ENERGI21

Strategy 2022

National strategy for research, development and commercialisation of new climate-friendly energy technology.

energi21

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The Energi21 Strategy 2022

Preface

The Energi21 strategic body was established by the Ministry of Petroleum and Energy in 2008 with the objective of promoting value creation and ensuring safe, cost-effective and sustainable utilisation of energy resources. This strategy is the fifth in the series, and is designed to ensure more coordinated and enhanced engagement in the business sector with respect to research, development, demonstration and commercialisation of climate-friendly energy technology for stationary purposes and transport.

Since the first Energi21 strategy was launched, the energy sector has undergone major structural changes in Norway and the rest of the world. The developments in new and renewable energy technologies would scarcely have been believed in the early 2000s. According to the International Energy Agency (IEA), the total global investment in renewable power generation in the past three years is around three times higher than fossil power generation and is driven by active policies that aim to reduce local emissions, and to limit greenhouse gas (GHG) emissions in accordance with climate agreements. As a result, technology costs have dropped rapidly, which further accelerates the pace of transition.

At the same time, the Intergovernmental Panel on Climate Change's (IPCC) most recent report reminds us that the green transition is not progressing fast enough to reach the 1.5°C goal and the pace must be accelerated even further. We also see that global supply chains, including those in the energy segment, are vulnerable, and that there is a connection between geopolitical unrest and the ongoing energy crisis in Europe. Overall, this leads to an increased need for regional supply chains and a desire to cut Russia gas dependency.

Analyses from Statnett show that power consumption may reach 220 TWh in 2050. This is an increase of around 50 per cent compared with current consumption. Offshore wind power, a technology Norway has yet to incorporate in its general power supply system, is expected to cover this increase. Green hydrogen is expected to play a major role in sectors that cannot be electrified, e.g. in industry and transport. As such, closer links are created between the various energy segments, increasing the complexity of the energy sector. Efficient framework conditions must be developed that can stimulate investments that are both commercially profitable for investors and cost-effective for society. There is also a great need for fact-based input on how to implement extensive measures in an environmentally responsible manner.

These examples show that the Norwegian energy sector has a pressing need for restructuring and that efforts must also be intensified in research, development, demonstration and commercialisation of climate-friendly energy technology. In the rest of Europe, the restructuring need is even more pressing, and the EU has set a high level of ambition for climate efforts, as well as funding for research and commercialisation.

Norway should utilise this restructuring need to create new green industries, both with a view to producing services and technology to cover the country's own needs, but, even more importantly, to position itself as a competitive supplier of energy solutions for Europe and the rest of the world.

This fifth Energi21 strategy aims to prioritise key areas that the board believes will bring particular benefits to Norway from even stronger and more targeted research efforts by private and public stakeholders. In the preparation of the strategy, the board emphasised extensive dialogue with industry stakeholders, research institutions and academia through several dialogue meetings and consultation rounds with many participants involved. Through this dialogue, we have obtained thorough descriptions of what kinds of development the stakeholders consider most beneficial. The Energi21 board believes that research and innovation initiatives first succeed when new knowledge and new solutions are applied and used. This will be an important topic for the Energi21 board in its follow-up of the strategy's recommendations.

The board is confident that this strategy enjoys the support of the industry and represents a broad view of its proposals for the further development of Norway's energy resources in the best interests of society. This includes achieving an internationally competitive energy sector.

Bjørn N Holsen
Chair of the Energi21 board

Summary

The Energi21 strategy document is Norway's national strategy for research, development and commercialisation of new climate-friendly energy technology. Its goal is to increase value creation and achieve efficient utilisation of resources in the energy sector by increasing research and innovation. The purpose of Energi21 is to ensure more coordinated and enhanced engagement in the business sector with respect to research, development, demonstration and commercialisation of climate-friendly energy technology for stationary purposes and transport. Energi21 was established by the Ministry of Petroleum and Energy in 2008.

This strategy is the fifth in the series and a revision of the previous strategy drawn up in 2018. The energy sector has undergone radical changes over the past four years. The market and technology are developing at a rapid speed and there is a greater focus on energy transition and industrialisation. As a consequence, energy carriers and sectors of society now need to work closer together.

The business sector is on board and sees value creation opportunities in the energy system of the future

The strategy is based on an extensive body of knowledge. Almost 700 actors from the business sector, research and innovation communities and academia have provided input and actively contributed to developing the strategy. The revision has included an assessment of knowledge and technology needs, the policy instruments needed to realise the industry's ambition in the energy markets of the future, and aims to help develop Norway's energy expertise and technology. The actors in the energy sector have made an incredible and highly valuable contribution, ensuring that the industry is behind common goals and that the research and innovation agenda is relevant to them.

The Energi21 strategy 2022

As an energy nation and with the national and international opportunities the energy system of the future represents, Energi21 has adopted the following vision:

Energi21's vision
Further develop Europe's best energy system.

Energi21 believes that Norway can develop an energy system that can contribute both at the national and international level. These contributions may be in the form of renewable and climate-friendly energy, industrialisation and business development, and last, but not least, an energy system with a reliable supply and the right quality.

According to Energi21, there are three main challenges to achieving the goals set out by the Ministry of Petroleum and Energy, and meeting Energi21's vision. The key challenges are:

Key challenges

- Decarbonising transport and industry.
- A reliable, competitive and environmentally friendly energy supply.
- Developing new green industries and marine energy technologies.

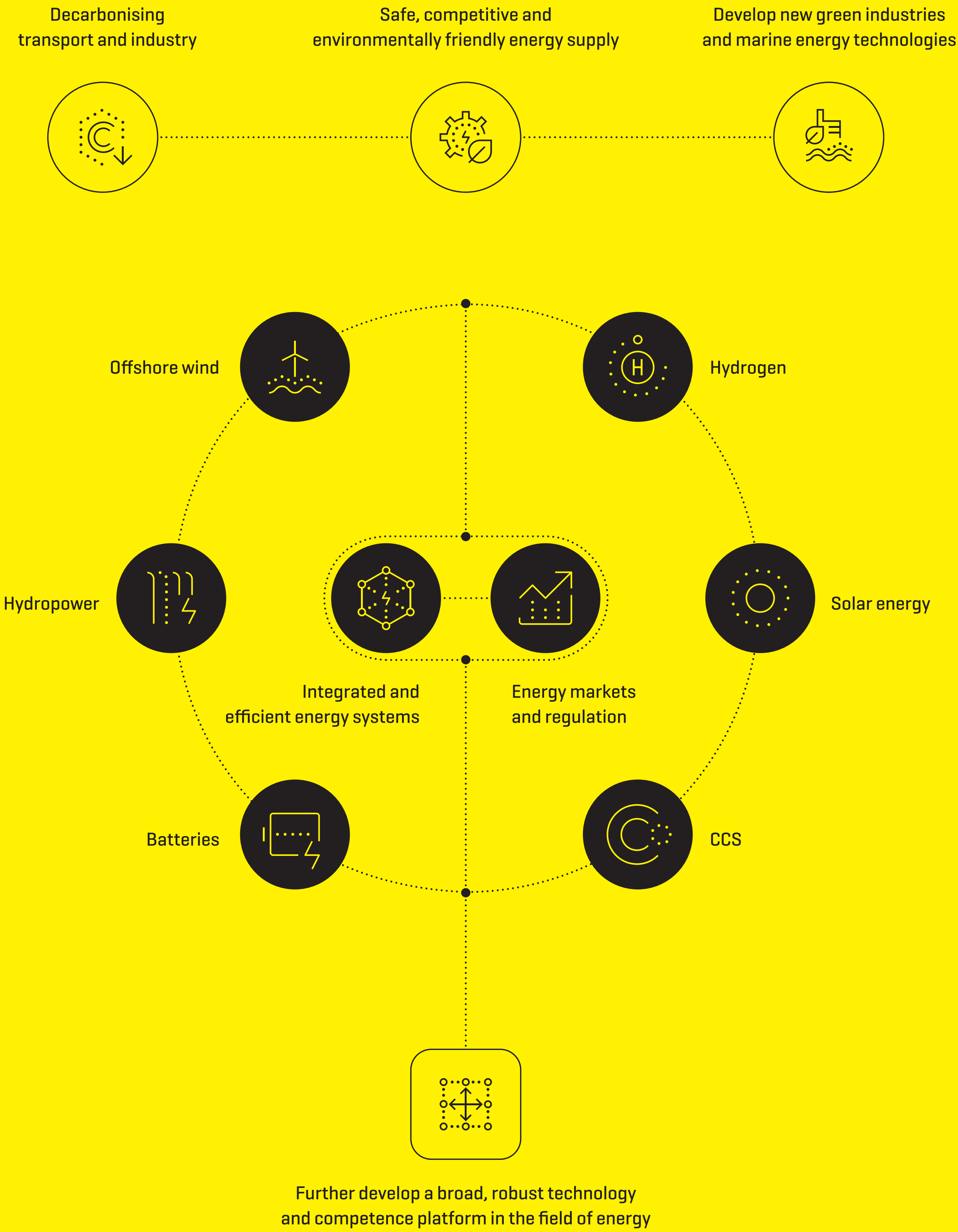

Figure 1 Energi21 strategy 2022

Energi21 places great importance on marine energy technologies based on the value creation potential inherent in the ocean and Norway's comparative advantages to win positions in this market.

The revised Energi21 strategy draws attention to focus areas that provide solutions to these three key challenges, given that research and innovation efforts are intensified.

Based on a comprehensive strategic analysis of all the technology and disciplines in the energy sector, Energi21 is prioritising *eight focus areas* in the revised strategy, *two of which are given special attention*. Figure 1 illustrates the Energi21 strategy and its focus areas, and there are links and transfer value between all of the strategy's focus areas.

The focus areas *"Integrated and efficient energy systems"* and *"Energy markets and regulation"* are given special attention. There is a strong link between these focus areas. Key research and innovation topics in *"Energy markets and regulation"* have a huge bearing on the implementation and adoption of technologies and solutions developed in the *"Integrated and efficient energy systems"* focus area. These fields are complex and cover numerous disciplines, technologies and solutions. *Integrated and efficient energy systems* are the linchpin of society's green transition.

This focus area is hugely important to supply security in future, the integration of climate-friendly solutions and societal value creation, as well as for securing a sustainable energy supply. The focus area *"Energy markets and regulation"* covers issues relating to social sciences, market design, legal issues and regulation. Energi21 also prioritises the following six focus areas:

- *Hydropower*
- *Offshore wind power*
- *Solar power*
- *Hydrogen*
- *Batteries*
- *Carbon capture and storage*

These are more technology-oriented focus areas that have a great bearing on supply security and flexibility in the energy system. They also play an important role in cutting greenhouse gases in sectors such as transport and industry, developing new industry and the green transition of society. The strategy's focus areas are described in brief in the next pages:

INTEGRATED AND EFFICIENT ENERGY SYSTEMS

An efficient and integrated energy system is the linchpin of the climate transition and a precondition for a reliable, competitive and environmentally friendly energy supply. Efficient and integrated energy systems are vital to achieving energy and climate policy goals to cut greenhouse gas emissions, boost industrialisation and achieve cost-effective utilisation of our energy resources. The power grid, systems operation and supply security are key challenges that have to be overcome to succeed with the green transition. Research and innovation activities will enable us to develop and apply solutions for a sustainable energy system for the future.

Selected key research and innovation topics

- Efficient and flexible interaction between different energy infrastructures, climate-friendly energy carriers and end users.
- Next-generation components and systems, for interaction between and efficient utilisation of existing and new energy carriers.
- Multidisciplinary analysis models, simulation tools and innovative management systems.
- Digitalisation and cyber security, efficient planning, monitoring, management and coordination across actors.
- Nature and the environment – comprehensive assessments of land utilisation in connection with the development of climate-friendly energy, handling of land-use conflicts and mitigation measures.

ENERGY MARKETS AND REGULATION

This focus area entails developing a framework for action and decisions relating to the timely transition of the energy system. The energy sector must be restructured to achieve climate and environment goals, at the same time that supply security must be safeguarded, costs kept down and unacceptable distributional effects avoided.

Onshore and offshore experience shows that technology adoption can run aground due to a lack of support from stakeholders. Knowledge of policy instruments is therefore important to ensure stakeholder involvement and efficient technology adoption in different markets and in society in general.

Selected key research and innovation topics

- Energy markets, regulation, energy security and energy consumption.
- Business and market models, private and public sector roles.
- Norway as a part of the European energy market – legal and economic topics and simultaneity in decision-making processes.
- Societal development and energy transition – resilience, efficiency, distributional effects and environmental friendliness.

HYDROPOWER

Hydropower is the backbone of the Norwegian energy supply and a competitive advantage in the transition to a climate-friendly society. The utilisation of natural water resources for power production is a key precondition for ensuring access to energy and achieving the energy transition in Norway, the Nordic countries and Europe. Hydropower production is vital for ensuring sufficient supply security in the power system.

An RD&I initiative in hydropower contributes to:

- ...a significant proportion of the renewable energy necessary for the electrification of transport and industry.
- ...maintaining a secure power supply through unique regulation capabilities and storage capacity, which will become more important in step with a higher proportion of variable renewable power in the Norwegian, Nordic and European power system.
- ...developing new green industries because hydropower offers a competitive and reliable renewable power supply.

Selected key research and innovation topics:

- The flexible role of hydropower in the national and European power system of the future.
- New technology and upgrading the hydropower system due to changed production patterns.
- Digital technology in hydropower production – combining physical and conceptual models with machine learning and taking advantage of new data sources to provide a better decision-making basis.
- Nature and the environment – environmental design and environmentally adapted hydropeaking, restoring nature in connection with upgrades and developing new plants.
- Climate change and effects on the hydropower system.

OFFSHORE WIND POWER

Norway has natural, world-class offshore wind power resources, and utilising this power is important for securing sufficient renewable power in the energy transition. Major concrete development plans are currently underway for offshore wind power both in Norway and around the world. At the same time, many actors in Norway have ambitions in this area, and there is considerable potential for developing a supplier industry for offshore wind power.

Expertise from the oil and gas industry and the maritime industry shows that Norway is well positioned to take market shares in the offshore wind power market of the future, for both floating and fixed wind turbines. The fact that the offshore wind power industry is moving towards deeper waters, further from shore and investing in bigger and bigger turbines presents new opportunities and research and innovation needs.

An RD&I initiative in offshore wind power contributes to:

- ...the renewable power needed for electrification, for new green industry and for the production of green hydrogen for transport and industry.
- ...considerable potential for exploiting offshore wind resources for power production. Expectations of rapidly falling costs mean that offshore wind power will contribute to a competitive power supply and export of power to Europe.
- ...the development of value chains for marine energy technologies. The development of a Norwegian offshore wind power industry can contribute to new jobs and further value creation for Norwegian suppliers in the maritime and offshore sectors.

Research and innovation needs are related, among other things, to industrialisation and commercialisation of the value chain, integration of offshore wind power plants in the power system and offshore area management. Reducing the costs of offshore wind power is an important goal for research and innovation initiatives.

Selected key research and innovation topics:

- *Offshore wind power plants* – efficient production, installation, operation and maintenance of floating and fixed turbines, methods and technology for cutting costs.
- *Offshore infrastructure and integrated systems* – flexible grids with upscaling opportunities and solutions for system integration and interaction with storage, production and transmission technologies.

- *Market design and legal issues* – design of energy auctions and tenders, and interaction between production onshore and offshore.
- *Environment and society* – methods for investigating and assessing environmental impacts, area and resource management and offshore planning and overall effects.
- *Digitalisation and cyber security* – weather monitoring and prediction models, interaction with the energy system, system security and big data management.

SOLAR POWER

The international solar power market is undergoing strong growth, and Norwegian industry actors in the processing industry have export ambitions based on the development of low-emission materials, by taking advantage of access to competitive renewable power and circular production processes. There is also growth in the domestic market, and research and innovation needs are linked, among other things, to the integration of solar power in the energy system. Norwegian actors are also involved in developing new solutions for floating and building-integrated solar power.

An RD&I initiative in solar power contributes to:

- ...decarbonisation in the form of distributed solutions for power and heat, particularly in areas with a poorly developed grid network.
- ...developing competitive renewable power and heat production, and giving consumers ownership of power and heat production.
- ...further value creation in the Norwegian processing industry targeting a growing solar market that emphasises low-emission materials and developing new concepts such as floating solar power and solar power integrated in infrastructure and buildings.

Selected key research and innovation topics:

- *Solar power in the system and digitalisation* – local solar power and heat solutions, flexibility and storage solutions for solar power and smart control of solar plants.
- *New concepts and technologies* – solar power plants, building-integrated solar power concepts and hybrid power plants.
- *Society and the environment* – framework conditions for local energy solutions, waste management and circular and industrial production.

BATTERIES

Developing and applying electric battery technology is crucial to the decarbonisation of transport, while it also presents an opportunity for developing new green industry. Norway already has an established processing industry based on key battery materials, and is a world-leading manufacturer of battery packs for the maritime sector. Several actors have also implemented plans for large-scale battery cell production. Developing a national battery value chain will require considerable investment in education and competence-building, access to international markets and maintaining Norwegian comparative advantages.

An RD&I initiative in batteries contributes to:

- ... decarbonisation of the transport sector.
- ... balancing the power grid and reducing peak demand, thereby improving delivery and supply security in a power system marked by growing variable renewable power production.
- ... developing new green industry that will generate thousands of jobs in the form of a Norwegian battery value chain based on established processing industry and newly established cell production that takes advantage of competitive renewable power and local access to important raw materials.

Selected key research and innovation topics:

- *Materials and raw materials* – materials and concepts to further develop li-ion batteries to improve their performance and reliability and competitive battery chemistry. Efficient battery cell production – energy-efficient, environmentally friendly, automated production and upscale design.
- *Battery utilisation* – integration in the power grid and adaption of battery properties for different end user applications.
- *Reliability, reuse and recycling* – sorting methods, battery design and materials selection for recycling. Nature and environment impacts in and of battery value chains.
- *Digitalisation* – digital traceability, robotisation and automation throughout the value chain.

HYDROGEN

Hydrogen plays a vital role in decarbonising the world's energy consumption, and the biggest need is found in the transport and industry segments. Considerable international investments are being made in hydrogen. Norway's biggest export market for natural gas, the EU, assigns hydrogen a key role in achieving the zero-emission goal for 2050. Norwegian industry and energy actors have implemented several large-scale and concrete development plans for producing and using hydrogen and hydrogen carriers such as ammonia.

Key research and innovation needs relate to the development of cost-effective, full-scale value chains and secure handling of hydrogen and ammonia.

An RD&I initiative in hydrogen contributes to:

- ... highlighting key technology for decarbonising industry and transport segments that are incompatible with electrification.
- ...developing a reliable energy carrier with transport and storage properties that provides the necessary flexibility, and thus supply security in an emission-free energy system.
- ...taking advantage of the great potential for developing new green industries in Norway throughout the value chain, with significant international export potential.

Selected key research and innovation topics:

- Secure use of hydrogen and hydrogen carriers.
- *Further developing cost and energy-efficient hydrogen value chains* – developing technologies and components throughout the value chain from production processes to end user applications. Standardisation of the value chain.
- *Integration of hydrogen value chains in the existing energy system* – interaction between national and international demand and available production resources.
- *Enabling framework conditions for establishing markets* – market design, legislation, regulations and incentive schemes.

CARBON CAPTURE AND STORAGE

The world is dependent on large-scale carbon capture and storage to reach the 1.5°C goal, especially sectors without good decarbonation options, and to achieve negative emissions. This focus area covers the capture, transport and permanent storage of carbon. Norway has a unique opportunity to take on a role in this area due to its leading technology and competence base, and its natural advantages.

This technology and competence base, which gives us an advantage over many other countries, has been developed over the course of many years of industrial experience and research in the field linked to the oil and gas, and maritime industries. Our natural advantages for participating in an international carbon capture and storage value chain are the storage potential in the North Sea and proximity to the demand for storage in Europe. Norway's strong global position in carbon capture and storage will be further consolidated when the Longship project becomes a reality in 2024.

Norway also has several ambitious business actors investing in the capture of industrial emissions both nationally and internationally. The main focus going forward will be on upscaling the technology into a commercial value chain by reducing costs and risk, and realising gains from the Longship project.

An RD&I initiative in carbon capture and storage contributes to:

- ...decarbonising industry and transport by capturing and storing carbon emissions from industrial processes and producing low-emission hydrogen.
- ...a reliable and competitive energy supply by increasing access to decarbonised energy resources based on Norwegian gas.
- ...establishing new green industry in Norway with international potential. A Norwegian carbon value chain also provides opportunities for exporting capture, storage and transport technology and increasing value creation for Norwegian suppliers in, among other things, the processing industry and the maritime and offshore sectors.

Selected key research and innovation topics:

- *New technologies and upscaling into a commercial value chain* – upscaling the value chain for storage on a gigatonne scale, efficient capture solutions for existing and new value chains and developing climate-positive solutions such as DACCS and BECCS.
- *Business and market models and frameworks for carbon capture and storage* – developing the market in a Norwegian and European perspective and efficient cooperation constellations between actors. Society and the environment – life-cycle emissions for carbon capture and storage and comparing concepts and application areas, and increasing society's acceptance.

Realising the strategy will require rapid, flexible policy instruments and green risk capital

Energi21 believes that research and innovation initiatives first succeed when new competence and new solutions are applied and used. It is particularly important to develop policy instruments that enable new technology to be commercialised and implemented more quickly, to keep up with the changing pace in the restructuring of the energy system, which is now needed to achieve the climate goals.

The upscaling and industrialisation of climate technology is pivotal to realising Norway's ambitions in the climate technology fields set out in the Energi21 strategy. It is important to establish knowledge of the challenges and opportunities relating to the supply of capital, financing and investor competence. Norway has unique preconditions for building a world-leading green business sector, but a great deal more risk capital is required to establish and lead the development of green value chains. One element of uncertainty if the government is to realise its goal of developing green industry is that the need for green risk capital may exceed its availability. State capital instruments may be a suitable means of raising risk capital and would reduce risk for projects in the Energi21 strategy's focus areas.

Energy research budgets must be increased

The rate of restructuring in energy systems is now much higher than previously. Energi21 therefore believes budgets must be increased to strengthen organisations' and enterprises' work on developing new technologies and solutions in order to bolster competitiveness and the green transition. It is also important to secure long-term knowledge development and further develop national research and education communities.

The business sector should take responsibility for technology leadership

Norway's comparative advantages in energy must be continuously developed in step with resource needs and developments in technology and markets. This will require the business sector, the authorities, and research and education communities to pull together.

The business sector must become involved in developing knowledge and technology by taking a risk and investing time and capital in research and innovation activities. The authorities should take steps to ensure efficient oordination of the ministries' different policy instruments, to enable the business sector to allocate resources to research and innovation projects.

Educational capacity and programmes must reflect the energy system of the future

The extensive restructuring and high level of investment require an increase in educational capacity to meet the needs in the years to come. This applies to every link in the chain, from fitters to PhD candidates in almost all disciplines. Multidisciplinarity is key to developing good solutions. For many of the challenges we need to solve, developing competitive technology is not enough, we also have to develop good framework conditions, markets and business models to be able to use low-emission technology on a grand scale.

Further develop a broad, robust technology and competence platform in the field of energy

Securing technology and competence is important across the thematic breadth of climate-friendly energy technologies. Continuous developments in both specific and generic technologies and disciplines will generate new opportunities and new solutions. The field of energy has a broad reach and covers many sectors. There is great transfer value between the disciplines and, based on the development of the energy system, interdisciplinary competence development and new collaboration constellations will become increasingly important. In addition to the strategy's eight focus areas, Energi21 believes it is important that efforts are also made to further develop other technology and knowledge areas. The other technology and knowledge areas and the strategy's focus areas benefit mutually from the results of research and innovation activities and together comprise Energi21's broad, robust technology and competence platform. The other technology and knowledge areas that Energi21 believes must be further developed are:

- Energy-efficient, smart buildings and cities.
- Energy-efficient industry.
- Climate-friendly energy technologies for maritime transport.
- Climate-friendly energy technologies for onshore transport.
- Climate-friendly energy technologies for aviation.
- Bioenergy and biofuels.
- Onshore wind power.
- Geothermal energy.
- Nuclear power of the future.
- Fusion energy.
- Wave and tidal energy.
- Airborne wind.

Some of the other technology and knowledge areas are immature and/or do not contribute as much to our national energy mix. Following the developments in these areas will nevertheless be worthwhile, and may prove useful to research and innovation efforts if technology and market developments show that they are significant to our energy system in purely technical terms and to national value creation (industrialisation and business development).

International research and innovation collaboration increases competitiveness

A targeted and prioritised focus on internationalisation in research, and technology and competence development is vital to bolstering and further developing the competitiveness of the energy industry. A presence in the international research and innovation arena increases the quality of knowledge development and internationally recognised R&D communities, and provides more opportunities for the business sector to win positions in the international energy market.

Other important measures for realising the Energi21 strategy

- Policy instruments for the green transition should be in line with the Energi21 strategy.
- Further develop joint initiatives and sector collaboration at authority level.
- Collaboration between NORWEP and Energi21.
- Collaboration between the ministries' 21 processes.

Compensation facility. *Photo: Erik Thallaug, Statnett*

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Energi21 – National strategy for research and innovation


NEXANS AURORA
Nexans. Electrify the Future.

The Energi21 strategy document is Norway's national strategy for research, development and commercialisation of new climate-friendly energy technology. The objective to Energy21 is to increase value creation and achieve efficient utilisation of resources in the energy sector by increasing investment in research and innovation in this area.

1.1

About the Energi21 strategy

The Energi21 strategy is prepared by representatives of the industrial sector, research institutions, academia and the authorities, on assignment from the Minister of Petroleum and Energy. It was first developed in 2008 and is revised regularly. The current strategy is the fifth in the series. The Energi21 strategy provides recommendations to the authorities and the business sector for Norwegian investments in research and technology development in renewable energy, energy transfer, energy conversion, energy storage, energy efficiency improvement and carbon capture and storage (CCS). It also addresses technologies and solutions for energy deliveries and energy-related propulsion solutions for transport purposes. The Energi21 mandate includes both onshore and offshore energy systems. The board also gives advice on the need for knowledge development in the social sciences, economics, market design, nature and the environment, and provides recommendations on funding and policy instruments addressing the whole innovation chain from research and development to testing, demonstration and commercialisation.

In addition to the energy sector, the Energi21 mandate includes technology and thematic areas of relevance to several other sectors. The strategic processes are multidisciplinary and involve stakeholders from many different technology and market areas. As such, the Energi21 strategy emphasises the utilisation of synergies and flow of expertise between sectors and industries.

1.2

Broad stakeholder involvement and implementation of strategic recommendations

The present strategy's knowledge base builds on an extensive process with broad stakeholder involvement. Almost 700 stakeholders provided input on necessary research and innovation efforts to meet the knowledge and technology needs of the future. The current strategy reflects the industry's ambitions in the energy markets of the future and necessary research and innovation efforts to meet knowledge and technology needs. The stakeholders who contributed input to the strategy development process are listed in Appendix 7.8.

1.3

The purpose of the Energi21 strategy

The strategy's objective is to provide advice on required research and development efforts, and to give an indication of how to prioritise between the various key areas. The strategy is intended to contribute to more coordinated and enhanced engagement in the energy sector with respect to research, development, demonstration and commercialisation of new climate-friendly energy technology for stationary purposes and transport. It also targets knowledge-building that can make Norway an important international supplier of environmentally friendly energy solutions, system services, knowledge and technology.

The Energi21 body wishes to establish a comprehensive approach to efforts targeting new climate-friendly technologies by linking authorities, the business sector, research communities and academia closer together. At the same time, the goal is to raise more support for energy research in general and contribute to strengthening R&D in the business sector. A further objective is to increase business development driven by research and innovation by commercialising the results from RD&I projects.

The Ministry of Petroleum and Energy's allocations to the Research Council of Norway, Gassnova and relevant funding and policy instruments under Enova are key elements in the follow-up of the strategy.

Reference is made to Figure 1, which illustrates Energi21's position in the Ministry of Petroleum and Energy's research and innovation system. Because of the energy system's rate of development and increased sector coupling, funding and policy instruments targeting the energy sector will be needed from several ministries. One example is developing greater knowledge of security and legal issues relating to the development of the energy system in the North Sea. The Ministry of Justice and Public Security will play an important role in this respect.

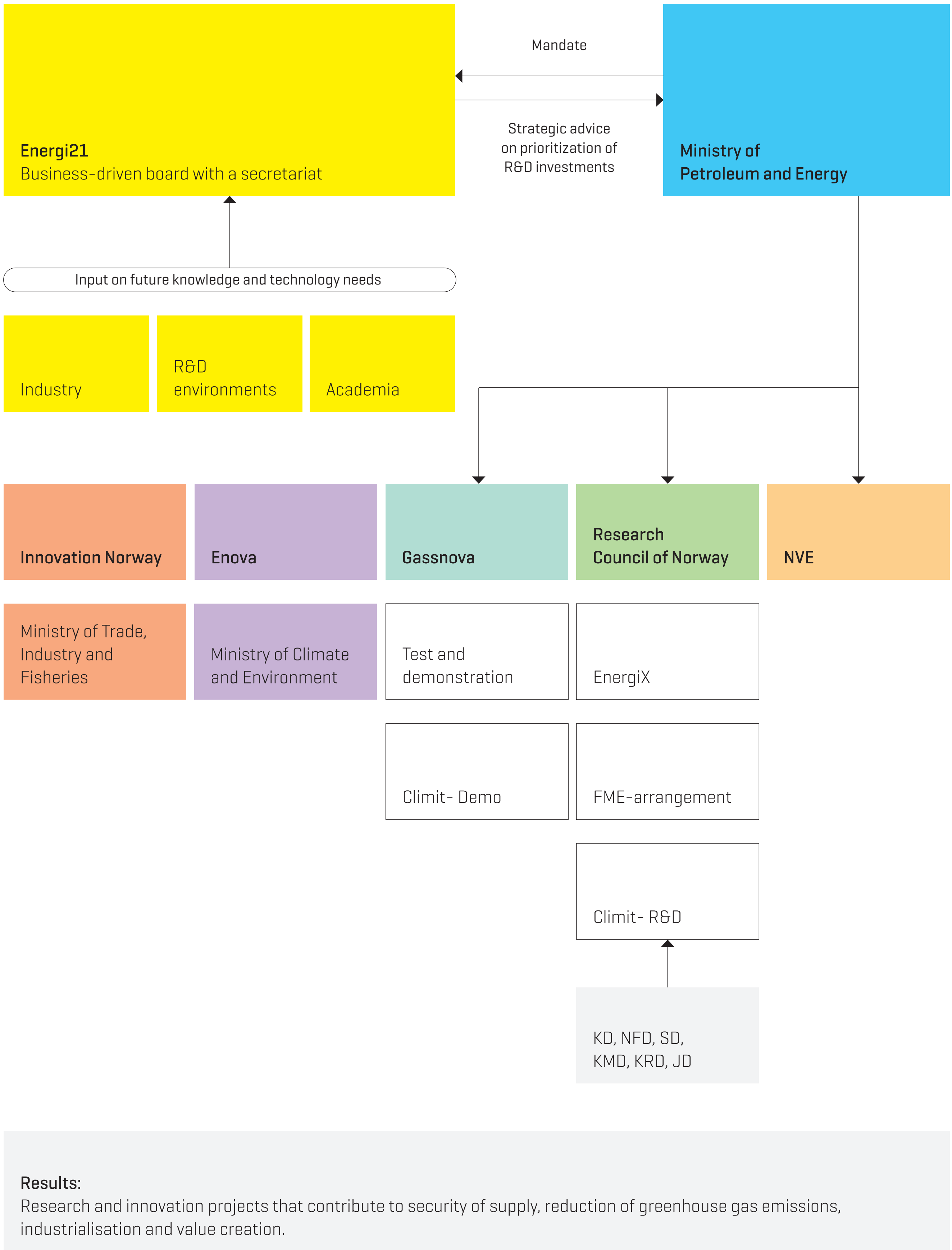


Figure 2 The organisation of energy research under the Ministry of Petroleum and Energy.[1]

1.4

Access to capital, funding and investor competence

The scaling and industrialisation of climate technology is pivotal to realising Energi21's strategic objectives. Access to capital, funding and investor competence will be important factors to that end. The Energi21 board therefore emphasises cooperation and dialogue with stakeholders in the financing and commercialisation of climate-friendly energy technologies.

1.5

The assignment from the Ministry of petroleum and energy

The Energi21 strategy is to reflect Norwegian energy policy and promote the achievement of the primary objective and sub-goals set out by the authorities[2] for energy research and innovation initiatives in the energy sector. Below is a description of these objectives.

One precondition for achieving these goals is a *whole system perspective* in the planning, design, operation and maintenance of the energy system. Access to capital, funding and investor competence are also essential factors for industrialisation and increased value creation.

1.6

Organisation of the Energi21 body's work

The Energi21 board is appointed by the Ministry and provides advice on how the Ministry's research allocations should be spent. The board is predominantly composed of representatives of business and industry, but research institutions, the authorities and Norway's funding and policy agencies are also represented. See Appendix 7.2 for more information about Energi21's board members. A permanent secretariat has been established to manage and help operationalise the strategy's recommendations. The secretariat also functions as a link between the authorities, the board, the business sector, research institutes and education communities.

1.7

Cooperation and interfaces with other 21 strategies

Several ministries have established advisory bodies and 21 processes with links to Energi21's mandate. The Energi21 body emphasises strategic cooperation with the other 21 processes to ensure comprehensive research and innovation efforts in the energy area. It is important to clarify the division of labour between the 21 processes in the most cross-cutting technology and thematic areas. One example is battery research, which is included in both Energi21 and Prosess21's mandates.

Primary objective
Increase value creation and ensure safe, cost-effective and sustainable utilisation of energy resources.

Sub-goals
- Ensure long-term knowledge and technology development.
- Promote competitiveness and increased value creation in the energy industry in Norway.
- Find solutions that facilitate a low-emission society.

[1] *The Energi21 strategy is also relevant to other ministries and funding agencies such as the Ministry of Trade, Industry and Fisheries (NFD) and Innovation Norway.*
[2] *Objectives set out by the Ministry of Petroleum and Energy in Energi21's mandate.*

Photo: Gassnova

2

The green transition entails major changes and opportunities for Norway

The transition to a low-emission society is well under way, driven by more stringent climate targets. The EU has launched the *Fit for 55* package, which addresses the extensive action required in many sectors to drastically reduce GHG emissions by 55 per cent towards 2030. We have adopted similar requirements in Norway. Nature conservation and protection of biodiversity are just as important as cutting GHG emissions.

The energy system is now subject to absolute and material requirements in order to achieve net zero emissions by 2050 in Norway and Europe. This requires extensive decarbonisation of the Norwegian economy through increased electrification from renewable energy, CCS and the use of hydrogen in several sectors such as transport, agriculture and heavy industry. It is also an absolute requirement that the energy system must be robust with a high level of delivery and security of supply. The energy system should also be economically efficient and be built and run as reasonably as possible, and prevent energy poverty.

The energy and energy price crisis we are currently experiencing as a result of disruption in the global energy markets and the war in Ukraine show the importance of security of supply. This is reflected in the EU's rapidly changing energy policy prioritisations, where energy policy has become a crucial part of European security polity.

The nation states are responsible for security of supply in Europe. The ongoing energy crisis will put self-sufficiency in relation to energy and security of supply high on the agenda for many years to come. The European Commission's plan "REPowerEU: Joint European Action for more affordable, secure and sustainable energy" from March 2022 addresses how Europe can establish framework conditions for maintaining a reliable supply of energy.

Self-sufficiency is necessary to reduce dependency on Russian natural gas. The EU's REPowerEU plan therefore points out the need to accelerate the development and integration of renewable energy resources and diversify gas deliveries. The plan especially points to increased investment in biogas, hydrogen, energy efficiency improvement, solar power and onshore and offshore wind power. Norway can play an important role in restructuring the energy system in Europe in several of these areas. This raises the question of what Norway can contribute and how we can best position ourselves in relation to the rest of Europe.

Although the situation is still very uncertain, there is much to indicate that restructuring the energy system to realise a low-emission society is being further propelled by the desire in Europe to become more energy self-sufficient.

2.1

Developments towards a low-emission society have accelerated

Developments towards a low-emission society have accelerated in the past few years. In Norway, The number of enquiries about capacity in the power grid for transport and industry has experienced strong growth. This is in addition to the continued drop in the costs of climate-friendly energy technology such as solar power, wind power and batteries. The scope of the changes is also bigger; for example, the UK and the EU aim to develop 100 GW offshore wind power by 2030, which corresponds to more than 400 TWh or 2.5 times the annual Norwegian power consumption. A further 300 GW are planned for development towards 2050.

Europe is on its way to an emission-free energy system by 2050, which will increasingly be characterised by:

- *A high proportion of renewable power generation that cannot be regulated*, primarily wind power and solar power.
- *Large-scale development of infrastructure*. Extensive development of infrastructure for electricity, hydrogen, CCS and bioenergy will be required.
- Energy storage and other flexibility solutions.
- The short-term flexibility needs will to an increasing extent be covered by technology that triggers flexibility with the end customers through the use of digital automatised solutions for shifting loads or by making flexibility more available through battery solutions, more efficient interaction with district heating systems and, in the long-term, maybe also hydrogen.
- *Flexibility needs between seasons* to ensure sufficient energy throughout the year as thermal plants are phased out. The need for technology and solutions that can deliver energy for longer periods when the generation of unregulated renewable energy is low, such as bioenergy, hydropower and hydrogen. Efficient interaction with a renewable district heating system may also play a part here.
- *Energy efficiency improvement* to reduce energy and power demand.
- *Sector coupling*. Large-scale use of emission-free energy carriers (primarily electricity and renewable district heating, but also hydrogen and bioenergy) in several sectors including transport and industry and for heating where natural gas is currently used. This means that several sectors will be linked into one common energy system, as opposed to the separate systems currently in play.

- *More active end users* who use distributed power and heat generation and energy storage, and optimise their own use of energy and power consumption.
- *Digitalisation* will be an important precondition for maintaining delivery and security of supply and automating the energy system. Digitalisation entails increased use of artificial intelligence, big data management, autonomous systems and the Internet of Things (IoT).

This development means that the energy system will become much more complex. This complexity will require a high degree of automation and digitalisation to maintain security of supply, ensure efficient operation and send the right price signals to the market.

Figure 3 illustrates the energy sector's role in the transition towards a climate-friendly society. The energy sector is the hub of the green transition and must deliver both renewable energy resources and climate-friendly energy technologies and solutions for the sectors of society that must be decarbonised.

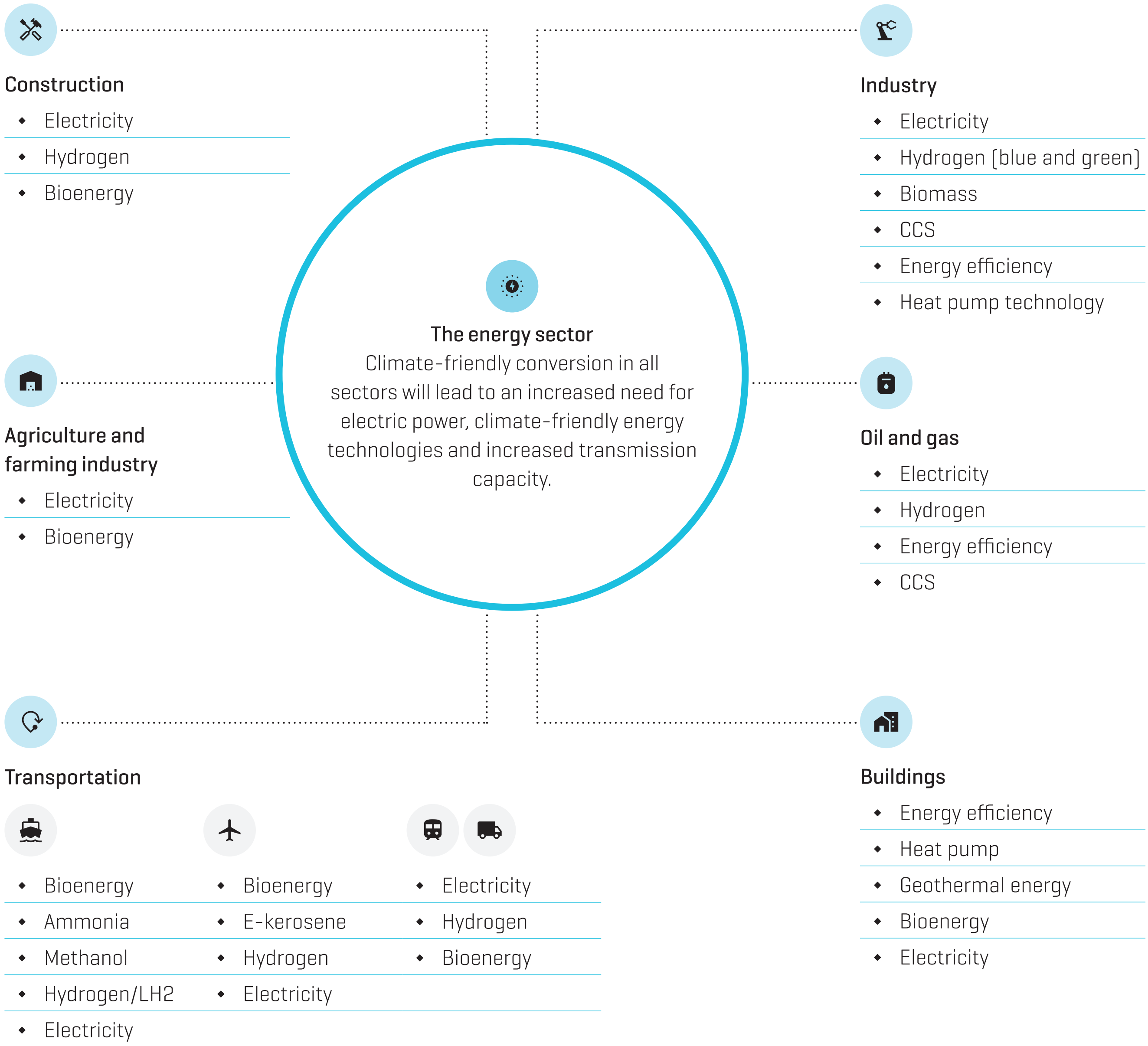


Figure 3 The energy sector is the hub of the green transition

2.2

The search for good solutions is well under way and market potential is great

The extensive changes ahead for the energy sector to realise a low-emission society will require substantial investments in the decades to come. Figure 3 shows an overview of several areas where increased activity is expected in connection with the restructuring of the energy system (Energi21, 2021).

The IEA's World Energy Outlook 2021 estimates that, in its Net Zero Emission scenario, investments in climate-friendly energy technologies must amount to USD 4,000 billion per year in the period 2026–2050 to achieve the zero-emissions goal. This is about four times the amount invested in 2016–2020.

The scope of investment is considerable in all parts of the value chain, so even though the estimates are uncertain, they represent a significant market potential for Norwegian trade and industry, including the supply industry. Several analyses[3] emphasise infrastructure, solar power, offshore wind, batteries and hydrogen as potential new export industries with a high value creation potential.

2.3

Restructuring of the energy system must protect biodiversity and the environment

Two important events since the previous Energi21 strategy in 2018 have been the launching of IPCC's (UN Climate Panel) Special Report on Climate Change and Land and the UN biodiversity panel IPBES's global analysis of environmental challenges. Both expert panels emphasise the importance of improving land-use management to handle both the climate and the nature crises. Land-use is central to both the emission and uptake of CO_2, and infrastructure and industrial development that require extensive areas of land may be unsustainable if this is not taken into account. IPBES has also stated that loss of nature is just as big a threat to humanity as climate change, because people depend on natural assets to survive. Robust ecosystems also contribute to reducing the impact of climate change. Encroachments on and degradation of natural areas is the biggest threat to biodiversity in Norway.

Restructuring the energy system is a complicated matter. Some forms of energy require the occupation of extensive land areas, which can contribute to loss of biodiversity and GHG emissions from the soil. Renewable energy with pertaining infrastructure should be developed in a manner that is considerate of biodiversity and that does not lead to emissions from natural carbon sinks. The panels' reports have increased our understanding of nature's role in climate change management, and other events have also raised awareness of the importance of nature in itself. The financial sector is no longer just talking about climate risk, but also about nature risk. The World Economic Forum (WEF) ranks the loss of biodiversity and ecological collapse as one of the five biggest threats to humanity in the next decades. In Europe, the EU's new taxonomy for sustainable activities now also requires companies to map and document how their activities affect biodiversity.

IPBES points to ecosystem restoration as an absolutely essential solution and has estimated that it is highly profitable from an economic standpoint. Investing in ecosystem restoration gives 10 times return on investment. This is why the UN has proclaimed 2021–2030 to be the Decade of Ecosystem Restoration. Ecosystem restoration means restoring and improving the ecological condition and natural assets in an area that has been degraded or destroyed. Mitigation measures that prevent or stop the loss of natural assets can also be part of ecosystem restoration.

2.4

Need to develop new marketing solutions and framework conditions

The current market design and other framework conditions for the power sector were developed at a time when we considered the job of developing the power system was finalised. The main task then was to operate the existing system as efficiently as possible. However, the challenge we are now facing is something completely different. We must now restructure the whole energy system to realise the goals of cutting GHG emissions in time. No one can fully predict what the energy system of the future will look like

[3] *For example, the Confederation of Norwegian Enterprise's (NHO) green electrical value chains initiative (2020), THEMA Consulting Group: Gjennomgripende endringer i energisystemet – en omverdensanalyse (2021) (in Norwegian only).*

Areas where we expect increased activity in connection with restructuring of the energy system
Supply of energy
More development of centralized and distributed power generation:
• Hydropower (large-scale and small-scale power)
• Offshore wind power
• Onshore wind power (but less in Norway until 2030)
• Solar power (large-scale, distributed, building-integrated, floating)
• More utilization of biomass as an energy source (biofuel, biogas, heat, BECCS)
• More development in some countries and shutdown of nuclear power in others (SMR, fusion power)
• More power production from other renewable technologies (wave, tidal, geothermal, etc.)
• Increased digitization of power production (measurement, control and artificial intelligence for optimal investments and D&V decisions
Transmission, conversion and storage of energy
Increased investments in:
• Smart grids (Sensor technology, autonomous system, IoT, big data management, artificial intelligence, cyber security)
• Distributed storage (batteries, V2G, hydrogen, thermal storage)
• Large-scale storage (pumped power, hydrogen storage, compressed air, battery parks, thermal storage)
• Production of green hydrogen
• Production of blue hydrogen
• Infrastructure for hydrogen (derivative production, distribution, G2P)
• Masked offshore grid and energy islands (hybrid projects, HVDC cables)
Demand for energy
• Increased installation of smart, automatic energy management (smart homes, commercial buildings and industry - measurement, control, artificial intelligence)
• Increased utilization of large-scale consumption flexibility (greater degree of flexibility in industrial consumption)
• Increased power demand for green industry (battery factories, data centers, electrification of existing industrial processes)
• Larger investments in CCS on industrial emissions (Incl. hydrogen production with CCS)
• Investment in negative emission technologies, Direct Air Capture with Carbon Storage (DACCS)
• More utilization of biomass as a raw material in industry and for consumer goods (e.g. bioplastic)
• More utilization of low-emission hydrogen for raw material and heat in industry
• Increased investments in energy efficiency in industry (e.g. heat recovery)
• Increased investments in energy efficiency in buildings (technology integrated into building materials, efficient appliances, insulation, materials)
• Increased digitization of transport (autonomous cars and ships, optimization of infrastructure, mobility as a service)
Increasing conversion to:
• Sustainable road transport (Battery electric, hydrogen, biofuels, incl. infrastructure)
• Sustainable shipping (Battery electric, hydrogen, ammonia, advanced biofuels, incl. infrastructure)
• Sustainable aviation (Advanced biofuels, e-kerosene, hydrogen, short-haul electricity)

Table 1 Areas where we expect increased activity in connection with restructuring of the energy system.

or what technologies and market solutions will win the day in the end. It is, however, likely that Norway's unique power system will be more closely linked with other energy carriers such as hydrogen and bioenergy, and even closer with power systems in other countries.

Our existing framework conditions and market design will not send the investment signals required to restructure the energy system in a cost-effective manner in time to achieve the climate targets, while also addressing considerations for biodiversity and security of supply. We will therefore need to further develop framework conditions and market designs that facilitate cost-effective restructuring of the energy system.

Most sectors of modern societies are critically dependent on their power system. Increased electrification increases vulnerability and the need to secure a robust power system. Increased digitalisation also makes us more vulnerable to cyberattacks. There is a need to balance production and consumption in the power system at real-time, which requires regulation and intervention. Electrification, changes in consumption and the restructuring of the production system mean that new methods must be used to balance the markets. This will to an increasing extent take place on the consumer side. The restructuring process will require new market solutions, the application of new technology and the development of new business models. A key challenge in this respect will be to utilise new solutions for balancing the system while keeping costs down.

As we approach 2050, we will experience more unforeseen incidents such as the energy crisis in Europe in the winter of 2022. If we are to succeed in realising a low-emission society, we must develop robust solutions that enable the energy system to handle such incidents. The development of good framework conditions will thus be vital to realising a low-emission society.

2.5

Norway's power system – a source of green industrial development

Norway is an energy nation that is well positioned for value creation in many areas of industry. Our national resource base, our technology and knowledge base and industrial experience mean we are well prepared to contribute to developing a low-emission society and to further developing a profitable energy industry with national and international market opportunities.

Today, Norway has Europe's best developed power system, most likely Europe's lowest total system costs and by far the highest level of renewable power generation. Two factors in particular are key to explaining why the Norwegian power system gives us a competitive advantage compared to other countries. Firstly, we have a renewable power system based on hydropower and secondly, we have a well-developed and more robust power grid than other countries.

Hydropower has been and remains the backbone of the Norwegian power system. Hydropower has several unique qualities that make the Norwegian power system highly competitive: it is cost-effective, flexible and close to 100 per cent emission free. The flexibility of hydropower also contributes to high security of supply.

We also have considerable natural resources on which to base the development of new renewable power generation, such as upgrading our hydropower, land-based wind power and solar power infrastructure. However, there is a particularly great potential in developing offshore wind power, both in the Norwegian part of the southern North Sea, closest to the continent and northwards along the coast. Offshore wind power represents an industrial opportunity that can help supply power for both domestic consumption and export.

Access to renewable energy means that we are well positioned for producing green hydrogen. We also have considerable industrial process expertise that gives us an advantage in further developing and establishing new green value chains such as solar power and batteries.

International energy and climate policy sets out requirements for reducing emissions in all economic activities, and the demand for goods and services with a low carbon footprint will continue to grow. Norwegian products manufactured in energy-intensive industries already have a very low carbon footprint due to Norway's emission-free hydropower when compared with similar products produced using fossil power. The flexibility and regulation capabilities of Norwegian hydropower can be used to further develop green industry in all of Norway based on a highly competitive power supply. We have a central grid, and the geographical distribution of hydropower facilities means that new industry can be established in many parts of the country.

Because hydropower generation is distributed over large parts of Norway and we use electricity for heating, our power grid is, in principle, better developed than in other countries. However, increased electrification and new green industries nevertheless mean that considerable investments must be made in the Norwegian power grid in the years ahead.

To keep the overall costs down, it is important to develop and use new technology and tools that can optimise use of the infrastructure. Among other things, we have the potential to take a position in grid and market optimisation, as well as smart charging for the transport sector, an area in which Norway is already ahead of the curve. It will also be important to facilitate sector coupling between different energy carriers, such as bioenergy, hydrogen, ammonia and electricity. In addition to localisation of industry, it is also essential to assess the need for heating and utilisation of surplus heat.

By further developing our role as a pioneering country and using new tools, we can, in addition to maintaining a cost-effective energy system, also help develop an internationally competitive supply industry.

2.6

We must seize the opportunities now

The search for new solutions has accelerated around the world, but we do not yet know which technologies will be most successful in the end. In many ways, developments in Norway are similar to those in other countries, but the situations are far from identical. It is therefore important that Energi21's key areas both support the European research agenda and safeguard and utilise the potential in areas that are unique to Norway.

The major changes ahead entail a greater need to strengthen the scope of research and innovation efforts and the range of technologies that are supported, both through increased research budgets in Norway and increased participation in the EU's research and innovation programmes. Extensive restructuring and the high level of investment require an increase in educational capacity to meet the needs in the years to come. This applies to every link in the chain, from fitters and engineers to PhD candidates in almost all disciplines. Multidisciplinarity is key to developing good solutions. For many of the challenges we need to solve, developing competitive technology is not enough. We must also develop good framework conditions, markets and business models to be able to utilise low-emission technology on a grand scale.

It is particularly important to develop funding and policy instruments that enable new technology to be commercialised and implemented more quickly in order to keep up with the changing pace in the restructuring of the energy system that is now needed to achieve the climate goals. Quicker commercialisation and implementation is key to utilising the market opportunities now emerging in the domestic and export markets.

The Energi21 strategy points to several areas where Norway should prioritise efforts in order to develop the best energy system in Europe. This entails an energy system that contributes to a safe, competitive and environmentally friendly supply of energy, decarbonises the transport sector and industry, and facilitates the development of new green industries and marine energy technologies.

Norway has several competitive advantages that makes it well positioned to develop the best energy system in Europe. Many of them are outlined in the next section.

2.7

Norway as an energy nation – our competitive advantages

The Norwegian power system is one of our competitive advantages. We also have several other advantages. For example, our considerable fossil energy resources combined with CCS technology provide a sound foundation for establishing successful value chains for blue hydrogen and ammonia targeting the export markets. We have experience of and facilities for storing CO_2, making us well positioned to take part in the development of CCS value chains together with other countries in the North Sea area.

Table 2 lists Norway's competitive advantages and the technology areas to which the various competitive advantages are relevant.

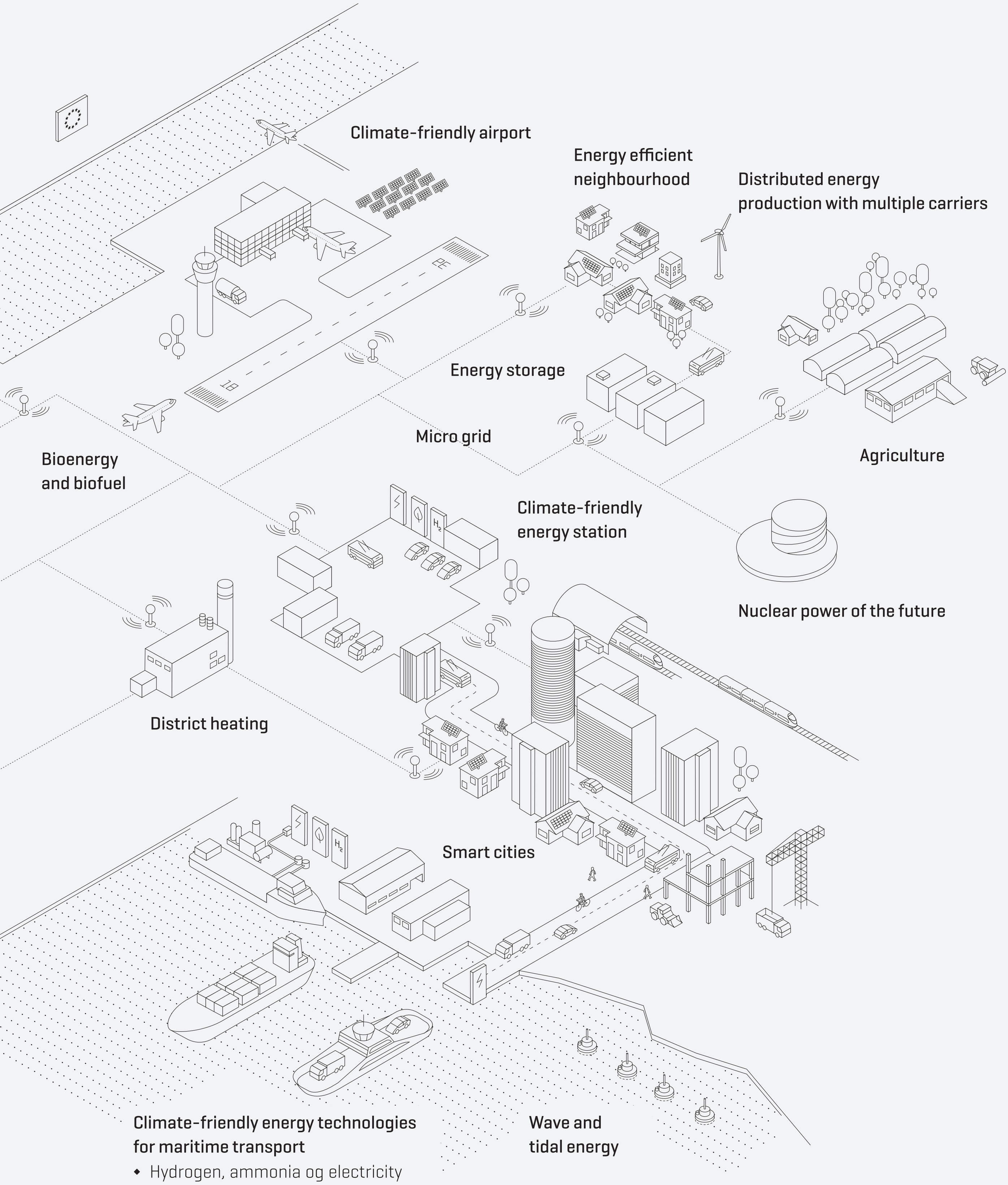
Competitive advantages	
Energy resources	**Relevant for the technology areas**
Major renewable energy resources	
• Water	• Hydropower
• Wind	• Offshore wind power
• Land-based and marine biomass	• Carbon capture and storage
	• Hydrogen (through electrolysis)
	• Batteries
	• Integrated and efficient energy systems
	• Energy markets and regulation
	• Transport
Natural gas[4]	
• Natural gas reforming to hydrogen with integrated capture and permanent storage of produced CO_2	• Hydrogen (through reforming)
	• Carbon capture and storage
	• Integrated and efficient energy systems
	• Energy markets and regulation
	• Transport
Expertise and experience	**Relevant for the technology areas**
Hydropower	
• Technology for tunnelling and underground facilities	• Hydropower
• High-pressure facilities, flexible solutions	
• Cost-effective project design, planning and operation	
• Advanced methods/systems for optimal monitoring and operation, including hydropeaking	
• Environmental design in both planning and operation	
• Energy disposal	
• Extensive industrial experience and research expertise	
Electric power systems expertise	
• Planning, construction and operation of electric infrastructure	• Integrated and efficient energy systems
• Electrical power components and parts	• Batteries
• Extensive industrial experience and research expertise	
Energy systems with high degree of electrification	
• Planning, construction and operation – modelling and optimisation	• Integrated and efficient energy systems
• Electrical power components and parts	• Energy markets and regulation
• Automated monitoring and operation of the power grid	
• Power markets – market design	
• Proportion of electric vehicles and charging infrastructure	
• Extensive industrial experience and research expertise	
• Sensor technology and digital solutions	

[4] *Decarbonisation of Norwegian natural gas is covered by the Energi21 strategy. Other utilisation of fossil energy resources is covered under the "Oil and gas in the 21st century" (OG21) strategy.*

Table 2 Norway's competitive advantages

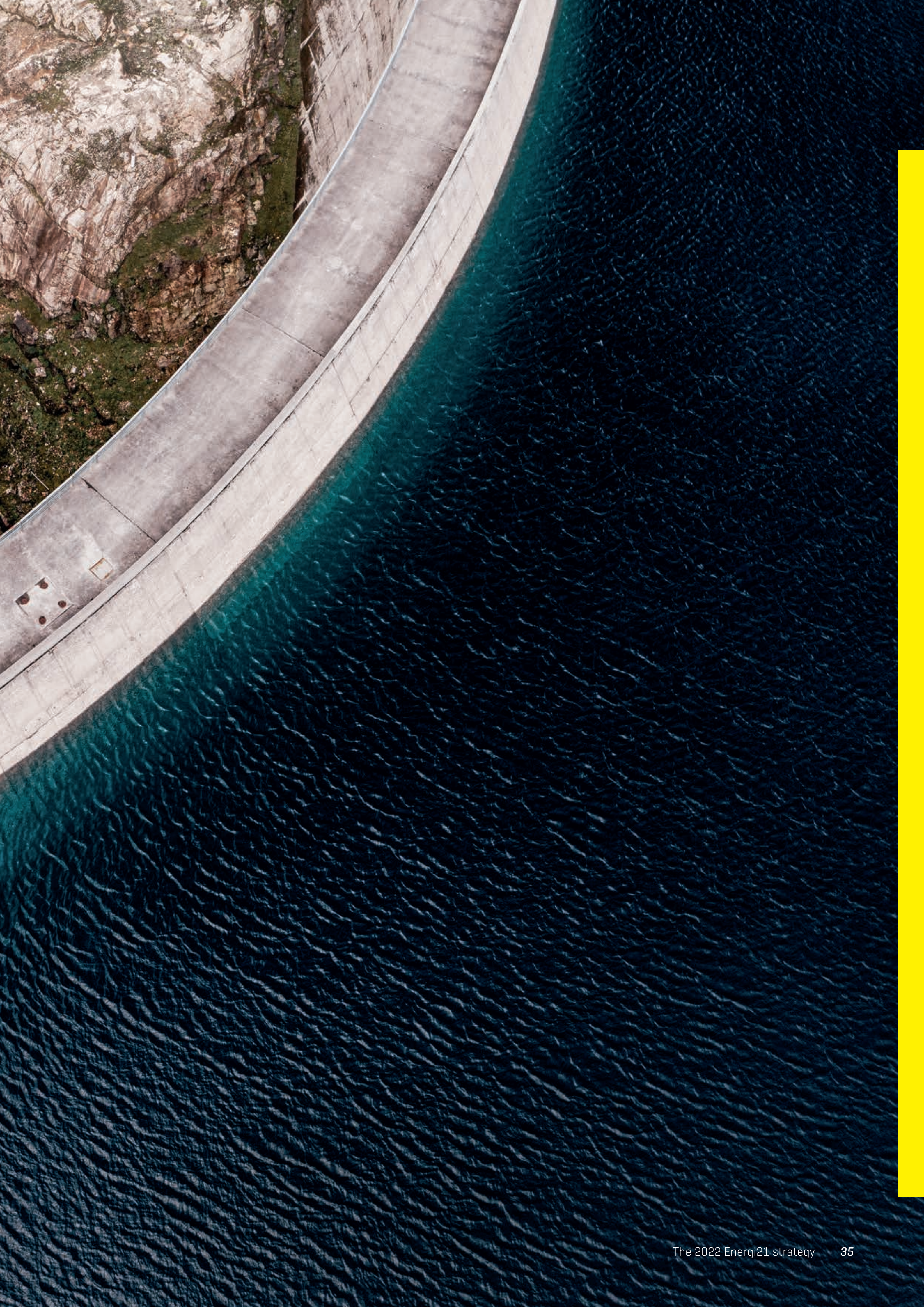
Offshore petroleum activities	
Construction, operation and maintenance of large offshore installations	Offshore wind power
Geology and geotechnics	Carbon capture and storage
Experience in carbon capture, transport and storage	Hydrogen
Sensor technology and digital solutions	Integrated and efficient energy systems
Project management	Energy markets and regulation
Subsea technology and subsea cables	
Marine operations, logistics, drilling and wells	
Commercial models, law	
Safety and the environment	
Materials and process technology	
Floating technology	
Extensive industrial experience and research expertise	
CO_2 storage capacity	
Maritime industry	
Marine operations	Offshore wind power
Specialised vessels	Batteries
Autonomous vessels	Hydrogen
Electrical systems in ships, battery modules	
Emission-free vessels – batteries, hydrogen and ammonia	
Process technology	
Extensive industrial experience and research expertise	Carbon capture and storage
CO_2 separation from natural gas and flue gas	Batteries
Refining for converting fossil fuels relevant for biorefining	Hydrogen
Electrolysis, natural gas reforming	Solar power
Hydrogen filling stations	
Heat-pumping systems	
Separation H2/CO_2	
Liquefaction, storage, and handling of liquid hydrogen	
Materials technology	
Extensive industrial experience and research expertise	Hydrogen
Metal/chemical refining (e.g. Si, FeSi, Al etc.)	Solar power
Materials for hydrogen technologies (ceramics, bipolar plates etc.) and batteries and solar power (silicon) etc.	Batteries
The Norwegian model for organisation of working life	
Effective cooperation and high level of trust between public authorities, employees and employers	All technology areas
Efficient innovation processes	
Digitalisation/ICT	
High digital literacy among the population	All technology areas
Automation in shipping, autonomous vessels	
Smart grids, monitoring of the power grid	
Power markets	
Market design	All technology areas
Legislation and development of incentives	
Nature, land use and resource management	All technology areas

Figure 3.1 Illustration of the digitalised, flexible and integrated energy system of the future


Climate-friendly airport
Energy efficient neighbourhood
Distributed energy production with multiple carriers
Energy storage
Micro grid
Agriculture
Bioenergy and biofuel
Climate-friendly energy station
Nuclear power of the future
District heating
Smart cities
Climate-friendly energy technologies for maritime transport
• Hydrogen, ammonia og electricity
Wave and tidal energy

3

The 2022 Energi21 strategy



The focus areas set out in the Energi21 strategy hold great potential for value creation in resource utilisation and further development of a supplier industry for national and international energy markets. The key areas also represent technology and thematic areas of material importance to ensuring security of supply in the climate-friendly energy system of the future.

Norway is strongly positioned in relation to its energy resources, technology and expertise, and industrial experience. As an energy nation and with the national and international opportunities the energy system of the future represents, the Energi21 board has adopted the following vision:

The Energi21 vision
Further develop Europe's best energy system.

The Energi21 board believes that Norway can develop an energy system that can contribute both at the national and international level. These contributions may be in the form of renewable and climate-friendly energy, industrialisation and business development, and last but not least, an energy system with reliable supply and the right quality of supply

According to Energi21, there are three main challenges to achieving the objectives set out by the Ministry of Petroleum and Energy and meeting Energi21's vision. The main challenges are:

Key challenges

- Decarbonising transport and industry.
- A reliable, competitive and environmentally friendly energy supply.
- Developing new green industries and marine energy technologies.

The Energi21 strategy places great importance on marine energy technologies based on the value creation potential inherent in the ocean space and Norway's competitive advantages to win positions in this market.

The revised Energi21 strategy draws attention to focus areas that provide solutions to these three main challenges, given that research and innovation efforts are intensified.

Based on a comprehensive strategic analysis of all the technology and subject areas in the energy sector, Energi21 has prioritised *eight focus areas* in the revised strategy, *two of which are given special attention.*

There are links and transfer value between the strategy's focus areas. Figure 4 illustrates the Energi21 strategy and its focus areas.

Particular attention has been given to the focus areas *"Integrated and efficient energy systems"* and *"Energy markets and regulation"*. There is a strong link between these areas. Research and innovation topics in "Energy markets and regulation" have a huge bearing on the implementation and adoption of technologies and solutions developed in the focus area "Integrated and efficient energy systems". Both areas are complex, and cover numerous disciplines, technologies and solutions. Integrated and efficient energy systems are the hub of society's green transition. This area is hugely important to future security of supply, the integration of climate-friendly solutions and society's value creation, as well as for securing a sustainable energy supply. The area "Energy markets and regulation" covers issues relating to social sciences, market design, legal issues and regulation.

The Energi21 strategy also prioritises the following six focus areas:

- Hydropower
- Offshore wind power
- Solar energy
- Hydrogen
- Batteries
- Carbon capture and storage

These are more technology-oriented focus areas that have a great bearing on security of supply and flexibility in the energy system. They could also play a crucial role in cutting GHG emissions, industrialisation and the green transition of society.

Efforts and investments must be comprehensive and encompass predictable access to public research funds, market incentives, and strong business involvement and participation. The focus areas are described in more detail in sections 3.1–3.8. Chapter 6 describes what measures could be necessary to realise the strategy's recommendations.

Figure 4 Energi21 strategy 2022

FURTHER DEVELOPING A BROAD, ROBUST TECHNOLOGY AND KNOWLEDGE PLATFORM IN THE FIELD OF ENERGY

It is important to secure technology and expertise across the thematic breadth of climate-friendly energy technologies. Continuous developments in both specific and generic technologies and disciplines will generate new opportunities and new solutions. The field of energy has a broad reach and covers many sectors. There is great transfer value between the technology areas and, based on the development of the energy system, interdisciplinary competence development and new collaboration constellations will become increasingly important. In addition to the strategy's eight key areas, Energi21 believes it is important that efforts are also made to further develop other technology and knowledge areas. The other technology and knowledge areas and the strategy's key areas benefit mutually from the results of research and innovation activities and together comprise Energi21's broad, robust technology and knowledge platform. The other technology and knowledge areas that the Energi21 board believes must be further developed are:

- Energy-efficient, smart buildings and cities.
- Energy-efficient industry.
- Climate-friendly energy technologies for maritime transport.
- Climate-friendly energy technologies for land-based transport.
- Climate-friendly energy technologies for aviation.
- Bioenergy and biofuels.
- Land-based wind power.
- Geothermal energy.
- Nuclear power of the future.
- Fusion energy.
- Wave and tidal energy.
- Airborne wind .

Some of the technology and knowledge areas are immature and/or do not contribute as much to our national energy mix. Following the developments in these areas will nevertheless be worthwhile, and may prove useful to research and innovation efforts if technology and market developments show that they are significant to our energy system in purely technical terms and for national value creation (industrialisation and business development).

THE STRATEGY CONTRIBUTES TO THE UN SUSTAINABLE DEVELOPMENT GOALS

The UN Sustainable Development Goals (SDGs) provide clear guidance on the factors that can ensure a sustainable development of society. The energy sector is directly linked to many of the SDGs and is important for realising several of them. The Energi21 strategy contributes in particular to the goals of:

Affordable and clean energy
Ensure access to affordable, reliable, sustainable and modern energy for all

Industry, innovation and infrastructure
Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.

Sustainable cities and communities
Make cities and human settlements inclusive, safe, resilient and sustainable.

Responsible consumption and production
Ensure sustainable consumption and production patterns.

Climate action
Take urgent action to combat climate change and its impacts.

Life below water
Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

Life on land
Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

Method for selecting the key areas

The Energi21 board has selected the key areas in this strategy based on an overall analysis of each area's potential to advance the Energi21 objectives. Thus, viewed collectively, the key areas will promote enhanced value creation based on Norwegian renewable energy resources, restructuring of the energy system and reduced emissions, and development of internationally competitive industry and expertise. The key areas also represent areas with high levels of research and innovation. A full description of the methods used to select the strategic priorities can be found in Appendix 6: Backdrop for strategic priorities.

Photo: Norwegian Institute for Nature Research (NINA)

3.1 Integrated and efficient energy systems

An efficient and integrated energy system is the hub of the climate transition and a precondition for a reliable, competitive and environmentally friendly energy supply. Efficient and integrated energy systems are vital to achieving the energy and climate policy goals of reducing GHG emissions, industrialisation and cost-effective utilisation of our energy resources. Challenges relating to the power grid, systems operation and security of supply are essential to overcome to succeed in the green transition. Research and innovation activities will enable us to develop a sustainable energy system for the future.

The strategy's key areas encompass onshore and offshore energy systems. There are extensive plans to develop power production and energy infrastructure in the North Sea, and a goal to electrify the continental shelf using land-based power. This will require research and innovation in both land-based and maritime technologies and solutions. Electrification, energy efficiency improvement and environmental considerations are important measures to reduce GHG emissions. In addition, integration and interaction between technologies and solutions for the decarbonisation of fossil energy resources and industrial processes are also key. In view of this, it is natural that research and innovation efforts should mainly target the power system and the interfaces between infrastructures for other energy carriers such as renewable heat and hydrogen, as well as consequences for biodiversity and the environment. Security of supply and digitalisation will be core factors in the development of knowledge and technology.

There is a strong link between the key area "Integrated and efficient energy systems" and "Energy markets and regulation". Research and innovation activities in the key area "Energy markets and regulation" will contribute knowledge that strengthens market development, industrialisation and adoption of technologies in society. The development in technology and social sciences must be harmonised.

Several of the RD&I topics in the other strategic focus areas are relevant for the development of the main focus area "Integrated and Efficient Energy Systems". In addition, there are links and transfer value between this area and the subject areas in the knowledge and technology platform.

THE STRATEGIC AREA "INTEGRATED AND EFFICIENT ENERGY SYSTEMS" COMPRISES THE FOLLOWING TECHNOLOGIES AND SUBJECTS

- All energy-related infrastructure for climate-friendly energy carriers on land and at sea and their interactions (electricity, renewable heat, hydrogen, biofuels), as well as infrastructure for CCS.

Physical infrastructure – relevant technologies

- Components for energy transfer.
- Energy storage technologies (chemical, mechanical, electrical and electrochemical, thermal).
- Energy conversion technologies (chemical, thermochemical, biochemical, electrochemical, HVDC, HVAC, etc.).
- Energy technologies ensuring the effective integration and electrification of sectors.
- Energy technologies that ensure efficient interaction and utilisation of energy from various sources, e.g. surplus heat.
- The potential for occupation of land by physical infrastructure and the impact this may have on local communities, the climate and biodiversity.

Energy efficiency improvement – technologies and solutions

- Energy-efficient production technologies.
- Energy-efficient technologies and solutions for the transfer of energy and systems operation.
- Energy-efficient industrial processes.
- Energy-efficient energy consumption in buildings, neighbourhoods, cities and in agriculture.
- Technologies and solutions for efficient energy tilisation and interaction between energy carriers.
- Utilisation of surplus energy/surplus heat.
- Technologies and solutions for reducing power demand in the power system.
- Energy-saving technologies and solutions for end users.

Digitalisation and cybersecurity

- Digital enabling technologies to connect and automate the physical infrastructure through ICT systems to improve the performance and profitability of the energy system, and strengthen security of supply.
- Relevant technology areas: artificial intelligence, big data management, autonomy, sensor technology, the Internet of Things (IoT).
- Technologies and solutions that contribute to a secure cyber-physical system.
- Legal aspects, privacy and data ownership related to commercial use.

Multidisciplinary analysis models, simulation tools and innovative management systems

- Cost-effective and sustainable design and operation.
- Reliable system operation.
- Technical aspects of dynamic and integrated power system operation.

Nature and the environment

- Land use impacts when upgrading existing and investing in new energy infrastructure.
- Effects of development, operation and maintenance of the energy system on biodiversity.
- Life cycle assessments and circular economy.

The ZEB-laboratory. *Photo: SINTEF Community and NTNU*

3.1.1
ELECTRIFICATION, ENERGY EFFICIENCY IMPROVEMENT, DIGITALISATION AND ENVIRONMENTALLY FRIENDLY DEVELOPMENT

Electrification, energy efficiency improvement, digitalisation and environmentally friendly infrastructure development are four essential climate measures.

Efficient and sufficient grid capacity for industrialisation and decarbonisation

The electrification of energy consumption is a key measure to cut GHG emissions in society. However, the challenge is to develop enough capacity in the grid to keep up with the pace of electrification and facilitate new green industries within the time frame for achieving the climate targets. The challenges relating to the power grid are driven by a strongly increasing demand for both energy and power, which necessitates investment in both power generation and the grid. This is costly and requires long time horizons. Even better utilisation of the existing power system can reduce these investment needs.

A large proportion of the power system is currently run with a significant safety margin due to an inadequate overview and lack of control possibilities. Developing and deploying new technology that contributes to increased utilisation of already invested capital is crucial to finding the most cost-effective solution to the need for increased electrification. Digitalisation provides opportunities such as better knowledge of actual available capacity in the power grid (lines, cables, transformers etc.) and how to utilise the flexibility of the power system (e.g. relocation of generation and load, use of energy storage), which will also reduce the need for a capacity increase. Central to this is the adoption of new digital technologies. Sensors, IoT, big data management and artificial intelligence are crucial technologies for success, as is the ability and willingness of grid companies to look at these solutions as an alternative and supplement to continuous new investments in new grids. Another important success factor is closer cooperation between the grid companies and increased digital interaction.

Energy efficiency improvement is important to ensure value creation and reduce GHG emissions

Energy efficiency improvement is particularly important to ensure value creation from Norwegian energy resources, competitive Norwegian industry and achieve a zero-emission society. Good use of natural energy resources is crucial to security of supply in both the present and future international energy situation.

Energy efficiency improvement is at the heart of a sustainable energy system along the entire value chain of all energy carriers, from generation to application. Energy efficiency improvement provides better energy utilisation and reduced energy demand. Saving energy is more cost-effective than building new capacity. Reducing energy and power use as well as utilising flexibility in industrial processes, buildings and cities increases security of supply, improves power balance and reduces the need to expand the capacity of the power system (both generation and transmission). In addition, energy efficiency improvement is an important measure to limit encroachments on nature during the energy transition.

Central parts of Norwegian industry produce large amounts of surplus energy/heat (about 20 TWh corresponding to 10 per cent of Norwegian energy consumption), which represents a significant resource. Utilization of this potential requires development of cost-effective technologies for converting surplus heat and for energy storage in a more integrated and efficient energy system. Surplus heat resources are expected to grow as a result of new industrial developments. A high degree of electrification will result in increased power demands and capacity needs in the power grid. Surplus heat utilisation represents sustainable utilisation of energy resources and can reduce investments in new energy infrastructure.

Preventing the degradation of nature

Preventing the degradation of nature is an important key climate measure. Already today, emissions from degraded marshland account for 11 per cent[5] of all Norwegian GHG emissions. Reducing land use requirements is therefore an essential climate measure in combination with electrification and energy efficiency improvement.

[5] *Norwegian Institute for Nature Research (NINA)*

3.1.2
SECURITY OF SUPPLY AND CYBERSECURITY ARE CRITICAL TO THE GREEN TRANSITION

A more complicated and complex energy system with many new and emerging stakeholders, rapid technological development, increased digitalisation and climate change increase the vulnerability of the energy system.

Large-scale electrification towards a zero-emission society will place increased demands on security of supply, as society's growing dependence on electricity increases. Considerable research and development of analytical methods etc. is required to find out how security of supply is affected by the changes and how it can be maintained on the path towards zero emissions.

Safe operation and development are essential to address the increased complexity and variability of the future energy system. There is a need for new risk and vulnerability analyses that also include vulnerability aspects related to increased levels of digitalisation and automation. In addition, better monitoring and management systems are needed to cope with a more dynamic power system. Priority should be given to the development of future operations centres with increased levels of automated network operation. This includes addressing stability challenges and bottlenecks.

The green transition challenges the stability of the Nordic power system

The Nordic power system is a separate synchronous system with a common frequency. The green transition will bring about a dramatic increase in converter-based power generation such as wind and solar power. In addition, there are direct current cables that are also connected to converters. Converters have different technical and physical properties than the synchronous generator, which delivers inertia in the event of frequency changes. Inertia is kinetic energy stored in the rotor of synchronous generators or synchronous compensators. Inertia helps to reduce the rate of frequency drops if any large production units fail, and also prevents the frequency drop from becoming too great.

Converters do not provide inertia to the system. With a greater proportion of converter-based production, the level of inertia will therefore drop. HVDC cables used for power import will also contribute to reducing the number of synchronous generators connected to the grid, thereby weakening the stability of the power system. Due to the physical properties of converters, new phenomena will arise that we do not have in today's system. In general, we are able to observe and analyse phenomena that occur with time frames of seconds (voltage stability, frequency stability, rotor angle stability). As of today, we have a great lack of knowledge about and little opportunity to observe expected new phenomena within milliseconds (resonance stability, converter-driven stability). Nor are current simulation models designed to analyse the behaviour of the power system in the millisecond range. Knowledge and systems should therefore be established to address challenges relating to a converter-based power system.

Increasing infrastructure development can increase the risk of landslides and erosion

The degradation of natural areas due to the construction of energy supply infrastructure may increase the risk of landslides and erosion. Mitigation measures to preserve and restore degraded natural areas will reduce the vulnerability of the energy system in a changing climate.

3.1.3
A WHOLE SYSTEM PERSPECTIVE IN PLANNING AND OPERATION IS ESSENTIAL

A cost-effective and sustainable transition to the emission-free energy system of the future will require all stakeholders operating along the value chains to take a whole system perspective, where production, transmission, energy conversion, energy storage and energy consumption are seen in context. In addition, it is important to include parameters related to nature and environment in the analyses. This includes the importance of limiting the loss of nature and natural assets, as well as knowledge of how this can be achieved in planning and operation. Understanding the role of technologies in the system and how they interact is important for cost and energy-efficient planning, design and operation of energy systems. Knowledge of factors that affect the balance between production and consumption of energy will also be crucial to maintaining security of supply. A whole system approach to system planning and operations will include knowledge of efficient energy markets and how technologies and marketplaces are utilised.

Strategies for utilising existing and investing in new infrastructure

The transition to zero-emission energy systems will also affect the Norwegian infrastructure for export of energy. Strategies for developing new or reused infrastructure should be developed based on comprehensive analyses of the Norwegian energy system in interaction with markets in our neighbouring countries. The capacity of the power system is already challenged. Furthermore, comprehensive electrification will require tools and analyses that enable the prioritisation of economically sound development or reinforcement of infrastructure. Thermal flexibility (district heating, district cooling, heat pumps, bioenergy) is available and affordable, and can be quickly deployed. By replacing direct electric heat with renewable heat, the power system is relieved. Increased use of renewable heat is a cost-effective alternative to grid development. Possibilities for re-use of infrastructure on the Norwegian continental shelf for future export of hydrogen should also be explored.

In addition, reuse of infrastructure on land will reduce carbon emissions and loss of nature, thus helping to increase the positive effects of new energy solutions on the climate.

3.1.4
SECTOR INTEGRATION – FLEXIBLE INTERACTION BETWEEN ENERGY CARRIERS AND END CUSTOMERS

A cost-effective and integrated energy system must ensure good interaction between all zero-emission energy carriers and with end customers. The use of electricity, renewable heat, hydrogen and biomass is very likely to be necessary. Systems that can use different energy carriers strengthen security of supply and increase the flexibility of the energy system. Flexibility in the energy system is of great value and will reduce investment costs in the power grid.

Flexibility from different energy carriers is relevant in areas with a vulnerable power supply, large power surpluses, a high share of unregulated power generation or limited transmission capacity in the power grid. Interaction with decarbonised fossil energy carriers and the CO_2 value chain will also be important.

Flexible interaction between energy carriers and end customers also requires cooperation between the different stakeholders planning and operating the energy system. Relevant elements in this context are:

1. Appropriate (cost-reflective) incentives and pricing mechanisms between different systems and stakeholders This relates to the “Energy markets and regulation” key area.
2. Digitalisation and standardisation of interfaces between stakeholders and systems.
3. Analysis and decision support tools, including data access, that highlight the value of sector integration and flexibility for the individual stakeholder and for society at large.
4. Tools and methods for ensuring economic utilisation in connection with the development of infrastructure.
5. Monitoring, and automation and control technology.

To increase sector coupling, the research and innovation agenda in energy systems must take a multidisciplinary approach and make strong use of the synergies between disciplines and industrial sectors.

An efficient and integrated energy system with new technologies on the consumption and production side will entail a greater need for good interaction across sectors and with end customers. For example, buildings will no longer be passive consumers of electricity, but start to take on roles as energy producers, energy stores and flexibility sources. Buildings have a great flexibility potential. Likewise, the transport sector has evolved from being a passive consumer of fossil fuels to being an active consumer of electricity that can optimise its consumption according to grid constraints and, in the long run, become an energy store and a flexibility source.

Agriculture can become a major contributor to the integrated and efficient energy system of the future, both as a supplier and producer of renewable energy, but also of renewable fuel such as biogas. The agricultural industry is critical to society and relies on reasonable energy prices. Farms that are self-sufficient in climate-friendly fuel, heat and electricity is a realistic picture of the agricultural sector’s future energy supply. Energy sources in agriculture can be developed in a relatively short period of time and are not as cost intensive as large-scale development projects.

Agriculture as a renewable power producer and fuel supplier

Norwegian farmers own 77 per cent of the land in Norway and have access to 16 TWh from small hydropower plants. The agricultural sector also has 960,000 buildings at its disposal that have a potential for generating power from solar cells and solar power. Livestock production produces biogas emissions, which when captured in biogas reactors and mixed with food waste, represent 10 TWh. Biogas can be used as fuel, and has great value creation potential. The agricultural sector is working on new value chains based on green methane, green CO_2 and green ammonia from biogas. Fish silage and waste-water sludge from the aquaculture industry are other novel substrate combinations that can help significantly increase the amount of this type of energy.

3.1.5
DIGITALISATION AND CYBERSECURITY IN A CYBER-PHYSICAL ENERGY SYSTEM

Digitalisation is an important tool and a prerequisite for realising a climate-friendly, cost-effective and reliable energy system. Cybersecurity is an important premise for maintaining security of supply in the energy system of the future.

Digitalisation technology has developed rapidly in recent years and is very likely to bring about fundamental changes in the operation, maintenance, preparedness and management of the energy system. Increased digitalisation will have an impact on how we operate and further develop our existing energy value chains.

Effective digitalisation requires coordinated and simultaneous efforts in three areas: (i) new technologies; (ii) secure and efficient access to quality data in the right format; and (iii) development of organisational ability and capacity (e.g. expertise).

By means of digitalisation, many more physical components can be equipped with sensors that, among other things, measure parameters related to energy use and the condition of the component. The sensors are networked with two-way communication. The data are collected and analysed, and control signals are sent back to optimise, for example, energy use and energy flow.

Digitalisation and efficient use of infrastructure

Digitalisation provides opportunities for better management of energy systems, better utilisation of existing infrastructure and reduced need for expansion. It will also help improve data quality and contribute to a more precise decision-making basis for investment processes and operation strategies. Digitalisation will be a prerequisite for maintaining security of supply, balance and interoperability between different energy systems and end customers. It thereby ensures functionality in an integrated and complex energy system.

Increased digitalisation entails increased vulnerability and security risks

The energy system is becoming an increasingly advanced cyber-physical system and large quantities of data are transported and stored. A data attack can have serious consequences and, at worst, hamper the operation of the energy system. Based on this, it is crucial that cybersecurity, data security and emergency preparedness requirements are emphasised in all processes from design to construction, operation and maintenance.

Examples of undesirable incidents include the loss of services, manipulation of data and outsiders gaining control of information systems. Developing knowledge and technologies to prevent cyber-attacks will be a key part of the digitalisation research and innovation agenda. The same applies to legal aspects of privacy and data ownership for the purpose of commercial use.

Digital enabling technology areas with potential for value creation

Five digital enabling technologies constitute the building blocks for the digitalisation of the energy sector: artificial intelligence, big data management, sensor technology, autonomy and the Internet of Things. These technologies are of great importance for:

- More efficient electrification of Norway and increased sector coupling.
- Increased Norwegian competitiveness in an international energy market.
- Cost-effective monitoring, management and operation of the energy systems.
- Cost-effective monitoring of environmental impacts and nature.
- Cost-effective investments in physical infrastructure and new energy solutions.
- Better utilisation of the energy system's capacity.
- Increased flexibility and dynamics in the energy system.
- Security of supply and defence against cyber-attacks.
- Improved provision of energy services to customers.
- Increased interaction and cooperation between stakeholders along the entire value chain.
- Business opportunities in digitalisation.
- Norway can create value by linking energy-related domain knowledge with digital technology and expertise.

Reference is made to the Energi21 report Digitalisation of the energy sector – Recommendations for research and innovation [www.energi21.no] for more detailed information about digitalisation of the energy sector and the application of digital enabling technologies, value creation and skills challenges.

The energy system of the future will require advanced management and control systems. This is fundamental for security of supply, benefits realisation from digitalisation, utilisation of flexibility, effective interaction between the power system and local energy resources, and more. Management and control systems for the next generation of energy system operations will be complicated and integrated, and the link to simulation tools for energy markets must be strengthened beyond the current level.

Digitalisation provides a more precise decision-making basis and a more sound basis for thorough analyses when investing and choosing operational strategies. For example, digitalisation makes it easier to utilise consumer flexibility, integrate larger amounts of unregulated renewable power generation and ensure efficient interaction between distributed energy resources (e.g. solar cells), local storage (e.g. batteries) and other parts of the energy system.

3.1.6
NATURE AND THE ENVIRONMENT

When developing sustainable energy systems, it is crucial that the impact on nature and the environment of planning, design, operation and maintenance processes is taken into account. For grid companies, for example, it is important that the framework conditions and regulations facilitate sustainable choices and that incentives are in place for making choices that take into account nature and the environment. A common framework and methodology must also be developed to be able to compare solutions and assess effects.

In order for the energy sector to meet the political and societal changes we are facing, research and innovation related to biodiversity must become an integral part of a whole-system investment in the energy system of the future.

We cannot solve the climate crisis without at the same time solving the nature crisis, solving environmental challenges and counteracting the loss of natural and species diversity. It is therefore necessary to look at research and innovation activities concerning the physical energy system in context with research and innovation activities concerning the consequences of land use and the effects on biodiversity. Sustainability and resource efficiency assessments are essential when developing parallel infrastructures for different types of energy carriers. This includes life cycle perspectives and sustainability in relation to natural resources and the environment. The circular economy will be a guiding principle for how the energy system and industry of the future are managed and operated.

All energy production will necessarily entail land disturbance and thus have an impact on nature. In addition to land use, some forms of energy production may entail different forms of pollution or emissions with a negative impact on nature. The impact on nature of the various technologies will depend primarily on whether development takes place on new land or whether facilities and infrastructure are developed in areas that are already affected. For example, there is a big difference between placing solar cells on rooftops or building large-scale ground systems.

In order to minimise the negative impacts on nature, the following principles should be followed:

- To increase energy efficiency at all stages, so that the total need for new developments is as small as possible.
- To select areas with care so as to avoid expansion into vulnerable ecosystems or areas with significant natural assets.
- To reduce the total impact on nature by seeking and finding solutions that produce the most energy with the least amount of land disturbance. Such an assessment should be made across technologies and include all necessary infrastructure.
- To work systematically to reduce the impact on nature by complying with the principles of ecosystem restoration and the mitigation hierarchy[6].
- To assess the overall impact on nature, where the production of energy carriers comes in addition to all other interventions with a negative effect.
- To stimulate more flexibility in the power system to make the best use of existing grid capacity, thereby reducing the need for expansion of infrastructure and investments in capacity.

On this basis, it is particularly important to include nature perspectives in research and innovation efforts aimed at "Integrated and efficient energy systems". By adopting a whole system approach to energy production and all infrastructure across technologies, it will be possible to achieve the least possible overall negative impact on nature, by expanding in the right areas and no more than is necessary.

3.1.7
NEED FOR MULTIDISCIPLINARY ANALYSIS MODELS AND SIMULATION TOOLS

To achieve an integrated energy system (stationary energy systems, energy systems for transport purposes and offshore energy systems), there is a need for simulation platforms for multidisciplinary technology evaluation (co-simulation). These simulation platforms will help combine parameters across sectors, disciplines and fields to a greater extent than at present, to assess technology choices in a larger context, identify important synergies and, not least, design an energy system with satisfactory security of supply. The temporal resolution of currently available simulation tools is too low, and it is not possible to analyse the power system's behaviour in millisecond ranges. Future analysis models must be more fine-meshed and have higher temporal resolution. The simulation models should also analyse impacts on nature, people and the environment. To find the best solutions, we also need map-based decision-making tools that balance considerations for competing land-use interests based on a transparent and verifiable methodology that allows different stakeholders to participate. Such tools can create a common understanding of necessary developments and reduce the level of conflict.

Against the backdrop of increased sector coupling, it is important to have tools that contribute to a common understanding of the energy system of the future across different disciplines and industries, which will help the energy sector to make decisions that will steer it in the right direction. A positive consequence of this is increased cooperation and better utilisation of flows of expertise and synergies between the different sectors. This is an important element of value-creating innovations for the supplier industry of the future. Examples include the development of energy technologies and services at the interface between the stationary energy system and the transport sector.

Digital twins are a useful numerical tool for establishing an understanding of the complexity and functionality of the energy system. They help create a virtual representation of the physical energy system through data and simulators for real-time calculations, optimisation, monitoring, control and better decision-making support. It is important to design models that all relevant stakeholders can have access to and use. A strategic boost is therefore needed on behalf of the entire energy industry and the energy authorities. The development of digital twins for the energy system can also be a business opportunity for Norway. To enable scaling of digital twins, reference architecture must be established. If Norway makes the right investments, we can set the agenda for offshore wind power, hydrogen and CCS in terms of representation of the physical energy system through data and simulators for real-time calculations, optimisation, monitoring, control and improved decision-making support.

3.1.8 VALUE CREATION POTENTIAL AND MARKET OPPORTUNITIES

The energy systems of the future represent a great value creation potential. This value creation is linked to technology/component and service development. The energy system is also an important prerequisite for the establishment of industrial enterprises and employment in general.

Major investments are needed in the energy system at the national and international level to meet the demands of renewable energy and industrial development. This includes investments related to upgrading of existing energy infrastructure and investment in new infrastructure. Globally, the IEA estimates that average annual investments in grid infrastructure in the years 2026–2030 will increase to USD 500 billion if the world is to reach its announced climate targets, and to as much as USD 800 billion if the energy industry is to achieve net zero emissions by 2050 (IEA, 2021). This is a significant increase from the historical investment level, which has been around USD 300 billion per year in the period 2016–2020. The increased investment needs represent market opportunities for the business sector, and especially for the supplier industry.

Major plans are in place for developing marine energy resources and technologies. For example, the EU's goal is 300 GW of offshore wind power by 2050, in addition to an additional 40 GW of capacity from other marine energy such as wave power, tidal power and floating solar power. This will require investments in the amount of EUR 800 billion, two thirds of which will go towards necessary infrastructure. In the North Sea, major projects are already under way. Several Norwegian stakeholders have mobilised and are planning to take part in these developments. Statnett has plans to establish an offshore grid both as a system operator and planner, and will facilitate an initial hybrid connection by 2030. It expects to invest NOK 60–100 billion in both the onshore transmission network and in the North Sea towards 2030. A similar amount is expected to be invested in regional and local distribution grids.

3.1.9 COMPETITIVE ADVANTAGES AND IMPLEMENTATION CAPACITY

Norway is well positioned to develop an efficient and integrated energy system with an emission-free energy supply, a strong power grid and a well-functioning energy market. In addition, our technology and knowledge base and our industrial experience provide opportunities for value creation through the further development of existing industries and the development of new supplier industries.

The implementation capacity of the business community and RD&I communities is strong, based on a robust knowledge and technology platform and industrial experience. Norwegian environments maintain a high international level of flexible and dynamic solutions for the energy system. We have a robust knowledge platform in systems engineering operations and control, as well as strong analysis environments in dynamic power system analyses. Norway also has relevant knowledge in power electronics and sensor technology from the offshore industry. This knowledge can be transferred to the monitoring, management and operation of the energy and power system, and the further development of digital solutions for energy and transport systems.

[6] *The Norwegian Environment Agency, Guide M-1941: Konsekvensutredninger for klima og miljø, section 4.1 (in Norwegian only).*

In renewable heating and cooling, Norway also has a strong industry cluster and supplier industry (machinery and pipes). In recent years, there has been an increase in Norwegian technology companies in the fields of water treatment, measurement, digitalisation, robotisation of operations and maintenance. The R&D communities collaborate and are located in several parts of the country.

Norway has an international competitive edge in the use of renewable electricity, and a transport sector with the world's highest electrification rate. We are therefore well positioned to act as a laboratory for testing and verification of climate-friendly technologies and solutions. In this large-scale electrical laboratory, Norwegian industry stakeholders can develop and test new technologies, solutions and services, which can then be deployed nationally and exported to an international market.

The ocean space represents opportunities for national value creation, through the utilisation of our energy resources and industrialisation. Norway has solid competitive advantages in marine energy technologies and the potential to win positions in a strongly growing market. A long coastline and vast marine areas will allow us to develop a domestic market for large-scale power generation and marine energy technologies and services. The country's industrial experience in shipping and oil and gas operations provides a good basis for sustainable and value-creating innovations. Relevant technologies and disciplines include subsea infrastructure, automation and logistics operations.

3.1.10 THE EU RESEARCH AND INNOVATION AGENDA

The EU emphasises research and innovation activities related to digitalised, efficient and integrated energy systems, and the topic is high on its research and innovation agenda. Both the European Green Deal and the European Strategic Energy Technology (SET) Plan define the energy system as an important prerequisite for the energy transition. There is extensive EU research in this area, and it forms a significant part of the Horizon Europe research programme.

The Horizon Europe 2023–2024 programme plan emphasises investment in projects in the field of efficient and integrated energy systems. Energy systems in Europe are more differentiated than in Norway and there is a great need for effective interaction between different energy carriers.

The Norwegian energy system must be developed in step with the European one. It is therefore important to harmonise our national knowledge and technology development with the EU research and innovation agenda.

3.1.11 THE INDUSTRY'S AMBITIONS FOR ENHANCING RD&I EFFORTS

Extensive changes in the energy system are expected nationally and internationally. The pace of development is rapid, and we need knowledge and technology that reflect this development. The industry has ambitions to respond to these developments by engaging in research and innovation activities on the following topics:

- Security of supply in the integrated and efficient energy system of the future.
- Cybersecurity in the integrated and efficient energy system of the future.
- Value creation in the development of industry, technologies and services.
- Stronger and increased pace of innovation for power and energy companies in interaction with entrepreneurs and supplier companies.
- Transition to an efficient, integrated and emission-free energy system based on comprehensive analyses of the Norwegian energy system in interaction with the European system.
- Modernisation and automation of energy supply with secure integration of various renewable energy carriers, infrastructures and energy technologies.
- Energy efficiency improvement, better energy utilisation and reduced energy and power needs.
- Effective decarbonisation of sectors and society at large to reduce GHG emissions.
- Technologies and solutions that lead to better energy utilisation by improving components and increased energy efficiency in industrial processes and among all consumer groups.
- A sustainable energy system with the least possible loss of biodiversity and environmental pollution.
- Knowledge-based development of infrastructure for future energy exports to a decarbonised EU.
- A digitalised energy system with efficient implementation of digital enabling technologies such as artificial intelligence, big data management, autonomy and IoT.
- Technologies, solutions and measures that will prevent cyber-attacks and reduce the vulnerability of the future integrated energy system.
- Test and demonstration projects in the existing energy system for testing technologies and solutions, in connection with operation, monitoring, maintenance and deliveries and interaction with end customers.

Today's energy system is not dimensioned or designed for the future power demand and energy mix. The business sector emphasises the need to enhance RD&I efforts that can ensure an energy system for the future with satisfactory security of supply and power generation, and which safeguards a flexible energy mix and contributes to value creation.

3.1.12
KEY RESEARCH AND INNOVATION TOPICS

The key area "Integrated and efficient energy systems" is broadly composed and includes many subject areas. Based on input from stakeholders in the industry, RD&I institutes and academia, as well as analyses of knowledge and technology needs, the Energi21 board recommends focusing research and innovation efforts on the following core topics:

Efficient and flexible interaction between different energy infrastructures, energy carriers and end users.

- Transition studies and solutions.
- Investment and operational modelling and analysis of the energy system at the local, national and international levels both onshore and offshore.
- Sector coupling and infrastructure linkage.
- Flexibility solutions, output issues, security of supply.
- Interaction between energy carriers and integration of different energy carriers with the power system.
- Models and area plans as tools for comprehensive energy planning on a regional basis (interaction between different types of infrastructure and good utilisation of their capacity, identification of flexibility potentials and utilisation strategies, the impact of weather on interaction in the energy system).
- Efficient development and utilisation of Norwegian energy infrastructure (transmission, distribution, storage along different time scales) to electrify and contribute to:
    1. integration of more variable, renewable energy.
    2. utilisation of local energy resources and flexibility.
    3. maintaining good security of supply in Norway in the green transition.
- Optimal development of infrastructure in co-used marine areas.
- How thermal heat, cooling and power (CHP) can balance output issues in the power system.
- Cost-effective development of energy export infrastructure to Europe (infrastructure interaction, interaction with the Norwegian and European energy systems).

Photo: *Håkan Wallen, Statnett*

Major investments in the energy system are needed at the national and international level to meet requirements for the delivery of renewable energy, flexibility and security of supply. This investment need is an opportunity to develop new innovative components and solutions. RD&I efforts should therefore emphasise the next generation of components and innovative system operation.

Next generation components and systems

- The next generation cable technology, electrotechnical components (smart components).
- Development of improved components (including material development) for the integrated energy system.
- The next generation power system.
- Intelligent components for conversion between energy carriers and energy storage.
- Adaptation of existing pipe infrastructure for transporting of H_2 and CO_2.
- Cost-effective and secure infrastructure for energy carriers and logistics chains (hydrogen, ammonia, CO_2).
- Large-scale energy storage and batteries.
- Fiscal measurement systems for integrated power/hydrogen/natural gas/biogas infrastructures enabling cross-energy trading.

Multidisciplinary analysis models, simulation tools and innovative management systems

- Dynamic and multidisciplinary analysis models and simulation tools.
- Energy system modelling that includes both the stationary system and the transport system.
- The next generation power of system operation.
- Develop a comprehensive modelling platform for knowledge building on the macroeconomic impacts of the energy transition, climate impacts, intersectoral interactions and interactions between different geographical levels (local, national and European).
- Digital twins for virtual presentation and numerical calculations.

Digitalisation and cybersecurity[7]

- Effective planning, monitoring, management, operation and maintenance using artificial intelligence (AI), big data management, autonomy and the Internet of Things.
- Sensor technology, advanced grid operation, security of supply.
- Cybersecurity and privacy.
- Systems and methods for better coordination and sharing of cybersecurity knowledge between stakeholders.

Central heating station in Ås. *Photo: Bjørn Blondal, Statkraft*

Nature and the environment

- Circular economy – efficient use of energy and re-use of materials throughout their life cycle.
- Weather and forecasting models for energy resources such as water/wind/solar.
- Land use and environmental impacts of different types of energy infrastructure.
- Develop a system for better land use to limit carbon emissions and loss of nature from the development of renewable energy.
- Develop methods for mitigating and restoring nature that has been degraded as a result of land being used to develop renewable energy facilities.
- Measures to address land-use conflicts between the renewable energy industry and other business activities.

3.1.13
MEASURES FOR IMPLEMENTATION

In the following, recommendations and relevant measures are described that are designed to help realise the industry's ambitions for an integrated and efficient energy system.

Measures for research, development and innovation

- Establish multidisciplinary knowledge-building and innovation projects of relevance to the development of "Integrated and Efficient Energy Systems" and support key RD&I topics.
- Establish a centre dedicated to the topic "Integrated and efficient energy systems" covering all energy infrastructures, production technologies and end users. This centre should have a strong link to topics emphasised in the "Energy markets and regulation" key area.
- Further develop the funding and policy instruments to ensure interaction and participation of all types of users in the projects. Particularly important for the RD&I topic: Multidisciplinary analysis models
- Continue the Green Platform Initiative and Pilot-E scheme.
- Scale-up of infrastructure concepts through increased use of pilot projects and testing in local energy systems. Contribute to faster realisation of infrastructure projects.
- Establish large-scale research infrastructure that enables collaborative projects across disciplines and national boundaries.
- Collaboration between authorities, expert groups and energy stakeholders on solutions targeting environmental challenges and loss of biodiversity when developing the energy system of the future.

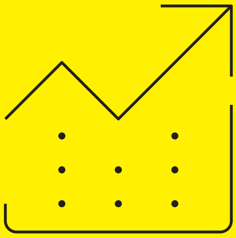
Commercialisation and market introduction measures

- Implement funding and policy instruments for faster implementation of RD&I projects.
- Risk-reduction measures for supplier companies related to the development of new technology.
- Coordinated application for funding for infrastructure and use of infrastructure to generate results faster.
- Comprehensive infrastructure planning by expanding the planning bodies to include more stakeholders.
- Simplify the implementation of pilot projects by adapting regulations or temporary exemptions – "regulatory sandbox".
- Increase parallel use of high TRL projects and knowledge-building projects to support the process towards commercialisation.

Measures for competence development and recruitment

- Make available transparent or open simulation models and data both nationally and in the EU. Data acquisition is currently challenging and means that some projects cannot be implemented or have reduced value.
- National, regional and local authorities must have expertise and access to tools to plan and implement comprehensive energy solutions.
- Strengthen educational capacity in the field of energy and digital literacy.
- Study programmes that give broad knowledge of different energy carriers, infrastructures and integration into the energy system, as well as digitalisation.

[7] *See the Energi21 report: "Digitalisation of the energy sector – Recommendations for research and innovation" for a more detailed description of RD&I topics*



3.2 Energy markets and regulation

The key area “Energy markets and regulation” is central to facilitating an efficient transformation of the energy system.

This key area entails developing a framework for action and decision-making relating to the timely transition of the energy system. The energy sector must be restructured to achieve climate and environmental goals, while at the same time safeguarding security of supply, keeping costs down and avoiding unacceptable distributional effects.

Onshore and offshore experience shows that technology adoption can run aground due to a lack of support from stakeholders. It is therefore important to ensure that knowledge of funding and policy instruments enhances stakeholder involvement and effective technology adoption in technology markets and society in general, and by end users in particular.

3.2.1 INVESTING IN ENERGY MARKETS AND REGULATION...

... is important for establishing framework conditions that stimulate the decarbonisation of transport and industry.

... is important for establishing framework conditions that help maintain security of supply, reduce GHG emissions and take account of biodiversity.

... is important for ensuring competitive framework conditions for power-intensive industry to keep costs down for households, other business activities and public services. It also paves the way for Norway to seize the opportunities presented by the new green industry, marine energy technologies and for supplier restructuring and development.

THE KEY AREA “ENERGY MARKETS AND REGULATION” INCLUDES THE FOLLOWING TOPICS:

- Energy markets and monopoly regulation.
- Energy security and changes in energy use.
- Business models, value chains, the roles of the private and public sectors.
- Legal and economic framework for the green transition, including infrastructure, components and a life-cycle perspective.
- Societal development and energy transition – resilience, efficiency, distributional effects and environmental friendliness.
- Norway as a part of the European energy market – legal and economic topics and simultaneity in decision-making processes.

3.2.2
THE IMPORTANCE OF THE RIGHT FRAMEWORK CONDITIONS FOR THE ENERGY TRANSITION AND NORWAY

The Norwegian authorities and society have set the target of achieving a zero-emission energy system by 2050. As early as 2030, GHG emissions are to be reduced by at least 55 per cent. Norway must see to that the restructuring of the energy system unfolds in a way that ensures climate and environmental targets are met and that the energy supply is as safe and cost-effective as possible.

The wide-ranging changes in the energy system will have an impact on public sector revenues and on the distribution of costs and benefits between the business sector, households and between countries. Major distributional effects pose the risk of increasing the level of conflict, which could in turn slow down therestructuring of the energy system.

Framework conditions for utilising energy resources and ensuring security of supply

The energy transition requires the deployment of large amounts of new renewable and zero-emission energy while fossil energy carriers are phased out. Successful restructuring requires the establishment of framework conditions that stimulate more use of renewable and zero-emission energy carriers and efficient use of energy. However, it also requires us to facilitate efficient utilisation and development of infrastructure for transferring energy to end users, both within and between countries. The transition raises questions related to investment incentives for new power generation and infrastructure, development of the offshore grid, hydrogen and CO_2 value chains, security of supply and the importance of more active customers in the energy system.

Investment incentives in production

An important question is whether the current market design ensures sufficient incentives to invest in new production in a future energy system that will mainly consist of renewable energy with very low marginal costs. Will sufficient new production be triggered by market prices in time, or will investments have to be co-financed through the use of support schemes?

With the prospect of a falling cost curve for new technology, stakeholders have an incentive to wait to invest. In such cases, it makes sense to design funding and policy instruments that nevertheless make it profitable for stakeholders to carry out the investments so that the cost reductions are realised. But what funding and policy instruments are most appropriate to ensure the effective development of new technologies such as floating offshore wind?

Development of new value chains

In order to utilise energy resources related to, for example, the production of green and blue hydrogen, including CCS, it will be necessary to establish completely new value chains in an area where there at present is barely a supply or a market. If we are to succeed, it will be necessary to develop a framework for the stakeholders that makes investment commercially profitable.

The timely development of adequate infrastructure on land and at sea

Another important question is what framework we will need to develop adequate infrastructure for transporting and storing energy for electrification and use of other zero-emission energy carriers. How are we to facilitate infrastructure development that makes the best use of the various energy carriers in the energy system? How do we build the infrastructure quickly enough to achieve the goals we have set ourselves? What incentives and decision-making processes must society further develop that also ensure acceptance for the implementation of infrastructure investments? In order to utilise our ocean-based energy resources, we must establish a new framework for the development of an offshore grid in cooperation with the countries around the North Sea. Important questions relate, among other things, to how the costs of infrastructure development are to be distributed between countries and stakeholders , han how it has to be organized., There are also several questions related to market design, for example the division of responsibilities between stakeholders and central grid companies, which price areas are defined, how bottleneck revenues are to be distributed and how closely markets should be integrated. Not least, there are a number of issues related to how to plan the utilisation of the ocean space, competition law issues and the removal/decommissioning of facilities.

Facilitating an active role for consumers

Technology developments enable customers to play a more active role in the energy system through better consumption management, increased self-generation and storage of energy and a greater degree of interaction with the collective energy system. This involves stronger integration of local generation, storage solutions, energy management and microgrid development into the energy system. The energy crisis in Europe clearly demonstrates the need for such s olutions. The sharp increase in electricity prices that households and businesses are unable to address themselves in the short term, or have substitutes for, are accelerating these developments. Establishing framework conditions that allow households and businesses to influence their own electricity bill to a greater extent is becoming more important to gain acceptance for the energy transition.

Security of supply
The energy and energy price crisis in Europe in 2022 shows the importance of security of supply and how vulnerable society is to unexpected events. Restructuring the energy system is an immense task that will inevitably lead to more unexpected events. An important question will be how we can mitigate the effects of this type of event on the energy system and the consequences for society. Should we facilitate greater flexibility between energy carriers than is required by purely economic considerations in order to maintain a higher security of supply? How can we establish solutions for flexibility and balance services to ensure a stable power system? To ensure that we maintain the momentum of the energy system transition, it is necessary to develop and adapt the framework of the energy system so that it is as robust as possible for events that could challenge security of supply.

Framework conditions to facilitate a sustainable low-emission society
Establishing the right framework conditions to reduce GHG emissions is, of course, crucial to succeed in the energy transition. At the same time, it is essential to take into account the requirements of nature conservation and biodiversity and, not least, to ensure that natural resources are used as efficiently and with as much care as possible. Some of the core issues to be considered are how to address areas where there is inadequate or no regulation aimed at reducing GHG emissions, how to handle unintended distributional effects and how to progress towards a more circular economy.

Reducing GHG emissions and protecting nature
Establishing framework conditions to reduce GHG emissions and protect nature can, for example, involve economic incentives such as funding schemes or taxes, market-based schemes (CO_2 allowances), but also legal requirements for stakeholders related to environmental standards and land use.

Transportation of concrete elements for Hywind Tampen. *Photo: Jan Arne Wold, Equinor*

Inadequate or lacking regulation can in many cases be a significant barrier to employing new technologies in the energy transition. An analysis carried out on behalf of Energi21 shows that more than half of the respondents involved in RD&I projects in the key area "Digital and Integrated Energy Systems" mention the lack of alignment of the regulatory framework as one of the top three barriers to further work in the area (Menon, 2021).

Distributional effects

The design of the framework conditions also has implications for the distribution of costs and benefits in society, and this is generally desirable. For example, we want to support the development of renewable production and to penalise the use of fossil energy carriers in order to bring about a change in behaviour. However, the transition can also have unfortunate distributional effects in that the costs for some groups in society are perceived as unacceptable. Major distributional effects pose the risk of increasing the level of conflict, which could slow down the transition of the energy system.

Circular economy

Facilitating a sustainable low-emission society also means that the framework conditions must facilitate a circular economy. In a circular economy, natural resources and products are used as efficiently and for as long as possible in a cycle, and as few resources as possible are lost. This involves, for example, minimising the loss from converting from one energy carrier to another and the loss on transfer of energy. Among other things, this will involve better utilisation of surplus heat from industrial processes and data centres, and requirements for recycling or reuse of components.

Framework conditions for developing a competitive and value-creating energy industry

Keeping costs down in the energy transition is important to ensure competitive framework conditions for power-intensive industry in the international market, but also for other business activities and households that demand goods and services. It is therefore key to design framework conditions for markets and monopoly activities that give incentives for cost-effective operation and development of the energy system. This entails framework conditions for minimising necessary infrastructure investments, making better use of existing infrastructure and for developing new markets and business opportunities.

A competitive energy industry

The energy transition is extensive and fast-paced. Both new production and new consumption must be connected to the grid. It will be important to develop a good framework to coordinate the location of new production and consumption to areas where the infrastructure investment required is lowest. Excessive investment in infrastructure also leads to unwanted encroachments on nature.

In order to keep costs down, it is also important to ensure that regulation stimulates the best possible use and re-use of existing infrastructure. The capacity of existing infrastructure can be better utilised through, for example, the development of local flexibility markets (market platforms), the use of storage solutions such as batteries and hydrogen, or by facilitating adapted regulation that, for example, opens the way for conditional grid connection.

Supplier and business development

The transition also offers great opportunities for supplier development and the establishment of new green industries in Norway. A central aspect of facilitating supplier and business development in Norway is the design of framework conditions for building new value chains where a market needs to be established (as is the case for hydrogen), and/or where commercial business models must be developed that stakeholders can participate in.

3.2.3 COMPETITIVE ADVANTAGES AND IMPLEMENTATION CAPACITY

Norway is an energy nation with a long and successful history of developing and adapting the energy system's framework conditions. We were quick to establish framework conditions for the development of hydropower, which is still the backbone of the Norwegian power supply. Already in 1909, steps were taken to ensure that the hydropower resources would remain in Norwegian hands. The development of hydropower has been an important factor in the development of Norway as a modern and industrialised country. In deregulating the sector in the 1990s, we laid the foundations for even more efficient use of our energy resources and infrastructure. Based on these experiences, Norway has played a key role in developing the market design for power markets in the Nordic region and Europe.

Norway has a long tradition of developing framework conditions adapted to changes in energy policies and the markets around us. The country has expert environments with experience of this area in academia and other research communities, and in the authorities, consultancy companies and business and industry. Legal research in Norway, for example, was recently evaluated through the JUREVAL project and is considered to be of high international quality with great societal value. Several FMEs[7] have also been established, such as NTRANS and INCLUDE, which focus on social science issues related to the energy transition.

[7] *FME centre: Centre for Environment-friendly Energy*

On this basis, Norway can continue to play a role in developing framework conditions for the energy sector that are well adapted to the challenges we now face. However, it is important to stress that the rate of change in the transition towards 2050 is quite different now than it has been in previous decades. This means that substantial research and development efforts will be required going forward to ensure good organisation of future framework conditions.

3.2.4
EU CLIMATE AND ENERGY POLICY TO FACILITATE A RAPID AND FAIR ENERGY TRANSITION

The EU's energy policy is in great flux. The EU's Fit for 55 package has been an important step in clarifying political priorities for the transition of the energy sector to meet the raised climate ambitions for 2030.[8] The ambitions and proposals for up-to-date rules and market conditions in the package lay down direct guidelines for the development of the energy sector, but also have an indirect influence through the decarbonisation of other sectors.

Fit for 55 comprises, among other things, a proposal for a revision of the Renewable Energy Directive and an increase in the renewable energy target from 32 to 40 per cent by 2030. The Directive also makes more stringent sustainability requirements of different technologies. It has also been proposed that the Energy Taxation Directive be revised to provide incentives for developing renewable and low-emission energy technologies and remove outdated incentives that support and sustain the consumption of fossil fuels.[9] In particular, it is proposed that the minimum levels of taxation on fossil fuels should be linked to energy content and environmental impact.

Tightening of the EU Emissions Trading System (EU ETS) and increasing allowance prices will have a direct impact on fossil power producers and an indirect effect by increasing the cost of energy-related emissions. The introduction of a carbon tax on the import of power and power-intensive goods such as aluminium, cement, iron, steel and fertilisers has also be proposed from 2026.[10] The development of a decarbonised Norwegian energy system could as such make Norwegian export-oriented industries in the EU more competitive.

To protect consumers and ensure a fair energy transition, the Fit for 55 package proposes the establishment of a new social climate fund of EUR 72.2 billion to help reduce negative distributional impacts related to climate and energy policies in the period 2025–2032.[12] The negative impacts the fund is intended to mitigate include price risk and energy poverty for households and small businesses, and it will also provide access to low-emission transport solutions. It will further help promote measures relating to energy efficiency improvement, energy saving and renewable energy.

In previous crises, the EU has chosen to ensure that efforts are also directed towards the achievement of long-term societal and climate goals. For example, it has been a goal that 37 per cent of the spending in the national recovery plans after the COVID-19 pandemic should contribute to the green transition. For the 22 national plans that have been approved so far, green funding is equivalent to 40 per cent, with the largest expenditure items being sustainable mobility, energy efficiency improvement, renewable energy and grid infrastructure.[13]

The war in Ukraine in particular has now further accelerated the transition that is necessary to reduce Europe's dependency on Russian natural gas in its energy supply. With the REPowerEU plan launched in March 2022, the EU has set the framework for further accelerating the development of renewable energy resources and diversifying gas supplies. The plan points in particular to increasing investment in biomethane, hydrogen, energy efficiency improvement, solar power and onshore and offshore wind power. In addition to stimulating the deployment of low-emission energy, the plan also aims to help reduce energy prices in the short term in order to protect consumers and the economy. This includes support schemes, price regulation measures and an assessment of improvement opportunities in energy market design.

This will likely mean further investment in the development of framework conditions for the energy system within the EU, which will be of great importance to Norway. It is therefore important that Norway intensifies its research and innovation efforts in this field. Although Norway is represented in the Horizon Europe research programme, the level of EU funding in Norwegian legal research is low, and in many institutions non-existent (JUREVAL, 2021).

[8] EC, 2021. COM(2021) 557 final.
[9] EC, 2021. COM(2021) 563 final.
[10] EC, 2021. Carbon Border Adjustment Mechanism. Factsheet.
[11] EC, 2021. COM(2021) 568 final.
[12] EC, n.d. Recovery and Resilience Facility. ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en (Accessed on: 15 March 2022)
[13] EC, n.d. Green transition. ec.europa.eu/economy_finance/recovery-and-resilience-scoreboard/green.html (Accessed on: 15 March 2022)

3.2.5
KEY RESEARCH AND INNOVATION NEEDS

Key research and innovation needs of stakeholders related to energy markets and regulation. It is vital that several academic perspectives are included in the research, including law, economics, sociology, etc., as well as science and technology perspectives.

- Relations between Norway and the EU/EEA related to economic and legal issues and common objectives.
- Restructuring and reuse of knowledge, expertise and systems from the oil and gas industry, but also restructuring and reuse of infrastructure and other facilities.

Energy markets, regulation, energy security and energy use, relations with Europe

- Norway's role in the future European energy market, including the degree of market integration, cross-border connections and other infrastructure and energy security, including:
  - What position do Norwegian and Nordic market solutions have in a European and international perspective?
  - How should the development of the offshore grid, the division into price areas, the division of TSOs' responsibility between countries and between TSOs and other stakeholders, and the management of bottleneck revenues, take place?
- Market design for managing increased flexibility and unregulated production, design of flexibility markets, sector coupling, international integration and competition law issues, including:
  - How can we ensure investments in sufficient renewable energy and flexibility in a market undergoing major changes?
  - What alternatives to "energy-only" markets are relevant, and how do they affect revenues and costs for all stakeholders?
  - How do different market designs affect security of supply and energy users in different areas of the country?
  - How will new energy carriers such as hydrogen affect and interact with the power market?
  - How will the interaction between district heating and electricity develop?
  - Knowledge of the integration of local production and management of energy use.
- Knowledge of the consequences of funding and policy instruments such as CFDs, certificate markets, subsidies, auction models and carbon pricing.
- Knowledge of funding and policy instruments that can trigger adequate electrification infrastructure and meet increased power demand.

Business and market models

- Knowledge of innovation, entrepreneurship and the role of the private sector.
- Develop low-carbon energy business models and build new value chains such as for hydrogen, CO_2 and batteries.
- Develop market models to enable more companies to offer flexibility, especially to households.
- Knowledge of customer behaviour, use of new technologies and solutions for active customer involvement.
- Circular economy related to the use of new technologies and to the development of new and existing value chains.
- Removal or decommissioning of power plants.
- Knowledge of how to ensure adequate capital access for climate technology.

3.2.6
MEASURES FOR IMPLEMENTATION

The Energi21 board recommends the following measures to meet the knowledge and technology needs of industry stakeholders and to realise their ambitions in energy markets and regulation.

RD&I

It is important that the measures implemented to address the key research and innovation needs facilitate close collaboration between the research communities and industrial sector and that a multidisciplinary approach is facilitated. This is crucial to make the research relevant and avoid it being conducted in "silos".

Education

- Develop courses of education that integrate multidisciplinary perspectives.
- Facilitate broad knowledge of legal education across areas of law, and highlight theme-based research in the educational pathway.
- Incorporate multidisciplinary insight and understanding of frameworks and regulations into technical disciplines in continuing and further education.

3.3 Hydropower

Hydropower is the backbone of the Norwegian energy supply and a competitive advantage in the transition to a climate-friendly society. The utilisation of natural water resources for power production is a key precondition for ensuring access to energy and achieving the energy transition in Norway, the Nordic countries and Europe. Hydropower generation is vital for ensuring sufficient supply security in the power system. The role that the flexibility of hydropower plays is in flux with the development of the power system, e.g. increased integration of variable wind and solar power and alternative forms of storage such as batteries. It is important to understand the interaction between hydropower and the rest of the power system and how to ensure optimal resource utilisation. Hydropower production is directly influenced by the climate, and how current and future climate change impacts production, nature and ecosystems, and market conditions for hydropower will become increasingly important. Furthermore, digital technologies will allow for cost reductions and further optimisation of resource utilisation.

3.3.1 INVESTING IN HYDROPOWER...

...contributes a significant proportion of the renewable energy necessary for the electrification of transport and industry.

...contributes to maintaining a secure power supply through unique regulation capabilities and storage capacity. This will become more important in line with a higher proportion of variable renewable power in the Norwegian, Nordic and European power systems.

...is important to develop new green industries since hydropower offers a competitive and reliable renewable power supply.

THE KEY AREA "HYDROPOWER" INCLUDES THE FOLLOWING TOPICS:

- Harnessing the flexibility of the hydropower system in interaction with the rest of the energy system.
- Hydropower technology for efficient and robust operation.
- Digitalisation – increased optimisation of planning, development, operation and maintenance and use of hydropower resources.
- Hydrology, inflow and climate adaptation.
- Flood control and multiple use of water and reservoirs.
- Potential for land-use impact on communities, nature and ecosystems.

3.3.2
MARKET DEVELOPMENT, OPPORTUNITIES AND CONSEQUENCES FOR NORWAY

The "Hydropower" key area makes a particularly positive contribution to utilising Norwegian renewable energy resources and is essential for security of supply in the power system.

Hydropower is essential for security of supply in the power system

Hydropower dominates the Norwegian energy system and hydropower reservoirs are essential to ensure security of supply in the power system. It is estimated that hydropower will play a role in new power generation in Norway towards 2030, with an estimated 6–9 TWh of new hydropower production (NVE, 2021 and Statnett, 2021). The role of hydropower as a flexibility resource should be further developed in order to increase efficiency within the framework of licences, thus contributing to system stability. Hydropower could also take on greater significance in a European perspective. With increased unregulated power generation in Europe, the demand for power will increase, in turn strengthening the value of Norwegian hydropower's flexibility and storage capacity. Increased output in the hydropower system can be achieved for example by converting to pumped storage hydropower plants or through new developments.

New hydropower requires encroachments on nature

The development of new hydropower plants can have a negative impact on nature and ecosystems locally, but also positive effects in the form of flood protection. In Norway, hydropower is currently seen as a technology with minor negative effects, relatively speaking. This is because our hydropower plants have already undergone major development, and because streamlining of production and resource use through upgrades and expansion of existing facilities will have a lower impact on nature than developing alternative forms of energy in new areas. When compared with other technologies, there is also a stronger tradition of incorporating nature conservation into both Norwegian hydropower management and research. However, we must continue efforts to limit new encroachments on nature and to utilise already degraded areas, as well as to investigate the potential to compensate for past degradation in order to achieve a net positive impact on nature.

Adequate and stable hydropower supply enables electrification, but hydropower will also balance an increasing share of variable generation going forward. Changes in production patterns as a result of increased variable power in the power system could affect local ecosystems. We should continue to develop knowledge and technology in order to find sustainable solutions that provide both more energy and more power in an environmentally friendly manner.

Market development and Norwegian value creation potential

Value creation from hydropower generation can be increased by more flexible generation over time horizons ranging from seconds to weeks and months. Flexible hydropower contributes to security of supply and the competitiveness of the industrial sector, and low emissions in the value chain are increasingly becoming a competitive advantage. The expected annual international investment in hydropower is relatively low at USD 71–94 billion in 2030 (NHO, 2020). There are opportunities for Norwegian hydropower stakeholders in the international market, and the Norwegian hydropower industry covers the entire supply chain with research communities, developers, operators, turbine manufacturers, electromechanical companies and digitalisation and remote operation companies. There may for example be a potential for an export industry based on solutions at the interface between hydropower expertise and digitalisation.

In most historic hydropower developments in Norway, operation and monitoring have been based on analogue systems, but the industry is now undergoing a transformation to optimise the hydropower system using digital technologies and solutions. Current digitalisation goals are to expand delivery capability, increase security and replace obsolete, analogue management systems. The potential for value creation from digitalisation lies in increased flexibility and efficiency during operation, increased efficiency in maintenance, reduced costs from better condition monitoring and less unplanned outages, improved security, HSE and security of supply. The digital elements include sensors, wireless platforms for real-time monitoring of power plants, river environments and reservoirs, condition monitoring of individual components, predictive maintenance systems, better decision-making support for power plant operators, new work order systems, measures for data security and automation of processes. This creates new research and innovation needs where great emphasis must be placed on interdisciplinary aspects that intersect all of the aforementioned topics. At the same time, it opens up opportunities for Norwegian industry to deliver solutions across the traditional industry boundaries.

3.3.3
COMPETITIVE ADVANTAGES AND IMPLEMENTATION CAPACITY

Norway has obvious geographical advantages in terms of hydropower, but it also has outstanding research communities within the whole spectrum of hydropower and robust stakeholders with long industrial experience in the field.

Norway has distinct natural advantages
Norway has a clear comparative advantage when it comes to hydropower in terms of its geography and climate. There are few regions in Europe with similarly good conditions for hydropower, and Norway is also Europe's largest hydropower producer. In addition, Norway has about half of Europe's storage capacity in hydropower. This can be utilised in a completely different way than today through increased installed capacity and pumped storage hydropower plants that can function as an efficient energy store, also in relation to factors (season, year) that cannot be covered in an economically efficient way by other storage technologies.

Leading technology and knowledge base
Norway has particularly strong hydropower research communities in areas such as planning, operation, optimisation of hydropower production and power market models. Research on large-scale balancing and energy storage, environmental impacts and environmental design has been strengthened through FME CEDREN. FME HydroCen is continuing much of this work with emphasis on hydropower structures, turbine and generators, markets and services and extended environmental design.

Bitdalsdammen. *Photo: Lars Petter Pettersen, Statkraft*

Research and innovation funding for hydropower projects is, according to a review of the Research Council's database, relatively modest. In the period 2017–2020, hydropower-related projects received NOK 200 million in R&D funds, which also triggered NOK 90 million in other funding (Menon, 2021). The majority of projects are at the higher end of the TRL scale (Menon, 2021). Equipment and technology suppliers are active in R&D projects. The Norwegian power system is in a class of its own in terms of the predominance of hydropower in the overall power supply. Due to relatively low research activity internationally, national investments are needed to ensure the necessary expertise on the role of hydropower in the energy transition. It is important to preserve hydropower expertise nationally both in terms of cost-effective and sustainable use of our water resources, but also to secure the recruitment of hydropower industry stakeholders.

Long industrial experience, but limited international success

Today, Norway has more than 1,500 hydropower plants and the majority of hydropower companies are state owned. Norwegian hydropower operators have over a hundred years of production experience and a broad knowledge base on operation in a distributed power system. The Norwegian hydropower industry had a turnover of NOK 10.6 billion in 2020, of which 90 per cent was domestic sales (Multiconsult, 2021). Turnover in the industry has remained stable in recent years, and contributes significantly to national employment in the renewable energy industry.

NORWEP[14] works, among other things, to strengthen Norway's international position in hydropower, but the hydropower industry has encountered reputational challenges in Europe. There are some smaller Norwegian stakeholders in the supplier market for large electromechanical components. A falling market and cost pressure are some of the challenges facing the Norwegian supplier industry (Menon, 2021). Possible new export opportunities include software and modelling solutions. Solar–hydro hybrid power plants also represent a new export opportunity, and may bring benefits for hydropower generation with reduced evaporation from the water surface and reduced sediment formation. In relation to digital solutions, it is possible to utilise the transfer of expertise from other segments of the energy industry such as oil and gas.

Norwegian hydropower projects have received around NOK 84 million in funding under Horizon 2020 (Research Council of Norway, 2021). The EU has hydropower projects in areas such as short-term flexibility (HydroFlex), pumped storage hydropower plants (XFLEX HYDRO) and fish and hydropower (FIThydro), but relevant EU research on hydropower is limited. Norwegian research institutions participate in networking activities under the auspices of the European Energy Research Alliance, the IEA and the DoE US without generating significant research funding.

3.3.4 KEY RESEARCH AND INNOVATION NEEDS

Key research and innovation needs are linked to the knowledge and technology needs of stakeholders along the entire hydropower value chain. Furthermore, the increasing role of hydropower as a provider of flexibility in the energy transition as well as digital solutions for optimisation of system operation are key topics for research.

The flexible role of hydropower in the national and European power system of the future

- Model development to understand the role of hydropower in the energy system of the future.
- Analyses of optimum utilisation of hydropower in the energy system based on system data.
- Market design and business models.
- Extended modelling of uncertain external factors such as emission and fuel costs, energy supply, etc.
- The potential of small hydropower plants for storage and flood control, and interaction with the power system.

New technology and upgrading of the hydropower system due to the changed production patterns

- New principles for plant design, and design, technology and materials relating to turbines, generators and control systems.
- Hydropower structures and multiple use of watercourses and reservoirs, for example for flood control. Calculate the costs of flexible operation (wear, likelihood of failure and increased maintenance, etc.).
- The role of hydropower in the circular economy.

[14] *NORWEP: Norwegian Energy Partners*

Digital technology in hydropower production

- Automated and cost-effective planning, development, operation and maintenance, for example fully automated drilling and blasting.
- Development of new sensor technology or other measurement/monitoring methods and utilisation of new data sources for improved decision-making bases and greater value creation opportunities from water resources.
- Digital twins for testing and demonstration along the entire value chain from component design to development/upgrading, as well as for operation and maintenance.

Combine physical and conceptual models with machine learning

- ICT security with increased digitisation.
- Open system description for developing virtual labs.
- Nature and environmental considerations.
- Impact on ecosystems and habitats through more flexible operations, as well as upgrades and improvements.
- Ecosystem restoration in connection with upgrades and extensions of existing and new hydropower plants.
- Environmental design of hydropower plants and environmentally adapted hydropeaking.
- Societal effects and acceptance of new production patterns.
- Mitigation measures and the potential for compensating for past environmental degradation to achieve a net positive impact on nature.

Climate change and effects on the hydropower system

- Changes in production potential (annual inflow and duration/magnitude/timing of hydrologic extremes).
- Climate change and ecosystem impacts in regulated watercourses and the effect of environmental measures.
- Reservoirs and their role in mitigating floods and reducing the risk of drought.

3.3.5 MEASURES FOR IMPLEMENTATION

The Energi21 board recommends that research, development, demonstration and commercialisation activities be undertaken targeting the most important research and innovation needs. The Energi21 board also recommends the following measures to meet the knowledge and technology needs of industry stakeholders and to realise their ambitions in the hydropower field.

RD&I

- Large-scale laboratories for testing of innovative solutions in collaborations between industry and research and education communities.
- Solutions for demonstration in existing facilities
- Virtual laboratories for cost-effective and flexible testing including open access to models of hydropower and power systems.
- Sharing of operational data, while taking into account considerations of competitiveness and societal security.
- Further develop model systems for the energy system, market, operation, maintenance, watercourses and environmental impacts that communicate with each other.

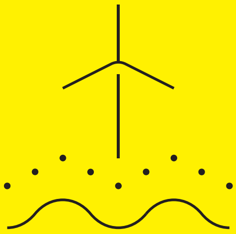
Commercialisation/market introduction

- Risk mitigation for long-running projects with uncertain returns.
- Develop flexibility markets.
- Ensure that hydropower becomes sustainable, including in the EU's taxonomy, and an important part of the green transition. Ensure transfer of knowledge-based information from the Norwegian authorities to the EU and promote EU investments in hydropower due to the increasing need for flexibility and hydropower's enhanced role as power storage.

Utdanning

Develop new national competence as the average age of stakeholders in the Norwegian hydropower industry is high. Generate new expertise, especially a combination of hydropower and digital competence, and make relevant study programmes more attractive to students.

Hylen power plant. *Photo: Lars Petter Pettersen, Statkraft*



3.4 Offshore wind power

Norway has natural, world-class offshore wind power resources, and utilising this power is important for securing sufficient renewable power in the energy transition. Major concrete development plans are currently underway for offshore wind power both in Norway and around the world. At the same time, many Norwegian stakeholders have ambitions in this area, and there is considerable potential for developing a supplier industry. Expertise from the oil and gas industry and the maritime industry shows that we are well positioned to take market share in the offshore wind power market of the future, for both floating and fixed-foundation wind turbines. The fact that the offshore wind power industry is moving towards deeper waters, further from shore and investing in bigger and bigger turbines presents new opportunities and research and innovation needs. Needs are related, among other things, to industrialisation and commercialisation of the value chain, integration of offshore wind farms in the power system and offshore area management. Reducing the costs of offshore wind power is an important goal for research and innovation initiatives.

3.4.1 INVESTING IN OFFSHORE WIND...

...contributes to renewable power that is needed for electrification, new green industry and for the production of green hydrogen for transport and industry.

...contributes a considerable potential for utilising offshore wind resources for power production. Expectations of rapidly falling costs mean that offshore wind power will contribute to a competitive power supply and export of power to Europe.

...contributes to the development of value chains for marine energy technologies. The development of a Norwegian offshore wind power industry can contribute to new jobs and further value creation for Norwegian suppliers in the maritime and offshore sectors.

THE KEY AREA "OFFSHORE WIND" INCLUDES THE FOLLOWING TOPICS:

- Fixed-foundation and floating offshore wind installations.
- Cost-reductions in development, operation and maintenance.
- Energy transmission and integration into the energy system, including hybrid cables, meshed offshore grids and energy islands.
- Offshore area management, environmental impact and social aspects.
- Market solutions, business models, regulation and law in a life-course perspective.
- Digitalisation.

3.4.2
MARKET DEVELOPMENT, OPPORTUNITIES AND CONSEQUENCES FOR NORWAY

The key area "Offshore wind" makes a particularly positive contribution to utilising Norwegian energy resources and to increasing competitiveness and value creation in the Norwegian energy industry. Offshore wind is probably the renewable power source with the greatest potential for growth in Norway in the long term.

Offshore wind can contribute large amounts of renewable power in Norway and Europe

The global potential is greatest for floating offshore wind, but at present, most of the installations are fixed-foundation facilities. Globally, 35 GW of offshore wind was installed by the end of 2020, of which 0.07 GW was floating offshore wind (GWEC, 2021). Large-scale development of offshore wind in the North Sea and the rest of the EU is planned, with targets of 60 GW by 2030 and 300 GW by 2050 (COM/2020/741). In addition, the UK plans to expand 100 GW in its marine areas. In May 2022, the Norwegian Government announced its ambition to allocate areas for 30 GW of offshore wind power by 2040.

In early 2022, Norway opened the door for applying for a 4.5 GW licence divided between two areas, Southern North Sea II and Utsira (Norwegian Government, 2021). Furthermore, the Norwegian Water Resources and Energy Directorate (NVE), on assignment for the Ministry of Petroleum and Energy, is investigating several areas off the Norwegian coast. The currently announced licences may be suitable for both fixed-foundation and floating offshore wind installations. Offshore wind has largely been too costly to compete on price without subsidies. The expectation is that the cost level of floating offshore wind will be able to compete with fixed-foundation offshore wind by around 2030. At the same time, Europe is experiencing a sharp rise in electricity prices in 2021/2022, and if the high price level persists, floating offshore wind power may become profitable sooner than previously assumed (NTNU and SINTEF, 2021).

New power generation generally contributes positively to security of supply in Norway in the face of increasing power demand. At the same time, an increased share of unregulated generation in the power system may result in greater fluctuations in available power generation. In the case of Norway, regulated hydropower will absorb part of this effect. The ambitious European plans for utilisation of offshore wind require development of the transmission grid. If grid development takes place in a coordinated manner between countries, it is possible to reduce costs and establish more robust solutions. Energy islands can function as nodes in a future offshore grid. The islands may be actual islands or platform-based solutions with HVDC converter stations for connection of offshore wind farms or other offshore energy-related activities, such as facilities for hydrogen production, CCS, filling stations for ships, or connection of oil and gas installations.

Huge investments in offshore wind entail great opportunities for the Norwegian export industry

The EU plans to invest EUR 800 billion towards 2050 in offshore wind development in order to achieve the objectives of its Offshore Renewable Energy Strategy (COM/2020/741). Two thirds of the investments will be earmarked for the development of grid infrastructure. Globally, investments in offshore wind are estimated to amount to USD 1,500–5,000 billion by 2050 (NHO 2020). Large-scale national and international investment in offshore wind offers opportunities to transform and further develop the Norwegian offshore supplier industry, especially in the field of floating offshore wind. Revenues from Norwegian offshore wind has grown over the past five years, and amounted to NOK 13.9 billion in 2020, of which 80 per cent was export (Multiconsult, 2021). NHO has estimated the turnover potential for Norwegian actors to be EUR 5 billion per year in 2030, while Norwegian Energy Partners has estimated an annual export potential of EUR 10 billion in 2030 (NHO, 2020).

Large-scale development has consequences for nature and the environment

Offshore wind is area-intensive, and there are several unknown effects, both negative and positive, on nature and the environment in connection with the large-scale development of offshore wind. Norway lacks knowledge about marine areas of biological importance and how offshore wind development can conflict with natural assets and other business interests.

In addition, the production of turbines and components for offshore wind entails the use of rare earth elements for magnets and steel and uses composites that are demanding to recycle. The EU Offshore Renewable Energy Strategy emphasises research and innovation on circular materials and the necessity of avoiding the use of critical raw materials in design and production (COM/2020/741).

3.4.3
COMPETITIVE ADVANTAGES AND IMPLEMENTATION CAPACITY

Norway has significant natural advantages, a strong technology and knowledge base and relevant industrial experience based on expertise from the petroleum industry and the maritime sector. In addition, Norwegian stakeholders are ambitious and aim to take market share internationally.

Norway has significant natural advantages

Norway has an enormous technical potential for both floating and fixed-foundation offshore wind due to large marine areas with good wind resources. The offshore wind resources in the North Sea and the Norwegian Sea are particularly good, and the total technical potential for offshore wind in the North Sea is many times that of Europe's power demand (IEA, 2019).

Strong technology and knowledge base

Norway has strong research and innovation communities in offshore wind. We also have extensive experience of targeted research and innovation efforts through investments in the Centres for Environment-friendly Energy Research. FME NorthWind (Norwegian Research Centre on Wind Energy) has several key stakeholders in its consortium and works on central issues for wind power development, such as wind resources, digital twins, system integration, marine operations, logistics, structures and integrity. Norwegian research communities also have extensive experience of research for the petroleum industry on topics that are also relevant to offshore wind, such as subsea structures, wave modelling, geological conditions and offshore area planning.

During the period 2017–2020, NOK 2.7 billion was allocated to businesses related to offshore wind, mostly for demonstration and pilot projects for floating offshore wind (Menon Economics, 2021). Of the 140 grants in this area, Hywind Tampen has received 85 per cent of the funding.

Relevant industrial experience and strong industry ambitions

A number of Norwegian stakeholders have high ambitions in offshore wind development. Heavy industry enterprises have announced 40–50 GW as a national ambition for 2050 (KonKraft, 2022). In 2022, several stakeholders are positioning themselves to participate in the call for proposals that applies to the Southern North Sea and Utsira area. Norway's first floating offshore wind farm and the world's first offshore wind farm connected to oil and gas installations, Hywind Tampen, will start production in the second half of 2022. In the supplier industry, Norwegian stakeholders have ambitions to take a market share of 15–20 per cent for floating offshore wind and 10 per cent for fixed-foundation offshore wind by 2030 (Federation of Norwegian Industries, 2021).

For Norwegian stakeholders, the areas of project implementation, maritime operations, vessel design, high-tech operation and maintenance services, subsea technology and cables are highlighted as possible competitive advantages (NHO, 2020; LO/NHO, 2021). In addition, Norway has a competitive advantage in floating offshore wind because it can transfer expertise from the oil and gas sector in areas such as offshore marine logistics and floating concepts.

Many countries are in the process of building up their own offshore wind industry and in order for Norway to preserve the competitive advantages outlined above, continued investments in offshore wind are required, as well as ambitious businesses and authorities. Inability to access international customers and markets is a barrier for Norwegian offshore wind operators that various organisations are working to overcome. In addition, lack of competitive prices and regulatory predictability also represent challenges for offshore wind operators (Menon, 2021).

3.4.4 OFFSHORE WIND IS A PRIORITY AREA FOR ACTION IN THE EU

Offshore wind is a priority area for action and research to implement the energy transition in the EU. Offshore wind is a central part of Cluster 5 "Climate, energy and mobility" in Horizon Europe and is included as one of ten low-emission energy technologies in Europe's Green Deal initiative the European Strategic Energy Technology Plan (SET Plan).

Norwegian stakeholders contribute to designing the EU research agenda for offshore wind, including through the European Technology and Innovation Platform on Wind Energy (ETIPWind) and the European Energy Research Alliance (EERA) programmes.

3.4.5 KEY RESEARCH AND INNOVATION NEEDS

Offshore wind has previously been too costly to compete on price without subsidies, but costs have dropped in recent years. However, it is still important to reduce the cost level further. Research and innovation activities should have cost reductions as an overarching objective. Key research and innovation needs are linked to the knowledge and technology needs of stakeholders along the entire offshore wind value chain and to the role of offshore wind in the energy transition.

Offshore wind farms – production, installation, operation and maintenance

- Methods and technology for cost reductions in the planning, development, operation and maintenance of floating and fixed-foundation offshore wind farms. This includes models and design tools for optimisation and management of offshore wind.
- Development of cost-effective, robust, safe and environmentally friendly components and systems.
- New concepts and infrastructure for industrialisation and standardisation in the value chain.
- Floating mobile offshore wind concepts.
- Development of methods and tools for the design of large offshore wind farms. Design and verification of undercarriage and anchoring systems for large wind turbines.
- Tools and analysis models for wind resources and flows, waves, bottom conditions and the marine environment.
- Optimal marine operations and logistics, including coordination of infrastructure.

Infrastructure and integrated systems at sea

- Development of a flexible meshed North Sea offshore grid that takes into account scale-up opportunities, new models and designs of new components.
- Development and further development of technologies such as new unleaded cable technology, subsea technology, floating HVDC platforms, and HVDC interoperability and stability.
- Models and solutions for system integration and interaction with storage, generation and transmission technologies, including energy islands or other types of nodes in an offshore grid.

Market design and legal issues

- Design and development of market design, business models, energy auctions and tenders.
- Interaction between onshore and offshore production, integration of markets between countries, hybrid networks and the role of system operators.

Environmental and societal issues

- Methods for investigating and assessing environmental impacts related to offshore wind.
- Environmental design to minimise impacts on marine ecosystems, seabirds and other adverse effects on nature.
- Design, recycling and reuse of components in a circular economy.
- Offshore area use and resource management and planning, including overall effects and optimal design of new offshore wind farms.
- Addressing land-use conflicts between offshore wind and other marine activities and natural marine resources.

Digitalisation and cybersecurity

- Artificial intelligence, big data management and the Internet of Things to streamline the monitoring, operation and management of wind farms, as well as ensure interaction with the energy system.
- Weather monitoring and prediction models.
- System security and big data management.

3.4.6 MEASURES FOR IMPLEMENTATION

The Energi21 board recommends that research, development, demonstration and commercialisation activities be undertaken targeting the most important research and innovation needs. In addition, The Energi21 board recommends the following actions to meet stakeholders' ambitions and realise the necessary research and innovation activities in the field of offshore wind:

RD&I

- Increased support for innovation and technology development.
- Demonstration programme for the large-scale development of offshore wind.
- Support and development of research infrastructure, e.g. laboratories, simulation tools and research vessels etc.
- Better data access from research infrastructure and industry.
- Schemes that stimulate international cooperation (the EU, USA etc.).

Commercialisation/market introduction

- Resource and site mapping. Development of land-use plans and stakeholder agreements on the management of offshore wind and natural resources.
- Development of standards adapted to offshore wind, also for soft issues such as safety procedures.
- Support to apply for funding from the EU.
- Strengthen joint international efforts across Norwegian environments (TEAM Norway, embassies).

Education

- Strengthen and coordinate study programmes in the field of offshore wind.

Dudgeon Offshore Wind Farm. *Photo: Jan Arne Wold, Equinor*


DOW OS

3.5
Solar energy

The international solar energy market is in strong growth. Norwegian stakeholders in the process industry have export ambitions based on the development of low-emission materials by taking advantage of access to competitive renewable power. There is also growth in the domestic market, and research and innovation needs are linked, among other things, to the integration of solar power in the energy system. Norwegian actors are also involved in developing new solutions for floating and building-integrated solar power.

3.5.1
INVESTING IN SOLAR ENERGY...

...can contribute to decarbonisation in the form of distributed solutions for power and heat, particularly in areas with a poorly developed grid.

...will contribute to developing competitive renewable power and heat production, and give consumers ownership of power and heat production.

... can contribute to further value creation in the Norwegian process industry targeting a growing solar power market that emphasises low-emission materials and to developing new concepts such as floating solar power and building- and infrastructure-integrated photovoltaics.

THE KEY AREA "SOLAR ENERGY" INCLUDES THE FOLLOWING TOPICS:

- Solar power and heat in the energy and power system.
- Large-scale and distributed production.
- Operation and maintenance related to solar power generation.
- Floating solar power.
- Building-integrated photovoltaics.
- Solar cells production.
- Production of raw and composite materials.
- New materials, concepts and technologies.
- Recycling, reuse and circular industrial production.
- Impact on society, nature and ecosystems.

3.5.2 MARKET DEVELOPMENT, OPPORTUNITIES AND CONSEQUENCES FOR NORWAY

The key area "Solar energy" contributes to increasing competitiveness and value creation in the Norwegian energy industry and to utilisation of Norwegian energy resources.

A growing solar energy market and stricter requirements for sustainable value chains strengthen the international position of Norwegian material and component manufacturers

The domestic market for solar power is growing, and the annual installation rate in 2020 was 40–50 MW (Solar Energy Cluster and FME SuSolTech, 2020). This growth has led to increased turnover in the development, installation and operation of solar systems in Norway, especially in construction. International investments and development plans for solar power are immense; it is estimated that USD 470-1,500 billion will be invested in the period 2020–2030 (NHO, 2020). The international solar thermal market is also growing, and in 2020, around 500 GW of thermal capacity was installed globally, equivalent to around 400 TWhth/year (IEA Solar Heating & Cooling Programme, 2021). The European market represents a significant share of the global market and growth is expected in district heating, industrial applications and building and construction.

The Solar Energy Cluster and FME SuSolTech (2020) have estimated that the Norwegian solar power industry will generate annual sales of between NOK 60–118 billion in 2030 related to the installation of solar power facilities in Norway, solar parks, process industries and floating solar power plants. A large and rapidly growing international solar power market provides sales opportunities for Norwegian upstream companies. Stricter emission requirements in the value chain strengthen the international competitiveness and export potential of Norwegian silicon and system components and solutions. Furthermore, silicon is defined by the EU as a critical raw material and is central to the development of robust value chains (COM/2020/474). Solar power is also important in the EU's updated industrial strategy, which supports scale-up and industrial initiatives, including the European Solar Initiative. The EU also wants to strengthen the security of supply of a European PV industry.

There are furthermore new national and international market opportunities to be found in the development of hybrid power plants (where solar power plants are combined with other types of power generation) and floating solar power technologies. The National Renewable Energy Laboratory (NREL) has estimated the technical potential for hybrid floating solar power facilities on reservoirs to be between 3 and 7.6 TW (Lee et al., 2020). So far, 2 GW of floating solar power has been installed globally and this is expected to increase to 10 GW by 2025 (DNV, 2021).

Solar power can contribute to increased distributed and integrated power generation

The development of solar power in Norway is growing and the Norwegian Solar Energy Cluster (Solenergiklyngen) and FME SuSolTech (2020) expect 1–4 TWh of new production by 2030. Towards 2040, NVE (2021) expects growth of 6–7 TWh compared to the current levels. The technical solar potential is significantly greater; Multiconsult and the Institute for Energy Technology (IFE) have estimated a potential of 32 and 50 TWh, respectively, for solar power installed on buildings (Solar Energy Cluster and FME SuSolTech, 2020). The potential for solar heat in Norway is also significant, and, in the short term, opportunities are particularly good in relation to heating in buildings, the district heating system and agriculture (Solar Energy Cluster and FME SuSolTech, 2020). Solar power in Norway enables distributed and increased power and heat production and can improve security of supply, especially in dry years. Increased solar power capacity in Europe also increases the demand for Norwegian regulated power.

Raw materials for cell production and the location of solar power plants are key environmental and climate challenges in the solar industry

The solar panel value chain often leads to societal conflicts and degradation of nature in connection with the extraction of raw materials. In addition, solar cells and collectors produced using fossil energy will reduce the technology's potential climate benefits. Solar power components produced with renewable power and using circular processes and materials significantly reduce the climate and material footprint of the production of solar panels and collectors.

The installation and operation phase of major solar ground installations is land-intensive and can lead to nature-related and land-use conflicts. Development of solar concepts integrated into buildings and other infrastructure can help reduce conflicts. Distributed solar power solutions give consumers the opportunity to become prosumers and produce their own renewable energy. Distributed solutions can also help increase security of supply in peripheral areas with less developed grids and contribute to increased self-sufficiency of renewable energy in critical industries such as agriculture. Solar power, especially on a smaller scale, also has the potential to meet increased power demand sooner than other technologies due to short lead times of one to two years.

3.5.3 COMPETITIVE ADVANTAGES AND IMPLEMENTATION CAPACITY

Norway has few geographical competitive advantages when it comes to the production of solar power or heat, but in turn has good prerequisites in the solar power value chain. In addition, Norway has strong research communities, especially in materials research, and we have a unique position as one of the few European suppliers of raw materials with long industrial experience.

Limited natural advantages for power generation, but significant advantages in the value chain

In Norway, solar irradiation on surfaces is 700–1,000 kWh/sq.m/ year. The potential for solar power decreases the further north you go (Solar Energy Cluster, n.d.). Local conditions such as geography, settlements and weather conditions also have a significant impact on production potential. One of Norway's advantages is the cool climate and snow, which help increase efficiency. The solar irradiation in Norway, especially in Southern and Eastern Norway, is almost equivalent to the conditions in countries such as Germany, where significantly more production capacity of close to 60 GW has been built up (NVE, 2021).

Topseed® produced by Elkem. *Photo: Elkem*

As regards the value chain, Norway has competitive advantages in terms of good access to competitive renewable power and raw materials. A low climate footprint in the value chain is increasingly emphasised in the EU, both in regulations and in concrete tenders, and will, according to suppliers, be one of the most important competitive advantages in the years ahead. Norway also has a good supply of raw materials such as quartz and carbon. Norwegian stakeholders have also developed circular processes based on waste from other process stages in the value chain as new raw material.

Strong technology and knowledge base

Norwegian R&D environments are advanced in materials research, especially silicon, power electronics, solar power systems and system integration. Recent research topics include hybrid power plants, floating solar power and circular production processes. The solar research communities are spread across the country and an FME for solar cell technologies, SuSolTech, has been established. FME SuSolTech aims to increase the size and number of jobs in the domestic solar cell industry.

In the period 2017–2020, Norwegian funding agencies granted NOK 1 billion divided between 157 solar power projects. This triggered other funding of NOK 580 million (Menon, 2021). Norwegian projects have also received EU project funding of NOK 77 million through Horizon 2020 (Research Council of Norway, 2021). Norwegian research groups play central roles in international initiatives such as the EU's EERA JP Photovoltaic Solar Energy programme and the IEA Photovoltaic Power Systems Programme.

Norway has unique industrial experience in Europe

The Norwegian solar power industry has a broad scope and includes, among other things, companies at the international forefront of their segments. Norway is one of the few countries in Europe that produces silicon, ingots and wafers. The availability of renewable energy, resource and energy efficient production, and to some extent circular processes, are becoming increasingly important competitive advantages with the introduction of emission requirements and eco-design in the solar power industry.

Modelling tools and smart management systems for solar power are areas where Norway is well positioned. Norwegian stakeholders are also involved in the development of new solar power concepts with future export potential, including floating solar power technology, hybrid power plants and building-integrated solutions. The development of floating solar technologies is based on the offshore industry's expertise in adapting facilities for more demanding conditions. Floating solar power is also being developed in combination with hydropower plants, where the facilities are installed in reservoirs and tend to have higher efficiency than land-based plants. Experience with optimisation and flexibility models from the power system and offshore industry can be further developed for the integration of hybrid energy and infrastructure solutions.

The Solar Energy Cluster is the industry's meeting place and has ambitions for industrial growth as well as working to promote international cooperation and the development and industrialisation of new and sustainable solar power solutions. The Norwegian solar power industry had a turnover of NOK 6.9 billion in 2020, of which international sales accounted for 85 per cent of the total turnover (Multiconsult, 2021). At the national level, solar capacity has grown steadily in recent years and employment is mainly linked to equipment deliveries (Multiconsult, 2021). The domestic market for solar power and heat is still at an early stage and further growth offers significant opportunities for local employment.

3.5.4
SOLAR POWER IS HIGH ON THE AGENDA IN THE EU

Solar power is a key energy technology to achieve the EU target of increasing the share of renewable energy by 2030. In 2021, this target is 32 per cent, but a proposal has suggested raising this to 40 per cent. The target will not only lead to large amounts of new renewable power generation, but also to increased focus on low-emission solutions for heating and cooling and the need for thermal solar concepts. The EU has solar power on its research and innovation agenda, and the European Commission is working on its own photovoltaics (PV) strategy to be launched in 2022. Several EU initiatives have been established for the development of a European value chain and there are plans to establish an IPCEI for PV. Improving the self-sufficiency rate of solar cells production and renewable power is increasingly emphasised. Several of the member states' national recovery plans as a result of the COVID-19 pandemic include funding schemes to stimulate the installation of solar panels. In addition, the EU has an increasing focus on low-emission cities and energy communities, including the development of local solutions for solar power and microgrids.

3.5.5
KEY RESEARCH AND INNOVATION NEEDS

Key research and innovation needs are linked to the knowledge and technology needs of stakeholders along the entire solar power value chain. The main overarching themes are research and innovation that provide cost reductions in the development, installation and operation of solar power and that increase the value of the solar power produced. The research topics can be roughly categorised as solar power in interaction with the power system, integrated and new concepts, and sustainable materials production.

Solar power in the system and digitalisation

- Integration of solar power into the power system.
- Flexibility and storage solutions for solar power (batteries and thermal).
- The effect of thermal energy solutions on power consumption and the energy system.
- Integration of solar heat in the process industry.
- Digitalisation and smart management of solar power plants.
- Project development tools and forecasts (resource mapping, system parameters).
- Performance and degradation of solar power systems in Norway.
- Solar plant operation and maintenance.
- Local energy solutions for solar power and heat as an alternative to grid connection.

New concepts and technologies

- Hybrid power plants (solar+water, solar+wind, solar+batteries, solar+X).
- Solar power and heat in agriculture (Agri-PV).
- New concepts for solar collectors.
- New technologies for floating solar power.
- New technology for building-integrated systems.
- Development of future circular processes for the production of materials for cost-effective and environmentally friendly (silicon-based) solar cells.
- Development of future materials for solar power in a circular economy.

Environmental and societal issues

- Regulation and framework conditions for local energy solutions as an alternative to grid connection.
- Measures to address land-use conflicts between the solar power industry and other business activities.
- Develop methods for better land use to limit carbon emissions and loss of nature from the development of solar power.
- Environmental impact of large-scale PV installations and nature considerations adapted to Norwegian conditions.
- End-of-life and circular industrial production
- Sustainable production processes and regulatory frameworks, and documentation for sustainability in production.

3.5.6 MEASURES FOR IMPLEMENTATION

The Energi21 board recommends that research, development, demonstration and commercialisation activities be undertaken targeting the most important research and innovation needs. The Energi21 board also recommends the following measures to meet the knowledge and technology needs of industry stakeholders and to realise their ambitions in the solar power field:

RD&I

- Continue the solar centre initiative.
- Funding and policy instruments for mapping solar resources.
- Secure opportunities for R&D projects at a higher TRL level and support participation in EU fora.
- Participate actively in the design of EU calls to ensure relevance to the Norwegian solar industry.

Commercialisation/market introduction

- Facilitate a broad domestic market.
- Facilitate the sharing of key data to plan and develop solar cells and solar thermal systems in Norway. This includes building data, production data, geographical data and grid data. Carbon footprint requirements can stimulate the Norwegian supplier industry in the international market. Take an active role in shaping EU processes (Eco design, Energy label for PV, Green Public Procurement).
- Harmonised methodology for estimating pricing and documenting sustainability.
- Norway should play an active role in the establishment of and participation in an IPCEI for PV and European initiatives to build European value chains.
- Actively participate in the design of relevant regulations such as the Eco Design Directive and the Energy Label and Green Public Procurement.

Education

- The solar power industry has a great need for capacity and, among other things, lacks installers. There is a need for more places on vocational programmes conferring a craft certificate and on bachelor's and master's degree programmes.

Photo: Equinor

3.6 Batteries

Developing and applying electric battery technology is crucial to the decarbonisation of transport, while it also presents an opportunity for developing new green industry. Norway already has an established process industry based on key battery materials, and is a world-leading manufacturer of battery packs for the maritime sector. Several actors have also implemented plans for battery cell production. Developing a national battery value chain will require considerable investment in education and knowledge-building, access to international markets and maintaining Norwegian competitive advantages.

3.6.1 INVESTING IN BATTERIES...

... is particularly crucial for the decarbonisation of the transport sector.

... can contribute to balancing the power grid and reducing power peaks, thereby improving delivery and security of supply in a power system marked by growing variable renewable power production.

... will contribute to developing new green industry that will generate thousands of jobs. This will be in the form of a Norwegian battery value chain based on established process industry and newly established cell production that takes advantage of competitive renewable power and local access to important raw materials.

THE KEY AREA "BATTERIES" INCLUDES THE FOLLOWING TOPICS:

- Processing of raw materials.
- Battery chemistry, battery cell production and battery systems.
- Process design for scale-up.
- Batteries in the power system.
- Batteries in applications, including hybrid systems.
- New materials, technologies and concepts.
- Charging technology and concepts, including high-power charging.
- Battery safety and control systems for batteries, including hardware and software.
- Recycling and reuse.
- Digitalisation and automation.
- Impact on communities, nature and ecosystems.

3.6.2 MARKET DEVELOPMENT, OPPORTUNITIES AND CONSEQUENCES FOR NORWAY

The "Batteries" key area makes a particularly positive contribution to decarbonising the transport sector, balancing the power grid and increasing competitiveness and value creation in the Norwegian energy industry.

Batteries enable high emission cuts in the transport sector, and Norway can produce low-emission batteries

Increased use of battery-electric propulsion systems in the transport sector is necessary to reduce GHG emissions in line with climate targets and is the largest single contributor to decarbonising the transport sector. At the same time, GHG emissions associated with the current battery production value chain are high, mainly from the production of raw materials and battery cell manufacturing. GHG emissions are largely related to the energy mix used in production (WEF, 2019). For example, a battery pack for use in an electric vehicle may have a 60 per cent higher carbon footprint if it is produced in a country where the production park is dominated by coal, nuclear power and natural gas compared to if it had been produced in a country with renewable production (L. Ager-Wick Ellingsen et al., 2014). Material and cell production in Norway based on hydropower can thus contribute to significantly reducing emissions in the battery value chain.

The battery market will see enormous growth in the coming years and there is a significant Norwegian turnover potential

Large international investments in batteries and battery production are expected towards 2030 due to sharply increasing demand, especially in the transport sector. Estimates of exactly how great the demand for batteries will be in the decades to come vary from analysis to analysis, but there is broad agreement that the market will grow from today's 300 GWh. A conservative estimate of demand in 2030 is 3,200 GWh, i.e. a tenfold increase, while some analyses estimate demand at over 5,000 GWh (Process21, 2022). The annual turnover potential for batteries in Norway is estimated by the NHO (2020) at EUR 9 billion per year in 2030, if national cell production is successful.

Part of the growing battery demand relates to battery systems for the maritime sector, an area where Norway already has leading stakeholders. The global market for such battery systems is expected to grow to around USD 1.9 billion per year by 2030 (Research and Markets, 2021). Norwegian stakeholders are active and have initiatives along the battery production chain. They have ambitions to take market shares at home and internationally, and the development of a Norwegian battery value chain entails great opportunities for establishing a new green industry. In addition, there are also several actors with initiatives in the field of battery return and recycling, which can benefit from the early phase-in of electric vehicles in Norway and growing waste streams.

The battery value chain has major challenges related to sustainability, nature and environmental impacts, but batteries can help reduce encroachments on nature in the long term

The impact on nature and the societal consequences of material extraction and recycling are key challenges in the industry. This applies in particular to the extraction of cobalt in Congo, graphite and nickel in China, and graphite and manganese in South Africa and Brazil (EU JRC, 2020). In addition to the challenges of the existing value chain, the growing battery demand may lead to additional pressure on vulnerable ecosystems and workers from the establishment of new mines for raw materials.

Today's lithium-ion batteries have a low recycling rate in the EU because the process is considered technologically demanding and costly. An EU proposal was made in December 2020 for a new Batteries Regulation that will set requirements for the battery industry in the areas of recycling, eco-design, sustainability and carbon footprint (COM/2020/798). The proposal also supports the reuse of batteries that will reduce the carbon footprint over the battery's lifetime. Increased reuse of batteries and recycling of raw materials will be essential to minimise the impact on nature and societal consequences of the battery value chain and to succeed in the sustainable decarbonisation of the transport sector. In the long term, the use of batteries in the power system can help reduce land disturbance and encroachments on nature from grid infrastructure by cutting local power peaks and facilitating more self-generation of power.

Battery cell production can increase Norwegian power demand and batteries in the power system can contribute to increased security of supply

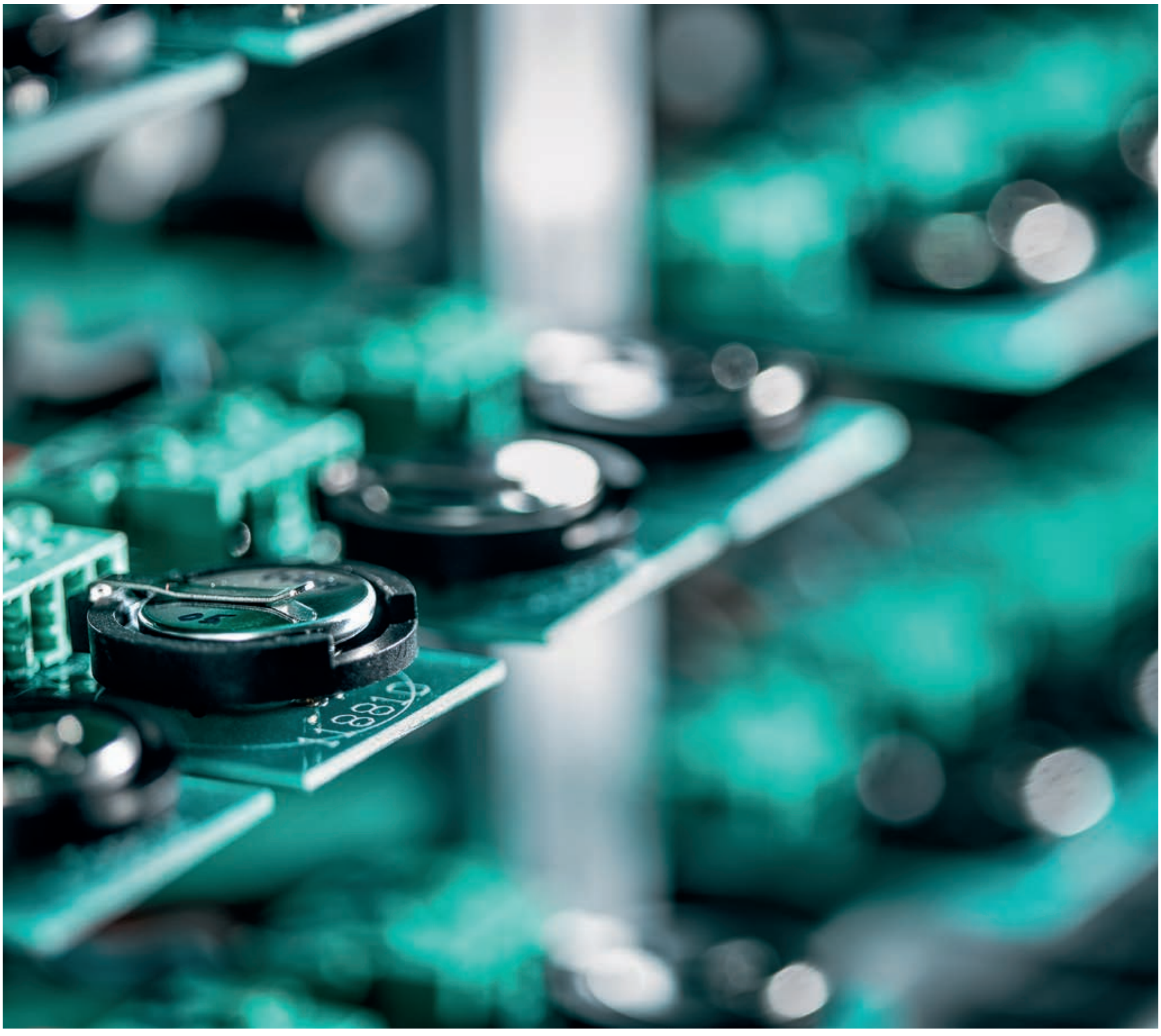
Battery production in Norway could lead to an increased power demand of 3–10 TWh in 2030 (THEMA, 2021), and could thereby utilise Norwegian energy resources to create jobs. More batteries in the power system can come from large-scale batteries, behind-the-meter batteries or electric car batteries and, at optimum use, can contribute to balancing and energy storage that will strengthen security of supply and reduce the need for grid development. Large-scale and flexible batteries in the power system will also be needed to balance the power grid with a higher proportion of renewable power. For the development and utilisation of offshore renewable power generation, batteries can also make an important contribution to security of supply and to the development of offshore renewable energy systems.

3.6.3
COMPETITIVE ADVANTAGES AND IMPLEMENTATION CAPACITY

Clear natural advantages from renewable power and availability of critical raw materials

Access to competitive renewable power for the production of raw materials and battery cells with a low carbon footprint comprise a key competitive advantage for Norwegian industry stakeholders. The EU emphasises the development of a green and circular battery industry. Among other things, it is expected that requirements will be made for documentation of carbon footprints in the value chain with the introduction of a classification system from 2026 and absolute limits for permitted footprints from 2027 (COM/2020/798).

In addition, Norway produces minerals and raw materials that the EU considers to be critical raw materials, including graphite, cobalt, manganese, silicon and nickel. Work is under way to establish strategic value chains to strengthen the security of supply of these raw materials in the EU, and participation in these value chains represents an export potential for Norwegian industry (Process21, 2021). A new Norwegian mineral strategy is set to be launched in 2022 and developed in the context of the EU's work and technologies for the green shift, including batteries.



Battery research at the IFE laboratory. *Photo: Institute for Energy Technology (IFE)*

Strong technology and knowledge base in materials technology and growing knowledge environments in batteries

Norway has advanced R&D environments in materials technology, while strong knowledge environments in batteries are currently being developed. With industry participation, the research communities are working together to develop materials and processes for a sustainable battery value chain, including recycling. Some research communities have already built up sound battery expertise and are collaborating with the world's foremost institutions in the field. The communities need access to joint research arenas and test infrastructure, and, at the end of 2021, funds were allocated for the establishment of the Norwegian Advanced Battery Laboratory, which are modern laboratories for battery research (Norwegian Government, 2021). Research groups can also participate in major European battery initiatives, but Norway is not part of the EU's IPCEI Batteries. This means that Norwegian stakeholders face greater barriers to participating in European battery investments than other European stakeholders.

Norway has a highly educated workforce, but there is a need for greater expertise in cell manufacturing and battery technology. Study programmes at vocational college and university level are also essential in order to establish a competitive battery value chain in Norway. As early as in 2024 and in subsequent years, large-scale cell manufacturing will be implemented that will require several thousand employees specialised in materials and battery technology, production and logistics (Federation of Norwegian Industries, 2021).

Norway has leading experience in the process industry, with cell manufacturing in the starting blocks

On the end-user side, Norwegian operators in shipping and stationary storage are leaders in the development and testing of battery applications and systems. In addition, there is a strong supplier industry in custom battery solutions. Norway already has an established process industry that produces and refines several essential raw materials and materials for battery production. Several major stakeholders in the energy sector and other industries are launching large-scale projects and have ambitions to participate in the drive for a national battery value chain. A number of projects are planned to be realised towards the middle and second half of the 2020s.

Norway has several industrial clusters with initiatives targeting a Norwegian battery value chain. The Eyde Cluster consists of stakeholders from the process industry, and one of its key areas is a battery value chain, with emphasis on strengthening of the member companies' deliveries to this segment. The Kongsberg Cluster is an industry-driven competence cluster and aims, among other things through the project Norwegian Battery Packing Network, to secure the position of a Norwegian battery value chain in international markets, with a particular focus on battery packs in various end-user sectors. In addition, the newly established industrial collaboration platform Battery Norway follows the EU battery strategy closely to promote national skills development and transfer and to strengthen the stakeholders' position and international cooperation opportunities.

3.6.4
BATTERIES ARE HIGH ON THE EU AGENDA

Since the launch of the Strategic Action Plan on Batteries in 2019, the EU has had a large-scale initiative to establish a European battery value chain with broad involvement from research and education institutions and industry. The initiative includes schemes such as the European Battery Alliance, IPCEI Batteries, Battery2030 +, BATT4EU, and Batteries Europe – European Energy Technology and Innovation Platform. Norway is a strong contributor to the European Battery Alliance and has a leading role and a strong position in the Batteries European Partnership Association (BEPA).

Through the EU research programme Horizon 2020, Norwegian actors have received around EUR 32 million for projects on batteries in the transport sector. The Horizon Europe programme will continue to issue battery-related calls with a budget of over EUR 900 million in the next programme period (BEPA, n.d.). These are prepared in collaboration with BEPA and the Zero Emission Waterborne Transport Partnership, and Norwegian stakeholders actively contribute to both these associations.

In December 2020, the European Commission launched the draft for the new Batteries Regulation to ensure a circular and sustainable European battery value chain. The new regulation includes, among other things, requirements related to the proportion of recycled raw material in batteries, due diligence programmes in the value chains and, as mentioned, maximum limits for carbon footprints (COM/2020/798). The draft was considered by the Council of Europe in the spring of 2022. The changes could further strengthen Norway's competitive edge in the battle for market share in Europe.

3.6.5
KEY RESEARCH AND INNOVATION NEEDS

Key research and innovation needs are linked to the knowledge and technology needs of stakeholders along the entire battery value chain. Research topics include materials, raw materials, battery cell manufacturing, battery utilisation, safety, reuse and recycling, and digitalisation.

Composite and raw materials

- Materials and raw materials for battery manufacturing and modules, including passive materials.
- Materials and concepts to further develop li-ion batteries to improve their performance and reliability, for example, li-ion batteries with iron phosphate cathodes (LFP) and nickel-manganese-cobalt cathodes (NMC).
- Materials, concepts and understanding of competing battery chemistries, based on solutions other than li-ion. This includes all-solid-state batteries (aSSB) and Na-ion batteries.
- Advanced polymer chemistry for optimised electrode design to enable e.g. "self-healing".
- Sustainable raw materials and materials for the battery value chain.

Efficient battery cell production

- Energy-efficient, environmentally friendly, and automated battery cell manufacturing.
- Process design for scale-up in and of the battery value chain.
- Cost studies along the value chain with a focus on development from pilot to large-scale deployment.
- Life cycle analyses and material flow analyses.

Battery utilisation

- Integration of batteries into the energy system and into the power grid in combination with variable renewable power generation.
- Adaptation of battery properties for various applications, e.g. adaptation of energy density, weight, land requirements, maintenance.
- High-power charging for batteries and charging systems.
- Control and sensory technology for batteries in battery system.
- Battery systems – electrical and thermal control.
- Charging technology for electric vessels and other applications.
- Hybrid zero-emission solutions for express boats and ferries, where batteries are combined with the use of hydrogen or ammonia fuels.

Safety, reuse and recycling

- System design and management systems for the safe use of used batteries.
- Sorting methods, battery design and materials selection for recycling.
- Methods for and automation in recycling processes.
- Impacts of battery value chains on nature and the environment.

Digitalisation

- Modelling from cell to system.
- Digital traceability.
- Digital twins for battery systems, production processes, etc.
- Robotisation and automation along the entire value chain.

3.6.6 MEASURES FOR IMPLEMENTATION

The Energi21 board recommends that research, development, demonstration and commercialisation activities be undertaken targeting the most important research and innovation needs. The Energi21 board also recommends the following measures to meet the knowledge and technology needs of industry stakeholders and to realise their ambitions in the battery sector:

RD&I

- Funding and policy instruments that cover the entire TRL scale, but it is particularly important that lower levels are covered. Establishment of a joint industrialisation centre for more mature projects, TRL > 5.
- Increase investment in industry-oriented research in Norway and cooperation at the Nordic and international levels.
- Increased support for new initiatives targeting known technologies and markets. Common infrastructure for scale-up and large-scale testing of battery systems in Norway.
- Continuation of STIM-EU (or equivalent) to ensure that Norwegian R&D stakeholders compete on the same terms in the competition for EU funding.
- Support for the development of intellectual property law and patenting.

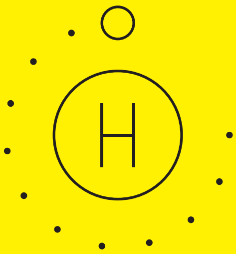
Commercialisation/market introduction

- Funding and policy instruments for SMEs should be more readily available, including support for EU applications.
- Common arena for qualification of processes, components, etc.
- Increased coordination in relation to the EU and internally in Norway in the vein of ETIP, IPCEI and BEPA – forums with industry stakeholders and businesses.
- Strengthen emerging cluster cooperation in the field of batteries.
- Norwegian terms, and funding and policy instruments, must be on a par with those of IPCEI Batteries.
- Funding for building pilot and full-scale facilities for the entire battery value chain.
- Establish a programme for the production of battery materials and battery cells that facilitates piloting and scale-up.

Education

- Knowledge-building with new and more vocational education programmes and student places. There is a need for further education programmes targeting the battery industry, and universities and university colleges need more professors.
- Cooperation between universities, university colleges, research communities and the industry.

Preparation for reusing batteries. *Photo: Batteriretur*



3.7 Hydrogen

Hydrogen plays a vital role in decarbonising the world's energy consumption, and the biggest need is found in the transport and industry segments. Considerable international investments are being made in hydrogen. Norway's biggest export market for natural gas, the EU, assigns hydrogen a key role in achieving the zero-emission goal for 2050. Norwegian industry and energy stakeholders have implemented several large-scale and concrete development plans for producing and using hydrogen and hydrogen carriers such as ammonia. The world's first hydrogen-powered ferry will start operations in the winter of 2022, and hydrogen-based solutions for other maritime vessels are under development. Key research and innovation needs relate to the safe management of hydrogen and ammonia, as well as the development of cost-effective full-scale value chains.

3.7.1 INVESTING IN HYDROGEN ...

... highlights key technology for decarbonising industry and transport segments that are incompatible with electrification.

...contributes to developing a reliable energy carrier with transport and storage properties that provides the necessary flexibility, and thus security of supply, in an emission-free energy system.

...represents a great potential for developing new green industries in Norway throughout the value chain, with significant international export potential.

THE KEY AREA "HYDROGEN" INCLUDES THE FOLLOWING TOPICS:

- Production of hydrogen and hydrogen carriers such as ammonia, methanol and other synthetic fuels (includes blue and green hydrogen).
- Production of electrolysers and fuel cells.
- Liquefaction of hydrogen.
- Hydrogen transport and components for the distribution and use of hydrogen (e.g. storage tanks, pipes and pumps).
- Use of hydrogen/ammonia in industry (input factor, heat) and transport (fuel cells, gas turbines).
- Safe handling and storage of hydrogen and ammonia.
- Integration and interaction with the energy system.
- Digitalisation.
- Impact on communities, nature and ecosystems.

3.7.2
MARKET DEVELOPMENT, OPPORTUNITIES AND CONSEQUENCES FOR NORWAY

The key area "Hydrogen" contributes positively to utilising Norwegian energy resources and to increasing competitiveness and value creation in the Norwegian energy industry by facilitating companies' export of hydrogen technology.

Production of hydrogen will help utilise Norwegian energy resources

Green hydrogen production could lead to an increased power demand of 3–9 TWh in Norway by 2030 (NVE, 2021; Statnett, 2021; DNV GL, 2021). Green hydrogen production can also introduce more flexibility into the power system. The resource basis for hydrogen exports from Norway is significantly greater for blue hydrogen than for green hydrogen, because the available gas resources for export are several dimensions larger than the power exports from Norway.[15] Norwegian natural gas can be further processed into blue hydrogen and the CO_2 can be captured and permanently stored on the Norwegian continental shelf. The link between hydrogen production from natural gas and the associated potential for handling large quantities of CO_2 can contribute to long-term value assurance of natural gas resources. Several stakeholders already have concrete plans for large-scale production of both green and blue hydrogen in Norway.

Hydrogen is a key technology for decarbonising certain segments of transport and industry

Hydrogen will play a central role in eliminating emissions of both greenhouse gases and local pollution in parts of the maritime sector, heavy transport, aviation and heavy industry. Hydrogen technologies are therefore necessary to achieve the climate targets and to make energy systems sustainable with net-zero GHG emissions. Norwegian stakeholders are currently actively working on the development and implementation of technologies and value chains for all four segments. At present, there are, for example, requirements for hydrogen propulsion for two ferry connections[16], the world's first ammonia-powered offshore vessel is under development, and in December 2021, Enova allocated around NOK 500 million to two projects with the goal of industrial use of hydrogen in production processes for steel and ammonia.

In a fully renewable power system without access to large energy stores in the form of hydropower, hydrogen will also contribute necessary large-scale energy storage by producing green hydrogen during periods of high renewable power generation.

Environmental impact depends on the type of hydrogen produced

Production emissions from green hydrogen are very modest, but production relies on large amounts of renewable power that could lead to significant land use and nature-related conflicts in connection with the development of power plants. Efficient utilisation of surplus heat from green hydrogen production will increase the efficiency of production. The production process also needs significant amounts of water as an input factor and can contribute to the degradation of water resources. Blue hydrogen will occupy less land, but the total environmental impact will depend entirely on the amount of methane and CO_2 emitted into the atmosphere during the extraction and transport of natural gas, as well as during the production of hydrogen. The impact on nature can be reduced by utilising existing gas infrastructure.

The reduction of GHG emissions from the use of hydrogen depends on the amount of CO_2 emissions associated with the input factors electricity (via electrolysis) and natural gas (via reforming). Renewable power and natural gas production with a low carbon footprint help reduce blue hydrogen emissions. The EU taxonomy sets requirements for how production should take place to ensure that the energy carrier contributes to reducing GHG emissions. The EU's strategy also highlights the need for more research into life-cycle analyses for hydrogen technology, including value chains and the use of critical raw materials (COM(2020) 301 final).

The development of a hydrogen value chain entails major investments

In the Hurdal Platform, the Government emphasises the need to develop a complete hydrogen value chain and intends to set annual production targets for blue and green hydrogen by 2030. In the EU, there are concrete plans for establishing hydrogen markets and value chains. The EU and the UK have set concrete production targets, the EU with a target of 40 GW of electrolysis capacity by 2030 and the UK with ambitions of 5 GW of production capacity from both blue and green hydrogen (COM(2020) 301 final; Secretary of State for Business, Energy & Industrial Strategy, 2021). With the launching of REPowerEU in March 2022, the EU has among other things increased its hydrogen ambitions to secure energy supply and accelerate market entry (COM (2022) 108 final). The ambition is to increase the use of renewable hydrogen by 15 million tonnes by 2030, of which 10 million tonnes will be imported and 5 million tonnes will come from increased production in the EU.

According to the Hydrogen Council (2021), there are global plans to invest USD 500 billion in hydrogen towards

15 *In 2020, Norway exported 1,087 TWh of natural gas and 25 TWh of electricity (https://www.ssb.no/statbank/table/11561). Future exports will depend on the rate of development of hydrogen production as well as natural gas extraction.*

16 *Norwegian national road Riksveg 13 Hjelmeland–Nesvik–Skipavik, MF Hydra, LH2 & Bodø-Lofoten*

2030. A European study (Hydrogen4EU) has estimated that the transition to a low-emission society will result in investments in the hydrogen value chain of EUR 1,500–2,700 billion by 2054 (Deloitte, 2021). The annual turnover potential for Norwegian stakeholders in green hydrogen and related technology is estimated to be EUR 1 billion in 2030, with a projected growth of up to EUR 7–20 billion per year by 2050 (NHO, 2020).

3.7.3
COMPETITIVE ADVANTAGES AND IMPLEMENTATION CAPACITY

Significant natural advantages in terms of renewable power and natural gas resources

From a European perspective, Norway has a good supply of competitive renewable power, which will be an advantage for green hydrogen production. In Norway, it will be possible to realise significant synergies between power and hydrogen production, not least to relieve grid development.
In addition, hydrogen production can provide synergies related to offshore wind power generation. Norway also has extensive natural gas resources that can be used to produce low-emission hydrogen on a scale that is far greater than the potential of green hydrogen production.

Strong technology and knowledge base with significantly increased investment

Norway has strong R&D environments in electrolysis, fuel cell technology and materials research, and a strong R&D community for hydrogen in general is under development. In 2022, two FMEs were established in the fields of hydrogen and ammonia, and extensive research is already under way on the combustion of hydrogen. Norwegian research communities are also internationally recognised in adjacent areas with transfer values to hydrogen, such as gas and CCS. Several research and innovation programmes support hydrogen projects, including the Research Council's programme for environment friendly energy, IPCEI (Enova manages Norway's participation), Pilot-E, Green Platform and centre initiatives such as Katapult Sustainable Energy.

Extensive industrial experience and high growth ambitions

Norway has sound industrial experience in electrolysis, storage systems and modelling. In addition, key Norwegian stakeholders have long experience in gas processing and ammonia production. Industry related to the production of fuel cells is also being established. The availability of good gas infrastructure and the recent establishment of a CCS value chain provide national opportunities for blue hydrogen production. In addition, Norwegian operators have more than 20 years' experience of CCS on the Norwegian continental shelf.

A number of Norwegian stakeholders are involved in projects in the hydrogen value chain, for both green and blue hydrogen. In their joint industrial policy platform for the period up until 2030, LO Norway (Norwegian Confederation of Trade Unions) and NHO have launched ambitions for large-scale industrial projects with installed power of 1.5–2 GW in green hydrogen (LO and NHO, 2021). A further objective is to establish a large-scale blue hydrogen production facility with a pertaining large-scale transport solution to Europe and to make an investment decision for a pilot plant for hydrogen production from offshore wind farms (LO Norway and NHO, 2021). The hydrogen interests of industry are safeguarded by, among others, the H2Cluster and Ocean Hyway Cluster, the latter with a specific focus on hydrogen for the maritime sector. Several maritime enterprises and groups are actively engaged in the development and initial use of hydrogen carriers, such as ammonia. In addition, several Norwegian industry stakeholders are investing in the development of end-user solutions for hydrogen.

3.7.4
TARGETED EFFORTS AND INVESTMENT IN THE EU PROVIDE MAJOR OPPORTUNITIES FOR NORWAY

Through various funding and policy instruments and regulations, the EU is committed to establishing a European hydrogen market. These targeted efforts provide Norwegian businesses with great opportunities for value creation and export of hydrogen and hydrogen technologies. Participation in European research, development and innovation projects provides Norwegian stakeholders with new partners and in-depth knowledge of the emerging market, thereby generating a competitive advantage in the EU. R&D funds for hydrogen technologies are primarily available in the "Clean Hydrogen Partnership", where Norwegian research institutes are strongly represented, and through IPCEI Hydrogen, of which Norway is a member and has to date nominated two projects for. Through the Horizon 2020 programme, Norwegian hydrogen projects related to the transport sector have received EUR 13.7 million (FNR, 2021).
While Norwegian R&D funds are available to develop both blue and green hydrogen projects, the main focus in the EU is on the development of renewable power generation and electrolysers.

3.7.5
KEY RESEARCH AND INNOVATION NEEDS

Key research and innovation needs are linked to the knowledge and technology needs of stakeholders along the entire hydrogen value chain. Key topics include safety, cost and energy-efficient value chains, the integration of hydrogen and hydrogen carriers into the existing energy system and framework conditions.

Safe use of hydrogen and hydrogen carriers

- Improve the knowledge base and further develop and supplement with new standards for safe use, production, local distribution, large-scale transport, and storage on land and at sea.
- Acceptance by society of the use of hydrogen on a wider scale and in new areas.
- Qualification and documentation of safety models and risk-based design.
- Human and organisational factors for the safe handling of hydrogen and hydrogen carriers in various forms.
- Digital and sensor-based monitoring systems, and remote-controlled operations.

Further development of cost and energy-efficient hydrogen value chains

- Development of technologies, components, and production processes along the entire value chain, including hydrogen from natural gas with a high CO_2 capture rate, electrolysis, conversion, transport, bunkering and storage technologies.
- Conversion to/from hydrogen derivatives such as ammonia and organic hydrogen carriers.
- Development of end-user applications for, for example, storage, and components such as valves, pumps, pipes, fuel cells, etc. in market segments such as industry and transport.
- Standardisation of solutions e.g. connections, tanks/containers, bunkering solutions and modular production.

Integration of hydrogen value chains into the existing energy system

- Harmonisation of national and international demand and available production resources, and economic investments. Potential for hydrogen export based on Norwegian resources.
- Optimal interaction and flexibility utilisation between hydrogen and power systems at different levels. Impact on nature and the environment in and of hydrogen value chains.

Enabling framework conditions (for market establishment)

- Legislation, regulations and incentive schemes.
- Market design, investor analyses.
- The authorities' role in promoting economically profitable development and investment in hydrogen technology and infrastructure.

3.7.6 MEASURES FOR IMPLEMENTATION

The Energi21 board recommends that research, development, demonstration and commercialisation activities be undertaken targeting the most important research and innovation needs. The Energi21 board also recommends the following measures to meet the knowledge and technology needs of industry stakeholders and to realise their ambitions in the hydrogen field:

RD&I

- Pursue the Green Platform scheme that facilitates high-level TRL research and innovation in close interaction with knowledge-building research at a lower TRL level.
- Establish a support programme for hydrogen that facilitates piloting and scale-up.
- Invest in hydrogen research infrastructure, including large-scale testing and piloting.
- Enhance European cooperation with increased Norwegian participation in IPCEI Hydrogen and establish multilateral research projects.
- Continue the STIM-EU scheme and support schemes to ensure the participation of Norwegian R&D environments in the EU Framework Programme and partnerships. Facilitate applications to the EU Innovation Fund and participation in Mission Innovation.

Commercialisation/market introduction

- Funding and policy instruments for the facilitation of comprehensive value chains for hydrogen production.
- Financial support schemes for the development of a domestic market using e.g. CFDs and procurement schemes.
- Strengthen and specify the Norwegian strategy for the development of hydrogen value chains.
- Use of available modelling tools to support decision-making for phasing-in of the solutions that provide the most efficient use of public investment in hydrogen infrastructure.

Education

- Education, continuing education and training to ensure hydrogen expertise for technology and business development.

Yara Herøya. *Photo: Yara*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3.8
Carbon capture and storage

To reach the 1.5°C target, the world is reliant on large-scale CCS. This key area covers the capture, transport and permanent storage of CO_2. Norway has a unique opportunity to take on a role in this area due to its leading technology and knowledge base, and its natural advantages. This technology and knowledge base, which gives us an advantage over many other countries, has been developed over the course of many years of industrial experience and research in the field. Our natural advantages for participating in an international CCS value chain are the storage potential in the North Sea and proximity to the demand for storage in Europe. Norway's strong global position in CCS will be further consolidated when the Longship project becomes a reality in 2024. Norway also has several ambitious business stakeholders investing in the capture of industrial emissions both nationally and internationally. The main focus going forward will be on scaling up the technology into a commercial value chain by reducing costs and risk, and realising gains from the Longship project.

3.8.1
INVESTING IN CCS...

...is necessary to decarbonise industry and transport by capturing and storing CO_2 emissions from industrial processes and producing low-emission hydrogen.

...contributes to a reliable and competitive energy supply by increasing access to decarbonised energy resources based on Norwegian gas.

...contributes to establishing new green industry in Norway with international potential. A Norwegian CO_2 value chain also provides opportunities for exporting capture, storage and transport technology and increasing value creation for Norwegian suppliers in, among other things, the process industry and the maritime and offshore sectors.

THE KEY AREA "CARBON CAPTURE AND STORAGE" INCLUDES THE FOLLOWING TOPICS:

- Carbon capture in industry, hydrogen production, waste incineration, maritime transport and power generation.
- Transport and injection of CO_2 (pipes, ships, intermediate storage).
- Large-scale, long-term storage of CO_2.
- Climate-positive technologies (permanent storage of CO_2 captured from the air (DACCS) and bioenergy with CCS (BECCS)).
- Integration into the energy system.
- Digitalisation.

3.8.2
MARKET DEVELOPMENT, OPPORTUNITIES AND CONSEQUENCES FOR NORWAY

The "Carbon capture and storage" key area makes a particularly positive contribution to decarbonising industry, value creation in the Norwegian energy industry and enabling climate-positive technology. Both OG21 and Process21, which are the strategic bodies for a comprehensive national research and technology strategy for the petroleum sector and the process industry respectively, also point to CCS as a priority area.

CCS is essential to cut the most difficult emissions

CCS is essential for the full decarbonisation of energy resources and of the industrial sector, especially within some segments where there are no good decarbonisation options. CCS in Norwegian industry can contribute to emission cuts of 5 Mt CO_2 per year (Process 21, 2020). In addition, possible emission cuts come from the waste sector, which according to Klimakur 2030 can reduce CO_2 emissions by 0.8 Mt per year from the waste incineration plants in Oslo, Bergen and Trondheim. The final application area for CCS is linked to the decarbonisation of Norwegian gas resources, and could capture large amounts of CO_2 that would otherwise be emitted in European countries. It will also be possible to capture CO_2 from gas power generation at oil and gas installations in Norway.

Norway is currently establishing Longship, a full-scale demonstration project for CCS that includes the capture, transport and storage of CO_2. The project has a total budget of NOK 25 billion and will contribute to the further development of technology and cost reductions throughout the value chain. Initially, carbon capture will take place at Norcem's facility in Brevik, the receiving terminal in Øygarden municipality, and permanent storage will be in the North Sea with a storage capacity of 1.5 million tons of CO_2 per year. The project is considered an important basic investment for establishing a Norwegian and international CCS value chain.

Enormous investment in CCS is needed to reach the 1.5°C target

The IEA's "Sustainable Development" scenario estimates a need for global investments in carbon capture, use and storage of USD 160 billion by 2030 (IEA, 2020). The really big growth is expected to come after 2030. According to the International Renewable Energy Agency (IRENA)'s World Energy Transition Outlook 2021, there will be a worldwide need to capture and store over 7 Gt of CO_2 annually from 2050 to limit global warming to 1.5°C. Most of this must be removed from the atmosphere using BECCS or direct air capture. Such large-scale carbon capture requires total CCS investments of USD 1,825 billion by 2050. The Intergovernmental Panel on Climate Change (IPCC) estimates a need for the annual removal of 5–10 Gt CO_2 from the atmosphere from 2050 (IPCC, 2018). In Europe, it is estimated that, in a net-zero emissions scenario, 1.2–1.8 Gt CO_2 must be stored per year from 2050 onwards (Hydrogen4EU).

Activity in this area is already accelerating, and in the past year, the capacity of announced CCS facilities under development has almost doubled to 111 Mtpa (Global CCS Institute, 2021). Establishing a Norwegian CCS value chain is important for business development related to blue hydrogen and industry in Norway, and for future market access in the EU. It also lays the foundations for the development of an export-oriented industry that can take part in an international market with the potential for strong growth, especially in the years after 2030.

CCS requires the use of land and can result in emissions

Like all infrastructure development and economic activities in general, establishing a value chain for CCS will require land, have an impact on the local environment and may in some cases lead to new types of emissions that need to be monitored and reported. Therefore, before any CCS facilities are established, the impact of the activity on total GHG emissions (including emissions from land disturbance), other emissions and on biodiversity should be assessed. However, waste gases from emission points will become cleaner overall because, in addition to CO_2, CCS facilities will also reduce other emissions such as particulate matter, dust and SOx. The disadvantages of CCS are limited compared to the benefits, meaning that the technology prevents CO_2 emissions, which will contribute to mitigating climate change. If the development of value chains for CO_2 takes advantage of existing infrastructure, for example by building on existing industrial sites, further impacts on land-use and nature will be limited.

CCS will also increase energy consumption from, for example, the CCS facility, the ships transporting CO_2 and the receiving terminal transporting CO_2 to the storage site. This energy consumption will ideally be covered by renewable energy and/or heat integration with the emission point in order to achieve the maximum emission reduction effect. The former may lead to increased land-use requirements if new renewable power generation needs to be built to meet the increased demand. The capture facility may also increase water consumption in the area. When storing CO_2, suitable areas and storage concepts are important to ensure permanent storage and prevent leaks. Monitoring and a focus on safety is a prerequisite for any establishment of large-scale CO_2 storage facilities. Norway has long experience of this from many years of CO_2 storage at Sleipner and Snøhvit.

Photo: Hydro

Increased utilisation of Norwegian energy resources

CCS also makes it possible to protect Norwegian natural gas assets and the potential for utilising the gas resources is significant. The production of low-emission energy carriers based on blue hydrogen can be done on a significantly larger scale than green hydrogen in the short to medium term. This will contribute to diversification of the energy supply and thereby strengthen security of supply. In order to realise negative emissions, increased utilisation of bioenergy resources combined with CCS will be important in the longer term. The actual capture process for CO_2 is energy-intensive and will lead to increased power demand, thereby increasing utilisation of Norwegian power resources.

3.8.3 COMPETITIVE ADVANTAGES AND IMPLEMENTATION CAPACITY

Norway has significant competitive advantages in CCS in the form of a geological storage potential, a leading technology and knowledge base built up over many years, and robust industrial experience with ambitious stakeholders.

Norway has natural advantages with extensive geological storage potential on the continental shelf

Norway has a significant geological potential for permanent CO_2 storage in the seabed under the North Sea, where the total storage capacity is estimated to be as high as 70–80 Gt CO_2 (Norwegian Petroleum Directorate, 2019). In addition, there is already extensive infrastructure on the continental shelf that is closely linked to the European market. North-western Europe and the UK in particular have significant carbon capture potential, where the CO_2 can be transported to and stored in Norway via pipeline and sea routes.

Leading technology and expert environments in CCS

Norway has robust CCS research communities, and has had FME centres working in the field since 2008. Norwegian R&D environments are and have been active in several major research projects, including on CCS technologies in power generation, and Nordic collaborative projects, including a virtual competence centre for CO_2 capture, transport and storage.

Research on and knowledge building in CCS technology in Norway is mainly funded through the CLIMIT programme, which is a collaboration that started up in 2005 between Gassnova and the Research Council of Norway. Since its inception, the programme has awarded just under NOK 3 billion to research and innovation projects. CLIMIT is an effective funding instrument for realising benefits from Norwegian RD&I projects by giving a number of industrial partners access to expertise and learning from the projects.

Norway also has an internationally recognised test centre for CO_2 capture – the Technology Centre Mongstad (TCM). The centre has been important to risk reduction and testing of the amine technology that has been selected for the capture facility at Norcem, which is part of the Longship project. The test facility is the world's largest and most flexible test centre on an industrial scale. It is also a knowledge centre that engages in extensive knowledge sharing. Through the ECCSEL partnership, additional testing facilities for CCS are available both in Norway and other European countries.

Long industrial experience in the petroleum industry is further strengthened with Longship

Norway has long industrial experience from a well-established petroleum industry with synergies for CCS. Among other things, Norway has two of the few operational facilities for offshore CCS at Sleipner and Snøhvit. Several Norwegian petroleum companies are internationally competitive and forward-looking participants in the energy transition with the ambition to participate in a Norwegian CCS value chain. Many stakeholders are already involved in the joint state and industrial venture Longship. Benefits realisation related to Longship is important to strengthen Norway's global position in CCS, and it will help identify new challenges that can best be solved through links to research and development. In addition to this, several other stakeholders are working on their own projects for large-scale CO_2 storage, potentially in combination with the production of blue hydrogen. With the Green Platform project LINCCS, several key actors want to build on the venture and develop commercial technologies to reduce costs in the CCS value chain.

Concrete transport and storage solutions, such as Longship, have stimulated interest in CCS among many industry stakeholders and contribute to carbon capture operators now wanting to establish themselves in Norway or base their operations on the Norwegian value chain. In the field of transport solutions, Norway has a leading maritime sector that can contribute to the development of large-scale maritime transport solutions in the CCS value chain. Norway also has large-scale projects for the development and implementation of carbon capture technologies. With public funding, Norwegian stakeholders have ambitions to test and implement capture technology on a large scale in the industrial sector, energy sector, waste incineration and ammonia production. One stakeholder has already constructed a mobile test unit for its technology which it uses to test the capture of actual gases from various industrial plants. International cooperation on market solutions and technology development will be important to reduce costs in the value chain and ensure broad roll-out of CCS technologies.

Investing in CCS value chains is critical to the EU's climate ambitions

Carbon capture, use and storage (CCUS) is a key part of the European Green Deal and one of the ten key areas of the EU Strategic Energy Technology Plan (SET Plan). Norwegian stakeholders are subject to the EU SET Plan, and some are also key participants in the Zero Emission Platform, which provides the EU with technical advice on the implementation of CCUS.

Research funds are available through Horizon Europe's fifth group. ACT[17] has also contributed to joint European research projects on CCUS technologies since its establishment in 2017. This activity will be pursued in the Clean Energy Transition partnership, linked to the challenge of achieving climate neutrality. Future calls designed under this partnership will continue to cover CCUS technologies. Through Horizon 2020, Norwegian stakeholders have received EUR 32.2 million for CCS projects, of which just over half is allocated to CO_2 capture (RCN, 2021). Several CCS projects that have received funding from Horizon 2020 or the Innovation Fund have taken the Norwegian value chain for CCS as their starting point.[18]

[17] *Accelerate CCS technologies, http://www.act-ccs.eu/, a co-funded project under the Horizon 2020 programme*

[18] *Four out of seven Innovation Fund projects awarded in November 2021 involve CCS. They include a project based on CO_2 storage on the Norwegian continental shelf and a project that explores possible storage on the continental shelf.*

3.8.4
KEY RESEARCH AND INNOVATION NEEDS

Key research and innovation needs are linked to the knowledge and technology needs of stakeholders along the entire CCS value chain.

New technologies and scale-up to a commercial value chain

- Scale-up of the value chain for CO_2 storage on a gigatonne scale, including geological mapping, measurement and monitoring, and simulation of long-term effects for safe storage.
- Effective carbon capture solutions from blue hydrogen production.
- Effective carbon capture solutions from existing industrial plants, the waste sector and in value chains, where good alternatives to decarbonisation cannot be found.
- Comprehensive and systematic development of large-scale transport and storage infrastructure.
- Increased cost and energy efficiency along the entire value chain including the development and use of digital tools.
- Scale-up and implementation of innovations in, for example, materials technology.
- Development of climate-positive solutions such as DACCS and BECCS.
- New uses for capture, transport and storing CCS in multiple and emerging commercial value chains, where good alternatives to decarbonisation are lacking, where carbon capture is relatively affordable or where access to carbon storage is possible.

Business and market models and CCS framework

- Faster scale-up of CCS technologies with lower risk (design, demonstrations, development of the legal framework and standards, measures to strengthen innovation processes, lessons learned from the full-scale project).
- Market development in a Norwegian and European perspective.
- Effective cooperation constellations between stakeholders.

Environmental and societal issues

- Increasing society's acceptance for CCS.
- Life-cycle emissions for CCS and comparing concepts and areas of application.
- Good knowledge and development of strategies and solutions for minimising the CCS value chain's impact on nature.

3.8.5
MEASURES FOR IMPLEMENTATION

The Energi21 board recommends that research, development, demonstration and commercialisation activities be undertaken targeting the most important research and innovation needs. The Energi21 board also recommends the following measures to meet the knowledge and technology needs of industry stakeholders and to realise their ambitions in the CCS field:

RD&I

- Continue centre initiatives and further develop grant schemes for R&D and demonstration projects, such as CLIMIT and participation in the Green Platform.
- Initiate the establishment of an IPCEI for CCS.
- Increase Norwegian participation in EU-funded. research projects to strengthen European cooperation
- Strengthen the physical and digital research infrastructure.
- Measures that strengthen the innovation process.

Commercialisation/market introduction

- Pursue international knowledge sharing and exchange of experience, in particular in Europe, e.g. in relation to EU taxonomy and funding.
- International cooperation on market solutions and technologies.
- Financial support schemes for the development of a domestic market using e.g. CFDs, procurement requirements etc.
- Establish investment in climate positive technologies (DACCS/BECCS), including the development of business models.

Education

- Develop study programmes in consultation with the industry, focusing on technology and digitalisation expertise related to the CO_2 value chain.

The CO_2 storage potential on the Norwegian continental shelf is large, here from Johan Sverdrup. *Photo: Ole Jørgen Bratland, Equinor*

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4

International research and innovation cooperation

A targeted and prioritised focus on internationalisation in research, technology and knowledge development is vital to bolstering and further developing the competitiveness of the energy industry. A presence in the international research and innovation arena increases the quality of knowledge development and internationally recognised R&D communities, and provides more opportunities for the business sector to win positions in the international energy market.

4.1

The EU's research and innovation arena

4.1.1
THE EUROPEAN GREEN DEAL STRENGTHENS MARKET OPPORTUNITIES FOR NORWEGIAN BUSINESSES

On 1 December 2019, the von der Leyen Commission took office and was quick to launch its green growth strategy, the European Green Deal (EGD). The EGD will transform the EU into a modern, resource-efficient and competitive economy, ensuring:

1. no net emissions of greenhouse gases by 2050.
2. economic growth decoupled from resource use.
3. no person and no place left behind.

This policy is now being realised through Fit for 55, a package of legislative proposals that will also be applicable to Norway via the EEA. These are intended to enable the EU to meet its climate targets, with particular emphasis on the increased ambition for 2030: reducing GHG emissions by at least 55 per cent by 2030 compared to the 1990 level. The EGD involves large-scale investment in the development and integration of renewable energy, the development of a European hydrogen market and emission-free industry and maritime transport, thus harmonising with Norwegian strategic investments and areas where Norwegian industry has significant competitive advantages.

In the aftermath of Russia's invasion of Ukraine on 8 March 2022, the EU Commission presented a a plan to make the EU independent of Russian fossil fuels by 2030 – REPowerEU. Initially, the focus is on reducing dependence on Russian natural gas by diversifying gas suppliers to the EU, increasing the pace of supply of renewable gas and replacing gas in heating and power generation. This could reduce EU demand for Russian gas by two-thirds by the end of 2022. The increased pace of transition planned in REPowerEU will also affect Norwegian stakeholders' market opportunities and increase the need for the development of low-emission technologies.

4.1.2
THE HORIZON EUROPE RESEARCH AND INNOVATION PROGRAMME

Research and innovation is an important instrument in the realisation of the EGD and for following up EU energy policy. Horizon Europe is the largest transnational research and innovation programme in the world with a budget of EUR 95.5 billion for the period 2021–2027. The funds are actively used to accelerate the transition to sustainability, to test and deploy innovative technologies and solutions on a large scale, and to engage citizens to participate in the transition.

Horizon Europe is structured in three pillars, "Excellent Science", "Global Challenges and European Industrial Competitiveness" and "Innovative Europe". Funding of ground-breaking, curiosity-driven research is continued under the "Excellent Science" pillar. The establishment of the European Innovation Council under "Innovative Europe" is Horizon Europe's most important new venture. Its objective is to support the development of ground-breaking and innovative technologies with commercialisation potential, as well as supporting and providing guarantees to small and medium-sized enterprises (SMEs) for market introduction and scale-up.

The thematic areas "Digital, Industry and Space" (Cluster 4) and "Climate, Energy and Mobility" (Cluster 5) in the "Global Challenges and European Industrial Competitiveness" pillar are most relevant to the Energi21 mandate and strategies' key areas. Norwegian business is well positioned for participation in projects in these two thematic areas, and there is considerable potential for further strengthening stakeholders' competitiveness through Norway's participation.

The objective for European industry is to take global leadership in clean and climate-neutral industrial value chains. The calls for proposals therefore focus on energy efficiency improvement, re-use and increased use of renewable resources in industrial processes. Calls related to digitalisation contribute to achieving the objective of creating a unified data market in Europe.

Calls in Cluster 5 target several of Energi21's key areas. They range from knowledge and tools that can support policy makers in the further development of technologies and systems necessary for the transformation to digital, efficient and zero-emission energy and transport systems. The main objective of the programme is to reduce the need for energy and to make energy supply climate neutral. The calls in the programme cover, among other things, efficient production and integration of renewable energy carriers, modernisation of energy infrastructure, innovative energy storage solutions, hydrogen technologies, value chains for battery production, decarbonisation of industry, the building and transport sectors, as well as energy and resource-efficient urban areas.

4.1.3
EU PARTNERSHIPS ARE IMPORTANT ARENAS FOR NORWEGIAN STAKEHOLDERS

Since 2002, partnerships have played an important role in the EU's research and innovation programme, in particular for "Global Challenges and European Industrial Competitiveness". The aim of the partnerships is to prevent fragmentation of the EU's overall research efforts and to strengthen the European research arena. A major revision of partnerships was made with the creation of Horizon Europe so that all now focus on the EU's political priorities and are more open and transparent. In total, 25 per cent of Horizon Europe funds go to partnerships, which is an increase from the former Horizon 2020 programme. Participation in the partnerships thereby provides an important arena for influencing the EU research agenda, and for positioning stakeholders for participation in project initiatives.

In general, there are three types of partnerships: co-funded, co-programmed and institutional. The calls for proposals relating to co-funded and co-programmed partnerships are included in the framework programme of Horizon Europe. Co-programmed partnerships are mainly entered into between the European Commission and private stakeholders. They have an influence on the design of a range of calls with high relevance to the partnership. Examples of partnerships that affect calls in Cluster 5:

- Batteries European Partnership.
- Zero Emission Waterborne Transport Partnership.
- Towards Zero Emission Road Transport Partnership.

Norwegian stakeholders are actively involved in all these partnerships. Co-funded partnerships are established between the European Commission and national research funders and authorities. In this category we find the Clean Energy Transition Partnership, which is of great relevance to Energi21 and in which the Research Council plays an active role. Institutionalised partnerships have their own legal basis, and issue calls for proposals for the framework programme's funding. Norwegian stakeholders actively participate in the Clean Hydrogen Partnership, the Clean Aviation Partnership and Europe's Rail Partnership.

4.2

Importance and impacts of EU cooperation

The EU's green growth strategy the European Green Deal and the climate package Fit for 55 create market opportunities for Norwegian business and industry and for the development of internationally competitive R&D environments. European cooperation is becoming increasingly important for Norwegian research. Since 1994, Norway has actively participated in and benefited greatly from the EU framework programmes for research and is actively involved in several initiatives under the EU Strategic Energy Technology Plan (SET Plan).

It is important that Norway participates in Horizon Europe in the field of energy and climate. Norwegian stakeholders also contribute to designing the EU research programmes through e.g. strategic work in the partnerships and the European Energy Research Alliance (EERA).

Norway's participation in the EU's research and innovation arena is of great importance for the competitiveness of Norwegian industry. It provides increased insight into the European market and strengthens cooperation with market players, it increases the quality of research communities, and contributes internationally recognised knowledge to the business sector. It also means that Norwegian research results are adopted in a European and international perspective, and thereby influence the EU's design of regulations for the European markets.

Internationally recognised knowledge is an important key to the competitive products, services and solutions of the future. It is therefore important that Norwegian industry and research communities participate with their knowledge wherever knowledge sharing and knowledge production takes place, and that they gain access to important international networks and resources through such sharing processes.

Norwegian universities and university colleges, research institutes, and the business and public sectors can all benefit from EU cooperation. Cooperation with knowledge communities, research networks and trade and industry in project consortia can lead to:

- mutual enhancement of research quality among national and international research groups.
- increased opportunities for international networks and international recruitment.
- access to newly developed and up-to-date international knowledge.

- greater career development opportunities for individual researchers.
- increased ability to innovate and compete in global and European markets.
- opportunities to share the costs of expensive research infrastructure and increase access to this infrastructure.
- increased attractiveness as a collaborator in Europe and internationally.
- raise businesses' international profile and make it easier to promote.
- the companies' products, services and knowledge resources.

Businesses have different preconditions for participation
Businesses have different preconditions for participating in the EU's research and innovation arena. Relevant factors include time, capital, expertise and experience. Larger companies are generally better equipped to devote the personnel and resources needed to obtain essential knowledge, produce funding applications and carry out and potentially lead EU projects. For a smaller company that may have its origins in a research group or institute, EU projects can be a way to gain valuable experience and establish networks. The degree to which a company is internationally oriented may be a significant factor in increasing interest and the desire for participation. These companies may see EU research and innovation cooperation as an opportunity to access networks of experts and market players and to gain insight into pioneering European research and knowledge, and knowledge-sharing activities.

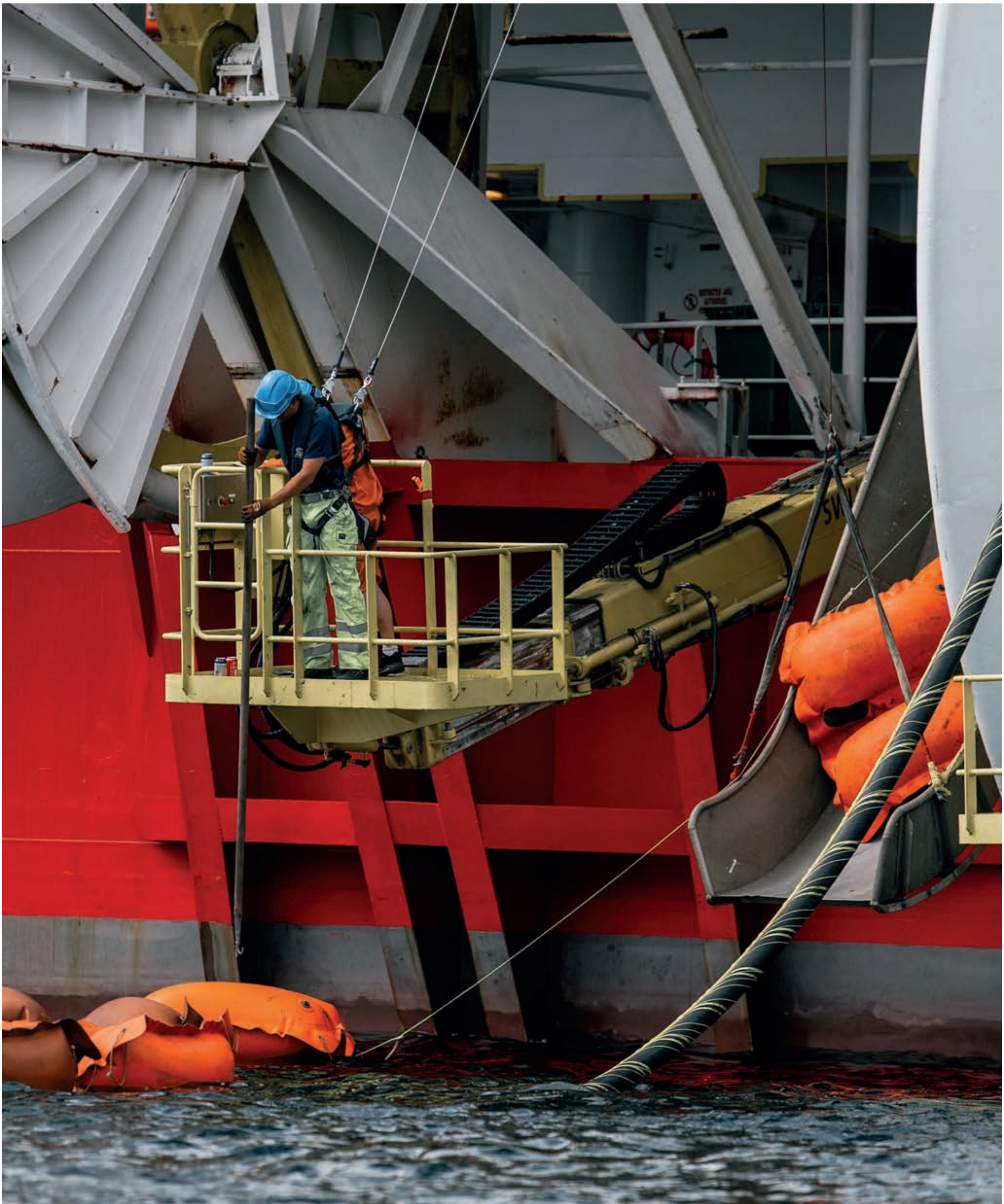
Norwegian research institutes, universities and university colleges with strong participation in Horizon Europe will be able to help facilitate accessibility to projects for Norwegian businesses. To do this, Norwegian R&D stakeholders must be able to use Norwegian-funded projects to build attractive expertise and research infrastructure, and good collaborations with the business community are also required. Furthermore, it is crucial to ensure that participation is financially viable, which currently requires additional Norwegian funding for participation in Horizon Europe projects.

4.2.1 THE ENERGI21 BOARD'S RECOMMENDATIONS CONCERNING PARTICIPATION IN THE EU'S RD&I ARENA

The Energi21 board believes it is important that the threshold for participation in the EU's research and innovation arena is lowered, and that the business sector understands the potential and value of international cooperation. In addition, R&D communities must have robust framework conditions that allow them to maintain a strong foothold in the EU's research and innovation programmes.

- The Energi21 board recommends strengthening efforts to mobilise businesses to participate in the EU's research and innovation arena and in international RD&I cooperation. Industrials clusters can be used more actively in this work.
- The Energi21 board recommends that government measures and funding and policy instruments help businesses to understand the value and potential of participating in the EU's research and innovation arena.
- The Energi21 board recommends strengthening R&D and business communities' ability to engage in active strategic positioning in the partnerships, and other arenas, in relation to the design of research agendas and calls, as well as networking.
- The Energi21 board recommends incentives to strengthen the R&D communities' ability to initiate, lead and attract business partnerships for EU projects. This includes access to knowledge-building funds in strategically important areas, building of critical research infrastructure and good platforms for collaboration between the business sector and R&D communities.

Funding Scheme to Increase Participation in International Energy Strategy Forums
The Funding Scheme to Increase Participation in International Energy Strategy Forums is part of the Research Council's research programme ENERGIX. The scheme has proven to be of great importance in mobilising stakeholders, has strengthened positioning in the EU arena and, indirectly, influenced participation in research and innovation projects. The scheme ensures that a sufficient number of Norwegian stakeholders contribute to the development of the EU's energy priorities and become familiar with European environments that have the potential for beneficial partnerships. It should be a goal for Norway to achieve a similar success rate in the new Horizon Europe programme as that in the former Horizon 2020. Active participation by businesses and research and education communities should be facilitated.



Cable installation vessel Nexans Aurora. *Foto: Nexans*

The Energi21 board recommends that the Funding Scheme to Increase Participation in International Energy Strategy Forums be further developed and that NOK 8.5 million of the ENERGIX budget be allocated to the scheme annually until 2026.

The RES-EU scheme is essential to success

Norwegian participation in Horizon Europe (HEU) has been assessed as one of the key tools for Norway to succeed with the transition challenges ahead. The Norwegian institute sector is increasingly drawing projects from the EU's framework programme, and this sector is particularly important in relation to the EU's priorities concerning societal challenges under Pillar 2 of the framework programme.

The current guidelines for the RES-EU scheme (formerly STIM-EU) have been a prerequisite in recent years for the institutes to be able to increase their investments in EU cooperation, in collaboration with the Norwegian private and public sectors. They have also made a marked contribution to increasing Norway's share of EU contributions and to national knowledge and technology development in the green and digital transition. RES-EU funding is only awarded to projects that have succeeded in the EU and is meant to compensate Norwegian institutes for basic allocations that are often low compared to that of European research institutes. The European Commission only covers about 60 per cent of the project costs.

Predictable framework conditions are essential in research and innovation, also at the European level. The RES-EU scheme is now subject to assessment and the Energi21 board is concerned that the scheme will be weakened, with significant consequences for further Norwegian participation in the framework programme. If this scheme is not maintained and strengthened, the institute sector will find itself unable to participate on competitive terms. This will have negative ripple effects for Norwegian trade and industry and public bodies that collaborate extensively with the institute sector in European research projects.

Without the institutes' prioritisation of the framework programme, Norwegian enterprises and public bodies will not be able to benefit from the opportunities available through the framework programme to the same extent as before, and the Government's ambition of a 2.8 per cent share of programme contributions will be difficult to achieve.

The Energi21 board considers the continuation of the RES-EU scheme, as it is currently designed, to be the most essential instrument for continued strong and increasing Norwegian participation in Horizon Europe.

The Energi21 board recommends that the RES-EU scheme be continued as it is currently designed, to ensure continued strong and increased Norwegian participation in Horizon Europe. This will also contribute to increased participation from Norwegian enterprises and public bodies. Since partnerships have become more important in HEU, it is recommended that the RES-EU scheme also include calls under the partnerships.

The Energi21 board believes that Norwegian stakeholders can make better use of the European research and innovation activity schemes than we have previously done. There are several initiatives that also represent opportunities for Norwegian stakeholders to receive funding for their research and innovation projects.

The EU Innovation Fund

The EU Innovation Fund is one of the world's largest investment funds for the demonstration and commercialisation of innovative low-emission technologies. The Innovation Fund expands Norwegian stakeholders' opportunities to receive funding for commercialisation of low-emission technology. The fund's key areas are harmonised with those of the Energi21 strategy, and the Energi21 board believes that the energy industry can make better use of this scheme. Funding awarded under the Innovation Fund increases commercialisation opportunities for projects that have previously received funding from the Research Council of Norway, Gassnova, Innovation Norway, Enova or directly under the national budget.

The Energi21 board recommends reinforcing efforts to mobilise the business sector to utilise the opportunities offered by the EU Innovation Fund.

Important Projects of Common European Interest (IPCEI)

IPCEI – Important Projects of Common European Interest is a European scheme that provides funding for innovative projects that require cross-border European efforts to be realised. Projects that are granted IPCEI status may receive funding for initial investment on an industrial scale that can be used to cover complete value chains. Norway is a member of IPCEI Hydrogen. Enova has primary responsibility for managing Norway's participation. IPCEI can be very valuable for Norwegian stakeholders and their opportunities for scale-up and commercialising products and services in Europe. A link to Europe's IPCEI scheme can help speed up development and give Norwegian companies opportunities to increase the quality of their projects.

The Energi21 board recommends that the authorities consider joining more of Europe's IPCEI initiatives. Participation in the EU IPCEI scheme could contribute to industrialisation in several of the Energi21 strategy's key areas. The Energi21 boards particularly recommends IPCEI initiatives targeting batteries and CCS.

European Digital Innovation Hubs (EDIH)

As part of the DIGITAL EUROPE Programme, the European Commission is establishing between 200 and 250 European Digital Innovation Hubs (EDIH). The purpose of the EDIHs is to help the business sector (with a special focus on SMEs and start-ups) and the public sector to adopt advanced digital technologies, including artificial intelligence. The Government has decided that two such digital innovation hubs will be established in Norway, and two consortia have applied for EU funds through the scheme.

The Energi21 board recommends that the authorities further develop Norway's participation in the EU's digital research and innovation initiatives. The establishment of digital innovation hubs in Norway is an important step in that direction.

4.2.2 RECOMMENDATIONS TO SAFEGUARD NORWEGIAN INTERESTS

The Energi21 board considers it important to strengthen participation and influence the development of the EU's research and innovation programmes. The EU research agenda should include topics of common interest to the EU and Norway, and the strategic work also strengthens R&D stakeholders' networks and position in relation to succeeding in establishing or participating in new projects. International research collaboration has great value for knowledge production in Norway and for the recruitment of knowledge resources to the industrial sector.

The Energi21 strategy harmonises well with the EU research and innovation agenda in the field of energy, but Norway is in a special position in some technology areas, especially hydropower, CCS and blue hydrogen. For technologies that are important in the European energy system (e.g. CCS), it is important to ensure that these are addressed in the EU's research and innovation system. For technologies of primarily national relevance, such as hydropower, it is important to have national schemes in place that address R&D needs. This is because it is natural to expect the CCS area to be addressed in European research – and extensive efforts have been implemented in this area for many years. In contrast, getting the EU to invest in hydrogen production from natural gas with CCS and hydropower is probably not very realistic, and other measures, such as national prioritisation, may need to be taken.

- The Energi21 board recommends active participation in the SET Plan, EERA and the partnerships to safeguard Norwegian interests and priorities, as well as to facilitate increased international research collaboration in the Nordic region and Europe.
- The Energi21 board recommends making active efforts in the further implementation of the EU's research and innovation programme, and other relevant programmes involving Norway, such as Horizon Europe and the EU Innovation Fund.
- Norway's interests related to hydropower, CCS and blue hydrogen should be specifically addressed, as these have a less prominent role in the EU research and innovation agenda compared to the Norwegian agenda.

4.3

Mission Innovation

Mission Innovation is an international collaborative initiative launched during the climate summit in Paris in November 2015. Norway was one of 21 countries that participated in its start-up. The objective of Mission Innovation is for the participating countries to accelerate climate-friendly energy technology development through R&D collaboration. An important aspect of Mission Innovation is a shared ambition to strengthen R&D investments. All participating countries have pledged to attempt to double their energy research investments over a five-year period. Other aims of the initiative are to increase collaboration on major common challenges and to facilitate private energy sector investments. Since then, the European Commission and two new countries have joined Mission Innovation.
In May 2021, the Sixth Mission Innovation Ministerial decided to launch Mission Innovation 2.0. During this phase, work will concentrate on missions in which interested members will play a role. As of April 2022, missions have been launched in two stages (first and second wave) and MI 2.0 now consists of the following missions:

- Zero-Emission Shipping.
- Clean Hydrogen.
- Green Powered Future.
- Carbon Dioxide Removal.
- Urban Transitions.
- Net-Zero Industries.
- Integrated Biorefineries.

In Zero-Emission Shipping, Norway, represented by the Research Council, the Ministry of Petroleum and Energy and the Ministry of Climate and Environment, has taken on the role of co-lead together with Denmark and the USA. The ambition is to contribute to at least five per cent of the global deep-sea fleet operating on zero emission fuel by 2030. The work is well under way and was presented at several seminars at COP26 in Glasgow in November 2021.
In the Carbon Dioxide Removal (CDR), co-led by the United States, Saudi Arabia and Canada, Norway's role thus far is that of a Core Mission Member. Gassnova and the Ministry of Petroleum and Energy represent Norway. CDR was launched as recently as at COP26 in Glasgow in November 2021 and is therefore in the start-up phase. The goal is to establish CDR technology that can reduce the CO_2 content in the atmosphere by 100 million tonnes per year by 2030.
Norway is also a Core Mission member of the Clean Hydrogen Mission. This is one of the broadest collaborations within Mission Innovation and is co-led by Australia, Chile, the EU, the UK and the US. The goal is for the countries to contribute to reducing end-to-end clean hydrogen costs to USD 2 per kg by 2030.

As regards the other missions, Norway has so far monitored their activities. If activities develop in other missions that are of interest to Norway, participation will be considered, but as a small country with limited resources, our priority has been to concentrate efforts on those that are considered most strategic.

> The Energi21 boards recommends further developing Norwegian collaborative positions in international research and innovation arenas where it has the most impact, such as: increased quality of knowledge development, access to and further development of new technologies, and network and market access for Norwegian and international players.

4.4

IEA, Nordic and bilateral research cooperation

The International Energy Agency (IEA) is the most important arena for energy research cooperation outside the EU. The IEA has nearly 30 member countries. It was established in 1974, and its main objective at that time was to prevent and counteract oil supply crises. Over time, all energy carriers and their use have been given a central place in the IEA's scope of application. Energy efficiency measures, statistics preparation, environmental policy, etc. are also key areas. The IEA has established a number of research programmes related to different aspects of the energy sector. These are brought together under the Technology Collaboration Programme (TCP). The partnerships are organised under various working parties that provide advice on strategic issues to the Committee on Energy Research and Technology (CERT), which has a more overarching position.

Norway is a member of some 20 of more than 40 such partnerships, which are divided into the areas of oil and gas, end-user technologies, renewable energy technologies and information exchange. The active Norwegian participants can be from industry, the research communities or the authorities, depending on the specific programme's activities. The Research Council of Norway is the coordinator of Norway's activities. More information about the IEA's technology collaborations and Norwegian participation can be found on the IEA's website.

The IEA prepares many scientific reports, including on the de-carbonisation of the energy system. These are reports at the global, regional and national levels. The reports receive great international attention and influence energy research as well as energy research policy. One of the more well-known reports is the annual "World Energy Outlook", which documents scenario and model-based analyses of the development of the world's energy system.

The Energi21 boards recommends dedicated funding schemes for participation in international working groups, such as within the IEA. Participation in such fora is essential for the establishment and maintenance of international networks. This in turn is important to achieve a position at the forefront of research and thereby influence the research and innovation arena in Europe (first and foremost).

4.5

Nordic Energy Research

Nordic Energy Research (NEF) is an energy research collaboration encompassing the five Nordic countries. The main objective is to support Nordic energy cooperation. NEF provides support to energy research projects that are of common interest to Nordic stakeholders and hold potential for cross-border research collaboration. The collaboration uses research to create a basis for energy-policy decision-making and to serve as a link between industry, research and politicians. NEF has a special focus on sustainable, competitive energy solutions. It is also active at European level. Nordic Energy Research has an annual research budget of NOK 40 million. Its head office is located in Oslo, Norway.

In recent years, NEF has revised its strategy and is increasingly the initiator of Nordic joint calls in areas that three or more countries have adopted as key areas. This is based on the European Commission's ERANET Cofund scheme under Horizon 2020. NEF acts as coordinator, but the research funding organisations in the respective countries provide the bulk of the funding. For example, a joint call for proposals under the Green Shipping programme was issued in 2021 and a call for proposals relating to hydrogen is planned for 2022. NEF also aims to become a joint Nordic force in the EU's Clean Energy Transition Partnership under the current Horizon Europe framework programme. Here, NEF has been given responsibility for coordinating parts of the partnership.

4.6

International cooperation on education

The need for expertise in climate-friendly technology areas will increase in line with investment plans and development projects in this field. There will be a need for both skilled workers with practical specialist expertise and candidates with theoretical and scientific knowledge. International cooperation between universities, university colleges and vocational colleges in targeted key areas can be a valuable measure to take advantage of different countries' specialist expertise and ensure recruitment of expertise for the future energy system. Access to expertise is also an important success factor for the establishment of new green industries and the further development of existing industries.

The Energi21 board recommends international cooperation on the training of candidates for future recruitment of expertise in the planning, design and construction of future energy systems.

This particularly applies to fields where challenges are anticipated in relation to the recruitment of skilled workers and candidates with theoretical scientific competence.

5

Further development of other technology and knowledge areas

In addition to the eight key priority areas where efforts will be intensified, it is necessary to continue and secure investment and further develop a number of other technology and knowledge areas. Taken together, the key areas and supplementary knowledge and technology areas form a robust and broad technology and knowledge platform in climate friendly energy technologies. Such a platform is essential to successfully decarbonise the energy sector and ensure competitive energy deliveries to all end users. A robust and broad platform is also essential to promote development within each of the areas independently, particularly because we do not know exactly which technologies will gain ground in the short and long term, and how quickly they will be integrated into the energy system. In view of this, it is important to have laid the foundation for good options in the form of other technology areas that can be developed as strategic key areas should the need arise.

In addition to the eight key priority areas, the Energi21 board recommends further developing technology and knowledge in the following areas:

- Energy-efficient, smart buildings and cities.
- Energy-efficient industry.
- Climate-friendly energy technologies for maritime transport.
- Climate-friendly energy technologies for land transport.
- Climate-friendly energy technologies for aviation.
- Bioenergy.
- Land-based wind power.
- Geothermal energy.
- Nuclear power of the future.
- Fusion energy.
- Wave and tidal energy.
- Airborne wind.

Brief summaries of these technology areas are provided below, while more detailed descriptions can be found in Appendix 5: Detailed information on further development of other technology and knowledge areas.

5.1

Energy-efficient, smart buildings and cities

Energy-efficient, smart buildings and cities is considered an important subject area to achieve a secure and sustainable energy supply in the energy transition. It is closely linked to the key area "Integrated and Efficient Energy Systems" and plays an important role in sector integration with efficient, local and emission-free power and heat utilisation and production. Buildings play a more active role in the energy system as consumers of energy, producers and flexibility resources, and energy infrastructure as part of comprehensive land-use planning is becoming increasingly important. Norway has a strong technology and knowledge base in energy-efficient buildings and cities, which offers business development opportunities.

- SINTEF has estimated the total energy efficiency potential of the building stock to be 23 TWh in 2050 by means of realistically increasing the rehabilitation of the building stock with energy upgrades, new passive buildings and subsequent maximum phase-in of heat pumps (SINTEF, 2022). The technical potential for power generation from solar installations in buildings is estimated at around 30-50 TWh (Solenergiklyngen and FME SuSolTech, 2020).
- Reducing energy and power consumption as well as utilising flexibility in buildings and areas increases security of supply, improves the power balance and reduces the need for land-intensive renewable power production and grid development. Streamlining, increased flexibility and local energy solutions can reduce the magnitude of encroachments on nature during the energy transition. Local power generation in particular can help spare natural areas from grid expansion and provide better resource utilisation.
- For the EU to reach its target of a 55 per cent reduction in GHG emissions by 2030, the required annual investment in the building stock totals EUR 275 billion by 2030 in the EU, with the lion's share allocated to energy efficiency improvement (EC, 2020).
- The EU is strongly committed to energy efficiency in buildings through the EU Renovation Wave and the Energy System Integration Strategy. It has also set targets for 100 energy-positive neighbourhoods by 2025, and through Horizon Europe, 100 climate-neutral cities by 2030.
- Norway has strong research environments in energy-efficient, smart buildings and cities that participate in relevant EU projects. Many have succeeded in receiving funds through the Horizon 2020 programme.
- Norwegian businesses are at the forefront of plus houses, and the construction sector is considered to be innovative with ambitions for the development of state-of-the-art buildings. There are several sustainability and environmental clusters and organisations in the building and real estate sector that work on digital innovation and efficient use of resources, including optimisation of energy consumption.

Key research and innovation needs include:

- The role of the end user in the energy system.
- Optimisation of local energy systems and their interaction with overall energy systems.
- Technology and tools for designing, planning and operating zero-emission, energy-flexible buildings and areas.

Selected actions include:

- Pursuing the centre initiatives and further developing grant schemes for R&D and demo projects in zero-emission buildings and areas nationally and internationally.
- Strengthening Norwegian participation in EU research projects and coordination with EU trends.

5.2

Energy-efficient industry

The development of energy-efficient industry makes a particularly positive contribution to the decarbonisation of Norwegian industry and to maintaining a secure and sustainable energy supply in Norway. Energy-efficient industry contributes to decarbonisation of the Norwegian industrial sector by reducing the consumption of fossil energy. It contributes to a secure, competitive and environmentally friendly energy supply in that it saves energy for other purposes. Energy-efficient industry also plays an important role in the key area "Integrated and efficient energy systems", including as a major energy end user and potential supplier of thermal energy in the form of surplus heat.

- Energy-efficient industry consists of three main areas: switching to more efficient energy carriers, incremental process improvements and increased utilisation of surplus heat.
- The utilisation potential of surplus heat from industry below 250°C is estimated at 20 TWh per year. In Norway's metal industry, 6 TWh in the range 100-250°C is unutilised (FME HighEff, 2021). There is also a significant potential for process rationalisation, but the potential is process-specific and thereby difficult to quantify.
- The EU has ambitious targets for energy efficiency improvement and research in the field of energy efficient industry, which is an important part of Horizon Europe and the European Strategic Energy Technology (SET) Plan.
- Norway has strong research environments that specialise in thermal energy and process and materials technology, and research groups working on energy-efficient industry have joined forces at FME HighEff. Norwegian research groups have also been successful in calls from Horizon 2020 and Horizon Europe.
- Norwegian industry is at the forefront of energy efficiency, and in combination with competitive renewable power, this constitutes a key international advantage.
- The potential for utilising surplus heat in industry remains high and will continue to grow in step with plans to establish battery factories and data centres.

Key research and innovation needs include:

- Improved core processes and practical process solutions that promote energy efficiency and reduced emissions.
- Digitalisation and automation of production processes.
- New and cost-effective technology solutions and methods for converting and upgrading surplus heat and increasing the utilisation of waste gases.
- Area plans and cross-sector cooperation for better utilisation of energy resources.

Selected actions include:

- Continuing the centre initiative and strengthening collaborative arenas for research and innovation
- Strengthen the physical and digital research infrastructure.
- Adapting framework conditions to bring about rapid industrial transformation, particularly in industries with long lead times.

5.3

Climate-friendly energy technologies for maritime transport

Climate-friendly energy technologies for maritime transport are particularly relevant for decarbonising the transport sector and developing new green industries and marine energy technologies. Decarbonisation of maritime transport will require a combination of several low and zero emission energy solutions, including electrification, hydrogen and ammonia. Propulsion systems and energy supply requirements will depend, among other things, on the size of the vessel, the operating pattern and local availability of energy infrastructure.

- The International Maritime Organisation (IMO) has a target of halving emissions from international maritime traffic by 2050, and Norway is a strong advocate of stepping up the target to zero emissions. The EU and Norway also have ambitious emission reduction targets for maritime transport.
- Energy-efficient operation, improvements and modification of existing ships, fleet renewal and the phasing-in of sustainable low and zero emission fuels will be key measures to achieve these targets.
- In its reference trajectory, DNV does not expect to see a significant element of low-emission fuel, including ammonia, hydrogen and methanol, in the Norwegian maritime sector until 2040. Targeted measures to promote RD&I in maritime transport could accelerate this development.
- Worldwide, it is estimated that an investment of approximately USD 1,000 billion by 2050 is required to meet the IMO's emission target for international maritime transport by 2050. NHO has estimated the Norwegian turnover potential in Europe for the maritime industry, i.e. carbon-free propulsion systems and infrastructure solutions, to be EUR 5 billion per year in 2030.
- Norway has leading research environments in low-emission maritime transport that are developing and testing new ship designs, control systems and low-emission fuel and propulsion systems. The research centre for zero emission energy systems, FME MoZEES, brings together Norwegian R&D communities working on maritime transport, and there are also more specialised centres and clusters for maritime R&D that address low and zero emission propulsion systems.
- Complete and internationally competitive maritime value chains with initiatives for the production of low-emission fuel, development of vessels and end-user solutions make Norway particularly well placed to take a leading role in climate-friendly maritime

Foto: Marcus Lindstrom, iStock

transport, including associated infrastructure solutions. Norway has long industrial experience of highly specialised shipbuilding industries with a high degree of complexity. Industry stakeholders have long experience from and are forward-looking in the development of maritime industries, shipping and the petroleum industry.
- As part of the EU's Fit for 55 package, maritime transport will be gradually included in the EU ETS from 2023. Fit for 55 and FuelEU Maritime also set binding requirements for reducing emission intensity from the maritime sector in the years ahead, and requirements for zero emission infrastructure in ports. The EU nevertheless has a somewhat less prominent focus specifically on maritime transport in its research programmes than Norway.

Key research and innovation needs include:
- The development and establishment of emission-free maritime value chains.
- Emission-free maritime propulsion systems.
- Effective development of infrastructure for low and zero emission energy carriers.
- Safety and guidelines related to the supply and use of new low and zero emission energy carriers.

Selected actions include:
- Stimulation of Norwegian stakeholder participation in research and demonstration projects.
- Funding for innovation projects for the industrial ector with potential in the domestic market.
- Funding for knowledge-building and researcher projects in key research topics.

5.4

Climate-friendly energy technologies for land transport

Climate-friendly energy technologies for land transport are essential for decarbonising road traffic, rail-based transport and non-road machinery such as construction and agricultural machinery. Decarbonisation of land transport will require a combination of several low and zero emission energy solutions to ensure adequate supply for reliable mobility and to achieve climate targets. The needs and requirements for propulsion systems and energy delivery will depend, among other things, on the size of the vehicle, the operating pattern and local availability of energy infrastructure.

- Road traffic accounted for 17 per cent of emissions in Norway in 2020, and the Norwegian Government has set a number of targets to increase the proportion of zero-emission vehicles in the different road traffic segments.
- Norway has a head start in the electrification of passenger cars, but for other segments such as heavy vehicles, agricultural machinery and construction machinery, there are currently few zero-emission alternatives. Parts of these segments will be electrified, but biofuels and hydrogen will also play an important role here.
- The transformation of the transport sector requires large-scale development of zero-emission infrastructure. First of all, massive expansion of the charging infrastructure is required, and the Government is working to establish a national charging strategy. For segments that are not electrified, the expansion of filling stations for either biogas or hydrogen is also required.
- The development of new infrastructure for zero-emission transport may demand large areas of land. Charging stations for all types of road transport occupy land and can also lead to grid expansion.
- Liquid biofuels are already well integrated into the existing filling infrastructure, but the current infrastructure is not adapted to biogas. Hydrogen filling stations also require additional safety zones to be established.
- Globally, an estimated USD 300 billion will need to be invested in electric vehicle charging infrastructure by 2030. The need for low-emission infrastructure for all land transport will be even more significant if we include hydrogen, hydrogen carriers and bio-based fuels. In the EU, the investment needs resulting from proposed zero emission infrastructure requirements are estimated to be at least EUR 300 billion by 2030.
- Smart solutions for charging infrastructure, especially fleet management and payment solutions, are highlighted as areas where Norway can take market share, and the global market potential for smart charging for EVs is estimated at EUR 11–16 billion in 2050.
- Norway has strong research environments in charging infrastructure and with strong interaction with the power system. In addition, we have growing environments in key propulsion technologies and carriers such as batteries and hydrogen.
- Norway has several projects working to establish low-emission supply value chains for the transport sector. Early electrification has helped to give Norwegian industry a head start in the development of charging and infrastructure concepts. There are also a number of Norwegian suppliers of battery systems, storage systems and filling infrastructure for hydrogen.

- The Green Road Transportation Programme launched in 2021 will contribute to the increased implementation of low and zero emission technology and energy carriers for vehicles and machinery, especially in the industrial segment. Several stakeholders have initiated projects for the phasing-in of low-emission technologies in transport segments. An example is the target of 100 heavy electric trucks and 100 hydrogen trucks in the Oslo region and Eastern Norway.

Key research and innovation needs include:

- Stationary and mobile concepts for fast and safe charging (including inductive concepts) and filling of hydrogen.
- Technologies and components for integrated and hybrid zero-emission propulsion systems.
- Effective market and business models for the development of a climate-friendly transport system, including increasing our understanding of the effects of incentive schemes for the transformation of the transport sector to zero-emission.

Selected actions include:

- Establishing a demonstration project with different types of infrastructure for electrification and zero-emission solutions for heavy transport.
- Financial support schemes for establishing a domestic market including e.g. procurement schemes.
- Requirements for low and zero emission vehicles and non-road machinery in public procurement.
- A national plan for the development of a comprehensive low-emission infrastructure.

5.5

Climate-friendly energy technologies for aviation

Climate-friendly energy technologies for aviation addresses the principal challenge of "decarbonising industry and transport". Aviation is demanding to decarbonise, firstly because it involves international activities and secondly due to technology and safety demands.

- There are several options for decarbonising aviation, including sustainable aviation fuel (SAF), electrification and hydrogen-powered aircraft. In the short term, only SAF can decarbonise the existing fleet, but electric aircraft are expected to play a role on short distance flights in just a few years' time. Based on its short runway network and forward-looking industrial and aviation stakeholders, Norway can be a springboard for further development of the electric aircraft market also beyond its national borders. Hydrogen powered aircraft are envisaged somewhat further in the future.
- Norway was the first in the world to introduce sales requirements on advanced biofuels with 0.5 per cent by 2020 and a target of 30 per cent by 2030. Demonstrations of advanced and synthetic fuels have been successful, but SAF is still somewhere between two and ten times more expensive to produce than fossil fuels depending on the maturity of the process.
- Norway has a number of plans for the production of SAF, based on both biofuels and synthetic fuels produced by electrolysis with CO_2 capture. SAF production in Norway is estimated to reach approximately 3 TWh per year in 2030.
- The EU's Green Deal emphasises the development towards zero-emission aviation and in pursuit of this, the EU has launched a proposal on implementing requirements for admixture of SAF. The admixture requirement is 5 per cent in 2030, with a minimum requirement for synthetic fuels, and a 20 per cent share from 2035, implying a significant increase after 2030 (ReFuelEU Aviation). This will lead to significant growth in the market for SAF and will also trigger considerable investment in production facilities in different areas of Europe.
- The NTNU Clean Aviation Partnership was established in 2021 with the goal of conducting multidisciplinary research for net zero-emission aviation by 2050. It is also a member of the EU Clean Aviation Partnership. There are also advanced research environments in electrotechnical components, low-emission infrastructure and advanced biofuels and biorefining.
- Norway has active stakeholders in several areas of the value chain for climate-friendly energy technologies for aviation, including fuel production, infrastructure and component design/development. Several Norwegian stakeholders in SAF production and development, both bio-based and synthetic, have ambitions to take market share internationally. Norwegian technical environments are also involved in developing solutions and components for electric aircraft, including electric aircraft engines.

Key research and innovation needs include:

- Application of new energy carriers: resource and energy efficient and sustainable production of bio-based fuels, compact and reliable battery systems including safe and efficient ultra-fast charging, and hydrogen concepts for aircraft (GH2 and LH2).
- Propulsion systems: fully electric powertrains, thermal integration of liquid hydrogen and electric powertrains, fuel cells with sufficient volume and energy efficiency for aviation, and jet engines for hydrogen.
- Digitalisation: cybersecurity, improved continuous condition monitoring of key systems including wireless communication with sensors, digital twins of energy and propulsion systems, including airport energy systems.
- Development of safe and efficient infrastructures for supplying low and zero emission energy to aviation.

Selected actions include:

- Establishing an Aviation21 process and green aviation programme/ innovation centre.
- Implementing clear regulations for accounting and documentation of climate effects when using sustainable fuel.
- Strengthening Enova's role in the establishment and development of sustainable fuel production facilities.
- The central government should pay the additional cost of sustainable fuel for its own employees' business travel. Consideration should also be given to requiring a high proportion of sustainable fuel for the purchase of public service obligation (PSO) routes.

5.6

Bioenergy and biofuels

Bioenergy is considered an important focus area because of its contribution to decarbonisation and a secure, competitive and environmentally friendly energy supply. Biomass for energy purposes also represents a potential for the development of new green industries based on Norwegian bioenergy resources.

- Transitioning to the use of energy carriers based on bio-resources is often the option for reducing fossil carbon with the shortest lead time for a large

LN-ELA, Avinor's electric aircraft. *Photo: Avinor* proportion of the industrial and transport sectors. This is particularly true in the segments that are demanding to electrify, such as aviation, non-road machinery, maritime transport and industrial processes that rely on carbon as an input. With limited adaptation, biofuels can in several cases replace fossil fuels and, in this way, contribute to Norway maintaining a secure energy supply.

- Norway has extensive bioenergy resources. Pöyry and Nordic Energy Research (2019) estimate the technical potential for bioenergy based on Norwegian forest, agriculture and waste to be 57 TWh. Almost 70 per cent of this potential comes from forest-based biomass. In the longer term, marine biomass will also be a potential energy resource. Approximately 13 TWh of the technical potential is currently exploited.
- Value chains for the production of energy carriers based on biomass are diverse and can contribute to the further utilisation of residual raw materials and waste. In the agricultural sector, there is considerable potential to use waste streams to produce bioenergy and biofuel on a small and large scale.
- In the longer term, bioenergy combined with carbon capture and storage will enable negative emissions.
- Value chains based on forest biomass require a large area and can have a major impact on nature. The use of bioenergy and biofuels and the assessment of climate benefits should also take into account what role the species from which the biomass originates plays in the storage and uptake of CO_2 in the ecosystem. Sustainable use of biomass will also be key to social acceptance when phasing in more use of bioenergy and biofuels.
- Bioenergy is expected to play an important role in the global energy system in the energy transition, with large investments anticipated in this area. To reach the 1.5°C target, the IEA estimates global annual investments of USD 14–35 billion in biogas alone leading up to 2040.
- The EU has a strong focus on the development of bioenergy from a bioeconomy perspective, and is imposing increasingly stringent sustainability requirements on bioresource use and refining. Biofuels and bioenergy are also one of the core areas of the EU SET Plan, with the EU emphasising the development of advanced biofuels for decarbonisation of the transport sector.
- There are established industry stakeholders across the entire bioenergy value chain in Norway, including equipment suppliers, manufacturers, managers and consumers. They cover the full breadth of bioenergy, including solid biomass, bioliquids and biogas. Several stakeholders also have aspirations to establish new large-scale production plants for liquid biofuels, including SAF.
- Norway has strong research environments in biotechnology and biochemistry, chemical engineering, process technology and conversion processes. Some research groups in the field of bioenergy have joined forces in the FME Bio4Fuels, and several of the groups actively contribute to a number of EU projects. Norwegian research communities have received EUR 9 million for projects related to bioenergy through Horizon 2020 (RCN, 2021).

Key research and innovation needs include:

- Identification and sustainable management of biomass for energy purposes, including community involvement, land use and changes in bioenergy potential due to climate change.
- Interactions between bioresources, agriculture and the circular economy. Combined biorefinery facilities with on-site utilisation of side streams.
- Life cycle analyses and certification of bioenergy.

Selected actions include:

- An updated bioenergy strategy with action plan.
- Funding for taking basic research to market, and infrastructure to support pilot-to-plant projects and establish more facilities.
- Risk relief for industry stakeholders and prioritisation of innovation activities targeting the commercialisation of technologies and utilisation of Norwegian industries.

5.7

Land-based wind power

Land-based wind power is a mature and competitive renewable technology. The technology can help meet the energy transition's growing power demands and ensure a secure and competitive power supply.

- It is uncertain how much new land-based wind power will be built in Norway by 2030. Any resumption of development will depend on the political climate and new licensing requirements. A revised licensing system, developed to ensure stronger local support, is expected to be launched in the course of 2022/23.
- Wind power plants are contentious, among other things because they are land-intensive, noisy and can be considered visual pollution. Wind power plants with associated infrastructure located in relatively untouched nature contribute to the fragmentation of natural areas, which can affect the local ecosystem.

- Investment needs in land-based wind power to achieve European climate targets are estimated at USD 6 billion annually, and globally at USD 146 billion by 2030. If Norwegian operators succeed in taking leading market share internationally, the total addressable market value for these operators is estimated to be EUR 12–40 billion in the period 2020–2030.
- Norwegian research environments in land-based wind power are recognised internationally, and some groups have joined forces in the FME NorthWind. Their research focuses, among other things, on digitalisation and sustainable development of land-based wind power.
- The strengths of Norwegian wind power operators lie in project development, modelling and operation and maintenance solutions, including optimisation of market operations and market integration. This also represents a growing export potential going forward. These stakeholders' activities in Norway will decrease with fewer projects, and activity must be moved abroad in order to maintain the expertise.

Key research and innovation needs include:

- Methods and tools, including machine learning, to optimise operation and maintenance.
- Further knowledge of the environmental and societal impact of wind power.
- Cost-effective solutions and mitigation measures for negative environmental and land-use impacts.

Selected actions include:

- Supporting Norwegian stakeholders' foreign investment.
- Access to land and opportunities to apply for licenses in Norway over time.

5.8

Geothermal energy

Geothermal energy plays an important role in the thermal system aspects of the energy transition and contributes in particular to a secure and competitive energy supply. Geothermal energy is taken from the earth's crust and depending on temperature, can be upgraded for use in heating, cooling and power generation.

- Norwegian geothermal plants currently produce 3.5–4 TWh of heat annually, and low-temperature geothermal energy can theoretically cover the national demand for heating and cooling of buildings.
- The flexibility potential of geothermal energy in the energy system at full utilisation is 10–15 GW power output. The utilisation of low-temperature geothermal energy helps to reduce power peaks in the grid, while geothermal seasonal heat stores and other storage concepts contribute to load balance.
- Geothermal concepts have low land-use requirements if located close to the end user and do not require further development of transmission infrastructure.
- To achieve the 1.5°C target, USD 24 billion per year must be invested globally in geothermal energy by 2050. The global economic potential for geothermal heat is over 800 GW.
- Deep geothermal energy is one of the working groups in the EU SET Plan. The EU's Horizon 2020 programme Geothermica promotes research and innovation for reliable, safe and competitive geothermal energy. Geothermal energy is also particularly highlighted in the development of low-emission and energy-positive buildings and areas.
- Norway has research environments in both deep and low-temperature geothermal energy, concentrated in the Norwegian Center for Geothermal Energy Research (CGER).
- A number of Norwegian stakeholders are working on the development and installation of low-temperature geothermal energy. There is also significant technology transfer potential from the oil and gas industry, which means that the Norwegian supply industry will be able to assert itself in the international market. In particular, Norway's experience with deep wells can be transferred to applications in, for example, geothermal power generation.

Key research and innovation needs include:

- Effective methods for geological, geochemical and geophysical surveying, both regionally and for prospect uses.
- Robust and cost-effective drilling and well technology.
- Methods for monitoring and limiting negative environmental impacts and for the safe management of the subsoil.

Selected actions include:

- Stimulation of Norwegian stakeholder participation in research and demonstration projects.
- Funding for innovation projects for the industrial sector with potential in the national market.
- Funding for knowledge-building and researcher projects in key research topics.

5.9

Nuclear power of the future

The nuclear power of the future is being developed in several areas and can make a positive contribution to maintaining a secure energy supply in the energy transition, especially in our neighbouring countries. Current efforts are targeting, among other things, the next generation of conventional nuclear power and small-scale modular reactors (SMRs).

- SMRs are being developed on several fronts, including in several of Norway's neighbouring countries, through both large and small companies. More and more countries are investigating the possibility of starting their own projects. There are over 70 SMR designs and concepts internationally, and most of them are still under development.
- The advantage of small modular reactors is that they are more flexible than conventional nuclear power plants, have lower costs, shorter lead times, better scalability and are safer.
- For many countries, the establishment of one or more SMR reactors can be a safer and more affordable route to decarbonisation of the power sector. A test reactor of fourth-generation lead-cooled SMR is in the planning phase by the companies Blykalla and Uniper in Oskarshamn, Sweden (TU, 2022).
- Norway has long experience of research on nuclear power through a number of research institutions, and an SMR simulator will be established in Norway in order to conduct research on the safety of future nuclear power.

Key research and innovation needs include:

- Operational reliability and cybersecurity in SMR.
- Heat exchange technology .
- System integration and uptime considerations.
- Safe handling and storage of waste.

Selected actions include:

- Funding of key research and innovation needs.
- Funding of participation in international research and innovation collaborations.

5.10

Fusion energy

If technology development is successful, fusion energy could represent a paradigm shift in the energy field. The technology will represent a reliable heat and power concept that requires little land and can contribute in the long term to almost unlimited amounts of competitive and safe energy.

- Unlike fission, fusion involves the process of fusing atoms which release heat. Light atomic nuclei are fused into larger and heavier atoms. This is typically hydrogen nuclei that are fused into helium. It takes vast amounts of energy to sustain the fusion process, and so far, no one has succeeded in extracting more energy than the amount put into the process.
- Fusion energy addresses the challenges of reliability and waste management associated with traditional fission power plants. This is because the process dies out by itself without any input of energy and because no radioactive waste is produced.
- Tokamak reactors are the most widely used reactors, and several major research projects and private enterprises are involved in the process of building pilot plants. The most ambitious of these aim to demonstrate net fusion energy (that you get more energy than you put in) by 2025, and to have a commercial-scale reactor in place by 2030.
- Some of the advantages of fusion energy are that the location of the plants is flexible and that it is largely independent of natural resources since there is sufficient supply of the necessary hydrogen isotopes used as inputs all over the world.
- There are currently a number of technological challenges that need to be addressed, including maintaining sufficient temperatures for continuous fusion and frequent component replacement.
- Norway does not have industry directly related to fusion energy, but we have research environments in areas such as northern lights, plasma and materials technology that participate in international research projects related to fusion energy.

Key research and innovation needs include:

- Materials technology specifically relating to magnets and superconductors.
- Small-scale reactors and scalable systems, modularisation.
- Heat exchange technology.

Selected actions include:

- Funding of key research and innovation needs.
- Norwegian participation in EUROfusion.
- Funding of participation in international research and innovation collaborations.

5.11

Wave and tidal energy

Wave and tidal energy utilises the movement of water to generate power. It is a relatively stable source of energy supply. The technology contributes to a secure energy supply and to the development of new marine energy technologies.

- Wave energy has great technical potential along the Norwegian coast. If 20 per cent of this potential is developed, it will generate 12-30 TWh of power.
- Wave energy is currently an immature technology with an installed capacity of 2.3 MW globally, but based on its project database, IRENA expects installed capacity to reach 100 MW in the coming years. Many concepts are still in the testing and demonstration phase, and it was not until 2020 that concepts were installed with a capacity of over 1 MW.
- Several developers of wave energy concepts in Norway are in the testing and piloting phases. In 2017, a wave power plant was connected to the grid in Norway for the first time. This was a full-scale pilot with a buoy rated at 100–200 kW. The technology is still relatively expensive but is expected to become competitive in time as a result of scaling up.
- To advance in this process, robust plants must be developed that withstand stresses caused by wave action, and support for patenting, scale-up and commercialisation of concepts will also be key. The development of new concepts will also provide opportunities for Norwegian certification environments and, in time, for a maritime service industry relating to the installation and operation of wave power plants.
- In Norway, there is little activity in the area of tidal power, and the realistic Norwegian expandable tidal potential was estimated in 2007 to be below 1 TWh, although the potential may in fact be greater.
- In its Offshore Renewable Energy Strategy, the EU has set a target of at least 1 GW of installed wave and tidal power capacity by 2030, with an increase to 40 GW by 2050.

Key research and innovation needs include:

- Development of robust systems that withstand stresses caused by wave action.
- Cost-effective concepts.

Selected actions include:

- Support for patenting, scale-up and commercialisation of concepts.

5.12

Airborne wind

Airborne wind is an evolving power generation technology designed to harness wind resources at altitudes between 200 and 1,500 metres. At these altitudes, wind resources are stronger and more constant, enabling a higher capacity factor. This means that the technology can contribute to a secure and sustainable energy supply in the long term.

- Airborne wind concepts are in an early commercialisation phase and are often wing or kite-shaped structures tethered to the ground.
- The location of a single airborne wind system is flexible and requires relatively little land and materials. Consequently, it is suitable for distributed renewable power generation onshore or offshore, but it is now also being developed for configurations in large power plants.
- Kitemill is the only Norwegian supplier (OEM) of airborne wind technology and is a leading player in the development of this technology internationally. Kitemill has received several grants from the EU's research programmes, including Horizon 2020, Interreg and the EU Innovation Fund, totalling more than NOK 100 million. Norwegian university environments are also active in concept and component development.

Key research and innovation needs include:

- Control systems and full automation of launch and landing of wind power kites.
- Lightweight and durable materials that tolerate a high number of cycles.
- Increased reliability, including technical operational reliability and regulatory aspects.

Selected actions include:

- Supporting Norwegian participation in IEA Wind Task 48 – Airborne Wind Energy.
- Funding of RD&I and demonstration, commercialisation and scale-up.

6

Realisation of strategic recommendations – efficient and flexible funding and policy instruments and long-term green risk capital

Instruments are needed that ensure the effective scaling-up of technology projects and the commercialisation of products and services. Access to long-term green risk capital in the scaling-up and commercialisation of industrial technology projects will be key to value creation during the "green" transition. In addition, funding and policy instruments and incentives for research and innovation projects, and the higher education system, should ensure access to skills, technologies and solutions synchronised with the pace and complexity of developments in the energy system.

6.1

Need for targeted, efficient and flexible funding and policy instruments

Industry needs access to skills, technology and solutions that are synchronised with the pace and the complexity of developments in the energy system. Current research and innovation activities may be perceived as being too long-term, as industry stakeholders would have preferred to utilise the results "yesterday". Trade and industry also face several barriers when it comes to commercialising and implementing new products in the market. It is essential to further develop and exploit Norway's advantages in the field of energy and not waste opportunities for value creation and jobs.

The Energi21 board recommends new, more flexible procedures for calls for proposals, funding allocation and implementation of RD&I projects, as a supplement to current practice.

6.2

Industry wants scale-up and implementation

The Energi21 strategy builds on input from business and industry on the potential for value creation, knowledge and technology needs, and relevant funding and policy instruments for research and innovation. As regards such funding and policy instruments and the realisation of RD&I activities, the industry's message is clear:

Loyalty to long-term goals combined with effective actions in a close time horizon are key to the successful realisation of industrial-sector ambitions. There is a need for targeted, efficient and effective policy instruments. There is much knowledge and many technologies available, but it is demanding to implement, scale up and commercialise the solutions in the market.

There will be a great need for practical and theoretical skills in the field of energy. New candidates must be trained, but also existing workers will need further education to operate and maintain the energy systems of the future.

In some technology areas, there are no well-established markets, and we must therefore pave the way for and develop them. It is important that public and private investments in energy-related research and innovation reflect these developments in terms of strength, pace, strategic direction and complexity.

The Energi21 board recommends a range of targeted research and innovation instruments that emphasise scale-up and implementation to promote industrialisation and supplier development.

6.3

Long-term risk capital for the development of green value chains

The scale-up and industrialisation of climate technology is pivotal to realising Norway's ambitions in the climate technology fields set out in the Energi21 strategy. It is important to establish knowledge of the challenges and opportunities relating to the supply of capital, financing and investor competence. The investor competence that both businesses and the investors themselves need the most are in scaling and industrialisation, as well as internationalisation.[19] A report by Menon for Nysnø Climate Investments on capital access for Norwegian climate technology[20] concludes that Norway has noteworthy negative results in terms of growth capital in the early phases of the commercialisation cycle. In the last three years, the country has had the lowest level of early-stage investment per capita. The analyses also show that the Norwegian market stands out by having the lowest level of early-stage investments from foreign asset management institutions.

Norway has unique preconditions for building a world-leading green business sector, but a great deal more risk capital is required to establish and develop green value chains. One risk if the Government is to realise its goal of developing green industry is that the need for green risk capital may exceed its availability. State capital instruments may be a suitable means of raising risk capital and would reduce risk for projects in the Energi21's key areas without distorting competition, as co-investment with private investors is assumed on the same terms.

The Energi21 board recommends a thorough analysis of challenges and opportunities related to access to capital, financing and investor competence for value creation projects pertaining to the Energi21 strategy's key areas.

This analysis should be conducted in a collaboration between investor environments, RD&I communities and businesses, with a focus on technology development for commercialisation. Furthermore, the solutions to this issue can only be developed through inter-ministerial cooperation.

The purpose of the analysis will be to generate knowledge on efficient design of long-term risk capital for the scaling and industrialisation of green technology projects.

6.4

Industry must become involved in taking responsibility for technology leadership

Norway's competitive advantages in energy must be continuously developed in step with resource needs and the developments in technology and markets. This will require the business sector, the authorities, and research and education communities to pull together.

The business sector must become involved in developing knowledge and technology by bearing more risk and investing time and capital in research and innovation activities. The authorities should take steps to ensure efficient coordination of the ministries' different funding and policy instruments, to enable the business sector to prioritise time and capital for research and innovation projects.

[19] *Energi21 report (2021) prepared by Menon et al. "Forsknings- og innovasjonsdrevet næringsutvikling".*
[20] *"Kapitaltilgang for norsk klimateknologi" (in Norwegian only): Vedlegg-1-Menonrapport-kapitaltilgang-klimateknologi.pdf (regjeringen.no)*

The Energi21 board recommends that the business sector take greater risks by investing time and capital in research and innovation projects.

The Energi21 board recommends that business and industry take responsibility for technology leadership and that boards and management groups are aligned with this strategic approach.

6.5

Energy research budgets must be increased

The rate of restructuring in energy systems is now much higher than previously. The Energi21 board therefore believes budgets must be increased to strengthen enterprises' work on developing new technologies and solutions in order to bolster competitiveness and the green transition. It is also important to secure long-term knowledge development and further develop national research and education communities.

With reference to the white papers Long-term Perspectives on the Norwegian Economy 2021 (Meld. St. 14 (2020–2021)) and Energy for Work (Meld. St. 36 (2020–2021)) as well as the last IPPC report, the green transition is so extensive and important for Norway that overall research and innovation efforts must be increased substantially.

A commitment to the development of climate-friendly energy technologies will affect several sectors of society and thus also several ministries (energy, forestry, agriculture, oceans, transport, climate/environment, construction, industry).

The energy system represents one of society's most important infrastructures. Solutions to future societal challenges will encompass both new and immature technologies, entailing major research and development needs. It is also necessary to increase R&D budgets in order for existing and new industries to develop new ideas and seize the opportunities referred to above.

As of 2022, there are many grant applications for research and innovation projects, and the industrial sector is showing commitment. This is a good starting point, and recommended budget growth will ensure the necessary knowledge and technology development for future business development and value creation.

Comments on recommended budget growth for CLIMIT

The budget for the CLIMIT programme has been reduced from 2017 to 2022. The Energi21 strategic body considers it important to strengthen funding so that the CLIMIT programme harmonises with the importance of CCS technologies in a climate-friendly energy system and in the development of a low-carbon society in Norway and internationally. It is also essential to have a research and innovation programme that is sufficiently robust to allow Norwegian RD&I environments, including Norwegian industry, to effectively contribute to prompt and good profit realisation of the Longship project and potentially also other full-scale projects.

Long-term knowledge development

The energy system will undergo an extensive transition that will take many years. It is therefore essential to strengthen long-term knowledge development in parallel with short-term efforts. Against this background, the Energi21 board recommends further developing the more long-term part of the project portfolio in ENERGIX (Collaborative and Knowledge-building Project for Industry – KSP-K projects). This is to ensure that critical expert groups build relevant knowledge and train more experts in collaboration with industry. This will also help strengthen Norwegian competitiveness in the EU's framework programmes.

The Energi1 board recommends further developing the long-term part of the research portfolio in parallel with short-term efforts to ensure that critical expert groups build knowledge for the energy systems of the future.

Budget growth and thematic prioritisation for long-term investment in centre initiatives

The Energi21 board recommends further developing the centre initiative by targeting cross-sectoral subject areas relevant to security of supply, future industrialisation and the green transition. The investment in the Centre for Environment-friendly Energy Research (FME) initiative has been and remains successful. Targeted and long-term investment in research and innovation projects involving collaboration between industry and research environments is positive for value creation, business development and the green transition.

In addition, targeted centre initiatives are a crucial platform for Norwegian industry and research environments' development of and participation in EU framework programmes; see also section 5 below.

Relevant cross-sectoral subject areas for centre investment are:

- Next generation flexible and efficient energy markets.
- Sustainable energy transition and cost-effective social innovation (environment, biodiversity, land use, behavioural psychology, attitudes etc.).
- Sustainable battery materials and systems.
- Research and innovation-driven business development and industrialisation (keywords: investor attractiveness, effective business models, finance and entrepreneurship, etc.).

The Energi21 board recommends strongly increasing the budget level of the ENERGIX and CLIMIT research programmes in the period 2023–2026. Priority should be given to increasing the budgets of research and innovation projects with a distinct business development profile and commercial opportunities.

The budget level for energy research should be sufficiently robust as to enable Norwegian RD&I environments, including Norwegian industry, to efficiently contribute to swift and successful profit realisation of RD&I projects.

The Energi21 board recommends strengthening long-term centre initiatives for research-driven innovation and supplier development by both increasing their budgets and covering more subject areas.

Priority should be given to cross-sectoral subject areas that support an environmentally friendly energy transition, industrialisation and security of supply.

6.6

Recommendations for the mandate of the state fund Enova

The Energi21 strategic body considers it important that Enova's mandate reflect the importance of energy supply and energy markets in reducing GHG emissions in the various sectors and industries in our society. It is also important that funding and policy instruments reflect the pace and scale of technology and market developments in climate-friendly energy technologies and solutions.

This includes the criteria for granting funding to research and innovation projects and assessing the relevance of energy technologies from a climate perspective. The Energi21 strategic body wishes to underline that emission reductions will be achieved faster with a digital, flexible and secure energy system.

Energy efficiency should be part of Enova's mandate

Reducing power consumption is an important climate measure. The electrification of transport, oil and industry, and the establishment of new industrial production rests on the availability of new power. The cheapest and most environmentally friendly way of producing this power is by improving efficiency. Enova's instruments aimed at energy efficiency in buildings and industry should be revitalised to enable realisation of our efficiency potential.

The Energi21 strategic body also wishes to point out that testing and demonstration activities are essential to accelerate the pace of technology development and contribute to the implementation of new climate and environmentally friendly solutions. The pilot and demonstration phase is demanding for companies with high risk and high capital needs. The Government's energy and climate technology initiative under the auspices of Enova is valuable for the development and commercialisation of future climate-friendly energy technologies. This is also relevant to Enova's new role of administering Norway's applications to the EU Innovation Fund, which provides funding for renewable energy, energy storage, energy-intensive industry and CCS projects. Companies need risk-relief instruments to take the innovation process all the way to commercialisation.

The Energi21 board recommends extending Enova's mandate to include the following areas:

- Energy efficiency improvement – for the entire energy system value chain (from production to consumption).
- Monitoring, operation and maintenance of the next generation energy system including use of digital enabling technologies (artificial intelligence, autonomy, big data management, IoT). Operations centres are included in this topic.
- The energy supply of the future with sector integration, interaction between energy carriers and end users.
- Energy technologies and energy solutions that decarbonise transport and industry.
- Green and blue hydrogen and ammonia, production, distribution, application and safety.
- Marine energy technologies and services (also included in renewable power generation).
- Sustainable battery materials and systems.
- Solar heating and hybrid production plants.
- Hydropower systems in the flexible energy system of the future.
- Carbon capture and storage (coordination with the EU Innovation Fund).

These are subject areas that lie within the Energi21 strategy's areas of action. All areas have a high level of innovation and potential for business and supplier development.

6.7

Policy instruments for the green transition should be in line with the Energi21 strategy

The arrangement of green transition programmes and RD&I allocations should reflect the key areas of the Energi21 strategy. This will ensure relevance and that business and industrial ambitions are followed up. The key areas have interfaces with several ministries and therefore require cooperation between the ministries' policy instruments and harmonisation of research and innovation priorities.

Norway has effective and coordinated public funding agencies that cover the whole scope of the innovation chain, but we will need even more dynamic and coherent policy instruments and incentives going forward. This applies, among other things, to funding instruments managed by the Research Council, Gassnova, Enova, NVE and Innovation Norway.

The Energi21 board recommends that funding instruments targeting the green transition of the energy sector are in line with the thematic priorities of the Energi21 strategy. This will ensure investment that is relevant to the business sector with the potential for value creation, efficient restructuring and industrialisation.

Photo: Institute for Energy Technology (IFE)

6.8

Further develop joint initiatives and cross-sector collaboration at central government level

The realisation of projects and activities that fall under Energi2l's key areas is dependent on sectoral cooperation between industry stakeholders and, not least, at the central government administrative level. The portfolio of research and innovation funding instruments in the field of energy must take a cohesive approach that contributes to cooperation between industry stakeholders and interfaces between relevant disciplines. Inadequate collaboration can lead to several negative consequences, such as disrupting long-term knowledge and technology development, technology areas falling between two (or more) stools, and little or no value creation. It is important that the ministries continue and enhance their good cooperation across sectors, as it has a major impact on knowledge and technology development and, not least, on business development in the energy field.

Funding schemes such as PILOT-E[21] and Green Platform[22] are often highlighted by the business sector as effective instruments as they reflect industry needs and are relevant to the market. They also have clear goals when it comes to supplier development and climate-friendly value creation.

Their objective is to accelerate the green transition of the business sector, facilitate new green value chains and ensure a sustainable energy system. This applies to funding schemes provided by the Research Council, Gassnova, Enova, Innovation Norway, SIVA, NVE, EksFIN and others. Joint initiatives such as PILOT-E and Green Platform are good examples of schemes with the uptake of results in the market. Knowledge exchange and cooperation with the state-owned investment company Nysnø Klimainvesteringer will also be beneficial.

The Energi21 board recommends reinforcing and further developing inter-ministerial joint efforts that provide support to research and innovation-driven green transition in the business sector.

The investment will help accelerate technology and knowledge development, facilitate green value chains and ensure a sustainable energy system for society.

The Energi21 board recommends further developing and reinforcing initiatives such as Green Platform and PILOT-E. These are funding schemes that have shown good results and made concrete contributions to the climate-friendly energy transition, industrialisation and value creation.

The Energi21 board recommends that the ministries further develop their good RD&I cooperation on cross-sectoral funding instruments, as this has a major impact on knowledge and technology development and, not least, on business development in the energy field.

21 *PILOT-E – Funding scheme for the Norwegian business sector | Enova*
22 *Green platform 2022 (forskningsradet.no)*

6.9

Collaboration between NORWEP and Energi21

NORWEP was established to assist businesses in the energy sector in internationalisation. The authorities and the industry are behind the initiative. Its purpose is to bring about increased turnover and employment in Norway by helping Norwegian energy companies to do business internationally. With a network of 30 advisers in different local markets, the organisation can help businesses to mitigate the risks involved in internationalisation. NORWEP has knowledge of how to do business in different technology markets, with insight into local markets as well as a network of decision-makers on the customer side. NORWEP's expertise is valuable for stakeholders endeavouring to win positions with their products and services. The Energi21 strategic body has been working with NORWEP for a long time and the cooperation is valuable for work on the strategy.

The Energi21 board recommends further developing its collaboration with NORWEP.

6.10

Important collaboration between the ministries' 21 processes

Several ministries have established advisory strategic bodies and 21 processes, and a number of these have links to the mandate of the Energi21 strategic body. There are synergies to be drawn from cooperation and the flow of expertise between the relevant 21 processes. Strategic collaboration between the 21 processes is important to establish comprehensive research and innovation efforts in the field of energy.

The table below shows which 21 processes have interfaces with the Energi21 strategy's key areas:

21-prosess	OG21	Prosess21	Maritim21	Transport21	Skog22	Digital21
Key area:						
Integrated and efficient energy systems	●	●	●	●	●	●
Energy markets and regulation	●	●	●	●	●	●
Carbon capture and storage	●	●	●		○	●
Hydrogen	●	●	●	●		●
Batteries		●	●	●		●
Hydropower		●				●
Solar power		●				●
Offshore wind power	●		●			●

The Energi21 board recommends a requirement for cooperation between the ministries' 21 processes to ensure harmonisation of strategic recommendations where appropriate. Collaboration and the flow of expertise between the 21 processes will ensure comprehensive knowledge development across industries and sectors.

The Energi21 board recommends that stakeholders involved in the different 21 processes work together to define subject areas and societal challenges where there is a need to clarify roles and responsibilities.

The Energi21 board recommends that a collaborative project be established between Digital21 and the other 21 processes on the importance of digital enabling technologies such as artificial intelligence, big data management, autonomy and the Internet of Things for the different sectors.

6.11

Strengthening educational programmes in both practical and theoretical subjects

Education communities are at the heart of securing workforces for the future. Climate-friendly transformation of society in general and development of the energy system in particular will entail a great need to enhance multidisciplinary skills in the energy sector. Greater electrification leads to increased integration between different sectors and domains, which in turn increases the need for workers with interdisciplinary skills. Progress is fast and the education system needs to keep pace with technology and market developments. Much has changed in the energy sector in recent years, particularly in the digital field. Making effective use of digitalisation technologies such as artificial intelligence, big data management, autonomy and the Internet of Things, for example, will require linking of ICT, cybernetics and energy system expertise.

Increased restructuring will lead to an increased need to develop new knowledge through new study programmes and specialisations and, not least, through further and continuing education, which the university and university college sector must deliver on.

The FME centres are good examples of the development of new knowledge that is of both high quality (mainly the universities' responsibility) and relevance (collaboration with industry). Students (master's and PhD) participating in the FMEs are often recruited into the companies participating as partners. This helps to renew the companies' knowledge and expertise, which in turn equips them for new research and innovation.

The energy transition will require access to candidates who can design, build and operate the energy system of the future. There is a need for both skilled workers and employees with more theoretical knowledge. To ensure workers with relevant skills for the energy system of the future, public bodies, education communities and the business sector must work together.

The Energi21 board recommends that industry, public bodies and education communities work together to design study programmes and further and continuing education that ensure access to a workforce with expertise for the energy system of the future.

The Energi21 board recommends reviewing the country's study programme portfolio relating to digitalisation of the energy sector to identify areas that must be strengthened (academic profile and investment).

The Energi21 board recommends further and continuing education in the field of ICT security. This is relevant for all disciplines in the energy field.

The Energi21 board recommends strengthening efforts in power electronics in energy-related education programmes to meet skills needs related to the design, construction and operation of digitalised and integrated energy systems.

Relevant measures include:

- Continuous cooperation between industry and academia on education programmes and learning objectives.
- Integrating more practical training in the industrial sector into education programmes. This applies to all levels of education.
- Enhancing investment in the Industrial PhD scheme and industry-relevant master's degrees.
- Integrating ICT skills into energy-r elated study programmes and ensuring graduates with relevant digital skills.

The Energi21 board recommends strengthening the education of skilled workers in electricity and electronics. Given the expected investments in the energy system, there will be an increasing need for workers who can construct and maintain the electricity grid. Mobilisation of future candidates is recommended already at lower and upper secondary level.

7

Appendices

7.1

Appendix 1: Energi21 – Mandate from the Ministry of Petroleum and Energy

Energi21 consists of a board of directors with a secretariat. The Energi21 strategy was prepared by the board.

Objective
The Energi21 strategy is based on Norwegian energy policy and promotes the primary objective and sub-goals set out by the authorities for energy research.

Primary objective:
To increase value creation and ensure safe, cost-effective and sustainable utilisation of energy resources.

Sub-goals:
- Ensure long-term knowledge and technology development.
- Promote competitiveness and increased value creation in the Norwegian energy industry.
- Find solutions that facilitate a low-emission society.

The strategy's objective is to provide advice to the authorities and industry on the approach and extent of required research and development efforts, and to give an indication of how to prioritise between the various key areas. The strategy is intended to contribute to more coordinated and enhanced involvement of the business sector with respect to research, development, demonstration and commercialisation of new climate-friendly energy technology for stationary purposes and transport.

It also targets knowledge-building that can make Norway an important international supplier of environmentally friendly energy solutions, system services, knowledge and technology. The strategy includes international research and technology collaboration, with particular emphasis on strengthening research and innovation collaboration with the EU and facilitating increased Norwegian participation in EU energy projects.

The Energi21 strategy strives to create a whole-system approach to efforts targeting new climate-friendly technologies by bringing the authorities, business sector and research communities closer together. At the same time, the goal is to raise more support for energy research in general and contribute to strengthening R&D in the business sector.

The tasks of the board
The Energi21 board's main task is to develop and regularly revise the national strategy for the research, development, demonstration and commercialisation of new climate-friendly energy technologies (the Energi21 strategy).
- The strategy must be communicated to and aligned with relevant stakeholders, i.e. the business community, research and technology environments and funding agencies (the Research Council, Gassnova, Enova and Innovation Norway).
- The board is to assess on an ongoing basis whether the revised strategy should be made more concrete, targeted and action-oriented.
- It must also assess the need to establish working groups in the key priority areas and follow up the work of any such groups.
- The board must maintain a continuous awareness of national strategies and activities relevant to the Energi21 strategy. This includes, for example, other 21 processes, the Government's overall hydrogen strategy, and the Government's carbon capture and storage strategy.
- The board must provide advice to allocating authorities and the business sector on research priorities under the Energi21 strategy.
- Furthermore, it must assist the research communities in mapping the types of expertise requested by business and industry.
- The board is to help coordinate research activities and motivate the business sector to increase investment in R&D activity in accordance with the Energi21 strategy.
- The board is to conduct an annual internal evaluation of its activities.
- The strategy must be updated every three to four years.

7.2

Appendix 2: The board of Energi21

Bjørn Holsen, Chair of the Board	Statkraft
Shazhad Rana	Microsoft Norway
Sonja Berlijn	Statnett and KTH
Kristian Voksøy Steinsvik	Hav Design AS
Unni Farestveit	Agder Energi
Eivind Heløe	Energy Norway
Ragnhild Katteland	Nexans
Henriette Undrum	Equinor

Erik Figenbaum	Institute of Transport Economics
Johan Einar Hustad	Norwegian University of Science and Technology (NTNU)
Anna Barnwell	Enova
Rune Volla	Research Council of Norway
Ingrid Sørum Melaaen	Gassnova
Inge Gran	SINTEF Energy
Nils Morten Huseby	IFE
William Christensen	Norwegian Ministry of Petroleum and Energy (OED)/ Observer
Tore K. Grunne	Norwegian Ministry of Petroleum and Energy (OED)/ Observer
Ane T. Brunvoll	Norwegian Water Resources and Energy Directorate (NVE)/ Observer

7.3

Appendix 3: Management and day-to-day activities of the Energi21 strategic body

Energi21 is an independent strategic body and reports directly to the Ministry of Petroleum and Energy.

The strategic work of Energi21 is led by a secretariat headed by Director Lene Mostue. The main objective of the secretariat is to ensure continuity, operationalise the Energi21 strategy and ensure that the mandate assigned by the Ministry of Petroleum and Energy is followed up. An important part of the work is dialogue and cooperation with the business community, research institutes and education communities through strategic work and input meetings, as well as projects that study and report on relevant topics.

- The Research Council of Norway provides office space and support systems for the Energi21 administration.
- Energi21 is financed by the Ministry of Petroleum and Energy and industry stakeholders through direct financial contributions.
- For more information on Energi21, see www.energi21.no
- or contact Lene Mostue directly by e-mail, at lm@rcn.no

7.4

Appendix 4: Introduction to international research and innovation collaborations

7.4.1
PARTICIPATION IN THE EU ARENA

"European Green Deal" – ambitions and policy framework

The EU's green growth strategy, the European Green Deal (EGD) or the EU Green Deal, is a new reform that sets out a more holistic approach across policy areas and sectors to integrate sustainability into future policy making processes and into existing EU legislation. The first part was presented in December 2019 by the EU Commission's President Ursula von der Leyen. A number of more specific thematic plans and strategies were then announced to achieve Europe's green transition. The EGD is expected to have a major impact on the EU's climate and environmental policy going forward, and is described as an important part of the European Commission's strategy to implement the UN 2030 Agenda and the SDGs. The objective of climate neutrality in the EU by 2050 governs its content, together with more sustainable and circular economic development. This includes less pollution, lower GHG emissions, better protection of biodiversity, better health, improved quality of life and new jobs.

The need for a broad partnership with the business sector, municipalities and regions through green innovation is highlighted, as well as the involvement of civil society and inhabitants in the transition. The Just Transition Fund and a separate taxonomy for sustainable investments are among the actions that have been implemented.

The production and consumption of energy is behind more than 75 per cent of the EU's GHG emissions. Decarbonising the EU's energy system is therefore critical to achieving the 2030 and 2050 climate objectives. The EGD focuses on three key principles for the energy transition:

1. ensuring a secure and affordable EU energy supply.
2. developing a fully integrated, interconnected and digitalised EU energy market.
3. prioritising energy efficiency, improving the energy performance of our buildings and developing a power sector based largely on renewable sources.

The previous European Commission (2014–2019) focused on the Energy Union. Published on 25 February 2015, the Energy Union Strategy was a key priority for the Juncker Commission. The Energy Union aims to help provide secure, affordable and clean energy for EU citizens and businesses.

The Energy Union is based on five dimensions:

- Security, solidarity and trust - diversifying Europe's sources of energy and ensuring energy security through solidarity and cooperation between EU countries.
- A fully integrated internal energy market- enabling the free flow of energy through the EU through adequate infrastructure and without technical or regulatory barriers.
- Energy efficiency - improved energy efficiency will reduce dependence on energy imports, lower emissions, and drive jobs and growth.
- Climate action, decarbonising the economy - the EU is committed to a quick ratification of the Paris Agreement and to retaining its leadership in the area of renewable energy.
- Research, innovation and competitiveness - supporting breakthroughs in low-carbon and clean energy technologies by prioritising research and innovation to drive the energy transition and improve competitiveness.

Since its launch in 2015, the European Commission has published several packages of measures and regular progress reports to ensure that the Energy Union strategy is achieved. The preparation and implementation of the national energy and climate plans are important contributions to achieving the Energy Union's objectives.

European Climate Law

The European Climate Law entered into force on 29 July 2021. It writes into law the goal for Europe's economy and society to become climate-neutral by 2050. It also sets the intermediate target of reducing net GHG emissions by at least 55 per cent by 2030, compared to 1990 levels. Climate neutrality by 2050 means achieving net zero GHG emissions for EU countries as a whole, mainly by cutting emissions, investing in green technologies and protecting the natural environment. The law aims to ensure that all EU policies contribute to this goal and that all sectors of the economy and society play their part.

More specifically, the objective of the Climate Law is to:

- Set the long-term direction of travel for meeting the 2050 climate neutrality objective through all policies, in a socially fair and cost-efficient manner.
- Set a more ambitious EU 2030 target, to set Europe on a responsible path to becoming climate-neutral by 2050.
- Create a system for monitoring progress and take further action if needed.
- Provide predictability for investors and other economic actors.
- Ensure that the transition to climate neutrality is irreversible.

Fit for 55

Fit for 55 is a set of proposals to revise and update EU legislation in a number of areas to help the EU meet its 2030 climate targets. Fit for 55 refers to the EU's target of cutting net GHG emissions by at least 55 per cent by 2030 compared to the 1990 level. The Fit for 55 package includes the following legislative proposals and policy initiatives:

- Reform of the EU emissions trading system.
- Effort sharing regulation.
- Land use and forestry regulations.
- The carbon border adjustment mechanism (CBAM).
- Revision of the energy efficiency directive.
- Revision of the renewable energy directive.
- Revision of the energy taxation directive.
- CO_2 emission standards for new cars and vans.
- The alternative fuels infrastructure regulation.
- Increasing the uptake of greener fuels in the maritime sector.
- Increasing the uptake of greener fuels in the aviation sector.
- The social climate fund.

National energy and climate plans

National energy and climate action plans (NECPs) describe the contribution of each member state to the EU's energy and climate objectives over a 10-year period. The scheme was established under the Regulation (EU) 2018/1999 on the governance of the energy union and climate action (the Governance Regulation). According to this regulation, the energy and climate targets described in the NECPs are non-binding. The exception is binding national targets for the annual reduction of GHG emissions during the current plan period.

Each member state draws up its plan according to a common template. The plan for each EU member state includes the following elements:

- Energy efficiency.
- Renewables.
- Greenhouse gas emissions reductions.
- Interconnections.
- Research and innovation.

The current plan period is for the period 2021–2030. The plans provide the EU with the opportunity to assess each member's plan and to measure and follow up on progress during the plan period. Based on a progress report submitted by the member states every two years, the Commission also monitors EU progress as a whole towards its energy and climate objectives. The regulation will continue beyond 2030. Before 2030 and every 10 years thereafter, each member state must prepare a new NECP. They must also develop a national strategy for energy and climate objectives for 2050.

The purpose of the NECPs is to contribute to achieving the 2050 targets.

EU Taxonomy

The EU Taxonomy was launched by the European Commission in 2020 and is a cornerstone of the Commission's action plan on financing sustainable growth. The scheme was designed to help achieve a common understanding of what economic activities are sustainable through defined environmental objectives. The aim is to shift capital and direct investment towards more sustainable companies and forms of production, and to help transform the EU into a competitive sustainable economy. The taxonomy will be particularly important for financial institutions, but also for consumers and businesses that need funding from these institutions, which can then be measured by whether or not their activities are defined as sustainable.

The Taxonomy Regulation contains six environmental objectives:

1. Climate change mitigation.
2. Climate change adaptation.
3. The sustainable use and protection of water and marine resources.
4. The transition to a circular economy.
5. Pollution prevention and control.
6. The protection and restoration of biodiversity and ecosystems.

To be classified as an environmentally sustainable economic activity, the activity must contribute to at least one of the six environmental objectives while avoiding significant harm to any of the other environmental objectives. The taxonomy will provide a more concrete and verifiable basis for how to define and report sustainable economic activities. The EU taxonomy has been incorporated into Norwegian legislation and is thus also legally applicable in Norway. Although part of the policymaking is still ongoing in the EU and thresholds for several sectors are not yet in place, the system indicates that it will have an impact on Norwegian consumers and the Norwegian business sector. Among other things, energy production from oil without CCS will not be defined as sustainable according to the taxonomy.

RePowerEU

RePowerEU is an ambition and a plan to make Europe independent of Russian fossil fuels well before 2030. RePowerEU was launched towards the end of 2022 in response to Russia's invasion of Ukraine. The plan's initial focus is on gas, with a goal to reduce Russian gas imports by two thirds by the end of 2022. The plan also outlines a series of measures in response to rising energy prices in Europe and to replenish gas stocks before the winter of 2023. REPowerEU seeks to diversify gas supply, accelerate the roll-out of renewable gases and replace gas in heating and power generation.

7.4.2 HORIZON EUROPE

The EU's research and innovation framework programme Horizon Europe is used as a strategic instrument to achieve policy objectives. When the European Green Deal was launched, a final call was established under the Horizon 2020 programme, the "European Green Deal call", in which EUR 1 billion was set aside to support research and innovation projects that could accelerate the EU's shift towards a green and sustainable society. Norwegian actors were involved in 23 of the 72 projects awarded funding, with overall funding of approximately NOK 470 million. The funding allocation shows that Norwegian institutions have a strong position in climate technologies, and as such are well positioned for further successful participation in the new research and innovation programme Horizon Europe. With a total budget of EUR 95.5 billion, this is the world's largest programme of its kind, and more than 35 per cent of its funds are set aside for projects that address climate change. Of this budget, EUR 5.4 million comes from the temporary, loan-funded NextGenerationEU support programme that the European Commission has established as part of the post-pandemic recovery plan.

The Horizon Europe programme represents an important investment in addressing and mitigating climate change through a shift towards more sustainable solutions. Digitalisation plays an important role in this transformation, with its inherent scope for radically new ways of managing energy systems, changed interaction between different market players and new business opportunities. Digitalisation is seen as going hand-in-hand with decarbonisation challenges and therefore has a very important position in Horizon Europe. The programme also aims to strengthen the competitiveness of European business and industry and contribute to economic growth.

Horizon Europe is structured in three pillars, "Excellent Science", "Global Challenges and European Industrial Competitiveness" and "Innovative Europe". "Excellent Science" supports ground-breaking, curiosity-driven research, and targets the most outstanding scientific communities in Europe, as well as mobility and research training. A key objective of Horizon Europe is to strengthen Europe's innovation capacity as this is essential to achieve a competitive business environment in a rapidly changing society. The establishment of the European Innovation Council (EIC) under the "Innovative Europe" pillar is the principal instrument for achieving that objective. Here, 70 per cent of the funds are earmarked for SMEs that can receive support for the development and scale-up of breakthrough technologies that could create new markets, or radically change existing ones, where the risk is too high for private investors. The programme also supports multidisciplinary research teams working on new methods to achieve technological breakthroughs, as well as projects working to mature new solutions and identify commercialisation models for them. Furthermore, cooperation within and between innovation ecosystems such as incubators, accelerators, clusters, etc. is strengthened through the "European Innovation Ecosystems" (EIE) scheme.

With a total budget of EUR 53.5 billion, "Global Challenges and European Industrial Competitiveness" is the most substantial pillar of Horizon Europe. Of this budget, around EUR 30 million is allocated to the areas "Digital, Industry and Space" and "Climate, Energy and Mobility", both of which coincide to a great extent with the Energi21 strategy. The calls under this pillar will contribute to achieving a set of objectives that include supporting the UN SDGs, helping to put Europe and the European business sector at the forefront of the development of new technologies and sustainable solutions, and increasing the competitiveness of the industrial sector, as well as strengthening the role of research in the development, implementation and support of EU policies.

The European Commission is responsible for developing the Horizon Europe programme. The annual work programmes are drawn up on the basis of a strategic plan, which has a particular impact on "Global Challenges and European Industrial Competitiveness". The current plan builds on an extensive process of obtaining the views of different stakeholders in the EU, both through dialogue and web-based input solutions. In addition, an expert group provided input to the strategic plan, and several stakeholders, including the Research Council, participate in strategic programme committees that take part in the development of both the strategic plan and the two-year work plans pertaining to the specific calls.

The EU partnership also plays an important role in funding and designing strategies and calls for proposals, with 25 per cent of Horizon Europe funding going to calls designed by and for European partnerships. These are partnerships between the European Commission and private and/or public actors and are intended to strengthen European research by reducing the fragmentation of the EU research and innovation landscape. Each partnership prepares a strategic research and innovation agenda, which is used as the basis for designing the calls. Partnerships that are co-programmed or co-funded directly affect the calls in the main programme, and are open to everyone. The former are entered into with private actors, while co-funded partnerships are entered into with national research funders and authorities. Institutionalised partnerships have their own legal basis, and issue calls for proposals for the framework programme's funding. They may have different restrictions on who can apply aside from the members of the partnership. Participation in partnerships is an important way for Norwegian actors to influence which research areas are emphasised in the European research arena. In addition, partnerships are an important arena for Norwegian actors to position themselves for participation in projects by increasing knowledge of EU policies, building networks with European stakeholders and by timely knowledge of upcoming calls. Norwegian actors are active participants in all the most relevant partnerships for the mandate of the Energi21 strategy. An overview of these partnerships is provided in section 7.4.3.

"Missions" is a new structure in Horizon Europe that was introduced to achieve concrete solutions in areas of major strategic importance to the EU. By putting together a portfolio of measures that may consist of, for example, research projects, policy guidelines and legislative measures, concrete progress is made that would not otherwise be achievable with individual measures. There is also a strong emphasis on active participation, and co-funding from private and public stakeholders, as well as citizens' engagement.

For Horizon Europe, the introduction of missions means that funding and calls are dedicated to each of the five missions. The mission "100 Climate-neutral Cities by 2030 – by and for the Citizens" is highly relevant to the Energi21 mandate. As the name suggests, it aims to transform 100 European cities into climate-neutral and smart cities by 2030, and to ensure that these cities act as experimentation and innovation hubs to enable all European cities to follow suit and make Europe climate neutral by 2050. Approximately EUR 350 million in Horizon Europe funding has been earmarked to address various challenges related to, for example, mobility, energy supply and urban planning for the period 2021–2023. The mission "Restore our Ocean and Waters" is also relevant to Energi21 through its objective of contributing to climate-neutral maritime transport, with associated Horizon Europe calls.

7.4.3 ENERGY-RELATED PARTNERSHIPS IN THE EU

The Horizon Europe partnerships address complex challenges and contribute to strengthening the European research arena by ensuring synergies between research programmes, preventing overlapping initiatives and ensuring adequate research efforts. At Horizon Europe's inception in 2021, there were 49 partnerships, the vast majority linked to "Global Challenges and European Industrial Competitiveness". Of these, there are primarily five partnerships with high relevance to energy research, all with Norwegian partners involved:

Clean Energy Transition Partnership (CETP)

The CETP is a co-funded partnership aiming to support the implementation of the European Energy Technology Plan (SET Plan). The partnership consists of national and regional research, development and innovation programmes in the EU member states and associated nations. The partnership's Strategic Research and Innovation Agenda (SRIA) is structured around eight challenges:

1. Optimised integrated European net-zero emissions energy system.
2. Enhanced zero emission power technologies.
3. Enabling climate neutrality with storage technologies, renewable fuels and CCU/CCS.
4. Efficient zero emission heating and cooling systems.
5. Integrated regional energy systems.
6. Integrated industrial energy systems.
7. Integration in the built environment.
8. Crosscutting dimensions.

Clean Hydrogen Partnership (CHP)

The CHP is an institutionalised partnership that aims to help realise a sustainable European hydrogen economy in line with the EU Hydrogen Strategy, thereby landing a crucial dimension in achieving the EU's climate objectives. The programme supports research and innovation in hydrogen production, distribution, storage and end-use technologies, and is a key instrument for making European industry competitive along the entire value chain.

Batteries European Partnership (BATT4EU)

BATT4EU is a co-programmed partnership between the European Commission and business stakeholders, research organisations and academia. The partnership is working to improve battery performance by increasing energy and power density, increasing the charging rate and improving cycle lifetime, and more than halving battery costs compared to 2019 values. The programme also focuses on ensuring safe use of batteries and the roll-out of the best available technologies for manufacturing and recycling operations. A final objective is to enhance the sustainability of the main supply chains of battery raw materials and achieve the lowest possible carbon footprint of the supply chain from raw materials extraction through battery manufacturing, use and recycling.

Zero Emission Waterborne Transport (Waterborne)

This co-programmed partnership aims to provide and demonstrate zero-emission solutions for all main ship types and services before 2030, which will enable zero-emission waterborne transport in the EU before 2050. The partnership will develop and demonstrate deployable technological solutions which will be applicable for the decarbonisation and the elimination of other harmful emissions, strengthen the competitiveness of green ship technology markets in the EU, facilitate the development and implementation of regulations and policies at national and international level, and facilitate the uptake of innovative technologies and solutions in the European maritime sector.

Towards Zero Emission Road Transport (2Zero)

2Zero aims to accelerate the transition to zero-emission road mobility in Europe. The co-programmed partnership covers all types of vehicles from cars, trucks and buses to two-wheelers and new concepts. The work is focused around:

- vehicle technologies and vehicle propulsion solutions for battery electric vehicles and fuel cell electric vehicles.
- integration of the battery electric vehicle into the energy system and related charging infrastructure.
- innovative concepts, solutions and services for the zero-emission mobility of people and goods.
- LCA and circular economy approaches for sustainable and innovative road mobility solutions.

Clean Aviation Joint Undertaking

The aim of this institutionalised partnership is to develop cutting-edge technologies for aviation. The ambition is for the technologies to be ready for deployment by 2035 enabling 75 per cent of the world's civil aviation fleet to be replaced by 2050.

Europe's Rail Joint Undertaking

This partnership aims to accelerate research and development in innovative technologies and operational solutions to increase capacity, flexibility, multimodality and reliability. As such, it will contribute to the realisation of the EU's policies and objectives for the rail sector, and the European rail supply industry. The partnership is institutionalised, and the Norwegian Railway Directorate is a member.

7.4.4 EERA

The EERA (European Energy Research Alliance) was established by the European Commission as the research pillar of the Commission's SET plan. It is the largest body for cooperation in energy research in Europe. Its objective is to catalyse and improve coordination of European energy research for a climate-neutral society by 2050. The EERA has become a key force in research and innovation policies related to the European energy sector. The alliance has 250 members from research institutes and universities, and includes over 50,000 researchers in 30 countries. It is a membership-based, non-profit association. The EERA emphasises in its work the effective use of research funds, better division of labour and coordination, and increased cooperation between European research institutions through 18 Joint Research

Programmes (JP). These joint research programmes cover the whole range of low-carbon technologies, as well as systemic and cross-cutting topics. The collaboration typically covers TRL levels 2/3 to 5/6. The EERA also includes a Policy Working Group (POL WG) that focuses on policy issues. Norwegian researchers are active in the EERA, and the President of the alliance is Norwegian (as of May 2017). The Executive Committee, which is the EERA's governing body also includes a Norwegian member. Norwegian stakeholders participate in most of the 18 JPs, and several of the JPs are also led by Norwegian researchers.

7.4.5 MISSION INNOVATION

Mission Innovation is a global initiative launched during the Paris Climate Summit in November 2015 that aims to accelerate the transformation needed to meet the Paris Agreement's GHG emission reduction targets. Norway was one of 20 countries involved in the start-up, and in the aftermath four more countries have joined, as well as the European Commission (on behalf of the EU). Mission Innovation's goal was for the countries to double their public investment in research and innovation in clean energy technologies from 2015 to 2020, and thereby accelerate progress. Other aims of the initiative are to increase collaboration on major common challenges and to facilitate private energy sector investments. Mission Innovation's member countries prioritised seven technology challenges as a basis for cooperation in the first five-year period:

- Smart Grids Innovation Challenge.
- Off-Grid Access to Electricity Innovation Challenge.
- Carbon Capture Innovation Challenge.
- Sustainable Biofuels Innovation Challenge.
- Converting Sunlight Innovation Challenge.
- Clean Energy Materials Innovation Challenge.
- Affordable Heating and Cooling of Buildings Innovation Challenge.

Mission Innovation 2.0 was launched on 2 June 2021, with 22 member countries as well as the European Commission. It has great ambitions to reinforce the cooperation between member countries and private stakeholders and thus accelerate innovation in selected technology areas. The work is centred around seven missions:

- Green powered future.
- Zero-emission shipping.
- Clean hydrogen.
- Carbon dioxide removal (CDR).
- Urban transitions.
- Net zero industries.
- Integrated biorefineries.

The goal is to build strong collaborative constellations of different countries, companies, investors and research institutes that together can address development needs, achieve sufficient activity and accelerate emerging solutions towards the market.

7.4.6 IEA, NORDIC AND BILATERAL RESEARCH COOPERATION

International Energy Agency

The International Energy Agency (IEA) is the most important arena for energy research cooperation outside the EU. The IEA has nearly 30 member countries. It was established in 1974, and its main objective at that time was to prevent and counteract oil supply crises. Over time, all energy carriers and their use have been given a central place in the IEA's scope of application. Energy efficiency measures, statistics preparation, environmental policy, etc. are also prominent aspects of its agenda.

The IEA has established a number of research programmes related to different aspects of the energy sector. These are brought together under the Technology Collaboration Programme (TCP). The partnerships are organised under various working parties that provide advice on strategic issues to the Committee on Energy Research and Technology (CERT).

Norway is a member of some 20 of more than 40 such partnerships, which are divided into the areas of oil and gas, end-user technologies, renewable energy technologies and information exchange. The active Norwegian participants can be from industry, the research communities or the authorities, depending on the specific programme's activities. The Research Council of Norway is the coordinator of Norway's activities. More information about the IEA's technology collaborations and Norwegian participation can be found at www.iea.no.

The IEA prepares many scientific reports, including on the de-carbonisation of the energy system. These are reports at the global, regional and national levels. The reports receive great international attention and influence energy research as well as energy research policy. One of the more well-known reports is the annual "World Energy Outlook", which documents scenario and model-based analyses of the development of the world's energy system.

Nordic Energy Research

Nordic Energy Research (NEF) is an institution under the auspices of the Nordic Council of Ministers for cooperation on energy between the five Nordic countries. Its objective is to promote and continue the Nordic cooperation in the field of energy. NEF provides funding for research, analysis and secretarial functions in energy projects that are of common interest to Nordic stakeholders and that have a potential for cross-border energy cooperation. NEF also acts as an intermediary between industry, research and policymakers, and creates a knowledge-based foundation for energy policymaking. It is also active at European level. NEF is co-financed by the Nordic countries and is currently the only joint Nordic institution in the field of energy research. It has an annual research budget of NOK 45 million (2022). Its head office is located in Oslo, Norway.

Bilateral cooperation

Norway (the Norwegian Ministry of Petroleum and Energy) and the USA (US Department of Energy) entered into a bilateral research cooperation agreement in the field of energy-related research and technology in 2004. Topics of relevance to Energi21 are carbon capture and storage, hydrogen research and new renewable energies. The cooperation agreement represents a formal framework between Norway and the USA to pursue long-term opportunities for research, development and demonstration cooperation in identified areas. In 2020, an addendum to the existing agreement was signed that specifically promotes bilateral cooperation in the field of hydropower research.

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7.5

Appendix 5: Detailed information on further development of other technology and knowledge areas

7.5.1
ENERGY-EFFICIENT, SMART BUILDINGS AND CITIES

Energieffektive og smarte bygg og byer er tett knyttet til satsingsområdet integrerte og effektive energisystemer. Området er sentralt for omstillingen i et system- og sektorkoblingsperspektiv, og kan spesielt bidra til en sikker og konkurransedyktig energiforsyning. Den norske bygningsmassen inkludert tappevann varmes hovedsakelig med elektrisitet. Smarte og energieffektive løsninger vil dermed kunne redusere kraftbehovet og frigi kraft til elektrifiseringen av Norge og til etableringen av nye grønne industrier.

Energy-efficient, smart buildings and cities includes the following topics:

- Power and energy flexibility.
- Building-integrated solar cells and other local/ integrated production technologies
- Distributed storage.
- Plus houses, zero emission neighbourhoods, neighbourhood energy systems – microgrids.
- Materials and solutions for energy efficiency improvement.
- Market solutions, business models, interaction with the energy system (thermal system and power system).

The topic of energy-efficient, smart buildings and cities is closely linked to the key area "Integrated and efficient energy systems". This is a vital area of the energy transition that links systems and sectors, and can make particular contributions to achieving a secure and competitive energy supply. The Norwegian building stock including tap water is mainly heated by electricity. Smart and energy-efficient solutions will thus be able to reduce power demand and free up power for the electrification of Norway and the establishment of new green industries.

Energy use in Norwegian buildings amounts to about 80 TWh, which corresponds to about 40 per cent of Norway's overall energy consumption (Multiconsult, 2021). SINTEF has estimated the total energy efficiency potential of the building stock to be 23 TWh in 2050 if we realistically increase the rehabilitation of buildings with energy upgrades, build new passive buildings and subsequently maximise the phase-in of heat pumps (SINTEF, 2022). The technical potential for power generation from solar installations in buildings is estimated at around 30-50 TWh (Solenergiklyngen and FME SuSolTech, 2020).

Reducing energy and power use as well as utilising flexibility in buildings and areas increases security of supply, improves power balance and reduces the need for land-intensive renewable power production and grid development. Improved efficiency, increased flexibility and local energy solutions can as such reduce the magnitude of encroachments on nature during the energy transition. Local power generation in particular can help spare natural areas from grid expansion and provide better resource utilisation.

In order for the EU to reach its target of a 55 per cent reduction in greenhouse gas emissions by 2030, the annual investment requirement in the building stock totals EUR 275 billion by 2030, with the lion's share allocated to energy efficiency improvement (EC, 2020). In Norway, commercial buildings alone have an estimated annual market potential for energy services and measures of NOK 12.5 billion in 2020 (SINTEF, 2020). With increased power demand in the coming years and limited concrete plans for power development, the power balance is expected to become tighter (Statnett, 2021). As a result, the value of and incentives for the implementation of energy efficiency measures are also increasing. The Norwegian Water Resources and Energy Directorate (NVE) has estimated a profitable energy efficiency potential in Norwegian residential and commercial buildings of 13 TWh based on a power price of NOK 1 or lower, and with higher prices, this potential can be expected to increase (NVE, 2021).

Competitive advantages and implementation capacity

Technology and knowledge base

With two FMEs, Norway has strong research communities in energy-efficient, smart buildings and cities. The current Research Centre for Zero Emission Neighbourhoods in Smart Cities (FME ZEN) and the former Research Centre on Zero Emission Buildings (FME ZEB) have also contributed to EU research. Norwegian research communities are at the forefront of EU projects such as ARV – Climate Positive Circular Communities and Synikia – Sustainable Plus Energy Neighbourhoods. Norwegian stakeholders have received EUR 31.2 million from Horizon 2020 related to energy use in buildings and areas (RCN, 2021).

Industrial experience
Norwegian businesses are at an advanced stage of the design, construction and operation of plus houses. Stakeholders in the construction sector have an interest in innovation and ambitions for the development of state-of-the-art buildings. Norway has several sustainability and environmental clusters and organisations in the building and real estate sector that work on digital innovation and efficient use of resources, including optimisation of energy consumption.

Strong focus on energy-efficient, smart buildings and cities in the EU
The EU is strongly committed to energy efficiency in buildings through the EU Renovation Wave and the Energy System Integration strategies. The EU has also set the goal of realising 100 energy-positive neighbourhoods by 2025 and through Horizon Europe, 100 climate-neutral cities by 2030.

Relevant research and innovation needs and measures

Key research and innovation needs
- Specification of sector integration (energy, transport, smart solutions) in buildings, neighbourhoods and cities. Comprehensive multi-infrastructure planning.
- Flexibility and locally based and distributed energy generation.
- The role of the end user in the energy system
- Technology and tools for designing, planning and operating zero-emission, energy-flexible buildings and areas.
- Optimisation of local energy systems and their interaction with overall energy systems.
- Digitalisation of the Norwegian building stock.
- Technological and societal factors that can trigger the rate of large-scale energy upgrades.

Selected actions
- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs
- Pursue the FME centre initiative and further develop grant schemes for R&D and demo projects in zero-emission buildings and areas nationally and internationally
- Strengthen Norwegian participation in EU research projects and align with EU trends.
- Strengthen physical and digital research infrastructure.
- Establish common e-infrastructure for buildings.
- Invest in technologies and services for energy efficiency improvement and flexibility, low-carbon materials, including new business models.
- Standards, laws and regulations – reduce barriers to local energy exchang.e
- Further develop education programmes in collaboration with industry, focus on building/area quality, technology and digitalisation expertise.

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7.5.2
ENERGY-EFFICIENT INDUSTRY

The development of energy-efficient industry makes a particularly positive contribution to the decarbonisation of Norwegian industry and to maintaining a secure and sustainable energy supply in Norway. Energy-efficient industry contributes to the decarbonisation of Norwegian industry by reducing the consumption of fossil energy. It contributes to a secure, competitive and environmentally friendly energy supply in that it saves energy for other purposes. Energy-efficient industry also plays an important role in the key area "Integrated and efficient energy systems", including as a major energy end user and potential supplier of thermal energy in the form of surplus heat.

Energy-efficient industry includes the following topics:

- Materials and solutions for energy efficiency improvement.
- Power and energy flexibility.
- Distributed storage.
- Market solutions, business models, interaction with the energy system.

Energy-efficient industry consists of three main areas: switching to more efficient energy carriers, incremental process improvements and increased utilisation of surplus heat. The utilisation potential of surplus heat from industry below 250°C is estimated at 20 TWh per year. In Norway's metal industry, 6 TWh in the range 100–250°C is unutilised [FME HighEff, 2021]. There is also considerable potential for process efficiency improvement through switching energy carriers to, for example, electricity and incremental process improvements, but the potential is process-specific and thus difficult to quantify.

Energy efficiency improvement in industry can help to free up power for the electrification of Norway, and can limit environmental impacts by avoiding development of the power grid and related infrastructure. Where fossil energy sources are used, energy efficiency improvement will also help cut GHG emissions directly. Norway's Climate Cure 2030 strategy estimates a possible emission reduction in sectors not included in the EU Emissions Trading System (EU ETS) of 300,000 tonnes of CO_2 equivalents in total for the period 2021–2030. There is also likely to be greater potential from the sectors covered by the EU ETS.

Norway has long experience of electrification and efficiency improvement of industry. The development of new technologies and system solutions for energy efficiency and decarbonisation of industry represents a significant export potential.

Competitive advantages and implementation capacity

Technology and knowledge base

Norway has strong research communities in thermal energy and process and materials technology. Norwegian research on energy efficiency in industry is led through a dedicated research centre for environmentally friendly energy. FME HighEff aims to contribute technologies and solutions to achieve a 30 per cent reduction in specific energy consumption and 10 per cent GHG emission cuts in the industrial sector. The research is centred around energy-efficient processing, utilisation of surplus heat, industry clusters and training. Norwegian partners have received EUR 9.2 million from Horizon 2020 related to energy use in industry [RCN, 2021].

Industrial experience

Norwegian industry is at the forefront of energy efficiency, and in combination with competitive renewable power, this constitutes a key international advantage [Prosess21, 2021]. In close collaborations between industry and research and education institutions, energy consumption is being improved by means of operational and process improvements and the development of new technological solutions [Process21, 2020]. Norwegian industry stakeholders have been working on energy management for many years. The potential for energy efficiency improvement is expected to decrease with reduced consumption and further efficiency improvement will require new and potentially resource-intensive advances in technology [Process21, 2020].

The potential for utilising surplus heat in industry remains high and will continue to grow in step with plans to establish battery factories and data centres. The potential for surplus heat can be challenging to trigger given the location of industry and a tradition of prioritising corporate resources for production. The use of surplus heat from industry should be seen in the context of the key area "Integrated and efficient energy systems", where sector coupling is a pivotal element.

EU perspective

For many years, the EU has followed the Energy Efficiency First principle and has ambitious energy efficiency targets for 2030 as part of the EU Green Deal. The Fit for 55 package proposes a further escalation of these objectives. It is also an important focus area of the EU Strategic Energy Technology (SET) plan. Strong energy efficiency targets have given rise to broad investment in research in the field of energy efficient industry, both previously through Horizon 2020 and through the current Horizon Europe programme. Norwegian research communities have participated in important international research projects through both of these programmes.

Relevant research and innovation needs and measures

Key research and innovation needs

- Improved core processes and practical process solutions that promote energy efficiency and reduced emissions.
- Digitalisation and automation of production processes.
- New and cost-effective technology solutions and methods for converting and upgrading surplus heat and increasing the utilisation of waste gases.

- Area plans and cross-sector cooperation for better utilisation of energy resources.
- Efficient utilisation of surplus heat with emphasis on challenges related to different temperature levels and variable supply.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Continue the centre initiative and strengthening collaborative arenas for research and innovation.
- Strengthen the physical and digital research infrastructure.
- Strengthen ground-breaking research schemes.
- Adapt framework conditions to bring about rapid industrial transformation, particularly in industries with long lead times.
- EU cooperation is important for increased understanding of cooperation opportunities with European actors.
- Improve cooperation between industry and the public sector in the field of research – the public sector as an enabler.
- Enhance education in green energy, and process and chemistry technologies.

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7.5.3 CLIMATE-FRIENDLY ENERGY TECHNOLOGIES FOR MARITIME TRANSPORT

Klimavennlige energiteknologier for maritim transport er spesielt relevant for å avkarbonisering av transportsektoren og for å utvikle nye grønne industrier og marine energiteknologier.

Maritime transport includes the following topics:

- Propulsion technologies for the maritime sector, including hybrid and flexi-fuel solutions, batteries, fuel cells and internal combustion engines.
- Conversion of fossil propulsion technologies to low-emission options.
- Infrastructure for shore power.
- Tank and storage technologies for alternative fuels on ships.
- Coastal and offshore energy supply infrastructure.
- Low emission energy carriers for the maritime sector, e.g. biofuels, batteries, hydrogen, ammonia and methanol.

The International Maritime Organisation (IMO) aims to halve emissions from international shipping by 2050 (IMO, 2018). This target will be revised in 2022, and Norway is one of the member states that has called for a zero emission target by 2050 (Norwegian Government, 2022). A revised strategy is expected to be published in 2023. Beyond this, as part of the Fit for 55 package, the EU has launched proposals to incorporate maritime transport into the EU ETS and to tighten requirements for the reduction of GHG intensity in maritime transport from 2025.

The Norwegian authorities have a target to reduce GHG emissions from domestic shipping and fisheries by at least 50 per cent by 2030 compared to 1990 levels (Ministry of Climate and Environment, 2021). The Norwegian Shipowners' Association's goal is that by 2030, all Norwegian shipping companies will exclusively order ships with zero emission technology and that Norwegian shipping will be climate neutral by 2050. Energy-efficient operation, modification of existing ships, fleet renewal and the phasing-in of sustainable low and zero emission fuels will be key measures to achieve these targets (Norwegian Shipowners' Association, 2020). Public and private stakeholders in Norway are working together to develop efficient and environmentally friendly shipping to achieve the climate ambitions of the Green Shipping Programme (GSP).

Electric ferries and shore power facilities have been commissioned on a large scale in Norway in recent years. This has increased power consumption in the maritime transport sector to around 0.3 TWh in 2022 (DNV, 2021). Direct power consumption is expected to increase further, with the further roll-out of electric vessels, to around 2 TWh in 2030, but this still only represents a fraction of the total energy consumption in domestic shipping (DNV, 2021). In its reference trajectory, DNV does not expect to see a significant element of low-emission fuel, including ammonia, hydrogen and methanol, in the Norwegian maritime sector until 2040. Targeted measures to promote RD&I in maritime transport could accelerate this development.

Worldwide, it is expected that in order to reach the IMO's emission target for international maritime transport by 2050, total investments of approximately USD 1,000 billion are required leading up to 2050 (Krantz et al., 2020). In other words, huge investments are required in maritime transport in the years to come to reach the climate targets. Norway has a world-leading maritime value chain and is skilled at addressing complexity in ship segments and low-emission technologies. The Norwegian maritime value chain is thus well equipped to take part in this market. NHO has estimated the Norwegian turnover potential in Europe for the maritime industry, i.e. carbon-free propulsion systems and infrastructure solutions, to be EUR 5 billion per year in 2030 (NHO, 2030). The EU proposal to require shore power connections in European ports by 2030 could significantly increase this potential (Fuel EU Maritime, 2021). Digitalisation and efficiency solutions contribute to energy and emissions savings, which in turn often lead to cost reductions. These technologies can also represent significant export potential. The development of low-emission solutions for maritime transport can also contribute to increasing the competitiveness of Norwegian logistics internationally. Furthermore, it can help to reduce the value chain emissions of Norwegian products and make them more attractive internationally. For example, sustainable shipping of products from the Norwegian process industry can help lower the products' climate footprint, and further reinforce the competitive advantage compared to alternative products from, for example, East Asia that are shipped with high fossil fuel emissions. This is becoming increasingly important as more emphasis is placed on climate footprint in a life-cycle perspective as part of e.g. tendering processes in Europe.

Competitive advantages and implementation capacity

Technology and knowledge base

Norway has leading research environments in low-emission maritime transport that are developing and testing new ship designs, control systems and low-emission fuel and propulsion systems. The research centre for zero emission energy systems, FME MoZEES, brings together Norwegian R&D communities working on maritime transport, and there are also more specialised centres and clusters for maritime research that address low and zero emission propulsion systems. In the field of digitalisation, platforms for the exchange of ship-related data are being developed as well as collaborative models and digital twins for use in the design, commissioning, operation and securing of complex integrated systems in the maritime sector.

There are a wealth of funding agencies that target climate-friendly energy technologies with several successful programmes, including Pilot-E and Enova's programmes for environmentally friendly maritime transport and support for shore power facilities. In the period 2017–2020, Norwegian funding agencies granted NOK 4 billion distributed between 671 allocations for projects on climate-friendly energy technologies for the maritime transport sector (Menon, 2021). In addition, the projects triggered a further NOK 4.8 billion in other financing (Menon, 2021).

The Maritime21 strategy for research, development and innovation for the maritime industry launched in 2022 prioritises the development and implementation of energy carriers, including infrastructure, based on low and zero emission technologies. The strategy points to further investment in hydrogen, ammonia and electrification with solutions for new ships and the conversion of existing fleets. It also emphasises sustainability and safety considerations in the selection of fuel solutions.

Industrial experience

Complete and internationally competitive maritime value chains with initiatives for the production of low-emission fuel, development of vessels and infrastructure and end-user solutions make Norway particularly well placed to play a role in climate-friendly maritime transport. Norway has long industrial experience of highly specialised shipbuilding industries with a high degree of complexity. Industry stakeholders have long experience from and are forward-looking in the development of maritime industries, shipping and the petroleum industry. Norway is also at the forefront of areas such as risk understanding and digitalisation.

The country will commission the world's first hydrogen ferry in 2022, and the ferry crossing the Vestfjord is scheduled to run on hydrogen in 2024. These projects help to give Norwegian industry a head start in climate-friendly maritime transport that should be further developed. In 2021, the world's first autonomous and fully electric container vessel commissioned by Yara started to operate between Herøya and Brevik. This is unique world-class expertise and illustrates the Norwegian maritime industry's level of ambition.

Norway can leverage specialist expertise to innovate new energy technologies and solutions for climate-friendly maritime transport and thus gain market share internationally. Ship systems, optimisation and logistics are areas where Norway is ahead of the field, with opportunities to take global positions (NHO, 2021). Norway has a number of strong industrial and research clusters in maritime transport and value chains, including GCE Blue Maritime Cluster, Ocean Autonomy Cluster, NCE Maritime CleanTech, Arena Ocean Hyway Cluster and, in autonomous transport, Sustainable Autonomous Mobility Systems Norway (SAMS).

In the field of fuel production, Norway has several initiatives for the production of low-emission fuels including ammonia and hydrogen. Several stakeholders have ambitions and concrete production plans that can be built up to supply maritime transport towards 2030. In the shorter term, Norway has manufacturers and initiatives under way for the production of LBG that can directly replace LNG in existing LNG vessels, but the volumes are currently limited. Stakeholders in maritime transport, other transport segments and industry can together increase the call for and promotion of low-emission fuel production in Norway. Just under 100 ports currently offer shore power and most facilities have been built with funding from Enova (Ministry of Industry and Fisheries, 2021). The establishment of shore power and the development of battery and charging concepts adapted to operating patterns are undergoing further testing and provide opportunities for the transfer of expertise and value creation potential internationally. This offers particularly great opportunities in relation to the EU if, as previously mentioned, it adopts shore power requirements that apply to major European ports from 2030.

EU perspective

As part of the EU's Fit for 55 package, maritime transport will gradually be incorporated into the EU ETS from 2023. Fit for 55 and FuelEU Maritime also set binding requirements for reducing emission intensity from the maritime sector in the years ahead and requirements for zero emission port infrastructure.

Norwegian projects have received grants from Horizon 2020 of around EUR 71.8 million for technology and social science research for maritime industries, including on vessels and maritime technology related to other ocean industries (RCN, 2021). The EU also focuses on maritime transport in its research programmes, but somewhat less prominently. Norwegian stakeholders actively participate in relevant arenas such as the Zero-emission Waterborne Transport partnership.

Relevant research and innovation needs and measures

Key research and innovation needs

- Development and establishment of emission-free maritime value chains: Comprehensive development along the maritime value chains for transport from production to end use that ensures a low climate footprint, cost and energy efficiency and secure energy supply in Norwegian ports. Security of supply and use of new climate-friendly fuels such as hydrogen in maritime vessels. Development of national and international regulatory frameworks and guidelines for the use of new energy carriers in maritime value chains.
- Maritime climate-friendly propulsion systems: Development of climate-friendly propulsion system technology (e.g. compact, light and efficient batteries and fuel cells, and gas turbines and IC engines for hydrogen, ammonia and methanol). Flexible solutions that can be adapted to e.g. the development of vessels and available energy carriers over time, including fuel flexibility. Demonstrations and system analyses.
- Effective development of infrastructure for low and zero emission energy carriers (electricity, hydrogen, ammonia, etc.) and for charging/filling along the coast to enable the use of climate-friendly maritime propulsion systems.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Increase the proportion of technology-neutral calls with requirements for actual emission cuts, continue investment in key technologies.
- Pursue centre initiatives/Green Platform/Pilot-E, etc., programmes that facilitate broad RD&I effort.
- Support the establishment of infrastructure for the distribution of zero emission energy carriers for maritime transport, as well as large-scale pilots for propulsion systems including fuel flexible technologies.
- Support schemes to promote climate friendly vessels in the domestic market, e.g. CFDs and procurement schemes.
- Develop courses of education in consultation with industry. Study programmes, continuing education and training to increase knowledge transfer and mobility between sectors.

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7.5.4
CLIMATE-FRIENDLY ENERGY TECHNOLOGIES FOR LAND TRANSPORT

Climate-friendly energy technologies for land transport are essential for decarbonising road traffic, rail-based transport and non-road machinery such as construction and agricultural machinery. Decarbonisation of land transport will require a combination of several low and zero emission energy solutions to ensure adequate supply for reliable mobility and to achieve climate targets. The needs of and requirements for propulsion systems and energy delivery will depend, among other things, on the size of the vehicle, the operating pattern and local availability of energy infrastructure.

Land transport includes the following topics:

- Low-emission fuel technology (biofuels, LNG, hydrogen, etc.).
- Low-emission propulsion systems (fuel cells, battery-electric systems, hybrid solutions, etc.).
- Charging and filling infrastructure.
- Market solutions, business models, interaction with the energy system.
- Autonomous transport.
- Digitalisation, mobility as a service.

Road traffic in particular is a significant source of emissions, accounting for 17 per cent of emissions in Norway in 2020 (Norwegian Environment Agency, 2021). To reduce GHG emissions from the sector, targets have been set for new passenger cars and light vans to be zero-emission by 2025, new city buses to be zero-emission or biogas-fuelled by 2025, and by 2030 all new heavier vans, 75 per cent of new long-distance buses and 50 per cent of new lorries must be zero-emission vehicles (Norwegian Public Roads Administration and Norwegian Environment Agency, 2022). Statnett and NVE's long-term power market analyses from 2021 estimate a power consumption in the transport sector of 10 TWh in 2030, and the lion's share of the growth will come from land transport.

Norway has already come a long way with the decarbonisation of the passenger car market through its electrification policies, and electric cars accounted for 63.4 per cent of new car sales in 2021 (Norwegian Environment Agency and the Norwegian Public Roads Administration, 2022).

[23] *Conversion factor: Sustainable aviation fuel = 9,8 kWh/ l.*

For other segments such as agriculture, there are currently few electric alternatives, including for tractors, which constitute the largest source of emissions from agricultural machinery (Norwegian Agrarian Association, 2020). Biofuels are currently considered the most relevant low-emission energy solution leading up to 2030. Although their production volumes are currently limited, there are electric alternatives in construction machinery, and these will dominate the low-emission segment towards 2030 (Ministry of Transport, 2021). Hydrogen-based alternatives are expected to contribute somewhat, but at around three times the cost, which is common to all zero-emission machinery (Ministry of Transport, 2021). As regards non-road machinery, challenges may arise if the machinery operates in remote areas with poorly developed grid networks, and if it requires significant power. For construction machinery, mobile supply solutions with sufficient capacity will be needed in addition to the low-emission machinery itself. Norway's railway network has to a large extent been electrified, but four lines are still diesel powered. Current alternatives to full electrification include battery electric or hydrogen solutions.

For passenger cars and vans, it is estimated that around 9,000 fast chargers will be needed by 2025 and 10-14,000 by 2030. This comes in addition to a sufficient power grid for normal charging at home (Norwegian Environment Agency and Norwegian Public Roads Administration, 2022). The Government presented ambitions through the Hurdal Platform for at least one fast charging station in all municipalities that do not have one by 2023, and for a national charging strategy to be drawn up and interconnected infrastructure developed (Norwegian Labour Party and Norwegian Centre Party, 2021).

The phasing-in of electric vehicles can contribute to increased flexibility in the power system by making use of the battery's storage properties. Flexibility can help shift the end user's consumption to lower-priced hours and curb the load on the grid. The establishment of charging solutions at home or, for example, at hotels utilises existing land. However, charging infrastructure with sufficient power for commercial transport developed along the main arteries could require grid upgrades and thus increase the impact on nature. Liquid biofuels are already well integrated into the existing filling infrastructure, but the current infrastructure is not adapted to biogas. Another challenge with bio-based fuels that must be taken into account is ensuring a sustainable origin, and preferably a local supply. Hydrogen filling stations also require additional safety zones to be established. For green hydrogen, there will also be efficiency losses from converting power to hydrogen compared to direct use in electric vehicles, and green hydrogen thus requires more deployment of renewable power.

Globally, an estimated USD 300 billion will need to be invested in electric vehicle charging infrastructure by 2030 (IEA, 2030). The need for low-emission infrastructure for all land transport will be even more significant if we include hydrogen, hydrogen carriers and bio-based fuels. The EU's Fit for 55 proposes setting requirements for the development of zero-emission charging and filling infrastructure with fast chargers every 60 km and hydrogen stations every 150 km on motorways (along the Trans-European Transport Network –TEN-T) (COM (2021) 559 final). The investment needed to upgrade the TEN-T to a multimodal transport system is estimated to be EUR 300 billion towards 2030. Smart solutions for charging infrastructure, especially fleet management and payment solutions, are highlighted as areas where Norway can take market share, and the global market potential for smart charging for EVs is estimated at EUR 11–16 billion in 2050 (NHO, 2020). Technology is developing rapidly and the limit for which segments of land transport will use which energy carriers will be entirely dependent on the total cost of ownership for each individual segment. This will in turn depend on technology development, particularly in the field of batteries and hydrogen with pertaining infrastructure.

Competitive advantages and implementation capacity

Technology and knowledge base

Norway has strong research environments in charging infrastructure and with strong interaction with the power system. In addition, we have growing knowledge environments in key propulsion technologies and carriers such as batteries and hydrogen. Norway has a centre of excellence in zero emission mobility, FME MoZEES, which covers maritime and land transport, including road and rail. The centre's contributions include research on battery and hydrogen technology and system solutions for heavy transport.

One of the key research topics in Transport21 is the establishment of zero emission solutions for transport, including zero emission solutions for means of transport and associated infrastructure. The strategy specifically highlights electricity, hydrogen and biofuel solutions.

Industrial experience

Norway has several projects for establishing low-emission supply value chains for the transport sector. These are described in the chapters Batteries, Hydrogen, Bioenergy, and Integrated and Efficient Energy Systems. There are concrete plans for establishing battery production for the automotive industry starting in the mid-2020s and initiatives for hydrogen production. Norway also has biofuel manufacturers and biogas technology.

The country does not have automotive manufacturers, but has several suppliers to the vehicle industry. Most of the deliveries are components that are relatively independent of the propulsion system, but in recent years, some companies have established themselves in the market for low-emission energy systems for vehicles. With an early electrification of the passenger car fleet, Norway has had an opportunity to develop and test new charging and infrastructure concepts. Pilot projects for new inductive charging concepts are among the initiatives. In addition, Norway has leading stakeholders in storage systems and filling infrastructure for hydrogen, especially in the construction of filling stations and the integration of battery and hydrogen systems.

The Green Road Transportation Programme launched in 2021 will help to increase the implementation of low and zero emission technology and energy carriers for vehicles and machinery, especially in the industrial segment. Several stakeholders have initiated projects for the phasing-in of low-emission technologies in transport segments. An example is the target of 100 heavy electric trucks and 100 hydrogen trucks in the Oslo region and Eastern Norway.

EU perspective

In 2020, the EU launched the Sustainable and Smart Mobility Strategy for decarbonising and transforming transport and mobility, with a view to achieving a 90 per cent reduction in GHG emissions in the transport sector by 2050. By 2030, at least 30 million of the cars on the road are to be zero emission, and the scope of rail transport is to be increased and electrified or run on hydrogen. Several EU countries have already decided, in their post COVID-19 recovery plans, to allocate a significant proportion of the budget earmarked for green transitions to sustainable mobility (European Commission, n.d.).

Relevant research and innovation needs and measures

Key research and innovation needs

Energy supply

- Efficient and compact electrolysers for filling stations.
- Stationary and mobile concepts for fast and safe charging, including inductive concepts.
- Stationary and mobile concepts for fast and safe filling of hydrogen.
- Safe handling of fuel.
- Co-location and establishment at transport hubs.

Components and design of zero-emission vehicles and non-road machinery

- Compact and lightweight batteries.
- Fuel cell technology (including knowledge of membranes), storage tanks and other core technology relating to hydrogen vehicles.
- Technologies and components for hybrid and low to zero emission propulsion systems.

Efficient, integrated transport systems and markets

- Smart transport systems that make better use of infrastructure.
- Integration of charging infrastructure into the power system.
- Effective market and business models for the development of a climate-friendly transport system, including increasing our understanding of the effects of incentive schemes for the transformation of the transport sector to zero-emission.
- Comprehensive understanding and complex models for the future mobility and logistics system, interdisciplinary issues related to transport and charging patterns, infrastructure, energy production, etc.
- Analysis of the interfaces between the green transition of the energy sector and of the transport sector as a basis for technology decisions in both sectors. Flexibility in the choice of energy supply for different transport segments.
- Complex models for energy and transport modelling including mobility patterns and end users.
- Digitalisation: autonomous vehicles, payment solutions, booking and sharing solutions.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Establish a demonstration project with different types of infrastructure for electrification and zero-emission solutions for heavy transport.
- Requirements for low and zero emission vehicles in public procurements.
- Provide funding for and freeing-up of land plots for the development of charging and filling infrastructure.
- Reduced case processing time in connection with establishing charging and filling infrastructure.
- CFDs for consumers of zero-emission energy carriers.
- Develop a national plan for the development of a comprehensive low-emission infrastructure.

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7.5.5 CLIMATE-FRIENDLY ENERGY TECHNOLOGIES FOR AVIATION

The area of climate-friendly energy technologies for aviation addresses the main challenge of "decarbonising industry and transport". Aviation is demanding to decarbonise, firstly because it involves international activities and secondly due to technology and safety demands.

Aviation includes the following topics:

- Sustainable aviation fuel (SAF), including biofuels and synthetic fuels/electrofuels.
- Liquefaction of hydrogen.
- All-solid-state batteries (aSSB).
- Fuel cells.
- Electric aircraft engines.
- Testing and certification.
- Airport energy infrastructure.

There are several options to decarbonise aviation, including sustainable aviation fuel (SAF), electrification and hydrogen-powered aircraft. In the short term, only sustainable aviation fuel can decarbonise the existing fleet. SAF can already be blended up to 50 per cent with conventional fuels under existing certification, and work is underway to increase this to 100 per cent. DNV GL (2021) estimates the potential for the production of SAF from existing and planned facilities in Norway to be approximately 3 TWh per year in 2030. The potential expressed in the companies' ambitions is greater and corresponds to up to 4 TWh of bio-based fuels and 4 TWh of synthetic fuels (DNV GL, 2021).

Electrification will also be an important option for decarbonisation in the years to come, but is currently limited to short distances with current battery technology prospects. In Norway, the airline Widerøe has ambitions to put into operation a nine-seat, battery-powered electric aircraft as early as 2026. Technology providers suggest that electric aircraft will be able to cover the entire short-haul network with over 30 passengers by 2030. Hybrid aircraft, based on both batteries and conventional or sustainable aviation fuel, will be able to extend the range while contributing to emission reductions.

Increasing the efficiency of the aircraft fleet through developments in aircraft design, energy-efficient engines and operation is also expected to reduce energy requirements and GHG emissions. It is a challenge that value chains for sustainable fuels, especially synthetic fuels, currently involve inefficient processes. The production of sustainable fuels and green hydrogen will require significant amounts of renewable power and is dependent on CCS. Strict requirements are also made of the classification of bio-based fuels as sustainable.

The SAF market is estimated to be worth USD 36 billion in the period leading up to 2030 (Businesswire, 2020). The EU Green Deal emphasises the development towards zero-emission aviation and in pursuit of this, the EU has launched a proposal on implementing requirements for admixture of SAF. The admixture requirement is 5 per cent in 2030, with a minimum requirement for synthetic fuels, and a 20 per cent share from 2035, implying a significant increase after 2030 (COM(2021) 561 final).

Investments in SAF production facilities in the EU are estimated at over EUR 10 billion by 2050 to meet the future demand resulting from the admixture requirement. Estimates do not take possible CCS and hydrogen production into account (COM(2021) 561 final). A number of stakeholders in Norway have pilot and demonstration facilities for the production of advanced biofuels and synthetic fuels and ambitions to scale up in the coming years. In addition, stakeholders in a number of European countries have large-scale projects under development to meet the future demand from the European aviation sector. Sweden, Denmark, Germany, the Netherlands and the UK have all initiated projects.

Sustainable aviation fuel (SAF) is defined by the EU as "drop-in" aviation fuel that is either:

- Synthetic aviation fuels – defined as renewable fuels of non-biological origin (RFNBO), which in practice are produced using hydrogen from electrolysis and carbon capture.
- Advanced biofuels – defined as biofuels that meet given sustainability requirements.

Competitive advantages and implementation capacity

Technology and knowledge base

The NTNU Clean Aviation Partnership was established in 2021 with the goal of conducting multidisciplinary research for net zero-emission aviation by 2050. It is also a member of the EU Clean Aviation Partnership. There are also advanced research environments in electrotechnical components, low-emission infrastructure and advanced biofuels and biorefining.

Industrial experience

Norway has active stakeholders in several areas of the value chain for climate-friendly energy technologies for aviation, including fuel production, infrastructure and component design/development. Several Norwegian stakeholders in SAF production and development, both bio-based and synthetic, have ambitions to take market share internationally.

Norwegian aircraft operators have ambitious goals to increase the supply and phase-in of sustainable fuels and enter into supply agreements with manufacturers. Norway was the first in the world to introduce sales requirements on advanced biofuels, 0.5 per cent by 2020 with a target of 30 per cent by 2030 (DNV GL, 2021). Demonstrations of advanced and synthetic fuels have been successful, but SAF is still between two and ten times more expensive to produce than fossil fuels depending on the maturity of the process (Avinor, 2021).

The network of airports in Norway is owned and managed by Avinor, a wholly-owned state limited company focused on climate-friendly solutions and sustainability. This provides opportunities for piloting and demonstration of new technologies. Norwegian technical environments are also involved in developing solutions and components for electric aircraft, including electric aircraft engines and electric seaplanes. Based on its short runway network and forward-looking industrial and aviation stakeholders, Norway can be a springboard for further development of the electric aircraft market also beyond its national borders.

Relevant research and innovation needs and measures

Key research and innovation needs

- Application of new energy carriers: Resource and energy efficient and sustainable production of bio-based fuels, compact and reliable battery systems including safe and efficient ultra-fast charging, and hydrogen concepts for aircraft (GH2 and LH2).
- Propulsion systems: Fully electric powertrains, thermal integration of liquid hydrogen and electric powertrains, fuel cells with sufficient volume and energy efficiency for aviation, and jet engines for hydrogen.
- Digitalisation: Cybersecurity, improved continuous condition monitoring of key systems including wireless communication with sensors, digital twins of energy and propulsion systems, including airport energy systems.
- Emission-free energy supply to/at airports: Charging and filling infrastructure and energy systems for zero-emission airports. Development of efficient and secure infrastructure.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Establish a Lutfart21 process targeting the aviation sector.

- Establish a green aviation programme/ innovation centre.
- Implement clear regulations for accounting and documentation of climate effects when using sustainable fuel.
- Strengthen Enova's role in the establishment and development of sustainable fuel production facilities.
- Stimulate phase-in through a fund solution for increased use of SAF.
- The central government should pay the additional cost of sustainable fuel for its own employees' business travel. Consideration should also be given to requiring a high proportion of sustainable fuel for the purchase of public service obligation (PSO) routes.
- Establish an aviation climate fund.

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7.5.6
BIOENERGY AND BIOFUELS

Bioenergy is considered an important subject area because of its contribution to decarbonisation, a secure, competitive and environmentally friendly energy supply and new green industries. Transitioning to the use of energy carriers based on bio-resources is often the option for replacing fossil fuels with the shortest lead time for a large proportion of the industrial and transport sectors. This is particularly true within the segments where electrification is problematic. In the longer term, the exploitation of bioenergy resources in combination with CCS can contribute to the realisation of negative emissions. Biofuels can in several cases, and with limited adaptation, replace fossil fuels and provide further security of supply. Bioenergy and biofuel also represent a potential for the development of new green industries based on Norwegian bioenergy resources.

Bioenergy and biofuels includes the following topics:

- Processes for production and processing of biomass for energy purposes.
- Logistics from resource to processing.
- New energy concepts/technologies based on biomass.
- End-user solutions for bioenergy.
- Negative emission technologies based on biomass.
- Sustainable management of bioenergy resources.

In 2020, Norway's production of biofuels was 13 TWh, and energy products from waste amounted to 5 TWh (Statistics Norway, 2021). Pöyry and Nordic Energy Research (2019) estimate the technical potential for bioenergy based on Norwegian forest, agriculture and waste to be 57 TWh. Almost 70 per cent of this potential comes from forest-based biomass. In the longer term, the production of marine biomass for fuel will also be a potential energy resource.

There are multiple value chains for the production of energy carriers based on biomass and they can contribute to further utilisation of residual raw materials and waste for energy purposes. The exploitation of bioenergy resources can also free up electricity used for heating for higher value uses. In the longer term, bioenergy/biomass combined with CCS will enable negative emissions.

The impact of bio-based energy carrier production on land use and nature depends on the type of raw material used. Value chains based on existing waste streams have a limited effect on biodiversity and land use. If the value chain is based on biomass from forests, on the other hand, this can have a major impact on nature. For example, half of the red list species in Norway live in forest areas. The use of bioenergy and the assessment of climate benefits should also take into account what role the species from which the biomass originates plays in the storage and uptake of CO_2 in the ecosystem. Sustainable use of biomass will also be key to social acceptance when phasing in more use of bioenergy and biofuels.

Decarbonisation is expected to result in a significant increase in the global demand for all types of bioenergy in the years to come. The IEA expects annual global investments in production plants for biomethane and biogas to increase from approximately USD 4 billion per year today to USD 14-35 billion per year by 2040 [IEA, 2020]. Increased phase-in of biogas and biomethane is also highlighted by the EU as an important instrument for decarbonising current natural gas consumption. The EU's proposed requirements for SAF are also expected to trigger the need for investments of EUR 10 billion in European production facilities by 2050 [ReFuel EU, 2021].

Competitive advantages and implementation capacity

Industrial experience

The Norwegian bioenergy industry had a turnover of NOK 3.2 billion in 2020, of which national sales accounted for 60 per cent [Multiconsult, 2021]. Equipment deliveries constituted half of the national turnover [Multiconsult, 2021]. Norwegian forest owners and farmers are important producers, managers and users of land-based biomass and are involved in the development of new energy solutions and further development of existing ones. NoBio [Norsk bioenergiforening] is an association for the Norwegian bioenergy industry that focuses on sustainable utilisation of national bioenergy resources.

Norway has several manufacturers of biogas plants that deliver competitive technology around the world. In recent years, Norway has started the development of large-scale, state-of-the-art production of, among other things, liquid biogas [LBG] based on industrial and forest waste. Such new start-ups will by the end of 2022 have the largest production capacity for LBG in Europe with close to 415 GWh per year [IEA Bioenergy, 2021].

Norway also has a growing production of liquid biofuels, including SAF. Several stakeholders have pilot plants under construction and are developing plans for full-scale biofuel production. Diverse value chains, dispersed raw material sources with significant processing needs and limited availability for sustainability reasons are potential challenges to scale-up and profitability in the production of bio-based energy carriers.

The oil and gas industry has process technology expertise that is transferable to the conversion of biomass and can help to further develop the processes involved in biomass refining. In addition, the Norwegian oil and gas industry is spearheading the development of a CCS value chain that, in combination with bioenergy, can contribute to realising negative emissions in the long term. In the aquaculture industry, there is also potential in the long term for development cooperation on third-generation bioenergy based on algae as a raw material.

Technology and knowledge base

Research communities in bioenergy have been brought together at the centre for environment-friendly energy FME Bio4Fuels, formerly CenBio. Norway has strong research communities in biotechnology and biochemistry, chemical engineering, process technology and conversion processes. We also have stakeholders at the forefront of sustainability and macro-analyses that contribute expertise to the IEA and the IPCC. Norway also participates in the IEA's Bioenergy Task 39 – Commercializing Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks.

EU perspective

The EU has a strong focus on the development of bioenergy from a bioeconomy and circular economy perspective, and is imposing increasingly stringent sustainability requirements on bioresource use and refining. Biofuels and bioenergy are also one of the main areas of the EU SET Plan, with the EU emphasising the development of advanced biofuels for decarbonisation of the transport sector. Norwegian stakeholders have received EUR 9 million for projects related to bioenergy through Horizon 2020 [RCN, 2021]. Research groups are actively contributing to a number of EU projects, including projects dealing with conversion processes of different raw materials by hydrothermal liquefaction [HTL].

Relevant research and innovation needs and measures

Key research and innovation needs

- Identification and sustainable management of biomass for energy purposes, including community involvement, land use and changes in bioenergy potential due to climate change. Facilities and technologies that can use different types of raw materials.
- Interactions between bioresources, agriculture and the circular economy. Combined biorefinery facilities with on-site utilisation of side streams.
- Life cycle analyses and certification of bioenergy. CCS in combination with bioenergy, and the potential for negative emissions.
- Marine sources of bioenergy in the longer term.
- Higher efficiency processing and energy efficiency improvement throughout the value chains.
- Thermochemical conversion and catalysis.
- Electrochemical conversion and hybrid solutions.
- Enzymes, microbiology and fermentation processes.
- Development of biomass conversion processes, including the development of new catalysts and reactions, reactors and processes on different scales.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- An updated bioenergy strategy with action plan.
- Collaboration with expert environments internationally and in the field of process technology.
- Digitalisation and application of digital twins in processes and research.
- Funding for taking basic research to market, and infrastructure to support pilot-to-plant projects and establish more facilities.
- Risk relief for industry stakeholders and prioritisation of innovation activities targeting the commercialisation of technologies and application of Norwegian industries.
- Financial support schemes for the development of a domestic market using e.g. CFDs and procurement schemes.
- Certification schemes for biofuels.
- Develop courses of education in consultation with industry. Study programmes, continuing education and training to increase knowledge transfer and mobility between sectors.
- Continuation and predictability of existing support programmes .

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7.5.7 LAND-BASED WIND POWER

Land-based wind power is a mature and competitive renewable technology. Technology can help meet the energy transition's growing power demands and ensure a secure and competitive power supply.

Land-based wind power includes the following topics:

- Resource mapping, modelling, wind forecasting.
- The role of wind power in the energy system.
- Operation and maintenance.
- Digitalisation.
- Community involvement, social acceptance and agreements.

Land-based wind power is the cheapest form of new renewable energy (NVEa, 2022) and Norway has some of Europe's best wind resources (NVEb, 2022). It is uncertain how much new land-based wind power will be built in Norway by 2030. In recent years, the development of land-based wind installations has been controversial and characterised by a lack of community involvement. This led to a halt in the processing of new licence applications from April 2019. The possible development of new capacity towards 2030 will depend on the political climate and new licensing requirements. From autumn 2022, plans have been made to resume revision of the licensing system to ensure stronger support in the local community.

Wind power plants are contentious, among other things because they are land intensive, noisy and can be considered visual pollution. The placement of wind turbines with associated road-building and grid connection infrastructure in relatively untouched nature contributes to the fragmentation of natural areas, which can affect migratory routes and habitats.

Investment needs in land-based wind power to achieve European climate targets are estimated at USD 6 billion annually, and globally at USD 146 billion by 2030 (IRENA, 2019). If Norwegian operators succeed in taking leading market share internationally, the total addressable market value for these operators is estimated to be EUR 12–40 billion in the period 2020–2030 (NHO, 2020).

Competitive advantages and implementation capacity

Technology and knowledge base

The research centre for environment friendly energy FME NorthWind is at the international forefront of wind power research and has a strong interdisciplinary collaboration, but its main focus is on offshore wind development.

Industrial experience

The strengths of Norwegian wind power operators lie in project development, modelling and operation and maintenance solutions. Norwegian stakeholders are strong in the optimisation of market operations and market integration (NHO, 2020). Technology and solutions for analysis and optimal operation and maintenance represent a growing export potential going forward.

The Norwegian land-based wind power industry had a turnover of NOK 17.3 billion in 2020, of which 80 per cent was national turnover (Multiconsult, 2021). There has been significant growth in national turnover in recent years, especially related to equipment deliveries for the development of wind power. There is great uncertainty going forward about the establishment of new land-based wind power in Norway, which means that Norwegian businesses are forced to seek opportunities abroad to maintain their competence.

Relevant research and innovation needs and measures

Key research and innovation needs

- Improve methods and models for wind and production estimates.
- Methods and tools, including machine learning, to monitor conditions and optimise operation and maintenance.
- Estimate and improve reliability, service life and efficiency of main components and systems.
- Further knowledge of the environmental and societal impact of wind power.
- Models for predicting impact on neighbours and any conflicts with the environment.
- Cost-effective solutions and mitigation measures for negative environmental and land-use impacts.
- Agreements and compensation arrangements.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Support Norwegian stakeholders' foreign investment.
- Access to land and opportunities to apply for licenses in Norway over time.

Sources

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7.5.8 GEOTHERMAL ENERGY

Geothermal energy plays an important role in the thermal system aspects of the energy transition and contributes in particular to a secure and competitive energy supply. Geothermal energy is taken from the earth's crust and depending on temperature, can be upgraded for use in heating, cooling and power generation.

Geothermal energy includes the following topics:

- Ground source heating and borehole thermal energy storage (BTES) for seasonal heat storage (low and high temperature).
- Medium-depth wells (400–1,000 m) and deep wells (1,000–3,000 m).
- Geological, geochemical and geophysical mapping.
- Reservoir characterisation, modelling and simulation.
- Reservoir stimulation.
- Well and drilling technology.
- Materials technology.
- Production planning with multiphase modelling.
- Instrumentation and monitoring technology.

Norway has 65,000 heating/cooling plants with a total installed power of 1,200 MW. The plants produce 3.5–4 TWh of heat annually. Low-temperature geothermal energy can theoretically meet the national demand for heating and cooling of buildings. It has not been profitable to develop power plants based on geothermal energy in Norway due to the depths necessary to achieve sufficient temperatures.

Geothermal energy is a stable and widespread source of energy supply, and can be exploited on a large scale or in the form of distributed solutions. The flexibility potential of geothermal energy in the energy system at full utilisation is 10–15 GW power output (GTML and Asplan Viak, 2021). The utilisation of low-temperature geothermal energy helps to reduce power peaks in the grid, and, in combination with heat pumps, contributes to energy efficiency. In addition, geothermal seasonal heat stores and other storage concepts can contribute to load balance. Geothermal concepts have low land-use requirements if located close to the end user and do not require further development of transmission infrastructure. Geothermal energy is also a secure source of supply that is better equipped to withstand climate change (IRENA, 2021a).

To achieve the 1.5°C target, USD 24 billion per year must be invested globally in geothermal energy by 2050 (IRENA, 2021a). The global economic potential for geothermal heat in 2050 is estimated at 800 GWh and power from hydrothermal systems is estimated at 70 GW (IRENA, 2021a). The Norwegian supply industry in the petroleum sector and geothermal industry with products and services in exploration, reservoir, drilling and well technology have opportunities to assert themselves in an international market that demands new solutions. The national market potential for Norway's current building stock is about 33 TWh, which represents a significant potential for jobs throughout the country and the value chain.

Competitive advantages and implementation capacity

Natural advantages

Norway is well-positioned to utilise geothermal energy for heating and cooling, but generally has too low a geothermal gradient to be able to utilise geothermal energy for power generation. This is more relevant in other countries.

Technology and knowledge base

Norway has research environments in both deep and low-temperature geothermal energy. The Norwegian Centre for Geothermal Energy Research (CGER) established in 2009 brings together Norwegian research groups within this area. Further investment in deep geothermal energy is important, firstly to strengthen Norway's opportunities in relation to a type of energy technology with significant potential in established and emerging markets, and secondly to ensure continued Norwegian participation in international research networks.

Industrial experience

A number of stakeholders, including drilling, consulting and design companies, are working on the development and installation of low-temperature geothermal energy. They are represented through NemiTek, which is a trade organisation for those working in HVAC, energy and environmental engineering, and NOVAP, the Norwegian heat pump association. The oil and gas industry can also contribute significant technology transfer potential, such as innovative and digital technologies in equipment and system deliveries for drilling and production facilities, flow assurance methods and infrastructure. Our experience with deep wells from the oil and gas industry in particular can be exported for use in geothermal power generation in countries with a higher geothermal gradient than Norway. New technologies will bring about opportunities for the use of offshore drilling technology for power generation on the continental shelf. Norwegian stakeholders are currently looking into the use of high-temperature hot water from the seabed for power generation and high-temperature well parks for storage of surplus heat and use in the district heating network.

EU perspective

Deep geothermal energy is one of the working groups in the EU SET Plan. The Research Council of Norway supports the EU's Horizon 2020 programme Geothermica, which promotes research and innovation for reliable, safe and competitive geothermal energy. Geothermal energy is also particularly highlighted in the development of low-emission and energy-positive buildings and areas.

Relevant research and innovation needs and measures

Key research and innovation needs

- Effective methods for geological, geochemical and geophysical surveying, both regionally and for prospect uses.
- Robust and cost-effective drilling and well technology
- Reservoir characterisation, modelling and simulation, and stimulation technologies that help to optimise development plans and production.
- Methods for monitoring and limiting negative environmental impacts and for the safe management of the subsoil.
- Development of instrumentation and monitoring technology (invasive/non-invasive).
- "Flow assurance", including prediction and handling of scale deposition.
- Materials technology for well and surface processing components.
- Production planning with multiphase modelling of flows in wells, reservoirs and pipelines.
- Cost-effective thermal seasonal storage.
- Deep geothermal energy combined with seasonal storage of heat.
- Offshore thermal wells – geothermal energy for power generation Utilisation of supercritical steam.
- Use of fluids other than water for heat production from cold/shallow wells.
- Optimal design of low-temperature geothermal systems in relation to heat/cooling capacity, energy optimisation and shallow reservoir construction. Interaction between well parks, heat pumps and energy needs.
- Geothermal energy in an integrated energy system.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Support for bilateral cooperation projects.
- Contribute to developing and funding networks among national representatives of universities, research institutes, business clusters and other industry.
- Stimulation of Norwegian stakeholder participation in research and demonstration projects.
- Funding for innovation projects for the industrial sector with potential in the national market.
- Funding for knowledge-building and researcher projects in key research topics.
- Facilitation and green loans/support schemes.
- Expand the scope of courses and programmes in geothermal energy in tertiary vocational education and higher education.

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7.5.9 NUCLEAR POWER OF THE FUTURE

The nuclear power of the future is being developed in several areas and can make a positive contribution to maintaining a secure energy supply in the energy transition, especially in our neighbouring countries. Current efforts are targeting, among other things, the next generation of conventional nuclear power and small-scale modular reactors (SMRs). France is working on the former through the development of the European Pressurised Water Reactor (EPR), while the latter is being developed on several fronts, including in Sweden, Estonia, Poland and the UK through both large and small companies such as Blykalla, Vattenfall, Fortum, Fermi Energia, NuScale Power and Rolls Royce SMR. There are over 70 small modular reactor (SMR) designs and concepts around the world, and most of them are still under development (IAEA, 2022). So far, only four SMR facilities globally are in the early completion phase, but an increasing number of countries are considering the possibility of initiating their own projects (IAEA, 2021).

Nuclear power of the future includes the following topics:

- Small modular reactors (SMRs).
- Next generation reactor technology.
- Heat exchange technology.
- Components and materials. technology for nuclear power.
- Safety and security and digitalisation in the nuclear power of the future.

The advantage of small modular reactors is that they are more flexible than conventional nuclear power plants, have lower costs, shorter lead times, better scalability and are safer. More efficient use of fuels is also highlighted as an advantage. For many countries, the establishment of one or more SMRs can be a safer and more affordable route to decarbonisation of the power sector. A test reactor of fourth-generation lead-cooled SMR is planned by the companies Blykalla and Uniper in Oskarshamn, Sweden (TU, 2022).

Norway has long experience of research on nuclear power through certain research institutions, and some of the most extensive and long-lived research projects in Norway concern nuclear power. Norwegian research communities have also recently started to work more on the topic of SMRs. Among other things, an SMR simulator will be established in Norway in order to conduct research on the safety of future nuclear power (Tecnatom, 2022).

There is limited commercial activity related to nuclear power in Norway, and value creation opportunities in this area are therefore few for Norwegian industry in the near future.

Relevant research and innovation needs and measures

Key research and innovation needs

- Operational reliability and cybersecurity in SMR.
- Scalable systems, modularisation.
- Heat exchange technology.
- System integration and uptime considerations.
- Safe handling and storage of waste.
- Legal frameworks and social acceptance for the phasing in of the nuclear power of the future.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Funding for participation in international research and innovation collaborations and national competence building.

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7.5.10
FUSION ENERGY

If technology development is successful, fusion energy could represent a paradigm shift in the energy field. The technology will represent a reliable heat and power concept that requires little land and can contribute in the long term to almost unlimited amounts of competitive and safe energy. Fusion energy addresses the challenges of reliability and waste management associated with traditional fission power plants. Unlike fission, fusion involves the process of fusing atoms which release heat. Light atomic nuclei are fused into larger and heavier atoms. This is typically hydrogen nuclei that are fused into helium. For the atoms to fuse and release heat, plasma with a temperature of 100 million degrees Celsius needs to be maintained over a longer period of time. The release of heat from the fusion process can be utilised by means of heat exchangers for power generation. It takes vast amounts of energy to sustain the fusion process, and so far, no one has succeeded in extracting more energy than the amount put into the process.

Fusion energy includes the following topics:

- Plasma physics – basic research.
- Magnets and superconductors.
- Fusion reactor concepts.
- Heat exchange technology.
- Components and materials technology for fusion.
- Digitalisation.

Tokamak reactors are the most widely used reactors, but more experimental magnetised target reactors and linear (colliding beams) reactors are also under development. The International Thermonuclear Experimental Reactor (ITER) is a major international collaboration with experimental start-up in 2025 for the development of a 500 MW Tokamak reactor. The programme also aims to establish demo power plants in the early 2030s. Several private companies also have ambitions to develop smaller reactors, and modularisation is important to succeed in faster scale-up. The ambitions involve pilot scale proof of concept (POC) to demonstrate by 2025 the feasibility of extracting more energy than the process uses, and the development of modular commercial concepts by the 2030s with multiple reactors that can be combined into a larger plant.

The advantage of modularisation is that the location of the plants is flexible, meaning that they can be placed closer to the customers. The technology is also largely independent of natural resources as there is a sufficient supply of the inputs consisting of hydrogen isotopes. There are currently a number of technological challenges that need to be addressed, including maintaining sufficiently high temperatures for continuous fusion and frequent component replacement. The technology is also met with scepticism and a lack of understanding of the difference between fission and fusion that must be addressed for possible broad application in the future.

Norway does not have industry directly related to fusion energy, but we have research environments in areas such as northern lights, plasma and materials technology that participate in international research projects related to fusion energy. Participation in international research projects is therefore important to gain access to expertise from abroad and develop expert environments in Norway.

Relevant research and innovation needs and measures

Key research and innovation needs

- Materials technology specifically relating to magnets and superconductors.
- Small-scale reactors.
- Scalable systems, modularisation.
- Heat exchange technology.
- System integration and uptime considerations.
- Legal frameworks and social acceptance for the phasing in of fusion energy.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Norwegian participation in EUROfusion.
- Funding of participation in international research and innovation collaborations.

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7.5.11 WAVE AND TIDAL ENERGY

Wave and tidal energy utilises the movement of water to generate power. It is a relatively stable source of energy supply. The technology contributes to a secure energy supply and to the development of new marine energy technologies. Wave energy has a great technical potential along the Norwegian coast, estimated at 600 TWh. Assuming an accepted expansion corresponding to 20 per cent of the potential and an annual efficiency of 10–25 per cent, the potential in Norway is estimated to be 12–30 TWh (Sweco, 2007).

Wave and tidal energy includes the following topics:

- Innovative wave energy concepts.
- Components and materials technology for marine energy technology.
- Role in the energy system.
- Cost-reductions in construction, operation and maintenance.

Wave energy is currently an immature technology with an installed capacity of 2.3 MW globally. However, based on its project database, the International Renewable Energy Agency (IRENA) expects installed capacity to reach 100 MW in the coming years (IRENA, 2020). Many concepts are still in the testing and demonstration phase, and it was not until 2020 that concepts were installed with a capacity of over 1 MW. Ocean Energy Europe (2020) estimates a cumulative installed capacity of at least 500 MW to be required as sufficient scaling to achieve energy costs of EUR 110/MWh (2020). Most of the projects implemented to date are relatively small, and there are several that now wish to focus on small-scale facilities adapted to niche markets such as oil and gas installations or the aquaculture industry (IRENA, 2020). Today's projects are dominated by the concept of oscillating water columns, while there are several projects in the planning focusing on point absorber concepts. The environmental impact of wave power installations is currently thought to be limited, but it will be necessary to coordinate interaction with other users of marine areas.

Several developers of wave energy concepts in Norway are in the testing and piloting phases. In 2017, a wave power plant was connected to the grid in Norway for the first time. This was a full-scale pilot with a buoy rated at 100–200 kW. The technology is still relatively expensive but is expected to become competitive in time as a result of scaling up. To advance in this process, robust plants must be developed that withstand stresses caused by wave action, and support for patenting, scaling-up and commercialisation of concepts will also be key. The development of new concepts will also provide opportunities for Norwegian certification environments and, in time, for a maritime service industry relating to the installation and operation of wave power plants.

Tidal energy is divided into two main concepts, tidal dams and water turbines, which exploit the height difference between the low and high tide and tidal streams, respectively. Of a total of 535 MW of ocean energy installed globally, tidal dams account for nearly 98 per cent, while tidal turbines account for the remaining nearly 2 per cent. The dominance of dams is due to the maturity of the technology, but growth is expected to come with the commercialisation of tidal turbines going forward. There is already a pipeline of more than 2.5 GW in projects for tidal turbines, in addition to the 10.6 MW already installed (IRENA, 2020). Tidal turbines are now being built on a MW scale and there is particularly high activity in the UK. In Norway, there is little activity in the field, and the realistic Norwegian expandable tidal potential was estimated in 2007 to be below 1 TWh, although the potential may in fact be greater (Sweco, 2007).

EU investment in technology development in the field of wave and tidal energy

In its Offshore Renewable Energy Strategy, the EU has set a target of at least 1 GW of installed wave and tidal power capacity by 2030, with an increase to 40 GW by 2050. A working group on ocean energy was established under the EU SET Plan to meet renewable power ambitions. The SET Plan also sets out cost reduction targets for both wave and tidal energy. The OceanSET project will help to put the working group's plans into action and promote information sharing between member states and key industry stakeholders. ETIP Ocean helps to define RD&I priorities in the ocean energy sector and, together with Ocean Energy Europe, has developed a growth scenario pointing to the possibility of 2.6 GW installed capacity by 2030 in European areas (Ocean Energy Europe, 2020). Scale-up of this magnitude could reduce energy costs to EUR 90/MWh for tidal turbines and EUR 110/MWh for wave energy.

Relevant research and innovation needs and measures

Key research and innovation needs

- Development of robust systems that withstand stresses caused by wave action.
- Cost-effective concepts.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Support for patenting, scaling-up and commercialisation of concepts.

Sources

- Stensvold, T. (2017), Norge har fått sitt første bølgekraftverk som leverer strøm til kraftnettet. Slik virker det. Teknisk Ukeblad. URL: https://www.tu.no/artikler/

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- IRENA (2020), Innovation Outlook - Ocean Energy Technologies. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Innovation_Outlook_Ocean_Energy_2020.pdf
- Ocean Energy Europe (2020), 2030 Ocean Energy Vision - Industry analysis of future deployments, costs and supply chain. URL: https://www.oceanenergy-europe.eu/wp-content/uploads/2020/10/OEE_2030_Ocean_Energy_Vision.pdf

7.5.12 AIRBORNE WIND

Airborne wind is an evolving power generation technology designed to harness wind resources at altitudes between 200 and 1,500 metres. At these altitudes, wind resources are stronger and more constant, enabling a higher capacity factor. Airborne wind concepts are often wing or kite-shaped structures tethered to the ground. There are two main concepts, those where the generator is aloft and those with a generator on the ground. Airborne wind is in an early commercialisation phase. The location of a single airborne wind system is flexible and requires relatively little area. Consequently, it is suitable for distributed renewable power generation onshore or offshore, but it is now also being developed for configurations in large power plants. A further advantage of airborne wind is that it requires less materials compared to traditional wind turbines.

Airborne wind includes the following topics:

- Innovative airborne wind concepts.
- Control systems.
- Components and materials technology.
- Role in the energy system.
- Cost-reductions in construction, operation and maintenance.

Kitemill is the only Norwegian supplier (OEM) of airborne wind technology and is a leading player in the development of this technology internationally. Kitemill has received several grants from the EU's research programmes, including Horizon 2020, Interreg and the EU Innovation Fund, totalling more than NOK 100 million. Norwegian university environments are also active in concept and component development. In recent years, an international community has emerged, with the establishment of industry organisations and airborne wind initiatives. The European industry organisation Airborne Wind Europe was established in 2018, with Kitemill as Norway's key contributor.

Relevant research and innovation needs and measures

Key research and innovation needs

- Control systems and full automation of launch and landing of wind power kites.
- Lightweight and durable materials that tolerate a high number of cycles.
- Increased reliability, including technical operational reliability and regulatory aspects.
- Effect on flying species, e.g. birds and bats.

Selected actions

- Implement research, development, demonstration and commercialisation activities targeting the most important research and innovation needs.
- Support Norwegian participation in IEA Wind Task 48 – Airborne Wind Energy.
- Funding of RD&I and demonstration, commercialisation and scaling-up.

Sources

- Airborne Wind Europe (2021), Airborne Wind Energy – an emerging renewable technology (16.04.2021). URL: https://airbornewindeurope.org/wp-content/uploads/2021/09/Airborne-Wind-Europe_Intro-Airborne-Wind-Energy_2-pager_2021-04-16.pdf
- Innspill til Energi21-prosess fra Kitemill (29.10.2021) og Airborne Wind Europe (17.11.2021).

7.6

Appendix 6: Backdrop for strategic priorities

The Ministry of Petroleum and Energy's mandate and guidelines for the Energi21 strategic body provide the backdrop for the selection of the strategic priorities. In 2016, the mandate was extended to include transport and a stronger international focus. Energi21's vision is that Norway will further develop Europe's best energy system. This means that the energy system must contribute nationally and internationally in the form of renewable, climate-friendly and predictable energy supplies with the right quality, as well as industrialisation and business development.

The Energi21 strategy is to comprise an integral component of Norwegian energy policy and promote the achievement of the primary objectives set out by the authorities for energy research:

- Increase value creation on the basis of national energy resources and utilisation of energy.
- Facilitate energy restructuring with the development of new technology to limit energy consumption and greenhouse gas emissions while efficiently producing environment-friendly energy.
- Develop internationally competitive industry and expertise in the energy sector.

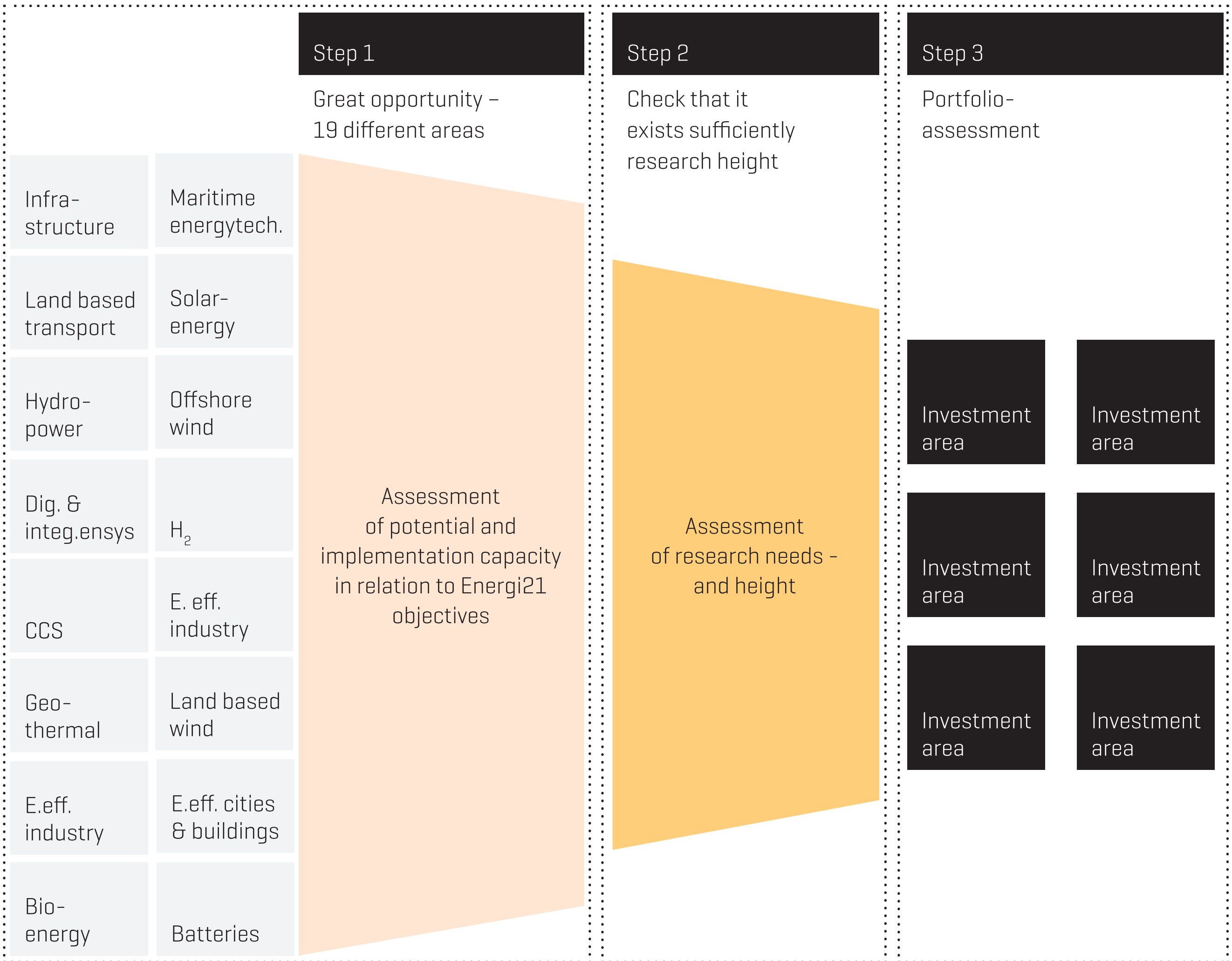


Figure 5 Method for conducting the comparative analysis

7.6.1
STRATEGIC REVIEW OF 19 TECHNOLOGY AREAS

The Energi21 strategic body's selection of key areas and recommendations for measures to be implemented are based on an analysis of 19 technology areas within the energy and transport system. The assessment encompasses factors deemed to be of importance for designating the strategy's key areas.

The strategic analysis describes each subject area (sections 3.1-3.8 and Appendix 7.5) that it considers particularly relevant for Norwegian stakeholders, the country's energy supply and industrial development. In addition, it identifies the following key elements:

- market opportunities and industry ambitions.
- strategic research and innovation topics.
- actions to take.

7.6.2
METHODS OF COMPARATIVE ANALYSIS USED

With the strategic review of thematic and technology areas its starting point, the board has thoroughly analysed each area in relation to its potential to achieve relevant Energi21 objectives, the status of research and research needed, and conducted an overall portfolio assessment. Figure 5 illustrates the methodology used. Although the process is illustrated in three steps in the figure, the process has in practice been iterative. Several assessments have been made of the division of subject areas, and the steps have been through several iterations.

Step 1: Assessment of potential and implementation capacity in relation to Energi21 objectives

In the first step, each key area is assessed in relation to each of the three Energi21 objectives. This step includes both an assessment of the technology area's potential for advancing each Energi21 objective and of Norway's implementation capacity within the technology area.

Assessment of potential for advancing the objectives

A technology area's potential for advancing the objectives is an assessment of its likely potential for helping to achieve the Energi21 objectives, which are, respectively, the potential for value creation based on Norwegian energy resources, potential for facilitating energy restructuring in Norway, and the potential for further developing Norwegian trade and industry and expertise. Each technology area's potential for advancing each objective is assessed according to the following defined sub-criteria:

Objective 1:

- What is the technology area's potential for increasing the utilisation of Norwegian energy resources?
- What is the technology area's potential for enhancing the flexibility of the energy system?

Objective 2:

- What is the technology area's potential for helping to reduce greenhouse gas emissions?
- What is the technology area's potential for facilitating energy efficiency improvement?

Objective 3:

- What is the (national and international) market potential of the technology area? Are there markets within the technology area where Norwegian stakeholders can supply products and services?

Assessment of Norway's implementation capacity

Norway's implementation capacity is an assessment of what it will take for Norwegian stakeholders to achieve success within each technology area and succeed in contributing to the Energi21 strategy's objectives. Implementation capacity is assessed on the basis of the following criteria:

- Level, quality and strength of the R&D groups and educational institutions within the technology area.
- Technology and knowledge base.
- Industrial experience.
- Are there companies or industrial clusters with the ambition, willingness and ability to take action in the technology area?
- Potential for the flow of expertise and synergies between sectors.

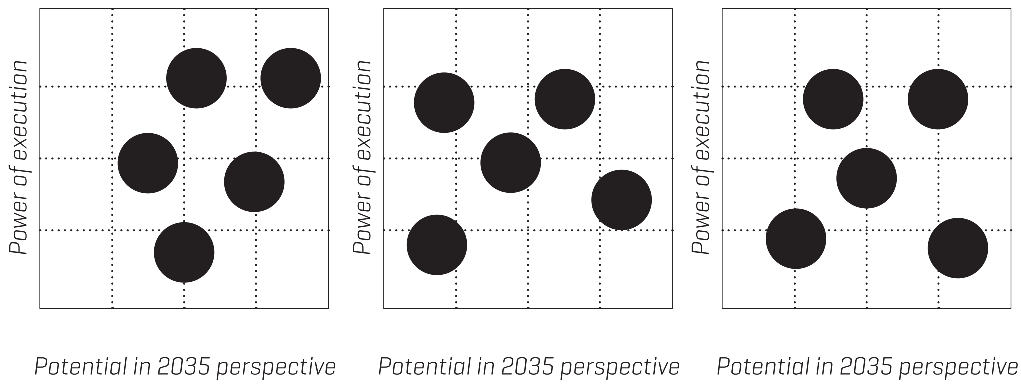
The first step of this strategic analysis is intended to broadly categorise the different technology areas in relation to the Energi21 objectives. Step 1 assesses a technology area's potential for advancing the objectives as well as the likelihood that Norwegian stakeholders will realise this potential. This step has been compiled and simplified into diagrams to illustrate the technology areas' relevance relative to each Energi21 objective.

Objective 1:
Increased value creation on basis of national energy resources and energy utilization.

Objective 2:
Energy transition through efficient energy use, lower greenhouse gas emissions and increased flexibility in the energy system.

Objective 3:
Enhanced competitiveness and increased value creation in the energy industry in Norway.

- R&D with world-leading competence.
- Industry players/ business clusters with ambitions (locomotive).



- Energy production based on national energy resources.
- Amount of contribution to flexibility in the energy system.

- Potential for reduction of CO_2 emissions.
- Potential for energy efficiency.

- Market potential.

Step 2: Assessment of level of research and research needs
The second step of analysis targets the level of research and research needed for each technology area. This is an important element to assess because the Energi21 strategy's recommendations presume there is a need for research and innovation activities. Each phase of the innovation chain is vital for achieving successful project implementation and commercialisation of results, and this has been emphasised in the analysis of the level of research and research needed. Assessments have been carried out of the following:

- The position of the technology in question and related technologies along the innovation chain, and whether there is a sufficiently high level of research.

Additionally, consideration is given to EU research activities within each technology area, along with the role that Norway can play in them and what steps Norway should take to gain a position in the EU research and innovation arena. The EU research agenda is described in more detail in Chapter 4.

Step 3: Portfolio assessment
Finally, an overall portfolio assessment of the key areas is carried out with a view to assessing whether the portfolio as a whole adequately supports all the Energi21 objectives.

7.6.3
INFORMATION SOURCES FOR THE STRATEGIC ANALYSIS

Strategic working meetings for each technology area were an essential part of the strategic review process. Representatives of public authorities, industry stakeholders and research groups attended the meetings to contribute relevant input and viewpoints. The meetings and the subsequent input rounds provided a strong foundation for the Energi21 strategy, which is mandated to bring the authorities, trade and industry and research communities closer together. Altogether, some 600 individuals took active part in the strategy processes. A complete overview of meetings and the companies the participants represented can be found in Appendix 8: Stakeholders represented at input meetings and in other dialogue.

In addition to the strategic working meetings, the Energi21 board maintained an ongoing dialogue with relevant industry representatives, authorities, policy and funding agencies and special interest organisations. This provided an integrated, realistic view of Norway's position within the various technology areas. Another basis for the strategic analysis was the assessments stemming from the Energi21 external factors assessment conducted in 2021, and the project and subsequent report on research and innovation-driven business development (Forsknings- og innovasjonsdrevet næringsutvikling – in Norwegian only). In addition, a number of other reports and document analyses by recognised sources and relevant publicly accessible information have informed the strategy. Last but not least, the Energi21 process drew upon the collective expertise of the board members, who represent stakeholders in a variety of areas within the energy and transport system.

7.7

Appendix 7: Glossary

R&D

Research and development (R&D) is any creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications.
R&D can be divided into three activities: Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Applied research is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, that is directed to producing new materials, products or devices; to installing new processes, systems and services; or to improving substantially those already produced or installed.

The basic criterion for distinguishing R&D from related activities is the presence in R&D of an appreciable element of novelty and the resolution of scientific and/or technological uncertainty. Source: OECD

Innovation

An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations. Innovations are based on the results of new technological developments, new technology combinations, or the use of other knowledge acquired by the enterprise. There are four types of innovation: product innovation, process innovation, marketing innovation and organisational innovation.
Source: OECD

Testing and demonstration (demo – D)

Testing and demonstration facilities are relevant for thematic and technology areas in which there is a need for verification and adjustment of technology products and solutions at a realistic scale. Testing and demonstration facilities may be standalone facilities or integrated into operational facilities.

Grid company

A company that owns and operates a power grid or grids for transmission of electrical power, such as a distribution grid and/or regional grid. Regulated monopoly.

Supplier company

A company that delivers equipment and/or services that are part of the value chain for energy production and consumption.

Technology supplier

A company that delivers technology and solutions that are part of the value chain for energy production and consumption.

Technology developer

An actor that develops new or improves existing technology. Actors may be supplier companies, R&D groups at universities and university colleges, or private individuals/entrepreneurs.

Technology user
An actor that procures and uses developed technology.

Reservoir
A natural or artificial lake for storing water in periods of high catchment inflow and low consumption. Stored water is used in periods of high consumption.

Reservoir capacity
The total volume of water (m3) that can be stored in a regulating reservoir between the highest regulated water level (HRWL) and the lowest regulated water level (LRWL). Reservoir capacity is also often measured as the amount of electrical energy that can be produced with the stored water.

Balancing power
Balancing power has more than one meaning. From a purely commercial perspective, in today's Nordic power market it represents a specific amount of power in kWh at a specific price. The price varies from hour to hour.

In a more overall perspective, balancing power addresses the need to stabilise the increasingly greater fluctuations that will occur in the power supply with a rising proportion of intermittent renewable power, e.g. wind power.

Power system balancing services
Services that supply output to compensate for intermittent power production by utilising the regulating abilities of hydropower produced from reservoirs.

Energy storage
Also known as energy accumulation. The process of storing energy for later use with the help of mechanical, thermal, electrical or chemical methods.

Energy system
Infrastructure that links together components and systems for energy production, energy transmission and energy consumption.

Energy
Energy is the capacity to perform work, and is the product of power and time. Electric energy is often measured in kilowatt hours (kWh). 1 kWh = 1000 watts hours. Other energy is measured in joules (J).

Power
The amount of work produced or energy transferred per unit of time. Power is measured per watt (W), which equates to 1 joule per second (J/s).

LCOE
Levelised cost of energy. The total cost to build and operate power-generating asset over its lifetime, divided by the total energy output of the asset over that lifetime. LCOE is measured in cost/kWh and is used to compare the costs of different technologies for generating electricity.

LCA
Life-cycle assessment. An analysis that calculates the environmental impact of a product or service over all the stages of its lifetime.

Power balance
The calculation of the balance between power supply and power demand within a given time period. The power balance can also be used to show how power demand can be covered under various conceivable conditions in relation to access to water, exchange of intermittent power, electricity prices, etc.

Technology Readiness Level (TRL)
A system for measuring the degree of maturity of a technology or concept. The TRL system consists of nine levels.

Co-simulation
Simulation tool that links multiple subsystems, subject groupings and disciplines.

Carbon capture and storage (CCS)
Encompasses the capture, transport and storage of CO_2 along the entire value chain.

Green Hydrogen
Hydrogen produced using electricity by means of electrolysis.

Blue hydrogen
Hydrogen produced from natural gas in combination with carbon capture and permanent storage.

SME
Small and medium-sized enterprises. Often used about enterprises with fewer than 100 employees.

BECCS
Bioenergy with carbon capture and storage. The process of capturing and storing CO_2 from biomass processing while producing energy.

Competitive advantages
A nation's advantage in a market, in comparison to one or more other countries, that can enhance potential to gaining a market position. An advantage may be linked to technology, expertise, resources, industrial experience, etc.

IPBES
The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. A global and independent science platform established in 2012.

IPPC
The Intergovernmental Panel on Climate Change, established in 1988.

FME
Centre for Environment-friendly Energy Research funded by the Research Council of Norway.

Horizon 2020
The EU Framework Programme for Research and Innovation for the 2014–2020 period. Horizon 2020 is the world's largest research and innovation programme with a budget of EUR 70 billion over seven years.

IEA
The International Energy Agency

7.8

Appendix 8: Stakeholders represented at input meetings and in other dialogue

Representatives from the following companies and institutions have participated in and contributed input to the strategic working meeting on offshore wind:

- Agder Energi
- Aker Offshore wind
- Aker Solutions
- Amon
- Baker Hughes
- BKK
- Deep Wind Offshore
- DNV
- Dof Subsea Norway
- Dr. Tech. Olav Olsen
- Energi Norge
- Energy Innovation
- Enova
- Equinor
- FME NorthWind
- Forskningsrådet
- Fred. Olsen Green Power
- Fred. Olsen Renewables
- GCE Node
- GCE Ocean Technology
- Giek
- Hafslund Eco
- HAV Design
- IFE
- JUS
- Lyse
- Microsoft
- NHH
- NORCE
- Norconsult
- NorSea Group
- Norsk Eksportkreditt
- NORWEA
- NORWEP
- NTNU
- NVE
- OED
- Seagust
- SINTEF
- Statkraft
- Statnett
- Total
- UIB
- UiO

Representatives from the following companies and institutions have participated in and contributed input to the strategic working meeting on hydrogen:

- Agder Energi
- Aker Carbon Capture
- Aker Clean Hydrogen
- Akershus Energi
- ASKO
- Avinor
- CICERO
- DNV
- Energi Norge
- Enova
- Equinor
- Forskningsrådet
- Gassco
- Gassnova
- Gen2Energy
- Greenstat
- HAV Design

- Horisont Energi
- Høgskulen på Vestlandet
- Hystar
- IFE
- Maritime Cleantech
- NHH
- NORCE
- Norconsult
- Norges Rederiforbund
- Norled
- Norsk Hydro
- Norsk Hydrogenforum
- NTNU
- NVE
- OED
- Oljedirektoratet
- RENERGY
- Safetec
- Shell
- SINTEF
- Sjøfartsdirektoratet
- Statkraft
- UIB
- Varanger Kraft
- Viken Fylkeskommune
- ZEG Power

Representatives from the following companies and institutions have contributed input to the strategic working meeting on infrastructure:

- ABB
- Advokatfirmaet Kluge
- Agder Energi
- Agder Energi Nett
- Aibel
- Aker Carbon Capture
- Aker Offshore wind
- Aker Solutions
- Altera Infrastructure
- Asplan Viak
- Benestad
- BKK Nett
- CapeOmega
- CINELDI
- Den Norske Turistforening
- DWO Energi Norge
- Equinor
- FME MoZEES
- FME NorthWind
- Forskningsrådet
- Fortum Oslo Varme
- Gassco
- Gassnova
- GCE Ocean Technology
- Haugaland Kraft Nett
- Høgskulen på Vestlandet
- Hydrogenforeningen
- Hynion
- IFE
- Linea
- LO
- Lyse elnett
- Mørenett
- Nexans Norway
- Norsk Industri
- Norce
- Norwegian Offshore Wind
- OED
- Petroleumsdirektoratet
- Reinertsen New Energy
- Sintef Energi
- Skagerak Nett
- Smartgridsentret
- Statnett
- Tensio
- Trønderenergi
- UIB

Representatives from the following companies and institutions have contributed input to the strategic working meeting on hydropower:

- Agder Energi
- BKK
- EDR Medeso
- Eksportfinans
- Energi Norge
- Forskningsrådet
- Gassnova
- Hafslund E-CO
- Hydro
- FME HydroCEN
- Miljødirektoratet
- Multiconsult
- NINA
- NORCE
- Norconsult
- Norske lakseelver
- NORWEP
- NTNU
- NVE
- OED
- Rainpower Scatec

- SINTEF
- Sira-Kvina
- Skagerak Energi
- Småkraftforeningen
- Statkraft
- SWECO
- Troms Kraft
- UIB

Representatives from the following companies and institutions have contributed input to the strategic working meeting on digitalised and integrated energy systems:

- ABB
- Agder Energi
- Aidon
- Asplan Viak
- Avinor
- BKK Varme
- Cognite
- Dalane Energi
- Elvia
- Energi Norge
- Enova
- Entelios
- EPOS
- Equinor
- FME CINELDI|
- FME NTRANS
- Forskningsrådet
- Fortum Varme Oslo
- Forus Næringspark
- Gassnova
- Glitre Energi Nett
- Heimdall Power
- Hydro
- IFE
- Ishavskraft
- Kongsberg Digital
- KTH
- Kvitebjørn varme
- Lede
- Lyse
- Microsoft
- NHH
- Nodes
- NORCE
- Norgesnett
- Norsk Fjernvarme
- NVE
- Siemens
- SINTEF
- Smart Innovation Norway
- Smartgridsenteret
- Statkraft
- Statnett
- Tensio
- Tibber
- UIB
- UiO
- USN
- ZERO

Representatives from the following companies and institutions have contributed input to the strategic working meeting on decarbonisation of energy resources and the industrial sector:

- Aker Carbon Capture
- Alcoa
- Baker Hughes
- Cicero
- CMR
- Elkem
- Energi Norge
- Enova
- Equinor
- Eydeklyngen
- FME NCCS
- FME HighEff
- Forskningsrådet
- Fortum Oslo Varme
- Gassnova
- Heatwork
- IFE
- JUS
- NHH
- NORCE
- Nordic Electrofuel
- Norges Lastebileierforbund
- Norled
- Norsk E-fuel
- Norsk Industri
- OED
- Oljedirektoratet
- Rederiforeningen
- Shell
- SINTEF
- Statkraft
- Statnett
- UIB
- Ulstein
- Vår Energi
- Yara

Representatives from the following companies and institutions have contributed input to the strategic working meeting on batteries:

- ABB
- Beyonder
- Cerpotech
- Corvus Energy
- Elkem
- Energi Norge
- Enova
- Equinor
- Eydeklyngen
- Freyr
- Future Materials Katapult
- Glencore Nikkelverk
- Hydrovolt
- IFE
- Innovation Norway
- Lede
- Morrow Batteries
- NGU
- NORCE
- Norges Forskningsråd
- Norled
- Norsk Hydro
- Norsk industri
- NTNU
- OED Pixii
- Repack
- Siemens Energy
- SINTEF
- Skagerak Energi
- Skagerak kraft
- Statnett
- TioTech
- UIB
- Universitetet i Agder

Representatives from the following companies and institutions have contributed input to the strategic working meeting on offshore energy technologies:

- ABB
- Agder Energi
- Doxacom
- Energi Norge
- Enova
- Equinor
- Forskningsrådet
- GCE Ocean Technology
- Havforskningsinstiuttet
- Havyard
- Hav Design
- Høgskulen på Vestlandet
- IFE
- Kitemill
- Nexans Norway
- NORCE
- Norwep
- Ocean Sun
- OED
- Oljedirektoratet
- Rederiforeningen
- RENERGY
- SINTEF
- Statnett
- UIB
- Wilhelmsen Group
- ZERO

Representatives from the following companies and institutions have contributed input to the strategic working meeting on solar energy:

- Agder Energi
- Akershus Energi
- Energi Norge
- Enova
- Equinor
- Forskningsrådet
- Høgskulen på Vestlandet
- IFE
- FME SuSolTech
- Inaventa Solar
- Multiconsult
- NHH
- NORCE
- Norconsult
- NorSun
- NTNU
- NVE
- OED
- Pixii
- REC Solar
- SINTEF
- Solcellespesialisten
- Solgrid
- Statnett
- UIB

Representatives from the following companies and institutions have contributed input to the strategic working meeting on bioenergy:

- Agder Energi
- Avinor
- Biogass Norge
- Biokraft
- Cambi
- Drivkraft Norge
- Enova
- Equinor
- Forskningsrådet
- FME Bio4Fuels
- Gassnova
- Hyperthermics
- IFE
- NMBU
- NOBIO
- Norges Bondelag
- NORSUS
- OED
- Oplandske bioenergi
- Silva Green Fuel
- SINTEF
- Statkraft Varme
- Statnett
- Treklyngen
- UIA
- UIB
- Viken fylkeskommune

Representatives from the following companies and institutions have contributed input to the strategic working meeting on land transport:

- ABB
- Drivkraft Norge
- Everfuel
- Evig Grønn
- Forskningsrådet
- H2Cluster
- Høgskulen på Vestlandet
- Hynion
- IFE
- ITS Norway
- Jernbanedirektoratet
- NHO
- Nettpartner
- Norges lastebileier-forbund
- Norsk elbilforening
- Norsk Hydrogenforum
- Norwegian Hydrogen
- Ruter
- Scania
- SINTEF
- UIB

Dialogue meetings:

- CGER
- Eksfin
- FME MoZEES
- FME SuSolTech
- EVINY
- IFE
- IEA Innovation Global Network
- Geothermal Energy Nordic
- NHH
- NINA
- NMBU
- Nasjonalt kompetansesenter for smartgrid
- Norsk elbilforening
- Norsk Fjernvarme
- Norsk Industri
- Norsk Solenergiforeningen
- NORCE
- NORWEA
- NORWEP
- NSM
- NVE-RME
- Nysnø
- SITNEF
- UIB
- UIO
- Forskningsrådets porteføljestyre for Transport, Energi og Lavutslipp

Dialogue and coordination with other 21 processes:

- OG21
- Prosess21
- Maritim21
- Transport21
- Digital21
- Skog22

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