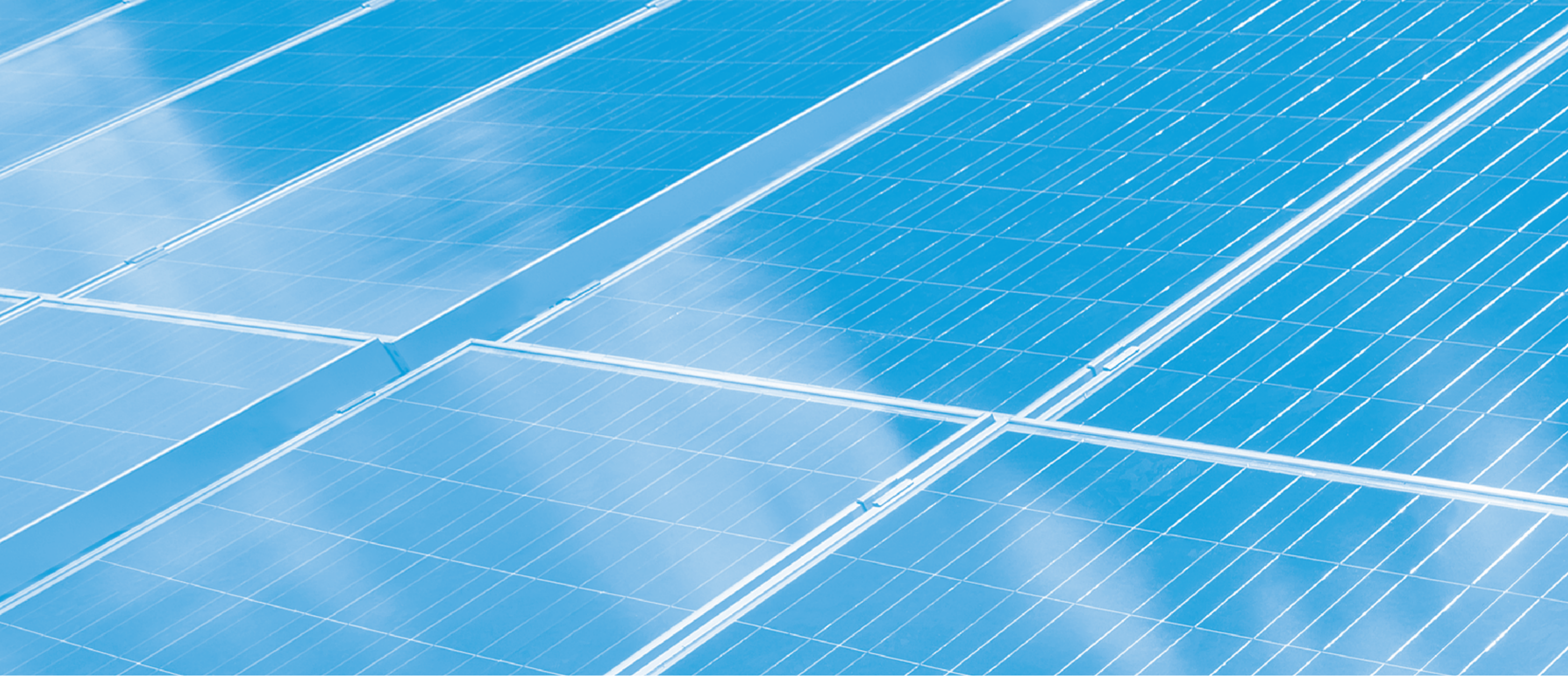


STRATEGIC RESEARCH AND INNOVATION AGENDA (SRIA)

Energy

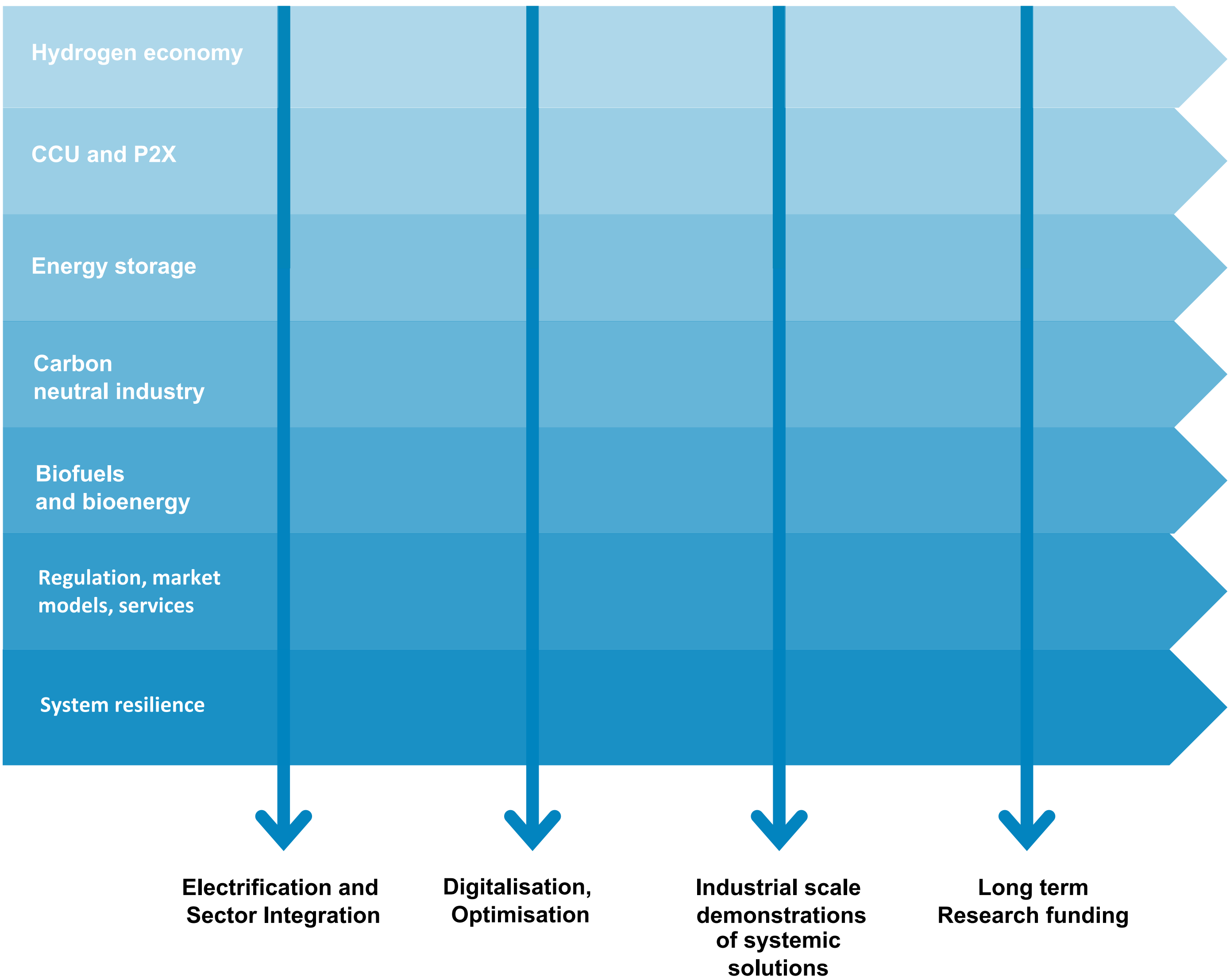
2022 Update

CLIC INNOVATION LTD

Contents

Foreword

This document is an update to the original CLIC Innovation's Strategic Research and Innoovation Agenda for Energy Systems (accessible at https://clicinnovation.fi/wp-content/uploads/2020/01/CLIC_SRIAenergia_Final_Printversion.pdf), which was published in 2019. Since then, energy transition has advanced at a significant pace, and geopolitical circumstances have affected the European energy markets at an unforeseen force. The energy crisis has raised new questions about self-sufficiency and system security, as well as rapidly increased the need to transition away from fossil fuels to produce electricity and heat. Meanwhile, technologies and applications, for example in hydrogen production and utilisation, have advanced towards large-scale industrial deployment faster than imagined. These changes highlighted the need for a quick update to the original 2019 Agenda.



Introduction – Addressing global challenges

The Strategic Research and Innovation Agenda (SRIA) is based on a vision that in the future Finland is going to have a lot of clean electricity generation, mostly onshore and offshore wind power. The price of electrical energy will be low or moderate at least part of the time, depending on the availability of variable renewable energy sources. Available and reasonably priced clean electricity enables electrification of several processes and significantly accelerates the green transition. This applies to the production of green hydrogen, carbon capture and utilization for various products, replacing fossil fuels on industrial processes and heating of buildings, and enabling sustainable transportation by electrification and synthetic fuels.

Along with clean electrification, sector integration between energy systems, including conversion processes and various energy storages, will play an important role. It enables the integration of large volumes of renewable generation by providing balancing options, including various types of energy storages, to the power system. However, a prerequisite for sector integration is the development of the regulatory environment and the markets and associated services. The regulatory environment is expected to bring new opportunities to zero-emission and low-carbon technologies, including biofuels and bioenergy, which is important from the Finnish perspective.

The complex system of systems is critical infrastructure, vital for society. Resilience and security of the system are of primary importance. Digitalisation is necessary for sector integration, and the utilisation of data from various sources enables the economic optimization and control of the system.

ETIP SNET is a European initiative that has been created to implement the European Strategic Energy Technology Plan (SET-Plan). It has published a vision for the future energy system called "Vision 2050: System of systems". This document outlines the future for a renewable energy-based system that is both reliable and cost-efficient. In the vision, different sectors (electricity, heating, cooling, gas, fuels, data, etc.) integrate on multiple system levels and form a dynamic entity. The vision is widely used as a future reference within European projects and initiatives, and it is in line with this Strategic Innovation Agenda for the Theme Group Energy of CLIC Innovation.

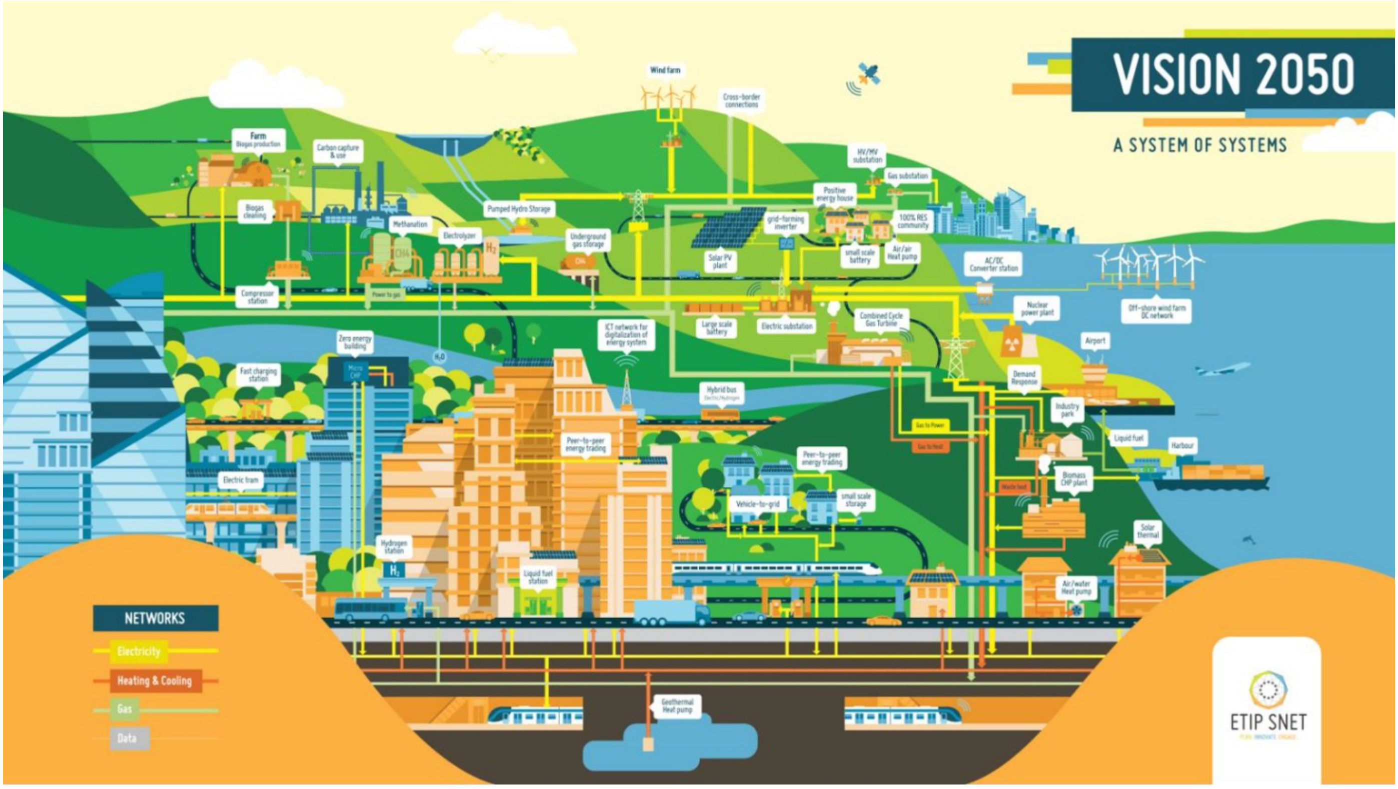


Figure 1. Vision 2050: A System of Systems by European Technology & Innovation Platform Smart Networks for Energy Transition (ETIP SNET). Available at https://smart-networks-energy-transition.ec.europa.eu/sites/default/files/documents/vision/ETIP-SNET_infographic.pdf

ENTSO-E, the European Network of Transmission System Operators for Electricity, has provided a very good illustration of the future sector integration, Figure 2. The illustration presents the central elements of sector coupling: the energy sectors, various types of storages, and conversion processes. In the future, the integration of the sectors will be even closer, e.g. the electrolysis for the production of hydrogen produces a lot of heat, which can be stored in thermal storages to be utilised directly in heating system, and the other side product, oxygen, can be utilised as well. Another example of closer connection between systems is the utilisation of the electric vehicles for providing ancillary services for the power system.

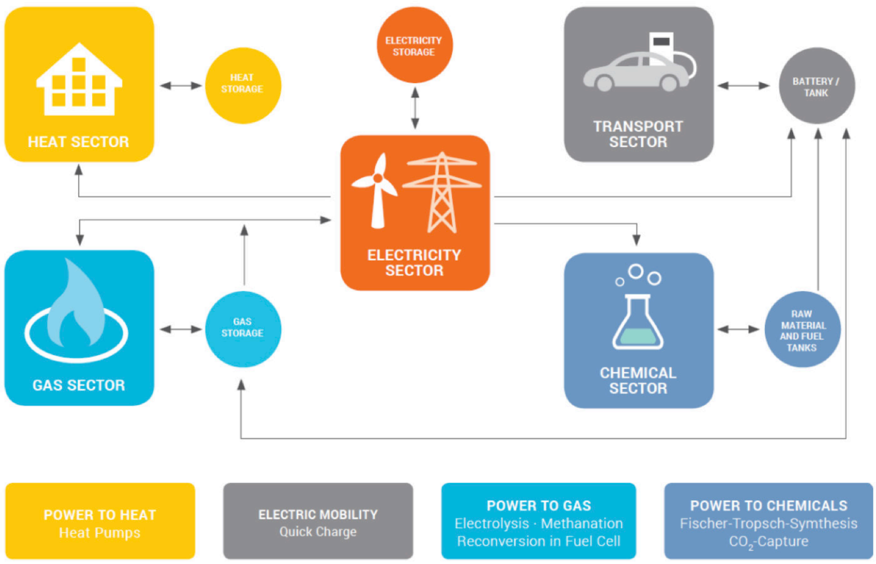


Figure 2. Sector integration. (ENTSO-E: Vision on Market Design and System Operation towards 2030. Available at https://vision2030.entsoe.eu

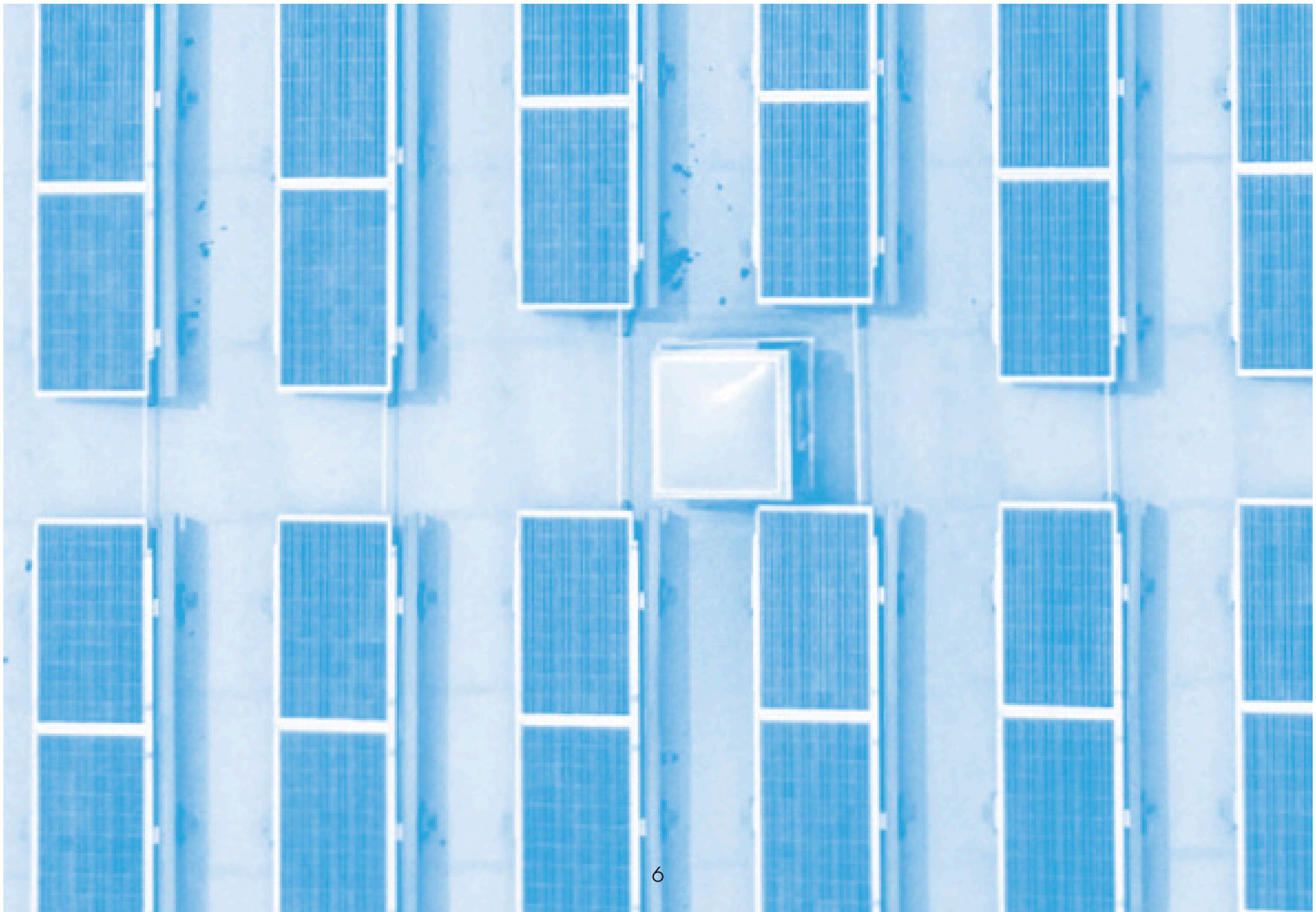
Focus areas for research and innovation

The shareholders of CLIC Innovation have identified critical areas where research, development and innovation (R&D&I) activities are most needed. This strategic research and innovation agenda (SRIA) for Energy presents these, which are:

1. Carbon capture and hydrogen production, and utilisation of CO_2 and H_2
2. Energy storage
3. Carbon-neutral industry
4. Biofuels and bioenergy
5. Regulation, market models, new services and digitalization
6. Systemic resilience of the energy system

A clear message of this SRIA is that more activities – joint projects, pilots and demonstrations, for example – are crucial. They must be supported with adequate funding. Maintaining the competitiveness of energy related companies, creating more business opportunities and accelerating the transition of the energy intensive industries towards carbon neutrality are all important.

The development of the market should not only be followed but shaped by research and innovation stakeholders. Hence, participation in market shaping activities is important. As regulation strongly affects the development of new market opportunities, close interaction should be built with regulatory bodies. Interaction with EU-level policymaking is also essential as EU policies have a considerable impact on all energy actors in the EU.



Carbon capture and utilization (CCU) and the utilisation of CO_2 and H_2

FOCUS AREAS

Emphasis of RDI activity in CCU and Power-to-H_2 areas should be placed on industry-integrated systems and full-chain approaches, where all the process side-streams are utilized, and all the necessary actors in the value chain are involved. More cost and energy efficient subprocesses and separation processes are needed to bring these new solutions to market. Technology and service development along the whole P2X value chain is required for efficient adoption by the market. To achieve this, there is a need for extensive ecosystem operations to bring the different actors together to pave the way for technology and market development jointly. Such ecosystem operations may also include joint market shaping activities.

RECOMMENDATIONS FOR FUTURE ACTIONS

There are vital R&D&I actions needed in:

- supporting electrolytic hydrogen production at lower costs
- utilisation of process side-streams, including excess heat from electrolysis
- modularity/scalability of synthesis technologies
- cost-efficiency of direct air and industrial CO_2 capture (utilising, e.g. electrification)
- CCU end-product development

In these actions, efficiency studies and life cycle analyses play an important role. Moreover, when it comes to the coordination of the research, there is an obvious need for:

- wider ecosystems that target larger demonstrations and business development, and
- roadmaps for national development, piloting and research needs.

Public support is needed for long-term applied research and piloting of the near-the-market CCU technologies. In addition to financing from the European Union, regional and national R&D programs addressing CCU and P2X could make a significant contribution to achieving the challenge.

Energy storage

CURRENT FOCUS AREAS FOR RESEARCH AND INNOVATION

The energy transition requires energy storages due to the intermittent nature of renewable energy sources. Solar energy utilisation in the form of thermal energy has a high increase potential in industry, residential and commercial sectors. Solar thermal energy (STE) technologies include solar collectors and space heating. Production and demand are balanced with storages ranging from short-term daily and weather variations to seasonal differences. These storages can be combined with geothermal energy by using heat pump technologies.

District heating provides smooth energy delivery solutions by integrating different energy sources, including renewable energy. In the electric power system, the generation and the consumption must be kept in balance. Solar power generated with photovoltaic panels is widely used. Electricity can also be produced with STE technologies where high temperature fluids are used via steam turbines and generators. Balancing solutions or short-term storages are needed in connecting with grids. The possibility of using heat storages is beneficial in STE technologies. Solar and geothermal solutions can work together in high temperature area as well.

The vision of the system of systems includes several energy systems (electricity, gas, heating and cooling, liquid fuels), energy conversion between the systems and many types of energy storages. Sector integration and energy storages not only enable wide scale utilisation of variable renewables-based power generation, but they also enable the improvement of the overall efficiency of the system by e.g. providing storage for the waste heat of the conversion processes. The production of hydrogen by electrolysis of water is of special interest with its by-products heat and oxygen. Thermal storages play an important role also in the decarbonisation of the heating and cooling systems, and both short-term and seasonal storages can be developed.

Batteries connected to the power system – in the future also the batteries of electric vehicles – will provide ancillary services like fast frequency response or virtual inertia to power system operators. The improvements in hydrogen production and other Power-to-X and energy storage technologies are anticipated to allow for radical reduction of the consumption of fossil fuels. Energy storages also contribute to the power system balancing and ancillary services.

While technologies exist, their integration to the energy system and market is still not fully developed. New business models are being tested by different players working in cooperation. Regulators are crucial to the conversation as in many countries, current regulations limit the roles of the owner and user of batteries. To be effective, building integrated solutions need to include storage solutions for different time windows. Dynamic storage can be introduced to existing industrial processes (P2X, for instance).

Daily and short-term storage is a key to adapt to weather conditions, variations in consumption and finding the balance between heat and electricity. Seasonal storage solutions will help in extending the use of sustainable energy. Situational awareness of storage capacities is crucial when optimizing any system.

RECOMMENDATIONS FOR FUTURE ACTIONS

The key research and development needs for energy storage include:

- A combination of different types of storages (hybrid storages, batteries & compressed air, heat, electricity, H_2, CO_2 and synthetic fuels)
- Heating and cooling organized in locally specific ways
- Methods for considering storage already in the planning phase of the energy systems, buildings or city plan, where spatial planning could be supported by different energy networks
- Development of control strategies for different systems, e.g. for short-term and seasonal storages
- Multicriteria optimisation and control on different levels of detail to cost-efficiently integrate electrical and thermal systems, and adapt them to local requirements and possibilities
- Development of business models, regulation schemes and taxation models

Carbon-neutral industry

CURRENT STATUS

Industry is responsible for a significant proportion of greenhouse gas emissions (GHG) across the world. The increase in the scale of industrial production has to large extent nullified the impact of the improvements in production energy efficiency. Moreover, transfer of industrial production from Europe to countries with lower production costs has most likely increased global emissions.

CURRENT FOCUS AREAS FOR RESEARCH AND INNOVATION

The gradual decarbonisation of the power system opens new possibilities for the reduction of industrial emissions through electrification. This is confirmed by a recent study of the challenges and opportunities in energy transition for energy-intensive industries [https://www.europarl.europa.eu/RegData/etudes/STUD/2020/652717/IPOL_STU(2020)652717_EN.pdf].

Metallurgy and product requirements need to be taken into account. Strong fluctuations of energy supply are not acceptable in industrial processes. According to the report, there is a range of technologically mature technologies available that can guide Europe's EIIs towards carbon neutrality by 2050. These can be divided into those that

- reduce the CO_2 emissions of current processes: energy efficiency, carbon capture and storage (CCS);
- replace fossil fuels for production: by electrification, biomass, low-carbon hydrogen or other synthetic fuels, or
- develop new production pathways with a lower CO_2 footprint: carbon capture and utilisation (CCU), process intensification and circular economy

RECOMMENDATIONS FOR FUTURE ACTIONS

New research is needed, especially in the following fields:

- Electrification of industrial and chemical processes or utilisation of biomass, low-carbon hydrogen or other synthetic fuels
  - Development of new process concepts
  - Development of new materials and components
- Low-carbon concrete production
  - Reducing the amount of cement in concrete
  - CO_2 hardening of concrete
- Low-carbon steel production
  - Hydrogen-enabled Direct Reduced Iron
  - Biomass-derived substitutes for fossil coke
- Maximal carbon efficiency of bio-based processes in the forest industry
  - Carbon capture utilisation and storage
  - By-product valorisation
- Efficiency improvements of industrial processes
  - Interaction between different industry sectors; new value chains

We expect that exciting opportunities will emerge from cross-cutting themes like sector integration. Such research should be realized in the form of large and long-running programs that focus on developing solutions that surpass sectoral borders. The R&D work should be coupled with policy development and supported by funding instruments that are targeted to de-risk innovative demonstration ventures.

Biofuels and bioenergy

CURRENT FOCUS AREAS FOR RESEARCH AND INNOVATION

The most important topics for further development in bioenergy include Bio-CCU/S, Bioenergy RES hybrids, acceptability of bioenergy and linkage to sustainable development goals of the United Nations [https://sdgs.un.org/goals].

Current focus areas include:

- Smart waste-to-energy concepts build on the use of waste and raw material streams (some also bio-based) to minimize the environmental impact caused by waste.
- Flexible bioenergy-hybrid renewable energy solutions have the potential to lower the costs involved in energy transition and enable large volumes of renewable, weather dependent (solar and wind) power generation. Biomass is an easily storable source of renewable energy that can be used to bridge temporal imbalances between energy supply and demand. Biomass and biofuels also enable smart sector integration of electricity, heat and transport.
- Bio-CCU/S is the only known large scale technology that facilitates the withdrawal of CO_2 from the atmosphere while at the same time producing energy. It is one of the most powerful tools in contributing to GHG emission reductions. Moreover, the captured CO_2 can be converted to different products, e.g. fuels and chemicals.


RECOMMENDATIONS FOR FUTURE ACTIONS

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Regulation, market mechanisms, new services, digitalisation

CURRENT FOCUS AREAS FOR RESEARCH AND INNOVATION

In general, the regulatory framework should be technology-neutral and enable interaction across sectors. Focusing on the management of the energy system, much attention is placed on distributed decision-making, advanced analytics based on available data and the potential applications of artificial intelligence (AI). In the future, the ICT infrastructure and the traditional energy system infrastructure will become more and more integrated. Research interests are targeted at distributed data management and analysis. Furthermore, conventional information models and semantic modelling of systems will remain an active area of interest due to the introduction of sector coupling and more complex networks involving multiple actors.

While technologies exist, the integration of energy storages to the energy system and market is still not fully developed. New business models are being tested by different players working in cooperation. Regulators are crucial to the conversation as current regulations limit the roles of the owner and user of batteries in many countries.

Decarbonization, Decentralization and Digitalization are the three important aspects of the change in energy systems. Decentralization of energy systems will enhance small scale production of renewable energy by multiple producers. Consumers of energy can also produce energy leading to the generation of prosumers. The energy transition toward more distributed energy systems and storage solutions will increasingly foment the transformation of consumers into prosumers. Digitalisation and AI will enable local generation, storage and demand-response mechanisms as part of the whole energy system, thus enhancing citizens' engagement as active part of the value chain. New business models and innovations need to be developed to incorporate prosumers into the energy systems. Utility organizations will also need to develop digital tools and platform to enable energy trading and energy efficiency monitoring for end users.

RECOMMENDATIONS FOR FUTURE ACTIONS

We have identified the following generic needs for research and development:

- International research for aligning the global and national regulation and objectives is needed. The geographical dimensions of regulation and objectives need to be clarified.
- Sector integration needs to be studied further. Coupling of the district heating, thermal storages, heat pumps and electricity systems is of specific interest.
- Storages within different time frames are increasingly important in balancing production and consumption.
- New services to integrate transport, heating, industrial processes and biofuels are needed.
- New business models, markets and actor roles require cross-cutting research. Open platforms should be developed for communication and energy trading between prosumers.The number of feasible energy production alternatives is continuously increasing. Decision making is distributing to producers, consumers and prosumers. Multi-objective optimization needs to be extended to all these areas.

Regulatory sandboxes are needed and favoured because within them, new services can be tested and developed in real-life circumstances. These sandboxes must enable early research and development and they should be planned and managed carefully to avoid unfair conditions for competition. As such, regulation must continuously develop to remain equal and to encourage – or force – all actors to play their part.

Systemic resilience of the energy system

CURRENT STATUS

Energy systems are part of critical infrastructure, and the society is highly dependent on e.g., the power system. During the past decades, a lot of attention has been paid to the elimination of disturbances caused by difficult weather conditions, taking into account the expected impact of the climate change. However, along with the digitalisation of the systems, cyber-attacks have become a major threat, and today they are a commonplace. The strong interdependence of systems, e.g. the power system and the communication infrastructure, should also be noticed.

Our energy system is still dependent on imported energy. This applies to all sectors of energy use, and the energy market is very vulnerable to external changes. In addition to price volatility, shutoffs of some energy carriers are possible. In this sense, the European power system has been additionally stressed since the fall of 2021, especially after the invasion of Ukraine and the restrictions of fossil fuels' supply from Russia. Well interconnected EU power markets can strengthen the overall efficiency, flexibility and resilience of the system, however inter-connectivity can also propagate undesired effects like price instability and volatility across the markets. Consequently, many European countries have adopted measures to protect and shield customers from skyrocketing prices of electricity, energy and fuels [https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices]. From a national perspective, different scenarios, including the worst-case ones, should be analysed both in normal conditions and in crisis conditions. Organizations need to develop social innovations to protect the most vulnerable sections of the society from energy poverty arising from high energy prices.

Other structural energy system changes will most probably bring new threats, which call for updating the threat landscape for expected system development scenarios. The resilient energy system requires consideration of and response to a wide range of technical and non-technical factors. The non-technical factors include the perspective of the end customers, from e.g. economic, health and safety point of view.

In power systems, solutions that provide more secure supply, like energy storages including batteries of electric vehicles, and microgrids, have been under development for a long time. However, practical implementations are still rather rare. Along with the rapid increase of the share of variable renewable generation, flexibility solutions are becoming vital. Another challenge is how to maintain system inertia when the share of power generated by traditional generators decreases.

RECOMMENDATIONS FOR FUTURE ACTIONS

- Multiple scenario-based threat analyses
- Use case examinations from various perspectives, system level simulation studies
- Development of means to increase preparedness and tools for mitigation of the impact of threats, including reserve power, microgrids and securing of critical energy users
- Protection of the most vulnerable customers from energy poverty
- Development and implementation of various types of energy storages, including batteries of electric vehicles
- Development of recovery plans and exercises for various subsystems of the energy system
- Ensure versatile energy mix with domestic energy sources and their supply chains

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Summary of the recommendations

CARBON CAPTURE AND HYDROGEN PRODUCTION, AND UTILISATION OF CO_2 AND H_2

- supporting electrolytic hydrogen production at lower costs
- utilisation of process side-streams, including excess heat from electrolysis
- modularity/scalability of synthesis technologies
- cost-efficiency of direct air and industrial CO_2 capture (utilising, e.g. electrification)
- CCU end-product development
- wider ecosystems that target larger demonstrations and business development, and
- roadmaps for national development, piloting and research needs.

ENERGY STORAGE

- A combination of different types of storages (hybrid storages, batteries & compressed air, heat, electricity, H_2, CO_2 and synthetic fuels)
- Heating and cooling organized in locally specific ways
- Methods for considering storage already in the planning phase of the energy systems, buildings or city plan, where spatial planning could be supported by different energy networks
- Development of control strategies for different systems, e.g. for short-term and seasonal storages
- Multicriteria optimisation and control on different levels of detail to cost-efficiently integrate electrical and thermal systems, and adapt them to local requirements and possibilities
- Development of business models, regulation schemes and taxation models

CARBON-NEUTRAL INDUSTRY

- Electrification of industrial and chemical processes or utilisation of biomass, low-carbon hydrogen or other synthetic fuels
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- Maximal carbon efficiency of bio-based processes in the forest industry
  - o Carbon capture utilisation and storage
  - o By-product valorisation
- Efficiency improvements of industrial processes
  - o Interaction between different industry sectors; new value chains

BIOFUELS AND BIOENERGY

- Carbon negative solutions, such as Bio-CCU
- Sustainable transportation fuels and r equired infrastructure for several sub-sectors of transportation
- Flexible plants with multiple outputs, e.g. pulp, timber, bioelectricity, heat, biocomposites, fibres, chemicals, and
- Biogas manufacturing processes and i nfrastructure
- Technology development in specific sectors like marine and aviation
- Need to develop new ecosystem-type approaches
- Possibilities of active carbon sinks in moving CO_2 to biosystems during growing seasons should be examined.

REGULATION, MARKET MODELS, NEW SERVICES AND DIGITALIZATION

- International research for aligning the global and national regulation and objectives is needed. The geographical dimensions of regulation and objectives need to be clarified.
- Sector integration needs to be studied further. Coupling of the district heating, thermal storages, heat pumps and electricity systems is of specific interest.
- Storages within different time frames are increasingly important in balancing production and consumption.
- New services to integrate transport, heating, industrial processes and biofuels are needed.
- New business models, markets and actor roles require cross-cutting research. Open platforms should be developed for communication and energy trading between prosumers.
- The number of feasible energy production alternatives is continuously increasing. Decision making is distributing to producers, consumers and prosumers. Multi-objective optimization needs to be extended to all these areas.

SYSTEMIC RESILIENCE OF THE ENERGY SYSTEM

- Multiple scenario-based threat analyses
- Use case examinations from various perspectives, simulation studies
- Development of means to increase preparedness and tools for mitigation of the impact of threats, including reserve power, microgrids and securing of critical energy users
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