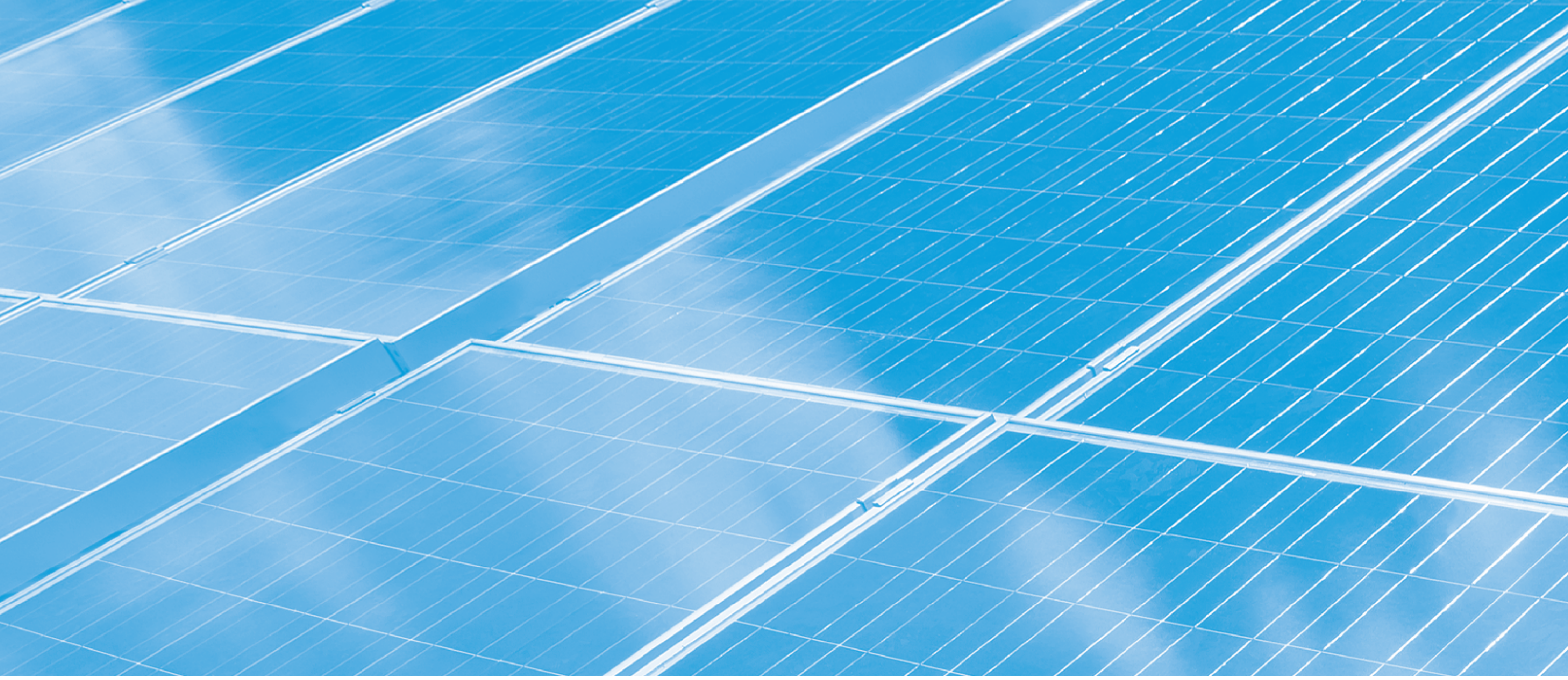


STRATEGIC RESEARCH AND INNOVATION AGENDA

Energy

CLIC INNOVATION LTD

Contents

Abbreviations

CAGR	Cumulative annual growth rate
CCU	Carbon capture and utilization
CCUS	Carbon capture, utilization and storage
CEM	Clean Energy Ministerial
CSP	Concentrated solar power
EASE	The European Association for Storage of Energy
EERA	European Energy Research Alliance
ETIP SNET	European Technology & Innovation Platform Smart Networks for Energy Transition
ETS	Emission trading system
FC	Fuel cell
GHG	Greenhouse gas
H2020	EU Horizon 2020 Framework Programme
IEA	International energy agency
P2X	Power to X
PHS	Pumped hydroelectric storage
PPP	Public-private partnership
R&D	Research and development
R&D&I	Research, development and innovation
SDG	Sustainable development goals
SMR	Steam methane reforming
SRIA	Strategic research and innovation agenda
TRL	Technology readiness level
UN	United nations
VRE	Variable renewable energy

Executive summary

Urgent action is needed by all countries to tackle energy-related greenhouse gas emissions if we are to meet the climate objectives of the Paris Agreement. The European Union has set an ambitious target for Europe to become climate neutral by 2050. We cannot achieve this ambitious target without fast and effective actions to lower CO_2 and other emissions, such as methane and black carbon. In addition to increased renewable energy production, it's crucial that we improve energy efficiency and introduce cleaner industrial processes. We also need to identify novel solutions to utilize CO_2. Improved cross-sectoral cooperation (energy, mobility, for example) and greater sector integration or sector-coupling (electricity, heat, gas) are needed to accelerate our transition to a greener, cleaner future. To successfully decarbonise, the entire energy system needs to become more flexible and adaptable.

At the same time, the ongoing global shift at-scale toward fast-growing smart energy markets offers enormous potential to businesses. However, to realize this potential, we believe that more knowledge, understanding, testing and piloting of solutions is needed.

In 2019, the shareholders of CLIC Innovation identified five 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 five focus areas, which are:

1. Carbon capture and hydrogen production, and use of CO_2 and H_2 as a raw material or energy source
2. Energy storage, including heat and electricity
3. Carbon-neutral industry
4. Biofuels and bioenergy
5. Regulation, market models, new services and digitalization

CLIC Innovation operates at the intersection between industry and academia to advance research, development, demonstration and innovation. To most efficiently progress in the selected focus areas for energy, we identified the following needs:

- More public funding is needed for longer-term research and development programs that provide enough resources to achieve results with impact.
- There is a requirement for more significant public financing for industrial-scale piloting and demonstrations that share risk.
- Close interaction should be built with regulatory bodies as regulation strongly affects the development of new market opportunities.
- Interaction with EU-level policymaking is essential as EU policies have a considerable impact on all energy actors in the EU.

The ongoing energy transition toward more sustainable and renewable sources requires cooperation across a vast array of disciplines. Only by working together can we tackle climate change mitigation challenges. CLIC Innovation continues to promote clean, sustainable energy solutions in a spirit of openness and co-creation. We have confidence in our approach, but caution that this SRIA will only succeed if the various actors are inspired by it to propose and participate in new projects and activities.

Foreword

CLIC Innovation is an open innovation cluster with a mission to facilitate creation of breakthrough solutions in three areas: bio-economy, the circular economy and energy. As a public-private-partnership CLIC Innovation uniquely gathers together industrial and academic competencies to achieve the set targets.

Building Strategic Research and Innovation Agendas (SRIAs) is the primary tool used at CLIC Innovation to set common targets and to define focus areas for a significant number of actors. It is the document you are reading, and an output of an intensive co-operation between the network of CLIC Innovation's owners and partners, comprising a broad group of stakeholders representing business and research in 2019.

This document identifies and describes the critical areas of research, development and innovation that are fundamental to meeting our energy challenges in the future. The development of this SRIA is an open and continuous process that goes far beyond CLIC Innovation. We actively invite other stakeholders to join and participate in the activities that originate from this SRIA. We commit to regularly re-evaluate the SRIA to ensure that it is up-to-date and relevant.

The current SRIA sets out five focus areas within energy:

1. CCU and hydrogen production, and the use of CO_2 and H_2 as raw materials or energy source
2. Energy storage (heat and electricity)
3. Biofuels and bioenergy
4. Solutions for carbon-neutral industries
5. Regulation, market models, new services and digitalization

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.

Addressing global challenges

The energy sector is currently undergoing a major transition. The global smart energy market is forecast to grow at a rate of 15% (CAGR) every year between 2016-2020. Every year over $2 billion is invested in smart energy. On the other hand, global investments in renewable energy fell in 2018, mainly due to decisions taken in China. [1] This demonstrates that uncertainty remains in the market, driven by political choices. The main focus for current investments is on reducing the share of fossil fuels and increasing renewable energy production. A dynamic energy system needs both flexible production and energy storage. The wide-scale adoption of electric vehicles, for example, will also drive significant changes in energy markets as well as broader societal changes.

The energy sector plays a crucial role in society. Providers must ensure that the supply of energy remains stable and reliable, while at the same time introducing a large amount of renewable energy generation into the system. Achieving high system resilience under all circumstances in an economically viable way is challenging. Introducing smartness to the system is one way to achieve both goals simultaneously.

The Global Clean Energy Ministerial (CEM) is a high-level forum that exists to promote policies and programs that advance clean energy technology, to share lessons learned and best practices, and to encourage the transition to a global clean energy economy. This initiative has set ambitious objectives on smart grids, improving cross-border connections, electric mobility and new technologies like CCUS, hydrogen solutions, nuclear energy, solar power and wind energy. Some of these themes are advanced through the global Mission Innovation initiative as Innovation Challenges [3].

The UN has defined a series of Sustainable Development Goals (SDGs) (Figure 1), several of which relate to the energy sector. Specifically, goals 7 “Affordable and Clean Energy”, 11 “Sustainable Cities and Communities” and 13 “Climate Actions” are all focused on the energy sector. These global challenges also serve as a basis for EU Grand Challenges and the Missions that are addressing them. Through this mechanism, the Sustainable Development Goals aligned to the coming Horizon Europe work programs.

Figure 1. UN Sustainable Development Goals. [2]

The EU 2030 Framework for Climate and Energy defines targets to help EU countries achieve a more competitive, secure and sustainable energy system and to meet its long-term 2050 greenhouse gas reduction targets. The strategy sends a strong signal to the market, encouraging private investment in new pipelines, electricity networks, and low-carbon technologies. The EU-level targets for 2030 are:

- At least a 40% cut in greenhouse gas emissions compared to 1990 levels.
- At least a 32% share of renewable energy consumption.
- An indicative target for improvement in energy efficiency at the EU level of at least 32.5% (compared to current projections).
- Support the completion of the internal energy market by achieving the existing electricity interconnection target of 10% by 2020, to reach 15% by 2030.

The Energy Union strategy builds on the 2030 Framework for Climate and Energy and the European Energy Security Strategy [4]. The Energy Union is made up of five closely related and mutually reinforcing dimensions: security, solidarity and trust; a fully integrated internal energy market; energy efficiency; decarbonizing the economy, and research, innovation and competitiveness.

The integrated SET-Plan supports these five dimensions as part of a new approach for European energy research and innovation (R&I) that is designed to accelerate the transformation of the EU's energy system and to introduce promising new energy technologies to the market.

ETIP SNET is a European initiative that has been created to implement the SET-Plan. It has recently published a vision for the future energy system called “Vision 2050: System of systems” [5]. 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. This vision is widely used as a future reference within European projects and initiatives.

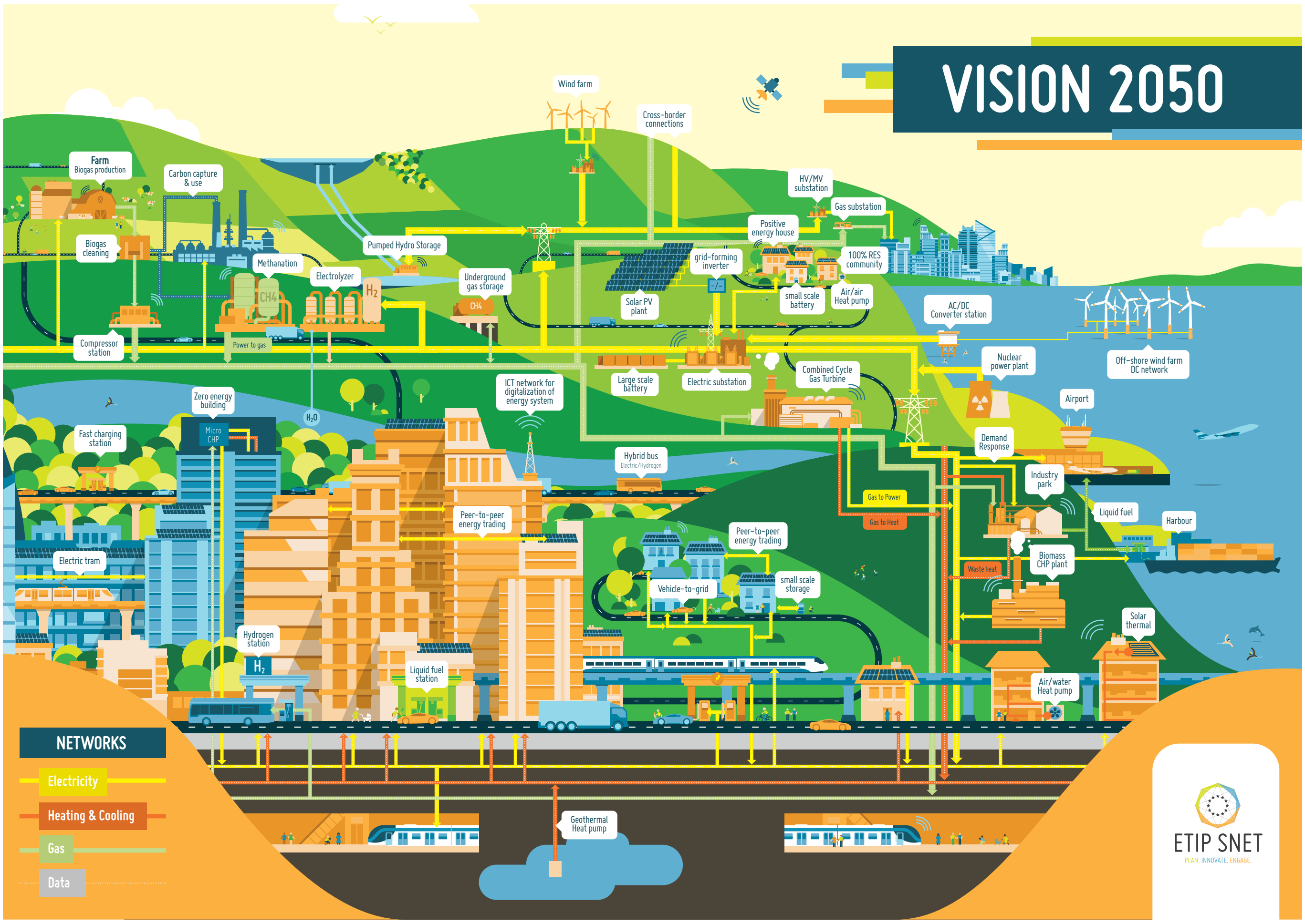


Figure 2. Vision 2050: A System of Systems by European Technology & Innovation Platform Smart Networks for Energy Transition (ETIP SNET). [5]

Focus areas for research and innovation

Carbon capture and utilization (CCU) and the use of CO_2 and H_2 as a raw material or energy source

CURRENT STATUS

Carbon Capture and Utilisation (CCU) is an area of huge interest for research and development. There are already commercial plants across the world that are achieving CO_2 conversion and utilisation. An estimated 70 research/demo projects, start-ups and established companies are currently using or planning to use, CO_2 to produce fuels, chemicals, polymers or proteins and store energy [3]. These projects range from being at the lab, pilot, demonstration and pre-commercial stages to commercial scale.

Fossil feedstocks produce over 95% of global hydrogen via steam methane reforming (SMR), and CO_2 capture is already a feasible operation. Across the world, 4% of hydrogen is produced by electrolysis and the electrolyser industry is small and fragmented. As an energy-intensive process, electrolysis requires cheap green energy to be competitive.

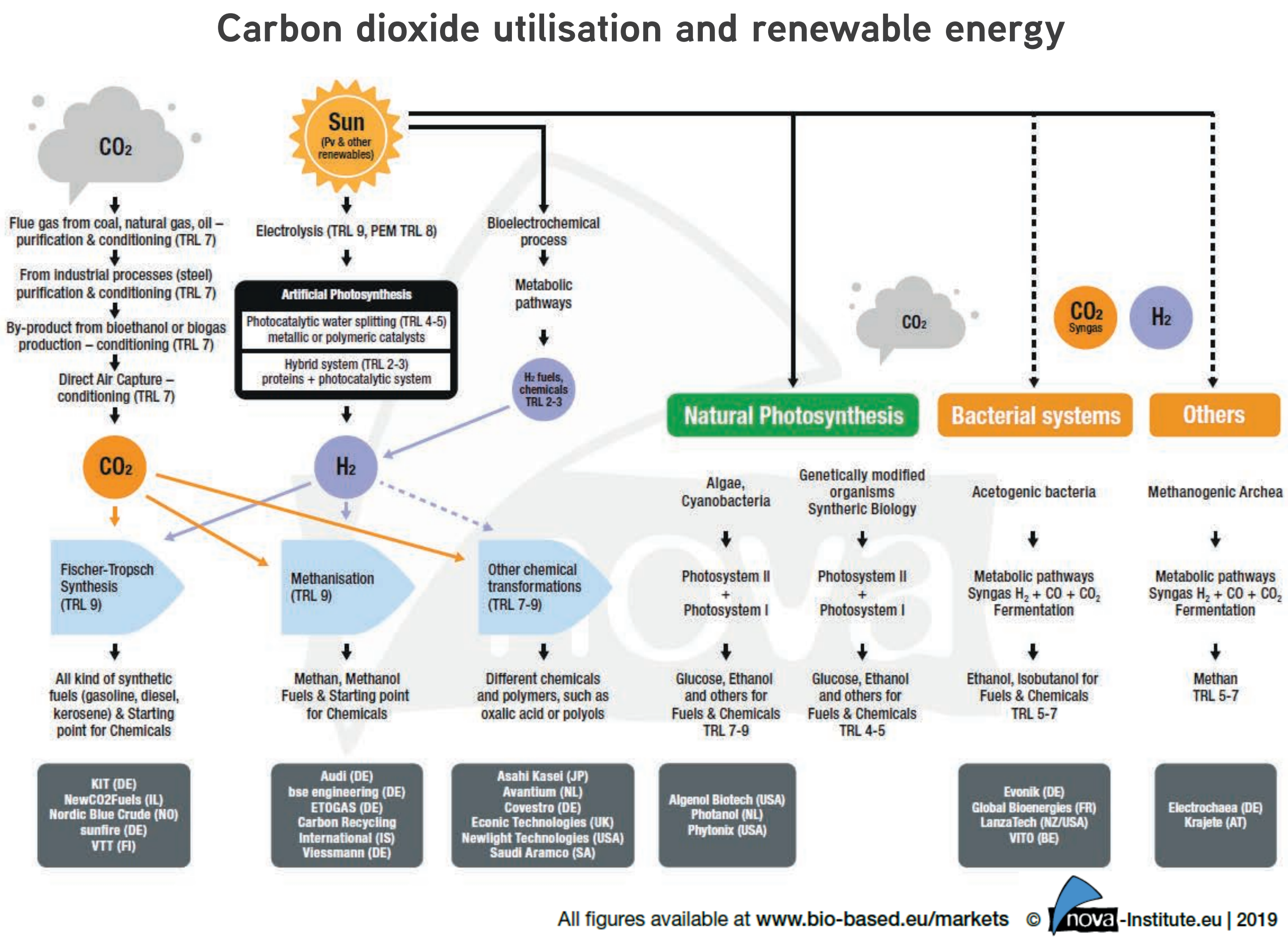


Figure 3. Overview of current CO_2 utilisation technologies with renewable energy-based hydrogen. [6]

OVERVIEW OF ACTORS, ECOSYSTEMS, POLICIES AND INITIATIVES

Figure 4 presents the leading actors and countries involved in the development of hydrogen-based renewable energy solutions. Regulation and political support are needed to speed up the introduction of clean hydrogen, CCU and power-to-x (P2X) at a commercial scale. Countries are required to convert the RED II directive into national laws by June 2021. According to the directive, the minimal share of renewable energy sources in fuel must grow from 5% today to 14% in 2030. CCU-based fuels can also fulfil this 14% share. While the negotiations around the RED II directive and the emissions trading system (ETS) revision have shown that CCU is present on the political agenda, support among is still quite low. National R&D funding is essential to increase the adoption of renewable energy systems long-term and push CCU and P2X initiatives toward markets.

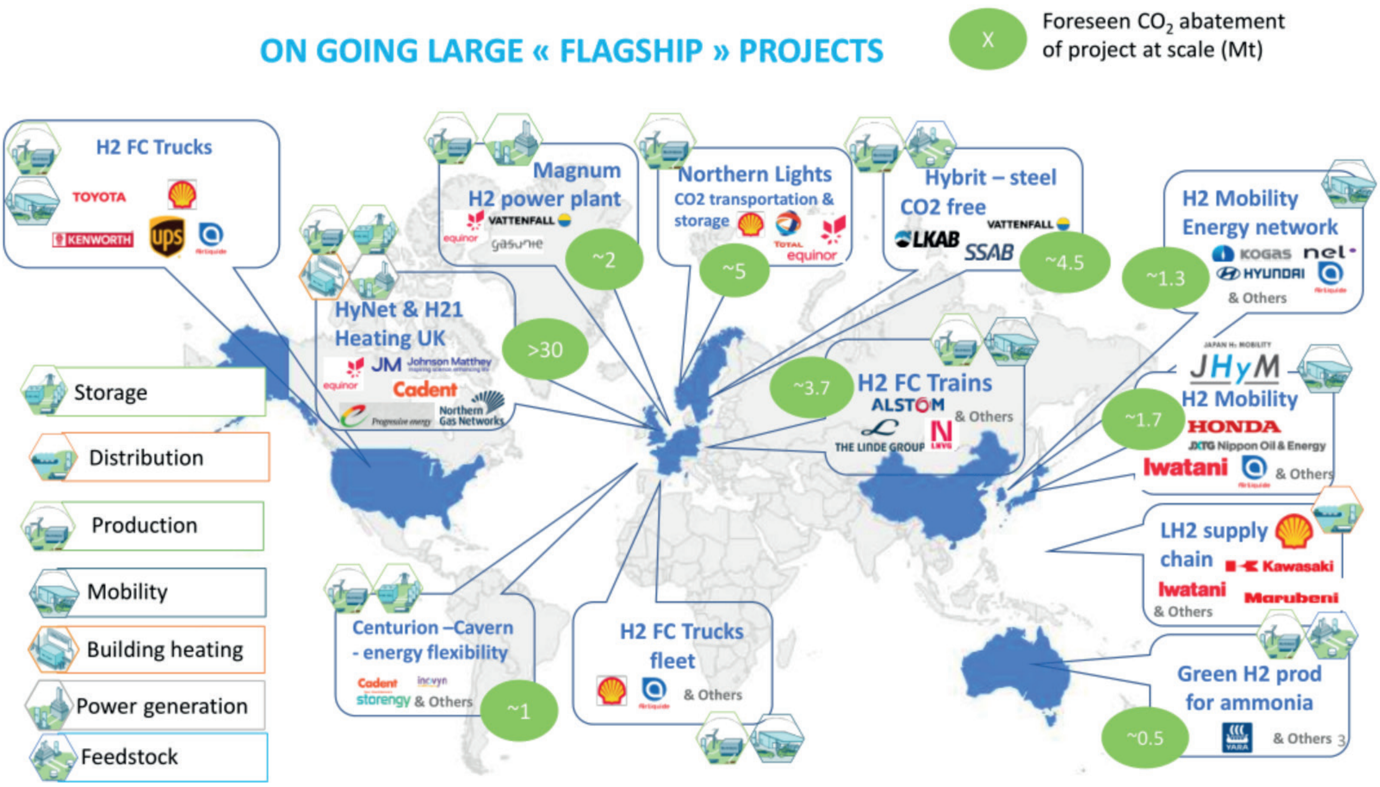


Figure 4. Key hydrogen initiatives towards a cleaner future. [7]

CURRENT FOCUS AREAS FOR RESEARCH AND INNOVATION

Figure 5 gives an overview of the development and market outlook of CCU applications where CO_2 (with hydrogen) can be used as feedstock. There is room for improvement in electrolysis technology in the production of clean hydrogen. Target areas include reducing the capital cost, enhancing the lifetime and durability, and increasing system efficiency.

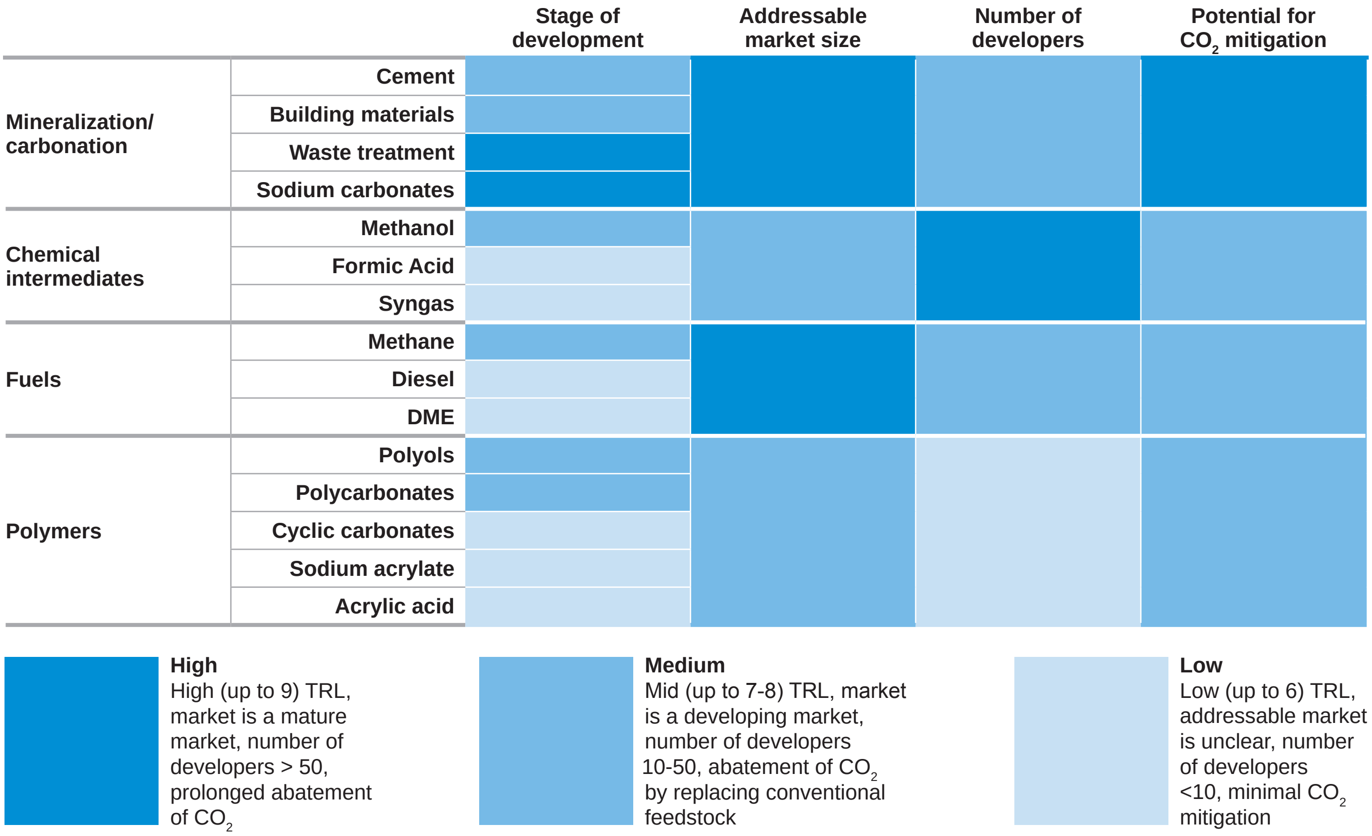


Figure 5. Comparison of the main CO_2 utilisation sectors. [8]

RECOMMENDATIONS FOR FUTURE ACTIONS

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

- supporting electrolytic hydrogen production at lower costs;
- 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.

Emphasis should be placed on industry-integrated systems and full-chain approaches where all process side-streams are utilized, and all necessary actors in the value chain are involved. More efficient sub-processes 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 wave for positive technology and market development jointly. Such ecosystem operations may also include joint market shaping activities. To be truly successful, it is imperative that the public support 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 STATUS

The global energy storage market has grown exponentially and continues to expand at an impressive rate. In 2013, the annual installed capacity was just 0.2 gigawatts (GW), in 2018 it was an incredible 3.1 GW. In the same year, the total capacity of the installed grid was approximately 176 GW. [9] The countries leading on energy storage are South Korea, China, the United States and Germany. New markets have emerged quickly wherever governments and utilities have created supportive mechanisms. Pumped hydroelectric storage (PHS) systems are the dominant form of electrical energy storage in the world today (with a 90% share of the installed power). [10] However, lithium-ion batteries are rapidly gaining a more significant share of the market. Today they make up almost 85% of all new installed capacity [11]. Figure 6 illustrates the different technologies that can be used to store energy. Due to the wide range of technologies, the TRL varies from five to nine. The main application area - and the fastest-growing - is the support for the grid-connected, variable, renewable generation. Different storage technologies are deployed for a variety of applications, primarily due to their differing energy-to-power ratios and reaction/discharge times. Cost is also a significant factor that influences energy storage choice.

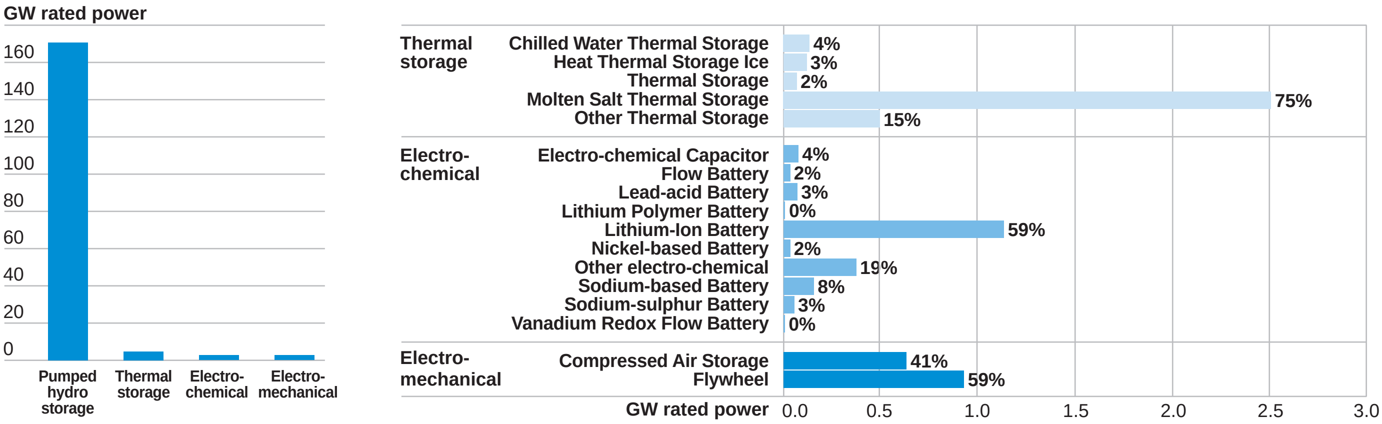


Figure 6. Global operational energy storage power by technology, mid-2017. [12]

Gathering accurate information on the global installed thermal storage capacity is challenging as most sources only refer to thermal storage of electricity. Thermal storage systems connected to district heating networks have been used for a long time. They're a cost-effective technology that can be used to increase the flexibility of district heating systems and CHP production, especially when combined with heat pumps and electric boilers. Sensible heat storage systems that utilize water as a storage medium are still the prevalent technology, both at small- and large-scale. The ground is often deployed as storage through ground heat pumps. The thermal mass of buildings is widely used for short term (daily) thermal storage. Some experiments have been recently conducted on novel storage methods of seasonal storage in Finland (e.g. Helios storage in Kokkola) and more widely in Sweden. Thermal storage can also be used for cooling, and as latent storage using ice or for storing snow from winter to summer. Molten salt solutions are used for storing electricity generated by CSP (Concentrated Solar Power). Scientists and researchers are increasingly investigating the potential for this method of thermal storage. More broadly, there is interest in innovative new power-to-x processes, like the production of synthetic fuels, as storage options for the future.

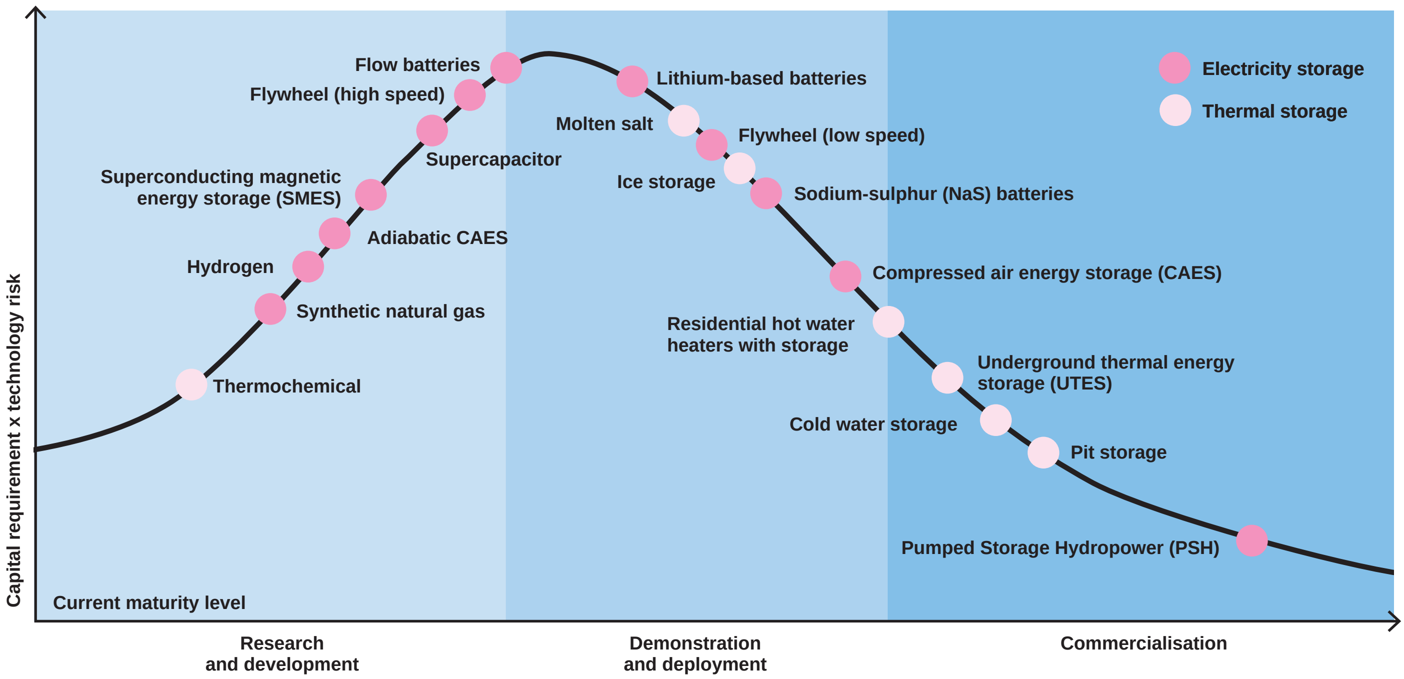


Figure 7. Maturity of different storage technologies. [13]

OVERVIEW OF ACTORS, ECOSYSTEMS, POLICIES AND INITIATIVES

Energy storage is a hot discussion topic among energy-sector specialists all over the world. The topic's popularity can be attributed to the massive increase of variable renewable energy production and the high level of maturity of the storage technologies compared to other means of providing system flexibility. Intensive development work is happening in the US, Europe and China. China leads both in the production and consumption of energy storage systems. [14] Major global players within the value chain include LG Chem., Beacon Power, LLC, BYD Company Ltd., ABB Ltd., Greensmith Energy Management Systems and Eos Energy Storage.

There have been several H2020 calls addressing the challenge of energy storage in recent years. Many of the funded projects have been collected under the BRIDGE initiative [15], which aims to increase knowledge sharing and the creation of concerted recommendations. The European Association for Storage of Energy (EASE) and European Energy Research Alliance Joint Programme on Energy Storage (EERA JP ES) are also active in the field, regularly publishing market reviews and strategy papers. IRENA considers storage to be one of the most promising enabling technologies to facilitate the integration of a high proportion of variable renewable energy (VRE) into the power system. [16] Finally, energy storage has also finally been included in the development of the Clean energy for all Europeans framework [17].

CURRENT FOCUS AREAS FOR RESEARCH AND INNOVATION

In anticipation of mass-market adoption, some storage technologies in low TRL are identifying and targeting early opportunities in territories that have a sensitive supply/demand equilibrium, or that have implemented incentive policies. [18] A general conclusion from one of the storage integration projects (EU H2020 STORY) was that technical, market, regulatory and social issues are highly interrelated. Focusing attention on each of these in parallel will ensure the efficient roll-out of small and medium-sized storage solutions.

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.

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 key to adapt to weather conditions, variations in consumption and finding the balance between heat and electricity. Seasonal storage solutions could 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 and electricity and synthetic fuels).
- Methods for considering storage already in the planning phase of the energy system.
- Development of control strategies for different systems and business models.
- Development of business models, regulation schemes and taxation models.

Solutions for seasonal storage, heat storage, enabling regulation schemes and new business models are crucial areas for development. Larger and more prominent industrial ecosystems are required to build and develop large-scale demonstrations and pilots. These demonstrations should be cross-cutting and bring together a broad range of actors from across the sector, from storage technology providers to energy market actors.

Carbon-neutral industry

CURRENT STATUS

Industry is responsible for a significant proportion of greenhouse gas emissions (GHG) across the world. Industrial production currently accounts for 24% of global emissions – a figure that rises by 1.3% every year. In tackling greenhouse emissions, process efficiency is critical. Many industries have been slow in reducing their total emissions, partly due to the long lifetimes of the investments that they have made and a lack of coordinated international regulation and policies.

The primary source of industrial emissions is the burning of fossil fuels for heat production at different temperature levels. Process heating is about 16% of final energy use in Europe and is mostly used at temperature levels above 500 Celsius. In many cases, electricity could be used as a replacement, and in other cases, synthetic fuels could be used.

Industrial emissions are also challenging to reduce because a large share of CO_2 is released as a by-product of chemical reactions. For example, breaking down calcium carbonate to calcium oxide and CO_2 at elevated temperatures - the principle reaction in cement making - accounts for approximately 50% of all CO_2 emissions from cement production. As these emissions originate from the chemical reaction itself, they cannot be mitigated by a shift to low-carbon energy. Similarly, in steelmaking, the reduction of iron ore to metallic iron is carried out using coal, which accounts for more than 80% of all CO_2 emission generated from steel production.

Switching to more sustainable raw materials or alternative chemistry is expensive, and requires sustained investment in research, development and deployment over several decades. However, planning and investments need to start well in advance of this as industrial sites have notoriously lengthy investment cycles. For example, a Nordic consortium is already developing a carbon-free steel mill but expects to have a solution ready by 2035. They will then begin to convert their mills to use this new technology, with the process completed by 2045 [19].
In addition to the actions of the manufacturer, new raw materials or processes could have some impact on product properties, which need to be accepted or even favoured, by the end-users.

OVERVIEW OF ACTORS, ECOSYSTEMS, POLICIES AND INITIATIVES

The cement industry, together with iron and steel making dominate total industrial emissions, representing 40% of the global 15 $GtCO_2$ emissions annually. China currently accounts for around 50% of global production in cement and iron and steel, and will, therefore, play a pivotal role in the effort to reduce worldwide industrial emissions. China is expected to remain the largest source of industrial emissions in the future, but the most substantial increases are expected to occur in India and Africa. It is predicted that there will be tripling of production capacity in cement and steel in these areas by 2050, significantly increasing emissions. [20]

In Europe, the industrial sector is part of the emissions trading system (ETS). As the cost of emissions allowances has started to increase due to the tightening regulation, industries are enthusiastically searching for cost-efficient ways to reduce their environmental impact. New low-carbon processes are estimated to be more expensive to both own and operate, leading to an increase in the cost of production. As many industrial products are traded globally, the higher costs of low-carbon processing cannot be transferred to an increase in prices. Therefore, some industrial actors are calling for an EU to set compensatory tariffs that ameliorate price differences between similar products with different carbon intensities.

CURRENT FOCUS AREAS FOR RESEARCH AND INNOVATION

Many industries have improved production energy efficiency [21]. However, most of the climate benefits realised to date have been offset by increases in the scale of industrial production. In recent years, European industry has become more actively involved in the climate-debate, with individual companies [22] or different consortiums [23] publishing position papers and reports that present their ambitious goals for achieving carbon neutrality by 2050. The gradual decarbonisation of the power system is considered by many to open up new possibilities for the reduction of industrial emissions through electrification; either directly or via heat pumps or indirectly via electrolytic hydrogen.

Europe's Energy Intensive Industries reviewed more than 80 low-carbon technology options [24] and identified the following main pathways for industrial decarbonisation:

- further improvements in energy efficiency and energy savings;
- process integration;
- further electrification of heat;
- further electrification of processes;
- use of low-CO_2 hydrogen;
- valorisation of CO_2 (CCU);
- sustainable use of biomass;
- carbon capture and storage (CCS); and
- higher valorisation of waste streams and materials efficiency.

RECOMMENDATIONS FOR FUTURE ACTIONS

New research is needed, especially in the following fields:

- Electrification of high-temperature industrial processes
  - 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 utilisation of the bio-based carbon from the forest industry
  - Carbon capture utilisation and storage
  - By-product valorisation
- Efficiency improvements for industrial processes

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 STATUS AND OVERVIEW OF ACTORS, ECOSYSTEMS, POLICIES AND INITIATIVES

The EU 2030 Framework for climate and energy defines targets to help Europe achieve a more competitive, secure and sustainable energy system and to meet its 2050 greenhouse gas reductions target. The Energy Union strategy builds upon the 2030 Framework for Climate and Energy and the European Energy Security Strategy.

The Energy Union is made up of five closely related and mutually reinforcing dimensions:

1. Security, solidarity and trust
2. Fully integrated internal energy market
3. Energy efficiency
4. Decarbonizing the economy
5. Research, innovation and competitiveness

The integrated SET-Plan supports these five dimensions as part of a new European energy Research & Innovation (R&I) approach that is designed to accelerate the transformation of the EU's energy system and to bring promising new zero-emissions energy technologies to market by fast-tracking the development and deployment of low-carbon technologies.

RED-II is expected to create market pull. This is especially true of SET-Plan context (Action 8), which is very strong from a Finnish perspective where participation is actively driven by the Ministry of Economic Affairs and Employment of Finland. Within European ecosystems, Finnish activities have been weakening in recent years. A lack of comprehensive, cross-sectoral joint research efforts in Finland is visible with separate projects failing to cohere and contribute to a shared objective.

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 SDGs. 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. Different waste streams are utilized according to the waste hierarchy, with a definite benefit arising from the ability to simultaneously utilize waste streams as raw material for products and energy. Specific concepts include the development of smart separation technologies, the thermal deconstruction of material streams and the upcycling of raw material to primary feed, with the recovery of valuable fractions as critical raw materials and fertilizers. These concepts contribute toward the crucial transition to decarburization, the smarter and more sustainable use of raw materials and the reduction of waste fractions. Together, they make a significant contribution to the targets of the SET-Plan/ Energy Union.
- 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 production. Biomass is an easily storable source of renewable energy that can be used to bridge temporal imbalances between energy supply and demand. Combining bioenergy with other renewable energy forms (so-called bioenergy RES hybrids) can offer the required flexibility in energy production while maintaining GHG benefits and low costs. The technology supports a cost-efficient transition to a low carbon energy system. It also contributes to low carbon energy itself and enables smart integration of energy markets in 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. In connection to indirect electrification of sectors that may otherwise be difficult to decarbonize (when the electricity sector on average already has a low-carbon intensity), directly or by offsetting historical emissions or emission across sectors, it is the most powerful tool in contributing to GHG emission reductions. This contributes significantly toward achieving the SET-Plan and Energy Union targets.

RECOMMENDATIONS FOR FUTURE ACTIONS

There is a requirement for new research into:

- carbon negative solutions;
- sustainable transportation fuels;
- flexible plants with multiple outputs; and
- biogas manufacturing processes and infrastructure.

Additionally, there is a need for technology development in specific sectors like marine and aviation. In the future, different renewable hybrid systems and multi-production concepts simultaneously producing energy and fuels are likely to increase in importance. Also, the management and optimization of biogas production and the optimization of the delivery chain are increasingly important.

All promising new technologies should be developed and demonstrated in collaboration and implemented at-scale. There is a need to develop new ecosystem-type approaches where a variety of actors and stakeholders are widely involved from the beginning. Adequate and sustained public financing is especially necessary for risk-sharing in demonstration activities.

Regulation, market mechanisms, new services, digitalization

CURRENT STATUS

The energy system is currently undergoing a significant transition towards a more sustainable future. This shift is mainly driven by the global challenge of climate change and the urgent need to reduce carbon emissions. The energy system plays a crucial role in the creation of a new system that's built on renewable energy options. While leading the move to renewable energy, the energy system must also fulfil two other basic requirements: reliability and affordability.

To reach these goals, the energy system needs to develop in several ways. The structure of the future energy system will become more distributed, meaning that there will be actors and components on multiple system levels. The operation of the system will become more dynamic and involve more time-critical functions and a greater number of real-time operations. To achieve this, flexibility is essential on all system levels and for multiple purposes. At the same, individual customers should be encouraged and supported to become more involved in the system and more aware of their daily energy use. New technologies in the smart energy system and new developments like 5G can increase awareness among individuals of their energy usage. Real-time connectivity and advanced data analytics can support customers to make better decisions on how they use energy. New communication technologies can enable the efficient management and transfer of huge amounts of information, but cyber-security remains a key consideration for all, particularly when sharing personal data covered by GDPR and in-country regulation.

Smart energy systems are more complex than our current energy supply system in several ways. They are real-time, more interconnected and increasingly involve new players. As the markets evolve, the roles of actors as well as hierarchies of distributed resources will change. The whole field can become scattered, and there may be competing platforms that serve the same purpose. At this point, information flows and interfaces become increasingly important. Digitalization can enable new solutions addressing this complexity. System integration becomes increasingly important in developing informative indicators and combining them with the domain expertise to solve energy system challenges in a more optimized way.

At a higher level, regulation and markets are developing and changing because of European and national strategies and initiatives. These processes and policies are the results of political decision-making. For example, the European Energy Strategy and Energy Union are strongly driving the development of regulation and markets. Certain more targeted packages such as "Clean energy for all Europeans" package provide more concrete pathways for change.

Sector coupling will become essential as sectors including mobility, industry, buildings and communication become more integrated and embedded within the energy system. The electrification of society continues at the same time as a concerted effort is taken to reduce emissions. To manage this potential contradiction, regulation and for statutory instruments like targeted taxation schemes are necessary to support electrification. Overall, the energy industry plays a crucial role in this development – and will continue to do so as society and technology develop at pace.

OVERVIEW OF ACTORS, ECOSYSTEMS, POLICIES AND INITIATIVES

Today, development and innovation are much more collaborative in business-to-business ecosystems. In many cases, research partners are also involved, especially when developing innovative new products or solutions, or where projects are complex or systemic. To succeed, innovation ecosystems must be agile and dynamic. When developing new market mechanisms and regulation, ecosystems should involve partners from the public sector to include their views, opinions and interests. Building regulatory sandboxes is a powerful tool for developing solutions.

CURRENT FOCUS AREAS FOR RESEARCH AND INNOVATION

Currently, a significant amount of research is focused on the means and technologies to reach the established and agreed emissions reduction targets. Further, industries are searching for competitive carbon-neutral solutions, combined with smart regulation. Sector coupling is an interesting research trend that is likely to draw a lot of attention in the future. In addition to the demands for the development of new technologies, other aspects like taxation schemes for combinations like electricity and heating, or power-to-X require development. 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. Ongoing projects utilize cutting-edge-computing level for local data and time-critical functionalities, with resource-intensive statistical-analysis is conducted in the cloud. As the data points increase, there are concerns that all of the data generated isn't being used effectively. One possible solution is the production of full-resolution data at edge level for accurate and real-time functions. Data is only then transferred and aggregated data to the cloud, where more detailed, long-term trend analysis can take place. 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.

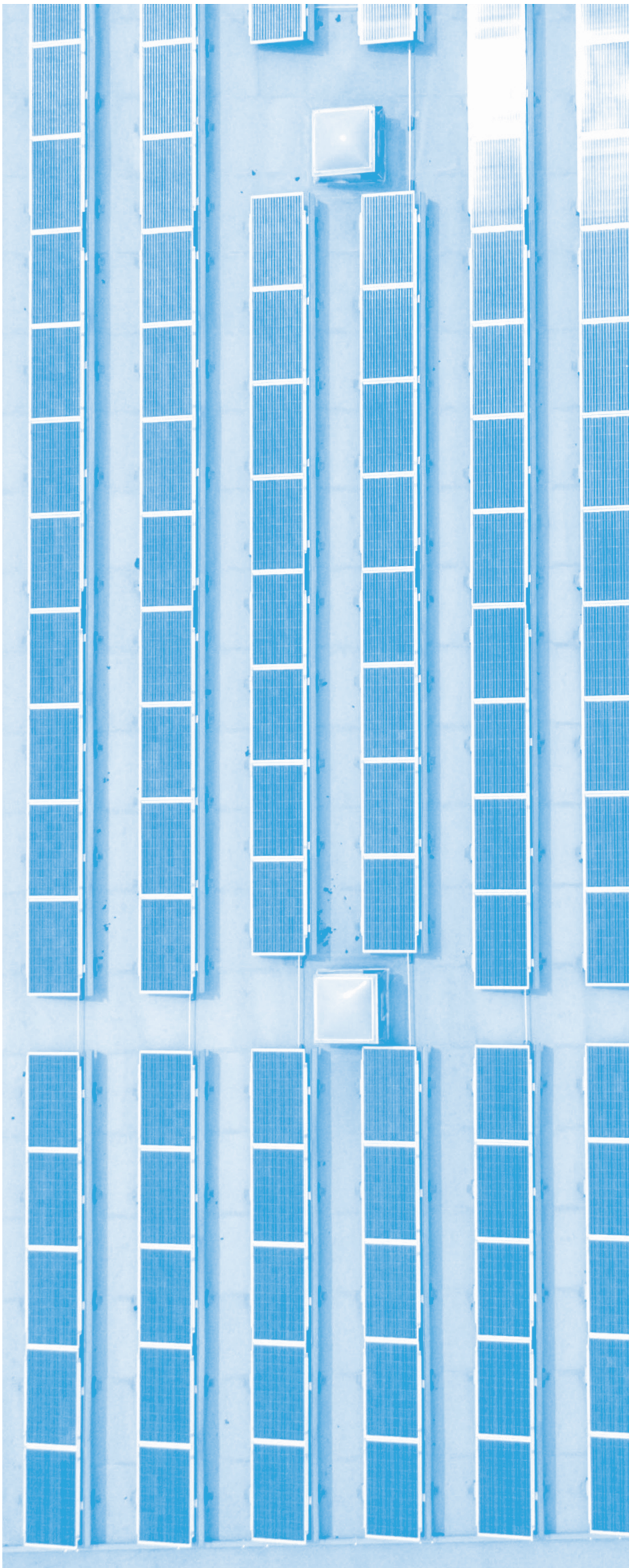
Market research is needed, too. Markets should be equal, and they should not distort competition. In the future, many new actors will be introduced to the system, and they will increasingly be distributed smaller players. Developing new market models that include new actors and involve individual customers is crucially important. As technology becomes embedded within the power supply system, a more detailed analysis of customer behaviour, new service models, dynamic contracting will become more common as there will be more accurate as real-time data is available.

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 coupling needs to be studied further. Coupling of the district heating 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.
- 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 phases, and be carefully planned and managed 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.



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About CLIC Innovation Ltd

CLIC Innovation is an open innovation cluster with the mission of facilitating creation of breakthrough solutions in three areas: bioeconomy, the circular economy and energy. The cluster operates as a public-private-partnership. CLIC Innovation Ltd is owned by 30 leading international companies and 16 research organizations committed to creating sustainable solutions for the world. The company is based in Helsinki Finland. For more information visit www.clicinnovation.fi

Finnish areas of strength in energy

The Finnish energy system, especially the smart electricity network, is advanced with a significant amount of automation. The energy market is transparent and open, enabling the introduction of new actors. Asset management methods for the energy system are well-developed. Finland has also developed a strong position in enabling new communication technologies, advanced data management and artificial intelligence. These are allowing for significant innovation within the energy sector.

The key Finnish technologies and areas of particular expertise include:

- smart grids and network automation;
- smart metering systems;
- asset management methods;
- information systems for the energy system and the market;
- energy conversion technologies (bioenergy, waste-to-energy, power-to-x, refineries);
- power electronics and drives;
- district heating and cooling systems;
- combined heat and power production; and
- system resilience during adverse weather conditions.

Finnish companies have excellent capabilities in:

- new distributed data management and processing solutions (cloud-edge architectures);
- new communication technologies (5G, private networks, mesh networks);
- advanced data analytics (artificial intelligence, machine learning);
- computational intelligence for integrating data-based solutions, modelling and domain expertise;
- local solutions (microgrids, off-grid solutions for communication links, etc.);
- sector coupling (CHP and integration of electricity and heating systems);
- solar energy (thermal and electricity); and
- building automation.

Finland provides an excellent testbed for new and innovative smart energy solutions. The country’s open and transparent energy markets and well-functioning co-operation models between companies and research institutes and universities make it the ideal location for new research. Discussion on regulation is open in Finland, with the regulator enthusiastic about testing new solutions and business models.

Finnish energy and climate strategy

The Finnish Government Programme released in 2019 sets an ambitious target for Finland to become carbon neutral by 2035. While there is a consensus that to reach the target series of parallel actions is necessary, the following activities have been considered as the most potent means for achieving this goal:

Advancing carbon dioxide solutions

There is a need for the rapid demonstration and large-scale deployment of atmospheric carbon dioxide solutions. We are excited by the potential for CO_2 removal from the atmosphere by combining biomass as a feedstock technology with carbon capture utilization and storage. The technology has applications in CHP plants, production of synthetic biofuels and refining forestry processes. The necessary measures include an industrial demonstration of the entire CCUS value chain, coupled with the ongoing development of pan-Nordic storage infrastructure. They also support the development of legislation to remove carbon dioxide from the atmosphere (the Emissions Trading Directive) and the market for emissions compensation.

Increasing system flexibility

The energy system needs to become more flexible at all levels of the system to cope with the sharp fluctuations of renewable production and its dependence on the weather. An ability to adapt is essential for establishing and maintaining a renewable energy system. Flexibility within the system is also essential for reliability and system cost. The key tools establishing flexibility are the widespread adoption of demand response, the promotion of energy storage and better sector coupling. All means should be developed at this stage.

Involving customers

The opportunities for individual customers to influence their energy choices and to contribute to the fight against climate change should be developed. We should develop opportunities for customers to participate in different energy markets through small-scale production, energy storage or controlled appliances. Market restrictions and entry thresholds that inhibit entry should be lowered, and general knowledge and acceptance towards demand response increased, for example.

Developing green mobility

Possible options for reducing transport-related greenhouse gas emissions include increasing the energy efficiency of transport and increasing urban public transport, the rapid renewal of vehicle fleets, vehicle electrification and the introduction of biofuels. For Finland, second-generation biofuels would be a cost-effective way of moving towards zero-emission transport, given the resource base and technology exports. Demonstrating the production of low-carbon transport fuels at an industrial scale will pave the way for low-carbon transport.

Improving the energy-mobility interface

The transition to electric transport poses specific challenges to the energy system that need to be addressed. At a national level, the impact may not be critical, but at the local level, adoption of electric vehicles at-scale could pose problems for the existing energy infrastructure. Challenges are likely to arise in electrical installations in buildings and at the lowest levels of the electricity distribution network. Implementing smart charging will provide a direct lifeline for large-scale traffic electrification. More broadly, the consideration and integration of electrical charging points and supporting infrastructure within the design and operation of energy and transport systems must be improved. As an example, new and improved ways of integrating bicycles into energy system optimization should be developed.

Cleaning industrial processes

It's critical that industrial emissions are reduced, but this is still difficult and expensive. The shift to a low-carbon power system creates opportunities for the reduction of industrial emissions through direct or indirect electrification. There is also growing interest in hydrogen as a source of power. The challenge involves managing the limited capacity of zero-emission, primary production for large-scale industrial electrification and the transfer of sustainable biomass to other sectors. Scientists have identified the full utilization of forest-based coal in products and carbon sinks, the electrification of high-temperature industrial heat, and emission reductions in cement and concrete manufacturing as significant opportunities for cleaning industrial processes.

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