 12min (5+C) earlier than expected. Likewise, a battery lifetime of 1 000 cycles has been achieved, and the target to double this number to 2 000 by 2030 will most likely be achieved sooner than expected.

The 2020 target for battery pack cost for automotive applications of 90 EUR/kWh has not been achieved (currently 150+ EUR/kWh), mainly due to lithium, cobalt, and nickel price volatility on mass adoption of technology and planned production output. However, the expected target of <75 EUR/kWh by 2030 is in line with current expectations.

The metrics on gravimetric and volumetric power density have been removed, since publicly available data is limited and does not allow for a transparent comparison of battery cells in this regard. Similarly, the cost for battery applications in the past was measured in EUR/kWh/cycle, but given that there is not a common approach among manufacturers on what a cycle is, this metric has been abolished, and only EUR/kWh is used at present.

For a more detailed breakdown of these targets, please refer to the KPI Benchmarking publication[53]. The most important targets are summarised below.

- Increase battery energy density by +60% compared to 2019 values.
- Increase battery power density by at least 30% compared to 2019 baseline and charging rate.
- Improve cycle lifetime by at least a factor of 2 compared to 2019 state-of-the-art values.
- Reduce battery cost by 60% compared to 2019 values.
- Ensure battery safety in the different targeted application sectors.
- Implement worldwide best available technologies in manufacturing and recycling operations.
- Enhance the sustainability of the main supply chains of battery's raw materials and achieve the lowest possible carbon footprint of the supply chain from raw material extraction through battery manufacturing, use and recycling.

Status of the activities

The majority of the strategic actions of the group have projects that report finished deliverables or successful completion. However, five are new and are expected to start in the coming years.

Raw materials

Research activities under Strategic Action (SA) 1 aim to create processing solutions for vital battery production components, focusing on lithium-ion battery chemistry for the next decade and establishing a European sodium-ion battery production ecosystem. SA2 focuses on the recovery of metals and chemicals from new sources such as industrial or urban wastes, developing novel cost and energy-efficient recovery methods and processes.

In the raw materials domain, at national level, The Polytechnic University of Catalonia leads the M4L project, which aims to develop safe, circular, and sustainable lithium battery metal technology using secondary resources.

Advanced Materials

Under SA1, projects will develop advanced materials with the aim of reducing cost while lowering the share of CRMs including by "design-for-recycling" strategies. SA2 will develop solid-state electrolytes, anode and cathode materials that exhibit enhanced thermal and electrochemical stability. For these two Actions, some projects have been completed and several are ongoing. An example of a project at regional level funded by the Research Foundation - Flanders, the University of Hasselt develops novel electrolytes for sodium-ion batteries. Deep eutectic solvents are cost-effective, performant, and non-flammable alternatives for conventional liquids and they can be readily incorporated in porous solids to form eutectogels.

SA3 focuses on developing various low-TRL chemistries to deliver on safety, cost, performance, sustainability and recyclability, with clear prospects for the feasibility of scale-up of the manufacturing processes. Beyond the ongoing EU-funded projects, in Flanders (Belgium), the Fugels project develops functionally graded electrodes for long lifetime lithium-sulphur batteries aiming to improve the durability of lithium-sulphur batteries as a next-generation battery technology.

Projects under SA4 will develop various safe and sustainable systems to enable beyond Li-ion batteries that deliver features fit for stationary storage, including extended cycle and calendric life, low cost, and a reduced dependence on CRMs.

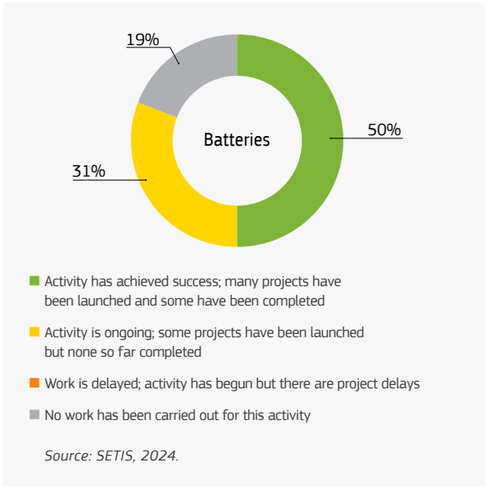
SA5 and SA6 are novelties in the IP with projects expected to start in 2026 and 2028. The former will develop safe and sustainable materials systems to enable low-temperature sodium-ion batteries to deliver on energy density, long cycle life and low cost, combined with a reduced dependence on CRMs. The latter is focusing on the development of biomimetic self-healing materials, targeting increased battery lifetimes.

Finally, projects under SA7 will develop autonomous high-throughput synthesis robotics and experiments, utilising European largescale characterisation infrastructures such as synchrotron and neutron facilities, building on the Horizon 2020 BIG-MAP project, it advances interface engineering and fully automated material discovery platforms.

As an example of a national project in this domain, in Spain, the MISIONES LION HD Project aims to stimulate the national battery materials industry, by further developing and testing several anodic, cathodic and other Liion materials and components. CIDETEC plays a central role in electrode and cell manufacturing, testing and validation, jointly with other partners in Spain.

Design

Projects under SA1 will translate the Safe and Sustainable by Design framework into practicable guidelines, defining common principles, tools and methodologies for evaluation of design for circularity. SA2 will capitalise on the results of previous and ongoing projects to embed smart sensing functionalities, enabling self-healing inside battery cells. This will enhance the performance, lifetime, reliability and safety of the whole battery system.



Source: SETIS, 2024.

Manufacturing

In the scope of SA1, projects aim to advance the integration of sustainable manufacturing processes into the existing and future production lines by reducing energy consumption, minimising the use of chemicals, improving safety and reducing costs. Projects under SA2 will develop innovative and multi-purpose production lines compatible with diverse chemistries and cell designs. This will be validated at pilot-level and will target the enhancement of existing gigafactories capacities (based on Lithium-ion).
Beyond the various ongoing EU funded projects, Floatech, a start-up in Spain advances silicon anode technology for lithium-ion batteries, scaling from ERC-backed research to CDTI-supported pilot plant.

The process creates nano-sized silicon in a textile format aiming to overcome challenges of volumetric expansion and enhancing storage capacity. In Germany, the ENTISE project led by Varta and funded by German Federal Ministry of Education and Research (BMBF) aims to develop a high-performance, cost-effective and environmentally friendly cell chemistry for sodium-ion batteries that can be used in a variety of end-use applications.

Application: Mobility

SA1 focuses on reliable thermal management systems for extreme conditions and enhancing cell energy/power density by replacing CRMs and cutting costs. Finalised

53 Batteries Europe, 2023, KPIs Benchmarking & Target KPIs, *[link]*

projects in this domain addressed BEV and PHEVs and applications for waterborne transport.

SA2 aims to develop cloud-based battery management of multi-application integration, targeting advanced algorithms and data analysis based on embedded sensors at different levels to enable virtual storage capacity aggregation towards grid flexibility.

SA3 aims to reduce the time to market of batteries by shortening the development time and costs of battery cells and systems by minimising the experimental testing effort while improving battery safety and reliability.

SA4 includes high-TRL activities for multiple applications (e.g., mines, ports, ferries, aviation and rail) where demonstrations will develop, design and prototype safe, lightweight and airworthy battery modules and packs. However, no projects have been carried out yet. At national level, in Spain, in a project coordinated by SEAT/VW, CIDETEC will develop and demonstrate a lithium-ion semisolid state battery cell technology aimed at automotive applications, while PERTE VEC CAPITAL project is developing various technologies for electric heavy-duty vehicles, leveraging EUR 63 million of investments.

Application: Stationary Storage

Projects under SA1 aim to develop next-generation long duration storage and ensure their commercial viability for integrating renewables to the grid. In SA2, activities focus on developing new and flexible battery management systems (BMS) that are adaptable to a variety of chemistries, making use of digital twins to enable the integration of real-time data. The focus of SA3 is on the optimisation of stationary storage to enable cross-energy sector coupling and aggregation of different technologies of batteries (hybrid) to provide energy to consumers and at the same time to improve grid quality and stability. Virtual batteries business modelling with advanced energy management system (EMS) is included in the scope.

An example from Spain, Endesa, is developing a 2.52 MW/12.60 MWh wind-hybrid zinc cathode battery system in Las Palmas to boost renewable integration.

Dismantling and Recycling

SA1 focuses on sustainable recycling processes for emerging chemistries like sodium-ion, Vanadium Redox Flow Batteries, and Li-metal batteries. It includes integrated methods and safe-proof techniques, emphasising direct electrode material recycling. SA2 aims to boost recycling flexibility, especially for lithium-ion batteries, adapting to changing compositions and transitioning to sodium-ion recycling. It targets higher recovery rates of lithium, graphite, electrolytes, binders, and membranes.

At national level, in Portugal, the NGS project focuses on sustainable recycling processes for lithium-ion batteries, and on mechanical processes and chemical processes to obtain nickel, cobalt, manganese and lithium compounds. In Spain, the BATERURGIA project supported by CDTI aims to innovate in lithium battery recycling, focusing on robotics and metallurgy for critical metals recovery.

Transversal Topics

The transversal R&I activities that cut across the value chain include 3 SAs. SA1 will capitalise on the outcome of the ongoing activity to broaden the LCA methodology so that it becomes applicable to a wide range of batteries, including stationary storage. SA2 will pilot the development of a working and applicable battery passport for batteries with external storage, applicable also to flow batteries. Future projects under SA3 will develop pilot lines for educational purposes, crucial for training a skilled workforce. These lines, both physical and digital, will be replicated across Europe, addressing the bottleneck of practical training access.

An example of a national project, in Portugal, the Batteries 2030 project focuses on the development of the third generation of lithium-ion and redox batteries of the future and their transfer to the urban environment, utilising various ICT tools.

Challenges

To become the global leader in sustainable battery cell and pack manufacturing, the European industry must rapidly address four major challenges to achieve its aspirations: competitiveness, sustainability, industrial upscaling, and market uptake.

Competitiveness – To prevent external dominance, Europe must produce competitive batteries that offer technical excellence, affordable costs, and efficient processes. This can be achieved through innovation and scale, enabling Europe to compete with other external manufacturers.

Sustainability – Battery manufacturing must align with sustainability goals, minimising environmental impact and promoting transparency. R&I is crucial for reducing carbon intensity and enhancing recycling, paving the way for a circular economy in batteries.

Industrial upscaling – To meet European market demand, high-volume gigafactories are essential. Upstream and downstream industries must upscale with automation, efficiency, and low environmental impact. R&I in refining, manufacturing, and recycling, linked with material research, is essential for cost-effective and sustainable processes.

Market uptake – Successful market uptake of batteries depends on both technical and non-technical factors. Integration into various systems, user-friendliness, and infrastructure are critical. Policy alignment and R&I in diverse areas are essential, requiring upstream engagement with policymakers to anticipate innovations.

Collaboration at the European level plays a crucial role in addressing these challenges. The working group needs to engage more stakeholders in battery technology, fostering closer industry-research collaboration to accelerate innovation implementation in the battery sector in Europe. Furthermore, deeper coordination is needed between the “European Batteries R&I Community” and national/regional funding agencies to enable the better monitoring of ongoing R&I activities and alignment of funding mechanisms across Europe.

Future plans

The IWG plan for the coming year includes various initiatives aimed at achieving the goals outlined in the Implementation Plan. This plan will be executed through annual calls, with the Batt4EU partnership expected to issue its initial calls in spring 2025, in close collaboration with the IWG. The Implementation Plan will be continually updated to guide calls in the 2026-2027 Work Programme.

Throughout the next year, the six working groups, the six task forces, and the National and Regional Coordination Group (NRCG) will maintain pivotal roles in IWG activities. Key outcomes will include updating the R&I Roadmap, which was first published in 2023, supporting the Batt4EU Work Programme, and providing guidelines on common reporting methodologies.

Simultaneously, various dissemination activities are planned to promote the work group outcomes, expand the European battery R&I ecosystem, and facilitate stakeholder collaboration. Events like the Batteries Europe Plenary Session 2024 and dissemination workshops for Task Forces’ position papers will be organised, and the IWG will co-organise the Battery Innovation Days 2024 (26-27 November 2024).

Moreover, discussions are underway for cross-collaboration activities, including the publication of a scientific paper on the battery passport with input from the Task Forces on Digitalisation and Sustainability, cross-fertilisation activities between the Task Force on Social Sciences and Humanities and the working groups, and a special publication on battery hybridisation.

An ongoing objective of the IWG, supported by various actions, is to enhance engagement across the entire European Battery R&I community and foster synergies across EU Battery R&I initiatives, networks, and projects.

Synergies

Several institutional initiatives, known as the 'European Batteries R&I Community,' aim to establish a competitive battery value chain in Europe, uniting stakeholders and providing structured support from basic research to industrial application. The IWG plays a central role in this framework, focusing on R&I activities and collaborating across policy, education, and business sectors.

Since 2022, the IWG has closely collaborated with the BEPA, resulting in the unified operation of the six Working Groups, the six Task Forces, and the NRCG. This collaboration has avoided duplication of work and aligned efforts effectively.

The IWG's close collaboration with the two IPCEIs on batteries has materialised in events like the Battery Innovation Days and exhibitions (e.g. Transport Research Arena). Additionally, information-sharing activities, including fact-finding missions in Japan and South Korea, presentations of IWG results to IPCEI companies, and information exchange via newsletters and social media, have strengthened ties.

Other activities within the 'European Batteries R&I Community' involve information exchange and alignment with initiatives such as Battery2030+, the European Battery Alliance (EBA250) and LiPlanet.

An objective for the working group in the upcoming year is to enhance collaboration with other relevant IWGs across the SET Plan. This could involve participation in new SET Plan cross-cutting Task Forces aligned with the IWG's work streams. For example, members of ongoing Task Forces on Education & Skills and Digitalisation are prepared to join corresponding SET Plan Task Forces.

In terms of collaboration with other European Partnerships, representatives from the Clean Aviation Partnership participate in Task Force hybridisation meetings. Furthermore, the Task Force collaborates closely with the StoRIES project to align perspectives on hybrid energy storage, while NRCG members contribute to the drafting process of the StoRIES Roadmap and SRIA.

RENEWABLE FUELS AND BIOENERGY

The supporting Coordination and Support Action (CSA) SET4BIO was closed at the end of 2023[54]. One major deliverable is the policy recommendations, as well as interactive maps of ongoing projects and networks. In total, 18 public deliverables were published by the SET4BIO project. One notable output is a booklet that describes five steps to accelerate the development of bioenergy across Europe and beyond[55].

The five proposed steps to accelerate development in this sector are as follows.

1. Align Research, Development, and Innovation (RD&I) strategies and funding programmes at national and EU levels with industry.
2. Harmonise data collection to facilitate monitoring and assessment of RD&I contributions to targets.
3. Support innovation actions throughout the TRL scale.
4. Establish a clear, stable, and predictable framework to guarantee market pull.
5. Enhance complementary collaboration at EU and global levels.

54 www.set4bio.eu
55 https://www.etipbioenergy.eu/publications-and-reports/

Recent developments

The focus of end-use sectors continues to shift, with electrification remaining a top priority in the road sector. Meanwhile, sectors such as aviation and shipping continue to rely on the technologies covered in this working group as the primary alternative.

In the second half of 2023, the ETIP Bioenergy published a new Strategic Research and Innovation Agenda[56] that sets out the research and innovation priorities for various value chains. The new SRIA provides an overview of the status of development and deployment of biomass technologies, including key research and innovation challenges. It also addresses the biomass supply for a growing bioeconomy industry, advanced conversion technologies, and emerging markets such as aviation and shipping. The document concludes with an outlook for biofuels beyond 2030.

A recent study by the Commission, "Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels"[57], highlights the crucial role of biofuels in reducing emissions in the transport sector. Biofuels are expected to contribute significantly to the objectives of the Fit-for-55 package and climate neutrality goals. As advanced biofuels become increasingly accessible, their role is anticipated to grow in the future, driven by the full commercial-scale development of technologies, processes, and value chains, supported by ambitious policies and sector-specific targets.

Status of the implementation plan

A proposal for an update to the Implementation Plan was presented by the support project SET4BIO. However, the IP still requires revision. The new SRIA of the ETIP Bioenergy provides good guidance for the revision. Currently, there are no changes to the IP, but this will need to be considered and reported in next year's reporting exercise.

SET4BIO also developed a toolbox for accelerating implementation, which can be applied to any technology besides bioenergy.

Status of the activities

Bioenergy technologies, including large-scale biomass cogeneration of heat and power, are developing, and demonstration activities are planned. However, scale-up and deployment have stalled somewhat, due to strong competition from other power supply technologies. The technology has future potential for grid balancing with more intermittent power.

The group has 13 activities, the majority of which have projects that report finished deliverables or successful completion. However, wide deployment has not yet been achieved. The potential is there, but work is still needed to overcome barriers and stimulate investments. There are currently 39 operational plants, producing a range of fuels, including:

- 16 hydrogenated vegetable oil (HVO) plants (with 8 producing both HVO and Sustainable Aviation Fuel, and 2 producing mainly SAF);
- 11 Ethanol plants;
- 5 Pyrolysis oil plants;
- 2 SNG/Hydrogen plants;
- 2 Methanol plants;
- 1 Syngas/biochar plant 1 BioLPG plant;
- 1 Isobutene plant; and
- 1 Diesel substitute plant.

A database of production plants is available on the ETIP Bioenergy website[58]. At 39, the number of operational plants has increased slightly from 37 last year, although some key plants have unfortunately been stopped or shut down. There are two plants under construction, a 50% reduction from last year, but the number of planned plants has increased from 18 to 25.

A monitoring report was published by SET4BIO, which describes the main results of monitoring the Renewable Fuels and Bioenergy sector. The report provides an overview of the development of the sector, including the deployment of advanced biofuels and the challenges and opportunities facing the industry. A KPI structure was developed to facilitate yearly monitoring and reporting of the relevant development in the sector.

56 Ibid.
57 European Commission: Directorate-General for Research and Innovation, Georgiadou, M., Goumas, T. and Chiaramonti, D., Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels – Final report, Georgiadou, M.(editor), Goumas, T.(editor) and Chiaramonti, D.(editor), Publications Office of the European Union, 2024, https://data.europa.eu/doi/10.2777/679307
58 https://www.etipbioenergy.eu/databases/production-facilities

The monitoring activities were based on market analysis and information gathered in other Work Packages in the SET4BIO project. The results and knowledge were used for the yearly reporting procedure in the SET Plan and as a basis for the further development of activities and corrective actions in the Implementation Plan. An overview of past reporting is included, as well as selected results from the projects.

Challenges

The policy landscape has undergone significant changes, primarily driven by the Fit-for-55 package and its related components. The unprovoked Russian invasion of Ukraine has further altered the drivers, with energy security becoming a pressing concern.

Biomass, a key component of renewable fuels and bioenergy, is readily available in Europe, as it can be grown and renewed on European soil. To ensure the successful implementation of these technologies, it is important for them to be further referenced in national policies and the NECPs.

It is crucial to increase the representation of countries in the working group, and to take steps to reduce investor uncertainty and promote deployment. The technologies in this working group are well established, and the market potential is clear, particularly in hard-to-electrify sectors such as aviation and shipping.

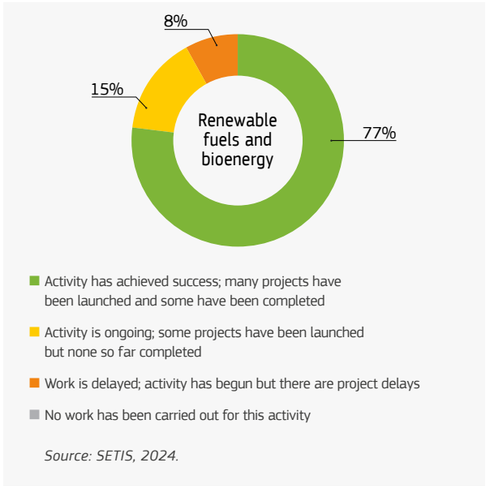
Future plans

Renewable fuels and bioenergy have significant potential to replace fossil fuels in various sectors, including:

- Existing and future vehicle and vessel fleets with combustion engines;
- Permanently in sectors such as shipping and aviation, where electrification is not feasible; and
- In the transition of sectors or segments where electrification will eventually take over.

Additionally, renewable fuels and bioenergy can play a complementary role in:

- Increasing the yield of biofuels or producing renewable fuels from non-biological origin (RFNBOs) using renewable hydrogen;
- Balancing the grid as intermittent energy sources continue to grow;
- Providing energy security benefits when coupled with energy storage; and
- Adding value under the cascading principle of the wider bioeconomy.



Source: SETIS, 2024.

The prospects and synergies for the bioenergy industry with other energy technologies are promising. Bioenergy is expected to be key for sustainable aviation and shipping in the future, with renewable liquid and gaseous fuels of non-biological origin (RFNBOs), hydrogen, and electrification serving as complements.

The concrete planning to meet the Implementation Plan goals will be updated later this year. It is clear that much work is needed to deploy these technologies on the market and to continue supporting new technologies as they progress through the TRL scale. The continued implementation of the European Green Deal and climate/energy ambitions in the EU will play a crucial role for the industry, requiring a system approach with a level playing field.

Synergies

The SET4BIO collaboration and other working groups and stakeholders were identified in a report called the Global Outlook. The key conclusions and recommendations from this report are as follows:

1. The number and content of platforms and initiatives related to bioenergy and renewable fuels sector shows that the sector is active in producing and disseminating information, collaborating internationally, and defining agendas for research, innovation, and deployment.
2. It is recommended to clearly define the scope and activities of different platforms and initiatives to enhance the complementarity of actions and to guarantee efficient collaboration. In the European context, defining the relations of key SET Plan pillars is of special importance.

3. Cooperation between platforms and initiatives within Europe has been established and takes place. Complementary collaboration on international level should be sought to gain global perspectives, promote European expertise, and learn from best practices.
4. Member States engagement is sought by many platforms and initiatives. This is important especially for SET Plan pillars to ensure coordinated actions with Member States. This working group has a strong Member States presence, which should be effectively utilised.
5. Renewable hydrogen is a cross-cutting topic with increasing interest. The scope of this working group is in bioenergy and renewable fuels for transportation, which has clear links to hydrogen value chains. It is important to define synergies between hydrogen value chains and the group's scope, as well as establish respective targets and KPIs.

CARBON CAPTURE AND STORAGE – CARBON CAPTURE AND UTILISATION

The Implementation Working Group on Carbon capture and storage – carbon capture and utilisation (CCS/CCU) was established in 2017. It is composed of 11 SET Plan countries[59], industrial stakeholders, non-governmental organisations and research institutions. The group is chaired by the Netherlands, Norway, and the Zero Emissions Platform – ZEP (the ETIP for CCS/CCU). Since May 2023, the biggest achievement is the publication of the report 'Achieving a European market for CO_2 transport by ship'[60], which was jointly developed by ZEP and the Carbon Capture & Storage Association (CCSA).

59 The Czech Republic, France, Germany, Hungary, Italy, Norway, the Netherlands, Türkiye, Spain, Sweden and the UK.
60 ZEP, 2024, Achieving a European market for CO2 transport by ship, *[link]*

Recent developments

Since May 2023, there have been significant policy developments in the CCS/CCU field. These include the Net-Zero Industry Act (NZIA) and the publication of the Communication "Towards an ambitious Industrial Carbon Management for the EU"[61]. The working group has provided input and guidance to European policymakers to support these policy developments.

The ZEP has published a number of papers to guide policy action, including the report on "Achieving a European market for CO_2 transport by ship"[62], which provides technical insights into CO_2 transport by ship and highlights the importance of this mode of transport to achieve the EU's injection capacity objective of 50 million tonnes of CO_2 per year by 2030. In addition, ZEP has also published "Recommendations on Carbon Removal Certification Methodologies"[63].

A webinar dedicated to the publication of this report took place in January 2024 and attracted over 200 participants. The ZEP has also expanded its membership base to 31 members.

Furthermore, the first edition of the Projects Network[64] took place in January 2024 and received excellent feedback from participants. The Projects Network provides a platform for project managers working on CCS/CCU projects in Europe to share information, discuss common issues, and present on-the-ground learnings and solutions stemming from their projects.

Status of the implementation plan

The R&I targets and activities are currently being updated to reflect the new EU policy objective of 50 million tonnes of CO_2 per year of injection capacity by 2030 and the modelling figures for 2040 and 2050 used by the Commission in the impact assessment of the proposed EU 2040 climate target. An update of the SET Plan Implementation Plan targets took place in 2020. The revision mentioned above will reflect the quantitative policy ambitions in terms of CO_2 stored, CO_2 used for e-fuels, and industrial carbon dioxide removals.

Status of the activities

The group has eight activities, of which the first five are ongoing, with significant progress being made, while activities six, seven and eight can already report some successfully completed projects and deliverables.

The first activity, 'Delivery of a whole chain CCS project operating in the power sector' includes the BECCS Stockholm project that plans to enter into operation in 2026. This bioenergy combined with carbon capture and storage (BECCS) plant has the potential to remove approximately 7 million tonnes of CO_2 in the first 10 years of operation. The project includes a smaller R&D facility at the site to gain experience and results before designing the full-scale plant.

Another relevant project is the Ørsted Kalundborg Hub[65], which was awarded a 20-year contract from the Danish Energy Agency in 2023. This contract includes the installation of carbon capture modules at the wood-fired Asnæs Power Station in Kalundborg and at the straw-fired Avedøre Power Station's in Copenhagen. The start of operations is expected in 2025 with a removal potential of 430 000 tonnes of biogenic CO_2 per year.

These three projects would become important contributors to low-carbon energy supply in the EU. The European Commission modelling under the proposed EU 2040 target climate impact assessment indicates that approximately 35 million tonnes per annum of CO_2 from bioenergy combined with carbon capture and storage (BECCS) and direct air capture and storage (DACCS) would be required in 2040 under the proposed EU climate objectives. These projects could become one of the key contributors and first-movers to these ambitions.

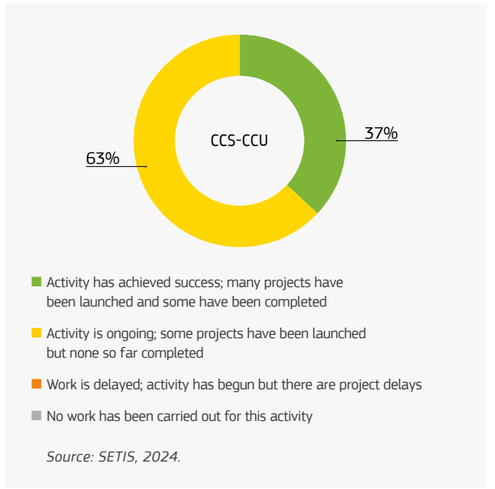
The second activity, 'Delivery of regional CCS and CCU clusters, including feasibility for a European hydrogen infrastructure', covers CCS and CCU clusters described under the Implementation Plan, including the Norwegian CCS cluster, the Rotterdam CCS and CCU cluster, the UK East Coast CCS cluster, and the Le Havre CCS cluster. For the Norwegian CCS cluster, the Brevik project, that is part of the Longship programme, is continuing its progress. Recent milestones include the installation of the absorber in August 2023. The East Coast Cluster is also progressing and has been prioritised as part of the UK Track-1 cluster. The Nautilus project includes emissions from Le Havre and has been selected as a project of mutual interest. One of the most important hydrogen projects in the pipeline is the RWE-Equinor plan to develop a hydrogen pipeline transporting low-carbon and renewable hydrogen to power plants in Germany. The intention is to produce up to 10 GW of low-carbon hydrogen in Norway by 2038 that can be transported via a pipeline to Germany[66]. Through these projects, CCS will make a material contribution to industrial decarbonisation and low-carbon energy supply.

The third activity, "EU Projects of Common Interest for CO_2 transport infrastructure", is making good progress. The Commission plans to start designing an EU Project of Common Interest for CO_2 transport and storage infrastructure in 2024 under the Industrial Carbon Management Strategy[67]. This project could be crucial in unlocking sufficient public funding for a cross-border CO_2 transport grid.

The fourth activity, "Establish a European CO_2 Storage Atlas", is also making good progress. The Commission plans to create an investment atlas of potential CO_2 storage sites under the Industrial Carbon Management Strategy by 2026. This atlas could be crucial in ensuring that adequate storage sites are quickly identified to reach the EU's 50 million tonnes of CO_2 per annum injection capacity objective by 2030.

The fifth activity, "Unlocking European Storage capacity", should be unlocked under NZIA via a mandatory contribution from oil and gas producers. The Northern Lights project and the Porthos project are expected to unlock storage soon.

The sixth, seventh, and eighth activities include projects and deliverables which have reached a successful conclusion. Next-generation CO_2 capture technologies are being developed, with recent examples including results from the DMX project in Dunkirk, France. The project announced CO_2 capture rates exceeding 90% with CO_2 purity levels of 99.5% or higher, and low-energy consumption in 2024. CCU projects are also progressing, including the Steelanol project in Ghent, which produced ethanol for the first time in November 2023. Several other projects, including AIR, Carbon2Business, and TRISKELION, are expected to become operational by 2030.



Modelling until 2040 under the impact assessment mentioned above foresees between 75 and 100 million tonnes of CO_2 captured every year to be used for e-fuels production. The ZEP continues to communicate the role of CCS/CCU in meeting energy and climate change goals. The Commission has asked Member States to include the role of CCS/CCU in the update of NECPs[68] scheduled in 2024.

Challenges

Although NZIA provides various tools to support the achievement of the 2030 objective, this will only be met if a large number of CO_2 capture, transport, and storage projects are successfully implemented within a short timeframe. This will require a substantial increase in funding instruments, such as the Innovation Fund[69], Connecting Europe Facility[70], and national subsidy schemes, to avoid significantly undershooting.

The first identified challenge is the limited public funding available to support the whole supply chain for the development of carbon capture and storage facilities. Therefore, both public and private funding must be increased to reach the NZIA target of the

61 COM(2024) 62 final, Towards an ambitious Industrial Carbon Management for the EU, *[link]*
62 ZEP, 2024, Achieving a European market for CO_2 transport by ship, *[link]*
63 ZEP, 2024, Recommendations Carbon Removal Certification Methodologies, *[link]*
64 *https://zeroemissionsplatform.eu/members-area/projects-network/*
65 *Orsted carbon capture and storage project*
66 *RWE-Equinor Hydrogen pipeline in the North Sea project*
67 COM(2024) 62 final, Communication Towards an ambitious Industrial Carbon Management for the EU, *[link]*
68 National energy and climate plans submissions *[link]*
69 *https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund_en*
70 *https://cinea.ec.europa.eu/programmes/connecting-europe-facility_en*

EU's 50 million tonnes of CO_2 per annum injection capacity objective by 2030. Another challenge is the identification and assessment of both onshore and offshore storage potential and addressing the various uncertainties regarding the potential for CO_2 storage. Finally, another issue is the public perception and acceptance for both offshore and onshore storage and CCS in general. A clear and consensual method to communicate the critical importance of CCS to communities located near potential CO_2 storage sites and to assess public acceptance of potential onshore CO_2 storage projects in these communities would be beneficial.

Future plans

Future plans of the working group are guided by the recently set policy target and modelling figures under NZIA. The group is currently working to update the research and innovation targets and activities that will support the achievement of this policy target and modelling figures.

The Zero Emissions Platform is also working on several initiatives, including:

- Publishing a note on how to best communicate CO_2 storage potential, to avoid misunderstandings about storage potential among policymakers and the general public. This note will include technical guidance for the development of the European storage atlas;
- Providing policy insight into how low-carbon products can incentivise CCS while supporting industrial decarbonisation; and
- Organising the second edition of the Projects Network, which has the potential to support information exchange between projects and contribute to their technical and commercial success.

Synergies

The ZEP, in collaboration with ETIP Bioenergy, organised a webinar on the state of play of BECCS. The webinar took place on 18 December 2023 and provided industry examples of BECCS deployment.

The purpose of this collaboration was to cooperate between ETIPs on a topic of common interest. BECCS is a crucial component of CCS/CCU and is expected to play a major role in delivering the volumes of industrial carbon removals required to reach net-zero by 2050.

The webinar focused on the added value of integrating bioenergy production into BECCS plants, in addition to the carbon removals component. The collaboration between ZEP and the ETIP Bioenergy created synergies, demonstrating that there are topics of common interest across specific climate technologies, such as bioenergy and CCS. This collective effort is directly relevant to the cross-cutting issue of accelerating the market uptake of R&I results, as it focused on the effective commercial application of BECCS technologies.

NUCLEAR SAFETY

The European Green Deal, Fit-for-55 policy package, and REPowerEU are driving forces behind the energy transition and industrial decarbonisation in Europe. Emerging technologies, such as small modular reactors (SMRs), are making significant progress and could play an important role in integrated energy systems, providing low-carbon energy with a relatively small environmental impact. SMRs are expected to help meet the increasing demand for clean electricity and hydrogen. They can complement conventional nuclear technologies and contribute to European climate mitigation and sustainability efforts by co-generating low-carbon electricity and heat reliably, consistently, and securely.

In the run-up to the 16th European Nuclear Energy Forum (ENEF) on 6 November 2023, Ministers from 12 EU countries and industry representatives called for collaborative efforts to accelerate SMR development. On 6 February 2024, the Commission adopted a communication titled 'Securing our future: Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society', announcing the launch of the European Industrial Alliance on SMRs. In the background to these developments, the Implementation Working Group on Nuclear safety continues its work according to its initial Implementation Plan with the goal of supporting the development of the nuclear industry and ensuring a safe and sustainable energy future.

Recent developments

Several significant developments have taken place in the nuclear energy sector at the EU level:

- The Nuclear Alliance of Member States supporting nuclear energy has been formally established.
- The European Industrial Alliance on SMRs has been launched by the Commission (DGs ENER, JRC, R&I, GROW), in cooperation with the industry (Nucleareurope), and the R&D&I ETIP (SNETP) with the regulators (ENSREG) as observers to facilitate and accelerate the development, demonstration, and deployment of the first SMRs projects in Europe in the early 2030s.
- Two co-funded partnerships on Nuclear Material (CONNECT-NM) and on the management of radioactive materials (including waste) have been prepared and are to be launched in 2024.
- The Olkiluoto 3 European Pressurised Water Reactor plant, which features modern proven technology and advanced new safety features, is delivering 1 600 MW capacity to the Finnish grid.
- Important decisions have been taken regarding the lifetime extension of the existing fleet, including the French fleet's "Grand Carénage" programme, Borssele NPP in the Netherlands, Paks NPP in Hungary, Loviisa NPP in Finland, and Dukovany NPP in the Czech Republic. Discussions are ongoing about additional reactors in Belgium.
- Actions have been taken to strengthen EU supplies and independence in nuclear fuel, including conversion and enrichment activities needed for VVER 1 000 and VVER 440 design reactors.
- Construction work has started on the first Polish nuclear power plant in Kopalino on the Baltic coast.
- The first deep geological repository in the world has reached the testing phase and will soon become operational in Onkalo, Finland.
- The Joint European Torus has successfully tested new solutions for future fusion power plants.

Status of the activities

Nuclear technologies play a crucial role in the energy and climate policies of the EU and its Member States. For Member States which do not use nuclear power, nuclear science maintains a role in non-power applications in fields such as medicine, industry, agriculture, environment and space.

The secure and safe use of these technologies is paramount, from the safety of existing and future power plants to protection from ionising radiation, and from the safe management of radioactive waste to decommissioning. Public and private research has a significant role to play in this effort.

Europe is at risk of losing its know-how and skills in this area, particularly given that fewer young people are pursuing careers in fission. In fusion, increased interest and investment outside the EU risks attracting talent away from the EU and undermining its leadership position.

The Euratom Treaty states that the Commission is responsible for promoting and facilitating nuclear research in the Member States and for complementing it by conducting a Community research and training programme (Art.4). This programme is to be adopted by the Council, acting unanimously on a proposal from the Commission (Art.7).

All Member States use radiation for non-power purposes, particularly medical. Given the necessary level of expenditure, it is challenging for individual Member States, especially those with lower research intensities, to reach the critical mass needed on their own. There are also the risks of duplication, fragmentation and unaddressed research gaps. For this reason, an EU-level Programme is necessary.

Taking into account various policy measures in Euratom research to address new developments in nuclear field and to coordinate the efforts made at Member State level, the following actions have been undertaken by the IWG:

- Supporting EU innovation on key enabling technologies for fusion energy with the goal of contributing to the design and development of first fusion power plant, maintaining EU industrial know-how and competitiveness, and leveraging EU scientific leadership and the ITER project.
- Adapting funding priorities and research directions with regard to the safety of existing nuclear power plants as well as future technologies, including Small and Advanced Modular Reactors.
- Contributing to the EU's resilience against crisis and global threats through the implementation of nuclear safeguards and support to nuclear security research and capacity building.
- Providing further support for the on-going Euratom co-funded European Partnerships in radiation protection, radioactive waste management and fusion energy, while ensuring partnerships' adaptation to evolving challenges, the needs of end-users and inclusiveness for all Member States.

The ITER Project

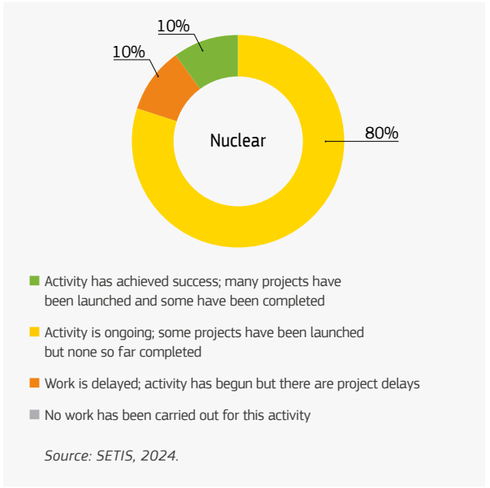
The ITER project, an international nuclear fusion initiative, has been delayed due to several reasons, including:

- Technical Challenges: The project encountered issues with the sizes of the joints of blocks to be welded together for the installation's chamber. Additionally, traces of corrosion were found in a thermal shield designed to protect the outside world from the heat created during nuclear fusion.
- COVID-19 Impact: The global pandemic also contributed to the delays.
- First-of-a-kind Components: The project faced challenges in completing these unique components. Notably, defects were discovered in the thermal shields, requiring the removal and replacement of all cooling pipes.
- Unrealistic Timelines: The project's director general, Pietro Barabaschi, admitted that the initial timeline was not realistic. The project's team is working on a new timetable to address these issues and meet the French nuclear safety agency's security requirements. Despite these setbacks, the team hopes to make up for the delays as it prepares to enter the full phase, scheduled for 2035.

The nuclear sector and the EU's net-zero target

The nuclear sector could play an important role in achieving the EU's net-zero target, provided that several measures are undertaken to enhance its competitiveness. These include:

- Strategic Autonomy: A comprehensive EU strategy is needed for the development and deployment of small (SMRs) and advanced modular reactors (AMRs), acknowledging their potential benefits and challenges.
- Innovative Nuclear Technologies: Major steps should be taken to increase the supply of advanced nuclear fuels and research and innovation capacities in this area.
- High-Assay Low-Enriched Uranium (HALEU): This type of nuclear fuel could potentially play a role in ensuring a more secure energy supply. HALEU paves the way for innovative reactor designs, enhancing efficiency and safety.
- SMRs and AMRs: SMRs are seen as offering potential solutions to energy supply issues and are likely to become a commercially viable nuclear product by the early 2030s. SMRs and AMRs could be used for district heating, desalination, heat processing for energy-intensive industries, and hydrogen production.



- Diversification of Fuel Supply: One of the main challenges is dependency on Russian nuclear technology, uranium, and fuel supplies. Many countries are trying to diversify their fuel supply.
- Modernisation and Optimisation: The European Commission launched a project called "Modernisation and Optimisation of the European Nuclear Supply Chain" to investigate possible solutions for the supply chain challenges currently facing European utilities and licensees of nuclear facilities.
- Management of Nuclear Waste: The solution appears to be deep geological disposals that should open in the EU between 2024 and 2035.
- Policy Debate: Groups of countries regularly disagree about the role of low-carbon energy sources (produced from nuclear) in the green transition and, consequently, in various pieces of energy and climate legislation.

Skills and Competences in the Nuclear Sector

The nuclear sector requires a variety of skills and competences to ensure its effective operation and development. It is therefore essential to focus on:

- Critical Competences: Retaining critical competences in the nuclear energy sector, including educational activities specific to the nuclear field;
- Nuclear Education and Training: Organising nuclear education and training in selected countries, including investigating different types of institutions, programmes, qualifications, funding mechanisms, and partnerships among academia, industry, labour market, and social partners;
- Skills in Nuclear and Radiation Safety: Maintaining and developing skills, competences, and knowledge in nuclear and radiation safety in the EU;
- Young Generation Involvement: Attracting and retaining talented youth in the sector, as many seasoned professionals are nearing retirement;
- Diversity and Inclusion: Boosting diversity and competitiveness in the nuclear field by encouraging more women to join the sector; and
- Public Education: Educating the general public about the potential of nuclear technology.

Challenges

The nuclear industry faces several challenges, including the following.

- The cost of finance and market design are significant hurdles that the industry must overcome.
- Political changes: Shifts in government policies and priorities can have a profound impact on the nuclear industry.
- Public misconceptions: Misconceptions about radioactive waste can be a significant challenge for the industry.
- Climate change: Climate change is already affecting the energy sector, and the nuclear industry is no exception.
- Aging power plants: Some power plants are showing signs of aging and require extensive maintenance to address corrosion damage.
- Workforce shortage: The nuclear power sector is facing a shortage of skilled tradespeople, which is exacerbated by the imminent retirement of the current nuclear workforce.

The success of the Implementation Working Group on Nuclear safety requires:

- The continuation of R&D programmes: Ongoing programmes of nuclear R&D are essential for maintaining the safe and efficient operation of existing nuclear power plants and fuel cycle facilities;
- Knowledge management: Effective knowledge management can benefit nuclear R&D organisations by mitigating risks, improving innovation, developing collaboration relationships, and making the best use of available funds; and
- Infrastructure development: Developing the infrastructure for a successful introduction or expansion of nuclear power requires a range of activities, including building national institutions, establishing a legal and regulatory framework, developing human resources and financial strategies, addressing radioactive waste management, and involving stakeholders.

By addressing these challenges and requirements, the IWG can play a crucial role in supporting the development of the nuclear industry and ensuring a safe and sustainable energy future.

Future plans

Prospects for the European nuclear industry in 2024 include:

- Strategic Autonomy: Nuclear energy and the promise of cost-effective SMRs is high on the EU's agenda[71].
- Industry Statement: The industry is ready to work in close partnership with governments to unlock the potential of nuclear energy and innovation.

The nuclear sector's plans in 2024 for the EU's climate and energy objectives are:

- Nuclear Safety: The EU is a global leader on nuclear safety. The Euratom safety framework requires EU countries to give the highest priority to nuclear safety at all stages of the lifecycle of a nuclear installation;
- Cooperation: The industry stands ready to work in close partnership with governments and other sectors to unlock the potential of nuclear energy and innovation;
- Strategic Label: Nuclear power to remain as a strategic technology for the EU's decarbonisation;
- Roadmaps to New Nuclear: based on the Nuclear Energy Agency (NEA) plans, the IWG together with the European Industrial Alliance on SMRs will provide Roadmaps on advanced technologies; and
- EU Green Deal Industrial Plan: the Commission has proposed to support all EU technologies (including nuclear) towards achieving the EU net-zero target by 2050.

Synergies

The European Nuclear Alliance, comprising representatives from 14 Member States and the European Commission, works together to recognise the role of nuclear energy in the decarbonisation of the economy.

The nuclear sector is motivated to collaborate due to the shared goal of unlocking the potential of nuclear energy and innovation, while ensuring nuclear safety and security. These collaborations bring added value by:

- Enhancing the resilience of critical infrastructure;
- Recognising the role of nuclear energy in achieving climate targets and security of supply; and
- Sharing experiences and innovations to drive progress in the nuclear sector.

These collective efforts are relevant to the themes of the prospective SET Plan cross-cutting task forces, particularly those focusing on energy, transport, digital infrastructure, and space.

Preliminary discussions on collaboration have started with the working groups on Energy systems and Sustainable and efficient energy use in industry.

The collaborations contribute to the strategic autonomy and future of nuclear energy in the EU, particularly in the context of the EU's energy security and climate ambitions.

71 European Industrial Alliance on SMRs, *[link]*

HYDROGEN

The Temporary Working Group (TWG) on Hydrogen focuses on cooperation, support, and uptake of research and innovation in hydrogen technology across Europe. The aim is to implement the results from the Strategic Research and Innovation Agenda of the European Research Area (ERA) pilot initiative Agenda Process on Green Hydrogen, published in 2022, using an integrated, systematic, and interdisciplinary approach to address research needs in the hydrogen sector and enhance cooperation among SET Plan countries[72].

The activities will include maximising and broadening the uptake of learnings from EU, national, and regional R&I programmes and hydrogen activities. These will be coordinated to identify the most effective funding instruments and frameworks for cross-border R&I collaboration.

The cooperation and synergies will enable Member States and SET Plan countries to strengthen Europe's position in the global market and maintain industrial competitiveness. This will have a positive impact if properly incorporated into the integrated SET Plan, Horizon Europe, national and regional hydrogen strategies, as well as the implementation of the Net-Zero Industry Act and National Energy and Climate Plans (NECP).

72 Austria, Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Greece, Hungary, Italy, Norway, Poland, Portugal, Romania, Spain, Slovenia, Sweden, and Türkiye.

Recent developments

In April 2024, the TWG Hydrogen finalised and submitted the Declaration of Intent, outlining the group's scope, overarching goals, and strategic targets. Several hybrid and virtual working meetings were held to advance the development of the Draft Implementation Plan. Ongoing work is focused on defining and elaborating activities within subgroups, which cover the entire hydrogen value chain, including cross-cutting issues such as collaboration, sustainability, and legal aspects. The importance of hydrogen as an integral part of a sustainable and secure future energy system in Europe requires striking a balance between short-term and long-term technical and non-technical support measures, complementing other initiatives. The group will promote the technological development, deployment, and scaling up of electrolysers coupled with renewable energies, as well as research into emerging hydrogen technologies. Viable business models for hydrogen production, transport, and use are expected to be developed from a Europe-wide analysis of supply and demand.

Challenges

Research, Innovation and Deployment

Although hydrogen technologies are only just emerging on the market, there is an expectation that a new, integrated hydrogen economy will be established, going beyond intensified research and innovation and taking into account national specificities. Successful market diffusion requires a holistic approach and a clear understanding of hydrogen within the future energy system.

Reduced production costs are expected to be linked to technological development and economies of scale. In addition to financing research and innovation, hydrogen technology producers face challenges in financing raw materials and intermediates, entering new markets, and minimising liability risks. Various instruments can be used to mitigate business risks, such as attracting private funding, forming public-private partnerships, and using public funding instruments. Furthermore, cooperation, good governance, and international standards are essential for building resilient infrastructure and creating a level playing field that enables a just transition.

Introduction of hydrogen in the energy mix

As part of the SET Plan, hydrogen technologies are crucial for a clean energy mix. The mission of the Hydrogen group is to establish transversal links with other IWGs, promote a coordinated pan-European approach, and identify viable solutions for renewable energy use and storage, as well as CO_2 utilisation.

The perspectives of different stakeholders (industry, research, politics, and civil society) must be considered to ensure acceptance. It is also essential to consider sustainability, eco-design, and circularity from the outset. Interdisciplinary teamwork is necessary to develop solutions and agreed certification standards. Moreover, regulatory issues such as safety, traceability, and licensing have yet to be addressed across the value chain, creating legal uncertainties.

Upstream assessment activities focusing on the different key aspects enabling the hydrogen economy, as well as transparent knowledge transfer, are required.

Future plans

The future plans of the group involve activities aimed at overcoming the main challenges. A key driver will be the implementation of the REPowerEU Hydrogen Accelerator goals, focusing on production, transportation, storage, and utilisation.

The selected assessment, collaboration, and knowledge-transfer activities will focus on several directions and cover the entire value chain for hydrogen deployment and its role in the energy mix. These will include:

- R&I in production, with short, medium, and long-term goals: definition, mapping of activities, interests, activation, and prognostics;
- analysis of demand and production capacity in Member States, and the related requirements for clean energy (for example, 10m t H_2 requires 130 GW of electrolysers, which in turn requires approximately 500 TWh of renewable energy) at various timescales (2030-2050), highlighting synergies between SET Plan IWGs;
- coordinated transnational convergence and cooperation on the transport and storage of hydrogen, requiring intense collaboration between Member States at the political, industrial, and research levels;
- analysis of legislative barriers and safety issues; and
- targeted support schemes to enhance education, skills development, and reskilling.

To successfully implement the defined targets, activity plans (fiches) will be developed, and working groups comprising representatives from different Member States and associated countries will be established accordingly. Every activity will incorporate cross-cutting issues such as safety and legislation in the field. Collaboration with other structures undertaking similar activities, particularly with other IWGs from the SET Plan, is also a priority. Several other general cross-cutting issues, including education and training, and EU-level legislative approaches, will be addressed in separate activity plans.

Synergies

The new Hydrogen working group has a two-pronged approach to its activities: (i) supporting the transition of new hydrogen technologies from R&I to market uptake, and (ii) introducing hydrogen into the energy mix to increase clean energy efficiency, in synergy with the activities of other IWGs. For example, hydrogen production, storage, and utilisation are closely linked to the development of renewable energy, requiring analysis of demand and production to inform decisions about the availability of renewable energy for hydrogen. Additionally, there are legislative issues of common interest, such as the temporal and geographical correlation in the revision of the Renewable Energy Directive.

Collaboration with the IWG on Batteries could be beneficial in terms of storage efficiency, as both technologies have their preferred application areas. Furthermore, hydrogen for combined heat and power could find a beneficial niche in countries where it is applicable, in collaboration with the IWGs on Efficiency in Buildings and Industry. Regarding applications in transport and mobility, besides being used in biofuels production, hydrogen can also be used to react with process CO_2 captured in industry with CCU (with efficiencies higher than 90%), providing key conditions for the production of e-fuels.

In practice, all of the current 14 IWGs have areas where hydrogen can be used to increase energy efficiency. Initially, priority areas will be identified. The work will begin with the organisation of joint working meetings and discussions. Based on these analyses, common activities will be defined and will commence when the synergy reaches a critical level of maturity.

CONCLUSION

The SET Plan remains a vital instrument in driving the EU's transition to a carbon-neutral future. By fostering collaboration among European stakeholders in clean energy R&I, further progress is being made towards achieving the net-zero target. The active participation of the working groups, alongside the ETIPs and EERA, demonstrates the effectiveness of the SET Plan's collaborative approach in working on common projects towards meeting this overall target.

The recent revision of the SET Plan has not only aligned its strategic objectives with European legislation, but has also reinforced the Steering Group by including it in the Net-Zero Industry Act. This legal anchoring is expected to provide momentum for strengthening the bridge between European research, innovation and manufacturing of new innovative technologies. It will also further strengthen the coordination of common R&I policies and planning for key European energy technologies.

This year's report highlights the progress made by the SET Plan stakeholders in all areas, and outlines their challenges, opportunities for growth and future plans. In the coming months, cross-cutting topics such as circularity & materials, digitalisation, skills, and investment needs, will be further analysed and addressed with the establishment of the task forces, which will be featured in the next year's report, while the drafting of the first SET Plan Terms of Reference are an important step towards harmonising and improving the work done by all stakeholders.

The Joint Research Centre of the Commission will continue working in collaboration with the Directorates-General for Energy and for Research and Innovation to improve this monitoring and reporting exercise to further reflect and showcase the SET Plan's success stories.

This report would not be possible without the active contribution of the SET Plan community, which plays a central role in collective efforts to meet the goals of the European Green Deal.

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LIST OF ABBREVIATIONS AND DEFINITIONS

AEP.....annual energy production
AI.....artificial intelligence
AMR.....advanced modular reactor
AR.....anti-reflective
BECCS.....bioenergy combined with carbon capture and storage
BEPA.....Batteries European Partnership Association
BEV.....battery electric vehicle
BIM.....building information modelling
BIPV.....building-integrated photovoltaics
BMBF.....German Federal Ministry of Education and Research
BMS.....battery management system
BPIE.....Building Performance Institute Europe
CAES.....compressed air energy storage
CAPEX.....capital expenditure
CCS.....carbon capture and storage
CCSA.....Carbon Capture & Storage Association
CCU.....carbon capture and utilisation
CEPI.....European association representing the paper industry
CET.....clean energy technology
CETPartnership...Clean Energy Transition Partnership
CFD&HT.....computational fluid dynamics and heat transfer
COE.....cost of energy
CPC.....compound parabolic collector
CPR.....Construction Products Regulation
CPVT.....concentrating photovoltaic thermal
CRM.....critical raw material
CRMA.....Critical Raw Materials Act
CSA.....coordination and support action
CSP.....concentrated solar power
CST.....concentrated solar thermal
DAC.....direct air capture
DACCS.....direct air capture with carbon storage
DC.....direct current
DG.....Directorate General
DG ENER.....DG Energy
DG GROW.....DG Internal Market, Industry, Entrepreneurship and SMEs
DG R&I.....DG Research and Innovation
DHC.....district heating and cooling
DUT.....Driving Urban Transitions to a Sustainable Future Partnership
EAF.....electric arc furnaces
EBA.....European Battery Alliance
EC.....European Commission
ECTP.....European Construction, built environment and energy efficient building Technology Platform
EEA.....European Economic Area
EED.....Energy Efficiency Directive
EERA.....European Energy Research Alliance
EGEC.....European Geothermal Energy Council
EHPA.....European Heat Pump Association
EMS.....energy management system
ENEF.....European Nuclear Energy Forum
EPBD.....Energy Performance of Buildings Directive
EPO.....European patent office
ERA.....European Research Area
ESDE.....Employment and Social Developments in Europe
ESF.....expert support facility
ESIR.....Expert group on the economic and societal impact of research and innovation
ETIP.....European Technology & Innovation Platform
ETS.....Emissions Trading System
EU.....European Union
EUR.....euro
EUSEW.....European Sustainable Energy Week
FOAK.....first-of-a-kind
FS.....flagship
GDP.....gross domestic product
GHG.....greenhouse gas
GW.....gigawatt
H_2.....hydrogen
HP.....heat pump
HTF.....heat transfer fluid
HVDC.....high voltage direct current
HVO.....hydrogenated vegetable oil
ICT.....information and communications technology
IP.....Implementation Plan
IPCEI.....Important Project of Common European Interest
ITER.....International Thermonuclear Experimental Reactor
IWG.....Implementation Working Group
JP.....Joint Programme
JPI.....Joint Programming Initiative
JRC.....Joint Research Centre
KPI.....key performance indicator
LCA.....life cycle assessment
LCOE.....levelised cost of energy
LCOH.....levelised cost of heat
LVDC.....low voltage direct current
MED.....multi-effect distillation
MS.....Member State
MSP.....maritime spatial plans
MV.....medium voltage
MW.....megawatt
NCST.....non-concentrated solar technologies
NEA.....Nuclear Energy Agency
NECP.....national energy and climate plan
NF.....nanofiltration
NPP.....nuclear power plant
NRCG.....national and regional coordinators group
NZIA.....Net-zero industry act
PCM.....phase change material
PCP.....pre-commercial procurement

PED.....positive energy district
PTC.....parabolic trough collector
PV.....solar photovoltaic
RD&I.....research, development and innovation
RE.....renewable energy
RED.....Renewable Energy Directive
RES.....renewable energy sources
RFNBO.....renewable fuels of non-biological origin
RHC.....renewable heating and cooling
RIC.....research, innovation and competitiveness
SA.....strategic action
SES.....smart energy systems
SET Plan.....Strategic Energy Technology Plan
SETIS.....Strategic Energy Technology Information System
SG.....Steering Group
SME.....small and medium-sized enterprise
SMR.....small modular reactor
SNET.....Smart Networks for Energy Transition
SNETP.....Sustainable Nuclear Energy Technology Platform
SNG.....synthetic natural gas
SOE.....solid oxide electrolyser
SRIA.....Strategic Research and Innovation Agenda
SRL.....Social Readiness Level
SSH.....Social Sciences and Humanities
STEM.....science, technology, engineering and mathematics
SWD.....staff working document
TES.....thermal energy storage
TF.....task force
TRI.....Transition Initiative
TRL.....technology readiness level
TWG.....temporary working group
TWh.....terawatt hour
ULI.....Urban Land Institute
UTES.....thermal underground storage
VC.....venture capital
VPP.....Virtual Power Plant
VVER.....water-water energetic reactor
WEC.....wave energy converter
ZEP.....Zero Emission Platform

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