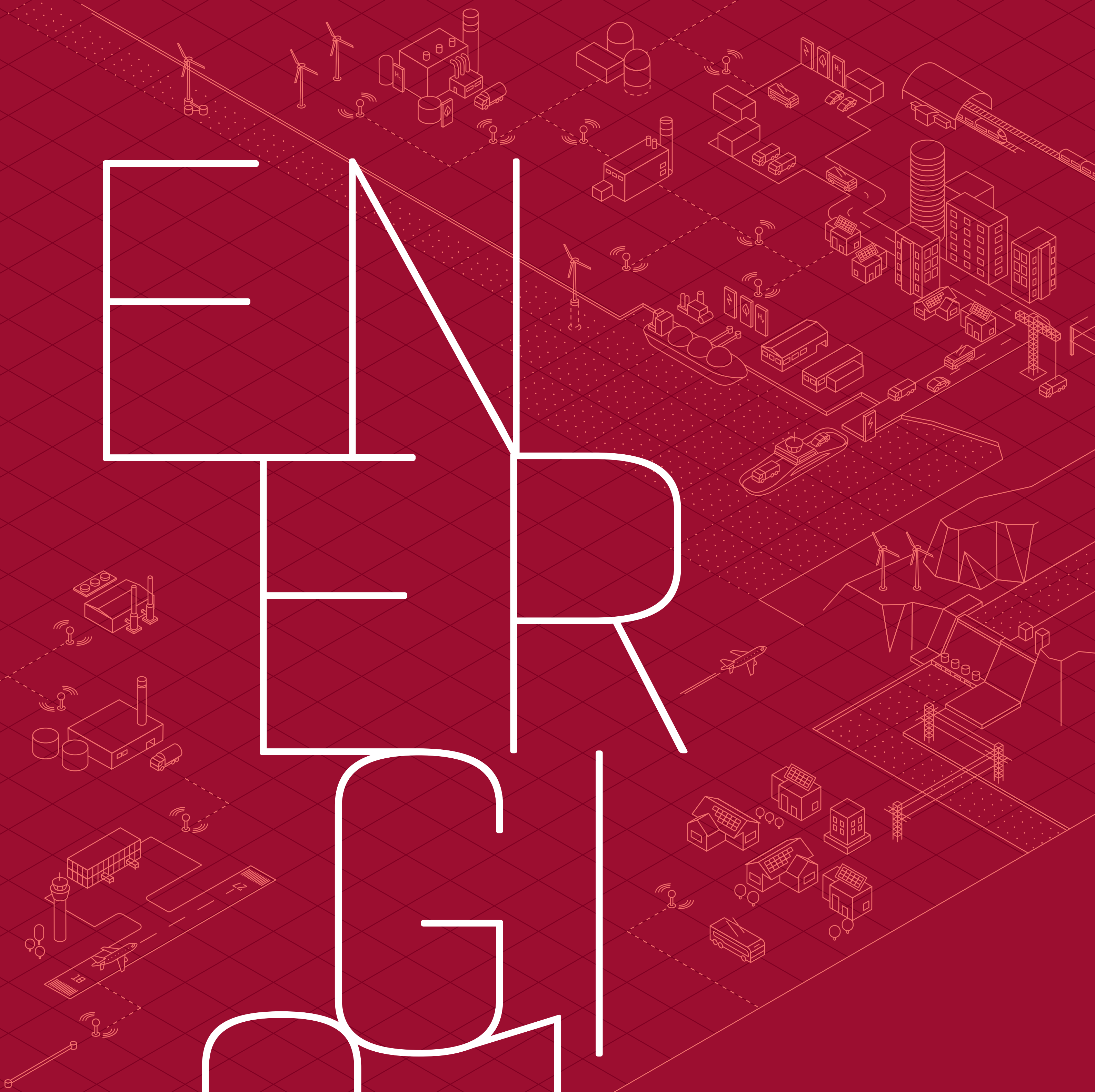

ENERGI 21

STRATEGY 2018

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

energi21

CHAPTER PHOTO CAPTIONS

Chapter 1: Turbine runner at Tokke hydropower plant.
Photo: Statkraft

Chapter 2: *Photo: Samuel Zeller on Unsplash*

Chapter 3: Spillway gates, Agder Energi. *Photo: Agder Energi*

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Chapter 5: Raggovidda wind farm, Varanger Kraft AS.
Photo: Bjarne Riesto

Chapter 6: X-ray analysis. *Photo: Elkem*

Chapter 7: Equinor, foundation at Dudgeon Offshore Wind Farm.
Photo: Eva Sleire

Chapter 8: Water vortex intake at Nedre Røssåga hydropower plant.
Photo: Statkraft

ENERGI21

Strategy 2018

Preface

The Energi21 board presents in this document the fourth national strategy for research, development, demonstration and commercialisation of new, climate-friendly energy technology. The Energi21 mandate has now been expanded to encompass energy technologies in the transport sector.

The strategy is targeted towards value creation and efficient utilisation of resources in the energy sector through investment in R&D activities and new technology to benefit society as a whole. Trade and industry have played a leading role in the strategy process, which has emphasised close cooperation with universities and research institutes.

Climate, security of energy supply, and competitiveness are the main drivers of the development of the national and international energy sector. Digitalisation and a focus on consumers will play a central role in the years to come. Interaction between technology and society, as well as assessments of sustainability and resource efficiency, will also become more important. Norway's energy situation is unique in that it has a power supply almost exclusively based on renewable forms of energy, excellent access to additional renewable energy resources, a well-established energy processing industrial sector, and plentiful oil and gas resources that can be processed into clean energy. Norway also has a unique basis in electrification of the transport sector that can be further expanded, and the country has a central position in maritime transport.

The Energi21 strategy addresses nationwide objectives for resource utilisation and development of an efficient, flexible energy system. It also deals with objectives for enhancing both Norwegian industrial competitiveness and Norwegian expertise to succeed in international energy markets.

Internationally, investment in R&D is rising sharply in the energy and transport sector and this represents a major component of the EU initiatives within the energy union and under the EU framework programme for research and innovation, Horizon 2020. It will be important for the Norwegian research community and trade and industry to maintain a strong foothold in research cooperation within the EU.

In the view of the Energi21 board, this strategy lays the foundation for a more targeted increase in public and private investments in RD&D towards new climate-friendly energy and transport technology. A long-term, concentrated research drive will yield major advances in terms of effectively utilising national energy resources, developing a digitalised, flexible and efficient energy system, and expanding an internationally competitive industrial sector.

We would like to take this opportunity to thank everyone who has provided input and taken part in the process, making it possible to draw up a broadly supported, integrated national R&D strategy for new climate-friendly energy technology. It is our hope that the recommendations provided here will be followed up and implemented by the Norwegian authorities and national industry.

Oslo, June 2018

Sverre Aam
Chair of the Energi21 board

Summary

The Energi21 board presents in this document the fourth national strategy for research, development, demonstration and commercialisation of new, climate-friendly energy technology. The strategy is targeted towards value creation and efficient utilisation of resources in the energy sector through investment in R&D activities and new technology to benefit society as a whole. Trade and industry has played a leading role in the strategy processes, and close cooperation with universities and research institutes has been emphasised.

The Energi21 strategic body was established by the Ministry of Petroleum and Energy in 2008 and is designed to promote coordinated, efficient and targeted efforts in research and technology for the energy sector. The strategic body has a permanent board with representatives from energy companies and suppliers, industry associations, research and educational institutions, and the authorities. Thematically, its mandate encompasses the entire stationary energy system as well as energy technologies for transport purposes. This includes land-based and maritime transport as well as aviation.

The Energi21 strategy is to be aligned with Norwegian energy policy, and the mandate sets out three primary objectives to which the strategic recommendations and energy-related research are to contribute:

Objective 1
Increased value creation on the basis of national energy resources and utilisation of energy;

Objective 2
Energy restructuring with the development of new technology to limit energy consumption and greenhouse gas emissions while efficiently producing environment-friendly energy;

Objective 3
Development of internationally competitive industry and expertise in the energy sector.

Activities carried out in Norway's research and innovation system should reflect the key areas set out in the Energi21 strategy. This applies to instruments used by the Research Council of Norway, Gassnova, Enova, the Norwegian Water Resources and Energy Directorate (NVE) and Innovation Norway.

Radical changes in the energy system – great need for research and innovation

The global energy system will be undergoing radical changes in the years ahead. In all likelihood, climate-friendly energy systems of the future will become more digitalised and more influenced by consumers' choices than is currently the case. Both the individual and society as a whole are important driving forces for the integration and realisation of new technologies and solutions. Consumers and consumer behaviour will play a key role in determining the future earning potential of industry actors.

There are enormous challenges to overcome and substantial restructuring is called for in order to meet national and international targets for sustainability and greenhouse gas reduction. Energy system development also holds a great potential for global and national value creation. Norway has a sound basis for future value creation based on its energy resources, power system and industrial experience. These factors will play a pivotal role in safeguarding the future security of supply, capitalising on opportunities for the transition to a low-emission society, and not least developing technology and services for domestic and international markets.

It will be increasingly important to obtain system-oriented insight and understanding of how the various technologies and solutions are interrelated and the extent to which they are mutually dependent. As energy systems become more digitalised and integrated, the energy sector's research and innovation agenda will have to adapt accordingly. Using multidisciplinary approaches that better exploit the synergies between disciplines and business sectors will be essential going forward.

The energy system is one of society's most important infrastructures. Solutions to future societal challenges will encompass both new and immature energy technologies and require large-scale research and development activity.

Key areas set out in the Energi21 strategy

In its fourth national research strategy, the Energi21 board recommends a substantial increase in energy technology investment and efforts targeting the following key areas:

- Digitalised and integrated energy systems
- Climate-friendly energy technologies for maritime transport
- Solar power for an international market
- Offshore wind power for an international market
- Hydropower as the backbone of the Norwegian energy supply
- Climate-friendly and energy-efficient industry, including Carbon Capture and Storage (CCS)

The key area "Digitalised and integrated energy systems" is an overall priority area by virtue of its crucial role in the future security of supply, integration of climate-friendly energy technologies and value creation in society. All six of the key areas hold great potential for value creation in resource utilisation and further development of a supplier industry for national and international energy markets.

DIGITALISED AND INTEGRATED ENERGY SYSTEMS

The key area of "Digitalised and integrated energy systems" encompasses all energy-related infrastructures and the interplay between them. This includes a range of issues relating to physical infrastructure, digitalisation, society, markets and consumers. Norwegian industrial actors and research groups possess a wide range of expertise in a number of areas involved in digitalised and integrated energy systems, such as energy infrastructure for transport, power electronics, smart grid solutions and more.

The Energi21 strategy supports the industry's ambitions to develop digitalised and integrated energy systems with reliable security of supply, low greenhouse gas emissions, and effective integration of new technologies for production, consumption and storage. Developments will also accommodate new business models, help end users to become actively involved, and ensure more effective operation and maintenance of the systems.

Some important research areas

- Integrated development of the energy systems, including the systems technology and market-related implications of changes in energy production, transmission and consumption.
- Digitalisation in the energy systems, including ICT/ cybersecurity and vulnerability.
- Cost-effective development of the energy systems with application of new energy technologies.
- Output issues and dynamic systems modelling.
- Effective targeting of policy, funding instruments and market design.
- Knowledge about society, societal structures and human behaviour.
- Business models for flexibility services and different types of market solutions.
- Sustainability, resource efficiency and environmental perspectives.

HYDROPOWER AS THE BACKBONE OF THE NORWEGIAN ENERGY SUPPLY

Hydropower plays a pivotal role in the Norwegian energy system and contributes significantly to the value creation and future potential of society to deliver energy and power to the national and international markets. Norwegian hydropower has a smaller climate footprint than other renewable energy technologies and its reservoir capacity holds major energy storage potential. Hydropower is critical for Norway's ability to develop a virtually zero-emission energy system while maintaining its security of supply. National hydropower resources can play a vital role in the transformation to a low-emission society in Norway and internationally. Norwegian industrial actors and research groups possess some of the world's leading hydropower expertise, which provides an excellent basis for the export of Norwegian solutions and services. It is essential to ensure that Norway maintains and further develops its hydropower expertise.

The Energi21 strategy supports the industry's ambitions to work to ensure that hydropower has a clearly defined role in the transition to a low-emission society and that the value of Norwegian hydropower increases by better utilising the flexible storage facilities of reservoirs in the context of national and European power systems.

Some important research areas

- Effects of climate change on precipitation, inflow and the environment; analytical and computer models.
- Tunnelling and underground facilities, including drilling and turbine technology.
- Digitalisation as a tool for increasing the competitiveness of hydropower.
- ICT/cybersecurity: ramifications of expanded digitalisation.
- Flexibility and balancing: market design and the value of flexibility.
- Environment-friendly, cost-effective construction and further development of hydropower facilities.
- Consequences of short- and long-term balancing: turbine and electromechanical stress, environmental impacts, biodiversity.
- Systems perspective: importance and role of hydropower in future energy systems.
- European energy policy: trends and ramifications for Norwegian hydropower.

- Hydropower's significance for value creation in society.

SOLAR POWER

Norway has an extensive technology and competency base in solar power, with major potential for further developing a competitive industry. Deliveries will mainly be to an international solar power market in rapid growth, and Norwegian actors are well equipped to strengthen their market positions. The Norwegian solar power industry already accounts for significant national value creation and export volume. This industry is built on the world-leading expertise in material and process technology of Norwegian research groups and industrial players. Norwegian actors have also gained an international position in development and operation of large-scale solar power plants. Norwegian industrial actors are also making strides in the relatively new area of floating solar power, where a combination of maritime and solar expertise puts them in a good position to succeed.

The Energi21 strategy supports the industry's ambitions to further develop a dynamic Norwegian solar energy cluster that is competitive internationally and can gain prominence in emerging markets. The Norwegian solar power cluster seeks to become a leader in quality and innovation and to develop new business models and solutions that combine solar power, smart control and digitalisation.

Some important research areas

- Development and demonstration of processes for future production of materials for cost-effective, environment-friendly silicon-based solar cells, as well as development of future materials for solar power. High-efficiency, cost-effective and environment-friendly silicon-based solar cells.
- Technology, concepts and solutions for floating solar power.
- Technology, concepts and solutions for building-integrated photovoltaics.
- Concepts and systems for reducing operational and maintenance costs and increasing energy conversion ratios for solar facilities.

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

Across Fjærland fjord, Statnett. *Photo: Johan Wildhagen*

OFFSHORE WIND POWER

There is significant potential for further developing an internationally competitive Norwegian offshore wind power industry. Offshore wind power is already Norway's largest renewable energy export industry, and Norwegian companies are well equipped to strengthen their market positions in this rapidly growing market. The world-leading expertise of Norwegian industrial actors and research groups in the petroleum and maritime sectors provides an excellent basis for developing technologies and services for offshore wind power. Norway
got an early start in floating offshore wind turbines, which affords Norwegian companies opportunities to compete in that market. The Energi21 board believes there is major, long-term potential for utilising Norway's substantial offshore wind resources for energy production.

The Energi21 strategy supports the industry's ambitions to further develop a Norwegian supplier industry for technology and services in the offshore wind power market, and to double the market share of Norwegian suppliers by 2030. In addition, companies in this field are seeking to position themselves early in the market development for floating offshore wind power. There are ambitions in the long term to utilise Norway's offshore wind resources and establish energy production on the Norwegian continental shelf.

Some important research areas

- Optimal foundation designs for floating and fixed-foundation turbines.
- Cost-effective, time-saving assembly and installation of offshore wind farms.
- Concepts and systems for reducing operational and maintenance costs and increasing energy conversion ratios;
- Digital solutions for offshore wind power.
- Efficient concepts for marine logistics (heavy maintenance) and robust solutions for access.
- Resource mapping and modelling – accurate forecasts currents for waves.
- Concepts and systems for reliable electric infrastructure (offshore subsea solutions).
- Offshore wind power's environmental and societal impacts.
- Multi-use maritime platforms with interaction between aquaculture, petroleum and offshore wind power activities.

CLIMATE-FRIENDLY AND ENERGY-EFFICIENT INDUSTRY, INCLUDING CARBON CAPTURE AND STORAGE (CCS)

There is considerable potential for emission cuts and improvements in energy efficiency in the industry sector, both in Norway and internationally. Norwegian industry and research groups are working actively on new emission abatement technologies in various fields, including energy efficiency, CCS, hydrogen and biomass.

Raising energy efficiency and implementing CCS are the two most effective ways to reduce emissions. Norwegian industry is world-leading in energy-efficient production from national resources, and together with Norwegian R&D groups has built up a knowledge base that will be useful in both national and international value creation.

Norway is playing a leading role globally in the field of CCS, which will be enhanced by public funding provided to achieve the Government's ambitions for full-scale CCS in Norway. A full-scale CCS project will create substantial commercial potential through the establishment of full-scale infrastructure for transport and storage of CO_2.

The Energi21 strategy supports the industry's ambitions to achieve substantial emissions cuts in industry by establishing full-scale CCS. The strategy also supports efforts to achieve technological breakthroughs in the use of hydrogen and biomass and utilisation of surplus heat for various purposes.

Some important research areas

- Improvement of processes, both incremental and ground-breaking.
- Technologies and methods for converting and upgrading surplus heat.
- Technologies and solutions for increasing hydrogen use/finding new areas of application for hydrogen in industry.
- Technologies and solutions for increased use of biomass.
- Hydrogen production from natural gas coupled with CCS.
- Cost-effective and energy-efficient CCS technologies with a minimum level of risk for industrial processes.
- CCS from industrial processes using biochar as a raw material (Bio-CCS). Utilisation of surplus heat for CCS.
- Long-term CO_2 storage.
- Digitalisation in industry, including sensor technology, continuous monitoring and analysis of large volumes of data.

CLIMATE-FRIENDLY ENERGY TECHNOLOGIES FOR MARITIME TRANSPORT

Norwegian actors got an early start in developing battery and hydrogen-electric propulsion for maritime transport. There are ample opportunities for testing and verification of new solutions in Norway's large domestic market for subsequent export to international markets. The maritime transport sector must be restructured in order to achieve emissions cuts, and large-scale deployment of climate-friendly energy technologies and alternative fuels such as electricity, hydrogen and biofuels will be necessary. Hybrid solutions using combinations of energy carriers will be essential for propulsion systems of future vessels. With its strong technology base and expertise in the maritime sector, materials and processes, Norway is in a good position to develop climate-friendly energy technologies for maritime transport.

The Energi21 strategy supports the industry's ambitions to take the lead in technologies and systems for battery and hydrogen-electric propulsion for maritime transport, and to achieve significant national emissions cuts as a result of access to climate-friendly energy and propulsion solutions.

Some important research areas

- Battery materials and systems and charging technology for electric vessels.
- Electrolysers, filling stations, and fuel cell technology and other core technology for hydrogen vessels.
- Biofuels for maritime transport.
- Automated solutions.
- Zero-emission hybrids using fuel cells, hydrogen and batteries for high-speed vessels and ferries.
- Emission-free maritime value chain including production, infrastructure and access to energy for climate-friendly energy technologies for maritime transport.
- Interdisciplinary research questions in the interface between maritime transport and the social sciences.

CONTINUE DEVELOPING A BROAD-BASED KNOWLEDGE PLATFORM

In addition to promoting the key areas set out in the Energi21 strategy, it is important to continue developing a broad-based knowledge and technology platform for the entire range of disciplines within the energy sector. No one knows for certain exactly which technologies will succeed in the future energy system or how quickly those technologies will be integrated. A dynamic knowledge platform provides greater leeway to adjust and adapt the direction of future research. In order to maintain a strong knowledge base and create opportunities for continued efforts, research activities in the following technology areas should be further developed: energy-efficient and smart buildings, hydrogen, bioenergy, carbon capture and storage (CCS), deep geothermal energy, climate-friendly energy technologies for land transport, climate-friendly energy technologies for air transport, land-based wind power, as well as the humanities, law and social science disciplines.

FULFILLING THE AIMS OF THE ENERGI21 STRATEGY

Fulfilling the aims of the Energi21 strategy will require involvement and effort from the business sector, research and educational institutions, and the authorities. Cooperation between these actors will be essential for achieving the Energi21 ambitions and ensuring that the necessary research activity is carried out. Unceasing focus on long-term objectives combined with effective action in the shorter term will be key to realising the ambitions. Business communities and industry must take part in knowledge and technology development by taking risks and investing time and capital in research and innovation activities. There will be a need for dynamic instruments and incentives that promote the efficient implementation of research activities, which in turn will provide rapid access to new knowledge, technology and solutions.

NORWEGIAN PARTICIPATION IN THE EU RESEARCH AND INNOVATION ARENA SHOULD BE EXPANDED

The Energi21 board recommends intensified efforts to influence EU research and innovation programmes in the aim of ensuring that initiatives on the EU research agenda address topics of common interest for the EU and Norway. Norway's positioning in the EU in the field of energy must be strengthened. There is a need to establish multiple bridgeheads, as Norway is an energy nation but not a member of the EU. Norwegian participation in the EU research and innovation arena is of prime importance for gaining prominence, raising the quality of research groups, contributing internationally recognised knowledge to the business sector, and enabling Norwegian research to be implemented in a European and international perspective. Internationally recognised expertise is a key to future competitive products, services and solutions.

IMPORTANT ACTIONS FOR REALISING THE ENERGI21 STRATEGY

1. Further develop a dynamic, unified framework of funding instruments to promote rapid innovation and results.
2. Increase the budget for research and innovation projects. The Energi21 board recommends an increase of NOK 480 million from current levels for the period 2019–2022.
3. Strengthen research and demonstration projects under Enova for commercialisation of research results.
4. Facilitate Norwegian participation in international research, testing and demonstration projects.
5. Further develop the PILOT-E scheme for enhanced supplier development. The Energi21 board recommends raising the budget by NOK 200 million.
6. Strengthen the funding instruments promoting innovation and renewal in the energy sector.
7. Ensure strategic cooperation between the ministries' industry-specific "21" strategy processes.
8. Establish innovative recruitment methods to ensure access to trained personnel and the necessary expertise.
9. Expand Norwegian participation in EU research and innovation programmes.

Statoil – Hywind Scotland mating of first wind turbine. *Photo: Kjetil Alsvik*

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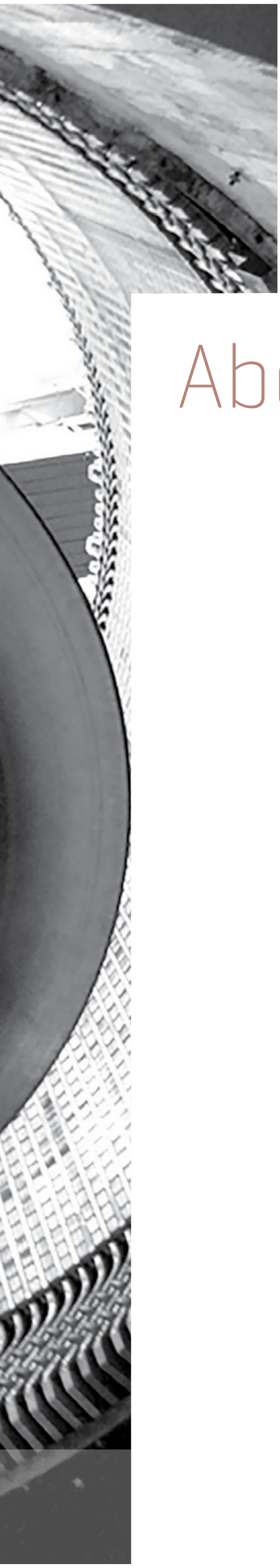


About Energi21

The Energi21 strategic body is an independent advisory body established by the Ministry of Petroleum and Energy in 2008. Energi21 provides advice to the authorities on the organisation of public allocations to research, both thematically and financially. The Ministry of Petroleum and Energy uses the Energi21 strategy as a basis for guiding its allocations to research, development, demonstration and commercialisation of new climate-friendly energy technologies. The Energi21 strategy is designed to promote coordinated, efficient and targeted development of knowledge and technology in the energy sector.

The Energi21 strategic body has a permanent board with representatives from energy companies, technology and service providers, industry associations, research and educational institutions, and the public agencies in the research and innovation system. The Energi21 board is appointed by the Minister of Petroleum and Energy. The members of the board are presented in Attachment 2 of this report.

Figure 1 below illustrates the position of Energi21 in relation to the funding agencies that promote the development of knowledge and technology in the energy sector, and where Energi21 recommendations are of relevance.

1.1

Subject areas set out in the mandate

The mandate from the Ministry of Petroleum and Energy stipulates guidelines for the activities of the Energi21 body and sets the priority focus areas and implementation measures for the strategy. The mandate is presented in Appendix 1. The Energi21 subject areas encompass the energy system's entire value chain (production, transmission, consumption) including CO_2 management and climate-friendly energy technologies for maritime, land-based and air transport. The transport segment includes energy supply for the transport sector and energy technologies used in power/propulsion solutions for the various modes of transport. The mandate also encompasses emissions reduction measures in industry. Solutions to raise energy efficiency in buildings and industry are considered part of the value chain for the stationary energy system.

1.2

Industry-oriented strategic processes based on wide-ranging involvement

This strategy is the result of detailed strategic processes with the extensive involvement of trade and industry, research and educational institutions and the authorities. This involvement is absolutely critical for the quality and relevance of the work and the ownership of the strategy's recommendations. Cooperation between the actors has been of key importance in the planning and implementation of the Energi21 body's strategic processes.

Nearly 300 participants from various thematic and technological areas have taken active part in the strategic process, as members of the reference group for the Energi21 external factors assessment, participants in the Technology Target Areas (TTA) working groups for land-based and maritime transport, and contributors in the strategic working meetings. The Energi21 body has also had a number of bilateral dialogue meetings with stakeholders from the research community and the business sector. Additionally, this strategy document was circulated for public consultative review, during which many actors provided detailed factual input regarding the strategy's content and focus. There has been widespread interest, effort and willingness to contribute in the strategic processes, and the resulting Energi21 strategy is the product of this valuable knowledge input.

Attachment 7 lists the individuals who actively participated in Energi21 strategic processes.

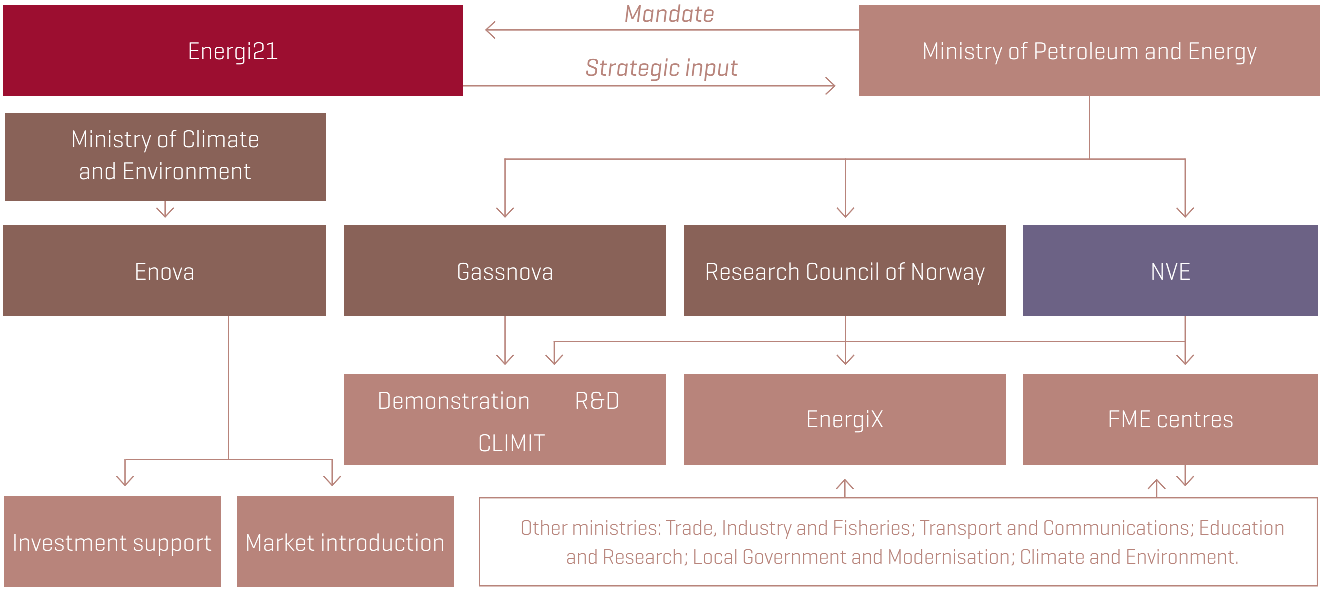


Figure 1 The organization of the energy research under the Norwegian Ministry of Petroleum and Energy.

1.3

Energi21 vision

According to the Energi21 body, Norway has a unique and valuable position in the energy sphere. Norway has a sound basis for future value creation based on its energy resources, power system and industrial experience. These factors will play a pivotal role in safeguarding the future security of supply, capitalising on opportunities for the transition to a low-emission society, and not least developing technology and services for domestic and international markets. The Energi21 vision highlights this potential for value creation. Achieving this vision will require a concentrated research drive to develop new climate-friendly energy-related knowledge and technology.

Energi21 vision
Norway – a climate-friendly energy nation
An international supplier of energy, power, technology and knowledge

1.4

Strategic objectives

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 . The framework of objectives established for Energi21 harmonises with the authorities' targets for energy-related research activities. These objectives lay the foundation for the Energi21 strategic recommendations. The strategy's priority focus areas are of great importance in achieving the objectives.

Energi21 – Strategic objectives

Energy-related R&D activities are to promote the following objectives

Objective 1: Increase value creation on the basis of national energy resources and utilisation of energy

Utilisation of national energy resources currently provides significant value creation in society and will continue to be important in the future. There is major resource potential as well as promising opportunities for satisfying national energy needs, supplying energy and system services internationally and developing technology products where renewable energy input is an important factor in the production process.

Objective 2: Facilitate energy restructuring with the development of new technology to limit energy consumption and greenhouse gas emissions while efficiently producing environment-friendly energy

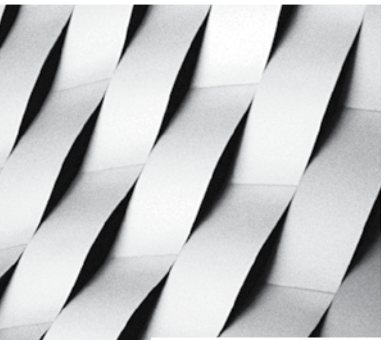
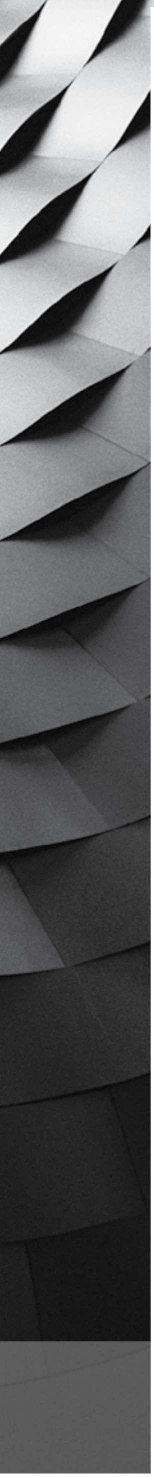
Energy restructuring comprises the phasing out of fossil energy sources in the energy system and phasing in of energy- and climate-efficient solutions such as new renewable production capacity, greater energy efficiency and enhanced flexibility. Energy restructuring also encompasses the implementation of climate-friendly energy technologies for transport and emissions-reducing technology and solutions for industry.

Objective 3: : Develop internationally competitive industry and expertise in the energy sector

Norway has an extensive technology and competency base for the energy sector, which puts the Norwegian business sector in a good position to gain a foothold in emerging energy-related markets, both nationally and internationally. It is important to capitalise on Norway's advantages to develop a business sector in climate-friendly energy technologies and solutions. Access to knowledge is a vital competitive advantage for Norwegian business, and dynamic educational and research environments are critical factors for recruitment and innovation in the energy sector. It is essential to give priority to measures to cultivate strong, competitive, internationally recognised research and educational communities that are well-positioned for international research cooperation.

[1] *Mandate from the Ministry of Petroleum and Energy to the Energi21 body*
[2] *Such as delivering power and flexibility*

2

Energy systems of the future

The global energy system will be undergoing radical changes in the years ahead. In all likelihood, climate-friendly energy systems of the future will become more digitalised and more influenced by consumers' choices than is currently the case. Both the individual and society as a whole are important driving forces for the integration and realisation of new technologies and solutions. Consumers and consumer behaviour will play a key role in determining the future earning potential of industry actors.

It will be increasingly important to obtain system-oriented insight and understanding of how the various technologies and solutions are interrelated and the extent to which they are mutually dependent. As energy systems become more digitalised and integrated, the energy sector's research and innovation agenda will have to adapt accordingly. Using multidisciplinary approaches that better exploit the synergies between disciplines and business sectors will be essential going forward.

2.1

Main drivers of development

The key drivers of future development of the energy system will be climate and environmental considerations, security of supply and economic factors. In particular, it is the balance and interaction between these three drivers that will be pivotal for how the system evolves. In addition to this, the rapid developments in digitalisation and artificial intelligence have major impacts on future energy and transport systems.

Climate and environmental considerations

Global climate policy is the fundamental driver for the development of energy systems. Targets for limiting human-induced climate change will continue to affect every aspect of the energy system, from the supply and consumption of energy to its transmission and storage. Global climate and environmental policies will have a significant impact on technology development, where political instruments have paved the way for the rapid development of renewable power-generating technologies. International emissions targets often require wide-ranging implementation of CCS technologies to capture emissions from fossil power generation and industrial activities, but this is still developing too slowly to achieve the targets set. The support for the Paris Agreement[3] will reinforce global climate and environmental policy.

Local pollution resulting from the use of fossil energy carriers for heating and transport is a major challenge in many cities. Solutions to local environmental problems typically involve implementing an assortment of measures. Some of the most important measures for energy restructuring include the use of energy from renewable sources to reduce emissions from fossil-based power plants; raising energy efficiency to reduce consumption of oil, coal and wood; and electrification of the transport sector. These measures are in keeping with the approach and need to invest in technological development set out in global climate policy.

Security of supply

Modern society is dependent on a reliable supply of energy. The energy sector's importance for society is growing, and an interruption of the energy supply can paralyse vital functions and processes. The energy system as a whole is a key infrastructure for general value creation in society, and safeguarding the security of supply is the energy industry's social mission and primary objective.

For Europe, which imports over 50 per cent of its overall energy consumed, security of supply is a key factor in energy policy development. The transition from fossil fuels to renewable energy carriers is therefore another important step towards reducing Europe's import dependence and ensuring its security of supply.

For Norway, which is not import-dependent, there is a different dimension to security of supply that is more important, namely, ensuring that the energy system can deliver energy when we need it. The energy system is more complex than other infrastructures in society. An immediate balance must be constantly secured between generation and consumption in the power system. Anticipated changes to come in the energy and transport system make it necessary to develop innovative technologies and solutions to maintain security of supply. Electrification of the transport sector and greater input of renewable and intermittent solar and wind power are examples of trends that pose challenges to how the system operates and necessitate measures to maintain security of supply.

Economic factors

Most countries give high priority to delivering energy to residents at a reasonable price. Keeping energy prices reasonable and ensuring security of supply are also important for ensuring competitiveness in the business sector.

An important objective for the transition to a low-emission society is to implement cost-effective measures. Achieving this means targeting efforts towards the development and design of effective markets, business models, regulatory frameworks and incentive schemes.

Economic growth is a goal that all economies share, but unless there is a strong focus on energy efficiency this can lead to a global increase in energy consumption. Electricity will gradually come to represent a greater share of energy consumption. The IEA World Energy Outlook 2017 estimates in its scenarios that demand for energy will drop somewhat in highly developed economies such as Europe, Japan and the US, while it is projected to grow in regions undergoing strong industrial development, such as India, Southeast Asia, Africa, the Middle East and Central and South America. The projected global increase in demand for energy in 2040 (compared to current figures) varies from 2.4 per cent in an environment-friendly scenario that meets the targets set out in the Paris Agreement, to 27.8 per cent in a less environment-friendly scenario, to 40.3 per cent in a scenario that continues with current policies.

ABB and Formula E Partner to write the future of e-mobility. *Illustration: ABB*

Norway additionally faces a restructuring in which petroleum activities are reduced in the long run and other industries must grow to maintain value creation. The bulk of growth in other industries will occur on the mainland and require more electricity than the petroleum industry currently does.

Digitalisation means that many more physical components (in the generation, transmission and end consumption of energy) will be equipped with sensors to measure, among other things, physical parameters related to energy use and the condition of the component. The sensors will be interconnected within the grid using two-way communication. These data will be compiled and analysed, and control signals will be returned to optimise energy use and more. The digitalised system will dramatically improve access to data, which in turn opens up new opportunities for reliable analyses and sound decision-making. This will provide energy companies with new and improved opportunities for efficient operation (enhanced utilisation of capacity, demand-side management and more cost-effective investments). Data processing and storage will become cheaper and more accessible due to e.g. cloud-based solutions. Software and methodology for analysing large amounts of data (including artificial intelligence, machine learning, pattern recognition and more) are advancing rapidly and becoming available for new applications.

Digitalisation and artificial intelligence

Technology development in digitalisation and artificial intelligence has advanced rapidly in recent years and may lead to fundamental changes in the operation and management of the energy system. Increased digitalisation also has i mplications for operating and further developing the existing value chains for energy. Firstly, new digital tools will promote more efficient operation and maintenance of existing value chains. Digitalisation provides a more accurate basis for decision-making regarding investments and makes it possible to automate a number of decision-making processes. Secondly, digitalisation can simplify or open up opportunities for restructuring of the energy system. Furthermore, digitalisation can e.g. make it easier to take advantage of demand response, integrate larger amounts of intermittent renewable electricity generation, and ensure effective coordination between distributed energy resources (solar panels and batteries) and the rest of the energy system. This will generate a need to develop new business models, to understand consumer behaviour and needs, and to develop new market designs, new types of regulatory frameworks and new incentives. The contours of this are already emerging today. As digitalisation extends its reach and becomes a more integral part of the energy and transport system, the business sector will need to give increasing priority to cyber-security and personal privacy.

3 *The Paris Agreement was a result of the UN Climate Change Conference (COP21) in 2016. It entered into force when the largest carbon-emitting countries such as China, the US and India ratified it. Its aim is to keep the increase in global average temperature to below 2°C and to pursue efforts to limit the temperature increase even further.*

2.2

Anticipated developments along the energy system's value chain

In the long term, the force and direction of various elements of the key drivers related to climate and environmental considerations, security of supply and economic factors, along with developments in digitalisation, will bring about far-reaching changes in the energy and transport system. The table below provides an overview of the most important trends in supply, transmission, demand and storage of energy.

Development relating to the supply of energy involves comprehensive replacement of energy production based on fossil fuels to energy production based on renewable resources. Hydropower, solar power, wind power, biomass and potentially hydrogen will be important energy carriers. The cost of generating electricity from solar panels and wind turbines has declined dramatically in recent years, and this is expected to continue. Developments in technologies for bioenergy, hydrogen and energy storage are also expected to lead to reduced costs.

On the consumption side of energy, developments include major efforts to raise energy efficiency, particularly in buildings and industry. CCS will also play a vital role in achieving emissions cuts in industry. Reducing emissions in the transport sector will require restructuring from fossil fuels

Table 1: Trends in supply, transmission and storage, and demand for energy

Supply of energy	• More development of
	  • **Hydropower**
	  • **Fossil-based electricity generation w/CCS**
	  • **Offshore wind power**
	  • **Onshore wind power**
	  • **Solar power** (large-scale, distributed)
	• More energy production based on **biomass** (electricity, heat)
	• More energy production from other **renewable technologies** (wave, osmotic, geothermal, etc.)
	• More development and decommissioning of **nuclear power**
	• **Increased digitalisation of power generation** (measurement, control and artificial intelligence for optimal investments and operations & maintenance decisions)

Transmission and storage of energy	• Increased investments in:
	  • **Smart grids** (flexibility of consumption and across energy carriers, exploit data capture for investment and operations decisions)
	  • **Distributed storage** (battery, hydrogen, heat storage)
	  • **Large-scale storage** (pumped-storage, hydrogen production, compressed-air, battery storage farm, natural gas storage)
	  • **HVDC connections** between countries

Demand for energy	• Increased installation of **smart, automated energy management** (smart homes, commercial buildings and industry – measurement, control, artificial intelligence)
	• Increased utilisation of **large-scale demand response** (greater flexibility of industrial consumption
	• Larger investments in **CCS/U for industrial emissions** (incl. hydrogen production with CCS)
	• More utilisation of **biomass as industrial raw materials**
	• More utilisation of **hydrogen** as a reducing agent
	• Increased investments in **energy efficiency** (heat recycling) **in industry**
	• Increased investments in **energy efficiency in buildings** (technology integrated into building materials, efficient devices, LED)
	• Increased **digitalisation of transport** (self-driving vehicles, optimisation of infrastructure use, mobility as a service)
	• Increased restructuring towards:
	  • **Sustainable road transport** (battery-electric, inductive charging roads, hydrogen, biofuels incl. infrastructure)
	  • **Sustainable shipping** (battery-electric, hydrogen, advanced biofuels incl. infrastructure)
	  • **Sustainable air traffic** (advanced biofuels)

ASKO. *Photo: Solenergiklyngen*

to more extensive use of electricity, biofuels and hydrogen. Advances in battery technology will play a key role in determining which new renewable technologies will succeed.

Developments in the transmission and storage of energy will involve relatively large investments to enable the energy system to accommodate an increasing volume of intermittent production. This includes increased capacity of transmission cables to other countries, more large-scale and distributed storage, and investment in smart grids. Batteries will also play an important role in meeting the increasing need for energy storage, both distributed for residential use and on a larger scale for use in the grid.

2.3

Digitalised, flexible and integrated energy systems of the future

No one knows for certain exactly which technologies will succeed in the future energy system or how quickly those technologies will be integrated into the system. But it is relatively certain that a future energy system will be characterised by three elements in particular:

- *Continued rapid development of many different technologies in parallel*
  A number of new technologies can be expected to be implemented for multiple energy carriers (e.g. bioenergy, hydrogen and electricity) and throughout the entire value chain (from production to transmission and storage to consumption). Technology development is proceeding rapidly, and reduced costs open up opportunities for efficiency gains as these technologies come into use.
- *Energy systems will be digitalised, integrated and become more complex*
  Energy systems increasingly involve interaction between a growing number of technologies with different characteristics in a cost-effective, reliable manner. This complexity increases as energy systems become more integrated across national borders.
- *Consumers will become active participants*
  In current collective energy systems, consumers play a mainly passive role in the system. Advances in technology are enabling more consumers to play an active part by better controlling their energy consumption, producing and storing part of their energy needs themselves, and gaining a greater degree of interactivity with collective energy systems.

These three factors entail that an integrated systems perspective must be employed to succeed in expanding the energy system as cost-effectively as possible while at the same time adhering to more stringent requirements for security of supply. This will lead to a system that is flexible enough to accommodate fluctuations in production and consumption in the short and long term, and that efficiently integrates all the components of energy and transport systems. The diagram below shows what the digitalised, integrated energy and transport systems of the future may look like.

When it comes to its restructuring needs, Norway's point of departure differs from that of other countries due to its large proportion of hydropower in the energy system. Development in Norway will share some common features with development in other countries, but will also be different in many ways. It is therefore essential that the key areas of the Energi21 strategy support the European research agenda while also addressing and drawing on areas specific to Norway. Further, the research and innovation agenda for the energy sector must be adapted to the developments now emerging and incorporate multidisciplinary approaches that better exploit the synergies between disciplines and industries.

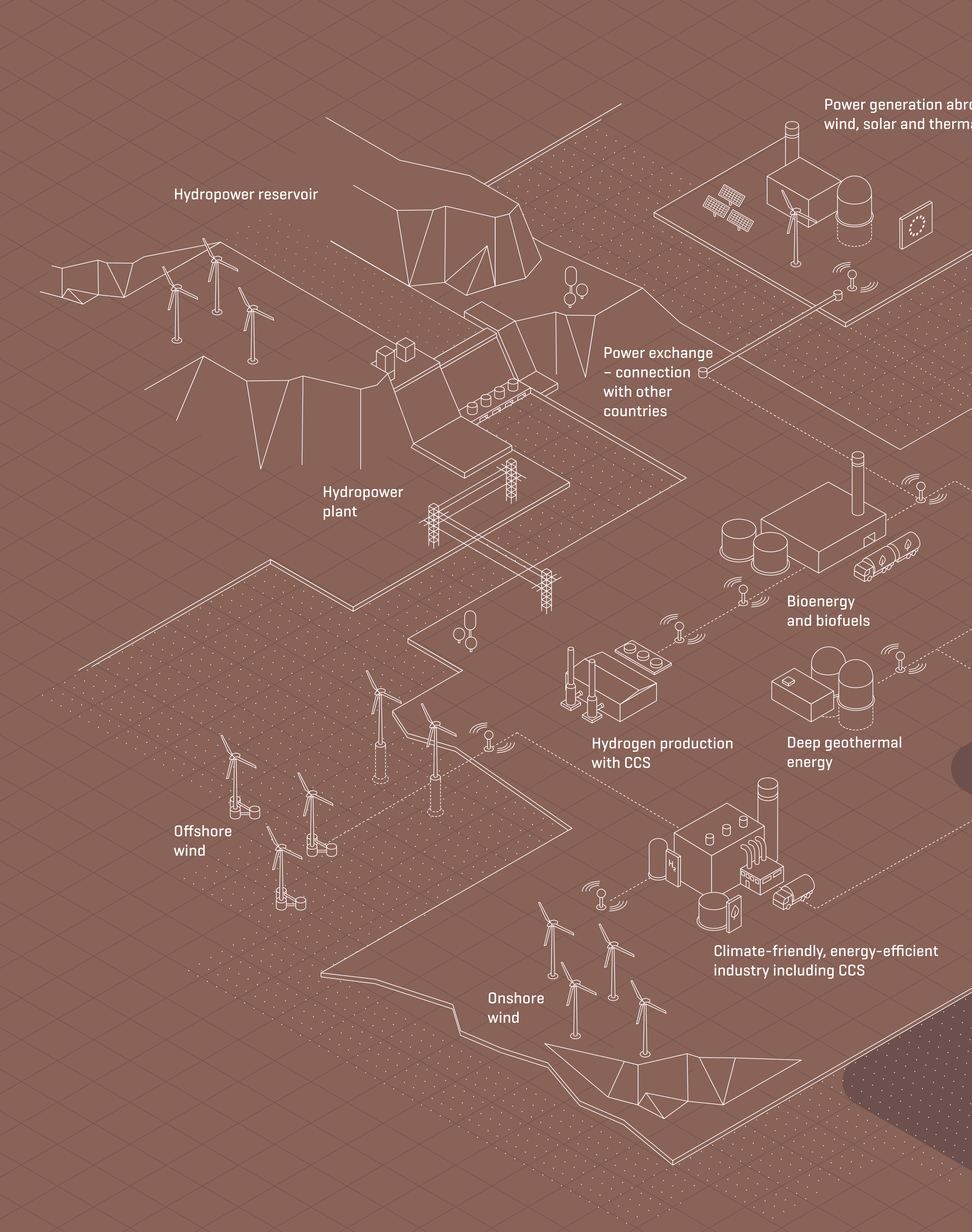
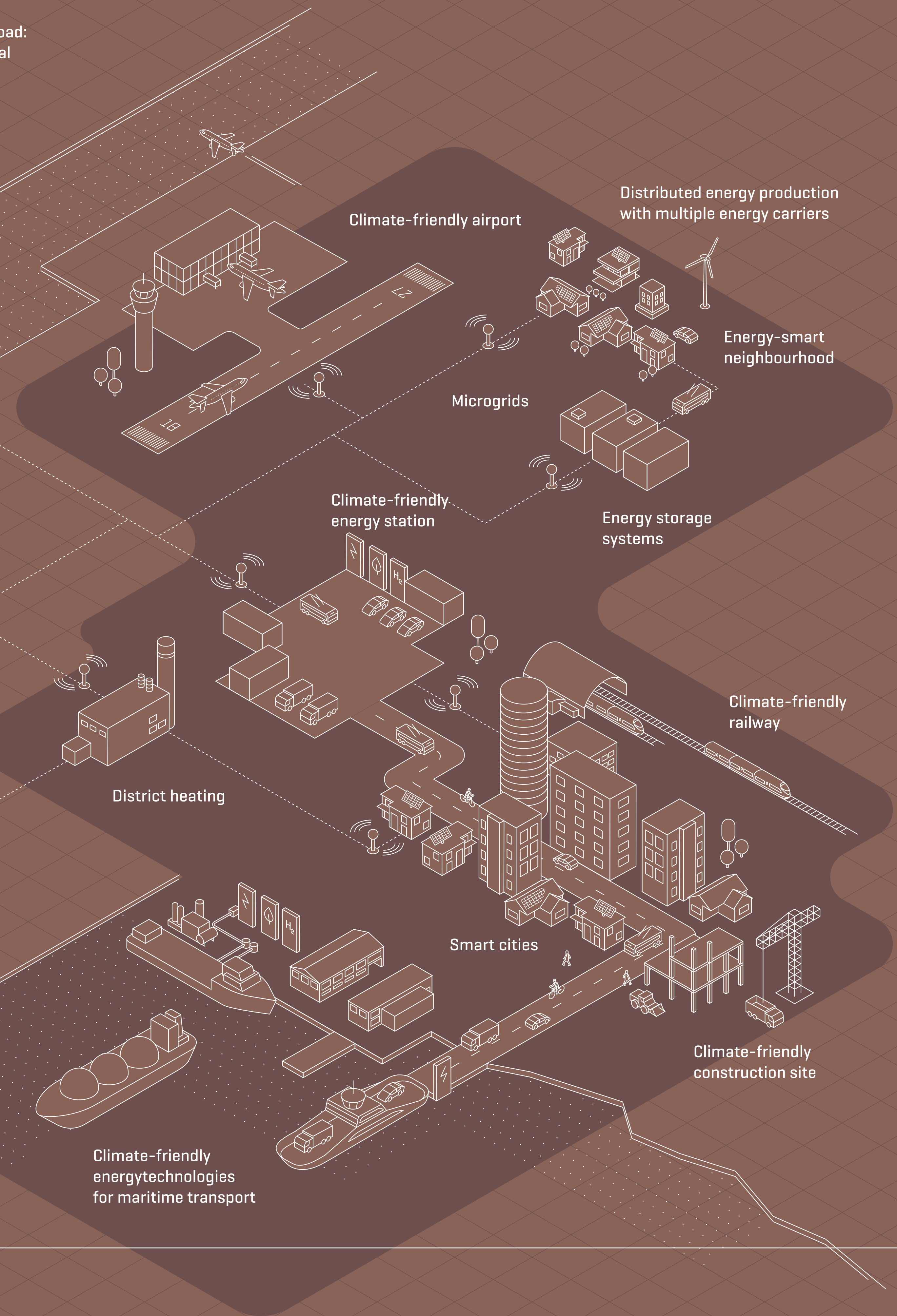


Figure 2.1 Illustration of the digitized, flexible and integrated energy systems of the future.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Distributed energy production
with multiple energy carriers
Energy-smart
neighbourhood
Microgrids
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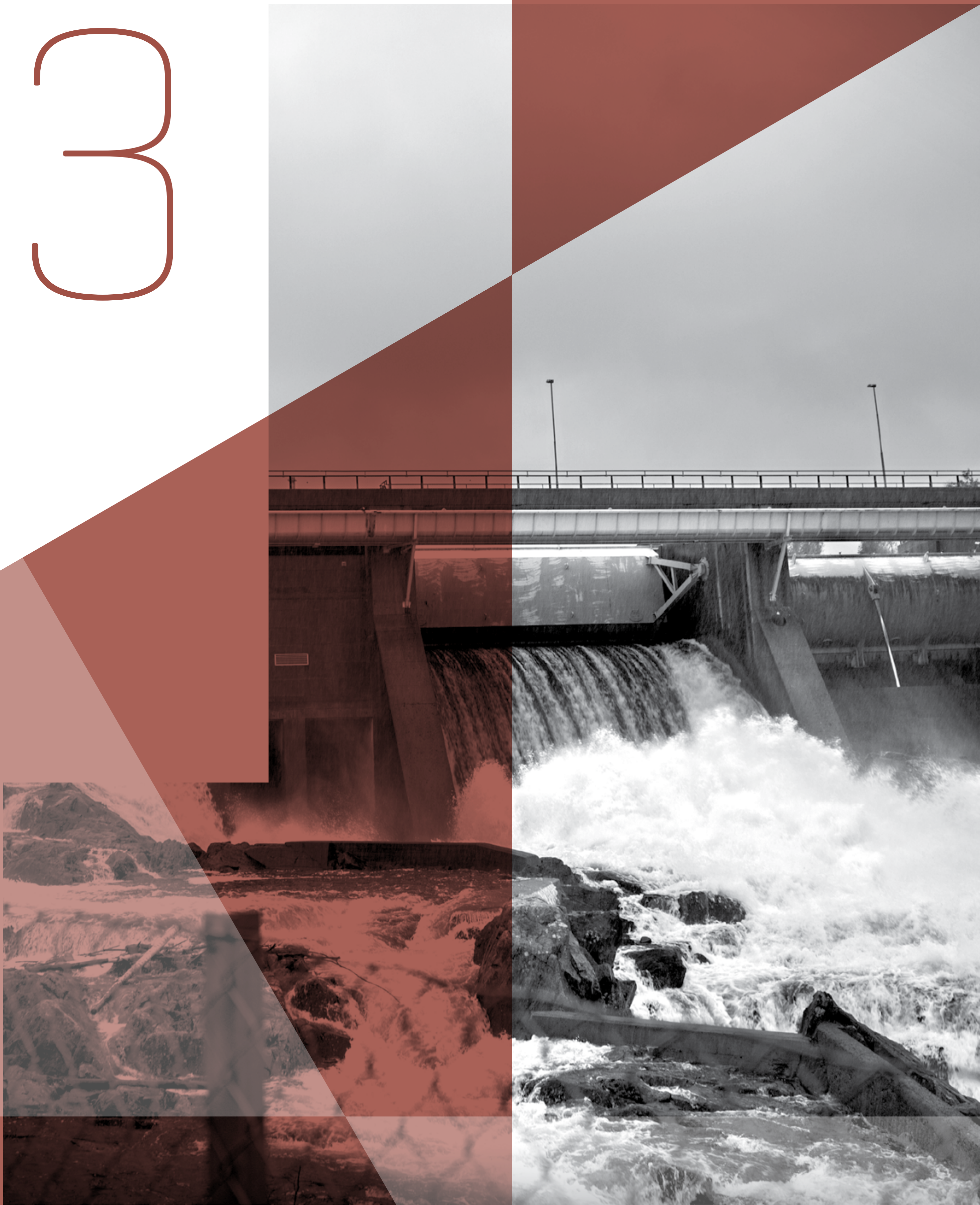
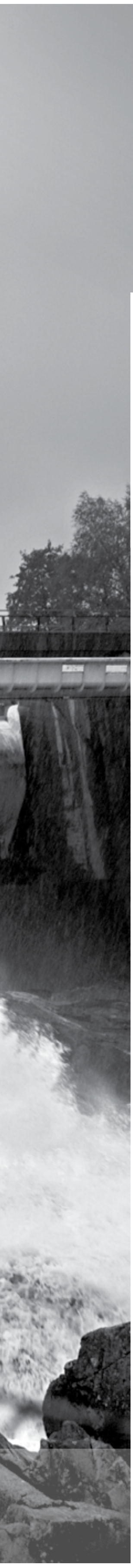
3





Norway as an energy nation – competitive advantages

Norway is an energy nation with an excellent basis for value creation in many business areas. Norway's access to national resources, technology and competence base and industrial experience provides a solid foundation for developing a low-emission society and further developing a profitable energy industry with opportunities in national and international markets.

The conditions are in place for Norway to become an important contributor of climate-friendly energy solutions in response to the global climate challenge. Norway's national energy resources also provide an excellent basis for supplying energy and power as well as climate-friendly products that require large amounts of energy to manufacture.

The flow of expertise between industries is increasingly important. Further developing existing knowledge and technology bases towards new markets may be a formula for success for innovation and product and services development. The Energi21 strategy emphasises the value of synergies and knowledge flow between industries as a vital source of innovation and renewal in the energy sector. Table 2 below shows Norway's key competitive advantages in the energy sector.

Table 2: Competitive advantages

Energy resources		Relevant for technology areas:
Major renewable energy resources	• Water • Wind • Land-based and marine biomass	• Hydropower • Offshore and land-based wind power • Maritime, land and air transport • Bioenergy • Climate-friendly and energy-efficient industry, including CCS • Hydrogen (through electrolysis)
Natural gas[4]	• Reforming of natural gas to hydrogen	• Maritime, land and air transport • Digitalised and integrated energy systems • Hydrogen (through reforming)
Expertise and experience		**Relevant for technology areas:**
Hydropower	• Technology for tunnelling and underground facilities • High-pressure facilities, flexible solutions • Cost-effective project design, planning and operation • Advanced methods/systems for optimal monitoring and operation • Environmental design in both planning and operation	• Hydropower
Electric power systems expertise	• Planning, construction and operation of power infrastructure • Electrical power components and parts	• Digitalised and integrated energy systems
Energy systems with high degree of electrification	• Planning, construction and operation – modelling and optimisation • Electrical power components and parts • Automated monitoring and operation of the power grid • Power markets – market design • Proportion of electric vehicles, and charging infrastructure	• Digitalised and integrated energy systems • Maritime, land and air transport (for electrification of transport) • Energy-efficient and smart buildings
Offshore petroleum activities	• Construction, operation and maintenance of large offshore installations • Geology and geotechnics • Experience in carbon capture, transport and storage • Sensor technology • Project management • Subsea cables	• Offshore wind power • Climate-friendly and energy-efficient industry, including CCS • Maritime transport

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

Table 2: Competitive advantages

Energy resources		Relevant for technology areas:
Maritime industry	• Marine operations • Specialised vessels • Autonomous vessels • Electrical systems in ships, battery modules	• Maritime transport • Land and air transport • Offshore wind power
Process technology	• Extensive industrial experience and research expertise • CO_2 separation from natural gas and flue gas • Refining for converting fossil fuels relevant for biorefining • Electrolysis, natural gas reforming • Hydrogen filling stations • Heat-pumping systems • Separation H2/CO_2 • Liquefaction, storage and handling of liquid hydrogen	• Climate-friendly and energy-efficient industry, including CCS • Maritime, land and air transport • Hydrogen • Solar power • Bioenergy incl. BioCCS
Materials technology	• Extensive industrial experience and research expertise • Metal/chemical refining (e.g. Si, FeSi, Al and more); • Materials for hydrogen technologies (ceramics, bipolar plates and more) and batteries and solar power (silicon) and more	• Maritime, land and air transport (batteries, hydrogen technologies) • Hydrogen • Solar power
The Norwegian model for organisation of working life	• Effective cooperation and high level of trust between public authorities, employees and employers • Efficient innovation processes	• All technology areas
Digitalisation/ICT	• High digital competency among the populace • Automation in shipping, autonomous vessels • Smart grids, monitoring of the power grid	• All technology areas
Legislation and development of incentives	• Nature, land-use and resource management	• All technology areas

Magnesium ferrosilicon (MgFeSi) manufactured by Elkem Bjølvefossen. *Photo: Elkem*

4

The 2018 Energi21 strategy

The key 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. In addition, the key areas represent thematic and technology areas of major significance for ensuring security of energy supply through future challenges related to climate change, new technology, new market solutions and new patterns of energy consumption in society.

4.1	Digitalised and integrated energy systems
4.2	Climate-friendly energy technologies for maritime transport
4.3	Solar power for an international market
4.4	Hydropower as the backbone of the Norwegian energy supply system
4.5	Offshore wind power for an international market
4.6	Climate-friendly and energy-efficient industry, including carbon capture and storage (CCS)

The development of knowledge and technology within the strategy's key areas is critical to the ability to develop a low-emission society, a climate-friendly energy supply, and climate-friendly industrial and transport sectors.

The Energi21 board recommends substantial growth and investment in the following key areas:

- Digitalised and integrated energy systems
- Climate-friendly energy technologies for maritime transport
- Solar power for an international market
- Hydropower as the backbone of the Norwegian energy supply
- Offshore wind power for an international market
- Climate-friendly and energy-efficient industry, including Carbon Capture and Storage (CCS)

HIGHEST PRIORITY TO "DIGITALISED AND INTEGRATED ENERGY SYSTEMS"

The Energi21 board recommends that particular focus and priority be given to research and innovation activities targeting "Digitalised and integrated energy systems". This is a highly complex and complicated technology area encompassing multiple scientific disciplines, technologies and solutions. Digitalised and integrated energy systems will be crucial to the future security of supply, the integration of climate-friendly energy technologies and the promotion of value creation in society. An insufficient level of investment could result in gaps in expertise and technology that entail negative consequences for society in the form of increased costs and reduced security of energy supply.

The achievement of effective initiatives requires access to ample, predictable public research funding, beneficial market incentives and the commitment and active participation of industry stakeholders.

The key areas are described in greater detail in Chapters 4.1 through 4.6.

ONGOING EFFORTS TO CREATE A BROAD KNOWLEDGE AND TECHNOLOGY PLATFORM FOR DEVELOPING THE ENERGY SECTOR

It is important to have know-how of relevance across the full thematic scope of the energy sector. Steady advances in specific and generic technologies and disciplines will continually open up new opportunities and contribute to new solutions. Chapter 5 and Attachment 3 contain descriptions of the following thematic and technology areas: Energy-efficient and smart buildings, Hydrogen, Bioenergy, Carbon capture and storage (CCS), Deep geothermal energy, Climate-friendly energy technologies for land transport, Climate-friendly energy technologies for air transport, Land-based wind power and other energy technologies that are part of the general knowledge and technology platform.

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 further represent areas open to a wide spectrum of research, with activities needed along various parts of the innovation chain. See Attachment 4 for a more complete description of the method used in selecting the strategic priorities.

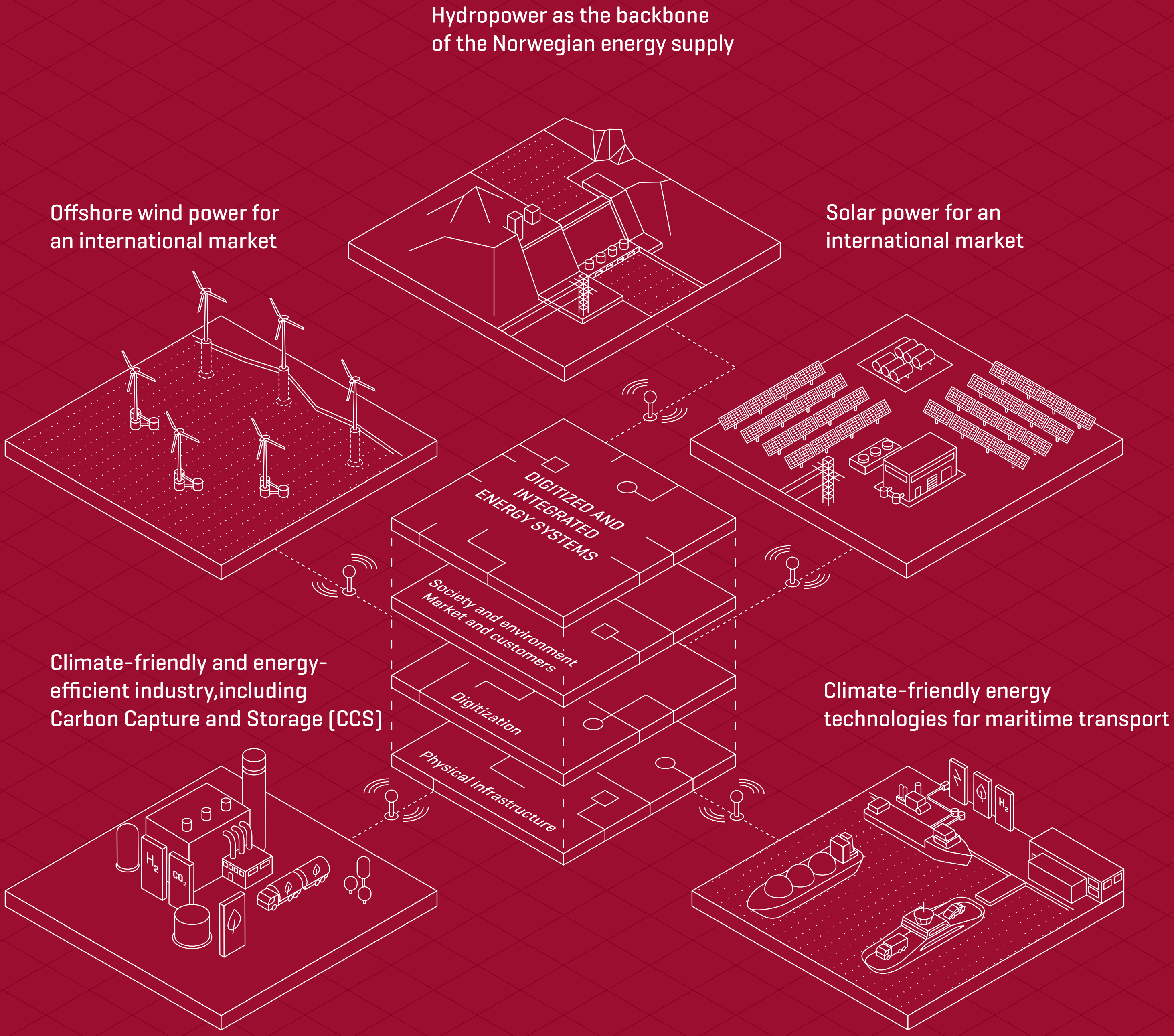


Figure 4.1 Strategic focus areas.

4.1

Digitalised and integrated energy systems

Concerted public and private investment in knowledge and technology development for digitalised and integrated energy systems is critical for future value creation relating to utilisation of Norway's energy resources, climate-friendly energy restructuring and building up a competitive business sector. There is a need to develop competence, technology and solutions that safeguard security of energy supply and the flexibility of the energy system and that promote emission-free power/propulsion solutions in the transport system.

SUMMARY

- The national and international energy systems are developing in the direction of more complex assemblies that integrate an increasingly wider range of technologies for both production and consumption. This will require adequate flexibility within the energy system and the capability to integrate all these technologies effectively.
- A digitalised and integrated energy system is a critical factor for achieving Norway's energy and climate-policy targets while safeguarding security of energy supply, through the optimal use of existing infrastructure and development of new components and materials, among other things.
- Development towards digitalised and integrated energy systems requires large-scale investments in energy-related infrastructure and digitalisation technology and solutions. Norwegian stakeholders can gain prominence in this market nationally and internationally, both in developing next-generation power system components and in digitalisation.
- An integrated systems perspective is critical for ensuring the efficiency of the energy system, and inadequate understanding of systems can have a negative impact on security of supply and cost-effectiveness.
- To a greater degree than is currently the case, coordination of subsystems will be optimised through the extensive use of automation, monitoring, control, and information systems.
- Norway is in an excellent position to develop a digital, integrated energy system that has near-zero emissions, a well-developed grid and a well-functioning energy market, as well as industrial stakeholders and research and educational groups with expertise in renewable and environment-friendly energy technologies.
- Key social science-related research issues include better understanding of consumer behaviour and the configuration of framework conditions and market design. It will also be important to know more about areas involving connections between political objectives and cooperation between public and private stakeholders, and the interaction between technology and society.
- It is important to expand knowledge about resource efficiency, lifecycle perspectives and sustainability in relation to natural resources and the environment.

The key area of "Digitalised and integrated energy systems" encompasses all energy-related infrastructures, technologies and solutions, and the interplay between them.
This includes infrastructures for and interplay between all climate-friendly energy carriers, with electricity clearly the most climate-friendly energy carrier in Norway. It also encompasses infrastructures and systems for CO_2, biomass, biogas and district heating.

This key area also encompasses systems for climate-friendly energy technologies for transport such as infrastructure for battery-electric and hydrogen. Included here is charging infrastructure and filling stations for battery-electric and hydrogen-electric vehicles and vessels. At the core of digitalisation are ICT solutions for use in physical infrastructure, smart buildings, urban areas and energy storage. Challenges within the ICT field comprise a significant part of the Energi21 strategy.

This area shares clear interfaces with social science-related research topics that are not covered under the Energi21 strategy but are of significance for development of the energy system as a whole. Examples include urban and regional planning and issues related to transport/communications beyond climate-friendly technologies for transport.

4.1.1 DEVELOPMENT OF THE ENERGY SYSTEM

Cost-effective development of the energy system requires an integrated systems perspective. It is not enough to expand physical infrastructure with sufficient capacity; it is also necessary to consider new digital technologies and solutions that provide completely new opportunities to develop efficient, flexible and optimised systems. At the same time it is essential to understand the impacts of framework conditions, market design and consumer behaviour on how the system develops. Therefore the key area of "Digitalised and integrated energy systems" is addressed along three dimensions:

- *Physical infrastructure:* This dimension encompasses all energy-related infrastructure in the energy and transport system, for all climate-friendly energy carriers. Included is infrastructure that accommodates large volumes of renewable, intermittent power production, consumers and buildings with local energy use, and storage and electrification of new application areas. This dimension includes infrastructure for CCS, climate-friendly transport, charging infrastructure and filling stations for battery-electric and hydrogen-electric vehicles and vessels.
- *Digitalisation:* This dimension encompasses digital technologies for linking the physical infrastructure through digital communications, collecting and exchanging data and analysing them to improve mechanical or systems performance. This includes smart control systems, smart grids with advanced metering infrastructure and DataHub, smart charging and filling station infrastructure for transport, smart buildings and smart interplay between all units.
- *Society and the environment, markets and consumers:* This dimension encompasses knowledge about management and the statutory framework, and about the impacts of the configuration of framework conditions, legislation and market design on development of the system. There is an environmental aspect that includes knowledge pertaining to sustainability and resource efficiency using various technologies. The aspect relating to markets and consumers encompasses knowledge about how to facilitate new, sound business models and services, and about understanding consumer behaviour in an electrified and digitalised energy and transport system. Also needed is knowledge about business development and innovation processes, and what leads to the proliferation of new technologies.

The development of the energy system entails a number of investments in physical energy infrastructure, automation and other ICT solutions with major market potential. There is a need for large-scale investments in the grid nationally and internationally to satisfy new system requirements for both upgrading existing facilities and new investments. Investments are also needed in charging infrastructure and filling stations for battery-electric and hydrogen-electric vehicles and vessels and those that can run on biogas. The investments in energy infrastructure must also make the system smarter and more efficient by implementing advanced control systems, automation, monitoring and information systems. Digital technologies enable more efficient operation and maintenance of energy infrastructure, with better condition monitoring, improved and predictive maintenance, and better utilisation of existing capacity.

Parallel to the development of physical infrastructure and ICT/digitalisation, Norwegian and international authorities are drawing up market designs and framework conditions to ensure optimal development of the system. Key issues in formulating the framework conditions are how to facilitate proper, efficient use of new technologies and digital solutions, and how to encourage new business models and stakeholders. In connection with the EU Winter Package,[5] proposals have been made to amend electricity market legislation in order to make the EU power market more integrated and efficient and enhance the ability of consumers to participate actively in the markets. A main focus of the new market legislation is to facilitate proper pricing of flexibility. This is important in light of anticipated higher demand for flexibility, and because proper price signals can activate new sources of flexibility, such as demand response, thermal flexibility, hydrogen and more.

[5] *The EU Winter Package (2016) comprises a number of directives and regulations to help the EU energy union to maintain its competitiveness and to ensure the EU remains a global leader in the clean energy transition.*

Changes taking place in the world's energy systems and related technology development are enabling consumers to take a new, more active role than previously possible. Through new, advanced solutions for energy management, their own production of energy, energy storage options and demand response, consumers are able to interact actively with the collective energy system. This makes it possible to organise microgrid solutions, either in isolation or connected to the collective system. And even as technological developments are enabling consumers to play a more active role, the sinking costs of distributed energy production and storage and advanced monitoring and control systems are making all this increasingly profitable from the consumer's standpoint. Consumers are seeking a greater degree of control over their own carbon footprint by e.g. controlling their own energy usage. The efforts of authorities in several countries to lay the foundation for broader consumer involvement is due to the fact that this has now become technologically possible, and that the consumers are actively interested. In turn, the authorities' objectives and the changing framework conditions are driving the development towards more active consumer involvement.

Developments in framework conditions, market design and active consumer involvement create opportunities and needs for new, innovative products, services and solutions, e.g. services for demand side management and aggregation services, and likely a number of other new services still on the horizon. Knowledge about the interaction between society and technology, coordination between public and private stakeholders, and greater understanding of consumer behaviour will be valuable for implementing viable solutions in the transition to a low-emission society.

Inadequate systems understanding and an inability to assess technology and solutions in an integrated perspective can have major negative impacts on security of energy supply and be very costly for society.

4.1.2 NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

Companies developing technology, solutions and systems are mainly in the supplier industry or consultants collaborating with research and educational institutions.

Norway has a number of strong companies with experience from cable technology and power electronics, for ICT and systems suppliers. Some Norwegian companies develop and produce charging infrastructure and hydrogen filling stations for battery-electric and hydrogen-electric vehicles and vessels, including systems for smart control of these in coordination with the rest of the energy system. Norway is a global leader in the deployment of electric charging infrastructure, and actors from among the energy and grid companies have taken an active role in this development. The energy sector is a key user of technology and solutions and plays an important role in setting the agenda for development. Effective cooperation between the sectors will be essential.

Charging station for buses and personal vehicles. *Illustration: ABB*

Norwegian research institutions and universities have competence in most subject areas related to energy systems of the future. There are Norwegian research groups on the global cutting edge in physical infrastructure and ICT/digitalisation, with expertise in power electronics, power transformers, medium-voltage switchgear, high-voltage cables, monitoring, control and protection of smart grids, and modelling of the market for energy and energy-related services.

In the field of social science-related energy research for future energy systems, Norway is home to research groups of high international calibre in the areas of environmental and resource economics, international energy and climate policy, energy systems analysis, restructuring and innovation, sustainability, and energy and transport. Expertise in interdisciplinary issues related to restructuring towards low-emission transport systems is of growing relevance, and Norway also has groups with high competence in this area.

There are a number of high-level groups in environmental and resource economics, and there are groups specialising in international energy and climate policy that have achieved international renown. In the area of energy systems analysis, there are Norwegian groups at the highest international level, in addition to respected groups in cross-sectoral energy systems modelling.

Restructuring and innovation is an interdisciplinary thematic area that is attracting wider interest as Norwegian authorities seek to realise targets for green growth, and several research groups have achieved acclaim here. The field of sustainability also has well-known research groups with particularly high expertise in lifecycle assessment.

4.1.3 CHALLENGES AND OPPORTUNITIES FOR NORWAY

Norway is in a good position to develop a digitalised and integrated energy system that is cost-effective and low-emission while providing reliable security of supply. An energy system with near-zero emissions, a well-developed grid and a well-functioning energy market forms a strong foundation, which can be further strengthened by the expertise of Norwegian industrial actors and research and educational institutions in renewable, environment-friendly energy technologies.

Norwegian research groups maintain a high international level in the area of flexible and dynamic solutions for the energy system. Norwegian companies are highly competent in systems technology operation and control, and have skilled groups for dynamic power system analysis. Norway also has relevant transferable know-how in power electronics and sensor technology from the offshore petroleum industry. This is knowledge that can be applied to monitoring, control and operation of the energy system, and to further developing digital solutions for the energy and transport systems. The process of digitalising Norway's energy system can also benefit from Norway's digital maturity, as demonstrated by Norway's high score on the EU Digital Economy and Society Index (DESI).[6]

Norway as a laboratory for an all-electric society

Norway's strong basis for developing a digitalised and integrated energy system also provides a good starting point for Norwegian business opportunities. Norway is ahead of other countries in the application of renewable electricity, with a stationary energy system that is nearly all-electric as well as the world's most fully electrified transport sector. The energy plans of several countries are setting a course towards more electrification, and Norway can provide knowledge and experience. The Norwegian building sector has longstanding experience in the use of electricity for equipment and for heating and cooling systems in buildings, as well as solid know-how about interaction and integration with the rest of the energy system. Furthermore, Norway has acquired experience and expertise in integrating electric vehicles and harmonising charging infrastructure with the grid. The conditions are in place for Norway to function as a laboratory for testing and verification of technology and solutions in an all-electric society. Within such a laboratory, Norwegian industrial stakeholders could develop and test out new technologies, solutions and services that could also be exported internationally.

Norway as a supplier of flexibility

The European power system is becoming more and more closely linked together, and the EU is seeking to introduce an integrated common power market. Europe also has a growing need for flexibility services, and Norwegian hydropower can help to fulfil this. Strengthening transmission capacity from Norway to Europe is therefore a likely development, and Norway could thus partially fill the EU's flexibility needs in restructuring from fossil dependency to a system powered by renewable energy. This represents an expanded market opportunity for Norwegian power producers.

Market design and framework conditions for effective development

Development towards a more complex energy system places new demands on how the Norwegian authorities configure the framework conditions and market design. The authorities need to facilitate development that is cost-effective while still safeguarding security of supply. This requires framework conditions that lead to viable, effective use of new technologies, including among other things cost-effective alternatives for grids that satisfy the need for security of supply. At the same time, Norwegian authorities are largely bound by EU directives and guidelines that are not always ideally designed for Norwegian conditions. Important research issues ahead will be developing market design and framework conditions that ensure the effective development of the Norwegian energy system.

[6] *Norway, Digital Single Market, https://ec.europa.eu/digital-single-market/en/scoreboard/norway*

Active consumers with increased involvement

The trend towards more active consumers entails greater insight into consumer behaviour. Authorities and industrial actors need to better understand consumer behaviour in the development of new framework conditions, business models, services and solutions. This gives rise to a number of questions at the societal level, e.g. what is needed for the market to implement new technologies and solutions. Knowledge about interactions and interdependencies between technology development, market design and consumer behaviour will be important for understanding what is needed to realise innovation and new business models, business opportunities and value creation. Other issues to explore are which stakeholders will drive energy system innovation and how innovation and the spread of technology take place.

With a digitalised and integrated energy system using multiple new technologies for both consumption and production comes a greater need for effective coordination across sectors. For example, buildings will no longer be passive consumers of electricity but will increasingly assume a role in energy production and storage and as a source of flexibility. Buildings have vast flexibility potential. Similarly, the transport sector is evolving from a passive consumer of fossil fuels to an active electricity consumer that can optimise its consumption of electricity according to limitations of the power grid, and can eventually provide energy storage and flexibility.

Flexible interaction between energy carriers

A digitalised and integrated energy system must also ensure effective coordination between all emission-free energy carriers. Achieving the climate targets will likely require the use of electricity, district heating, hydrogen and biomass, making effective coordination between energy carriers essential. Systems that can accommodate different energy carriers strengthen security of supply and increase energy system flexibility. Flexibility from multiple energy carriers is important in areas with a vulnerable power supply, or with a large power surplus, or with a large proportion of intermittent power production and limited transfer capacity in the grid. The interplay with decarbonised fossil energy carriers and the carbon value chain will be important. Assessments of sustainability and resource efficiency will be needed, including lifecycle perspectives and sustainability in relation to natural resources and the environment.

New, more stringent requirements for preparedness and cybersecurity

The vulnerability of the energy system increases as it becomes more complex in light of many and new stakeholders, rapid technology development, increased digitalisation and climate change. There will be a need for more stringent requirements for preparedness and cybersecurity. The energy system is becoming an increasingly advanced ICT system that is monitored and controlled by computer systems. Large volumes of data are transferred and stored. A cyber-attack could have serious consequences and in the worst case impede operation of the energy system. There is a heightened need to ensure that a digitalised and integrated energy system is resilient and reliable and can withstand challenges such as power outages, technical faults, human error, natural disasters and criminal acts. Research in the field of safety and security is therefore vital.

4.1.4
AMBITIONS FOR THE INDUSTRIAL SECTOR

The industrial sector has indicated the following ambitions for digitalised and integrated energy systems during the Energi21 process:

- To develop cost-effective digitalised and integrated energy systems with reliable security of supply and low greenhouse gas emissions, and which withstand large-scale climate impacts.
- To integrate new types of production, consumption and storage.
- To effectively integrate new technologies in the transport sector, and achieve effective interplay between the energy and transport systems.
- To ensure that Norway becomes a global leader in electrification of the transport sector.
- To ensure proper, cost-effective application of new technologies and solutions, including digitalisation and alternatives to grids.
- To develop a digitalised energy system, realise new business models, help end users to become actively involved, and ensure more effective operation and maintenance of the systems.
- To design, integrate and implement resilient ICT systems that are highly secure.
- To develop a Norwegian supplier industry for technologies and services for the digitalised and integrated energy systems.
- To innovate new energy services in keeping with developing flexibility and new business models.
- To achieve stronger, faster-paced innovation within electricity and energy supply, with more industrial actors actively involved.

4.1.5
ACTION AND IMPORTANT RESEARCH AREAS

The Energi21 board recommends the following action and research areas to realise and meet the industrial actors' knowledge and technology needs for digitalised and integrated energy systems:

Action

- Enhancing incentives and framework conditions that substantially accelerate the pace of innovation in the energy sector.
- Establishing closer, more coordinated collaboration between the ICT, power, construction and energy industries.

- Establishing an energy cluster where Norwegian energy stakeholders and other prominent actors in the energy system collaborate on carrying out innovation projects.
- Improving the funding instruments for RD&D in the industry.
- Facilitating and providing funding for large-scale testing and demonstration facilities for developing flexible solutions.
- Taking advantage of Norway's electrified energy system as a real-life laboratory for testing new technologies and solutions.
- Carrying out research, development, demonstration and commercialisation activities within the strategic research areas identified below.

Strategic research areas

Technology

- Next-generation cable technology, electrotechnical components and smart distribution grids.
- System technology and operation solutions and related implications of increased integration of local production, distributed storage facilities, flexible resources, future buildings and urban areas, and new consumer groups.
- Comprehensive development of the energy and transport system, with smart grids, stationary and mobile energy storage and smart buildings. Use areas with buildings and distributed energy resources as active nodes within the grid.
- Predictive models for load profiles of buildings and utilisation of local flexibility.

Digitalisation

- Solutions for more effective monitoring, data collection, control and management, data analysis and improved asset management.
- The role of digitalisation throughout the entire value chain for the energy and transport system.
- Output issues and dynamic system modelling, continual updating and improvement.
- Security of supply, ICT/cybersecurity and vulnerability in a digitalised and electrified society.
- Alternatives to grid development – analysing the cost-effectiveness and security of supply of grid alternatives and different sources of flexibility.

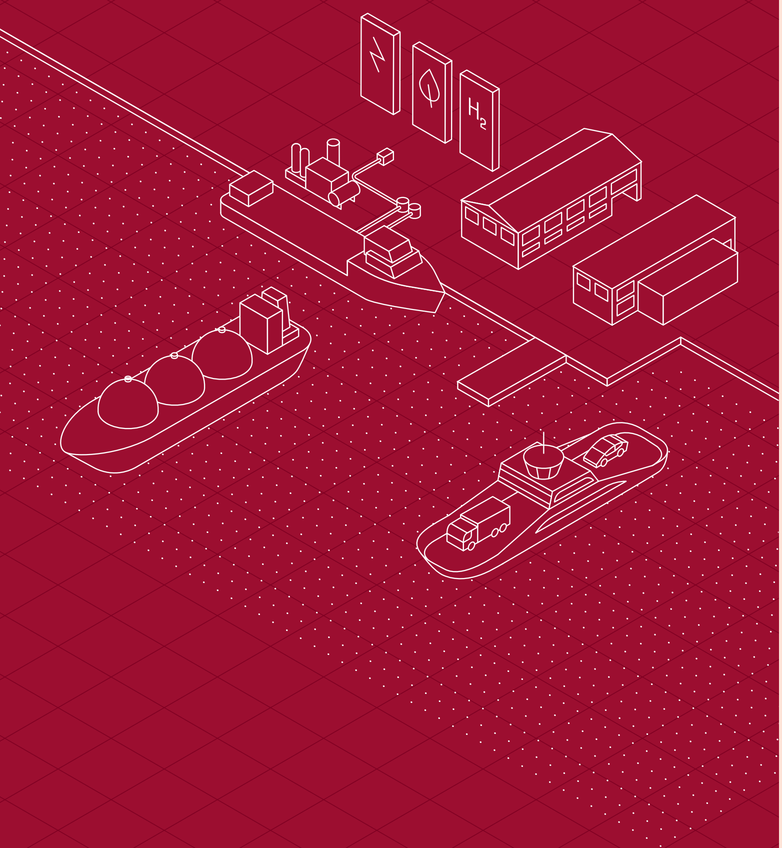
Social science-related issues (regulation, markets, psychology)

- Knowledge about management, the statutory framework, financial instruments, and national and international markets.
- Models and tools for market modelling, and comprehensive assessments of infrastructure for climate-friendly energy carriers.
- Effective targeting of policy and funding instruments, market design – including innovative price signals, local trade platforms, flexibility products and tariffs.
- Business models for different types of market solutions.
- Innovation and diffusion of new technologies, including understanding the interaction between technology and society.
- Develop local market design for microgrids, micromarkets and energy islands.
- Knowledge about consumer behaviour, application of new technology, and solutions for active consumer involvement.
- Knowledge about society and behaviour, societal structures, the attitudes and actions of the various stakeholders, as well as research on power structures and public planning.
- Knowledge about sustainability and resource efficiency, including lifecycle perspectives and sustainability in relation to natural resources and the environment.

Operations centre – monitoring, control and operations. *Photo: Hafslund ASA*

4.2

Climate-friendly energy technologies for maritime transport



The Energi21 board considers action in the maritime transport sector to be important in the transition to a low-emission society. The sector can achieve substantial reductions in emissions by introducing climate-friendly energy technologies and fuel options. In addition, there is considerable potential for value creation through further development of Norway's internationally competitive businesses in the field of climate-friendly maritime transport energy technologies.

SUMMARY

- The maritime transport sector will have to undergo a transformation process to reduce greenhouse gas emissions. However, decarbonisation of the sector is a challenging task since a large share of its activity takes place outside national and international jurisdictions.
- The climate-friendly energy technologies that can be used by maritime transport depend to a large extent on the type of vessel, with fewer technology options available for larger vessels. Biofuels can become an important environmentally friendly alternative for larger vessels in the future. However, biomass is a limited resource with several competing areas of application, and it is unclear which applications will become the largest consumers.
- Norwegian authorities introduced environmental requirements for shipping at an early stage, which means that Norwegian stakeholders can gain a head start in the development of low-emission solutions. New solutions can be tested and verified in Norway's large domestic market.
- Norway's strong technology base and expertise in the maritime sector provide a sound basis for continued value creation.
- Norway has a robust electricity grid that provides security of supply, renewable energy resources and natural gas, and extensive knowledge of materials and processes. All of this provides an excellent framework for the production of hydrogen, batteries, electrolysers, fuel cells, hydrogen tanks and so on.
- Norwegian industry is playing a pioneering role in the development of battery-electric solutions for maritime transport, and supplied the propulsion systems for the world's first all-electric ferry.
- Norwegian companies have long industrial experience and expertise in using hydrogen, and are therefore in a good position to develop core technology and components for maritime transport.
- Norway can exploit and combine expertise in various areas of technology such as battery-electric propulsion, fossil fuels or biofuels and hydrogen-electric propulsion in the development of hybrid solutions.
- The maturity of climate-friendly energy technologies for maritime transport is fairly low at present, and they are more costly than conventional technologies. In the time ahead it will be important to find a framework and market design that provides incentives for investments in climate-friendly energy technologies, and to reduce both vessel and infrastructure costs.
- Automation will result in changes and improvements throughout the value chain, and Norwegian companies are playing a pioneering role in this field.

4.2.1 MARKET DEVELOPMENT AND ANTICIPATED ROLE

The maritime transport sector faces considerable challenges in reducing greenhouse gas emissions in the time ahead. Emissions must be reduced while at the same time transport needs are expected to grow. Norwegian domestic shipping has set the target of cutting greenhouse gas emissions by 40 per cent by 2030. To achieve this, it will be necessary to use a substantial share of alternative fuels with low carbon emissions.[7] This means that we should consider using various technologies, including hydrogen- and battery-electric solutions, biofuels, and combinations of these in hybrids.[8]

Norway introduced environmental requirements for shipping at an early stage, and Norwegian authorities intend to include these in public procurement processes to promote environmentally friendly solutions.[9] Emissions from international shipping are continuing to rise, and this trend must be reversed to achieve international climate targets.

For the moment, battery- and hydrogen-electric solutions are suitable for smaller vessels such as ferries and high-speed vessels. As a result of the steep drop in battery costs,[10] battery-electric propulsion has become a more cost-effective way of reducing greenhouse gas emissions from ferries and other vessels that are used for relatively short routes. Hydrogen-electric propulsion is a less mature technology, but projects are under way to make use of hydrogen in maritime transport. Hydrogen technology is also of interest as a way of increasing the range of battery-electric vessels. Batteries for use in hybrid solutions are of interest for many types of vessels, and their use is likely to become more widespread.

Biofuels are the main option for larger vessels at present,[11] before any technological breakthrough is made in fuel cell and other hydrogen technologies.[12] According to the IEA's Beyond 2°C scenario (B2DS), biofuels will account for half of all fuel consumption by shipping in 2060.[13] In contrast to the B2DS scenario, projections by other sources such as the International Transport Forum[14] point to hydrogen and ammonia (requiring solutions for liquefaction, storage and handling) as very important fuels for shipping.

4.2.2 NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

The Norwegian maritime cluster includes companies along the entire value chain for maritime transport, and has world-leading technology and expertise. This cluster provides a good basis for further development of climate-friendly energy technologies for maritime transport. Many companies in the maritime cluster are already involved in such developments.

As regards battery-electric propulsion, there are Norwegian firms that produce battery modules and battery materials, and others that provide advisory and engineering services. For example, Norwegian suppliers provided the electric propulsion system for the world's first all-electric ferry.[15] Several Norwegian suppliers of charging infrastructure for land transport have technology and expertise that is relevant and transferable to maritime transport.

There is growing activity in the development of hydrogen-driven vessels in Norway, and Norwegian partners are engaged in a project to develop the world's first ferry using hydrogen fuel cell propulsion. Norwegian companies can supply all parts of the ferry apart from the fuel cells themselves. Several world-leading Norwegian companies that supply hydrogen technologies for land transport (electrolysers, tanks) have technology and expertise that is relevant and transferable to maritime transport.

Several stakeholders are also developing hybrid solutions for maritime transport, the most usual solution being a combination of batteries and an internal combustion engine. There are also examples of the use of fuel cells in combination with batteries and conventional fuels.

Biofuels for maritime transport can largely be used in the same types of vessels and be supplied using the same infrastructure as fossil fuels, and the main difference is at the production stage. A few Norwegian companies are engaged in the production of biofuel both from imported rapeseed and soybean and from waste. There are also Norwegian companies in various parts of the biogas value chain, and two Norwegian producers of biogas plants supply competitive technology for the international market. In addition, several companies are considering the possibility of establishing

7 Green Coastal Shipping Programme (2016) Charting a Course for Green Coastal Shipping. This document also describes two other types of action to reduce emissions: technical measures and operational measures. These are outside the scope of the Energi21 mandate.
8 LNG is not further discussed as it is outside the scope of the Energi21 mandate
9 See for example the Norwegian National Transport Plan
10 See for example Bloomberg New Energy Finance (2017), New Energy Outlook 2017
11 Nuclear power is also technically possible, but is not generally endorsed
12 See for example International Energy Agency (IEA) (2017), Energy Technology Perspectives 2017
13 International Energy Agency (IEA) (2017), Energy Technology Perspectives 2017
14 International Transport Forum (2018), Decarbonising Maritime Transport – Pathways to zero-carbon shipping by 2035.
15 Store norske leksikon, https://snl.no/Ampere_-_bilferge (Ampere - electric car ferry)

large-scale production of biofuel from forest biomass. It has recently been decided to build a demonstration plant in Norway for production of advanced biofuel.

Leading Norwegian research groups and industry partners have been brought together under the umbrella of one of the Centres for Environment-friendly Energy Research (FME centres), and are working on hydrogen- and battery-electric solutions, with a special focus on maritime areas of application. Together, they have extensive knowledge of battery materials, fuel cells and electrolysers, and hydrogen storage in metal hydrides. Norwegian research groups also have internationally recognised expertise in modelling and analysis of hydrogen systems and value chains, and world-class materials expertise.

The most important research groups, industry partners and other stakeholders working on biofuels are involved in cooperation in another FME centre. There are also internationally recognised Norwegian research groups working on the climate benefits of using forest to produce biofuels.

4.2.3 CHALLENGES AND OPPORTUNITIES FOR NORWAY

Norway has a strong maritime cluster, a large domestic market and a well-developed electricity grid, and sets strict environmental requirements, all of which provides a good basis for the development of climate-friendly energy technologies for maritime transport. A number of activities and initiatives involving new climate-friendly propulsion solutions for ferries, high-speed vessels and offshore vessels are already under way. Norway is playing a pioneering role in this field, and can gain a head start on other countries. This can be an advantage as the decarbonisation of shipping in other countries and international shipping becomes necessary, since Norwegian companies will be able to supply technologies and services in the international market. Climate-friendly energy technologies for maritime transport will thus play a part both in the transformation of the energy system in Norway and in the development of Norwegian industry.

There are a few strong industry-led initiatives in Norway relating to battery materials and battery modules, but no production of battery cells. Several companies are focusing on maritime applications for batteries, including battery modules for maritime transport and advisory and engineering services for optimal use of large battery systems. Norwegian research and educational institutions have strong expertise in electrochemistry and materials technology, and there are research groups working on battery technologies.

There are several factors that put Norway in a good position to establish battery cell production: a robust electricity supply system that provides security of supply; well-established process industries and a strong knowledge base in materials and process technology; sites available for industrial activities; and a cold, dry climate. Establishing production of batteries (cells and modules) for maritime use would give Norway an opportunity to establish its position in a growing market at an early stage.

Norway is also in a good position to develop hydrogen-electric solutions for maritime transport. Its advantages

Future of the fjords, an all-electric catamaran. *Photo: Brødrene AA* include the availability of cheap, emission-free electricity that can be used to produce hydrogen by electrolysis, and supplies of natural gas, which can be used to produce emission-free hydrogen by reforming coupled with CCS. There are also abundant unutilised natural resources that can be used to generate intermittent renewable electricity, which is suitable for hydrogen production. Over time, Norway has built up a knowledge base on hydrogen technology through research and educational institutions, industrial production and use of hydrogen, and more recently in the land transport sector. Norwegian stakeholders are playing a pioneering role in the development of hydrogen-electric solutions for maritime transport.

The hydrogen industry is growing internationally, but it will take some time before hydrogen-electric solutions for maritime transport can be commercialised. This is mainly because of challenges related to the high costs of fuel cells and electrolysers and a lack of rules and standards.

Hybrid solutions combine different energy carriers in a vessel's propulsion systems and for other energy-intensive activities. Until now, the most common solution has been to combine batteries and an internal combustion engine, but emission-reduction requirements are driving a trend to equip more vessels with battery-electric propulsion, using hydrogen to increase their range. In addition to lower emissions, the advantage of hybrid solutions is a more stable engine operation that saves fuel, reduces emissions further and causes less wear and tear. Norwegian stakeholders are well placed in the hybrid sector.

The use of climate-friendly energy technologies for maritime transport involves several challenges. Low technological maturity and a low penetration rate result in higher costs for vessels using these technologies, and it is also expensive to develop the necessary energy infrastructure. In the time ahead it will therefore be important to find a framework and market design that provides incentives for investments in climate-friendly energy technologies, and to reduce both vessel and infrastructure costs.

Research and development activities relating to biofuels largely focus on fuel production, since biofuels can be used in the same vehicles, vessels and infrastructure as conventional fuels. There are a few companies in Norway that produce biofuels, but the sector is fragmented. In the maritime transport sector, liquefied biogas (LBG) can be used in LNG vessels, but as yet there are not sufficient volumes of biogas available in the market. Future use of biogas for marine transport will be dependent on the establishment of more LBG production plants.[16]

Norway has extensive forest resources that can be used in biofuel production, but the production processes are energy- and capital-intensive and the technology is not very mature. Although the IEA expects maritime transport to use large volumes of biofuels in the future, both land and maritime transport will be competing for these fuels. Sustainability and the availability of resources are important themes in biofuel research and production. Biofuels should be used in a way that maximises their climate benefits, and the resources should be used in areas where there are no other good options.

4.2.4
DIGITALISATION AND MARITIME TRANSPORT

Digitalisation opens up new opportunities in shipbuilding, where innovative and improved production methods based on digital technology can be used for new vessels. Digitalising vessel operation may result in improvements in energy efficiency, for example through optimisation of the choice of route and speed with a view to minimising fuel consumption. It will for example be possible to use data from other vessels to optimise the choice of route.

The development of autonomous vessels will make further improvements in energy efficiency possible, particularly in cases where the absence of crew members who are paid by the hour makes it possible to reduce speed for certain shipments. In addition, energy needs can be reduced by removing crew facilities such as cabins, the galley and mess, and personal safety equipment from autonomous vessels. Digital solutions can also improve safety by making ferry operations, predefined routes and arrival procedures more predictable. Solutions will also be needed for automation of port services and processes, since fully autonomous vessels can only be used if port services are autonomous too.

Norwegian stakeholders are at the forefront of developments in automation and autonomous vessels. They have developed automated solutions for processes on board vessels, and autonomous and/or remotely controlled vessels. Autonomous vessels are being tested at several sites in Norway, with the involvement of both companies and research institutes. For example, a test bed for autonomous shipping technology has been established in part of the Trondheimsfjord, and both NTNU and Sintef will be testing new solutions in the area. Yara International is planning to have the world's first fully electric and autonomous container ship in operation from 2018, using technology supplied by Kongsberg Maritime.

[16] *DNV GL (2016), Realisering av null- og lavutslippsløsninger i anbudsprosesser for ferjesamband (Achieving zero- and low-emission solutions in procurement processes for ferry services)*

4.2.5
APPLICABILITY IN OTHER AREAS

Climate-friendly energy technologies for maritime transport are widely applicable in other areas. For example, much of the expertise and technology for producing batteries for maritime transport will also be useful in stationary applications in the energy supply system and for non-road mobile machinery and other means of transport. Similarly, technologies for the use of hydrogen in maritime transport will be relevant for land transport and other uses in the energy supply system. Moreover, biofuel production is relatively independent of the area of use, and techniques developed for large-scale production of biofuel from forest biomass will be applicable for many purposes.

Solutions developed for the maritime sector may have important implications for the petroleum sector. The oil and gas industry is looking for alternatives to traditional offshore power supply systems, and solutions such as battery technology, fuel cells and hybrid systems can all play an important part. Cross-cutting industry needs of this type strengthen the commercial basis for climate-friendly technologies and solutions for maritime transport.

4.2.6
AMBITIONS FOR MARITIME TRANSPORT

The maritime transport sector has indicated the following ambitions for climate-friendly energy technologies during the Energi21 process:

- To achieve substantial cuts in greenhouse gas emissions from maritime transport.
- To establish an emission-free value chain for maritime transport in Norway.
- To develop new automated solutions and fully autonomous vessels.
- To establish pilot production of battery cells in Norway, with large-scale production as a long-term aim.
- To establish large-scale production of battery modules for maritime transport.
- To develop leading hybrid solutions for maritime transport.
- To develop and establish infrastructure for hydrogen- and battery-electric propulsion.
- To develop the Norwegian maritime industry so that it can take the lead in low- and zero-emission solutions for the maritime sector:
  - by becoming a world leader in hydrogen technology for maritime transport;
  - by becoming a world leader in battery-electric propulsion for maritime transport;
  - by being at the forefront in developing a market for connecting ships at berth to shoreside thermal infrastructure.

4.2.7
ACTION AND IMPORTANT RESEARCH AREAS – MARITIME TRANSPORT

The Energi21 board recommends the following action and research areas to realise the sector's ambitions and satisfy the knowledge and technology needs of industrial operators as regards climate-friendly energy technologies for maritime transport:

Action

- Establishing pilot battery cell production
- Testing and verifying hydrogen-electric, battery-electric and hybrid ferries and other ships.
- Including requirements for zero-emission solutions in public procurement processes.
- Supporting efforts to phase in infrastructure for climate-friendly energy technologies for maritime transport.
- Carrying out research, development, demonstration and commercialisation activities within the strategic research areas identified below.

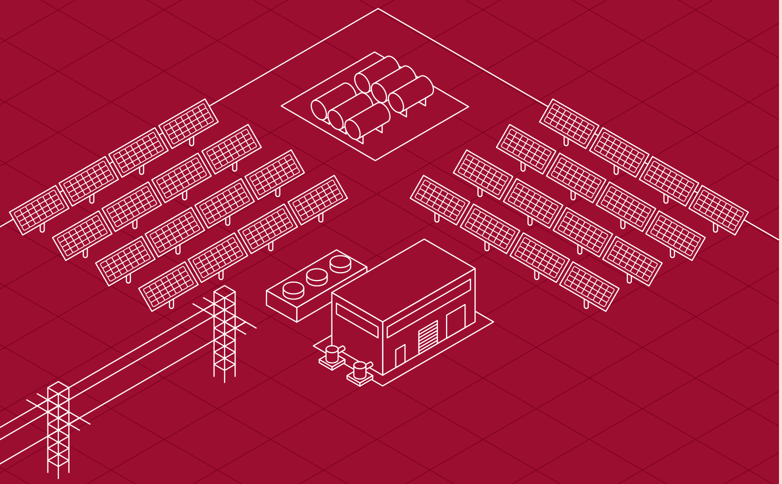
Strategic research areas

- Battery systems and charging technology for electric vessels.
- Materials for battery production and battery modules.
- Materials and concepts for batteries that have higher energy density and are safer than Li-ion batteries, for example solid-state batteries.
- Safety aspects of the use of new climate-friendly fuels such as hydrogen in maritime transport.
- Electrolysers, fuel cell technology, filling stations and other core technology for hydrogen vessels.
- Process development (pretreatment, preprocessing, upgrading) for biofuel production from biomass and for new energy carriers for hydrogen. Hydrogen used in biofuel production to improve conversion efficiency from raw materials to products.
- Automated solutions for ships, port services and processes.
- Zero-emission hybrids using fuel cells, hydrogen and batteries for high-speed vessels and ferries.
- Emission-free maritime value chain including production, infrastructure and access to energy for climate-friendly energy technologies for maritime transport.
- Interdisciplinary research questions in the interface between climate-friendly energy technologies for maritime transport and the social sciences.

Silgrain® from Elkem Bremanger. *Photo: Elkem*

4.3

Solar power for an international market



The global market for solar power is growing rapidly, with substantial growth projected in the years ahead. Norway is in a strong position to achieve continued value creation by further developing a competitive supplier industry for solar cell materials and technological solutions. For this reason the Energi21 board wishes to highlight solar power as a key area and recommends intensified efforts in research, development and commercialisation.

SUMMARY

- Solar power is one of the fastest-growing renewable energy technologies. Projected annual growth in installed capacity is 11 per cent until 2040. Growth such as this entails enormous investment, estimated at USD 2.5 billion by 2040.[17]
- The cost of solar power has decreased by 75 per cent since 2009,[18] and solar power is already competitive with new coal capacity in Germany, Spain, Italy, the US and Australia. By 2021 solar power is expected to be competitive with coal in China and India as well.
- Costs are projected to continue falling. Bloomberg New Energy Finance (BNEF) estimates cost reductions of 66 per cent by 2040.
- Electricity from solar cells is expected to comprise a significant share of overall energy production in many countries in the years to come. BNEF (2016)[19] projects solar power to account for 15 per cent of global electricity production by 2040. Norwegian production of electricity from solar power is still expected to comprise only a modest share, although lower costs and new building regulations may prompt larger volumes of solar power in the long term. BNEF (2017)[20] estimates just 6 GW of solar power in the Nordic region in 2040, however.
- Market development is opening up opportunities for suppliers and other stakeholders that supply technology or solutions for the solar power value chain.
- The Norwegian solar power industry accounts for significant national value creation, with a 2016 export value of roughly NOK 3 billion.[21] Export value is mainly from sales of produced silicon-based materials (wafers, ingots) in the process and materials industry.
- The Norwegian solar power industry is supported by a competency base within the process and materials industry.

4.3.1
MARKET DEVELOPMENT AND ANTICIPATED ROLE

In recent years, solar power has become competitive with new coal capacity in many countries, including Germany, Spain, Italy, the US and Australia. By 2021 solar power is expected to be competitive with coal in China and India as well.[22] Due to its falling costs and increasing competitiveness, solar power is expected to comprise a significant share of overall energy production in many countries, which will bring about far-reaching changes in their energy systems.

In recent years the growth rate of solar power has been high. From 2005 to 2016 the annual growth in installed capacity averaged 45 per cent. In 2013 total installed capacity was 130 GW, while in 2016 it had increased to approximately 300 GW.[23]

Recent years' projections for cost reductions and the expansion of solar cells have proven too conservative when compared to actual figures. Looking ahead, projections for solar power call for continued strong growth in volume and major cost reductions. For instance, BNEF (2017) projects 4 500 GW of installed capacity and cost reductions of 66 per cent by 2040.[24]

International growth can be grouped into two types of markets, centralised (large-scale) solar power farms and distributed solar power stations. These two types are developing differently in different parts of the world. Centralised solar power farms are proliferating in China, India and the Middle East as a result of increased demand for electricity, while in many countries distributed solar power stations are expected to multiply. BNEF (2016)[25] projects 62 per cent of solar power growth will be from centralised farms, with the remaining 38 per cent from distributed solar power stations. Floating solar power is a more immature field, but one with expected growth and a number of large-scale projects underway.

While the market for decentralised systems is also expanding in Norway, it remains small. There is less incentive in the Norwegian market than in countries that are restructuring their power systems from fossil sources to renewables. Nevertheless, high consumer prices and sinking costs may make solar power profitable in Norway as well. Digitalisation, changed end user behaviour and smart houses and smart cities will also promote greater expansion of distributed solar power in Norway and demand for building-integrated photovoltaics.

4.3.2
NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

Norwegian companies are targeting a variety of segments in the value chain. In recent years a number of new companies have emerged, particularly in downstream activities. Upstream, Norway has a number of companies that produce silicon, ingots and wafers. Norway's upstream companies account for the largest export share in solar power by supplying silicon-based solar cell materials to the international market. These companies export large amounts of components to the international solar power market, and the volume sold internationally exceeds Norwegian demand by a wide margin. Norwegian companies are thus dependent on succeeding internationally against stiff competition. To maintain these companies' market share and advantages in high-quality products made using renewable energy, this industry engages in constant research and development in collaboration with Norwegian research groups. Norwegian producers have plans to scale up from current capacity levels.

Downstream, a number of new companies have emerged in recent years, and new concepts and business models are developing. In the domestic market, companies are developing business models for distributed solar power. Internationally, a number of Norwegian companies are operating in project development and the development of centralised, large-scale facilities. As new stations are completed, the market for their financing, service and operation grows.

Norwegian research groups in solar power have collaborated with the solar industry to establish high expertise in materials technology, particularly in silicon, and some Norwegian companies have earned an excellent reputation internationally.

4.3.3
CHALLENGES AND OPPORTUNITIES FOR NORWAY

The solar power market's rapid growth and associated investments are creating opportunities for the Norwegian solar industry. The sheer size of the international solar market means that even niches represent substantial potential for value creation, and a number of Norwegian suppliers are already operating within such niches, where it is substantially easier to exploit advantages and sustain competitiveness. It will be possible for more Norwegian companies to develop niche-based activities and gain a foothold.

The Norwegian solar power industry supplies competitive products to the international solar market. This technology base can form the basis for new spin-offs and new initiatives, which has been amply demonstrated. Downstream there are a number of companies that have achieved a certain stature and are competitive in project development and the development of centralised, large-scale facilities.

Floating solar power facilities represent a relatively new area which may prove interesting to Norwegian companies.

17 Bloomberg New Energy Finance (2017), https://www.bloomberg.com/view/articles/2017-06-16/investing-trillions-in-electricity-s-sunny-future
18 Bloomberg New Energy Finance (2017), https://www.bloomberg.com/news/articles/2017-06-15/solar-power-will-kill-coal-sooner-than-you-think
19 Bloomberg New Energy Finance (2016), New Energy Outlook 2016, Solar
20 Bloomberg New Energy Finance (2017), Beyond the Tipping Point
21 Eksportkreditt (2016), https://www.eksportkreditt.no/no/case/fornybareksporten-oker-men-veksttakten-ma-opp/

Several companies are already becoming actively involved, especially among technology developers and solar farm owners. Norwegian companies may be able to exploit the competitive advantages from the offshore industry for floating solar power facilities. Floating solar power is a relatively young field with a great need for research.

The Norwegian solar power industry is supported by a flexible, well-established research base. Over the past 15–20 years Norway has achieved a level of research capacity and competency that provides an excellent knowledge platform for further development of the Norwegian solar power industry. Activities in solar and other industries, and in associated research groups, have generated a high level of expertise in materials and process industries.

The manufacture of high-grade silicon and the first segments of the silicon value chain require access to large amounts of electricity and cooling water. Norwegian companies benefit from their access to cheap, emission-free energy, which helps to keep their prices competitive and reduces carbon footprint. The low carbon footprint is expected to become increasingly important as emissions requirements for all economic activity become more stringent. Energy prices in Norway are expected to remain low and competitive ahead.

4.3.4 DIGITALISATION AND SOLAR POWER

Digitalisation in solar power unleashes significant potential for reducing the costs of operating and maintaining solar power farms, as do better weather forecasting and optimisation of production. In the production of solar cell materials, digitalisation allows for expanded use of automation and robotisation and reduced labour intensity. This will benefit Norwegian companies since their labour costs are relatively high compared to other countries.

Digitalisation also creates opportunities for distributed solar power in the interface between smart buildings, distributed storage, demand response and smart grids. Using digital solutions such as VPP and DERMS,[26] real-time data can be analysed and applied to optimise electricity production and consumption.

4.3.5 AMBITIONS FOR SOLAR POWER

The solar power industry has indicated the following ambitions during the Energi21 process:

- To build up a silicon-based solar industry for the future, comprising:
  - a supplier industry that is at the European forefront in quality and innovation;
  - market niches where Norway can take advantage of its competitive advantages;
  - competitive development, operation and maintenance of large-scale solar power plants.
- To develop new business models and solutions that combine solar power, smart control and digitalisation.
- To develop a dynamic Norwegian solar energy cluster that is competitive internationally and can gain prominence in emerging markets.
- To cultivate prominent research and educational institutions that are attractive as international partners.

4.3.6 ACTION AND IMPORTANT RESEARCH AREAS – SOLAR POWER

The Energi21 board recommends the following action and research areas to realise the ambitions of the solar industry and satisfy the knowledge and technology needs of industrial operators:

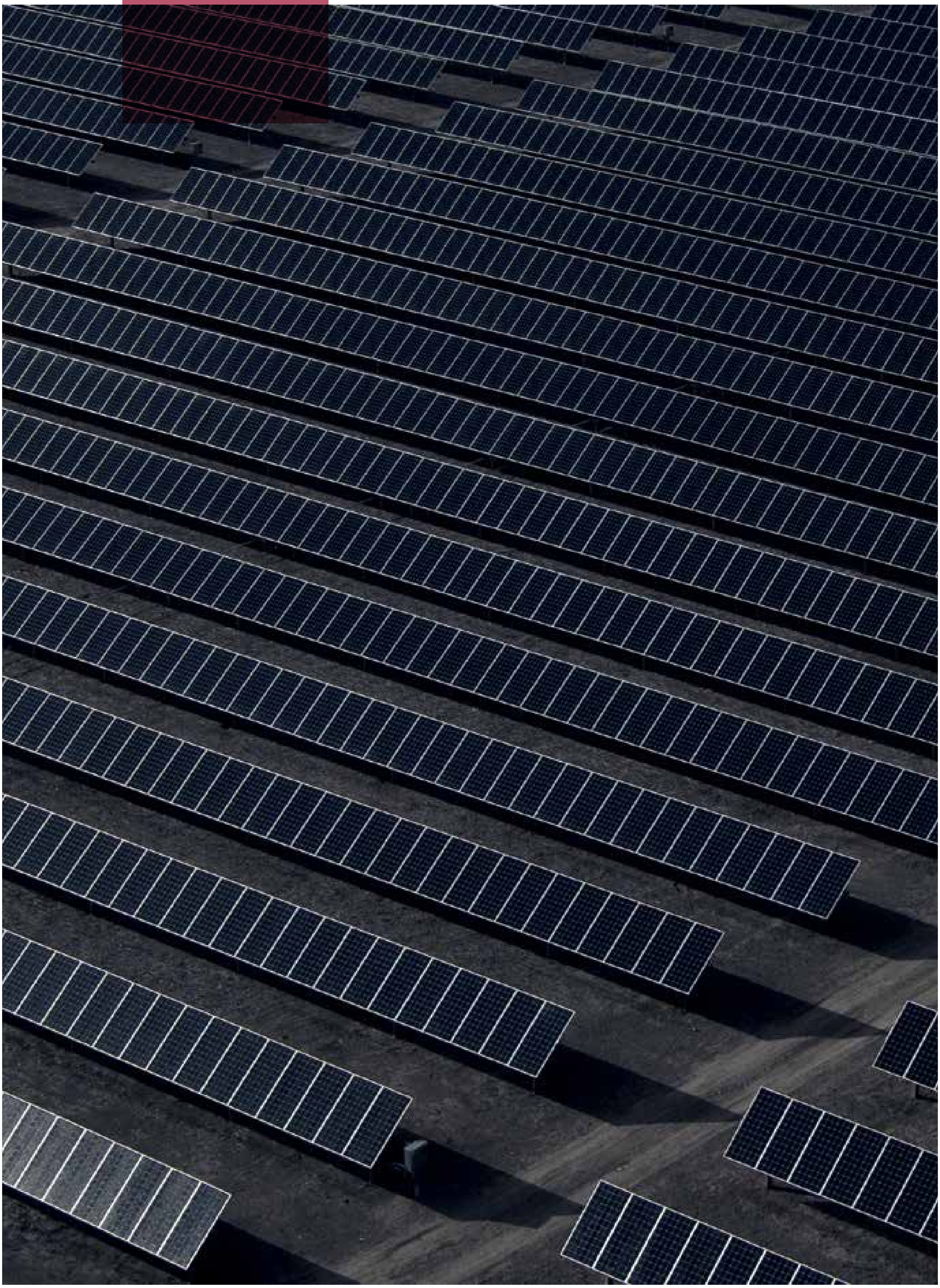
Action

- Make it simpler for international partners to participate in Norwegian research projects.
- Introduce measures to commercialise research results related to solar power.
- Unify and coordinate ongoing research on solar power.
- Ensure that universities supply enough candidates with relevant competency and that they choose career paths in the solar industry.
- Carry out research, development, demonstration and commercialisation activities within the strategic research areas identified below.

Strategic research areas

- Development of processes for future production of materials for cost-effective, environment-friendly silicon-based solar cells, as well as development of future materials for solar power.
- Technology, concepts and solutions for building-integrated photovoltaics.
- Technology, concepts and solutions for floating solar power.
- Concepts and systems for reducing operational and maintenance costs and increasing energy conversion ratios.
- Interdisciplinary research questions in the interface between solar power technology and the social sciences.

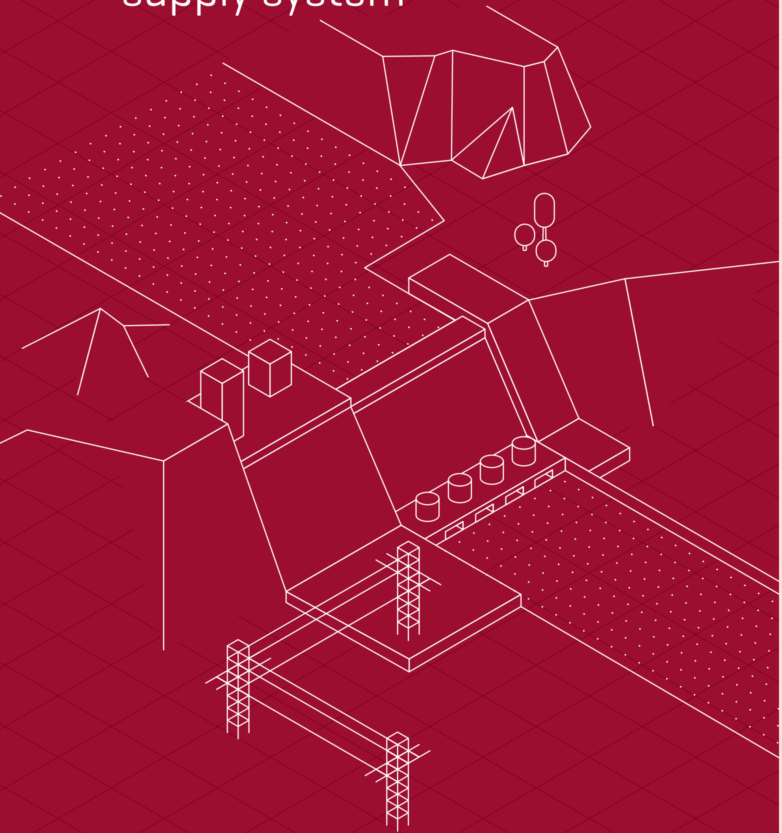
[22] *Bloomberg New Energy Finance (2017), New Energy Outlook 2017*
[23] *IRENA (2017), https://www.irena.org/solar*
[24] *Bloomberg New Energy Finance (2017), New Energy Outlook 2017*
[25] *Bloomberg New Energy Finance (2016), New Energy Outlook 2016, Solar*
[26] *Bloomberg New Energy Finance (2017), Digitalization of Energy Systems. VPP = Virtual power plants, DERMS = Distributed energy resource management systems.*



Solar farm. *Photo: American Public Power Association on Unsplash*

4.4

Hydropower as the backbone of the Norwegian energy supply system



Hydropower is the mainstay of Norway's energy system and electricity supply system. Effective use of hydropower resources is crucial for value creation in Norway. The Energi21 board considers that hydropower should be retained as one of the strategy's key areas because of its potential for value creation in the future and its importance for security of supply.

Both in Norway and in Europe as a whole, the share of renewable, intermittent power production is increasing, more flexible consumption patterns are emerging, and more options are becoming available for reducing greenhouse gas emissions through the electrification of new areas of use. In the time ahead, it will be necessary to determine how Norwegian hydropower best can play a part in these changes – in other words, which are the areas where hydropower has competitive advantages over other technologies that can provide the same electricity balancing services.

SUMMARY

A growing international hydropower market

- In 2016, hydropower production totalled about 4000 TWh worldwide, corresponding to about 70 per cent of the world's renewable electricity production.
- There are major plans for expanding hydropower plants internationally, and according to the IEA's Beyond 2°C Scenario (B2DS), hydropower production will be in excess of 5700 TWh in 2030.
- The growth in hydropower production globally means that there will be a large market of interest to Norway's world-leading hydropower expertise.
- However, most of the growth will be outside the OECD area, in regions where market conditions are challenging.
- The construction of new cross-border interconnectors and the need to phase out fossil electricity production in Europe will open up a wide range of opportunities for value creation from hydropower.

Importance of hydropower to Norwegian society

- Hydropower production plays an important role in Norway, and its high value creation benefits Norwegian society as a whole.
- However, expectations that electricity prices will be persistently low in the years ahead mean that the Norwegian hydropower sector must seek to lower costs and at the same time increase income from production.
- The use of hydropower to provide balancing services for the Nordic and European markets offers a potential for value creation.
- The average age of Norwegian hydropower installations is high, and large-scale upgrading and expansion projects will need to be carried out in the years ahead. During these processes, there will be opportunities for integrating new technology and solutions and for making better use of hydropower resources.
- Digitalisation and digital solutions play an important role in new technological advancements, and offer a potential for optimising operations and reducing costs.
- Norwegian hydropower can play an important part in meeting the challenges of climate change by making it easier to switch from fossil to renewable energy sources in the Nordic and European power supply systems. The hydropower sector can play an important role in flood control, and this will become more important in a changing climate with more frequent and more severe extreme weather events.
- More knowledge is needed about what part the hydropower sector can play in phasing out fossil energy production in Northern Europe.

4.4.1
MARKET DEVELOPMENT AND ANTICIPATED ROLE

Global hydropower production is expected to increase in the years ahead. According to the IEA's B2DS scenario, hydropower production is projected to increase from about 4000 TWh in 2016 to more than 5700 TWh in 2030.[27] The largest increase will probably be in Asia, Latin America and Africa. The greatest unutilised hydropower potential, an estimated 7195 TWh/year,[28] is in Asia.

In Europe, there is a focus on upgrading and expanding hydropower installations, partly so that they can be adapted to interact dynamically with intermittent renewable sources of energy (wind, solar, etc.). The need for flexible electricity production and energy storage is increasing with the large rise in the share of intermittent renewable energy sources, and this need can be met by hydropower plants that have flexible production capacity. In the time ahead, Norway will be focusing on arrangements for hydropeaking, further development of small-scale hydropower, upgrading and expanding existing plants and more sustainable hydropower production.

4.4.2
NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

The Norwegian hydropower industry currently consists of more than 80 power companies with large-scale hydropower in their portfolios, a number of technology suppliers, and consultancy firms with expertise in the field.

The Norwegian hydropower industry is in a good position to take part in the large-scale international expansion of hydropower production. Over 100 years' experience of hydropower development and operations has given Norway a great deal of knowledge, broad experience and strong competitive advantages. However, Norwegian participation in international hydropower development is limited, and there are relatively few Norwegian suppliers in the international market.

Several Norwegian hydropower-based research groups have achieved international recognition. Research conducted through earlier FME centres has included a great deal of pioneering work by several Norwegian hydropower groups on environmental aspects and impacts of hydropower. There are also Norwegian research groups with strong expertise in high-head Francis turbines and insulation materials in transformers. Steps are being taken to transfer this knowledge to the field of generators. Norwegian research groups are also recognised for their expertise in modelling the hydropower system, including hydrology, optimisation of production and energy systems.

The current research activities under the FME centre focus on four main areas: hydropower structures, turbines and generators, markets and services and environmental design.

4.4.3
CHALLENGES AND OPPORTUNITIES FOR NORWAY

Large-scale hydropower > 10 MW

The average age of large Norwegian hydropower installations is high, and large-scale upgrading and expansion projects will need to be carried out in the years ahead to maintain production.

Existing installations will have to be adapted to new regulatory regimes brought in in response to climate change. This will make it possible to consider flood protection in connection with reinvestment in existing infrastructure. New technologies and solutions can be introduced together with other upgrades. Reinvestments can also boost utilisation of energy resources by improving efficiency and increasing production capacity.

Upgrading and expanding hydropower installations requires large-scale investment. In the years ahead, the hydropower industry is expecting low electricity prices and stiffer competition from other centralised and decentralised renewable electricity generation, battery technologies and demand-side flexibility. In addition, both Norway's taxation system and the possible outcome of the revision of conditions in hydropower licences are putting hydropower at a competitive disadvantage relative to other renewable energy technologies. The hydropower industry is more heavily taxed than other land-based industries, and the taxation system is largely based on taxing the income from energy sales. At the same time, ageing hydropower installations will require large-scale upgrades, and there is growing demand for large-capacity installations. The hydropower industry will therefore need to lower costs and at the same time increase income from production in order to strengthen its competitive position (for example through sales of balancing services, as described below).

Digital solutions are important tools for improving cost effectiveness, and efficiency gains can be achieved through solutions that optimise the running and maintenance of hydropower plants. Introducing digital solutions in old installations is a challenging process, but reinvestment projects offer opportunities for implementing new technologies.

International development of hydropower capacity offers opportunities for the Norwegian industry. Norwegian companies have world-leading expertise and long industrial experience, and could achieve a strong position internationally. However, so far few of them are involved in international hydropower projects. One complication they will meet is that most of the growth will be outside the OECD area, in regions where market conditions are challenging. Risk-mitigation instruments will therefore be needed. The form of ownership of Norwegian hydropower producers may also be a limiting factor for their international activities.

[27] *International Energy Agency (IEA) (2017), Energy Technology Perspectives 2017*
[28] *World Energy Council (2016), World Energy Resources Hydropower 2016*

Norway has a strong position in the hydropower sector today, with internationally recognised expertise and technologies. It is important for Norway to maintain and further develop its expertise in order to maintain this position. The average age of employees in the sector is high, and future value creation by the industry will depend on the transfer of expertise to younger employees. It will therefore be necessary to strengthen and further develop educational and training institutions to ensure adequate recruitment to all segments of the hydropower value chain. In addition, there will be a need to develop new expertise and new technologies for the hydropower system of the future, in fields including production planning and efficient operations, and to design hydropower installations in a way that takes the environment and climate change into account. It will also be necessary to establish a high level of expertise in ICT/digitalisation.

Balancing services

The European power supply system has begun a large-scale shift away from fossil and towards renewable energy sources. The share of intermittent renewable sources of energy such as solar and wind is rising rapidly, and this reinforces the need for power reserves and flexible production capacity. Norway has half the reservoir capacity in Europe, and can therefore play an important role as a supplier of flexibility for the European market.

To realise Norway's potential for providing balancing services, it will be necessary to expand waterway and turbine capacity and the installed capacity of generators. It may be appropriate to boost the output from turbines in Norway's hydropower plants and install pumps where suitable.

Closer integration between the Norwegian and European power supply systems can also be achieved by reinforcing the Norwegian transmission grid, installing more DC cable capacity and perhaps developing a meshed North Sea offshore grid. Market mechanisms will also have to be developed to provide payment for balancing services in a future market situation. Providing balancing services may enable Norwegian hydropower producers to become more profitable, and may also have climate benefits by substituting Norwegian hydropower for the use of fossil fuels in other European countries. More insight into the framework for supplying renewable energy or balancing services, including balancing power, will be valuable in the years ahead.

Three different levels of ambition can be distinguished for making greater use of Norwegian hydropower resources to provide flexibility:

- *Level 1:* Making optimal use of existing Norwegian hydropower facilities, with ordinary levels of maintenance and existing power lines, for electricity production when wind and solar power is in short supply elsewhere in Europe.
- *Level 2:* Making greater use of resources by installing more turbine capacity at existing facilities so that output can be increased, and by increasing the capacity of cross-border cable links.
- *Level 3:* Using reservoir capacity more fully by installing more turbine and pumping capacity at existing reservoirs to allow pumping of water when there is a surplus and quick reservoir drawdown when there is a shortage, significantly improving grid capacity and resilience and establishing several new cross-border interconnectors.

Power house under construction, Iveland hydropower plant. *Photo: Agder Energi*

Level 1 can be achieved through the current regime for system development. Levels 2 and 3 will require structural measures at the national and European levels. All three levels require a smoothly functioning power supply system with a well-developed transmission grid and a European-level power market with access for Norwegian hydropower. This is discussed in Chapter 4.1.1 "Digitalised and integrated energy systems". It will also be important to exploit opportunities for closer integration between the electrical grid and the thermal energy supply systems.

Realising the potential for balancing services will require major investments in Norwegian hydropower plants, the electricity grid and interconnectors. At the same time, there is uncertainty regarding the value of flexibility. Uncertainty as regards the future return on balancing services makes it more difficult to reach investment decisions. In addition, time scales are creating a challenging situation for Norwegian hydropower. It is time-consuming to construct power lines and other infrastructure to provide balancing services, whereas intermittent renewable power supplies elsewhere in Europe are being developed rapidly, and the demand for flexibility is rising. This increases the likelihood that the demand for flexibility will be met by other competing technologies, and it is likely that a combination of technologies will be used.

Small-scale hydropower

There has been considerable interest in the development of small-scale hydropower in recent years, and there are unused licences for small-scale hydropower projects totalling about 3 TWh. Key issues relating to such projects include their profitability, environmental impacts, grid connections and the expertise of developers.

Small-scale hydropower plants are largely designed as scaled-down versions of large hydropower facilities. These are marginal investments, making it necessary to ensure cost-effective solutions for development and construction and reliable long-term revenues throughout plant lifetime. Low electricity prices and the winding-down of the electricity certificate market will make further development of small-scale Norwegian hydropower more challenging. However, the industry is focusing strongly on innovation and construction costs, and has been achieving results. Another option for improving returns on small-scale Norwegian hydropower may be hydrogen production.

4.4.4 DIGITALISATION AND HYDROPOWER

The rapid reductions in levelised cost of energy (LCOE) for new sources of renewable energy are posing a growing challenge to the position of the hydropower sector. Cost reductions are changing the competitive position of hydropower and require a strong focus on how to deal with the new situation.

Introducing digital solutions can increase income and reduce costs, thus improving the competitiveness of hydropower.

For example, waterways and dams can be inspected and monitored using drones and digital image analysis tools. Maintenance tasks can be carried out more effectively using virtual reality technology to receive instructions and document work. In addition, advanced processing of signals and data from operations can be used to understand the condition of components and identify faults as they develop, and thus optimise maintenance, upgrading and expansion projects and operation of facilities.

There are very different types of Norwegian hydropower installations, and their average age is high, which can make it difficult to implement and use new digital solutions. On the other hand, reinvestment projects planned for the near future offer opportunities for implementing new technologies such as machine learning and artificial intelligence.

4.4.5 AMBITIONS FOR HYDROPOWER

The hydropower industry has indicated the following ambitions during the Energi21 process:

- To ensure that Norwegian hydropower has a clearly defined role in the transition to a renewable society.
- To increase the value of Norwegian hydropower by making better use of reservoir flexibility integrated with the Norwegian and European energy supply systems.
- To increase access to the European electricity market, including the balancing markets.
- To promote environmentally friendly, cost-effective construction and further development of hydropower capacity in Norway and internationally.
- To ensure optimal, cost-effective operation, maintenance and upgrading of the Norwegian hydropower system, including the introduction of new digital solutions.
- For Norway to have world-leading expertise in hydropower and lead the way in implementing R&D results.
- To strengthen Norwegian hydropower-related expertise and the industry to achieve national objectives and be an attractive partner internationally in the ownership, construction and operation of facilities.
- For Norway to have an internationally leading supplier industry.
- To market Norwegian hydropower actively as a cost-effective, reliable source of flexibility for European markets.

4.4.6 ACTION AND IMPORTANT RESEARCH AREAS – HYDROPOWER

The Energi21 board recommends the following action and research areas to realise the ambitions of the hydropower industry and satisfy the knowledge and technology needs of industrial operators:

Technological solutions for cost effectiveness along the whole value chain, including digitalisation

Precipitation, inflow and the environment

- Better data and models for the impacts of climate change on runoff and on catchment areas, including ungauged catchments.
- Sociological perspectives on changes in the threats to hydropower facilities.

Tunnelling and underground facilities including drilling and turbine technology

- Further development of Norwegian special expertise (solutions, methodology, knowledge) on engineering and construction of underground facilities, including tunnels, power plants, turbines and outlets.

Erosion and sediment transport (including international issues)

- Technological solutions for dealing with sediment in reservoirs, tunnels and turbines.
- Environmental assessments of different solutions for dealing with sediment in reservoirs and rivers.

Digitalisation as a tool for increasing the value of Norwegian hydropower and improving its competitiveness

- Condition-based and predictive maintenance, more efficient operation and better utilisation of water resources.
- Better methods for calculating the remaining lifetime of turbines and generators.
- Better calculation models for (re)investments and maintenance (risk and lifetime).
- Robotisation and automation of monitoring and maintenance to minimise risk (HSE), reduce costs and improve quality.

Digital security

- Security as the degree of digitalisation increases.
- Security of energy and power supply in an integrated, renewable energy system.
- Standardisation along the whole value chain in hydropower projects (engineering and construction/upgrading) to reduce costs (contracts, planning, development, operation/maintenance).

Flexibility and balancing

Market design and the value of flexibility

- Design of effective markets and valuation of flexibility.
- Business models for delivering power and flexibility through cross-border interconnectors.
- Competitiveness of hydropower relative to competing storage technologies and management of consumption.
- Technological solutions for making production more flexible, including integration with waterways and the electricity grid.
- Optimal, profitable upgrading of existing hydropower plants in competition with other technologies.

Consequences of short- and long-term balancing (examples)

- Turbine and electromechanical stress.
- The environmental impacts of hydropeaking (changes in operating patterns).
- Regulatory framework taking into account environment and society in line with Norway's climate and environmental targets.
- Adaptation of legislation to future market opportunities and greater use of hydropeaking.
- Rapid changes in electricity flow in cables, and a large number of DC cables out of Norway.

A systems perspective on the importance and role of hydropower

- A better understanding of hydropower-related drivers, developments and impacts in Norway and in the EU and of the role of hydropower in future energy systems in Norway and internationally.
- Improving the environmental standing of large-scale hydropower in Europe. The value of (public) services other than energy production (multi-use of river systems, flood protection, climate regulation, etc.).
- The value of a reliable electricity supply and access to sufficient power (transport, industry, data storage).
- The value of system services: frequency regulation, stability.
- The framework for hydropower in both Norway and the EU, and conditions that are needed to optimise the use of hydropower resources for value creation.
- Interactions between flexible production of hydropower and intermittent energy sources and consumption in the Norwegian, Nordic and European power supply systems.
- Climate change and its impacts on the hydropower sector, including the climate-related benefits and drawbacks of hydropower.

Need for expertise, innovation and value creation

- Implementing measures specifically targeted towards bachelor, master and doctoral level programmes, and ensuring researcher recruitment. Strengthening cooperation between academia and business and industry.
- Establishing collaboration between Norwegian and international research institutions and universities to further enhance development.

- Establishing large-scale laboratory facilities for innovation-oriented research together with business and industry.
- Ensuring that there are funding instruments for major testing and demonstration projects, with the aim of testing and implementing more R&D results (from theory to application)
- Supporting pilot projects and commercialisation of research results through funding instruments for later stages of the innovation chain.
- Further developing research centre schemes.
- Providing risk-mitigation instruments for stakeholders that are interested in establishing themselves internationally. It will be important to involve all agencies in the research and innovation system (the Research Council, Innovation Norway and Enova).
- Marketing Norwegian hydropower expertise internationally.
- Enhancing knowledge about the part hydropower can play in phasing out fossil energy production in Northern Europe, focusing on greenhouse gas emissions from the hydropower industry itself, particularly in a life-cycle perspective.
- Investigating interdisciplinary research questions in the interface between hydropower and the social sciences.

Øvre Forsland hydropower plant. *Photo: Helgelandskraft*

4.5

Offshore wind power for an international market

The key area of offshore wind power holds opportunities for value creation in the short term from developing a supplier industry, and in the long-term from the utilisation of national wind resources.

SUMMARY

- The market for offshore wind power is growing, and capacity doubled from 2013 to 2016. At the end of 2016, global installed offshore wind power capacity was 14.4 GW. Bloomberg New Energy Finance (BNEF) (2016)projects 120 GW of new offshore wind power capacity globally by 2040.
- Offshore wind power (fixed foundation) has achieved major cost reductions in recent years, a trend expected to continue in the years ahead. BNEF (2017) predicts cost reductions of 71 per cent for offshore wind power by 2040, driven by experience, competition and economies of scale.
- Currently, most offshore wind power facilities receive some form of subsidy, but in Germany one competitive bidding process for building offshore wind power capacity has already been won without subsidies.
- Norwegian suppliers' exports to the offshore wind power market totalled NOK 5 billion in 2016, making it Norway's largest renewable energy export industry.
- Current development is targeted at an international market where Norwegian suppliers of technology can gain prominence. Norway has expertise from the petroleum and maritime sectors that is transferable to offshore wind power, but it is essential to further develop this know-how to maintain this competitive advantage.
- Norway is in a good position to win a share of the floating offshore wind power market, where Norwegian stakeholders have an early start.
- Norway also has extensive experience and expertise in metocean, geophysics and resource mapping, which are important fields for operating offshore wind power facilities.
- The theoretical energy potential from Norwegian offshore wind power is so large that utilising it must be based on supplying power to an international market with adequate infrastructure. In the long term, this could become an important source for satisfying some of Europe's future demand for renewable energy.

4.5.1
MARKET DEVELOPMENT AND ANTICIPATED ROLE

At the end of 2016 there was approximately 14 384 MW of installed offshore wind power worldwide, representing growth of roughly 65 per cent from 2014. Offshore wind power now accounts for roughly three per cent of all installed wind power capacity in the world, compared to just 1.7 per cent in 2011.[29] The market for offshore wind power is growing, and BNEF (2016) projects another 120 GW of new offshore wind power capacity globally by 2040.[30]

In 2016, the average turbine rating for offshore wind power was approximately 4.8 MW, and the average wind farm generated 380 MW.[31] These figures are respectively 15 and 12 per cent larger than the previous year. The trend towards increasingly high-capacity turbines and wind farms is expected to continue in the years to come.

Europe has taken a leading position in offshore wind power development, and in 2016 had just under 13 GW[32] of installed capacity, nearly 90 per cent of the global total. Continued strong growth in offshore wind power is projected for Europe, and Wind Europe estimates capacity of 70 GW in 2030.[33]

The market for offshore wind power currently lies outside Norway, with Europe an important, leading market. Although Norway has good wind resources and a large theoretical potential for offshore wind power production, it is not currently profitable to expand offshore wind power in Norway. In the long term, cost reductions and good wind resources will contribute to enhanced profitability and opportunities to speed up development.

As an alternative to generating power to transmit via the electrical grid, offshore wind power can be used in connection with other offshore installations. For instance, offshore wind power connected to petroleum platforms or fish farms could provide a niche for wind power facilities on the Norwegian continental shelf.

4.5.2
NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

In recent years, a number of Norwegian companies have targeted offshore wind power. Many of these are transitioning from petroleum activities and reapplying their know-how, and many have successfully gained a foothold in the market for offshore wind power. There is also substantial transfer value from the maritime industry. In recent years, offshore wind power has been Norway's largest renewable energy export industry, and in 2016 these exports amounted to NOK 5 billion.[34]

Some Norwegian suppliers and energy companies have already found success in this market, particularly in Denmark, Germany and the UK. Norwegian companies are hoping to significantly increase their export of technology and services to a growing offshore wind power market, with a stated ambition of achieving a 10 per cent market share for Norwegian suppliers by 2030, up from the current five per cent.[35]

Norwegian research groups have wide-ranging expertise in a number of fields of relevance to offshore wind power. Special competency has been established, among other places at a Centre for Environment-friendly Energy Research (FME), in modelling of offshore structures as well as integration of wind power into the energy system. A number of Norwegian research groups have been actively involved in EU projects. Norway also has dynamic groups in marine operations and vessel operations.

In addition, Norway has research groups and expertise in computational fluid dynamics and metocean, built up at an FME centre among other places. The world's top expertise in these areas, however, is found at research groups abroad.

4.5.3
CHALLENGES AND OPPORTUNITIES FOR NORWAY

The competency base that Norwegian companies have acquired from petroleum activities and the maritime industry has high transfer value for offshore wind power. It is widely agreed that this expertise represents industrial business opportunities in offshore wind power. NORWEP (2017)[36] identifies seven particularly promising areas for Norwegian suppliers in the offshore wind power value chain, including project management, subsea cables, offshore platforms for transformer stations, turbine foundations, installation methods and support services, maintenance and inspection, and vessels and equipment. Another Norwegian strength is expertise in metocean, geophysics and resource mapping, which are vital for all phases of the offshore wind power industry, from planning and design to operations and maintenance.

New and improved methods and technology for installing and anchoring foundations at sea – for both fixed-foundation and floating turbines – together with efficient operational and maintenance systems may help to reduce the costs of offshore wind power substantially. This opens up opportunities for Norwegian companies to develop new technology

[29] *Global Wind Energy Council (2016), Global Wind Statistics 2016*
[30] *Bloomberg New Energy Finance (2016), New Energy Outlook 2016*
[31] *Wind Europe (2016), The European offshore wind industry - key trends and statistics 2016 (for Europe)*
[32] *Wind Europe (2016), The European offshore wind industry - key trends and statistics 2016*
[33] *Wind Europe (2017), Wind energy in Europe: Scenarios for 2030, Central Scenario*
[34] *EEksportkreditt.no, https://www.eksportkreditt.no/no/case/fornybareksporten-oker-men-veksttakten-ma-opp/ (Renewable exports are up – but faster growth is needed.)*
[35] *Norwegian Wind Energy Association (NORWEA), Federation of Norwegian Industries, and Norwegian Shipowners' Association (2017), Havvind, et nytt norsk industrieventyr (Offshore wind power, a new Norwegian success industry).*
[36] *Norwegian Energy Partners (2017), Norwegian Supply chain opportunities in offshore wind.*

and services for a growing international market. Norway is in a strong position to take a share of the market for floating wind power, where Norwegian companies have an early start. The world's first floating wind farm became operational in 2017, with a Norwegian developer, Norwegian technology and a large proportion of Norwegian subcontractors. Floating wind power is expected to grow in importance due to limited availability of near-coastal waters as well as conflicts with fisheries and shipping interests. Additionally, there is a great resource potential in deeper waters, and an estimated 80 per cent of Europe's offshore wind power resources are to be found at depths of 60 metres or more.[37]

The market lies primarily outside Norway. This affects the industrial structure, which is largely comprised of companies concentrating on international opportunities. These Norwegian companies need to succeed in a highly competitive international market with various degrees of protectionism. Thus it is essential to target Norway's instruments towards assisting Norwegian companies in this context. This applies not least to instruments and funding far along the innovation chain.

4.5.4
TECHNOLOGICAL CHALLENGES AND THE NEED FOR COST REDUCTIONS

Although the costs of offshore wind power facilities are high compared to generating energy from conventional energy sources, they have decreased sufficiently in recent years to make some fixed-foundation offshore wind projects profitable without subsidies. The industry is striving to make offshore wind power competitive with other energy production technologies, and offshore wind power is expected to achieve major cost reductions in the coming years. BNEF (2017) projects cost reduction of more than 70 per cent for offshore wind power by 2040, driven by experience, competition and economies of scale.[38]

An important objective of technology development and R&D activities is to reduce costs through the entire service life of wind power facilities. One of the primary factors for cutting costs involves developing larger turbines with higher capacity, lower weight and greater reliability. New, improved methods and technology for installing and anchoring foundations at sea – for both fixed-foundation and floating turbines – together with efficient operational and maintenance systems may also help to reduce the costs of offshore wind power substantially.

4.5.5
DIGITALISATION AND OFFSHORE WIND POWER

In the key area of offshore wind power, digitalisation offers a potential for reducing the costs of operating and maintaining wind farms. Digitalisation can also enhance weather forecasting and help to optimise power generation while minimising downtime. Estimates indicate that digitalisation of renewable, intermittent power production may reduce operational and maintenance costs by 10 per cent, increase power generation by 8 per cent and reduce downtime by 25 per cent.[42].

4.5.6
AMBITIONS FOR OFFSHORE WIND POWER

The offshore wind power industry has indicated the following ambitions during the Energi21 process:

- To develop a Norwegian supplier industry for the offshore wind power market, and double the market share of Norwegian suppliers, currently five per cent, by 2030.
- To establish long-term power generation from Norwegian offshore wind resources.
- To build up Norwegian companies' technological and industrial expertise and develop solutions that:
  - increase energy production from wind farms;
  - cut costs throughout the entire value chain, from design to decommissioning.
- To build up a strong competence and commercial base for solutions for floating wind power in early-phase market development.
- To further develop Norwegian expertise and services in metocean modelling and resource mapping.

4.5.7
ACTION AND IMPORTANT RESEARCH AREAS – OFFSHORE WIND POWER

The Energi21 board recommends the following action and research areas to realise the ambitions of the offshore wind power industry and satisfy the knowledge and technology needs of industrial operators:

Action

- Carrying out test projects in collaboration between Norwegian and international companies.
- Supporting companies seeking to apply relevant Norwegian expertise in offshore wind power on the international market.
- Establishing funding instruments for commercialisation and implementation of research results.
- Encouraging Norwegian authorities to assume an active and proactive role in EU demonstration programmes in order to drive wind power costs down. Strategic cooperation with other countries on development and testing of technology should be considered.
- Carrying out research, development, demonstration and commercialisation activities within the strategic research areas defined on the following page:

[37] *Wind Europe (2017), Floating Offshore Wind Vision Statement.*
[38] *Bloomberg New Energy Finance (2017), New Energy Outlook 2017*

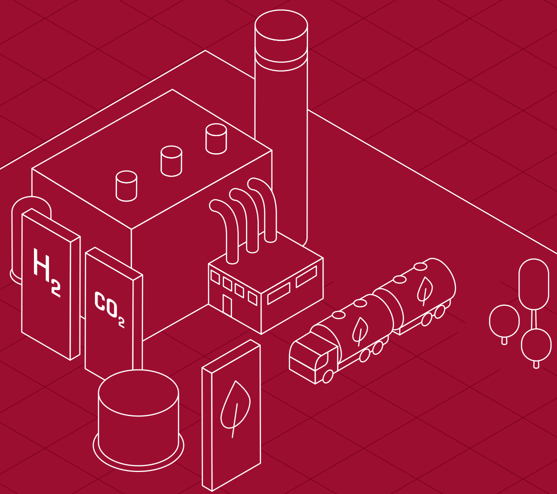
Strategic research areas:

- Optimal foundation designs for floating and fixed-foundation turbines;
- Cost-effective, time-saving assembly and installation of offshore wind farms;
- Digitalisation for enhanced control and decision support, optimisation of design regarding service-life costs and revenues and potential for cost reductions.
- Efficient concepts for marine logistics (heavy maintenance) and robust solutions for access;
- Concepts and systems for reducing operational and maintenance costs and increasing energy conversion ratios;
- Resource mapping and metocean modelling – precise models of meteorological and oceanographic conditions on both macro- and micro-levels.
- Fluid-structure interaction;
- Concepts and systems for reliable electric infrastructure (offshore subsea solutions);
- Enhanced knowledge about offshore wind power's environmental and societal impacts;
- Multi-use maritime platforms with interaction between aquaculture, petroleum and offshore wind power activities;
- Interdisciplinary research challenges in the interface between offshore wind power and social science.

Edda Fjord at an offshore wind farm. *Photo: Norwegian Shipowners' Association*

4.6

Climate-friendly and energy-efficient industry, including carbon capture and storage (CCS)



Climate-friendly and energy-efficient industry is a high priority under the Energi21 strategy. This key area includes both energy efficiency and CCS. One theme that is highlighted here is the production of hydrogen from natural gas coupled with CCS, given the wide range of applications for hydrogen in the energy and transport system and in industry.

Climate-friendly and energy-efficient industry can play a major role in the transition to a low-emission society, and there is considerable potential for the development of an internationally competitive sector.

SUMMARY

- Internationally, industry accounts for 18 per cent of total greenhouse gas emissions.[39]
- The IEA expects that:
  - Energy efficiency measures will provide 14 per cent of the emission reductions needed in industry by 2040.
  - By 2040, CCS can be used to capture and store 9 per cent of global emissions from industry and heat and power production.
- Manufacturing industries account for 22 per cent of greenhouse gas emissions in Norway, and according to the process industries' roadmap, CCS and Bio-CCS will provide more than half the emission reductions needed to achieve the Norwegian process industries' vision of reducing emissions to zero by 2050.
- Norwegian industry is world leading in energy-efficient production from national resources.
- Norway produces substantial quantities of nickel, cobalt, silicon, graphite and manganese alloys. These products are used in current types of battery chemistry and in battery production today and will be used in future battery solutions.
- The metal industry and research groups have started R&D on new technology to increase the use of biomass as fuel. This will be of crucial importance for achieving carbon-neutral production.
- Norway's industrial sector is in the unique position of being able both to develop products with a low carbon footprint and to become an important supplier of emission-free energy to the rest of Europe.
- Solutions for all stages of CCS, from capture to transport and permanent offshore storage, are needed for CO_2 emissions from industrial production and heat and power production in the energy system.
- Norway is playing a leading role globally in the field of CCS, which will be enhanced by public funding provided to achieve the Government's ambitions for full-scale CCS in Norway. The full-scale CCS projects will boost Norwegian expertise considerably and create substantial commercial potential through the establishment of full-scale infrastructure for transport and storage of CO_2.
- Norway has Internationally recognised research groups, industrial companies and technology suppliers with world-leading expertise in CCS.
- There is a great deal of capacity for CO_2 storage on the Norwegian continental shelf. This can provide a basis for commercial activities based on deliveries of CO_2 from other countries for permanent storage in formations below the North Sea.

4.6.1
EMISSION CUTS BY NORWEGIAN INDUSTRY AND THE IMPORTANCE OF CCS

There is considerable potential for emission cuts and improvements in energy efficiency in the industry sector, both in Norway and internationally.

Internationally, industry accounts for 18 per cent of total greenhouse gas emissions,[40] and CCS and energy efficiency will be the most important solutions for reducing emissions in the future. Internationally, energy efficiency measures result in lower emissions because there is a high share of fossil energy sources involved. Other important ways of reducing emissions are improving material efficiency, fuel switching, replacing raw materials and introducing new technologies (including CCS). About 19 per cent of the additional emission cuts needed in the 2DS relative to the RTS would come from technologies and processes that are not yet commercially available, so that there is a need for substantial research and technology development.[41]

CO_2 emissions from industry include both emissions associated with the use of fossil energy sources and CO_2 emitted during industrial processes. For example, CO_2 is a by-product of the cement manufacturing process. CCS is often the only option for achieving substantial cuts in such emissions.

In Norway, manufacturing accounts for 22 per cent of greenhouse gas emissions, and these emissions were reduced by 40 per cent between 1990 and 2014. Further emission reductions will require technological breakthroughs, as much of the potential for reducing emissions by using commercially available technologies has already been realised. CCS and greater use of hydrogen and biomass are new options for of achieving further emission cuts in Norwegian industry.[42]

According to the process industries' roadmap, CCS and Bio-CCS[43] will provide 56 per cent of the emission cuts needed to achieve their vision of combining growth and zero emissions by 2050. The roadmap recommends that research on CCS should be strengthened, and that the central government should establish infrastructure for carbon transport and storage and provide support for industrial carbon capture facilities.[44] The IEA expects that by 2040, it will be possible to use CCS to reduce global CO_2 emissions by 9 per cent. This will require the removal of about 1500 Mt CO_2 per year[45] by almost 4000 carbon capture facilities of similar size to those in the planned full-scale Norwegian CCS project. The development of CCS technologies will be vital for achieving the necessary emission cuts, and the global CCS market is expected to grow. Producing hydrogen from natural gas coupled with CCS can provide part of the solution in the transition to a renewable society. Equinor (formerly Statoil) is considering the use of hydrogen produced from natural gas coupled with CCS in connection with electricity production, in gas infrastructure and as fuel for large ships. This may help Norway to maintain its leading position as an environmental and natural gas nation in the time ahead.

In addition to CCS, energy efficiency measures will be important. There is still considerable potential for enhancing energy efficiency by utilising surplus heat from industrial installations in Norway. This "waste" heat is surplus energy that can be used in carbon capture processes. Low-temperature surplus heat can also be used in local and district heating systems, but the potential in this area of application is limited because industrial installations are often located far from potential heat consumers. Further developments in technology are still needed to allow electricity generation from low-temperature surplus heat.

Suppliers that develop new CCS technology and energy-efficiency technology for the industrial sector can expect a substantial international market to develop. Large companies in Norwegian energy-intensive industries that develop their own energy-efficient, low-emission processes will be able to use their smaller climate footprint as a competitive advantage.

4.6.2
NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR, INDUSTRY AND RESEARCH GROUPS

Companies that will play an important role in developing an energy-efficient industrial sector with lower greenhouse gas emissions can be divided into two categories, those in the energy-intensive industries and suppliers of technology and equipment for the sector. In large-scale projects, both categories of companies often play an integral role in development, and this is necessary to achieve the best results.

Norway has a substantial, world-class energy-intensive sector, which is involved in the development of strong technology and expertise clusters. In Norway, this sector has achieved considerable improvements in energy efficiency and cuts in greenhouse gas emissions over a long period. Competitiveness in these industries is closely linked to specific energy costs, and demand for products with a small carbon footprint is expected to rise in the years ahead. Given their leading technology and abundant supplies of renewable energy, there is a potential for increasing value creation by the energy-intensive industries in Norway.

[39,40] *Meld. St. 27 (2016-2017) A greener, smarter and more innovative industry*
[41] *Ibid.*
[42] *Norsk industri (2016), The Norwegian Process Industries' Roadmap*
[43] *Bio-CCS means the use of biomass for energy purposes combined with CCS. Also known as BECCS*
[44] *Norsk industri, https://www.norskindustri.no/dette-jobber-vi-med/energi-og-klima/aktuelt/rapport-anbefaler-regjeringen-ga-videre-med-ccs/ (Roadmap recommends that the Government should continue to support carbon capture projects), March 2018*
[45] *IEA (2017), World Energy Outlook 2017, difference between the New Policies Scenario and the Sustainable Development Scenario*

Several carbon capture technologies are now nearing the commercialisation stage. These are technologies that the industry has been developing with support from the CLIMIT programme and in cooperation with Norwegian CCS research groups. In addition, extensive R&D is being carried out to develop cost-effective solutions for carbon capture technologies and improvements in industrial processes. New options may be possible for carbon capture from various industrial processes, for example involving different ways of modifying the main processes or solutions for integrating industrial processes with the use of already available surplus heat to enhance energy efficiency in industrial installations.

Norway has developed world-leading expertise in offshore CO_2 transport and storage through the Sleipner and Snøhvit projects, which involve industrial-scale storage of CO_2. This expertise will be of crucial importance in the development of Norwegian storage sites that can also be used to store CO_2 from other countries, thus providing substantial potential for industrial development.

Norwegian research groups have world-leading expertise in several areas of CCS. Research groups and industry are cooperating at an FME centre on finding innovative solutions and developing expertise in CCS. In addition, Norwegian and international partners along the entire technology chain have become engaged in plans for full-scale CCS demonstration plants in Norway. They have been building up expertise both on industrial CO_2 sources where various types of carbon capture technology can be used and on infrastructure for permanent CO_2 storage.

Norwegian stakeholders also hold a strong position in the energy efficiency field. Norwegian universities and research institutes have world-leading expertise in fields including process integration and systems thinking, and expertise of high international calibre in heat pump technology. Another FME centre can offer internationally leading expertise, with focus areas that include the use of surplus heat in heat pumps and heat-to-power conversion.

4.6.3 CHALLENGES AND OPPORTUNITIES FOR NORWAY

Norwegian industry is well placed to boost value creation in the years ahead on the basis of sound expertise, technology, energy efficiency and low greenhouse gas emissions.[46] Further development of energy-efficient processes with low greenhouse gas emissions will have implications for Norway's competitive position. The industrial sector and supplier industries together with Norwegian research groups have developed a great deal of expertise, and Norwegian industry is in a good position to continue the development of world-class technology.

Norwegian industry and research groups are working actively on new emission abatement technologies in various fields, including energy efficiency, CCS, hydrogen and biomass.

CCS can be used to remove CO_2 emissions from industrial processes where process emissions derive from the raw materials and not from fuels. This applies for example to chemicals and cement manufacture and to the metallurgical industry. CCS is also of interest in waste management. Since a large proportion of waste consists of biological material, Bio-CCS offers opportunities for achieving negative emissions.

Norcem-Aker Solutions test module for CO_2 capture. *Photo: Gassnova*

Over time, Norway has put considerable resources into CCS, and Norwegian companies and research groups have built up substantial expertise and industrial experience in CO_2 storage, which can provide a basis for new industrial developments.

Solutions for all stages of CCS, from capture to transport and permanent offshore storage, are needed for CO_2 emissions from industrial production and from the large segments of the energy system involved in heat and power production in the energy system. Norway has a strong global position in CCS, which will be strengthened by realisation of the plans for full-scale CCS demonstration projects in Norway. These are expected to lead to valuable results, including the development of expertise and demonstration of the entire chain from carbon capture to transport and storage. In addition, the infrastructure that is built may provide a basis for industrial development through storage of CO_2 from other countries.

Together with full-scale demonstration activities, major investment in research and development will be needed. Demonstration activities will reveal new challenges, which can be most effectively dealt with by extensive, targeted R&D. In addition, long-term R&D will be needed to develop new carbon capture and storage solutions that are much more cost-effective than today's technology.

Social science research will also be needed to identify a commercial and regulatory framework to promote commercialisation of CCS.

Norway's industrial sector is in the unique position of being able both to supply products with a low carbon footprint and to become an important supplier of emission-free energy to the rest of Europe. In this context, hydrogen production coupled with CCS is an important technology area for the future. Globally, industry is the sector that uses most hydrogen, particularly in the manufacture of ammonia and methanol and in refineries. There may be new areas of application for hydrogen in industry in the future, for example as a reducing agent and an energy source. At present, hydrogen is produced largely from fossil fuels (without CCS) because the cost is considerably lower across the world and greater capacity is available than for electrolysis. In addition, there is a potential for Norway to produce hydrogen through reforming of natural gas coupled with CCS.

In many production processes (for example silicon, ferrosilicon and aluminium production), carbon is used as a reducing agent, and it is not currently possible to operate these processes without carbon. At present, fossil sources (petroleum coke and coal) are used, but in theory these could be replaced by biomass. However, there are barriers relating to cost levels, the availability of sustainable biochar and its quality. Nevertheless, several Norwegian companies are considering the use of biomass to reduce emissions. Bioenergy can also be combined with Bio-CCS, which is an option for reducing greenhouse gas emissions.

Norway has substantial expertise in process technology and materials science, and industrial production of many basic materials for future battery solutions, such as nickel, cobalt, silicon, graphite and manganese alloys. These products are also used in current types of battery chemistry and in battery production today. Norway is not a major supplier of these basic materials in the battery value chain today, but there are wide-ranging opportunities in recycling solutions in which Norwegian process industries can play an active part.

Norway is at the forefront of high-grade heat-to-power conversion, and this expertise should be applied to gain a competitive advantage in heat-to-power conversion at lower temperatures as well.

4.6.4 DIGITALISATION AND INDUSTRY

According to the 2017 white paper on Norway's industrial policy[47], there is a large potential for further digitalisation in Norway, with a low level of digitalisation in 53 per cent of the manufacturing sector and only 17 per cent describing themselves as advanced users. The level of digitalisation in the Norwegian manufacturing sector is near the average for the EU, but lower than for the other Nordic countries.

Digitalisation involves more widespread use of sensors in physical components of energy infrastructure, the analysis and use of large quantities of data and a growing degree of computerised control and robotisation. In industry, the digitalisation potential is linked particularly to production operations and predictive maintenance based on precise, up to date information on the condition of in-service equipment. Furthermore, digital solutions can allow the use of autonomous processes and fully computerised control of production processes. Technology for autonomous processes and robotisation is rapidly evolving, and the growing complexity of the tasks that can be carried out using machines is an important factor here. There may be considerably fewer human operators in industrial installations in the future than there are today.

4.6.5 AMBITIONS FOR THE INDUSTRIAL SECTOR

The industrial sector has indicated the following ambitions for climate-friendly manufacturing and CCS during the Energi21 process:

- To expand energy-intensive industries in Norway and achieve substantial cuts in emissions from the sector.
- To produce hydrogen from natural gas coupled with CCS.
- To develop a supplier industry for the energy-intensive industries, including technologies for reducing greenhouse gas emissions and for using and storing surplus heat.

[46,47] *Meld. St. 27 (2016-2017) A greener, smarter and more innovative industry*

- To use low-temperature surplus heat for various purposes (CCS, recovery of resources, etc.).
- To establish a framework for sharing risk and responsibility appropriately so that large-scale international carbon storage in the North Sea basin can be put into practice.
- To develop commercial business models for CCS that expand business opportunities and boost industrial development.
- To establish industrial clusters that make use of synergies between industrial operators and their partners where the industrial sector is aiming to improve integration of energy systems, energy use and CCS.
- To integrate CCS into industrial processes as an international tool for realising climate benefits and producing climate-friendly products.
- To develop ground-breaking technological concepts for CCS that can offer lower costs, improve energy efficiency and minimise technical and financial risk.
- To reduce specific energy consumption and specific greenhouse gas emissions and optimise resource use.
- By 2022, to have planned, completed and put into operation full-scale CCS infrastructure consisting of:
  - carbon capture from Norwegian industry;
  - a flexible CO2 transport solution with interim storage;
  - central carbon storage in the North Sea basin.

- To ensure the development of expertise and cost-effective solutions through knowledge dissemination and national and international cooperation on technology.

4.6.6
ACTION AND IMPORTANT RESEARCH AREAS –INDUSTRY

The Energi21 board recommends the following action and research areas to realise the sector's ambitions and satisfy the knowledge and technology needs of industrial operators:

Action:

- Developing a top-level network on CCS including both industry and politicians to build up mutual expertise and boost confidence and predictability
- Creating arenas of cooperation and encouraging projects partnering industry, supplier companies and research groups to facilitate the development of technology and solutions that will save energy and reduce emissions.
- Developing business models for low-carbon energy (using CCS) through dialogue between industry and decision makers, both nationally and internationally.
- Initiating R&D activity within the strategic research areas identified below.
- Norwegian authorities should continue and develop grant schemes for research, development and demonstration projects on CCS nationally and internationally. There should be a focus on opportunities for joint callsfor proposals and for seamless transitions between different funding instruments.

- Further developing funding instruments for ground-breaking research.
- Supporting the development of emission abatement measures in industry.
- Further developing training programmes in cooperation with industry, combined with expertise in digitalisation.
- Boosting international knowledge sharing and exchange of experience and continuing international cooperation. Following up the 2017 EU implementation plan for CCS and CCU.
- Developing the role of the state as a commercial actor, both as owner of resources and as a contracting authority, linked to requirements for climate-related solutions in procurement processes.
- Ensuring cooperation between Energi21 and Prosess21 on relevant topics.

Strategic research areas:

- Cost-effective and energy-efficient CCS technologies with a minimum level of risk for industrial processes and electricity production, along the whole chain from basic research to innovation and demonstration.
- Carbon capture from industrial processes using biochar as a raw material or energy source (Bio-CCS).
- Hydrogen production from natural gas coupled with CCS.
- Improvement of processes, both incremental and ground-breaking.
- New technology and new solutions for increasing the use of biomass in metal manufacturing, including an industrial initiative for biochar.
- Technologies and solutions for increasing hydrogen use/finding new areas of application for hydrogen in industry.
- New, cost-effective technological solutions and methods for converting and upgrading surplus heat.
- Further development of technical components for heat pump systems and other components to optimise climate-friendly, energy-efficient industrial processes.
- Long-term CO_2 storage.
- New technologies for energy storage integrated with the energy system.
- Utilisation of CO_2 by strategically important industries in Norway, including CO_2 injection for enhanced oil recovery (EOR).
- Social science research on the commercial and regulatory framework for CCS.
- Interdisciplinary research questions in the interface between technology and the social sciences.

[53] *EOR – Enhanced Oil Recovery*

Strengen – Celsa. *Photo: Celsa*

5

Further development of a wide-ranging knowledge and technology platform

No one knows for certain exactly which technologies will succeed in the future energy system or how quickly those technologies will be integrated into the system. It is important to continue further expanding the knowledge and technology platform to extend beyond the strategy's key areas, primarily because these other subject areas will play a role in the energy systems of the future, but also because there is an independent need forfurther development. In light of this, it will be important to lay the foundation for a wide range of options in the form of additional fields that can be developed as strategic key areas if the need arises.

In addition to the six key priority areas, the Energi21 board recommends the development of a wide-ranging knowledge and technology platform in the following areas:

- Energy-efficient and smart buildings
- Hydrogen
- Deep geothermal energy
- Bioenergy
- Climate-friendly energy technologies for land transport
- Climate-friendly energy technologies for air transport
- Land-based wind power
- Other climate-friendly energy technologies with value-creation potential
- Humanities, law and social science disciplines in the interface with Energi21 technology areas

The summary below covers these technology areas except for the last two. Please refer to Attachment 3 for more detailed descriptions.

5.1

Energy-efficient and smart buildings

According to the Energi21 board, energy-efficient and smart buildings are an important field for developing a low-emission society. Buildings will come to play a more active role in the energy system as energy consumers, energy producers and a flexibility resource. In addition, Norway has extensive technology for and expertise in energy-efficient buildings, which provides opportunities for business development.

- The construction sector is a major energy consumer, accounting for 30 per cent of energy use worldwide. Efficient utilisation of energy is an overall objective, and advances in the construction sector are important for establishing a low-emission society.
- Buildings of the future will be an important component of the flexible energy system. The trend in the construction sector is towards "smart building" concepts and ultimately "Smart Cities and Communities", and the sector's development must be increasingly viewed as part of the restructuring of the energy system.[48]
- Smart, energy-efficient buildings can serve as a flexibility resource in the power system (thermal storage and power management) in addition to reducing energy consumption.
- New requirements and new technology will ensure that the buildings of tomorrow are built to low-energy and zero-energy standards, and in the long run will become net producers of energy.
- The slow rate of turnover in buildings makes it essential to exploit the potential for energy efficiency in existing buildings. This potential is substantial.
- New technologies and new building requirements create opportunities for Norwegian actors.
- Norwegian companies and research and education communities active in the construction field have wide-ranging expertise in materials use. Norwegian R&D on systems integration of smart, energy-efficient buildings and cities is also of high quality.
- Norway has come a long way in the design, construction and operation of energy-plus buildings, with widely recognised expertise that is sought after internationally.

5.2

Hydrogen

Hydrogen as an energy carrier can play an important role in several ways in the climate-friendly energy and transport system of the future. The Energi21 board believes that hydrogen can be used to contribute to value creation through the use of Norway's water, wind and gas resources, and as an emission-free energy carrier in a future low-emission society. There is a potential for supplier development in the field of hydrogen technology and solutions.

Various hydrogen technologies and solutions have a role to play in developments in the key areas "Climate-friendly and energy-efficient industry, including carbon capture and storage (CCS)", "Climate-friendly energy technologies for maritime transport" and "Digitalised and integrated energy systems".

- Hydrogen has properties that make it suitable for decarbonising energy production, distribution and storage, and also energy end-use in transport, industry and heating buildings.
- There is a potentially large market for emission-free hydrogen,[49] which would offer opportunities for exports of emission-free Norwegian hydrogen and hydrogen technologies.
- Norway has abundant renewable energy resources that can be used to produce emission-free hydrogen by electrolysis, and natural gas that can be used to produce hydrogen through steam methane reforming combined with CCS.
- Norwegian companies have cutting-edge expertise in electrolysis, filling station technology and compressed hydrogen tanks, long industrial experience of hydrogen technologies and research and education institutions with extensive knowledge of materials and processes.

- The role hydrogen can play in the transformation of energy and transport systems is somewhat uncertain because of challenges related to competitiveness and costs and to infrastructure and technology development.
- Hydrogen must be produced without greenhouse gas emissions if it is to play a part in the transition to a low-emission society, i.e. through electrolysis using renewable power or from fossil energy sources coupled with CCS.

5.3

Deep geothermal energy

There is significant potential to develop geothermal energy production technologies and services aimed at an international market. Such technologies and services will comprise innovations from the oil and gas sector and new technological services directly derived from the sector. Developing a supplier industry in deep geothermal energy has value-creation potential.

- Deep geothermal energy is an important resource in the future international energy supply.
- The ability to produce baseload electric power that is also scalable is a major advantage in a power system increasingly reliant on variable sources.
- Geothermal energy can be used for direct heating or in energy storage systems.
- Geothermal energy technology has a significant potential in both established and emerging markets, and is a priority area in the EU's Strategic Energy Technology (SET) Plan.
- Significant cost reductions are needed to make the technology more competitive.
- EGS (enhanced geothermal systems) are potentially disruptive technologies with large global potential, in addition to substantial potential for energy recovery from supercritical wells.
- Norwegian research, business and industry have comparative advantages based on Norway's petroleum activities, in among other things reservoir modelling and seismic surveying for well drilling and production optimisation.
- Substantial opportunities exist to develop national expertise and technologies in an international market and to contribute to a green shift.

5.4

Bioenergy

Biomass is an energy resource of importance for value creation and emission cuts in several sectors. Biomass from forest offers the greatest unrealised potential, and by-product streams from processing of biomass for various purposes should be used to produce energy. Marine biomass from algae may hold further potential.

Bioenergy is important for developments in the key areas "Climate-friendly and energy-efficient industry, including carbon capture and storage (CCS)", "Climate-friendly energy technologies for maritime transport" and "Digitalised and integrated energy systems".

- Biomass is an important energy source in Norway, and consumption for energy purposes currently corresponds to about 18 TWh per year.[50] The Norwegian Water Resources and Energy Directorate estimates that the realistic potential at present is about 23 TWh.
- Forest is the largest source of biomass in Norway, and consumption of forest resources for energy purposes currently corresponds to about 14 TWh per year.[51]
- Norway's bioenergy resource potential may increase in the period up to 2030. An analysis published in 2015 by the Norwegian Environment Agency estimated that the potential could be increased to 30 TWh, most of it derived from forest biomass. This is based on the assumption that greater use is made of biological residues from households, agriculture and forestry, and that harvesting of forest increases to around 15 million m^3 as a result of an increase in the proportion of mature forest.
- The amount of biomass available can be further increased through cultivation of marine biomass in the form of algae. Norway has expertise and natural resources that put it in a very good position to produce bioenergy from algae, but further research and technology development are needed.

48 *Discussed under the key area "Digitalised and integrated energy systems"*
49 *Produced by electrolysis using renewable power, or from fossil fuels coupled with carbon capture and storage (CCS)*
50 *Norwegian Water Resources and Energy Directorate (2014), Bioenergi i Norge (Bioenergy in Norway)*
51 *Norwegian Environment Agency report (2014): Kunnskapsgrunnlag for lavutslippsutvikling (Knowledge base for low-emission development)*

- Biofuels for the transport sector are of growing interest, and their use has been identified as necessary for achieving emission targets. The authorities have increased the biofuel quota obligation for road transport, and are thus driving demand upwards.
- Almost all the biofuel consumed in Norway is imported, and consumption totals 3.9 TWh biodiesel and bioethanol.[52] There are very few Norwegian manufacturers of liquid biofuels, one of which produces advanced biofuel[53] from by-product streams in a biorefinery.[54]
- Several companies are planning the production of advanced biofuels in Norway, but full-scale production will probably not be reached before around 2020.
- Biofuels are particularly important for heavy freight vehicles and long-distance transport, segments where there are few other climate-friendly alternatives available at present. According to the IEA's Beyond 2°C scenario (B2DS), biofuels will account for 32 per cent of all energy use in the transport sector in 2060.
- Bioresources can also be used in other ways than for energy purposes, and it is vital to ensure profitable, sustainable utilisation of biomass and to consider the value chain as a whole. Co-location of businesses and integrated biorefineries will be at the core of this approach. Bioenergy for biofuels and stationary applications will be derived from various fractions of feedstocks converted in such facilities.
- Using biomass for purposes where fossil fuels are currently used can result in considerable emission reductions. Examples are transport fuels, various chemicals, plastics and other materials. In addition, the process industries have identified the use of biomass in the form of biochar as an important measure for reducing greenhouse gas emissions.

5.5

Climate-friendly energy technologies for land transport

- A large-scale shift to climate-friendly energy technologies is required in the land transport sector in order to achieve emission targets and help to establish a low-emission society.
- This transformation process will trigger large-scale investments globally and thus provide opportunities for Norwegian suppliers.
- Climate-friendly energy technologies must be further developed to achieve wider deployment and more areas of use, and there are major challenges involved in finding solutions for heavy freight and long-distance transport.
- Norway is a pioneer of electrification of the passenger car stock, and can use this head start to build stronger expertise in systems thinking and the integration of new transport solutions.
- Norway has a robust electricity grid that provides security of supply, and large energy resources. This provides a good basis for electrification of the transport sector.
- Norwegian expertise in electrochemistry and materials technology provides opportunities for battery production. There are already suppliers of battery modules for industry and transport in Norway.
- Norway has long industrial experience and expertise in using hydrogen, and is in a good position to develop core technology and components. Norway already has suppliers of hydrogen technology which are leaders in the global market.
- Second- and third-generation biofuels will be part of the solution for achieving emission targets, but the technology is still costly and not yet commercially available.
- Digitalisation will result in changes along the entire value chain for land transport, and there is a potential for developing and offering new transport solutions and services.

5.6

Climate-friendly energy technologies for air transport

In the long term, restructuring the air transport system to accommodate climate-friendly energy technologies will be essential to achieve national and global emissions targets. Energy technologies of particular interest in this context are biofuels, electricity and hydrogen or hydrogen carriers such as NH3. Norway is well positioned for early adoption and use of electric aircraft, with suitable passenger capacities, flight distances, short-runway characteristics and access to electrical power infrastructure.

- Norway's short-runway airport network provides a basis for early adoption and use of electric passenger aircraft, and is appropriate for:

[52] *Statistics Norway, https://www.ssb.no/natur-og-miljo/artikler-og-publikasjoner/bruk-av-biodrivstoff-i-transport [Use of biofuels in the transport sector]*
[53] *From Miljødirektoratet.no: Advanced biofuels are produced from residual materials and waste from food and beverage manufacturing or the agricultural or forestry sector*
[54] *Zero Emission Resource Organisation (ZERO, 2017), Bærekraftig biodrivstoff [Sustainable biofuels]*

- expected performance of first-generation electric aircraft;
- expected passenger capacity;
- expected flight distances;
- short-runway characteristics and electrical power infrastructure.

- The challenges of using biofuels (second- and third-generation) in aviation are tied to excessive cost and insufficient production scale.
- For electric aircraft, the challenges involve the development of slim, compact electric motors and higher-capacity, lower-cost batteries.
- In Norway, the airport operator Avinor has taken a leading active role in environmental and climate efforts and has drawn up a strategy for adapting the country's airports to accommodate sustainable air transport.

5.7

Land-based wind power

Land-based wind power enhances national value creation through the land-based utilisation of wind resources, and the Energi21 board anticipates the expansion of land-based wind power in Norway in the coming years.

Land-based wind power also plays an important role in the key area of "Digitalised and integrated energy systems", where the interaction between different technologies and the energy system is a central theme.

- Globally installed land-based wind power capacity has grown by some 14 per cent annually over the past five years, amounting to roughly 472 GW in 2016.
- The Norwegian-Swedish market for green electricity certificates has been a key driver for expanding land-based wind power in Norway. As cost levels decline, wind power is likely to become more competitive soon, and it will be the price of electricity that determines new development.
- Norway has some of Northern Europe's best wind resources.
- Land-based wind power is a mature technology, but continual advances will further enhance its cost-effectiveness and energy output.
- Norwegian companies with reliable solutions have opportunities as subcontractors in this market, and some are already working in this capacity.
- Norwegian companies are looking to expand their activities as owners of wind farms in Norway and abroad.

Norwegian Railway Directorate. *Photo: Øystein Grue*

6

International research and innovation cooperation

Climate-friendly energy systems of the future will require innovative solutions developed through multidisciplinary national and international cooperation within research, innovation and education. The Energi21 board sees international research cooperation as a crucial part of successful knowledge and technology development for tomorrow's energy systems.

Norwegian presence in international research and innovation arenas is of prime importance for gaining a prominent position, raising the quality of research groups, contributing internationally recognised knowledge to the business sector, and enabling Norwegian research to be implemented in a European and international perspective. Internationally recognised expertise is a key to future competitive products, services and solutions. For Norwegian research groups it is therefore important to take their knowledge wherever knowledge sharing and knowledge production is taking place, and to gain shared access to major international networks and resources. European cooperation is increasingly important to Norwegian research. Since 1994 Norway has participated in and benefited greatly from the EU framework programmes for research, and it is an active participant in several initiatives under the EU Strategic Energy Technology Plan (SET Plan).

6.1

Participation in the EU arena

The EU's research and innovation arena is the main priority for Norway's international research and innovation cooperation. The funds Norway prioritises for European research cooperation represent a large share of the total resources Norway invests in knowledge development and research activity.[55] The objective of strong Norwegian participation is an important way to enable national R&D groups, the business sector and public agencies to benefit from the authorities' international research investments.

Energy and transport are key areas in the EU's research and innovation programmes, infrastructure schemes (such as the European Strategy Forum on Research Infrastructures (ESFRI)) and regional initiatives.

6.1.1 ENERGY UNION

EU energy and climate policy strongly supports the Paris Agreement (COP21).[56] Through its energy union, the European Commission has established a strategy for EU countries to fulfil their Paris Agreement obligations and help to achieve EU energy and climate goals. The EU's energy and climate policies are designed to address the goal of increased supply security, sustainability and competitiveness.

The energy union channels efforts towards five dimensions: security of supply; the internal energy market; decarbonisation of the economy; energy efficiency to moderate energy demand; and research, innovation and competitiveness. As part of the fifth dimension, the European Commission seeks to improve coordination between national research programmes. The goal is a more integrated EU approach and better utilisation of the national and EU resources invested in research and innovation. Important focus areas for strengthened innovation and competitiveness are new-generation renewable energies, smart technologies that make consumers an active force in the energy market, energy efficiency, and a more sustainable transport sector.

6.1.2 THE SET PLAN

An important tool for realising the energy union's fifth dimension – "research, innovation and competitiveness"– is the EU Strategic Energy Technology Plan (SET Plan). The SET Plan is the EU's cooperative arena for accelerating the development and deployment of strategically important thematic and technological areas. The SET Plan is an important element of the technology pillar in EU energy and climate policy.

Energy union's 5th dimension R&I, Competitiveness priorities	SET- Plan (10 Key actions)
No. 1 in Renewables	1. Performant renewable technologies integrated in the system 2. Reduce costs of technologies
Smart EU Energy System with consumer at the centre	3. New technologies & services for consumers 4. Resilience & security of energy system
Efficient Energy Systems	5. New materials & technologies for buildings 6.Energy efficiency for industry
Sustainable Transport	7. Competitive in global battery sector (e-mobility) 8. Renewable fuels 9. CCS/U 10. Nuclear safety

Table 2: The energy union's fifth dimension with its associated focus areas and the SET Plan's 10 priority action areas, which are designed to help realise energy union objectives through increased research, development and innovation.

It aims to increase cooperation between countries and to coordinate relevant financial tools along the entire energy technology innovation chain[57], including market introduction support.

The table below identifies how key actions prioritised under the SET Plan help to achieve the four objectives of the energy union's fifth dimension.

The SET Plan's priorities are dynamic and constantly evolving, though the EU's overall energy and climate objectives for 2030 and 2050 remain fixed. The plan influences energy research priorities, funding instruments and various forms of energy research cooperation. There is a clear link between the SET Plan's priorities and the calls for proposals issued in the EU Framework Programme for Research and Innovation, Horizon 2020.

6.1.3
ORGANISATION OF SET PLAN EFFORTS

The European Commission heads the SET Plan Steering Group and hosts its secretariat. The Steering Group is made up of representatives of EU countries and associated countries as well as the European Commission. The Steering Group ensures that SET Plan activities are carried out in accordance with its strategy and action plan.

Norway holds an observer position (with the right to speak) in the Steering Group and is represented by the Ministry of Petroleum and Energy. The Research Council of Norway takes part as national expert.

European Energy Research Alliance - EERA

EERA was established by the European Commission as the SET Plan's research pillar. EERA has 250 member organisations from institutes and universities, encompassing more than 50 000 researchers active in the field of energy. EERA typically covers Technology Readiness Levels (TRLs) 2/3 to 5/6.

EERA's activities emphasise efficient use of research funding, improved coordination and division of labour, and expanded cooperation among European research institutions through the 17 EERA Joint Programmes. The universities are also represented as observers on the EERA Executive Committee through the European University Association/ European Platform of Universities in Energy Research & Education (EUA/EPUE). Many universities are EERA members as well.

EERA participates in the SET Plan Steering Group, where it provides progress updates on its Joint Programmes and implementation plans for the 10 key action priorities. SINTEF Energy is one of 15 institutes constituting EERA's core group. In addition, as of June 2018 the chair of EERA is a Norwegian. Norway is also represented in EERA's Joint Programmes and leads the programmes on Carbon Capture and Storage, Energy Efficiency in Industrial Processes, Smart Cities and Geothermal.

European Technology & Innovation Platforms (ETIP)

European Technology & Innovation Platforms (ETIP) is an industry-led group of stakeholders active in specific systems or technology areas. The individual platforms (ETIPs) typically cover TRL levels 5/6 to 9. There are nine ETIPs that deal with energy. In addition, there are public-private partnerships (PPPs), joint undertakings (JUs) and joint technology initiatives (JTIs). Of particular importance in the energy field are Sustainable Process Industries through Resource and Energy Efficiency (SPIRE), the Energy Materials Industrial Research Initiative (EMIRI) and the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). The FCH JU, in which Norway is represented, channels nearly all fuel cell and hydrogen R&D in Europe.

SET Plan information system (SETIS)

The Strategic Energy Technologies Information System (SETIS) prepares analyses, documentation, statistics and other support materials for decision-makers.
http://setis.ec.europa.eu/

Efforts to develop a roadmap for energy R&D and innovation under the SET Plan have been under way since 2014. The result is a roadmap of recommended actions, instruments, investment needs and time schedules. There are 14 implementation plans covering a variety of thematic areas. In essence the implementation plans amount to a common plan for energy research and innovation in Europe that has been accepted by the SET Plan countries, the business sector and stakeholders in education and innovation. The plans contain priority actions and focus areas with TRLs from 2 to 8/9. Funding for these must come from the countries and the stakeholders themselves, so the primary use of the EU's funding instrument is to mobilise individual national efforts and create value for Europe as a whole. The R&D tasks given priority in the implementation plans are expected to influence the design of calls for proposals under Horizon 2020 as well as the targets of the next framework programme to come.

6.1.4
HORIZON 2020

Horizon 2020 is the EU's Framework Programme for Research and Innovation for the 2014–2020 period. It is the world's largest research and innovation programme, with a total budget of EUR 77 billion. Horizon 2020 is important to Norwegian research efforts, which draw on the programme to enhance the quality and relevance of Norwegian knowledge and technology development. Norway participates in

[55] *The Government's Strategy for research and innovation cooperation with the EU, 2014*
[56] *United Nations Climate Change, http://unfccc.int/2860.php*
[57] *Innovation chain: research, development, testing and demonstration, commercialisation.*
[58] *European Economic Area (EEA) Agreement (1994) and EEA Joint Committee decision of 16 May 2014*

Solar laboratory at Institute for Energy Technology (IFE) Kjeller. *Photo: IFE*

Horizon 2020 on an equal footing with EU countries.[58] Horizon 2020 provides support to the EU's Europe 2020 growth strategy, including the flagship Innovation Union initiative and development of the European Research Area (ERA). The results of the programme are intended to create jobs and drive economic growth while strengthening Europe's position in research, innovation and technology.

The programme covers the entire innovation chain from idea to application (market). Special emphasis is given to innovation, with a focus on business sector participation and the benefit to society of project results. New instruments have also been introduced to secure access to risk capital and boost commercialisation and innovation.

Secure, Clean and Efficient Energy is one of seven Societal Challenges prioritised in Horizon 2020. The energy programme has a total budget of EUR 5.1 billion. The programme provides support for projects related to:

- energy efficiency and smart systems in Europe's building stock;
- global leadership in renewable energy technologies;
- solutions providing for smart, low-emission energy systems at consumer level;
- smart regional, national and cross-border energy systems;
- smart cities and towns with integrated, low-emission energy systems;
- a goal of zero emissions from fossil-based power plants and CO_2-intensive industry.

Priority is given to interdisciplinary research and innovation efforts, and social science research is given greater focus than in previous framework programmes.

6.1.5 COORDINATION BETWEEN ENERGI21 AND THE EU RESEARCH AND INNOVATION AGENDA

The Energi21 strategy document harmonises well with the EU research and innovation agenda for the energy sphere. The SET Plan and Energi21 strategies have multiple focus areas in common as well as actions needed to realise objectives and ambitions.

The Energi21 board recommends:

- continued efforts to influence EU research and innovation programmes in the aim of ensuring that initiatives on the EU research agenda address topics of common interest for the EU and Norway;
- activities to facilitate increased research cooperation between the EU and EEA countries linked to the countries' national R&D budgets;
- effective dialogue and communication between the Energi21 board and Norway's SET Plan representatives concerning national and European scientific priorities.

6.1.6
IMPORTANCE AND IMPACTS OF EU COOPERATION

Increasing the participation of the energy industry in the EU arena is important, and Energi21 is supportive of such efforts.

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

- Mutual enhancement of research quality among national and international research groups;
- Increased opportunity for international networks and international recruitment;
- Access to newly developed knowledge;
- Greater career development opportunity for individual researchers;
- Increased ability to innovate and compete in global and European markets;
- Effective international solutions in sustainable energy supply and the transport sector.

EU cooperation also provides opportunities for Norway to share the cost of large-scale research infrastructure and to increase access to such infrastructure.

Active participation in EU projects may also increase attractiveness as a partner in Europe and around the world.[59] It increases an organisation's international visibility while providing promotional opportunities for its products, services and knowledge resources.

The Energi21 board recommends:

- Continued efforts to increase the participation of researchers, research and education groups and business operators in EU framework programmes for research and innovation.

6.1.7
NORWEGIAN PARTICIPATION IN HORIZON 2020 AND INTENSIFIED EFFORTS

Norwegian actors are performing well in Horizon 2020's energy programme. The Norwegian share of the EU contribution was 4.7 per cent in 2017, and every fourth application was recommended for funding. This equates to a success rate of 25 per cent. The most successful energy areas as measured in project funds granted are energy systems, carbon capture and storage (CCS), hydrogen and fuel cells as well as smart cities and towns.[60] The potential benefits of European research and innovation cooperation could be better utilised in a number of other subject areas.

Differing frameworks for business sector participation

The various energy sector stakeholders have differing frameworks for establishing and implementing EU research and innovation cooperation. 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 the interest and desire for participation. Companies with extensive international activities 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, knowledge and knowledge exchange activities.

Energi21 attached importance to instruments designed to lower the threshold and reduce the difficulties of business sector participation in EU research.

Energi21 recommends the following measures to increase Norwegian business sector participation in EU research activities:

- Annual survey documenting barriers to business sector participation in EU projects. Based on the study's findings, develop solutions and measures to help companies better utilise the scope of opportunities associated with EU research and innovation cooperation. The survey may be tailored to account for different industry structures in the different fields. Whether or not major Norwegian players are active in a given field makes a difference to the approach taken.
- Stronger financial incentives for research institutions to incorporate the Norwegian business sector in projects they participate in or lead.
  - Centre schemes (Centres for Environment-friendly Energy Research (FME)) in thematic areas where increased EU cooperation is sought. One possibility is an incentive scheme introducing the option of dedicated internationalisation funds for EU participation in existing, and possibly new, FME centres as a "no cure-no pay" scheme.

[59] *The Government's Strategy for research and innovation cooperation with the EU, 2014*
[60] *Source: Research Council of Norway*

Energi21 recommends the following measures to increase participation by Norwegian research groups in EU research:

- Reward EU participation and cooperation with a leading European research group when assessing applications submitted to the Research Council.
- Establish a principle for covering costs of participation in research projects for the research groups (corresponding to Research Council rates):
  - Need for measures for research institutes (increase rate for the Scheme to encourage increased participation in the EU framework programme among research institutes (STIM-EU))[61]
    - Include a special quantification system (not the same as in STIM-EU) for EU participation in connection with basic funding for research institutions.
- Continue and strengthen measures related to participation in EU strategic processes.
- Continue strategic development of large-scale research infrastructure (National Financing Initiative for Research Infrastructure (INFRASTRUKTUR), participation in the European Strategy Forum on Research Infrastructures (ESFRI)).

6.2

Mission Innovation

Mission Innovation[62] is a collaborative international 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 try 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 June 2017 the European Commission assumed leadership of the Steering Committee from the US Department of Energy (DOE). Mission Innovation's member countries have prioritised seven technology challenges as a basis for collaboration:

- 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 does not, however, have a large secretariat; nor are there any plans to establish an arena for administering joint research funding. Operationalising the initiative will probably require bilateral and multilateral cooperation agreements and the use of already established cooperation arenas, such as the International Energy Agency's Technology Collaboration Programmes, in which the European Commission is a partner through Horizon 2020.

Norway has signalled that it will participate in all seven prioritised technology challenges, but it has reported particular interest in those involving smart grids, carbon capture and storage (CCS) and biofuels. To date, the main activity has been identifying common challenges and opportunities. Norway is paying close attention to how the efforts develop. Specific collaboration initiatives will be considered as they arise.

The Energi21 board recommends:

Further developing collaborative Norwegian positions in international research and innovation arenas where the effect would be greatest, such as increased quality in knowledge development, access to and improvement of advanced technology, and access to networks and markets for Norwegian and international stakeholders.

6.3

IEA, Nordic and bilateral research cooperation

IEA cooperation

The International Energy Agency (IEA) is the most important collaborative arena outside the EU. Norway participates in 20 of the IEA's 38 Technology Collaboration Programmes (TCPs). These are programmes in the main areas of energy use, renewable energy and fossil fuels energy. Important topics under the energy use area include buildings, energy storage, district heating, heat pumps and energy systems. In the renewable energy area, Norway takes part in solar energy (photovoltaics and solar heating), wind energy, ocean energy, hydropower, bioenergy, geothermal energy and hydrogen energy. Within fossil fuels energy, Norway is active in programmes on greenhouse gas technologies (CCS etc.), oil and gas technologies and enhanced oil recovery. More information about IEA technology programmes and Norwegian participation is available at www.iea.no.

Skjerka hydropower plant. *Photo: Agder Energi*

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 institution 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.

[61] *The present status for universities and the business sector is satisfactory*
[62] *Mission Innovation, http://mission-innovation.net/*

Bilateral research collaboration

The United States is the most important country for bilateral cooperation outside the EU, and is also the country with the largest number of respected research institutions. Norway also has a longstanding favourable tax treaty with the United States that makes research stays at US universities attractive for Norwegian researchers. Bilateral collaboration with rising research nations outside Europe and the United States should be given priority if it would increase research quality, help to develop vital knowledge and allow Norwegian business interests to access international markets. Strong and rapidly emerging economies in Asia are areas of interest, and Japan, China and India are priority partner countries. Japan, for example, is of great interest in hydrogen technology while China is increasing its R&D efforts significantly and has a larger R&D budget than Europe.

7

Achieving the strategy's recommendations

Building tomorrow's climate-friendly energy and transport system will require considerable investment in research, innovation and increased commercialisation to promote development of future products and services.

7.1	Further develop a dynamic framework of funding instruments to promote rapid innovation
7.2	Increase the budget for research and innovation projects
7.3	Strengthen research and demonstration projects for commercialisation of research results
7.4	Facilitate Norwegian participation in international research and demonstration projects
7.5	Further develop the PILOT-E scheme for enhanced supplier development
7.6	Strengthen the funding instruments promoting innovation and renewal in the energy sector
7.7	Ensure strategic cooperation between the ministries' industry-specific "21" strategy processes
7.8	Establish innovative recruitment methods to ensure access to trained personnel and the necessary expertise

Substantial restructuring is called for in order to meet national and international targets for sustainability and greenhouse gas reduction. The UN Sustainable Development Goals emphasise the environment and climate as separate goals as well as priority areas under other goals and as a cross-cutting dimension of the sustainable development agenda. The challenges to be solved are large in scale, but they also hold a great potential for global and national value creation.

Better growth, lower emissions – the Norwegian Government's strategy for green competitiveness identifies activities targeted towards environment-friendly energy as one of the main priority areas needed within research, innovation and technology development to realise the ambition of becoming a low-emission society by 2050.

The Energi21 strategy is based on industrial ambitions for future value creation and on assessments of future knowledge and technology needs. Fulfilling the aims of the Energi21 strategy will require involvement and effort from the business sector, research and educational institutions, and the authorities.

Cooperation between these actors will be essential for achieving the Energi21 ambitions and ensuring that the necessary research activity is carried out. Unceasing focus on long-term objectives combined with effective action in the shorter term will be key to realising the ambitions. Business communities and industry must take part in knowledge and technology development by taking risks and investing time and capital in research and innovation activities.

Norway has a well-established, coordinated research and innovation system that encompasses the entire innovation chain. But looking ahead, there will be a need for even more dynamic instruments and incentives to promote more rapid knowledge-building, more efficient implementation of research activities, faster technology development and accelerated implementation of new technology and solutions in the market.

Activities carried out in Norway's research and innovation system should reflect the key areas set out in the Energi21 strategy. This applies to instruments used by the Research Council of Norway, Gassnova, Enova, the Norwegian Water Resources and Energy Directorate (NVE) and Innovation Norway.

The Energi21 board proposes the following measures to realise the strategy's recommendations:

1. Further develop a dynamic, unified framework of funding instruments to promote rapid innovation and realisation of projects.
2. Increase the budget for research and innovation projects.
3. Strengthen research and demonstration projects for commercialisation of research results.
4. Facilitate Norwegian participation in international research and demonstration projects.
5. Further develop the PILOT-E scheme for enhanced supplier development.
6. Strengthen the funding instruments promoting innovation and renewal in the energy sector.
7. Ensure strategic cooperation between the ministries' industry-specific "21" strategy processes.
8. Establish innovative recruitment methods to ensure access to trained personnel and the necessary expertise.

7.1

Further develop a dynamic framework of funding instruments to promote rapid innovation

New technology must be developed, new knowledge is called for and a faster pace of innovation is critical for achieving the climate targets while strengthening national value creation. Research is inherently long-term and time-intensive, but we should seek to implement the results more quickly and design incentives for creating tomorrow's solutions.

The research community will be constantly challenged to generate research results that address the business sector's needs for new technologies and solutions. Therefore it is vital that Norway's public agencies in the research and innovation system are dynamic and able to adjust to the needs of trade and industry and society at large to realise projects and results more quickly.

The Energi21 board recommends:

- The Energi21 board recommends further developing the public agencies in the research and innovation system for the energy sector, in step with the need for rapid development of technology and knowledge. Instruments are needed to promote prompt realisation of research and innovation projects and more rapid market implementation of results by the business sector.

Programmes:	Current budget levels (2018), NOK million	2019 NOK million	2020 NOK million	2021 NOK million	2022 NOK million	Total growth NOK million
ENERGIX	416.5	+90	+90	+90	+90	+360
CLIMIT-FoU	92	+10	+10	+10	+10	+40
FME	182	+20	+20	+20	+20	+80
Total	691	+120	+120	+120	+120	+480

Allocations from the Ministry of Petroleum and Energy comprise NOK 535.6 million of the 2018 total.

7.2

Increase the budget for research and innovation projects

The Agreement on Climate Policy reached in the Storting in 2008 resulted in a significant rise in funding for research and development relating to climate-friendly energy technologies in 2009 and 2010. Since then, there has been no corresponding increase, however.

The development of new climate-friendly energy technologies is essential for value creation related to resource utilisation and supplier development. The level and pace of research and innovation activities will be critical to be able to take advantage of opportunities and gain prominence in relevant markets. There is also a need for rapid market introduction of climate-friendly energy technologies for meeting Norway's emissions commitments.

Many countries are now investing significant public resources in technology development related to environment-friendly energy, both to meet their own climate commitments and to enhance competitiveness in their respective business sectors. The need to accelerate the development of environment-friendly energy technologies in order to achieve the climate targets is also the starting point for activities under Mission Innovation,[63] cf. Chapter 6.9.

In the report *Better Business, Better World*,[64] presented in Davos in 2017, business leaders and civil society representatives calculated the business opportunities that the UN Sustainable Development Goals open up within four different economic systems. The estimated annual value creation potential totalled USD 12 trillion (10–12 times the size of the Norwegian oil fund). Many of these opportunities are in the spheres of energy, transport and infrastructure, which are encompassed under the Energi21 strategy. With its substantial energy resources, industry in the energy and energy-intensive sectors, and research groups, Norway is particularly well-equipped to achieve new value creation within environment-friendly energy and low-emission technologies.

A concerted effort to develop climate-friendly energy technologies will involve a number of different sectors (energy, forestry, agriculture, the oceans, transport/communications, climate/environment, construction, industry) and thus multiple ministries. In recent years, there have been significant costs to society due to climate change, including in Norway. Compensation related to damages from natural disasters and surface water has increased substantially, and in the period 2008–2017 amounted to NOK 8.9 and 10 billion, respectively.[65]

The energy system is one of society's most important infrastructures. Solutions to future societal challenges will encompass both new and immature energy technologies and require large-scale research and development activity. Additionally there is a need to expand R&D budgets to enable existing and new industry to develop new ideas and seize the opportunities discussed above.

As of 2018 there is a large volume of applications for funding for research and innovation projects, with a high level of interest from the business sector. This is a solid starting point, and the recommended budget growth will provide the knowledge and technology development needed for future business development and value creation.

The Energi21 board recommends:

- The Energi21 board recommends a budget increase of NOK 480 million in public funding for research and innovation projects in the energy sector for the period 2019–2022.
- This budget growth is to be administered by the Research Council through the budgets of the Large-scale Programme for Energy Research (ENERGIX), the Norwegian RD&D CCS Programme CLIMIT R&D) and the Centres for Environment-friendly Energy Research (FME) scheme. The Energi21 board recommends that the distribution of funding to thematic areas follows the key areas set out in the Energi21 strategy. The table below shows recommended budget growth for the period 2019–2022 distributed across the ENERGIX programme, the CLIMIT R&D programme and the FME scheme.

[63] *http://mission-innovation.net/*
[64] *http://report.businesscommission.org/*
[65] *Finance Norway*

Installation of new spiral case at Iveland hydropower plant. *Photo: Agder Energi*

7.3

Strengthen research and demonstration projects for commercialisation of research results

It is very important to strengthen research and demonstration projects in order to achieve rapid deployment of new technological solutions. Technology development entails substantial costs and high risk for companies. Public funding instruments must be adapted to the need for capital and in relation to risk profile in the different phases of the innovation chain, from R&D to commercialisation. Although ideation, research and concept development are demanding phases, the companies' risks and need for capital multiply exponentially when projects reach the pilot and demonstration phase.

The Government's initiative to promote new energy and climate technology, administered by Enova, is essential for developing and commercialising future climate-friendly energy technologies. A number of key areas in the Energi21 strategy require the testing and demonstration of projects in order to develop suppliers towards an international market.

Enova's funding instruments are well-designed and encompass all the key areas set out in the Energi21 strategy. These instruments give companies the chance to advance in their innovation pathway and move closer to commercialisation of technologies and services. However, this is assuming that Enova employs the strategy's recommendations as its basis when these are relevant to the allocation and prioritisation of grants from the Climate and Energy Fund. To achieve an integrated innovation chain, it is important to focus on continued development and realisation of results from research activities when allocating grants from the fund.

The Energi21 board recommends:

- The Energi21 board recommends that Enova employs the strategy's recommendations as its basis where these are relevant to the allocation and prioritisation of grants from the Climate and Energy Fund. The Government's initiative for energy and climate technology, administered by Enova, will play a vital role in addressing the key areas set out in the Energi21 strategy.

7.4

Facilitate Norwegian participation in international research and demonstration projects

Many Norwegian industrial actors develop technology exclusively for the international market. The absence of a domestic market means they need entry into international research and demonstration projects. A case in point is offshore wind power. The market for floating offshore wind power technology is relatively immature, its development is occurring on the continental shelves of countries other than Norway, and risk-mitigation instruments are needed.

If the Norwegian public agencies within the research and innovation system are to help Norwegian companies to position themselves for developing internationally competitive technologies, the funding instruments currently in place must be adapted for this purpose. Internationally oriented funding instruments should both be targeted towards Norwegian industry actors and at the same be adapted to the EU state aid rules.

The Energi21 board recommends:

- Further developing funding instruments that help Norwegian companies to position themselves for and develop internationally competitive technologies and services.
- Establishing funding instruments that afford Norwegian companies the opportunity to participate in international research and demonstration projects.

7.5

Further develop the PILOT-E scheme for enhanced supplier development

The PILOT-E scheme provides funding for Norwegian trade and industry, and was launched as a collaboration between the Research Council, Innovation Norway and Enova. The scheme is designed to assist companies through the entire technology development pathway and promote more rapid development and deployment of new products and services within environment-friendly energy technology.

The PILOT-E scheme has been well received by the business sector and research groups. The scheme has relevance for technology areas with societal challenges, national markets and a potential for business and supplier development.

The Energi21 board recommends that the relevant agencies within the research and innovation system (Research Council of Norway, Enova, Gassnova and Innovation Norway) continue their effective cooperation on creating a unified framework of funding instruments along the entire innovation chain from concept to market. Their joint funding instrument, the PILOT-E scheme, should be further developed and strengthened to accommodate more funding announcements in more technology areas that have benefit to society and potential for supplier development.

The Energi21 board recommends:

- The Energi21 board recommends further developing a unified framework of funding instruments along the entire innovation chain and strengthening the PILOT-E funding scheme for enhanced supplier development and value creation within selected technology areas. In 2018 the PILOT-E scheme had a total budget of NOK 100 million. The Energi21 board recommends increasing this by NOK 200 million over the period 2019–2022 to a total of 300 million.

7.6

Strengthen the funding instruments promoting innovation and renewal in the energy sector

It is the Government's stated ambition for Norway to become one of Europe's most innovative countries in the long term. The Research Council promotes innovation based on existing industry as well as on research results from universities and research institutes. The universities and some of the research institutes have established technology transfer offices (TTOs) for verification of the research results that are best suited for commercialisation.

The TTOs receive funding for their activities under the Research Council's programme Commercialising R&D Results (FORNY2020). In addition Innovation Norway has established a seed fund with private capital where newly established companies may seek equity in an early phase. As these companies mature, there are venture funds of both private and public nature (via Investinor) that can inject further equity as the need increases.

Increased allocations under the FORNY2020 programme and establishing more seed funds to help young companies gain access to early-phase equity should be considered. These are important funding instruments that pertain to all business segments. Companies in the field of sustainable energy must be ensured appropriate standing in the overall context of a funding instrument system of this type.

The Energi21 board recommends:

- Strengthening funding for innovation and new thinking via FORNY2020.
- Increase annual allocations to the FORNY2020 programme from NOK 300 million to NOK 600 million in keeping with the work programme.
- Strengthening funding for innovation and new thinking via seed funds.
- Increase Innovation Norway's investments in seed funds by NOK 1 billion.
- Strengthening funding for innovation and new thinking via the Research Council's Innovation Projects.
- Expand the frameworks for funding to Innovation Projects under the Research Council's Large-scale Programme for Energy Research (ENERGIX) and the Norwegian RD&D CCS programme (CLIMIT).

7.7

Ensure strategic cooperation between the ministries' industry-specific "21" strategy processes

Several of the Energi21 strategy's key areas will be dependent on sectoral cooperation at the central government administrative level to be realised. Inadequate strategic cooperation leads to a lack of continuity, with certain technology areas ending up in a "no-man's land" and much-needed development of knowledge and technology falling by the wayside. Insufficient knowledge and technology development is unfortunate for research and industry actors alike as well as for value creation in general within the technology areas in question.

It is essential that the ministries continue to cooperate effectively across sectors. This is of the utmost importance for knowledge and technology development and, not least, business development within the energy sector.

A number of ministries have initiated and established advisory "21" strategic bodies and drawn up strategy documents corresponding to the Energi21 initiative. Some of these have scientific mandates that share an interface with the Energi21 sphere of activity. In addition there are synergies to be gained from closer cooperation between these strategy processes.

The table below shows which "21" strategy processes share an interface with key areas in the Energi21 strategy:

The Energi21 board recommends:

- The Energi21 board recommends cooperation with the OG21, Digital21, Prosess21, Maritim21, Hav21, Skog22, Bygg21 and Transport21 strategy processes in order to harmonise strategic key areas and exploit the synergies found in the overlapping areas in their scientific mandates. This will facilitate integrated research strategies and development within the relevant thematic and technology areas.

	OG21	Digital21	Prosess21	Maritim21	Hav21	Skog22	Bygg21	Transport21
Digitalised and integrated energy systems	x	x	x			x	x	x
Climate-friendly and energy-efficient industry, including CCS	x	x	x			x		
Climate-friendly energy technologies for maritime transport	x	x		x	x	x		x
Offshore wind power for an international market	x	x		x	x			
Solar power for an international market		x	x					
Hydropower as the backbone of the norwegian energy supply		x						

7.8

Establish innovative recruitment methods to ensure access to trained personnel and the necessary expertise

The energy industry is developing rapidly and is becoming ever more dependent on human knowledge resources capable of innovating and participating in multidisciplinary, cross-sectoral collaboration. Tomorrow's digitalised and integrated energy system will be dependent on businesses and access to know-how that are dynamic and adapt quickly to the challenges at hand.

Digitalisation as well as the anticipated general developments in technology, markets and society at large will require faster renewal of competence and more combined specialties. One example is taking good advantage of the opportunities inherent in digitalisation, where achieving the desired functionality and benefit will require ICT as well as discipline- and industry-specific expertise.

It is important that new graduates from energy-related educational programmes possess up-to-date, relevant ICT skills that the energy industry needs. Developments in ICT lead to challenges and opportunities that the industry has to address. In recent years some 500 new student places in ICT have been created, with only a small number of these in energy-related education.

Access to the right candidates is dependent on competent educational environments as well as promoting science studies along with future-oriented combined specialties at early educational levels. Cooperation between the authorities, educational institutions and trade and industry is necessary for updating curriculums, conducting practical training and marketing job opportunities in the energy sector.

The Energi21 board recommends:

- The Energi21 board recommends developing instruments to support innovative knowledge development and recruitment methods to ensure that the energy industry will have access to personnel with future-oriented expertise.
- In this context, cooperation between research and educational institutions and the authorities is essential when designing future educational programmes.

Innovative knowledge development can be strengthened in the following ways, among others:

- Closer links between the business sector (individual companies and industrial clusters) and academia through e.g. ongoing cooperation on curriculums and competency objectives that are in line with industry's needs.
- More work practice integrated into the educational programmes, where the host company receives more compensation.
- Strengthen the Industrial Ph.D. scheme and efforts to promote industry-oriented master's-level education.
- Adapt existing laboratory facilities to new demands for competence.
- Integrate ICT expertise into energy-related educational programmes and ensure that the energy industry has access to candidates with relevant ICT skills.
- Strengthen efforts to promote power electronics in energy-related educational programmes in order to meet the need for competence in design, construction and operation of digitalised and integrated energy systems.

Transmission tower work, Statnett. *Photo: Johan Wildhagen*

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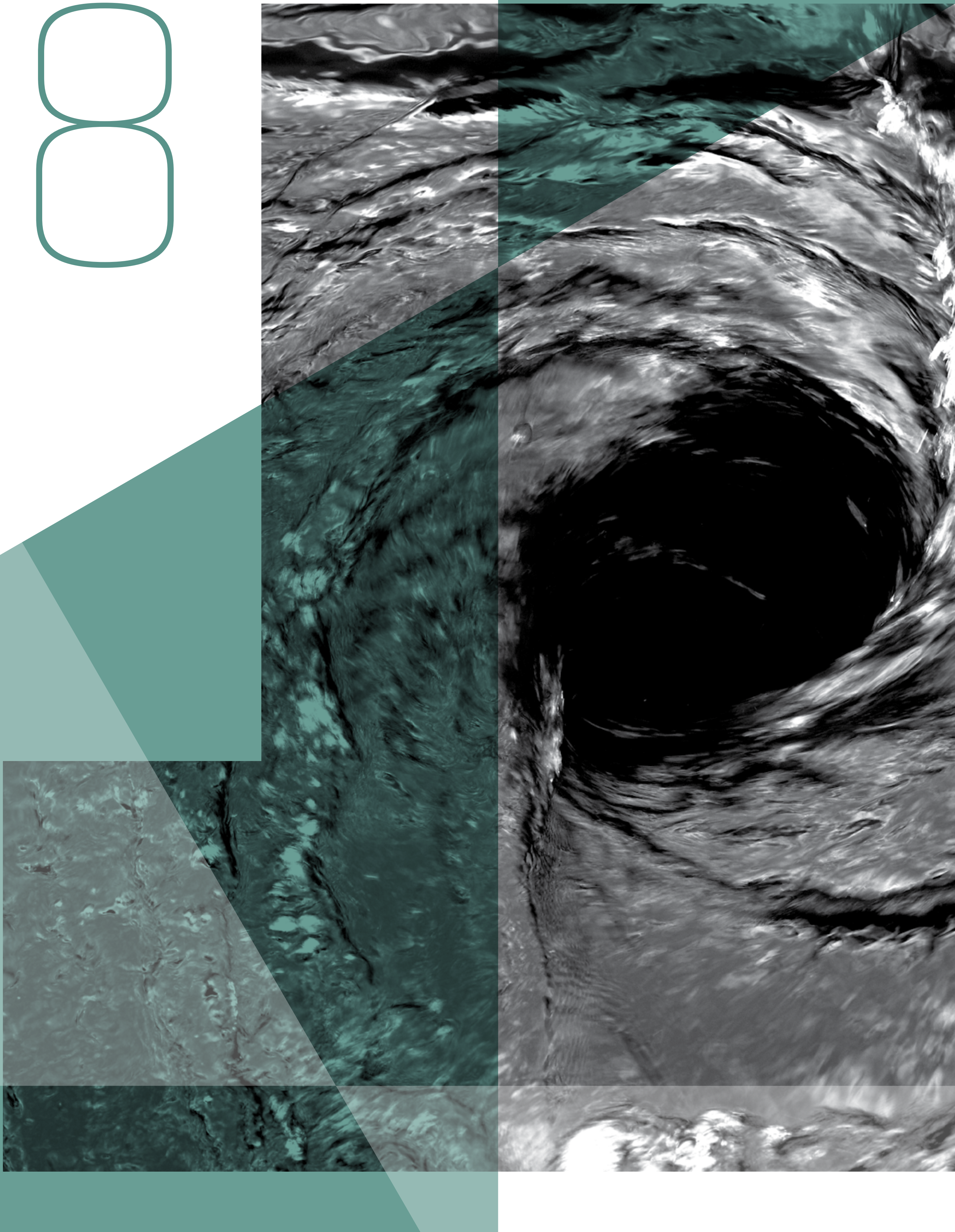


Attachments

Attachment 1

Energi21 – Mandate from the Ministry of Petroleum and Energy

The Energi21 board is appointed by the Minister of Petroleum and Energy. The purpose, responsibilities and tasks of the board are set out in the mandate issued by the Ministry of Petroleum and Energy. The mandate is presented below.

Mandate for Energi21, 1 November 2016

The objective of the Energi21 strategy

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, which are:

- To increase value creation on the basis of national energy resources and utilisation of energy.
- To facilitate energy restructuring with the development of new technology to limit energy consumption and greenhouse gas emissions while efficiently producing environment-friendly energy.
- To develop internationally competitive industry and expertise in the energy sector.

The objective of the strategy is to ensure sustainable value creation and security of energy supply by improving coordination of and energy industry participation in research, development, demonstration and commercialisation of new energy technology for stationary purposes and transport.

The strategy will also target knowledge-building activities that can make Norway an important supplier of environment-friendly energy, system services, knowledge and technology to Europe.

To achieve this, the strategy is also to encompass international cooperation on research and technology, with a particular emphasis on strengthening research and innovation collaboration with the EU and promoting increased Norwegian participation in EU energy projects.

The strategy is to foster integrated thinking around the development of new energy technology by bringing the authorities, trade and industry and research communities closer together. Another aim is to generate greater support for energy research in general and encourage industry to increase its investment in R&D activities.

The tasks of the board

The Energi21 board is to organise and lead the process of drawing up and implementing the revised Energi21 strategy in accordance with its purpose. The strategy must be drawn up in communication with and based on needs of the relevant stakeholders, such as energy companies and supplier companies, research communities, allocating authorities, the Research Council of Norway, 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. The board is also to assess the need to establish working groups in the priority focus areas and follow up the work of any such groups. The board must remain apprised and take adequate account of national strategies and activities of significance for the Energi21 strategy. These include, for example, the Government's bioenergy strategy, the Norwegian Hydrogen Strategy and the authorities' carbon capture and storage (CCS) initiatives.

The board is to provide input to the allocating authorities (including the Research Council, Enova and Innovation Norway) and the energy industry regarding research priorities in relation to the Energi21 strategy. The board is to assist the research communities in mapping the types of expertise that will be required by energy companies and the supplier industry.

The board is to help to coordinate research activities and motivate energy companies (their boards and management) 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 is to be updated every two to three years.

Attachment 2

The Energi21 board and administration

The Energi21 board is appointed by the Minister of Petroleum and Energy:

Sverre Aam, chair,	SINTEF Energy Research
Ragne Hildrum,	Statkraft
Anne Jorun Aas	SIGLA
Sigrid Hjørnegård	Energy Norway
Lars Kr. Vormedal	Statnett
Arne Sveen	ABB
Unni Farestveit	Agder Energi AS
Erik Figenbaum	Institute of Transport Economics
Olav Bjarte Fosso	Norwegian University of Science and Technology (NTNU)
Nils Morten Huseby	Institute for Energy Technology (IFE)
Rune Volla	Research Council of Norway
Hans Jørgen Vinje	Gassnova
Audhild Kvam	Enova - until 1 Feb 2018
Gunnel Fottland	Enova - from 23 Feb 2018

Observers:

William Christensen	Norwegian Ministry of Petroleum and Energy
Torgeir Knutsen	Norwegian Ministry of Petroleum and Energy
Tore Grunne	Norwegian Ministry of Petroleum and Energy
Jun Elin Wiik Totain	Norwegian Water Resources and Energy Directorate (NVE)

Attachment 2.1

Management and day-to-day activities of Energi21

The day-to-day strategic activities are headed by Director Lene Mostue.

The Energi21 board reports directly to the Ministry of Petroleum and Energy.

The Research Council provides office space and support systems for the Energi21 administration. The administration consists of one position affiliated with the Research Council of Norway.

Energi21 is financed by the Ministry of Petroleum and Energy and industry stakeholders.

For more information about Energi21
see www.energi21.no

or contact
Lene Mostue directly at lm@rcn.no.

Attachment 3

Technology areas recommended for inclusion in a knowledge and technology platform

In addition to the six key priority areas, the Energi21 board recommends the development of a wide-ranging knowledge and technology platform in the following areas:

- Energy-efficient and smart buildings
- Hydrogen
- Bioenergy
- Carbon capture and storage (CCS)
- Deep geothermal energy
- Climate-friendly energy technologies for land transport
- Climate-friendly energy technologies for air transport
- Land-based wind power
- Other climate-friendly energy technologies with value-creation potential
- Humanities, law and social science disciplines in the interface with Energi21 technology areas.

3.1

Energy-efficient and smart buildings

The Energi21 board considers energy-efficient buildings and smart buildings to be an important focus area for the low-emission society of the future. Buildings are playing a more active role in the energy system, as both consumers and producers of energy and as a flexibility resource. Norway, moreover, has a well-established technology and competency base in energy-efficient buildings that is a source of potential business development opportunities.

Summary:

- The construction sector is a major energy consumer, accounting for 30 per cent of energy use worldwide.[66] Efficient energy utilisation is an overriding objective, and advances in the construction sector are essential to the development of a low-emission society.
- Advanced buildings are an important component of a flexible energy system. Construction sector trends favour "smart buildings", leading ultimately to "smart cities and towns". As the construction sector develops, its connection to the overall energy system must be given more emphasis.[67]
- Smart, energy-efficient buildings can serve as a flexibility resource in the power system (thermal storage and power management) in addition to reducing energy consumption.
- New requirements and new technology will ensure that the buildings of tomorrow are built to low-energy and zero-energy standards, and in the long run will become net-producers of energy.

[66] *International Energy Agency (IEA) (2017), Energy Technology Perspectives 2017*
[67] *Addressed in the Chapter "Digitalised and integrated energy systems"*

- The slow rate of turnover in buildings makes it essential to exploit the potential for energy efficiency in existing buildings. This potential is substantial.
- New technologies and new building requirements create opportunities for Norwegian actors.
- Norwegian companies and research and education communities active in the construction field have wide-ranging expertise in materials use. Norwegian R&D on systems integration of smart, energy-efficient buildings and cities is also of high quality.
- Norway has come a long way in the design, construction and operation of energy-plus buildings, with widely recognised expertise that is sought after internationally.

3.1.1 MARKET DEVELOPMENT AND ANTICIPATED ROLE

Annual energy use for the operation of buildings in Norway totals 80 TWh. The potential for reducing energy use is estimated to be 10 TWh by 2020 and 40 TWh by 2040.[68] Internationally, energy use in buildings accounts for 30 per cent of total energy consumption, and the potential for energy-efficiency gains is large.[69] The EU has determined that by 2020 all new buildings are to be "nearly zero-energy buildings", a directive that creates major opportunities for the suppliers of systems and services for such buildings.

Energy efficiency has been steadily improving for many decades, aided in Norway by among other things increasingly strict regulations on technical requirements for buildings. In its Agreement on Climate Policy in 2012, the Storting resolved to "tighten the energy requirements contained in the building code to passive-house level in 2015". Energy-use requirements for buildings were subsequently strengthened with effect from January 2016. The new requirements are expected to boost the energy-efficiency of buildings by 20–25 per cent compared with previous requirements.[70] The design of future regulations remains uncertain, but additional energy-efficiency requirements can be expected in keeping with the Agreement on Climate Policy's target of a "nearly zero-energy level in 2020".

In the EU, the definition of a zero-energy building depends on building structure and may include building-integrated energy production. Norway's approach differs, since all the country's electric and district heating power already derives from renewable sources. The EU directive allows for discretion in defining nearly zero-energy buildings nationally, and in Norway the natural course would be to design technology-neutral regulations based on the energy system we have. Having energy-efficient and smart buildings is an objective in any case. That means new technology in buildings and in their interfaces with the energy system will be needed for both energy management and energy exchange.

The potential of existing technology to cut energy consumption in today's building stock is also great. In the city of Oslo, for example, energy consumption in today's building stock could potentially be reduced by about 3 TWh,[71] or some 30 per cent. Good system models are needed for modelling building stock, comparing energy-efficiency measures and releasing the full potential of the measures chosen.

Much attention has been paid to reducing energy consumption for building heat by adding insulation to existing buildings and developing passive houses.[72] In older buildings, space heating accounts for some 30–45 per cent of energy use and is therefore a source of potentially large energy-efficiency gains. In new and rehabilitated buildings, space heating will account for between 5–15 per cent of energy use,[73] so reducing other forms of energy use will be important.

Currently there are a number of mature energy-efficiency technologies that could be implemented in the market, with barriers that are largely execution-related. Yet there is still a need for new energy-efficiency technologies and solutions, especially in materials technology and systems and operational engineering. Smart-building technologies and solutions are undergoing rapid development and are expected to become a significant factor in the way buildings use energy. Technological developments in such areas as IoT,[74] sensors, data processing and machine learning are helping to make energy use as efficient as possible. Smart buildings can also improve interaction with the energy system in general by optimising energy and power consumption and utilising local production and storage.

3.1.2 NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

The building sector encompasses many companies with widely varying competencies, approaches and levels of ambition. Architects, consulting engineers, property developers, electrical installers and installers of systems for heating, ventilation, air-conditioning and sanitation are all represented along with various technology and equipment manufacturers and suppliers. These actors have three main focus areas: building structure (insulation, windows, etc.), technical systems (control systems, ventilation, etc.) and supply (electricity, tap water, heating, cooling).

Several Norwegian companies are actively engaged in developing energy-efficiency expertise with respect to buildings, and several of them compete in designing sustainable zero-emission buildings.

Norway has a number of high-quality research groups with a focus on energy-efficient buildings and a level of expertise equal to that of globally leading Nordic institutions. These groups have made great strides in their work on highly insulated facades using innovative wood, glass and aluminium materials as well as energy-efficient technical systems and system solutions to ensure a good indoor climate and a high degree of comfort. Most of Norway's universities and large university colleges have expertise in energy-efficient buildings and technical systems, and offer instruction in those subjects.

Through the Centres for Environment-friendly Energy Research (FMEs), several research groups and companies have focused attention on energy use, emissions and materials use in a lifecycle perspective. Locally based renewable energy production has been another FME focus.

3.1.3
CHALLENGES AND OPPORTUNITIES FOR NORWAY

Opportunities in this area can be divided into two broad categories: 1) the value of reducing energy and power consumption, including associated climate, environmental and economic benefits, and 2) value creation stemming from the supply of technology, systems, expertise and advice to the Norwegian and/or international construction markets. Such opportunities are related to efficient energy use in new buildings and existing building stock. To date, innovation activity in the sector has been low, but ambitious objectives, including those put forth in the property sector "roadmap" for the period through 2050, may be a sign of change.

Increasingly strict building regulations which approach zero-energy standards target the energy-saving potential to be unlocked by new technology and new solutions. The content of future building regulations will affect how the building stock develops. Heat pumps could well play an even greater role than before, while solar cells and solar heating become more prevalent. Sharply falling prices have made solar cells more practicable, even in Norway. Building-integrated solar cells will likely become available for a variety of roof, window and facade types. Well fields for heating and cooling systems are another viable alternative, given Norway's combined need for heating and cooling of building stock. Norway has some of Europe's largest geothermal well fields for heating and cooling systems.

Norway was an early force in the development of energy-efficient, low-emission buildings, and in 2014 Norwegian actors unveiled the world's first energy-plus rehabilitated building. The rehabilitation of this existing office building achieved energy savings of 90 per cent.[75] A number of companies and research groups took part in the project, which incorporated a great deal of pioneering work. Several other energy-efficient, low-emission building projects have been carried out in recent years by research groups and companies acting in concert, resulting in a valuable base of expertise. Norwegian projects have been attracting international attention, and Norway is at the forefront of energy-plus building development.[76] However, a better understanding of the environmental footprint of these buildings throughout their lifecycles is still needed, as are more advanced methods of lifecycle assessment (LCA).

The area of smart power management is undergoing rapid technological development and is expected to have major importance for building-centred energy use in future. As stricter energy-efficiency requirements come into effect and buildings eventually begin to produce their own energy, the need for smart energy management increases. New digital solutions, sensors, control programmes, connected devices and other developments make energy consumption more intelligent while optimising and automating it. Smart power management can also improve interaction with the energy system in general. The market potential for smart building technologies and services is large.

Given the slow turnover rate of buildings, estimated at 2 per cent annually, the effects of zero-energy and energy-plus standards have a long time perspective. More products and solutions that promote energy savings in existing buildings must therefore be developed as well. Some 50–80 per cent of buildings that will be in use in 2050 have already been constructed. Energy consumption in existing building stock is a major challenge, with existing buildings requiring 2.5 times the energy per square metre that new buildings are expected to use.[77] In rehabilitation projects, the existing structure limits one's range of choices. Understanding energy technology in isolation is not enough, and good solutions are not necessarily the same for existing buildings as for new buildings.

3.1.4
DIGITALISATION AND SMART BUILDINGS

As described in the preceding section, rapid technological development is occurring in the smart building sector. This development springs largely from digital technologies such as IoT, sensors, data processing and machine learning, which make it possible to improve energy management in individual buildings and to facilitate interaction between buildings and the energy system in general.

68 *Ministry of Local Government and Modernisation working group on energy efficiency of buildings*
69 *International Energy Agency (IEA) (2017), Energy Technology Perspectives 2017*
70 *Ministry of Local Government and Modernisation, https://www.regjeringen.no/no/tema/plan-bygg-og-eiendom/plan--og-bygningsloven/bygg/innsikt/faktaark-om-nye-energikrav-til-nybygg/id2461620/ [Fact sheet on new energy requirements for new buildings]*
71 *STREK 2020: A report commissioned by the city of Oslo in 2012 on how to increase energy efficiency in buildings and reduce the use of fossil fuels for heating in private homes, part 3a, by Energidata Consulting and Xrgia*
72 *Grønn Byggallianse and Norsk Eiendom (2016), roadmap of recommendations for the property sector through 2050*
73 *Ibid.*
74 *IoT: Internet of Things*
75 *Powerhouse.no*
76 *Energy-plus building: one that generates more energy during its operational phase of life than was used in the production of building materials and in the construction, use and disposal of the building*
77 *Grønn Byggallianse and Norsk Eiendom (2016), roadmap of recommendations for property sector towards 2050*

3.1.5
AMBITIONS FOR ENERGY-EFFICIENT AND SMART BUILDINGS

The ambitions of stakeholders involved with energy-efficient and smart buildings are as follows:

- To achieve efficient energy utilisation in Norway's building stock.
- To increase local and building-integrated renewable energy production.
- To develop smart and energy-efficient buildings at the international forefront.
- To develop LCA analysis for buildings – development of common tools for the entire industry.
- To achieve flexible integration of energy-efficient buildings with the energy system (electricity, heating, cooling).
- To promote better planning of green areas, with buildings, energy infrastructure, local resources and flexible systems viewed in relation to one another.

3.1.6
ACTION AND IMPORTANT RESEARCH AREAS – ENERGY-EFFICIENT AND SMART BUILDINGS

The stakeholders involved with energy-efficient and smart building systems will give priority to the following action and research areas to realise ambitions and satisfy the knowledge and technology needs of tomorrow:

Action:

- Supporting measures to implement and commercialise research results related to energy-efficient buildings.
- Increasing investment incentives for energy-efficiency measures and improving regulations.
- Helping to follow up the Bygg21 strategy process for the construction industry and ensuring that energy use is included on the agenda.
- Promoting a Centre of Excellence for smart energy use in buildings.
- Increasing incentives for better planning of green areas, both new and rehabilitated, as well as regulatory adjustments.
- Carrying out research, development, demonstration and commercialisation activities within the strategic research areas identified below.

Strategic research areas:

- Materials and solutions for boosting efficiency in existing and new building stock.
- Incentives to stimulate development and implementation of new integrated energy solutions.
- Buildings and their connection to the energy system in general, including flexibility of the power grid, transport and other industries.
- Methods and incentives for realising planned, estimated, simulated energy use and monitoring of system performance.
- Technical and economic optimisation of local and building-integrated renewable energy production and consumption profiles for low-energy, zero-energy and energy-plus buildings.
- LCA analysis for buildings – including models for estimating energy consumption and greenhouse gas emissions throughout the lifecycle of buildings.

3.2

Hydrogen

Hydrogen as an energy carrier can play an important role in several ways in the climate-friendly energy and transport system of the future. The Energi21 board considers that hydrogen can be used to contribute to value creation through the use of Norway's water, wind and gas resources, and as an emission-free energy carrier in a future low-emission society. In addition, there is a potential for supplier development in the field of hydrogen technology and solutions.

Hydrogen technology and solutions have a role to play in developments in the key areas "Climate-friendly and energy-efficient industry, including carbon capture and storage (CCS)", "Climate-friendly energy technologies for maritime transport" and "Digitalised and integrated energy systems"

Summary:

- Hydrogen has properties that make it suitable for decarbonising energy production, distribution and storage, and also energy end-use in transport, industry and heating buildings.
- There is a potentially large market for emission-free hydrogen[78], which would offer opportunities for exports of emission-free Norwegian hydrogen and hydrogen technologies.
- Norway has abundant renewable energy resources that can be used to produce emission-free hydrogen by electrolysis, and natural gas that can be used to produce hydrogen through reforming coupled with carbon capture.
- Norwegian companies have cutting-edge expertise in electrolysis, filling station technology and compressed hydrogen tanks, long industrial experience of hydrogen technologies and research and education institutions with extensive knowledge of materials and processes.
- The role hydrogen can play in the transformation of energy and transport systems is somewhat uncertain

because of challenges related to competitiveness and costs and to infrastructure and technology development.

- Hydrogen must be produced without greenhouse gas emissions if it is to play a part in the transformation of energy and transport systems, i.e. through electrolysis using renewable power or from fossil energy sources coupled with CCS.
- However, hydrogen produced through electrolysis using renewable power or from fossil energy sources coupled with CCS is not currently competitive with hydrogen produced from fossil fuels without CCS.

3.2.1 MARKET DEVELOPMENT AND ANTICIPATED ROLE

Hydrogen is an emission-free energy carrier with properties that make it suitable for use in the process of transforming the world's energy and transport systems into low-emission systems. Hydrogen as an energy carrier is suitable for decarbonising energy production, distribution and storage, and also energy end-use in transport, industry and heating buildings.

In power systems with an increasing proportion of renewable, intermittent production capacity, hydrogen can meet the need for flexibility and energy storage. In addition, hydrogen can be used as fuel in gas-fired power plants, with some adjustments. Hydrogen's properties also make it suitable for long-distance distribution, and as an energy buffer to manage imbalances in the energy system. These roles have so far largely been filled by fossil energy carriers.

Hydrogen can also play a part in the transformation of the transport sector. It is suitable for both large and small road vehicles, but is considered to be particularly relevant for heavy long-distance vehicles because it offers higher energy density and a longer range than batteries. Using hydrogen in the transport sector will eliminate local emissions of particulate matter in addition to reducing greenhouse gas emissions. In the maritime transport sector, hydrogen is suitable for use in smaller vessels and in ferries and high-speed vessels. Hydrogen can also be used to complement purely battery-electric vessels. Hybrid solutions of this kind can meet the needs of many different types of vessels and operations. For the railway sector, hydrogen is an alternative for non-electrified stretches of line, either alone or in combination with overhead lines and battery propulsion.

The industrial sector uses most hydrogen at present, but this is based largely on hydrogen produced from fossil energy sources. Technology for reforming natural gas that is already available can cut emissions by 55–65 %, but further emission reductions will be needed in the future. Provided that it is produced without emissions, hydrogen can also contribute to emission reductions when it is used in new areas, both as an energy source and as a raw material.

In countries where natural gas is used to heat buildings, hydrogen may be a cost-effective option for reducing emissions. Hydrogen can be distributed through the existing system for natural gas, thus reducing the need to use electricity for heating and the need for costly expansion of the power grid.

If it is used for the purposes described above, hydrogen can play an important part in transformation of the energy and transport system. This would result in an increase in global demand for emission-free hydrogen. The Hydrogen Council estimates that global demand may reach 78 EJ in 2050,[79] ten times the current level. The Institute of Energy Economics in Japan believes that hydrogen produced from fossil sources coupled with CCS will be an important part of Japan's energy supplies in future. However, a number of challenges must be addressed before the full potential of hydrogen can be released. In particular, there are challenges relating to competitiveness and costs and to infrastructure and technology development. In addition, hydrogen must be produced without greenhouse gas emissions, either through electrolysis using renewable power or from fossil energy sources coupled with CCS.

3.2.2 NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

Norwegian industry has long experience in the production and use of hydrogen, and several Norwegian stakeholders have been involved in early stages of the development of hydrogen technology. Moreover, a number of Norwegian companies have positioned themselves as world leaders in their fields in recent years. They are playing a leading role in electrolysis technology, hydrogen filling stations and hydrogen tanks, and are supplying an international market. Norwegian industry is also playing a pioneering role in the development of technology for reforming natural gas coupled with CCS and the development of hydrogen technology for maritime purposes.

Norwegian research groups have strong expertise in several hydrogen technologies. These include high-temperature fuel cells and electrolysers, with a special focus on proton-conducting ceramics. Norway has world-class materials expertise in this field. Norwegian research groups also have a high level of expertise in low-temperature fuel cells and electrolysers, alkaline electrolysis, hydrogen combustion and hydrogen storage in metal hydrides. Norwegian research groups are at the forefront internationally in modelling and analysis of hydrogen systems and value chains.

[78] *Produced by electrolysis using renewable power, or from fossil fuels coupled with carbon capture and storage (CCS)*
[79] *Hydrogen Council (2017), Hydrogen scaling up*

3.2.3 CHALLENGES AND OPPORTUNITIES FOR NORWAY

Use of hydrogen will promote value creation based on Norway's renewable energy resources and natural gas (coupled with CCS), emission reductions and flexibility if it is used in the Norwegian energy and transport system, and if hydrogen and hydrogen technologies are exported to an international market.

Norway has natural comparative advantages as regards hydrogen production. It has abundant supplies of renewable energy that can be used to produce emission-free hydrogen through electrolysis. In addition, emission-free hydrogen can be produced from Norway's natural gas resources through reforming coupled with CCS. At present, most hydrogen is produced by reforming natural gas. In this process, CO_2 is available for capture at higher concentration and pressure than is the case post-combustion. This simplifies the capture process and subsequent transport and storage, provided that there is existing infrastructure for CO_2 transport and storage. Norwegian stakeholders are involved in ongoing development activities for technologies and membranes for CO_2 capture during hydrogen production from natural gas, which may simplify and reduce the cost of hydrogen production in the future. Production of hydrogen from natural gas coupled with CCS is suitable for the supply of large volumes, and the potential expansion of the international market for hydrogen would result in interesting export opportunities. Electricity production from gas-fired power plants fuelled with hydrogen could help to meet demand in the European power system.

Both the process and other industries and research and education institutions in Norway have a great deal of expertise in and long experience of hydrogen technologies. Norwegian stakeholders also have extensive knowledge of materials and processes, which provides a good basis for the development and improvement of electrolysis and fuel cell technology and technologies for carbon capture from fossil fuel reforming. Norway is playing an active part in EU research projects on hydrogen. Growth in the international market would provide opportunities for export of Norwegian technologies and solutions, and would enable Norwegian companies to consolidate their leading positions in their fields.

If hydrogen is used in Norway, there is a potential for achieving emission reductions both in the transport and in industry. Norway is in a good position to develop and deploy hydrogen technologies for land transport, although deployment of hydrogen-electric vehicles remains low at present. Norway was one of the first countries to establish hydrogen filling stations that are open to the public. Norwegian companies have cutting-edge expertise in electrolysis, filling station technology and compressed hydrogen tanks and long industrial experience of hydrogen technologies, and Norwegian research and education institutions have extensive knowledge of materials and processes. Hydrogen technologies for maritime transport are less technologically mature, but Norwegian stakeholders are leading the way and are engaged in a project to develop the world's first ferry using hydrogen fuel cell propulsion. The complete ferry, with the exception of the fuel cell itself, can be delivered by Norwegian companies.

The Norwegian industrial sector has long experience of the production and use of hydrogen in manufacturing processes, and has substantial expertise and experience in using hydrogen for industrial purposes. The sector is seeking to expand the use of hydrogen to achieve emission cuts, and a technology development project is under way to replace coal with hydrogen in the production of titanium dioxide.

Hydrogen can also play a part in the Norwegian power supply system. One potential use is to produce hydrogen in areas with surplus electricity and limited grid capacity. The hydrogen can be stored locally and used to generate power that is fed back into the electricity grid, or distributed for use in other areas. Hydrogen is also an alternative to direct supply to the power grid when production capacity for intermittent power (run-of-river power, wind power) is being developed, since it can be costly and challenging to connect this capacity to the grid.

There is uncertainty about the part that hydrogen will play in future energy and transport systems, since there are a number of difficulties that must be resolved before the full potential of hydrogen can be unleashed. In particular, there are challenges relating to competitiveness and costs and to infrastructure and technology development.

If hydrogen is to play a part in reducing greenhouse gas emissions, its production must be emission-free. However, emission-free hydrogen is not currently competitive with hydrogen produced from fossil fuels (without CCS). This means that the industrial sector, which is the sector that uses most hydrogen at present, mainly uses hydrogen derived from fossil fuels. Current prices for electricity, fossil fuels and CO_2 result in a considerable price difference between electrolysis and production from fossil fuels (without CCS).[80] Further technology development is needed for production from fossil fuels coupled with CCS, and it is not yet competitive. However, Norwegian industrial stakeholders and research groups that are involved in ongoing projects for hydrogen production from natural gas coupled with CCS are optimistic about the competitive position of this method compared with other production methods, provided that the existing demonstration technologies can be scaled up and there is sufficient demand in the market.

There has so far been little deployment of hydrogen vehicles in the transport sector, even though most of the technology is available. It is uncertain how strongly the numbers of hydrogen vehicles can be expected to grow in the future, and there are wide variations between estimates of the future proportion of hydrogen-electric vehicles. The main reasons for not expecting widespread use of hydrogen-electric vehicles are barriers relating to energy efficiency and the high costs of infrastructure, fuel cells and storage tanks.

Scale is an important cost driver of the production of hydrogen technologies, and an increase in production volume drives costs down. In the transport sector, the issue of scale must be considered in conjunction with the low penetration of hydrogen vehicles and infrastructure. The limited number of vehicles provides little incentive to develop infrastructure, and vice versa. Nevertheless, further reductions in costs can be achieved, for example for fuel cells, by continuing the development and improvement of various key components of hydrogen technology.

3.2.4
DIGITALISATION AND HYDROGEN TECHNOLOGY

As mentioned in Chapter 2, digitalisation involves more widespread use of sensors in physical components of energy infrastructure, the analysis and use of large quantities of data and a growing degree of computerised control and robotisation.

Using digital solutions in large industrial plants for hydrogen production based on reforming fossil fuels will open up opportunities for optimising operation and maintenance and automating and robotising production processes. In the case of hydrogen production by electrolysis, digitalisation will make it possible to improve coordination and optimise integration with the rest of the energy system, for example by ensuring that capacity constraints in the power grid are taken into consideration in hydrogen production.

For end uses of hydrogen, digitalisation can play a role in optimising energy use in industry, in buildings and in various modes of transport. Hydrogen can also provide a source of flexibility in the energy system of the future because it can be produced in periods when there is a surplus of electricity and be used to generate electricity when there is a shortage. Digitalisation will make it easier to integrate and coordinate the use of hydrogen and other energy carriers.

3.2.5
AMBITIONS FOR HYDROGEN TECHNOLOGY

The hydrogen industry's ambitions are as follows:

- For emission-free hydrogen to bring about substantial cuts in emissions from the Norwegian transport sector.
- To establish hydrogen infrastructure for road, rail and sea transport in Norway.
- For hydrogen vehicles and vessels to be competitive by 2025: it will be important to scale up as necessary.
- To establish an industrial value chain based on hydrogen production, for example synthetic fuels, fish farming, or the like.
- To establish hydrogen production in areas where there is an electricity surplus and capacity constraints in the power grid.
- To develop and establish hydrogen production from Norwegian natural gas, including capture, transport and storage of CO_2.
- For Norwegian stakeholders to be world leaders in hydrogen technologies, including fuel cells, electrolysis and technologies for producing hydrogen from natural gas coupled with CCS.
- To establish the export of emission-free hydrogen to the international market.

3.2.6
ACTION AND IMPORTANT RESEARCH AREAS – HYDROGEN

The hydrogen industry will give priority to the following action and research topics to realise its ambitions and satisfy the knowledge and technology needs of tomorrow:

Action:

- Establishing funding instruments for the commercialisation of hydrogen technologies.
- Supporting the development of systems for using hydrogen in early markets.
- Establishing funding instruments for the establishment of hydrogen infrastructure.
- Introducing requirements in public procurement processes in order to promote the integration of hydrogen vehicles and vessels into the transport system.
- Establishing a national hydrogen strategy, as proposed in the white paper on energy policy.
- Carrying out research, development, demonstration and commercialisation activities within the strategic research areas identified below.

Strategic research areas:

- Cost-effective production processes for key fuel cell technologies.
- Fuel cell systems for hydrogen vehicles and vessels, including hybridisation with other technologies.
- Technology for electrolysis and hydrogen filling stations, including solutions for bunkering larger vessels.
- Effective hydrogen tanks, including solutions for bunkering fuel on board vessels.
- Effective systems for reforming natural gas coupled with CCS.
- Safety aspects of hydrogen use.
- Framework, policy and funding instruments for and barriers to the integration of hydrogen into future energy and transport systems.
- Investor analysis: what is needed to stimulate investment in hydrogen technology and solutions?
- Role of the public sector in the development of hydrogen technology and solutions for a low-emission society.

[80] *For example, the process industries' roadmap for green competitiveness states that electrolysis is currently around twice as expensive as reforming natural gas.*

3.3

Deep geothermal energy

There is significant potential to develop geothermal energy production technologies and services aimed at an international market. Such technologies and services will comprise innovations from the oil and gas sector and new technological services directly derived from the sector. Developing a supplier industry in deep geothermal energy has value-creation potential.

Summary:

- Deep geothermal energy is an important resource in the future energy supply.
- The ability to produce baseload electric power that is also scalable is a major advantage in a power system increasingly reliant on variable sources.
- Geothermal energy can be used for direct heating or in energy storage systems.
- Geothermal energy technology has significant potential in both established and emerging markets, and is a priority area in the EU's Strategic Energy Technology (SET) Plan.
- Significant cost reductions are needed to make the technology more competitive.
- EGS (enhanced geothermal systems) are potentially disruptive technologies with large global potential.
- Norwegian research, business and industry have comparative advantages based on Norway's petroleum activities.
- Substantial opportunities exist to develop national expertise and technologies in an international market and to contribute to a green shift.

3.3.1
MARKET DEVELOPMENT AND ANTICIPATED ROLE

Internationally, geothermal energy from deep wells is a growing source of heating and electricity generation. From 2010 to 2015, such electricity generation rose 15 per cent to an annual level of 73.5 TWh, based on production in 24 countries. Direct use of heat from deep geothermal resources increased 17 per cent during the same period, reaching an annual production level of 0.263 EJ (73.1 TWh) in 2015. This energy is largely produced from conventional hydrothermal sources. As new technologies are introduced, however, commercially exploitable resources have grown. New technologies that improve reservoir stimulation, extend well depth and accommodate higher temperatures pave the way for enhanced geothermal systems (EGS) and the exploitation of supercritical resources. In its "Technology Roadmap"[81] for geothermal energy, the International Energy Agency (IEA) estimates that geothermal electricity generation can rise to 1 400 TWh annually by 2050 if there is sufficient investment in research, development and demonstration of innovative technologies, with special focus on EGS.[82] This would lead to hundreds of billions of dollars in investment and provide major opportunities for Norwegian companies with a background in advanced technology developed for the petroleum sector. Norwegian suppliers of exploration, reservoir, drilling and well technology products and services have the potential to compete successfully in an international market in search of new solutions. Established markets in the United States and Asia offer promise, but so does Europe, where the SET Plan's focus on deep geothermal energy development provides opportunities for Norwegian companies. Major opportunities for positioning Norwegian companies also exist in emerging Asian, African and South American economies where geothermal resources are more naturally accessible.

3.3.2
CHALLENGES AND OPPORTUNITIES FOR NORWAY

Due to its petroleum activities, Norway has strong comparative advantages in deep geothermal energy. Exploration, reservoir, drilling and well technologies as well as instrumentation, measurement technology and geological expertise are all important areas with development potential in the context of geothermal energy. Norwegian stakeholders have also developed expertise and experience in topside utilisation of heat . There are synergies to be gained from knowledge flows between the petroleum sector, land-based industry and renewable energy.

Norwegian stakeholders have two related core challenges: 1) to become familiar with international geothermal activities, markets and networks, and 2) to transfer and further develop their geothermal sector expertise, technologies, services and products.

There is a need for national instruments and projects that together can enhance expertise and expand infrastructure in Norwegian research groups and trade and industry, as well as facilitate collaboration. Although national activities based in the petroleum sector are a source of strong synergies, there are specific challenges to be resolved, including high temperatures, different geological conditions and a need for cost reduction. Although deep geothermal energy may become a source of heat production nationally, it is unrealistic to expect a significant domestic market for deep geothermal energy technology to develop in the short to medium term. National research and development funding must therefore contribute to international cooperation and network development, with a focus on projects that boost participation in the international arena and elicit service and supply contracts for geothermal technology development internationally. Additional projects will be important to underscore market opportunities for a growing number of Norwegian industrial clusters and stakeholders.

3.3.3 NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

In the past 10 years, national R&D stakeholders have built up a strong geothermal energy research base with projects supported by the Research Council of Norway, Horizon 2020 and Norwegian and international industrial interests, among other funders. Norwegian research groups hold key positions in international networks and have good relations with international partners.

Norwegian industry has also begun to see the potential of deep geothermal energy production, in large part based on experience from the oil and gas sector experience but also as an extension of established enterprises that produce shallower energy wells. Norwegian suppliers have provided services and solutions related to drilling, wells, advanced measurement technology and more, and many kinds of companies are showing greater interest in geothermal energy technology. Norway has a strong geothermal energy research network, and one of the country's strongest industrial clusters has defined geothermal energy as a growing market. A number of Norwegian companies are also working actively to secure technology positions that will provide a competitive advantage internationally.

3.3.4 AMBITIONS FOR DEEP GEOTHERMAL ENERGY

The ambitions of the deep geothermal energy industry are as follows:

- To develop the Norwegian supply industry and research communities:
  - increasingly oriented towards an international market for deep geothermal energy;
  - based on globally leading oil and gas expertise.
- To provide competitive geothermal energy production solutions and help lower technical risk in geothermal projects:
  - geothermal resource mapping and characterisation, both regionally and in prospect areas;
  - drilling, completion, stimulation and instrumentation of deep geothermal wells;
  - cost-effective and sustainable production of geothermal resources;
  - power generation from EGS and supercritical resources.

3.3.5 ACTION AND IMPORTANT RESEARCH AREAS

Action:

The deep geothermal energy industry will give priority to the following action and research areas to realise its ambitions and satisfy the knowledge and technology needs of tomorrow:

- Supporting knowledge-building and researcher projects in key research areas.
- Supporting innovation projects for industry with potential in the international market.
- Encouraging Norwegian participation in international research and demonstration projects.
- Developing and supporting networks among national stakeholders from universities, research institutes, business clusters and other parts of the business sector.
- Supporting bilateral cooperation projects.

Important research areas:

- Effective methods of geological, geochemical and geophysical mapping, both regionally and in prospect areas.
- Robust and cost-effective drilling and well technologies.
- Reservoir characterisation, modelling and simulation technologies that help to optimise development plans and production.
- Effective reservoir stimulation to ensure commercial flow rates.
- Methods for monitoring and limiting negative environmental impacts, such as CO_2 and H_2S emissions and unacceptable levels of induced seismicity.
- 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.
- Utilisation of supercritical steam.
- Production planning with multi-phase modelling of flow in wells, reservoirs and pipelines.
- Technology concepts for surface utilisation and conversion of heat.

All of these areas have a clear interface with research needs in the petroleum sector. The big difference lies in the margins. Commercial power generation is a low-margin business requiring cheap, simple solutions.

[81] *Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation, European Commission, Brussels, 15 Sept. 2015, 6317 final, 2015*

[82] *Technology Roadmap, Geothermal Heat and Power, OECD/IEA, International Energy Agency, [online] available at https://www.iea.org/publications/freepublications/publication/Geothermal_Roadmap.pdf*

At the same time, there is great potential for adapting existing technology from the oil and gas sector to serve the geothermal industry. Many of the technologies to be developed in connection with the areas listed above will be generic in nature, with relevance to other energy sectors and areas of society. (Developments in drilling technology, for example, will be relevant to hydropower generation, electricity distribution, advanced materials technology and ways of understanding underground features.)

Technology concepts for surface utilisation and conversion of heat (the final item on the list above) overlap with the Energi21 priority technology areas of "Climate-friendly and energy-efficient industry, including carbon capture and storage (CCS)" and "Digitalised and integrated energy systems".

Outside of technology, areas that could merit consideration from a national perspective include financial and environmental risk mitigation, business model development and decision-making support tools.

3.4

Bioenergy

Biomass is an energy resource of importance for value creation and emission cuts in several sectors. Biomass from forest offers the greatest unrealised potential, and by-product streams from processing of biomass for various purposes should be used to produce energy. Marine biomass from algae may provide further potential.

Bioenergy has a role to play in developments in the key areas "Climate-friendly and energy-efficient industry, including carbon capture and storage (CCS)", "Climate-friendly energy technologies for maritime transport" and "Digitalised and integrated energy systems.

Summary:

- Biomass is an important energy source in Norway, and consumption for energy purposes currently corresponds to about 18 TWh per year. The Norwegian Water Resources and Energy Directorate considers that the realistic potential at present is about 23 TWh.[83]
- Forest is the largest source of biomass in Norway, and consumption of forest resources for energy purposes currently corresponds to about 14 TWh per year.
- Norway's bioenergy resource potential may increase in the period up to 2030. An analysis published in 2015 by the Norwegian Environment Agency estimated that the potential could be increased to 30 TWh, most of it derived from forest biomass. This is based on the assumption that greater use is made of biological residues from households, agriculture and forestry, and that harvesting of forest increases to around 15 million m^3 as a result of an increase in the proportion of mature forest.
- The amount of biomass available can be further increased through cultivation of marine biomass in the form of algae. Norway has expertise and natural resources that put it in a very good position to produce bioenergy from algae, but further research and technology development are needed.
- Biofuels for the transport sector are of growing interest, and their use has been identified as necessary for achieving emission targets. The authorities have increased the biofuel quota obligation for road transport, and are thus driving demand upwards.
- Almost all the biofuel consumed in Norway is imported, and consumption totals 3.9 TWh biodiesel and bioethanol.[84] There are very few Norwegian manufacturers of liquid biofuels, one of which produces advanced biofuel[85] from by-product streams in a biorefinery.[86]
- Several companies are planning the production of advanced biofuels in Norway, but full-scale production will probably not be reached before around 2020.
- Biofuels are particularly important for heavy freight vehicles and long-distance transport, segments where there are few other climate-friendly alternatives available at present. According to the IEA's Beyond 2°C scenario (B2DS), biofuels will account for 32 % of all energy use in the transport sector in 2060.
- Bioresources can also be used in other ways than for energy purposes, and it is vital to ensure profitable, sustainable utilisation of biomass and to consider the value chain as a whole. Co-location of businesses and integrated biorefineries will be at the core of this approach. Bioenergy for biofuels and stationary applications will be derived from various fractions of feedstocks converted in such facilities.
- Using biomass for purposes where fossil fuels are currently used can result in considerable emission reductions. Examples are transport fuels, various chemicals, plastics and other materials. In addition, the process industries have identified the use of biomass in the form of biochar as an important measure for reducing greenhouse gas emissions.
- Biogas is produced mainly by anaerobic degradation of sewage sludge, organic waste and manure. Biogas production in Norway totals around 1 TWh a year, and there is a potential for reaching 5 TWh in 2030.[87] Using biogas in the transport sector reduces greenhouse gas emissions by about 70–80 % compared with using fossil fuels.[88]

3.4.1 MARKET DEVELOPMENT AND ANTICIPATED ROLE

There are various applications for bioresources, and in Norway biomass used for energy and heating purposes is equivalent to 18 TWh per year.[89] Forest resources used for energy purposes correspond to about 14 TWh per year.[90] Up to 2030, the resource potential for bioenergy may rise by about 30 TWh,[91] but there is some uncertainty about this figure because there is a lack of commercial assessments. Forest biomass offers the largest resource potential.

Organic waste, sewage sludge and manure are the forms of biomass that are used to produce biogas. Norwegian production of biogas is currently about 1 TWh per year. Norway's potential for biogas production is 5 TWh in 2030. Biogas provides climate benefits because its use avoids greenhouse gas emissions related to waste management; because residual products from biogas production can replace fossil-based fertiliser in agriculture; and because biogas that is upgraded to biomethane can replace fossil fuels in the transport sector.

There has been some decline in fuelwood use in Norway in recent years, but fuelwood is still the most important form of bioenergy in terms of annual energy volume (5–6 TWh) and installed capacity (10 GW). Bioenergy for stationary purposes will increasingly become an element of an energy system based on integrated heat and power. In the transport sector, demand for biofuels is expected to increase in response to targets for emission reductions in the sector and increases in the biofuel quota obligation.[92] Biofuel consumption in Norway rose steeply from 2015 to 2016, from about 188 million litres to about 423 million litres, which corresponds to about 10 % of total fuel use for road transport.[93]

Using biofuels is an important means of reducing greenhouse gas emissions from the transport sector, particularly from heavy vehicles and vessels and from planes, where no other options are available at present. Although battery- and hydrogen-electric propulsion systems are becoming available for more and more transport purposes, biofuels will continue to account for a substantial proportion of energy use in the transport sector for many years. In its B2DS scenario, the IEA estimates that biofuels will account for 32 % of energy use by the transport sector in 2060, mainly in the heavy freight and long-distance transport segments.[94]

Before biogas can be used in the transport sector, it must be upgraded to biomethane and then compressed to form CBG[95] or liquefied to produce LBG.[96] CBG and LBG have the same chemical composition as compressed and liquefied natural gas (CNG, LNG), and can therefore be used in the same vehicles, vessels and infrastructure. However, there is a lack of gas infrastructure for both land and maritime transport, and this is a key barrier that must be eliminated before biogas can be used more widely. Using biogas in the transport sector reduces greenhouse gas emissions by about 70–80 % compared with the use of fossil fuels. Currently, most Norwegian biogas is used for electricity and heat production, but its use as a transport fuel is expected to increase.[97]

Internationally, there is growing awareness that biomass is a finite resource that must be managed and utilised sustainably. There is an international trend towards the development of an integrated bioeconomy,[98] where various purposes for which bioresources are used are considered together in order to improve sustainability, economic performance and resource utilisation. With this approach, biomass for energy purposes will to a large extent be derived from by-product streams in processes where biomass is processed for other purposes.

One of the overall goals of the Government's bioeconomy strategy is to increase value creation and employment, and much of the potential for value creation is considered to lie in more processing of resources to manufacture products with a high rate of return. Another goal of the strategy is to reduce greenhouse gas emissions, which makes it more important to consider the use of bioresources for purposes for which no other renewable options are available, such as chemicals, plastics and other materials and for various industrial uses.

Many different industries and fields of expertise are involved in the use of bioresources, and it is therefore important to take a cross-disciplinary approach to the opportunities and challenges that arise. It will also be crucial to ensure that good cross-cutting ideas and solutions involving a range of disciplines and industrial sectors receive attention and are not overlooked. Sustainable management of bioresources should be high on the agenda in the years ahead. Work being done as part of Norway's Skog22 strategy for the forestry and wood industry will be very important in ensuring an integrated approach.

83 *Norwegian Water Resources and Energy Directorate (2014), Bioenergi i Norge [Bioenergy in Norway]*
84 *Statistics Norway, https://www.ssb.no/natur-og-miljo/artikler-og-publikasjoner/bruk-av-biodrivstoff-i-transport [Use of biofuels in the transport sector]*
85 *From Miljødirektoratet.no: Advanced biofuels are produced from residual materials and waste from food and beverage manufacturing or the agricultural or forestry sector*
86 *ZERO (2017), Bærekraftig biodrivstoff [Sustainable biofuels]*
87 *Avfall Norge, https://www.avfallnorge.no/bransjen/nyheter/biogass-verdifullt-effektivt-og-kliman%C3%B8ytralt [Biogas: valuable, effective and climate-neutral]*
88 *Zero (2017), Bærekraftig biodrivstoff [[Sustainable biofuels]]*
89 *Norwegian Water Resources and Energy Directorate (2014), Bioenergi i Norge [Bioenergy in Norway]*
90,91 *Norwegian Environment Agency (2015) Klimatiltak og utslippsbaner mot 2030 [Climate mitigation measures and emission trajectories up to 2030]*
92 *See for example miljodirektoratet.no*
93 *Norwegian Environment Agency, http://www.miljodirektoratet.no/no/Nyheter/Nyheter/2017/April-2017/Kraftig-okning-i-bruk-av-biodrivstoff-i-2016/ [Steep rise in biofuel consumption in in Norway in 2016]*
94 *International Energy Agency (IEA) (2017), Energy Technology Perspectives 2017*
95 *Compressed biogas*
96 *Liquefied biogas*
97 *Sund Energy (2017), Muligheter og barrierer for økt bruk av biogass til transport [Opportunities for and barriers to wider use of biomass for transport purposes]*
98 *From Familiar resources – undreamt of possibilities: the Norwegian Government's bioeconomy strategy. "[... sustainable, effective and profitable production, extraction and use of renewable, biological resources for use in food, feed, ingredients, health products, energy, materials, chemicals, paper, textiles and numerous other products."*

3.4.2
NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

The bioenergy sector is fragmented, with a few large companies and many small ones. There are Norwegian companies in various parts of the biogas value chain, including two producers of biogas plants that can supply competitive technology for the international market. There are also Norwegian companies that handle wet organic waste, manufacture pellets and develop furnaces and incinerators of various sizes for district and local heating.

Norwegian forest owners and farmers play an important role as producers, managers and users of land-based biomass. Demand for cellulose fibre for paper production is declining, creating a need for new approaches to the use of forest biomass. New value chains and products will be important to maintain value creation in the forestry and agricultural sector. So far, declining demand for Norwegian forest biomass has resulted in lower activity in the Norwegian forestry and wood industry and larger export volumes than previously. There is a new focus on the bioeconomy, and industrial and research activities have been started to increase the production of materials, and other materials, biofuels and energy from biomass. By-product streams from advanced biorefineries are used for the production of advanced biofuels.

Commercial actors are showing growing interest in biofuel production in response to the increases in the biofuel quota obligation being brought in by the authorities. Although the biofuel quota obligation does not favour biofuel produced in Norway, it is boosting interest in building and operating biofuel plants in Norway to some extent. Several Norwegian companies are planning to start production of advanced biofuels in Norway in the next few years.

Norwegian research groups in biofuels are highly respected internationally, and Norway is carrying out top-calibre research on microbiology, biogas and enzymes and on catalytic upgrading of biofuels. In addition, Norwegian research on the climate benefits of using forest to produce biofuels is internationally recognised. Norwegian research groups and a number of industry partners are involved in research cooperation on biofuels through one of the Centres for Environment-friendly Energy Research.

3.4.3
CHALLENGES AND OPPORTUNITIES FOR NORWAY

Forest constitutes the largest resource base for biomass in Norway, and the annual increment is about 26 million solid cubic metres.[99] Of this, 15 million solid m^3 is the sustainable yield,[100] i.e. the amount of timber that can be removed each year without making it necessary to reduce the harvest at a later date. Roundwood removals in Norway currently total about 10 million solid m^3 per year.[101] This means that it would be possible to increase the harvest by 5 million solid m^3 per year. In addition, it would be possible to use 3–5 solid m^3 of forest residues[102], with an energy content of 6–10 TWh.

Not all biomass from forests should be used for energy purposes. About half of the stemwood component of Norwegian forest resources consists of high-quality sawlogs[103], which should not be used for energy purposes or to produce biofuel. However, the production of sawn timber also results in by-product streams of wood chips and other residues, which account for about 60 % of the sawlogs and can be used for biofuel production. The remaining half of the stemwood is pulpwood[104], which can be used in biofuel production but is currently mainly used for production of cellulose, pulp and fibreboard by the wood processing industry, and to produce wood, pellets and chips for energy purposes. About one third of the forest resources consist of forest residues, which can be used for biofuel production. Forest residues are generally left where the timber is harvested, and are readily available, but the return on their use is low.

Given the prospects of stiffer competition for biomass at both national and international level, it will be important to promote sustainable use of the bioresources that will give the highest value creation and the greatest climate benefits. This means that biomass should be used for purposes where there are no other suitable, climate-friendly options, for example for fuel, chemicals, plastics and other materials and for industrial purposes. Future uses of bioresources will form part of large bioeconomic value chains where bioenergy is produced from waste and by-product streams.

In the longer term, it may be possible to increase biomass production. A changing climate and more active forest management may expand the forest resource base, and there are also opportunities to make use of marine biomass. Norway has expertise and natural resources that put it in a good position to utilise algae for bioenergy, but technology development and demonstration projects are still needed. The opportunities for cultivating and using marine and terrestrial biomass have been referred to as the "future blue-green field". Cultivation of marine biomass is highlighted in the HAV21 strategy.

Norway is in a good position to continue the development of biogas technologies and solutions based on expertise and experience from the process industries. This includes areas such as optimisation, management, systems engineering, separation techniques, reactor technology and reactor modelling. More knowledge is also needed about species choices, cultivation technology and preprocessing. A shift is expected in the biogas industry from small-scale plants based mainly on waste to large-scale energy production, and this industrialisation process will involve challenges. New and planned large-scale plants will be able to produce liquid biomethane for the transport sector, and will be able to use large volumes of substrate from forestry, agriculture and aquaculture.

There are also interesting possibilities for using LBG as a hydrogen carrier, and it can be used in high-temperature fuel cells. Methanisation of CO_2 using hydrogen from electrolysis is another interesting possibility, and involves re-using CO_2 to produce methane that can be used in fuel cells.

3.4.4
AMBITIONS FOR BIOENERGY

The bioenergy industry's ambitions are as follows:

- To developing a broad-based understanding of what constitutes sound, climate-friendly management of Norway's biomass resources;
- To promote increased activity and greater value creation through investment in the Norwegian forestry and wood industry, including the establishment of more advanced industrial plants for production of timber, biofuels and other wood-based chemicals and materials;
- To promote increased activity and greater value creation in connection with energy recovery from waste and by-product streams from households, manufacturing and other industrial activity, including the aquaculture industry;
- To increase Norwegian expertise and boost technology development relating to energy-oriented processing of forest biomass, forest residues and waste and by-product streams with a substantial energy content.

3.4.5
ACTION AND IMPORTANT RESEARCH

The bioenergy industry will give priority to the following action and research areas to realise its ambitions and satisfy the knowledge and technology needs of tomorrow:

Action:

- Supporting the commercialisation and industrialisation of new technologies and solutions from Norwegian companies and research and educational institutions.
- Supporting the development of technology and value chains for new bioenergy products from forest biomass, household waste and by-product streams from aquaculture and other commercial activities.
- Following up the EU's work on bioenergy. Make use of opportunities to exert an influence on and promote the development of a suitable and predictable framework for Norwegian stakeholders.
- Following up the Skog22 strategy with cost-effective, sustainable energy solutions, focusing mainly on heat and fuel.
- Carrying out research, development, demonstration and commercialisation activities within the strategic research areas identified below.

Strategic research areas:

- Integrating bioenergy into energy systems of the future as part of the bioeconomy.
- Bioenergy production as an integral part of future biorefineries.
- Identifying barriers to greater use of bioenergy in the Norwegian system, including barriers to the use of forest residues and low-quality biomass.
- Sustainable biofuels for the transport sector, with a special emphasis on aviation and long-distance and heavy freight transport on land and at sea.
- Making better use of waste and by-product streams for heat, power and fuel.
- Technologies and solutions for large-scale biogas production.
- Enzymes, microbiology and fermentation processes.
- Methanisation of CO_2.
- New types of sustainable Norwegian biomass on land and in the sea, including marine biomass and algae.
- Using bioresources for purposes where few other renewable options are available, for example for chemicals, plastics, other materials and industrial purposes.

3.5

Climate-friendly energy technologies for land transport

Land transport is responsible for substantial greenhouse gas emissions. The introduction of climate-friendly energy technologies for land transport is of crucial importance for achieving the necessary emission reductions. According to the Energi21 board, land transport will play a pivotal role in the transformation to a low-emission society. In addition, this sector has the potential to develop an internationally competitive industry.

Land transport is important for developments in the key areas "Climate-friendly energy technologies for maritime transport" and "Digitalised and integrated energy systems".

[99] *Statistics Norway, National Forest Inventory (2016)*
[100] *Skog22*
[101] *SSB.no, https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/skogav (Commercial roundwood removals)*
[102] *Consisting of branches and tops of trees*
[103] *High-quality wood that can be used in sawmills to produce timber*
[104] *Norwegian Environment Agency (2014) Knowledge base for low-carbon transition in Norway*

Summary:

- A large-scale shift to climate-friendly energy technologies is required in the land transport sector in order to achieve emission targets and help to establish a low-emission society.
- This transformation process will trigger large-scale investments globally and thus provide opportunities for Norwegian suppliers.
- Climate-friendly energy technologies must be further developed to achieve wider deployment and more areas of use, and there are major challenges involved in finding solutions for heavy freight and long-distance transport.
- Norway is a pioneer of electrification of the passenger car stock, and can use this head start to build stronger expertise in systems thinking and the integration of new transport solutions.
- Norway has a robust electricity grid that provides security of supply, and large energy resources. This provides a good basis for electrification of the transport sector.
- Norwegian expertise in electrochemistry and materials technology provides opportunities for battery production. There are already suppliers of battery modules for industry and transport in Norway.
- Norway has long industrial experience and expertise in using hydrogen, and is in a good position to develop core technology and components. Norway already has suppliers of hydrogen technology which are leaders in the global market.
- Second- and third-generation biofuels will be part of the solution for achieving emission targets in the transport sector. Some technologies have been demonstrated commercially, while scaling up others remains costly for the present.
- Using biogas for land transport has climate benefits, and Norway could increase its biogas production from the current level of 1 TWh to 5 TWh in 2030.[105]
- Digitalisation will result in changes along the entire value chain for land transport, and there is a potential for developing and offering new transport solutions and services.

3.5.1 MARKET DEVELOPMENT AND ANTICIPATED ROLE

Land transport accounts for about 23 % of Norway's greenhouse gas emissions,[106] and ambitious targets have been set for reducing emissions from this sector. The white paper Norway's Climate Strategy for 2030 (Meld. St. 41 (2016–2017) sets out the Government's ambition for the transport sector to be virtually emission-free/climate-neutral by 2050. Achieving this ambition will require considerable effort and effective measures throughout the transport system, including a large-scale shift from fossil to emission-free energy carriers in the land transport sector.[107] The latter will require widespread use of climate-friendly energy technologies for land transport, including battery- and hydrogen-electric propulsion and biofuels.

Internationally, land transport accounts for about 11 % of greenhouse gas emissions,[108] and according to the IEA's 2°C scenario (2DS), about 21 % of total emission cuts by 2060 must be made in the transport sector.[109] The largest proportion of the reductions will be in land transport. It will be a very challenging task to achieve the emission targets for this sector, and fundamental changes will be required throughout the global transport system. The transformation process will involve huge investments, which will open up market opportunities for technologies, solutions and services for climate-friendly energy technologies to be used in land transport.

The challenges and opportunities involved in the transformation of the transport system will vary from one vehicle segment to another. All available climate-friendly transport technologies can be used for lighter vehicles such as cars and vans, and constant technological improvements have made electric options available for shorter distances for trucks and buses as well. In future, there will have to be a large proportion of electric vehicles in these vehicle segments in order to achieve emission targets.

There are fewer alternatives available for heavy vehicles for use over longer distances (trucks and other freight vehicles, long-distance coaches) because of limitations on range and battery capacity. It is therefore a more challenging task to decarbonise these vehicle segments. Improvements in battery-electric solutions will make battery-electric propulsion a possibility for parts of this segment, but other options will still be needed in 2060.[110] Hybrid solutions are an alternative in the short and medium term. According to the IEA's Beyond 2°C scenario (B2DS), biofuels will account for a substantial proportion of energy use by heavier vehicles by 2060, but limited availability of biofuels may prove to be a problem in the long term. Electric propulsion may be the only real option in the long term, but this will require further development of technology[111] for both hydrogen-electric and battery-electric propulsion.

There seems to be general agreement that growth is expected in the battery-electric segment of land transport vehicles, although the speed and timing of the phase-in varies from one projection to another. There is more disagreement about how widely hydrogen-electric vehicles will be used in the future. Some projections, for example in Energy Technology Perspectives 2017 (IEA), indicate that hydrogen deployment will remain low as a result of barriers relating to energy efficiency and the high costs of infrastructure, fuel cells and storage tanks. Others, for example projections from ZERO and the Hydrogen Council, suggest that hydrogen will play an important part in the transformation of land transport. The Hydrogen Council states that 25 % of cars, 30 % of trucks and 25 % of buses will need to run on hydrogen by 2050 to achieve the IEA's 2DS.[112]

The railways in Norway are already largely electrified, except for a few stretches where diesel trains are used, and that need to be converted to zero-emission technology. Solutions using a combination of overhead lines and battery- and hydrogen-electric propulsion are possible.

3.5.2 NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

There are no car manufacturers in Norway, but there are several suppliers of parts and components to the international automotive industry. These companies produce components that are relatively independent of the propulsion system, such as bumpers and wheel suspension, but nevertheless have knowledge and experience that it will be possible to build on. As regards energy technologies and solutions specifically for climate-friendly land transport, there are Norwegian companies and other stakeholders working on various technologies all along the value chain.

As regards the production of battery-electric propulsion solutions, there are some Norwegian companies that supply battery materials for battery cell production outside Norway, and some that produce battery modules for industrial purposes and maritime transport. There are also a number of Norwegian companies that develop and manufacture charging infrastructure, and these also operate in the international market.

In the field of solutions for hydrogen-electric propulsion, there are world-leading Norwegian companies that manufacture electrolysers, compressed hydrogen tanks and filling stations. There are also some Norwegian firms that operate hydrogen filling stations in Norway, but so far there are relatively few filling stations. However, several companies have ambitions to build up a network of hydrogen filling stations by 2020.

Biofuels are used in the same types of vehicles and supplied through the same infrastructure as fossil fuels; the differences are at the production stage. A few Norwegian companies are engaged in the production of biofuel both from imported rapeseed and soybean and from waste. There are few companies engaged in this field at present, but several are considering the possibility of establishing large-scale production of biofuel from forest biomass. It has recently been decided to build a demonstration plant in Norway for production of advanced biofuel. There are also Norwegian companies in various parts of the biogas value chain, including two producers of biogas plants that can supply competitive technology for the international market.

Norway also has research groups working with charging infrastructure and interaction with the energy system, as well as with batteries, hydrogen and biofuels.

There are several leading research groups in Norway working on battery materials and technologies, and Norway has substantial expertise on silicon anodes. The research groups are working on silicon, graphene, various types of coatings, solid electrolytes, metal hydrides, magnesium-ion batteries and other materials for the next generation of batteries.

Within hydrogen technologies, Norway has top-notch research groups working on high-temperature fuel cells and electrolysers, with a special focus on proton-conducting ceramics. These groups have world-class materials expertise. In addition, Norwegian research groups have a high level of expertise in low-temperature fuel cells and polymer electrolyte membranes. Norwegian scientists are also working on alkaline electrolysis. Moreover, the Norwegian research community has wide-ranging expertise in hydrogen storage in metal hydrides, and is at the forefront internationally in modelling and analysis of hydrogen systems and value chains.

Within biofuels, there are several Norwegian research groups of top international calibre. Examples of areas where Norway is in a particularly strong position are microbiology, biogas and enzyme research and catalytic upgrading of biofuels. Norway is also involved in internationally recognised research on the climate benefits of using forest to produce biofuels. A Norwegian researcher has been chosen as contributing lead author for one of the chapters of the next assessment report from the IPCC.

3.5.3 NORSKE UTFORDRINGER OG MULIGHETER

Norway is a pioneer of electrification of the passenger car stock, and has the highest proportion of electric cars in the world. Norway can use this head start for new value creation, for example by developing and testing new solutions and services in the domestic market. These can then be exported to an international market when other countries have also made more progress in electrification. Norway is in a good position to develop an all-electric transport system, since it has a robust electricity grid, well-developed energy infrastructure for transport, and renewable electricity resources.

Battery materials and battery modules are being produced by companies in Norway, but there is no production of battery cells. The strong market growth for batteries is

[105] *Avfall Norge, https://www.avfallnorge.no/bransjen/nyheter/biogass-verdifullt-effektivt-og-kliman%C3%B8ytralt (Norwegian only)*
[106] *Avinor, National Rail Administration, Norwegian Coastal Administration and Norwegian Public Roads Administration (2016) Grunnlag for klimastrategi (Basis for Norway's climate strategy)*
[107] *The white paper on Norway's climate strategy presents three main types of measures to reduce emissions from transport: reducing the volume of transport, switching to more environmentally sound forms of transport and eliminating or reducing emissions from specific means of transport. Energi21's mandate covers the third of these*
[108] *IPCC (2014), Fifth Assessment Report of the Intergovernmental Panel on Climate Change*
[109] *IEA (2017), Energy Technology Perspectives 2017*
[110] *Ibid*
[111] *Ibid*
[112] *Hydrogen Council (2017), Hydrogen scaling up*

opening up opportunities for supplying materials, production technology and battery cells. Battery cell production in Norway could be of interest since there are plentiful supplies of renewable, low-cost electricity, the climate is suitable for battery cell production and industrial sites are available. There are also dynamic research groups in electrochemistry and materials technology, both fields that are relevant to the production of battery cells.

Several companies in Norway are engaged in the development and production of electric charging infrastructure, and there are ongoing development activities in the field of smart charging with demand response. This kind of charging infrastructure has the potential to become an attractive export, particularly to countries with a less robust electricity grid than Norway. Internationally, there is considerable activity within the development, testing and demonstration of technology for continuous wireless power transfer to moving vehicles. The Norwegian Public Roads Administration and companies in the transport industry are also reviewing possibilities for demonstrating such technology in Norway. In the long term, technology of this kind, combined with battery and hydrogen technology, can help to provide a solution to the problem of limited range and battery capacity for heavy freight transport.

Norway is well prepared in several ways to develop and deploy hydrogen technologies for land transport. Norway was one of the first countries to establish hydrogen filling stations that are open to the public. Norwegian companies have cutting-edge expertise in electrolysis, filling station technology and compressed hydrogen tanks, long industrial experience of hydrogen and research and education institutions with extensive knowledge of materials and processes. In addition, Norway has both renewable and fossil energy resources that can be used to produce emission-free hydrogen through electrolysis or steam methane reforming combined with CCS.

Increasing the penetration of hydrogen technology for land transport involves challenges relating to the cost of both the hydrogen itself and of vehicles and infrastructure. Scale is an important cost driver for production of hydrogen by electrolysis. Hydrogen vehicles are currently not in widespread use, which results in a low rate of utilisation of hydrogen filling stations and keeps the price of hydrogen high. Scale is also important for the production of hydrogen technology; an increase in production volume drives costs down. However, there are also still ways of reducing costs through the further development of various key components of hydrogen technology.

There are some companies in Norway that produce biofuels, but biofuel consumption in Norway is largely based on imports. However, Norwegian companies need to respond to the stepwise increases in the biofuel quota obligation, which are adding to the pressure to speed up technology development and to produce sufficient quantities of biofuels. Norway has extensive forest resources that can be used in biofuel production, but the production processes are energy- and capital-intensive and the technology is not very mature. In the longer term, the availability of bioresources may limit the use of biofuels for land transport because there may be a greater need for these resources in other sectors.

Charging infrastructure. *Photo: ABB*

Norway produces around 1 TWh of biogas per year at present, but currently only a small proportion of this is used for transport purposes. Biogas is considered to have a potential to play a larger role in the transport sector in the future,[113] and production in Norway may increase to 5 TWh by 2030. Norway's expertise and experience from the process industries put the country in a good position to continue the development of technologies and solutions for the biogas sector.

As described above, Norway is in a good position in a number of ways for value creation based on climate-friendly energy technologies for land transport. One factor that may complicate the position of Norwegian companies is the lack of a Norwegian car manufacturing industry[114]. This means that instead of acting as domestic suppliers, they are dependent on success in a highly competitive international industry with demanding customers. Norwegian manufacturers of car parts are succeeding as suppliers in this market, and have valuable experience and expertise that they can build on. However, there are indications that the automotive industry itself is interested in driving the shift to electrification and new transport solutions. For example, several car manufacturers have started their own production of batteries, charging infrastructure and transport services (e.g. car sharing).

3.5.4 DIGITALISATION AND CLIMATE-FRIENDLY LAND TRANSPORT

Digitalisation will result in changes along the entire value chain for land transport, from vehicle manufacture to end users and the development of new transport technologies and services. Digitalisation will have an impact on all low-emission technologies, but so far there has been more digitalisation of the transport structure for electric vehicles than for other low-emission technologies.

A digital land transport system will make use of digital solutions throughout the system: for charging points, filling stations, parking, road toll systems and so on. In the longer term (2025), self-driving vehicles may be introduced, which would open up even more possibilities in the transport system. There will be vehicles that communicate with users, other vehicles, roads and other transport infrastructure, and that become an integral part of smart cities. Thus, digitalisation can play a part in the development of connected, green and efficient transport systems, which will benefit both users and society as a whole.

Digitalisation will allow the expansion of sharing economy services and of "Transport as a Service" solutions. Norway can gain a position in this market by exploiting the country's high degree of electrification in combination with new digital technologies. Norway can make use of its capacity for cooperation across sectors to develop sound, sustainable transport solutions that are closely integrated with other services in smart cities. The solutions can be tested and verified in the domestic market before they are sold internationally.

Digitalisation is making software development increasingly important, and if Norway builds up expertise in this field, it will be possible to export knowledge to a large international market. Expertise from the maritime sector and the development of autonomous underwater vessels could be transferred to autonomous solutions for use on land. In addition, Norway has a strong ICT community.

3.5.5 APPLICABILITY IN OTHER AREAS

Climate-friendly energy technologies for land transport are widely applicable in other areas, as is also the case for maritime transport technologies. Much of the technology and knowledge concerning batteries and hydrogen technologies for land transport can be transferred to other areas of application. In the case of biofuels, production is relatively independent of the area of use, and production techniques developed for advanced biofuels can be used for various purposes.

3.5.6 AMBITIONS FOR CLIMATE-FRIENDLY LAND TRANSPORT

The industry's ambitions as regards the development of climate-friendly land transport are as follows:

- For Norwegian land transport to lead the way in the use of climate-friendly energy technologies for land transport and achieve its emission targets.
- For Norwegian land transport to be digital, smart, and closely integrated with the energy system.
- To establish battery cell and fuel cell production in Norway.
- To develop an internationally competitive supplier industry for climate-friendly propulsion solutions and transport systems on land:
  - charging technology and associated services for electric cars, buses, heavy vehicles and other commercial vehicles (connection to the electricity grid, including energy storage systems for "peak shaving").
- To develop key components for hydrogen vehicles and filling stations, which will bring down costs and enhance competitiveness.
- To develop cost-effective technology for the production of second- and third-generation biofuels.
- To develop innovative solutions for electrification of the railways (for example battery- or hydrogen-electric propulsion).
- To develop new digital transport solutions and services.

[113] *Sund Energy (2017)*
[114] *It is considered unrealistic to expect this situation to change*

3.5.7
ACTION AND IMPORTANT RESEARCH AREAS – CLIMATE-FRIENDLY LAND TRANSPORT

The road transport industry will give priority to the following action and research areas to realise its ambitions and satisfy the knowledge and technology needs of tomorrow:

Action:

- Including requirements for zero-emission solutions in public procurement processes.
- Supporting efforts to phase in infrastructure for climate-friendly energy technologies for land transport.
- Establishing demonstration projects for different types of infrastructure for electrification of heavy freight transport.
- Establishing a pilot production line for battery cell production in Norway.
- Carrying out research, development, demonstration and commercialisation activities within the strategic research areas identified below.

Strategic research areas:

- Battery technology and battery materials, development of technology for key components.
- Electrolysers, fuel cell technology and other core technology for hydrogen vehicles.
- Charging technology (stationary and dynamic) for electric vehicles and hydrogen filling stations.
- Technology for using wood and forest residues for biofuel production.
- Technologies and solutions for large-scale biogas production.
- Cost-effective hybrid solutions
- Smart transport systems to make more effective use of the road network and energy.
- Climate-friendly and environmentally sound solutions for heavy freight transport and long-distance transport.
- Effective market and business models for the development of a climate-friendly transport system.
- Developing an integrated understanding of the transport system of the future, interdisciplinary research questions relating to transport patterns, road use, vehicle density, etc.

3.6
Climate-friendly energy technologies for air transport

In the long term, restructuring the air transport system to accommodate climate-friendly energy technologies will be essential to achieve national and global emissions gargets. Energy technologies of particular interest in this context are biofuels and electricity. Norway is well positioned for early adoption and use of electric aircraft, with suitable passenger capacities, flight distances, short-runway characteristics and access to electrical power infrastructure.

Summary:

- Norway's short-runway airport network provides a basis for early adoption and use of electric passenger aircraft, and is appropriate for
  - expected performance of first-generation electric aircraft;
  - expected passenger capacity;
  - expected flight distances;
  - short-runway characteristics and electrical power infrastructure.
- The challenges of using biofuels (second- and third-generation) in aviation are tied to excessive cost and insufficient production scale.
- For electric aircraft, the challenges involve the development of slim, compact electric motors and higher-capacity, lower-cost batteries.
- In Norway, the airport operator Avinor has taken a leading active role in environmental and climate efforts and is seeking to adapt the country's airports to accommodate sustainable air transport.

3.6.1
MARKET DEVELOPMENT AND ANTICIPATED ROLE

Air traffic in and from Norway produces some 2.8 million tonnes of CO_2 equivalent annually, or about 5 per cent of Norwegian greenhouse gas emissions. In 2015, greenhouse gas emissions from all domestic civil aviation accounted for 2.4 per cent of Norway's total greenhouse gas emissions (1.3 million tonnes out of 53.9 million tonnes of CO_2 equivalent). These are the emissions addressed in the Kyoto Protocol and reported by Statistics Norway. Greenhouse gas emissions from aviation fuel sold in Norway for international purposes (that is, for trips whose first destination is out of the country) accounted for an additional 1.5 million tonnes of CO_2 equivalent.

In 2015, total global emissions from aviation represented about 2 per cent of global greenhouse gas emissions. While air traffic growth in Western Europe and the United States is expected to be relatively moderate over the next 10 years, strong growth is expected in other parts of the world.[115] Total greenhouse gas emissions from aviation are therefore expected to increase in the years ahead.

Replacing the existing fleet of aircraft with new, lighter airplanes running on more efficient engines is the most important way to reduce emissions at present. Increased use of lighter materials such as composites and aluminium as well as fuselage and wing improvements and new engine technologies are among the measures anticipated. More efficient use of airspace and optimisation of landings and departures are also important in reducing emissions. In addition, airport operations (energy-efficient, climate-friendly buildings) and airport transport services (land-based transport) play a role in the overall greenhouse gas emissions associated with air transport.

In the longer term, it will likely be possible to reduce aviation emissions by phasing in biofuel-, hydrogen- or electric-powered aircraft.

Since 2009, thousands of civilian flights globally have employed biofuels. The first Norwegian biofuel-powered flights were carried out in 2014 by Norwegian Air Shuttle and Scandinavian Airlines (SAS), and since 2016 Oslo Airport has been the first international hub in the world to supply aviation biofuel. Avinor's goal is that 30 per cent of all aviation fuel sold at Avinor's airports in 2030 will be sustainably produced biofuel. That corresponds to 400 million litres of jet fuel. In 2017 there were five certified production processes for jet biofuel, and more are under development.

The use of biofuel involves several challenges. One is that the fuel must be produced sustainably, meaning that the use of biomass from forest to fuel should meet certain requirements pertaining to balanced timber production, protection of biodiversity, and that the fuel must fulfil EU sustainability criteria.

Another challenge is the present lack of a well-functioning jet biofuel market. Market volumes are too small and large-scale production has not been established. As a result, the costs are uncompetitive, though they are expected to fall in the long term.

It is unclear what roles hydrogen will play in future energy and transport systems, as a number of challenges must be resolved before the full potential of hydrogen technology is unleashed. One role of hydrogen may be as a range extender. However, there are special challenges related to competitiveness and costs, and to infrastructure and technology development. Technological breakthroughs will be needed for hydrogen to have a role. In its future scenarios the International Energy Agency has therefore assigned little significance to hydrogen use in air transport.[116]

Aviation electrification is in a period of rapid development. In the view of major aircraft manufacturers, limited-distance commercial flights by airplanes carrying up to 70 passengers could be technically possible within 10 years. A number of major actors now see commercial opportunities for electric aircraft. Siemens and Airbus have signed a cooperation agreement and Boeing has invested in a company that is developing new electric aircraft. The main challenges are tied to the development of slim, compact electric motors and larger-capacity, lower-cost batteries.

For small aircraft, battery capacity is already sufficient for training flights. Toyota, Airbus, Google, Uber and some Chinese companies are among those investing heavily in the development of passenger-carrying drones (air taxis).

3.6.2
NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

There are few Norwegian actors active in air transport. Airlines such as SAS and Norwegian Air Shuttle are experiencing demanding competitive conditions and have cut resources for climate and environmental efforts. In Norway, the airport operator Avinor has taken a leading role in environmental and climate efforts and is seeking to adapt the country's airports to accommodate sustainable air transport.

Statkraft, Quantafuel and BioZone are among the actors active in biofuel.

3.6.3
CHALLENGES AND OPPORTUNITIES FOR NORWAY

In 2030, electric passenger aircraft may be on the market, especially aircraft designed for up to 50 passengers and short flight distances with limited runway length. Such planes will be suitable for use in Norway's short-runway airport network.

Norway is well positioned for early adoption and use of this type of electric aircraft, with suitable passenger capacities, flight distances, short-runway characteristics and access to electrical power infrastructure.

The industry as represented by Avinor, the Norwegian Air Sports Federation, Widerøe and SAS has established a long-term electric aircraft development project and made the case that Norway can become an innovation centre and a testing arena for the development of electric aircraft.

3.6.4
AMBITIONS FOR CLIMATE-FRIENDLY AIR TRANSPORT

The industry's ambitions as regards the development of climate-friendly transport solutions are as follows:

- To establish Norway as an "electric laboratory" for the development of electric aircraft;
- To reduce the cost of biofuel.

3.6.5
ACTION AND IMPORTANT RESEARCH AREAS

The air transport industry will give priority to the following action and research areas to realise its ambitions and satisfy the knowledge and technology needs of tomorrow:

Key R&D areas and action in the fields of bioenergy, hydrogen and climate-friendly energy technologies for maritime and land-based transport, together with digitalised, integrated energy systems, are of relevance in acquiring the knowledge and technology needed to develop climate-friendly air transport energy technologies. These areas are closely interlinked, with high knowledge transfer value between them.

115 *Avinor (2017), "Bærekraftig og samfunnsnyttig luftfart" (Sustainable, socially beneficial air transport), Report 3*
116 *International Energy Agency (IEA) (2017), Energy Technology Perspectives 2017*

3.7

Land-based wind power

Land-based wind power enhances national value creation through the land-based utilisation of wind resources, and the Energi21 board anticipates the expansion of land-based wind power in Norway in the coming years.

Land-based wind power also plays an important role in the key area of "Digitalised and integrated energy systems", where coordination between different technologies and the energy system is a central theme.

Summary:

- Globally installed land-based wind power capacity has grown by some 14 per cent annually over the past five years, amounting to roughly 472 GW in 2016.
- The Norwegian-Swedish market for green electricity certificates has been a key driver for expanding land-based wind power in Norway. As cost levels diminish, wind power is likely to become more competitive soon, and it will be the price of electricity that determines new development.
- Norway has some of Northern Europe's best wind resources.
- Land-based wind power is a mature technology, but continual advances will further enhance its cost-effectiveness and energy output.
- Norwegian companies with reliable solutions have opportunities as subcontractors in this market, and some exist already.
- Norwegian companies are looking to become owners of wind farms in Norway and abroad.

3.7.1 MARKET DEVELOPMENT AND ANTICIPATED ROLE

More than 90 countries[117] now have installed wind power. At the end of 2016, total installed capacity worldwide was 472 GW.[118] This is expected to increase to some 1700 GW by 2040, equivalent to a total global production exceeding 5 000 TWh.[119]

There is great potential for utilising land-based wind power in Norway. At the end of 2017 Norway had roughly 1 165 MW of installed land-based wind power capacity, with production of some 2.85 TWh.[120] The potential is significant and with existing mature technologies can be realised without requiring new research. The common Norwegian-Swedish market for green electricity certificates has helped to promote the expansion of land-based wind power, and the Norwegian Wind Energy Association (NORWEA) estimates wind power production in Norway will exceed 10 TWh in 2020. The value of Norwegian wind power is enhanced by the potential for coordination with the nation's hydropower system. Hydropower plants with pumped-storage capacity could enhance this even more. Due to diminishing costs, wind power will likely be profitable without subsidies within a few years. The Norwegian Water Resources and Energy Directorate (NVE) estimates that 15 TWh of new wind power capacity will be installed by 2030.[121]

3.7.2 NORWEGIAN STAKEHOLDERS, BUSINESS SECTOR AND RESEARCH GROUPS

Companies can be classified into two groups: energy companies that construct and utilise wind power, and suppliers of related technology and services. There are currently no Norwegian full-service suppliers but rather companies operating as subcontractors. Several Norwegian companies are positioning themselves for wind power development internationally.

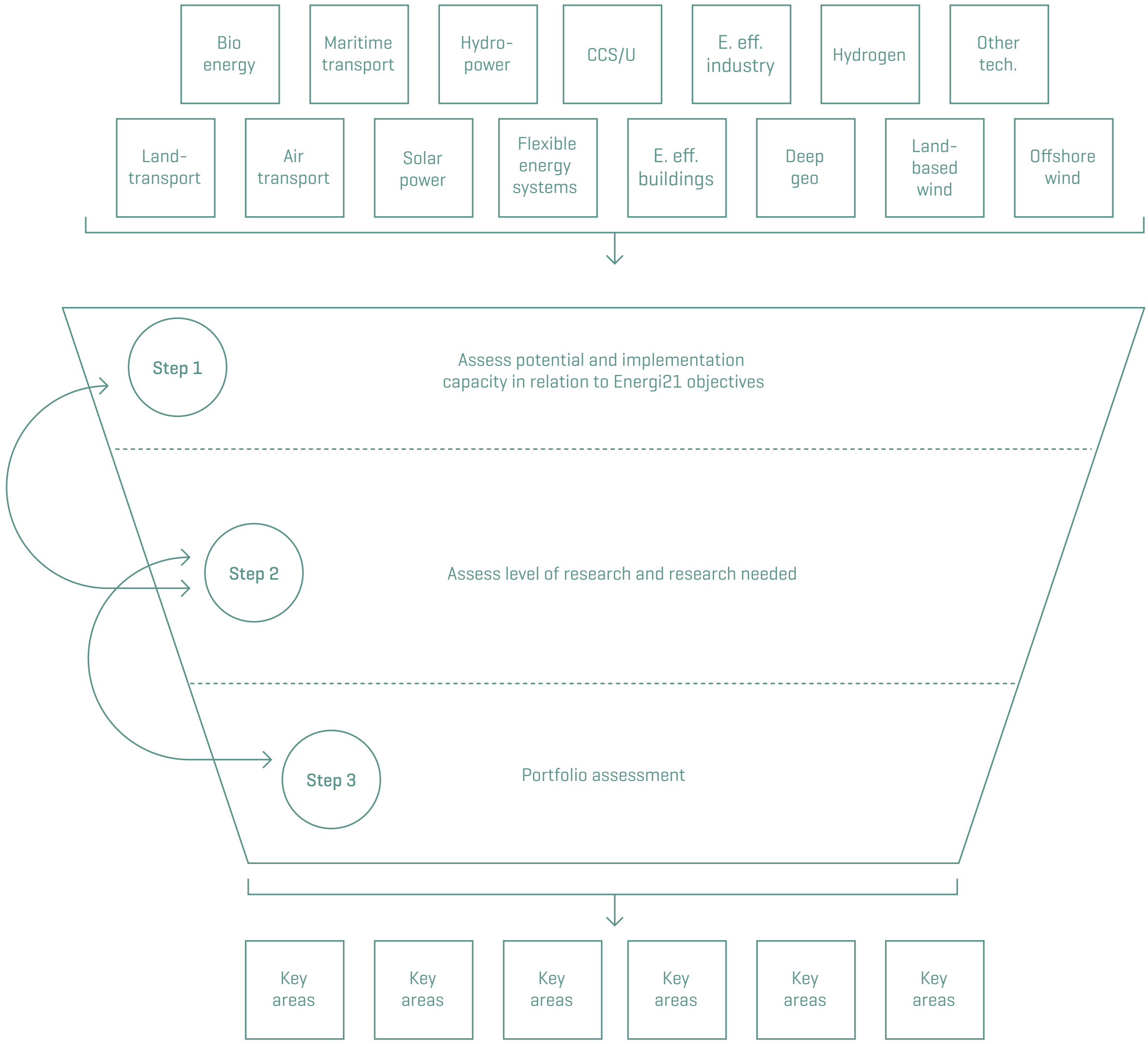
3.7.3 CHALLENGES AND OPPORTUNITIES IN NORWAY

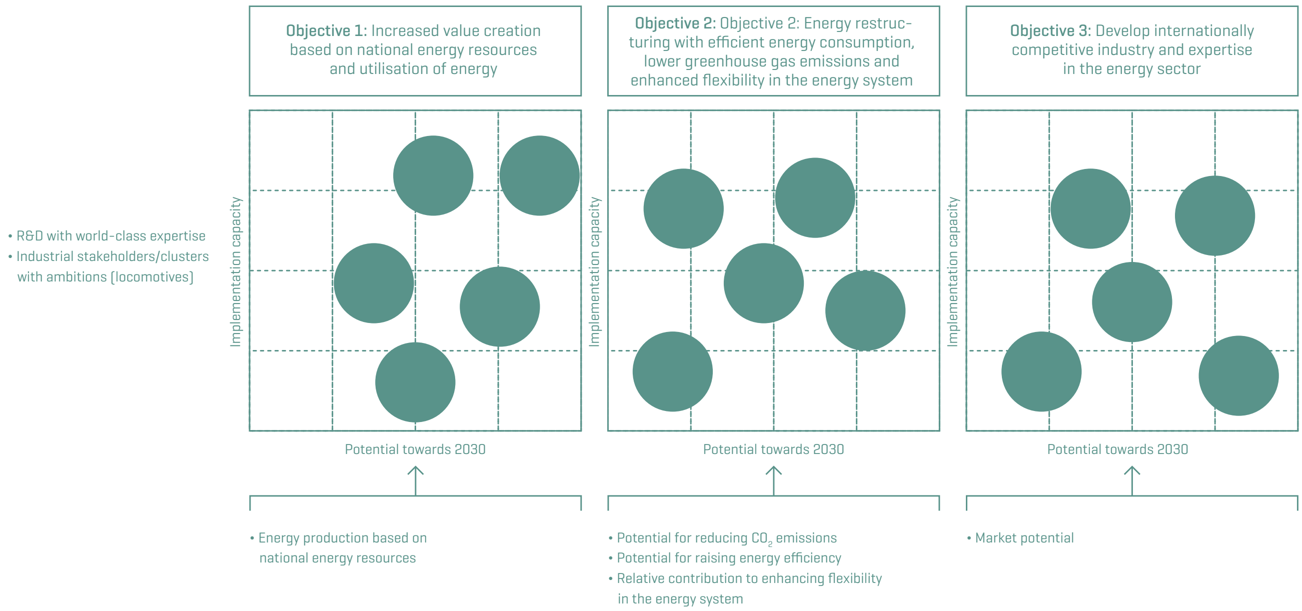
Norway has some of Northern Europe's best wind resources, and wind power will likely be profitable without subsidies within a few years. Market opportunities will still be available to Norwegian companies for delivery of components and services for specific development projects and for subcontracting within the value chains of the major wind turbine producers. New solutions within these chains could create significant value due to the large market size. However, there are certain challenges to utilising land-based wind power, such as visual pollution, noise and environmental issues.

3.7.4 TECHNOLOGY DEVELOPMENT

Although land-based wind power may be considered a mature technology, further technology development is still needed to raise cost-effectiveness and energy production. The technology areas involve wind turbine technology, meteorology and forecasting, concepts and designs of wind farms, efficient integration into the power grid, and condition-based operation and maintenance for increased reliability.

117 *Global Wind Energy Council, http://gwec.net/global-figures/graphs/*
118 *Global Wind Energy Council (2016) Global Wind Statistics 2016*
119 *Bloomberg New Energy Finance (2016), New Energy Outlook 2016*
120 *Vindportalen.no, http://www.vindportalen.no/Vindportalen-informasjonssiden-om-vindkraft/Vindkraft/Vindkraft-i-Norge (Wind power in Norway)*
121 *Norwegian Water Resources and Energy Directorate (NVE, 2017) energy market analysis for 2017–2030*


Bio energy
Maritime transport
Hydro-power
CCS/U
E. eff. industry
Hydrogen
Other tech.
Land-transport
Air transport
Solar power
Flexible energy systems
E. eff. buildings
Deep geo
Land-based wind
Offshore wind
Step 1
Assess potential and implementation capacity in relation to Energi21 objectives
Step 2
Assess level of research and research needed
Step 3
Portfolio assessment
Key areas
Key areas
Key areas
Key areas
Key areas
Key areas


Objective 1: Increased value creation based on national energy resources and utilisation of energy
Objective 2: Objective 2: Energy restructuring with efficient energy consumption, lower greenhouse gas emissions and enhanced flexibility in the energy system
Objective 3: Develop internationally competitive industry and expertise in the energy sector
• R&D with world-class expertise
• Industrial stakeholders/clusters with ambitions (locomotives)
Implementation capacity
Implementation capacity
Implementation capacity
Potential towards 2030
Potential towards 2030
Potential towards 2030
• Energy production based on national energy resources
• Potential for reducing CO_2 emissions
• Potential for raising energy efficiency
• Relative contribution to enhancing flexibility in the energy system
• Market potential

3.7.5
DIGITALISATION IN LAND-BASED WIND POWER

As described in Chapter 2, digitalisation entails expanded use of sensors as well as larger volumes of more precise data on physical parameters. More powerful computing makes it possible to analyse and utilise these data, and there is wider use of automation and robotisation to perform increasingly complex tasks.

As is the case with offshore wind power, digitalisation in land-based wind power unleashes significant potential for reducing the costs of operating and maintaining wind farms. Digitalisation can also enhance weather forecasting and help to optimise power generation and reduce downtime. Estimates indicate that digitalisation of renewable, intermittent power production may reduce operational and maintenance costs by 10 per cent, increase power generation by eight per cent and reduce downtime by 25 per cent.[122]

3.7.6
AMBITIONS FOR LAND-BASED WIND POWER

The land-based wind power industry's ambitions are as follows:

- To increase the cost-effectiveness of utilising available wind resources.
- To make land-based wind power profitable without subsidies by 2020.

3.7.7
ACTION AND IMPORTANT RESEARCH AREAS – LAND-BASED WIND POWER

The land-based wind power industry will give priority to the following action and research areas to realise its ambitions and satisfy the knowledge and technology needs of tomorrow:

Action:

- Carrying out research, development, demonstration and commercialisation activities within the strategic research areas identified below:

Strategic research areas:

- *Wind resources (prognoses):*
  - Enhance methods and models for estimating wind and power production.
- *Cost-effective operation and maintenance and technology:*
  - Optimise operation and maintenance, methods and tools.
  - Estimate and enhance reliability, service life and efficiency of primary components and systems.
- *Environmental and societal issues:*
  - Generate knowledge about the impacts of wind power on the environment and local communities.
  - Develop cost-effective solutions and measures for reducing negative impacts on the environment and land areas.

Attachment 4

Backdrop for strategic priorities

The Ministry of Petroleum and Energy's mandate and guidelines for the Energi21 body provide the backdrop for selection of the strategic priorities. In 2016 the mandate was expanded to encompass environment-friendly transport and a stronger international focus. The purpose of Energi21 is to help Norway become a climate-friendly energy nation and an international supplier of energy, power, technology and knowledge.

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.

4.1

Strategic review of 14 technology areas

The Energi21 body's selection of key areas and recommendations for measures to be implemented are based on an analysis of 14 technology areas within the energy and transport system. The assessment encompasses factors deemed to be of importance for designating the strategy's key areas.

In its strategic analysis the Energi21 board describes the factors (Chapters 4.1–4.6 and Attachment 3) that it considers particularly relevant for Norwegian stakeholders, the country's energy supply, and industrial development. In addition, it identifies the following key elements:

- industry ambitions;
- strategic research areas;
- actions to take.

4.2

Method of comparative analysis used

With the strategic review of thematic and technology areas as 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 3 illustrates the methodology used. Although the figure outlines a three-step process, in practice the process has been an iterative one, with multiple assessments of categorisation of technology areas and multiple iterations performed on each step.

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 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?

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 restructuring?
- What is the technology area's potential for enhancing the flexibility of the energy system?

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. This encompasses assessing Norwegian stakeholders' experience and technology and competency base and has been assessed for all Energi21 objectives using the following defined sub-criteria:

- What is the current level of R&D groups and educational institutions within the technology area?
- Are there companies or industrial clusters with the ambition, willingness and ability to take action in the technology area?

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. Step 1 has been compiled and simplified into diagrams to illustrate the technology areas' relevance relative to each Energi21 objective.

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 development activities. Each phase of the innovation chain is vital for achieving successful commercialisation of results, and this has been emphasised in all the strategic analyses of the level of research and research needed. Assessments have been carried out on 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;
- whether, within the technology area in question, the integration of technologies into the energy system creates new research needs, or new research needs arise within the energy infrastructure;
- the impacts of ICT/digitalisation on the technology area, including opportunities and positive effects as well as research needs that arise as a result of digitalisation;

[122] *Bloomberg New Energy Finance (2017), Digitalization of Energy Systems*

- the need for new business models and market design for efficient implementation and development of the technology area, or whether the technology area generates a need for new business models and new market design.

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. Chapter 6 discusses the EU research agenda.

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, how the different objectives will be weighted, and the overall contribution towards national security of supply.

4.3

Information sources for the strategic analysis

Strategic working meetings for each technology area were an essential part of the strategic review process. Represented at these meetings were public authorities, industry players and research groups 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*. A total of nearly 300 individuals took active part in the strategy processes.

In addition to the strategic working meetings, the Energi21 board maintained an ongoing dialogue with relevant authorities, representatives within the research and innovation system, and special interest organisations. This provided an integrated, realistic view of Norway's position within the various technology areas. This dialogue enabled the Energi21 board to obtain a good overview of the level of Norwegian research groups within the various technology areas. Each technology area contains a paragraph about Norwegian research groups' expertise and how this measures up to international standards.

Another basis for the strategic analysis was the assessments stemming from the Energi21 external factors assessment conducted in 2016, as well as a number of other reports and document analyses by recognised sources and relevant publicly accessible information. 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.

Attachment 5

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.

Energy company

A company that delivers electricity, heating or other energy services.

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 (m^3) 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 do work, and is the product of power and time. Electrical energy is often measured in kilowatt hours (kWh). 1 kWh = 1 000 watt 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 a 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. 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.

TRL
Technology Readiness Level. A system for measuring the degree of maturity of a technology or concept. The TRL system consists of nine levels.

SME
Small and medium-sized enterprises. Often used about enterprises with fewer than 100 employees.

Carbon capture and storage (CCS)
Encompasses the capture, transport and storage of CO_2 along the entire value chain.

Bio-CCS
The use of carbon capture and storage in processes utilising biochar as raw material.

Competitive advantage
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.

TCM
Technology Centre Mongstad. TCM is the world's largest facility for testing and improving carbon capture technologies.

IPPC
The Intergovernmental Panel on Climate Change, established in 1988.

FME
Centres for Environment- friendly Energy Research (FME) 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.

FP7
The EU Seventh Framework Programme for Research and Technological Development.

IEA
The International Energy Agency.

2DS: Under the IEA's Energy Technology Perspectives, the 2°C Scenario (2DS) lays out an energy system pathway and a CO_2 emissions trajectory consistent with at least a 50 per cent chance of limiting the average global temperature increase to 2°C by 2100.

B2DS: The Beyond 2°C Scenario (B2DS) explores the possibilities for reducing greenhouse gas emissions beyond 2DS, using maximum deployment of technologies that are already available or in the innovation pipeline (not unforeseen or new technologies).

BNEF
Bloomberg New Energy Finance.

NORWEA
The Norwegian Wind Energy Association.

NORWEP
Norwegian Energy Partners.

Vedlegg 6

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Charging infrastructure for electric vehicles. *Photo: ABB*

ENERGI21
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Publisher
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Design
TANK Design

Translation
Alison Coulthard
Carol B. Eckmann
Walter Gibbs
Darren McKellep

Print
07 Gruppen
Oslo, June 2019

ISBN: 978-82-12-03773-1 (Print)
ISBN: 978-82-12-03774-8 (PDF)