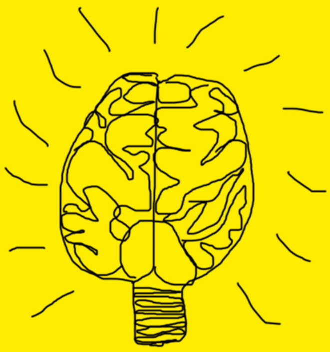
New Energy Coalition

RESEARCH AGENDA
energy systems

the road to 2050…



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Content

SUMMARY

This research agenda outlines the focus for the research efforts of New Energy Coalition (NEC) for the upcoming years. The introduction explains the mission of NEC, its thematic division and the system approach we employ. We summarize the key scenarios for 2050 and the global needs for a future energy system. Subsequently, the crucial research challenges to reach a sustainable future, collected from our partners in knowledge institutions and companies, are divided into focus areas matching the NEC themes: Local Energy Systems, Industrial Transformation and North Sea as an Energy Region. Finally, the steps towards implementation of the agenda in research projects are described.

0. INTRODUCTION

1.1 NEW ENERGY COALITION

The climate crisis is one of the biggest threats facing humanity today. Agreements made at the international level highlight the urgency of addressing the causes of this crisis, including the emission of CO_2. A more sustainable global energy supply is an essential part of any attempt to reduce emission levels. This is why we are working to achieve an energy transition: from an energy system based primarily on fossil fuels to a more sustainable system of energy generation, storage, distribution and use. Such a transition is only possible if industry, science and government work together to achieve breakthroughs in research and technology, economic and social applications and people's thoughts and actions. New Energy Coalition (NEC) wants to make a substantial contribution to this ambition.

> *Our mission: to make a substantial contribution to the energy transition at the national and international level.*

NEC wants to contribute to a sustainable energy future and to the development of the Northern Netherlands as a leading, dynamic energy region. With this in mind, it develops, enhances and disseminates knowledge and expertise relating to energy, trains professionals and contributes to an excellent climate for innovation and activities in the energy sector in the Northern Netherlands. NEC initiates, facilitates, coordinates and implements programmes and projects and acts as a central pivot in an extensive partner network as a driving force and discussion partner to bring organizations together.

We and our partners focus our activities on the following five themes:

- Local Energy Systems

- Industrial Transformation
- North Sea as an Energy Region
- Hydrogen
- Greening of the Gas System

These themes are consistent with national and international developments and with the regional context of the Energy Valley region (the three northern provinces of Drenthe, Friesland and Groningen, as well as north Noord-Holland). There is some overlap between the themes; consequently, they reinforce each other and contribute jointly to a robust energy system.

1.2 SYSTEM APPROACH

NEC is working on innovation, research and education activities within the five themes listed above. These themes each concern part of the energy system and, together, are the subject of a large proportion of the present focus in innovation and research. The NEC approach is unique in that it considers the energy transition from multiple perspectives. Of course, technological innovation is important, but the energy transition is equally an economic issue, a social issue, a spatial planning issue, a legal issue, and more. Our vision therefore needs to combine all of these perspectives if we are to make the very most of the energy transition: a system-based approach.

This entails that we consider the energy system as a complete system of energy sources, production facilities, end-user installations, infrastructure, markets, actors and roles by which society's demand for energy is met. In analyzing this system, and more importantly, how to make this system more sustainable while fostering its reliability and affordability, the focus is not only on the development of each separate part of the system, but also explicitly how these parts relate to each other and how they interact.

Together with its partners, NEC aims to study different energy forms and carriers (e.g. electricity, heat exchange, gases, liquids, solids such as coal and biomass) and technologies (e.g. generation, transport, conversion, storage and use) in different contexts (e.g. buildings, industry, transport) and at various scales (regional, national, European and global), taking a multiple-perspective, integrated approach. It specifically aims to address the changes required to integrate sustainable solutions into the energy system, also known as system integration.

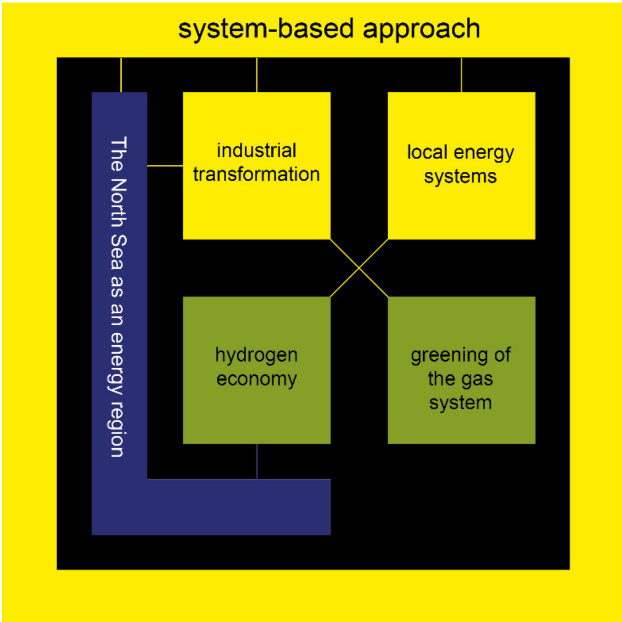
In further exploring this system integration, we make a distinction between two system levels in our themes:

- Local Energy Systems, focusing on buildings (domestic customers) and small to medium-sized businesses (commercial customers);

- Industrial Transformation, focusing on industry (large commercial customers).

These two themes each address a part of the users of the energy system with very different demands and focus areas. Within these themes, further distinction can be made between on-shore and off-shore systems. The general focus is on on-shore systems, but we also have a specific focus on the development of the off-shore system for the Netherlands in our theme North Sea as an Energy Region.

Unlike local energy systems and industrial transformation, this theme does not address a specific system level, but rather a geographical area with a unique set of characteristics. The North Sea area offers many opportunities for energy generation, and has the resources required to increase the sustainability of the present energy system. We can therefore consider the North Sea region from the perspective of specific system-based issues, making it a highly suitable area for numerous case studies.



Within the energy system, two NEC themes also focus specifically on molecular energy carriers: hydrogen and green gas. Hydrogen and green gas provide considerable potential for future applications that focus on, for example, flexibility to ensure the reliability and affordability of the system. How they fit into the future energy system and what contribution they can make to the energy transition constitutes a specific focus of our system-based approach.

In sum, NEC research therefore primarily takes a system-based approach, while distinguishing where possible between the Local Energy Systems and Industrial Transformation themes, to clearly separate the system's target groups. We then go on to integrate this with and identify specific issues within the themes of North Sea as an Energy Region, Hydrogen and Greening of the Gas System.

NEC has initially chosen to focus its research agenda on the themes of Local Energy Systems, Industrial Transformation and North Sea as an Energy Region. However, we expect (and prefer) these three themes to often relate to Hydrogen and the

Greening of the Gas System. The goal and realization of this agenda is explained below.

1. THE RESEARCH AGENDA: THE ROAD TO 2050

NEC aims to work together with its partners to make a substantial contribution to the energy transition. The ambitions for this transition are clear, as expressed in the Paris Agreement, the EU 2030 targets and the Dutch Climate Agreement. The main objectives of the Climate Agreement are[1]:

- a significant CO_2 reduction: by 49% in 2030 increasing to 80–95% in 2050, compared to 1990
- 70% of electricity in 2030 from renewable sources (35 TWh p/a on land, 49 TWh p/a at sea)
- 1.5 million buildings off the gas grid by 2030 and all (8 million) buildings by 2050
- a circular industry by 2050 with almost no greenhouse gas emissions
- climate neutral agriculture by 2050
- zero emissions mobility by 2050

However, the pathways by which we will achieve this transition are less clear, as different routes can be taken to achieve the Climate Agreement objectives. Some considerable challenges also stand in the way of achieving these objectives. There are technological challenges, of course, but also social challenges, such as public opposition, the fair distribution of costs and benefits and an affordable energy supply. The future is therefore very unclear. NEC aims to draw up a clear agenda, based on which it and its partners can contribute to the knowledge required to achieve the objectives set for 2050.

2.1 RESEARCH AGENDA HORIZON

NEC has identified various 'horizons' with respect to the focus of energy transition research and knowledge development:

- Research and knowledge development focusing on horizon 1 (integration of already accepted options) and 2 (further development of available technology and knowledge to ready for use options) aims to reveal pathways that can be followed over the next five years. These pathways can be explored to identify what is possible right now.

[1] See https://www.klimaatakkoord.nl/klimaatakkoord, 2019.

• Horizon 3 focuses on pathways for the next five, to 10, 20 or 30 years (the medium to long term). These medium to long-term pathways allow us to focus on points much further in the future.

The outcomes of research that focuses on horizon 3 can be used to explore pathways that lie somewhat less far into the future. Finally, by exploring the pathways that lie in horizons 1, 2 and 3, we can produce a roadmap by which we can steer a successful energy transition.

In developing its research programmes, NEC and its partners are working to create such a roadmap. Much of the research within these programmes will focus on the longer term issues, to help us understand future pathways. At the same time, research will also focus on horizons 1 and 2. This may also include research that focuses on end applications, but only where this research clearly contributes to the roadmap.

The added value of NEC research programmes lies in this combination of research aiming at horizons 1, 2 and 3. By developing and carrying out long-term research that is of a more fundamental nature, it is possible to identify and address any needs for applied, short-term research, and to initiate such research. This integration of fundamental and applied research is essential for ensuring that research outcomes have the optimum social and economic impact.

2.2 THE FUTURE ENERGY SYSTEM

An organized, coherent and well thought-out approach is needed to be able to develop transition pathways. This, in turn, requires clear methods and methodology.

In the case of this agenda, it is clear that the climate objectives from the Paris Agreement, and more specifically, the Dutch Climate Agreement need to be reached by 2050. To ensure that the pathways we design actually lead towards these objectives, we need to have some idea of what the future looks like. To get an idea of this, we consider what we know now: what are the generally-accepted scenarios and outlooks for the period 2030–2050, for example? While recognising the climate ambitions, we also need to be realistic. From here, we go on to formulate specific research needs.

2.2.1 Current Expectations for 2050

Various energy outlooks have already been published for the year 2050, for example by the International Energy Agency (IEA),[2] the Intergovernmental Panel on Climate

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[2] International Energy Agency, *World Energy Outlook 2018*, OECD/IEA 2018.

Change (IPCC),[3] the European Commission (EC)[4] and, relating specifically to infrastructure in the Netherlands, CE Delft (for Netbeheer Nederland).[5] Although these reports do not paint the full picture and cannot predict the future, they do give an informed idea of what the energy system might look like in 2050 based on current knowledge. We briefly describe these ideas below.

2.2.2 Global

Based on current figures, the IPCC[6] expects CO_2 emissions to continue to increase up to 2050, with the energy sector as the main contributor. Opportunities are, however, available to limit emissions in the sector, such as increased energy efficiency, a switch to other forms of renewable electricity generation, nuclear power and carbon capture, utilization and storage. Most IPCC scenarios for 2050 support this. However, such options will need to be combined if we are to reduce CO_2 emissions. Therefore, each scenario includes many different sustainable energy sources as well as a mix of nuclear energy, carbon capture, utilization and storage and biomass or biogas. Based on current developments, the IEA predicts that the EU will be a global leader in a sustainable energy system by 2050.[7] We will therefore need a more flexible system towards 2030 and beyond, and further investments will be required in power plants, networks, storage and demand-driven solutions.

2.2.3 Europe

The EC[8] predicts a significant drop in the price of renewable electricity generation towards 2050, and that solar, wind and geothermal energy will be the most cost-effective options by that year. The price of non-renewable energy is expected to increase considerably towards 2050, with the exception of nuclear energy and brown coal, which will cost roughly the same as at present. Within the EU, the largest shift in the energy mix is expected to be from crude oil (-7%) to electricity (+7%). In the transport sector, the share of diesel in the fuel mix is expected to decrease, although it will still be significant (51%), particularly for commercial vehicles, while petrol is expected to show the largest decrease (-11%). This change will also be seen in the case of private vehicles, with a 49% decrease in the proportion of petrol and diesel

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[3] Intergovernmental Panel on Climate Change, *Assessment Report 5: Mitigation of Climate Change, Chapter 7: Energy Systems*, Cambridge University Press: New York, USA, 2014.
[4] European Commission, *EU Reference Scenario 2016: Energy, transport, and GHG emissions. Trends to 2050*, European Union, 2016.
[5] CE Delft, *Net voor de Toekomst: Achtergrondrapport* (A future network: Background report), 22 November 2017.
[6] Intergovernmental Panel on Climate Change, Assessment Report 5: *Mitigation of Climate Change, Chapter 7: Energy Systems*, Cambridge University Press: New York, USA, 2014.
[7] International Energy Agency, *World Energy Outlook 2018*, OECD/IEA 2018.
[8] European Commission, *EU Reference Scenario 2016: Energy, transport, and GHG emissions. Trends to 2050*, European Union, 2016.

cars by 2050, to be replaced primarily by hybrid cars. Total energy consumption will remain roughly the same as current levels. Hydrogen (fuel cell) cars are still not expected to form a significant share of the total fleet due to the high costs, although these costs will decrease slightly. Note that these predictions are based on policy currently in place. As far as energy imports are concerned, dependence on imports and the cost of imported energy are expected to continue to increase in the EU towards 2050. Electricity prices are also set to increase, with the largest increase coming from network charges. The relative cost of electricity is expected to increase the most for households. Total system costs relative to gross national product are expected to decrease slightly compared with current levels, but not before they first increase (in particular between 2020 and 2035).

2.2.4 The Netherlands

As already highlighted above, an increased focus on energy from renewable sources is expected, which will have a significant impact on our energy infrastructure and its use. A study carried out specifically for the Netherlands makes predictions about the 'future network'.[9] These predictions are based on four scenarios for a climate neutral energy system by 2050; one focusing on a more decentralized energy system, one on a more centralized system, one focusing on international cooperation (import) and one in which there is little to no external control and in which 'the market' controls the system based on the carbon price. The scenario outcomes differ enormously, from low to high levels of renewable energy on land, the use or lack of use of green gas, zero to high levels of hydrogen electrolysis, average to high levels of hydrogen applications in the transport sector, low to high levels of fuel cell storage and the widespread use of heat networks and heat pumps to more hybrid heat pumps that use both electricity and green gas or hydrogen. The only shared outcome across the scenarios is a 25% decrease in CO_2 emissions due to improved energy efficiency and a relatively stable gas buffer for storage and flexibility. The expectation is that a mix of scenarios will be achieved by 2050. The different scenarios are each expected to impact differently on the energy system infrastructure, although the scenarios based on international imports and limited control will have very little effect. If a more decentralized or more centralized network is chosen, or a mix of both, considerable investments will be required in the existing infrastructure, in particular in the electricity grid. Every scenario assumes that it will be possible to transport and distribute other carriers such as hydrogen using the existing gas network, assuming the necessary changes are made. The choice of scenario will ultimately be a political

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[9] CE Delft, *Net voor de Toekomst: Achtergrondrapport* (A future network: Background report), 22 November 2017.

decision, in which cost, public support and security of supply will all play an important role.

2.2.5 Global needs (for 2050)

The main question based on the above described scenarios remains: will we reach our climate goals for 2050? The future is difficult to predict, which can e.g. be seen from the predictions on oil prices and use, which have been traditionally an important indicator for the (global) energy sector.[10] The scenario outcomes described above do not specifically anticipate any breakthroughs or disruptions in the social or technological sphere, which are of course possible. These would impact the transition pathways and may cause some unexpected effects. However, the unknown also presents opportunities, as technological and social breakthroughs can cause a transition acceleration. Assuming that such an acceleration would be welcome, we propose a number of essentials for the energy system in 2050:

- **Having an energy system with an acceptable energy price.** Whilst the commodity price of electricity will change drastically in the years up to 2050 because of low operational costs for renewable electricity production, the focus will shift from a strong commodity orientation towards a service oriented price for electricity supply. Also the value for hydrogen and green gas will become higher in the future, because of the need for sustainable fuels for e.g. heating and transport. For all energy forms, costs of infrastructure will also be (remain) and important factor for the total costs of supply.
- **Having sufficient energy sources available for meeting reasonable energy demands.** Energy from sources other than oil and gas is needed. Renewable electricity, green gas, biomass and bioliquids are candidates for replacing these sources in the future. Yet, their current availability is limited due to various limitations: space, economic aspects, social acceptance for the production of such energy.
- **Having sufficient technology available for a sustainable, reliable and affordable energy system.** In order to safeguard the sustainability, reliability and affordability of the future energy system, a number of technological breakthroughs are necessary. For example, energy storage technology should be further developed, efficient conversion of energy carriers becomes (even more)

[10] About 30 years ago, the IEA predicted that the oil price would increase to about US $28 per barrel in 2005 and then stabilize. The price was, however, $56 per barrel in 2005, increasing to about $100 per barrel over the next 10 years and peaking at $145.31 per barrel in 2008. Demand for oil also failed to follow the predicted path: in 1994, the IEA predicted that demand would total 45 million barrels a day in 2010, whereas the actual demand by the end of 2010 was over 87 million barrels a day. See International Energy Agency, *World Energy Outlook 1994*, OECD/IEA 1994, and International Energy Agency, *Oil Market Report 2010*, 10 December 2010, OECD/IEA 2010.

important, and energy infrastructures should be further developed with integrated efficient monitoring and control equipment.

- **Ensuring CO_2 capture, storage, and utilization.** CO_2 is an important source of our current climate problem. However, it can also be a resource for several (industrial and agricultural) processes. Therefore, CO_2 should be used responsibly, at the appropriate scale, whilst capturing and storing CO_2 when it cannot be used. Various barriers need to be removed to make CO_2 capture storage and utilization an effective tool in solving the climate puzzle. These barriers relate to technology, but also to legal aspects, planning, and social acceptance.
- **Having efficient demand side installations**. Demand side installations are installations such as factories, residential housing, and office buildings. Demand side installations use energy when a surplus is available. This use should be as efficient as possible.
- **Having green, affordable transport.** The most important fuels for current day transport, gasoline and diesel are being phased out. This implies that alternatives are needed. Currently, electricity and hydrogen are being proposed as such alternatives. Yet, both alternatives need further development, not just on their technology, but also on their integration into the existing system.

To summarize, meeting all of these essentials should result in a highly efficient, flexible and hybrid energy system by 2050, in which we are able to switch easily between different energy carriers, in which greenhouse gas emissions belong to the past, and in which affordability has reached an acceptable level. So, how do we reach this point, and how far are we now? **Which challenges do we need to overcome to realize these essentials in 2050?**

In the remainder of this agenda, we identify (part of) the research needed to achieve the climate objectives. We do not aim to be exhaustive in all possible pathways towards 2050; rather the research challenges below have been tested against two questions: "Does solving this challenge contribute significantly to reaching the scenarios and essentials above?" and "Can we – NEC and its partners specifically – have an actual impact in this area?". This is done in the context of the themes of Local Energy Systems, Industrial Transformation and North Sea as an Energy Region.

2. THEMATIC RESEARCH CHALLENGES

This section focuses on the specific research challenges for each theme. We first introduce each theme by outlining the general future challenges. Based on the input from researchers, companies and societal organizations, we then go on to define the specific research challenges and questions.

3.1 LOCAL ENERGY SYSTEMS

Local energy systems provide small to medium-sized end users with energy for domestic purposes, commercial use and mobility. This demand has traditionally always been met by a highly-controlled, centralized system. This system incorporates several large energy sources or producers, with end users in the Netherlands being supplied with energy first through a transmission network and then through a clearly defined distribution network. However, the energy transition is putting this system under pressure: we need to stop using fossil fuels for the production of electricity and stop using natural gas for i.a. heating purposes; Groningen gas is being replaced with heat pumps, green gas, residual or geothermal heat (networks) or even hydrogen. Also, the mobility sector needs to achieve zero emissions; combustion engine based vehicles need to make way for electric vehicles in particular, and possibly hydrogen vehicles. The focus is therefore shifting towards renewable electricity, alternative gasses such as green gas and hydrogen, and heat from geothermal sources, or residual heat. Large share of this energy supply will come from the decentralized/local level.

This growth in sustainable, decentralized generation is drastically changing the way in which 'local' energy needs are met. To facilitate such a transformation we need to expand the range of tools available to us. We need to ensure that the necessary investments can be made to achieve a successful energy transition: economic, social and technological ones. Although several tools (e.g. participation models, innovative energy network designs, decentral electricity production facilities, etc.) are already available – after all, the energy transition has been underway for some time – some fundamental challenges still remain, for which no suitable solutions have yet been found.

There is still a lot of uncertainty regarding the spatial integration of renewable energy into local energy systems. This also includes a debate on the suitability of resources for usage in local energy systems (e.g. is hydrogen suitable for use in the built environment? Or is it more efficient from a system perspective to utilize it predominantly in other parts of the energy system). There are also many questions concerning infrastructure aspects of local energy systems, such as how to coordinate the construction and use of infrastructure in such a way as to ensure the efficient integration of renewable sources, and therefore limit the costs to society. Here, the challenge is not just to manage the total costs, but to ensure that the costs and benefits associated with the energy transition are fairly shared.

If we are to deal with these issues in a logical, coherent manner, we need to consider the challenges that lie before us and the ideal solutions, while also taking into account their feasibility. We also need to make sure that the proposed transition pathways towards sustainable local energy systems are clear and transparent.

3.1.1 Research challenges in Local Energy Systems

In developing the proposed transition pathways for the theme local energy systems, the following aspects are considered key for New Energy Coalition: organization of the (local) energy system; digitalization; access to energy; and technological development. The relevant challenges and questions that belong to these aspects are further elaborated below.

a. Organisation of the (local) energy system

The central question is how to (re)organize the energy system in such a manner that it will remain reliable and efficient, whilst becoming more sustainable. There should be a clear and balanced framework in which all actors in the energy system can act as freely as possible, without jeopardizing the functionality of the energy system. In order to further explore this question, the following elements are to be considered in research:

- Proper configurations for more local control of the energy system, and the relation between 'higher' (transmission) and 'lower' (distribution) system levels.
- Organisation of energy communities; effective forms of organisation and the interaction between the community system and the main (public) system; which roles do all (potential) actors have in an energy community?
- Role(s) of current (e.g. consumers, system operators and energy service providers such as suppliers) and new (e.g. prosumers, local energy communities and (small) energy service providers) actors in future energy systems.
- Role of governments and regulators in local energy systems; how should these interact with the (other) players in local energy systems, and society in a broader context.
- Interaction between (future) living environment and the energy system, taking into account regional differences (not one size fits all), and options for location-bound decision making.
- Decision-making in energy systems; which actors decide on the development of the local energy system, which actors should decide? Which information

should be made available to which actors, and should the decision-making model be democratic?

- Regulation of (negative) external effects of energy systems (e.g. by CO_2 pricing).
- Innovative decision models on development of (local) energy systems, taking into account various variables (e.g. environment and consumer values), making use of cost-benefit analysis including local variables, consumer preferences, (system) efficiency of resource use, and potential negative effects which are difficult to monetize.
- Pros and cons of the current (liberalized) market setting and potential alternative settings, striving for a market design that is stimulating technological development.
- Use of 'adaptive management', in which energy system design would include sufficient flexibility to deal with (unexpected) developments in the energy transition.

b. Digitalisation

In addition to new organisational options, the further digitalisation of the energy system is one of the key aspects in the local energy systems research agenda of NEC. Digitalising is expected to play a crucial role in the technical control of the energy system, adding further efficiency and convenience. However, with increasing digitalisation, also concerns regarding (cyber) security and privacy are increasing. In order to increase the existing knowledge base on how to create a digitalised energy system which is both convenient and secure, the following is to be further explored:

- Development of (more) digital services that can create further convenience, control and safety for the energy system and its users.
- Using the 'internet of things' in an optimal manner, including control-design that allows end-users to remain in charge of their energy supply.
- Methods to ensure privacy for (household) consumers in a highly digitalised energy system.
- Further development of smart grids, contributing to energy system architectures that integrate existing knowledge and innovations in a user-friendly and efficient energy system.
- Further development of demand-side response tools, including benefits and challenges posed by (electric) mobility, and storage options.
- Big data versus rich data; e.g. using advanced statistical models to limit (big) data to useful data, also in relation with ensuring privacy, and to reduce the required resources for producing and processing the relevant data in local energy systems.

c. Access to energy

Energy systems are designed for facilitation of energy consumption. The most crucial element for such facilitation is to ensure access to energy for (household) consumers. Various (international) treaties and (national, and European) laws have embraced the idea of energy as a basic right (up to a certain extent), and pose several requirements on energy access. Yet, the energy transition is an expensive quest, which will require significant investments from society. As such, new system designs should protect access to energy. To define the concept of energy-access in such designs, the following elements are to be further investigated:

- The willingness and ability of society to pay for energy-access to clean and sustainable energy; costs of access versus sustainability goals.
- To what extent the costs of the energy transition should be socialised, and to what extent socialisation would increase or decrease the effectiveness of the energy transition and the access to energy for certain consumers. What would be a 'just transition'?
- Whether an energy transition which is focussing on end-user affordability is possible.
- Participation of citizens and (household) consumers; what is participation (how could and/or should it be defined, and what are the pros and cons of the potential different models? To what extent should participation be part of the energy transition in local energy systems?
- Relevant user-perspectives; e.g. which motives, preferences are most relevant for (which specific) end-users, and whether new user-classes should be added to the existing user-classes.
- The design for an energy-based society, and to what extent new energy systems influence society.
- Relationship and potential synergies between sustainable housing, green mobility and (household) energy demand. To what extent could an integrated approach to these elements create efficiencies?
- How people interact in new energy systems, and what broader societal effects can be expected because of new energy systems.
- How to balance collectiveness versus autonomy in new energy systems.
- How to enable self-sufficiency of consumers.
- Finding (new) standards for minimum levels of access for end-users.
- Defining the extent to which (household) consumers have a right to access information in the (local) energy system(s).

d. Technological development

To facilitate the energy transition, the existing technology base should be further developed. Whilst people make the decisions, these decisions are limited by certain boundaries, of which technology is an important one. If the technological options are not ready in time, it will be difficult to successfully complete the energy transition. The following elements are specifically considered:

- The use of hydrogen, green gas and other biofuels and gasses (also see other NEC theme's) in local environment. This includes questions on resource efficiency.
- Increased efficiency for solar cells to reduce the required space for the production of solar energy. More specifically, the further development of tandem solar cells, putting together semiconductors with complimentary absorption capabilities to increase efficiency of the solar cells.
- Further development of optimization algorithms, e.g. by using machine learning tools.
- Technical system development, e.g. by technical control options, and advanced management systems.
- Development and further integration of decentral production facilities in energy networks.
- Storage options, in various forms, such as electrons (batteries), heat, compressed air, gases (e.g. hydrogen), and how these technologies can be used to optimise local energy systems.
- Integration of mobility in existing energy networks, including charging/fuelling infrastructure.
- Scalability of technological options, defining the scale at which technologies should be developed.
- Ease of use and maintenance as a precondition for new (smart) equipment and appliances.

3.2 INDUSTRIAL TRANSFORMATION

One of the sectors facing major sustainability challenges is industry. Including the use of energy carriers as a feedstock, 40% of the grand total of Dutch energy consumption is accounted for by the industry. The ambition of the industrial sector is included in the Dutch Climate Agreement and aims to reduce its CO_2 emissions by half in 2030 and almost completely by 2050.

Multiple roadmaps and research programs[11] have already indicated the general pathways that are most promising. These pathways generally revolve around three concepts:

- minimizing energy demand per product (energy efficiency);
- changing to renewable energy supply;
- greening of the industrial feedstock (including circularity).

Firstly, energy efficiency has always been a topic of interest in industry and improvements are expected to continue based on, among others, digitalization and advanced process modelling. Yet, to meet the climate targets, break-through innovations are required. Human factors such as awareness, activation and training of staff and management can enable such changes going beyond incremental improvements.

The second and third pathway focus on transitioning to renewables as both an energy source and a feedstock for industrial processes. This includes replacing fossil fuels for both high- and low-temperature heat by green fuels, as well as finding green drop-in alternatives for processes that need carbon as a raw material. Considering the capricious nature of renewable energy and market optimization, the energy grid will remain under continuous pressure, and these pathways will rely on the transition to an industry that can quickly respond to peaks in, or shortages of, energy supply and product demand, and as such even serve as a nation-wide energy buffer.

Finally, reducing industry emissions can be achieved by measures such as Carbon Capture, Utilization, and Storage (CCUS). While carbon storage is an end-of-pipe solution, it could play an important role for the upcoming years when the emissions from the industry are still highly significant, although storage only appears viable off-

[11] (a) VEMW, *'Samen op weg naar minder'* (2016); (b) VNCI, *'Roadmap for the Dutch Chemical Industry'* (2018); (c) '*Eindrapport Industrietafel Noord-Nederland: Reductie CO2 Emissie (2018)*'; (d) several 'Meerjarige Missiegedreven Innovatie Programma's (2019)' focussing on industry; (e) Chemport Europe, *'Industrie Agenda Eemsdelta'* (2019); (f) University of Groningen *'Academic roadmap smart industries'* (2015).

shore. Especially the re-use of emissions (i.e. as a carbon source) seems interesting on the long-term.

Starting from the described system approach, we would like to study the challenges ahead in a systematic way, and test their proposed ideal solutions for viability. Crucially, the proposed transition pathways towards a more sustainable industry defined in this research agenda should be clear and accountable for all parties involved.

3.2.1 Research challenges in Industrial Transformation
The NEC research program will focus on main challenges divided across four categories: the above three topics that contribute most to emission reductions according to the industrial and academic reports, and an overarching research line that enables industries to transition to the new business models needed to implement them. Below we describe the challenges that we believe can be addressed by NEC together with its knowledge, society and industrial partners, based on their input.

a. Corporate Transformation
The industrial transformation starts off as a corporate transformation. How are the many aspects of sustainable development successfully merged into corporate strategy? A significant portion of the Dutch economy is formed by chemical industry, which is particularly capital-intensive with a long investment cycle. Therefore, we consider it important to investigate:

- Design of agile business models and business model transitions that facilitate responses to new laws and regulation, such as emission trade and/or taxes. Such business models should also take into account the value of social benefits and goodwill to be able to compete with current strategy. In addition, a transition away from high capital investments and fixed assets to more nimble options could be investigated.
- Regulation of the energy transition. This includes legal and economic research on e.g. climate law, cross-border energy initiatives and ways to price industry emissions. Pricing may stimulate new business models, but legal (in)consistencies in current (international) regulations and how the mix of different pricing instruments can be optimized for effectiveness and efficiency of the energy transition are still to be determined. Carbon leakage and how border tax adjustments could prevent it (ship technology, not waste) are an important example to investigate, as well as how costs and benefits to society or ecology are calculated.
- Workforce agility and human-centred manufacturing. Energy supply or demand-driven manufacturing comes with a need for even more flexibility in the

workforce, while cognitive models can help create an environment that helps employees be creative and thrive in a smart industry.

- Markets for sustainable products. Can we replace products that are hard to recycle or produce in a sustainable way or can we find sustainable alternatives? Easily attainable green chemical routes could be a starting point of product development and economic studies. The valorisation of pure O_2 streams from electrolysis is an example with immediate impact.
- Chain integration of industries. How can industries create a symbiosis where product, heat and/or waste streams are used to create additional value? What are the legal, economic and technical implications of such collaborations? Is there a place for an independent matchmaker for waste markets?
- Global benefits vs. local initiatives. Weighing the impact of various small sustainable initiatives that we can do easily and locally versus large, potentially complex international projects requires a holistic, systemic view, but will maximize the efficiency of our investments. The effect of specific elements of the energy transition (e.g. higher energy efficiency, increased biomass feedstock) on global value chains can be determined by input/output analyses and provides crucial input to such decision-making.
- Operational management and supply chains for renewable energy and feedstock. Optimization of maintenance calendars as well as material and energy flows along the value chain will provide a renewed challenge in the future energy landscape.

b. Efficiency

Once a decision for a sustainable corporate strategy has been taken, operations and technology have to be adapted to promote energy efficiency. The predicted average industrial efficiency improvement rate is 1% per year,[11b] based on incremental as well as break-through innovations in industrial processes. At this rate, these gains will contribute significantly over the 30 year period to 2050. NEC can accelerate this process by making sure successes and best practices are gathered, analysed and shared among relevant industries. We expect to make the largest contributions by focusing on the following challenges:

- Advanced (chemical) production processes and process intensification. New catalysts and reactor designs can produce materials under milder conditions.
- Digitalization and process modelling (Industry 4.0). Advanced models (including digital twins) of industrial processes allow real-time control of the manufacturing, but also simulation of how these processes would be affected by e.g. more sustainable feedstock or lower temperature. Artificial intelligence may be embedded to manage interconnected systems and make sense of the large amounts of data they might generate.

- Monitoring and sensors. Keeping track of production processes as well as environmental emissions can only occur with advanced measurement of reaction mixtures and outputs.
- Process integration. Optimizing production as a whole, rather than each separate element, can lead to significant gains in heat and material recovery. Specific design for energy systems, with mass/energy balances and indicative component sizes for emerging process are a good starting point for techno-economic calculations, environmental impact calculations and, eventually, technology ranking completing the systemic approach.

c. Renewables as energy input

A big challenge for industry is adapting to a new, renewable energy source. An increase in supply and a drop in the (relative) price of renewable electricity is anticipated, making electrification of both heat and chemistry one of the major routes to decarbonize the industry. In any case, research that designs production processes based on variable energy sources, or allows efficient interconversion of energy (including power-to-X and reversible fuel cells) will allow for a flexible industry that can take full advantage of demand side response (DSR) opportunities. Considering the expertise and industrial activities within the network of the NEC, we want to focus on:

- Agile manufacturing. Supply and domestic demand of renewable energy fluctuates. Increasing (or switching) production at will, depending on the energy available, will not only lower the energy cost of the industry, but actually set up the industrial sector as an energy buffer that balances the grid.
- Electrification of chemistry. Redox chemistry and fuel cells are currently not as popular due to the cost of electricity and alternative reaction mechanism based on cheap fossils. Preparing electrochemical routes towards products (ideally based on CO_2 as carbon source) will allow the switch towards a majority electric input, while keeping in mind grid congestion as a potential hurdle.
- Renewable heat. We need alternative energy sources for low and high temperature heat processes. The development of electric boilers, furnaces or heat pumps is challenging and does not primarily take place within the NEC's network, but the combustion of green fuels (e.g. hydrogen, biogas, -liquids and/or -solids) and how heat is transferred to the reactants, especially for high temperature heat, is something that is seen as a key research topic. E.g. oxyfuel processes could simultaneously improve fuel efficiency, lower NO_x emissions and valorise electrolyser O_2 streams.
- System integration of renewable energy in the industrial context. Transportation of electricity is currently being limited by the grid. Proactive network operators

need research to decide if they should invest in parallel backbones for renewable gases instead, develop their role as an aggregator of supply and demand further or focus on smart grids or other technologies. Perhaps, the development of smart grids and hybrid energy generation (combined solar, wind, tidal, wave, biomass etc.) can keep energy supply more constant, ensuring optimal grid usage and constant production. In any case, considering new infrastructure now involves a complex group of stakeholders the economic and political feasibility of renewable alternatives from distributed sources need to be studied before their system integration is possible on the necessary scale, and has strong ties to all five NEC themes.

d. Greening of the feedstock

Not everything can be electrified. Molecular input will still be necessary to create materials. Note that hydrogen and green gas are separate themes for the NEC, but extending their use (and other small molecules such as ammonia, methanol and formic acid) as a feedstock in industry is worth a special mention here. In general, changing feedstock in individual industrial chemical processes (e.g. naphtha to refined biomass) will require such specific (applied) chemical engineering knowledge that it will likely go beyond the expertise of the NEC. Instead, the main focus areas for our research agenda are:

- Biobased chemicals. Biomass will play an important role in the transition to emission-neutral industries, although (world-wide) availability will likely limit its use as a fuel to < 10% of the overall energy demand.[11b,12] However, optimization of biomass as a source of more advanced biobased chemicals (biorefinery to e.g. proteins, platform chemicals and green fuel drop-ins) will provide a great alternative to fossil-based chemistry. Lignocellulose residue especially makes an abundant source of feedstock.
- Recycling of materials. While mechanical recycling is already being largely exploited in the Netherlands, chemical recycling of materials will allow circular use within the materials chain. Innovative solutions to reusing e.g. polymers are needed to drastically reduce the amount of feedstock required for materials. In any case, feasibility research on replacing current materials with more easy-to-recycle alternatives can make impact on the short term.
- Carbon capture and utilization. In a fully circular scenario, CCU provides part of the necessary carbon source for the industry. Electrochemical and biological conversion of captured CO_2 are two of the major routes to be explored for carbon

[12] (a) VEMW, '*Decisions on the industrial energy transitions*' (2017); (b) Commissie Corbey, '*Duurzame biomassa in de chemiesector*' (2012).

usage, as well as thermodynamically downhill reactions with bulk chemicals. CO_2 conversion to specialty chemicals (such as polycarbonates) can already be profitable currently. To allow CCU, sustainable, cost-effective, and widely applicable solutions to capture and use CO_2 need to be developed. In particular, bio-energy with CCS (BECCS, mature technology with open questions on spatial and business cases) and eventually direct air capture (DAC, technology and business cases in pre-commercial stage) represent the most promising "negative carbon" solutions that will be needed to reach a full net-zero world where even emissions from hard to decarbonize sectors are mitigated. Large-scale storage of industrial CO_2 (CCS) will be important in the transition to 2050, but considering its short-term implementation and end-of-pipe nature will not be the main focus of the NEC research agenda for Industrial Transformation (also see North Sea as an Energy Region).

- Life-cycle analyses. To maximize the impact of available resources and investments industries need to be able to differentiate various feedstock options, technology (including operations) and products on their renewable nature on a system level. Specific applied life-cycle analysis (LCA) on relevant topics (e.g. CCU) and research into methods to standardize LCAs are both to be stimulated.

3.3 NORTH SEA AS AN ENERGY REGION

In the last years several important developments with regards to energy in the North Sea can be discerned:

- the large-scale development of affordable offshore sustainable energy production, in particular offshore wind capacity (increasing to possibly 60 GW in the Dutch part of the continental shelf in 2050, corresponding to a cumulative investment around € 150 billion; up to 180 GW in the North Sea at large);
- changes in terms of conversion, transport, potential storage, and the integration of offshore generated energy in the (onshore) energy system;
- the decommissioning, and potentially reuse, of oil- and gas platforms and related infrastructure.

In addition to these developments, more solutions for offshore energy production are being explored, such as floating solar parks, offshore biomass or the generation of wave and aerodynamic energy. Also, CO_2 capture and storage (CCS; use is an important topic for the theme industrial transformation) is increasingly considered to play a role in using the North Sea for making a more sustainable energy system.

A parallel development is the recognition that the North Sea area is used for many different activities, thereby generating significant challenges for spatial planning and ecology. Fishery, shipping, energy producers, the military , and food producers need space in the North Sea area for their activities. Also, some space is reserved for nature conservation purposes. Policy makers and stakeholders seem to realise that this requires careful policy making, but also that multi-use of the limited available space and utilising the synergies that can be created between these different activities will increase the value of the North Sea. This has led to a national Dutch North Sea agreement between different users of the North Sea in 2019. In this agreement much attention is paid to the social, legal, economic and ecological impact of the above developments in the field of energy.

Next to considering the developments in the Dutch part of the North Sea, it is also important to view these developments in an international context. The ambitions of the other countries surrounding the North Sea (hereafter: North Sea countries) to develop offshore renewable energy production are also high[13]. At EU-level energy ministers from the North Sea countries agreed to extend and intensify their cooperation on the development of offshore wind energy production. This cooperation focusses on a more action-based approach, including on-site

[13] https://windeurope.org/about-wind/reports/our-energy-our-future/#overview

development, development and optimisation of grids, onshore grid (interconnection) development, and harmonisation of technical standards[14].

The developments above will have a significant impact on the future energy system for 2050, but also how the North Sea itself will look like in the future. Based on these developments we can identify the research challenges for realizing the ambitions for the (re)development of the North Sea area as a future energy hub for sustainable energy. These challenges are described in more detail in the following section.

3.3.1 Research challenges in North Sea as an Energy Region

Considering the developments described in the section above it is possible to zoom in on the specific research challenges that the NEC research programme can address. To begin with, several national and international research and innovation programs and agendas on energy related developments in the North Sea have already been developed in this area[15]. These programs and agendas outline the general challenges, but also some research challenges in the North Sea as an energy region. Together with the input received from researchers and business and societal partners during several working sessions these programs and agendas form the basis of this research agenda.

The NEC research programme focusses on two specific challenges: 1. enabling large scale offshore renewable energy production and 2. exploiting opportunities for energy system integration at the North Sea. Research challenges dealing with the multi-use of space and the societal, ecological, economic and legal impact of large scale renewable energy production and energy system integration options are included when describing the research challenges under 1. and 2.

a. Enabling large scale offshore renewable energy production

As stated above the ambition is to increase the production of renewable energy considerably. This requires substantial upscaling of offshore wind energy production and of alternative means of renewable energy production at sea. The NEC research

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[14] https://windeurope.org/newsroom/news/north-sea-ministers-extend-and-intensify-cooperation-on-offshore-wind/

[15] i.e. the 'Meerjarige Missiegedreven Innovatie Programma 1: Renewable electricity at sea as part of the Integrated knowledge and innovation agenda for climate and energy (2019); The TKI System Integration program from which research projects are funded focused on offshore system integration. From this TKI, MMIP 13: *A robust and socially supported energy system* will be developed; the NWO program PhD @ Sea (2019); GAM van Kuik et al., *Long-term research challenges in wind energy - a research agenda by the European Academy of Wind Energy* , Wind Energy. Sci., 1, 1–39, 2016; TKI Wind op Zee, *The Netherlands' long-term offshore wind R&D agenda* (2019).

programme wants to support this ambition by focusing on the following research challenges.

Enable the production of large scale offshore wind energy at acceptable costs and under safe and socially and ecologically acceptable conditions

Many technological bottlenecks need to be solved to ensure considerable efficiency and cost reduction, for example in the field of aerodynamics, materials of wind turbines and foundation techniques. Much of this required research concerns engineering research that is done in the Netherlands mainly at TU Delft and ECN.TNO. The NEC partners offer limited expertise in these engineering issues (exception is expertise in materials, see below). Therefore, the NEC research programme focusses less on the engineering aspects, although NEC will reach out to experts at TU Delft and ECN.TNO. This is facilitated by the fact that some of the UG and HUAS researchers have positions or very close connections at ECN.TNO and TU Delft. This helps to build bridges between the focus of the NEC research programme and wind engineering expertise at TU Delft and ECN.TNO.

The NEC research programme will focus on the following items in the value chain of offshore wind energy production:

Planning

- new forms of institutional and policy structures, including legal and regulatory frameworks, that facilitate balanced decision making on the planning of investments in and the location of wind farms. This includes development of novel concepts for the financing and auctioning of wind farms; a new framework for balancing the interests of offshore wind producers with the interests of producers of alternative energy producers and of other users at the North Sea and nature conservation (see also under energy system integration); and arrangements that facilitate the planning of cross-border wind parks and international collaboration.
- societal acceptability of large scale offshore wind parks. This includes social innovation that contributes to acceptability of large scale wind energy production, e.g. social and ecological impact assessments and involvement of stakeholders and citizens in decision making on offshore wind parks.
- resource assessment and wind characterisation, linking up with the Dutch Offshore Wind Atlas (DOWA) and integrated energy system modelling and analysis (see under energy system integration).
- techno-economic analysis of innovative forms of wind energy production such as floating wind farms.
- planning of (transboundary) offshore meshed electricity grids, including new ways of financing; market designs; cost benefit analysis, taking in societal and ecological impacts; cross border coordination.

Installation

- optimization of the logistics of installing wind farms.
- minimisation of ecological effects during installation of offshore wind mills.

Operation

- optimization of operation of offshore wind farms by developing new control tools (e.g. sensors); digital twins; and methods for data processing as well as algorithms that are important for the control of wind farms. These tools and methods connect separate wind farms and enable the integration of large quantities of wind energy into the energy system. They thereby support electricity grid stability onshore, e.g. by frequency and voltage control and ramping up and down on demand. Legal issues concerning digitalization at sea.
- new business models to make the production of offshore wind energy profitable (see also under energy system integration).
- innovation in wind turbine blade materials. Specific technological research could take place with regards to the development of new coatings of wind turbine blades (incl. characterisation of nanostructured materials) and degradation processes of materials.

Maintenance

- optimization of the (planning of) maintenance of wind farms through data processing, smart control design using artificial intelligence, digital twinning, and robotics, and legal issues concerning the use of these digital support systems.

Decommissioning

- innovative materials that are easier to recycle.
- development of new legal and organisational framework and business models in order to make efficient decommissioning of wind parks possible.

Enabling large scale alternative offshore renewable energy production

We also foresee an increase of renewable energy production at the North Sea by other more early-stage technologies. The NEC research programme can contribute to further development of these technologies by focusing on:

- techno-economic analyses of these early-stage technologies to determine their technical and economic feasibility and potential contribution to a renewable energy supply, thereby specifically analysing the potential of combining these technologies with each other and with offshore wind and oil & gas production (see also under energy system integration).

- analysis of the social, spatial, ecological, economic and legal impact of large scale application of these technologies.
- solar technology development for floating solar parks. For offshore application it is important to obtain higher efficiencies so that the dimensions of the devices can be reduced, e.g. by the fabrication of tandem solar cells.
- cultivation of offshore biomass. Aquaculture mainly for protein or carbohydrate production rather than only gasification.
- generation of wave energy by deploying wave energy converters in dense arrays to significantly increase resource efficiency.
- generation of tidal energy.

b. Exploiting opportunities for energy system integration at the North Sea
Renewed efforts on the topic of energy system integration can also contribute to reducing the costs for offshore sustainable energy, reducing environmental concerns, increasing available space (e.g. by more efficient use), and to balancing the energy system during times of high and low energy demand, and thus to a reliable and affordable energy system. We thereby define energy system integration in the broad sense, meaning that we look at the interaction and interdependency between different energy forms and carriers, technologies, sectors and stakeholders and how integration thereof influences the overall energy system, but also broader, the organisation and spatial planning of the North Sea.

Within this main challenge we distinguish three specific areas on which the NEC research programme focusses:

Strategic planning and coordination in a multi stakeholder and international context
Decision making on and governance of activities at the North Sea takes place in a complex setting with many different stakeholders (countries, users and citizens). Therefore new ways of assessment of initiatives and investments and new ways of coordination of activities need to be designed. The NEC research programmes can contribute by focusing on:

- development of cost benefit analyses that not only weigh the financial costs and benefits, but also societal and environmental impacts and costs and benefits that result from integration of activities (incl. non-energy). This should also include the consequences of the landing of offshore energy with regards to e.g. safety, spatial planning, (grid) infrastructure, public perception and policy making onshore.
- developing and harmonising novel institutional frameworks (internationally) for governing the North Sea, including design of new ownership structures; ways of distributing responsibilities; and modes of supervision, especially concerning

multi-use of space and cross-border collaboration. Modes of public participation in policy making on offshore issues is also a relevant topic.

- development of a legal integrated framework.
- integrated energy system modelling and (data-)analysis that will support strategic decision making on investments and regulatory design, including spatial and environmental parameters.
- development of tools and institutional arrangements that stimulate collaboration between multiple stakeholders.
- planning and coordination of decommissioning and reuse of existing oil and gas infrastructure (platforms and pipelines) aligned with plans for development of offshore renewable energy production at the North Sea.

Development of new business models

Investment decisions with regards to offshore renewable energy production are now mainly based on the electricity price, but the business case for an offshore wind park or alternative renewable offshore energy production is not self-evident. New ways of value creation need to be developed and energy system integration plays an important role therein. The NEC research programme can contribute by focusing on:

- innovative concepts to create synergy and thereby value, by combining different offshore activities such as energy, fishery, nature conservation and aquaculture, but also different forms of energy production.
- ways to create value by efficient grid integration strategies for offshore renewables to solve the intermittency issue onshore, for example, with the use of offshore energy storage as a buffer or to reduce the necessary cable capacity.
- spin-off from the landing of offshore energy with regards to strengthening or creating economic activities (storage, hydrogen, industry, data, etc.).
- analysis of the effects of renewable energy import in EU (e.g. cheap import of onshore generated solar energy from the Middle East) and collaboration with neighbouring countries on the business case of renewable offshore energy production at the North Sea.

System design

The NEC research programme also aims to give insight in the specific characteristics of an integrated energy system, technologically as well as from a techno-economic perspective. The NEC research programme specifically focusses on:

- techno-economic analysis of different storage and conversion options at sea or on shore, such as power-to-X (including hydrogen) and hydropower-type offshore energy storage, combined with analysis of the social, spatial, ecological, economic and legal impact of such storage and conversion options.

- development of integrated production-conversion-storage-transport solutions, incl. reuse of existing gas- and oil infrastructure, integrated energy island concepts and hybrid energy systems.
- development of combined renewable energy production technologies such as integrated wind-, solar-, tidal-, wave- and biomass- energy production.
- development of digital twins of hybrid energy production and storage systems for purposes of control and optimization, as well as predictive maintenance.
- storage of CO_2 and transport to storage sites and to industrial clusters for use (see for CCS and CCU also the research agenda Industrial Transformation).
- technological innovation supporting multi-use (e.g. corrosion resistance, interfacing energy sources).

3. IMPLEMENTATION OF THE AGENDA

As described above, our research activities focus on knowledge development relating to the energy transition and on taking a pivotal role in the global energy transition research network. We aim to integrate research programmes that focus on the medium to long term with additional innovation projects that focus on the short term, ensuring that our research has added economic value.

Our primary ambition for the coming years is to expand our existing portfolio of applied and academic energy research projects at the University of Groningen and the Hanze University of Applied Sciences, while also actively seeking new partnerships. When considering new initiatives of New Energy Coalition or opportunities for projects, their place within the system transformation is of primary concern. We test their match with either Local Energy Systems or Industrial Transformation themes, to clearly separate the topic's target groups. Subsequently, we integrate the topic with the themes North Sea as an Energy Region, Hydrogen and Greening of the Gas System. If the research topic matches the focus areas we have marked as challenges in the above lists, we will actively support project development. Funding from the strategic partners of New Energy Coalition will be available for research project proposals linking up with this research agenda.

New Energy Coalition can take various roles in research projects and consortia: initiator / main organiser; full partner; or a support role (e.g. letters of support or dissemination). In all cases, we will consider in kind co-financing with manpower or cash co-financing using the funds our partners pay into the coalition. We aim to multiply such funding by applications to regional to international funding schemes such as the Dutch NWA, InterReg or Horizon 2020 programs. A list of funding opportunities for the thematic research agendas will be included in the Appendix of this document in the near future.