Federal Ministry
for Economic Affairs
and Energy

Innovations for the Energy Transition

7th Energy Research Programme

of the Federal Government

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Content

Preface

The energy transition is one of the greatest challenges facing society today. Our economic and energy policy is built around ensuring an energy supply that is reliable, climate-friendly and affordable, and around using energy efficiently. The degree to which we succeed in realising the energy transition will determine the way in which our society develops, safeguards prosperity, and conserves natural resources. So we need to take diligent and determined action to continually optimise our implementation strategies.

We are in the middle of a deep-reaching restructuring of our energy system. The key challenges involve increasing the share of renewable energy and expanding the grid infrastructure needed to transport it. They also include improving our energy efficiency and reducing carbon emissions in the energy sector. These are enormous tasks which we can master better and more effectively through the use of innovations and new technologies. But the way in which we support research and development needs to be different to in the past. It is essential that we connect existing technologies with new ones across different sectors, use the opportunities of digitisation, enable the use of new business models, and secure the involvement of a higher number of actors. To make this ambitious project a success down the line, we need to lay the right foundations today. This is where energy research has a key role to play.

The Federal Government's 7th Energy Research Programme, entitled "Innovation for the Energy Transition", sets out guidelines for energy research funding over the coming years. The Federal Government lays down a new strategic approach and trains the programme's focus on technology and innovation transfer. This includes the use of living labs to bring new, promising technological solutions to the market, and to explore and master the challenges under real-life conditions. The experience gained will set the course for implementing the technologies tested on a large scale later on. Greater involvement by young, creative startups will also play an important role in this process.

The new programme strengthens technology and innovation funding in the energy sector and also adds a new focus on systemic and societal questions. This involves placing a greater focus on the major, overarching trends in the energy sector. One of these is sector coupling, which enables interaction between the heat, transport and industrial sectors and is crucial for the development of the system as a whole. Another is digitisation, which plays a key role in modernising the energy system.

Lastly, the Federal Government's 7th Energy Research Programme is also designed around developing closer networking in research at both international and at European level. After all, the energy transition is, and will remain, a global-level challenge. In its preparation of the new programme, the Federal Ministry for Economic Affairs and Energy hosted a broad-based consultation process in which it surveyed a large number of stakeholders from science and business about the innovation steps needed in order to make the energy transition a success. This is because the new programme seeks to foster applied research and development in particular and to support the transformation of highly innovative ideas into successful products and processes. The results of the consultation process were fed into the development of the Energy Research Programme – undertaken by the Federal Ministry for Economic Affairs and Energy together with the Federal Ministry of Education and Research and the Federal Ministry of Food and Agriculture.

It is now crucial that a large number of actors from science, business, and civil society get involved in the energy transition based upon this programme. The Federal Government's 7th Energy Research Programme will serve as a strong driver of innovation. It offers a broad variety of comprehensive funding opportunities for project partnerships. We invite you to get involved and help shape the restructuring of our energy system!

1. Summary

With its 7th Energy Research Programme – Innovations for the energy transition, the Federal Government aims to follow up on the successes achieved in energy research in recent years, take new initiatives and define priorities for research funding and innovation policy in the energy sector. The programme is the outcome of an extensive consultative procedure involving actors from associations and enterprises, research and scientific organisations, members of research networks and Länder representatives.[1] As a strategic element of energy policy, the programme is aligned with the energy transition and will address current and emerging challenges in an integral, **coherent funding policy** approach. These are largely determined by the key targets of energy policy: halving primary energy consumption by 2050 compared with 2008 and achieving a renewables ratio of 60% to gross final energy consumption.[2] Through almost complete decarbonisation, the energy sector must additionally help ensure that Germany is largely greenhouse-gas neutral by 2050.

In the years ahead, the energy research policy framework will be defined by four basic principles:

1) The Federal Government sees expediting **technology and innovation transfer** as a prerequisite for the efficient, intersectoral implementation of the energy transition and an urgent task for energy research policy. This is why it is introducing "Living Labs for the Energy Transition" as a new programme pillar and will support the innovation process from the development to the commercialisation of technologies in an integral approach. The Federal Government will also make it easier for young enterprises with high innovation transfer ability and innovative power to benefit from the programme.

2) The Federal Government will augment the established instrument of direct funding for limited-term projects with a defined topic, which is best suited for raising the responsiveness and flexibility of government funding strategies. It will **broaden the research spectrum of project funding** previously centred on individual technologies to encompass systemic and intersystemic issues of the energy transition:

   - In keeping with the motto, 'efficiency first', project funding in *energy transition in the end-use sectors* will focus on the efficient use of energy and the reduction of consumption. In addition, the aim will be to step up the integration of renewables, primarily in the buildings sector. Energy-efficient and low-carbon industrial processes and carbon recycling will play a key role in the industrial sector.

   - Project funding will also address interfaces with the transport sector by promoting modern energy technologies, such as batteries and fuel cells, the production of biogenic and synthetic fuels and the analysis of the repercussions of new mobility schemes on the energy sector.

   - Research funding in *power generation* will address the entire range of renewable energies and thermal power stations.

   - Research work on electricity grids, energy storage and sector coupling will be assigned to the thematic cluster of *system integration*.

   - The promotion of *intersystemic research topics* will comprise energy system analysis, energy-related aspects of digitisation, resource efficiency, CO_2 technologies, materials research and societal aspects of the energy transition.

   - Nuclear safety research will focus on technical-scientific supervision of nuclear power stations operating up to the end of 2022 in Germany, the ensuing post-operational phase, the disposal of radioactive waste, radiation protection and the longer-term maintenance of competencies.

3) A special feature of the Energy Research Programme consists in its dual strategy for the funding instruments deployed: Complementary to project funding, the Federal Government supports **institutional research funding** for the Helmholtz Association of German Research Centres (HGF). This pools the resources of individual research centres to pursue long-term research objectives of government and society and addresses complex research topics, particularly when these call for the use of specific large-scale equipment. The new Energy Research Programme will help enhance the complementarity and closer interlinkage of both instruments to promote their joint application.

1 Documentation at energieforschung.de

2 Energy Concept 2050 at bmwi.de

4) With the 7th Energy Research Programme, the Federal Government will seek to **network international and European research work more closely**. At European level, the Strategic Energy Technology (SET) Plan defines extensive measures for innovations in energy technology, from research to market introduction. Germany's involvement includes strategic projects in renewable energies, smart energy systems, energy efficiency and sustainable transport and at global level it takes part in the IEA's so-called technology collaboration programmes, the main instrument of international cooperation. Collaboration will be stepped up with other international organisations, such as the International Renewable Energy Agency (IRENA) and scientific exchange will be facilitated in a number of bilateral and multilateral initiatives, such as Mission Innovation (MI) or the Science & Technology Cooperation (STC) Agreements.

The Federal Government's 7th Energy Research Programme will be implemented by the three Federal Ministries for Economic Affairs and Energy (BMWi), of Education and Research (BMBF) and of Food and Agriculture (BMEL) and was instigated under the lead agency of BMWi. The Federal Government has recognised that previous notions of strict thematic demarcations and linear sequences of innovation processes fail to cater properly for the challenges posed by the rapid developments in the energy sector. In this programme, it has therefore opted for an **inter-ministerial, thematic programme setup** for its project funding, underscoring the coherence of research-policy goals in the energy sector. The tried and tested division of labour among the ministries will be retained and geared to the so-called Technology Readiness Level (TRL) of the topics and technologies to be investigated, which is also the basis for the EU framework programme, *Horizon 2020*.

Figure 1: Technology Readiness Level (TRL) in project funding under the 7th Energy Research Programme

TRL level	Definition
1	Scientific research has observed a basic principle that may be eligible for a technology/process, etc.
2	The mode of operation and possible applications of a technology/process, etc. have been formulated in scientific terms.
3	The critical function of individual elements of the technology/process, etc. has been validated in the laboratory/a test environment.
4	The general function of the technology/process, etc. has been validated in the laboratory/a test environment.
5	The technology/process, etc. has been implemented in an applied overall system and its general feasibility has been validated.
6	The demonstration facility/setup functions in a simulated operational environment.
7	Prototype with systemic properties is in place and has been tested in an operational environment.
8	The commercial model/prototype is available and meets all requirements for final application.
9	Commercial application.

Table 1: Federal Government's 7th Energy Research Programme

In EUR thousands	Target	Government draft	Plan data		
	2018	2019	2020	2021	2022
BMWi	**639,700**	**725,205**	**725,798**	**723,800**	**723,745**
Project funding	595,596	682,980	682,980	682,980	682,980
Institutional funding (DLR)	44,104	42,225	42,798	40,820	40,765
BMEL					
Project funding	46,803	46,803	46,803	46,803	46,803
BMBF	**506,613**	**515,601**	**528,018**	**521,809**	**521,809**
Project funding	133,427	133,261	133,355	133,355	133,355
Institutional funding (HGF, without DLR)	373,186	382,340	394,663	388,454	388,454
Total	**1,193,116**	**1,287,609**	**1,300,599**	**1,292,412**	**1,292,357**

On a scale of 1 to 9, the TRL rates the scientific-technical status of a technology. As a general rule, projects aiming at the development stage of TRL 1 to 3 and therefore assigned to basic applied research are funded by BMBF. BMWi is responsible for research work closer to the application stage as of TRL 3. BMEL assists research nearing application as of TRL 3 with a thematic focus on energy production from biomass. The instrument of living labs to promote developments nearing commercialisation is based on TRLs 7 to 9.

Under its 7th Energy Research Programme for 2018 – 2022, the Federal Government will provide a total of some EUR 6.4 billion for researching, developing, demonstrating and testing viable future technologies and concepts. This amounts to an increase of about 45% on the previous period of 2013 – 2017. At federal level, government research funding in the energy sector is financed from the federal budget and the special Energy and Climate Fund (ECF), which is deployed under the programme solely for direct project funding in the non-nuclear sector, usually for carrying out large-scale projects with a particular multiplier effect for the energy transition.

Ministerial and budget responsibilities in project and institutional funding under the 7th Energy Research Programme are summarised in table 1.

The figures in the table are based on the Federal Budget Act for 2018, the government draft for the 2019 federal budget and financial plans until 2022 dated 6 July 2018. The selected timeframe is based on the federal financial plans and bears no relation to the unlimited framework programme term. Changes can be expected to be made in the years ahead. The budget plan is contingent on the availability of funds.

2. Introduction

Enérgeia was coined by Aristotle as a philosophical concept to denote the effective force that transforms potential into reality. The purposive production and use of energy therefore goes back to the beginning of human civilization and is still a driving force behind economic activities today. People, then, have long known how to put the creative potential of energy to use for their own benefit. It was, however, not until the industrial revolution that energy consumption per person rose sharply. Ongoing progress in energy technologies has gone hand in hand with increasing prosperity and social developments. In recent decades, though, there has been a growing focus on the risks of resource availability, especially the impacts on climate and the environment and this has called the fossil-fuelled energy system into question. With the agreement reached at the 2015 United Nations Climate Change Conference in Paris, the international community made a commitment for the first time to keep the rise in the earth's temperature well below 2°C compared to pre-industrial levels and to pursue efforts to limit the increase to 1.5°C. Foremost, this calls for rethinking all facets of the energy system. As history shows, however, energy transitions do not come about overnight. Although the strategic shift towards renewables is largely recognised as necessary today, it is not easy to put into effect.

2.1 Energy-policy challenges

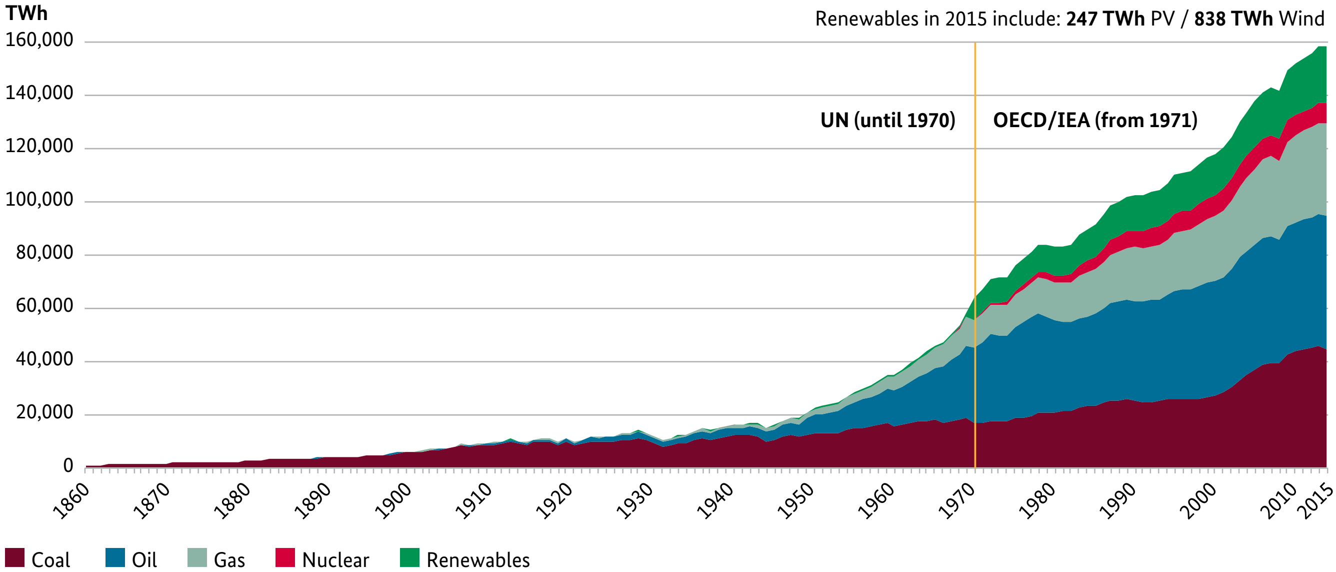
An analysis of the initial global climate and energy situation highlights the scale of the transformation process that has been set in motion. Since the beginning of the machine age in the 19th century, worldwide primary energy consumption has continued to rise, much improving the quality of life for many people. Global energy demand can be expected to increase, since on the one hand many people still consume very little energy and on the other the world population continues to grow. The actual challenge, however, is that 81% of world energy consumption is still met with fossil fuels. Solar and wind power afford very great potential, but they currently meet less than two per cent of energy demand. The status quo therefore stands in stark contrast to the demands and commitments of international climate protection and there is a need to make much more progress at all levels.

Germany's record is somewhat better: Primary energy consumption has declined compared with 1990 and the renewables ratio has risen in previous years. This is also the outcome of energy policy reform and the attendant shift in the energy sector. There has been a fundamental change in the uncontested position of fossil and nuclear fuels over decades. Today, German economic and energy policy is based on the reliable and environment-friendly supply of energy at affordable prices and its efficient use. Yet despite all the successes achieved, in the coming decades we face the enormous task of radically transforming the energy landscape of a modern, industrial economy. With its Energy Concept, the Federal Government has paved the way for future energy supply in Germany and set the key target of curbing greenhouse gas emissions by at least 80% compared with 1990 by 2050.

Accelerating the commercial expansion of renewable energies

To achieve the aim of decarbonising the energy system, policymakers have decided to use renewable energy such as wind and solar power for electricity generation, biomass and geothermal energy for heat supply and electromobility, alternative drives and a fuel mix, including synthetic fuels, for the transport sector. This transition is currently progressing at different speeds in the individual sectors. While tangible success has been achieved in the power sector, the heating and transport sectors are only making slow progress. An integral approach, up to and including the smart coupling of the heating, mobility and electricity sectors in combination with storage technologies, could speed up this trend and contribute to attaining the target of raising the share of renewable energies in gross final energy consumption to 60% by 2050.

Figure 2: World primary energy consumption from 1860 until 2015*



* Data from 1860 until 1949 from United Nations (1956), based on Regul (1937), from 1950 until 1970 from United Nations (1976), from 1971 from OECD/IEA (2017). Data on renewable energy generation includes only hydropower until 1970.

Sources: REGUL, Dr. Rudolf, 1937. Energiequellen der Welt: Betrachtungen und Statistiken zur Energiewirtschaft. In: Schriften des Instituts für Konjunkturforschung. Sonderheft 44, S. 1-78.
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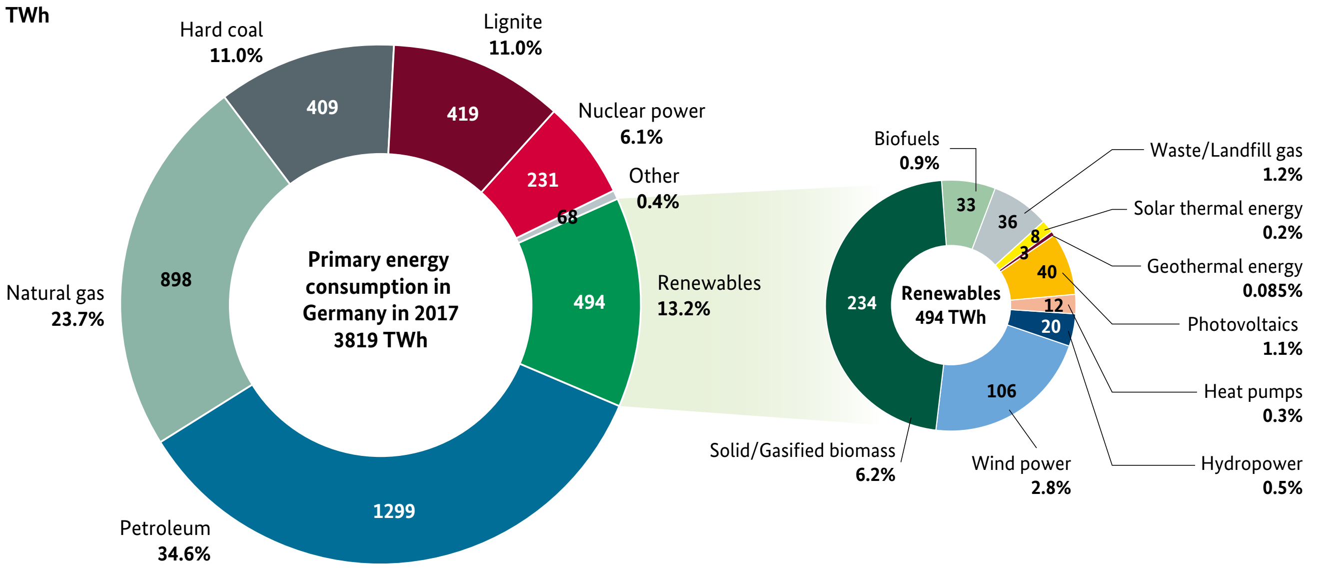
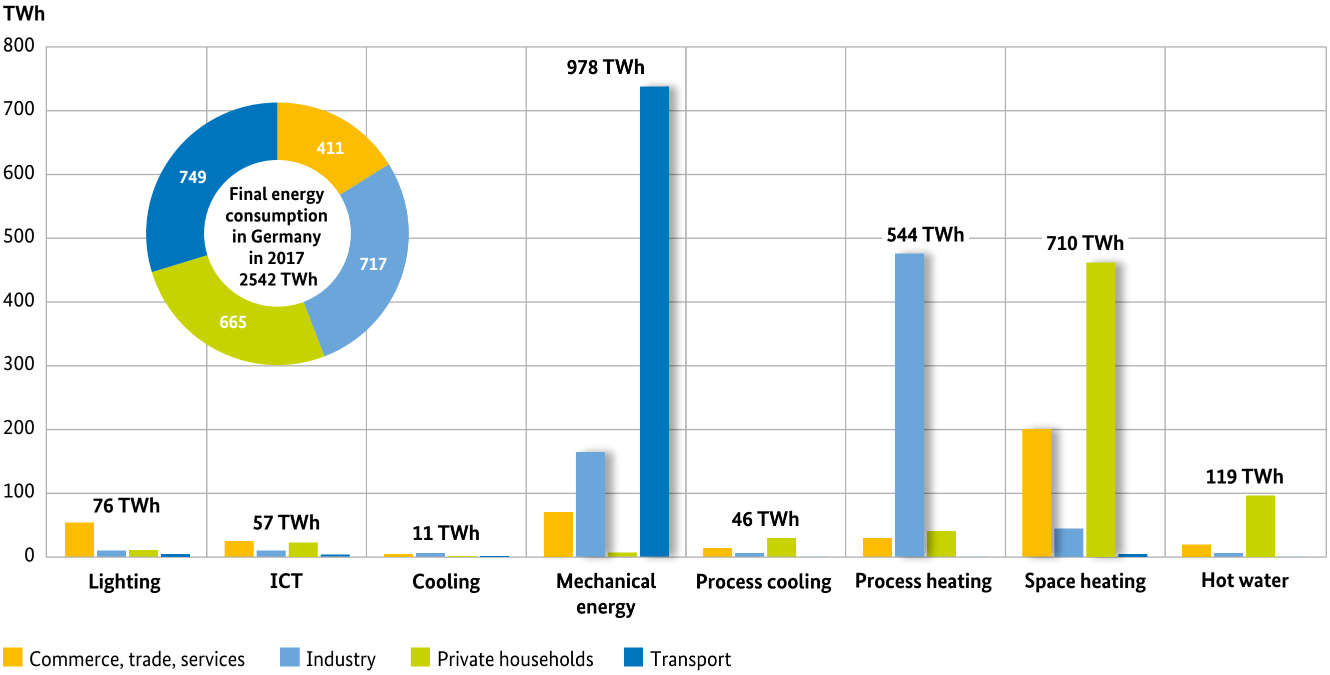
Figure 3: Primary energy consumption in Germany in 2017



Source: BMWi energy data, January 2018

Figure 4: Final energy consumption in Germany in 2017 by sector and application



Source: Working Group on Energy Balances

Raising energy efficiency at all system levels

The only way to attain high ratios of renewables in energy supply is to drastically reduce energy consumption at the same time and the only way to do this without having detrimental effects on the prosperity of a modern industrial and service society and the competitiveness of the German economy is to raise energy efficiency in all the demand sectors by a large margin. This is why 'efficiency first' is a central leitmotif of German energy policy and is also the basis for increasing energy productivity in our industry-based economy. The Federal Government is drawing up an ambitious, intersectoral energy-efficiency strategy for this with the aim of halving primary energy consumption by 2050 compared with 2008.

Making smart use of energy infrastructure

A special feature of the energy sector consists in the existing long-lasting, interwoven and capital-intensive energy infrastructure that has been built up over decades, such as mining plants, power stations, pipelines, distribution grids or storage facilities. They prolong the requisite period of adjustment to new supply capacities. To speed up the transformation process in the transition phase in particular, there is a need to find innovative ways of making use of the present infrastructure geared to the goals of the energy transition and devise smart networks to link these with the new facilities. These can enhance the speed and economic efficiency of the energy transition. Of particular importance in this connection is the modernisation and expansion of power grids. Another concern is to make use of the synergies and flexibility options afforded by sector coupling, integrated storage technologies and scope for decentralisation.

Securing energy supply

Business and industry and society in general depend on reliable energy supply. On the one hand, this requires the permanent availability of technically and commercially viable forms of energy. A strategically important task with economic, security and social policy relevance, on the other, is ensuring a technologically robust and resilient supply system to cope with increasing volatile input and digital networking. Future success will depend on striking the necessary balance among digital progress, social acceptance and minimising risk.

Advancing environmental and climate protection

To secure energy supply in the long term, it must be brought into permanent line with natural resource conservation and climate protection. Substituting fossil and nuclear fuels with renewables will make major contributions to this. Besides the urgent tasks of reducing greenhouse gas emissions and local air pollution, issues of resource and material efficiency and environmental protection and nature conservation will be essential as criteria for assessing the future viability of modern energy and efficiency technologies.

Taking account of social impacts

Technological progress goes hand in hand with social change. While technologies with beneficial effects are quickly adopted in everyday life, the uncertainties entailed in this kind of change, such as employment effects, impacts on prosperity or health or acceptance issues and changes in behaviour are major concerns for people in the course of the energy transition. Of particular societal relevance are processes of structural adjustment in traditional energy regions, where the repercussions of the transition process make themselves more felt due to the heavy geographical concentration, because they also affect the future viability of regional economic and employment models as well as the man-made landscape. Although it is the primary task of economic and industrial policy in general to create future prospects for a region and plan change to alleviate adverse social impacts, energy policy bears particular responsibility in this connection.

2.2 Strategic goals of energy research policy

As a key element of energy policy, publicly-funded energy research pursues the policy goals of the Federal Government and addresses major challenges posed by the energy transition. To achieve these goals and improve the effectiveness of the requisite transformation process, current technologies will have to be upgraded on a continuous basis. There is also a need to put more new innovative ideas into practice and to bring these new technological and non-technological innovations successfully onto the market.

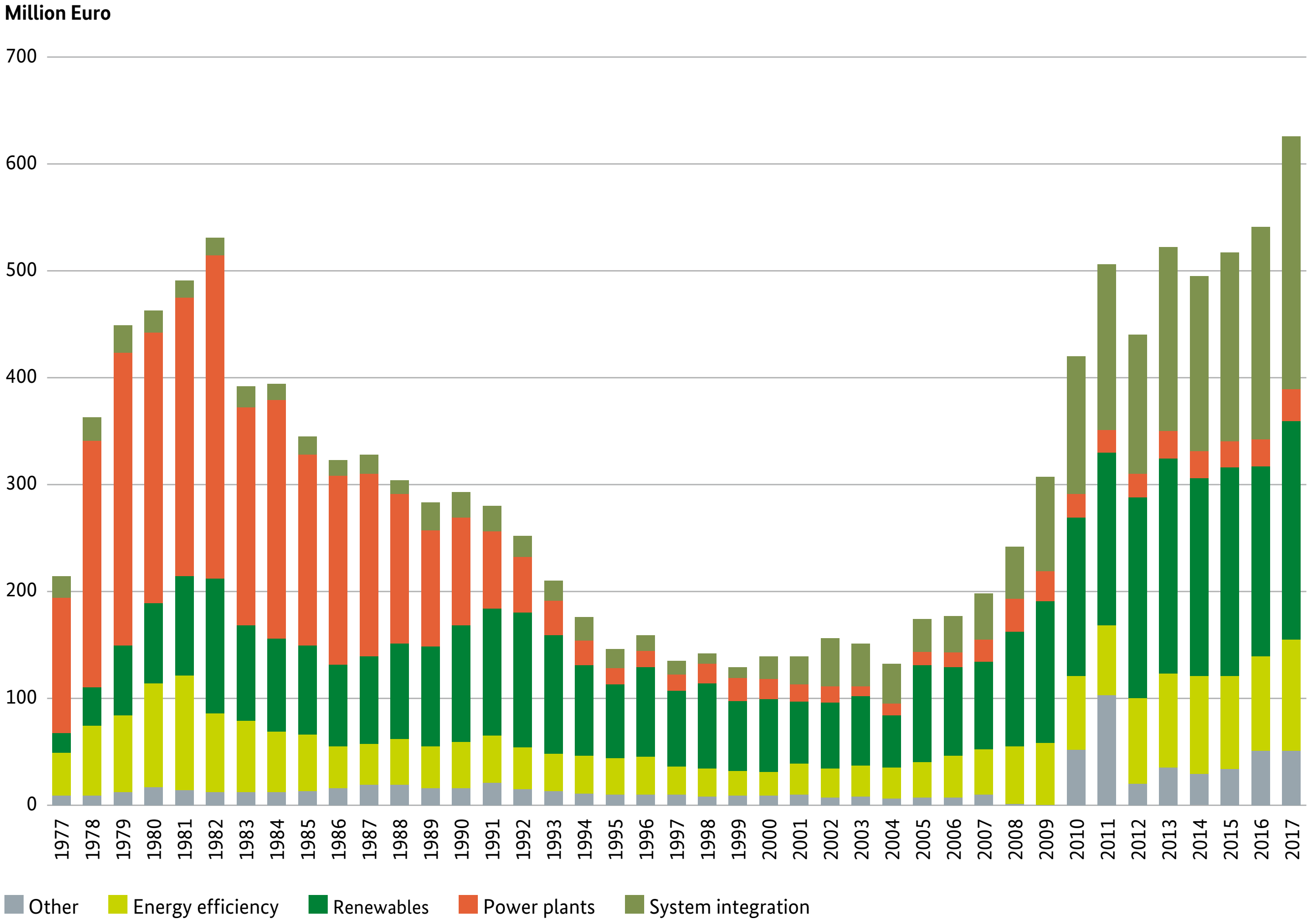
- **Expediting the energy transition**
  The key aim of funding research is to develop innovative, integral solutions to meet the challenges of the energy transition and launch them onto the market quickly. This will be supported with a broad funding approach along the entire energy chain with a special focus on results transfer. In addition to technological aspects, close attention will also be paid to non-technological factors in the energy transition, such as social processes or an enabling environment for innovation and their interaction. Particular priority will be attached to innovative technologies and concepts that can contribute to making substantial advances in raising efficiency and integrating renewable energies in demand sectors, while also attaching importance to the complex tasks in the heating sector (space heating and process heat).

- **Strengthening industrial locations**
  Funding energy research makes major contributions to modernising the German and European economies and securing them as a location for industry. The concern is to take up new trends, such as digitisation, where appropriate, maintain and upgrade technological competencies in the energy sector and also improve export opportunities for innovative energy technologies. This is why research funding will also be directed at technologies for the world markets, especially in developing and newly industrialised countries. Mobilising innovation potential in small and medium-sized enterprises and young businesses will also play a special role.

- **Managing societal risks**
  With its technology-neutral programmatic approach, energy research contributes to developing a broad range of technological options for the energy transition and making them available for practical application. This affords the requisite scope to be able to respond to currently unforeseeable developments in future. As climate and environmental impacts are not confined to national borders, high-efficiency renewable energy technologies and system solutions must also be developed with a view to contributing to solving problems worldwide.

These long-term, overarching aims go beyond commercial perspectives and timeframes, which is why government engagement is necessary in the strategically important energy sector to pave the way for innovative technologies, from development to testing to market penetration and social acceptance. Known 'market deficits' need to be offset when it comes to specific problems, such as the prolonged time horizons for technological innovations or the associated high economic and technological risks.

Figure 5: Project funding for non-nuclear energy research in Germany from 1977 to 2017 (adjusted for inflation, baseline year 2010)



Source: Project Management Jülich, profi-database

2.3 Framework and organisation of energy research policy

For the first time in the 1970s, the Federal Government set out the goals, priorities and funding instruments for its energy research policy in a multi-year programme. Since then, this has been regularly updated in response to shifts in energy policy, technological progress and additional issues. The now 7th sequel of the programme will be directed at the energy transition and has been drawn up under the leading agency of the Federal Ministry for Economic Affairs and Energy (BMWi). The Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Food and Agriculture (BMEL) are engaged in the programme with their own remits.

The Federal Government has evaluated individual examples of interministerial initiatives and has gained insights on how technological progress takes place in many areas of the energy system. Prime features are a faster pace of development, overlapping innovation phases and reciprocal thematic and sectoral interactions as innovation drivers.

To prevent fragmentation, the 7th Energy Research Programme has therefore adopted an **interministerial and thematic approach**. Ministerial tasks, including budget responsibility, have not been altered and in project funding will be assigned in keeping with the Technology Readiness Level system from TRL 1 to 9. The technological maturity envisaged in a project will be taken as a point of reference, while allowing for certain allocation overlaps in the transition of phases between milestones for TRL 3 and TRL 7 due to the complexity and uncertainties entailed in an innovation process.

Based on this approach, tasks in the 7th Energy Research Programme will be assigned as follows:

- **BMWi** will take leading responsibility for the programmatic direction of the energy research policy of the Federal Government and take charge of funding projects nearing the application stage, except for biomass (TRL 3-9). In consultation with the responsible ministries, it will issue research-policy directives on institutional funding for the HGF's Research Field Energy and be responsible for DLR energy research. It will represent Germany in international and European research policy bodies in the energy sector and promote project-related multilateral research collaborations.

- **BMBF** will take charge of project funding in basic applied research for the entire thematic spectrum of the programme (TLR 1-3), bear responsibility for all institutional funding in the HGF's Research Field Energy, excluding DLR, and collaborate in drafting policy directives for the HGF Research Field Energy. Moreover, it will promote junior scientists and academic exchange and scientific collaborations both at EU level and with international partners.

- **BMEL** will be responsible for project funding in biomass use for energy generation (TRL 3-7).

The new programme setup will enhance the tried and tested division of labour among the ministries by affording new scope for **harnessing synergies in thematic collaborations**. This will enable the programme to promote innovation more effectively in particularly dynamic areas of the energy transition and improve 'value for money' in research funding. The new thematic focus will also help advance European and international networking at programme level. The synergetic and cooperative approach will therefore also apply to interfaces between energy research and technology programmes of other policy fields with a peripheral bearing on energy, in industrial, construction, transport and climate policy, for example. Thematic reference will be made to these interfaces and European programme networking in the specialist chapters.

Cooperation with federal ministries that bear prime responsibility for heavily energy-dependent portfolios will play a major role, including the Federal Ministry of Transport and Digital Infrastructure and own programmes for putting viable future solutions into practice. Close consultation will take place on measures in the Energy Research Programme with a direct bearing on this.

When developing and implementing funding strategies for energy research, the Federal Government will attach importance to engaging in transparent dialogue with all relevant actors in this sector. This will assure the coordination of research activities, guarantee the high practical relevance of research and support the transfer of innovations to the energy sector. For this, the Federal Government has set up facilities to foster this exchange among the scientific community, business and industry and policymakers:

- The Energy Transition Research and Innovation Platform (R&I Platform) acts as an advisory body for overarching issues of funding policy in energy research. Members of the plenum are policymaking, energy sector, research and social institutions.

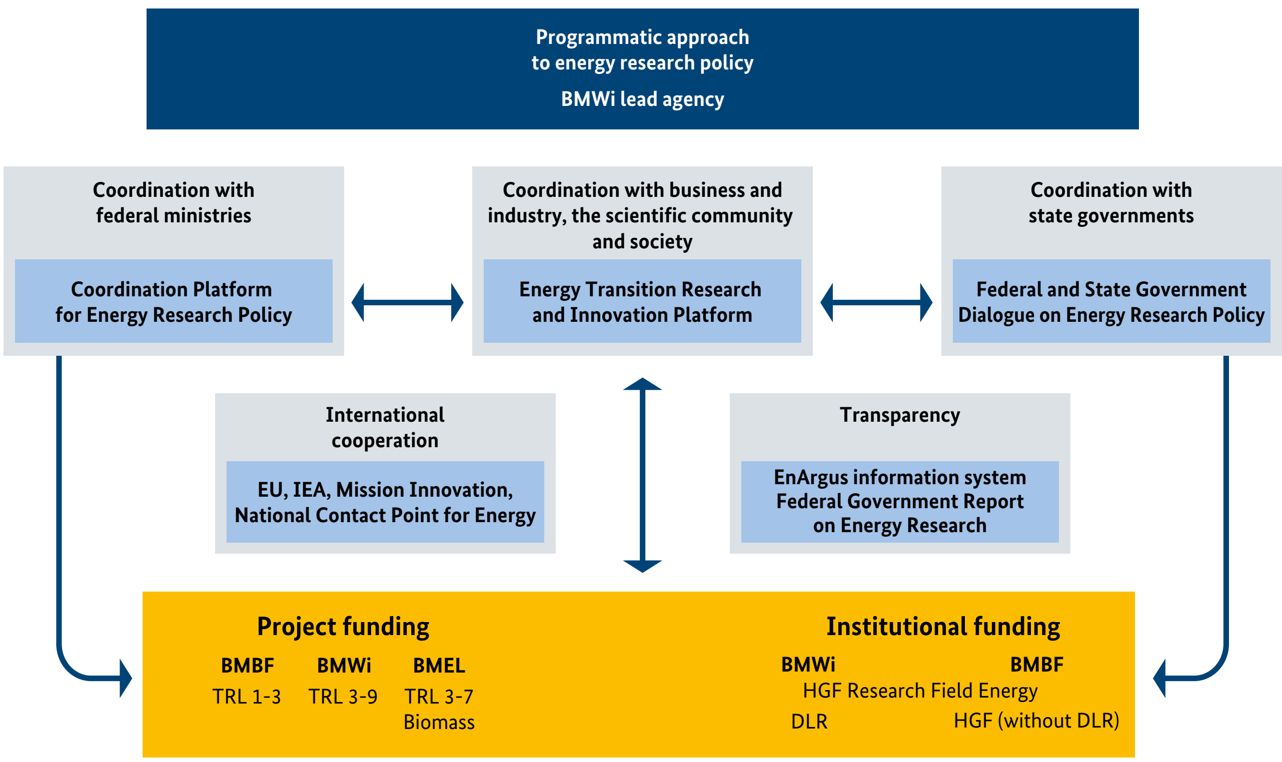
- The R&I Platform receives expert assistance from the Energy Research Networks. These are available to all interested experts and are organised and planned by the actors themselves. About 3,500 members are currently engaged. The science academies' project, Energy Systems for the Future (ESYS), also channels its findings into the R&I Platform.

- The joint programmatic approach raises the need for regular consultation and coordination among the ministries taking part in the 7th Energy Research Programme. The established Coordination Platform for energy research policy will therefore be strengthened and extended where necessary.

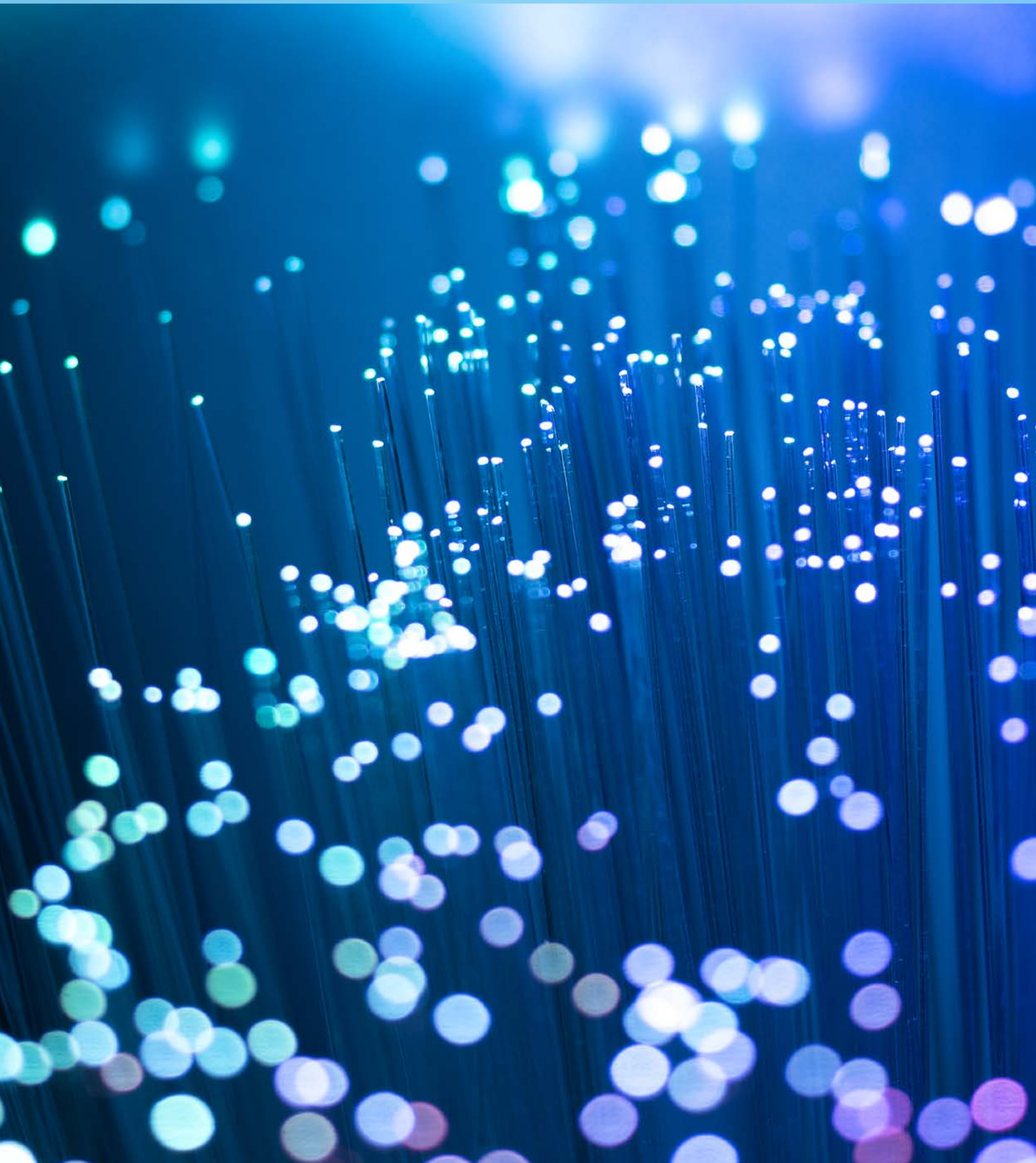
- The annual Federal and State Government Dialogue on energy research policy will step up exchange with the states and expand cooperation in selected areas.

The 7th Energy Research Programme will make contributions to the Federal Government's High-Tech Strategy, the implementation of the National Climate Action Programme 2050, the National Innovation Programme for Hydrogen and Fuel Cell Technology and the National Energy and Climate Plan under the EU Energy Union. It also makes up part of the Federal Government's energy-efficiency and digitisation strategies.

Figure 6: Institutional setup for energy research



3. Focus: Technology and innovation transfer



3.1 Living labs for the energy transition

After having made major progress in many areas, the energy transition is now entering a new phase. While the initial main concern was with expanding renewable energies and energy-efficient technologies, greater focus will now be placed on systemic issues. Power generation and consumption can no longer be treated as separate issues: They must be seen together as part of a networked energy system. For example, developing smart energy infrastructures, networking them in neighbourhoods, sector coupling or digitisation are topics that cannot be adequately investigated under artificial conditions in the laboratory. Current research funding strategies need upgrading in response to closer networking in the energy system at all levels and the new active role that many actors will play in the energy transition. New funding formats must communicate a shift from assisting individual technologies to systemic research aid that also takes account of the social impacts of the energy transition. For this reason, both innovative technologies and integral energy schemes will in future be tested with the aim of extensive decarbonisation in an experimental environment for a limited term and in a delimited space under realistic conditions in systemic interaction with a view to marketability. With the new Energy Research Programme, the Federal Government will therefore establish the living labs for the energy transition as a new pillar for research promotion. These will be designed on a larger scale and encompass a broader thematic range than demonstration projects to date, but they can also afford a means of 'regulatory learning'. This way, technological and regulatory findings can interact in practice and point to potentials for systemic optimisation. Scope for the requisite legislative measures, such as an experimentation clause in laws and regulations or exemptions, will be explored based on the research report "Potential and Requirements of Regulatory Innovation Spaces" (Living Labs).

The living labs for the energy transition will address the main systemic challenges for German energy policy in clearly demarcated large-scale pilot projects. They will play a spearheading role in transforming the energy system and deal with research topics that play a key role for implementing the energy transition, initially focussing on sector-coupling technologies, such as large-scale electrolysis facilities with waste heat use in regions with grid bottlenecks, large-scale thermal storage units for the carbon-neutral, sustainable use of existing energy infrastructures, technologies for CO_2 use or the smart networking of energy infrastructure in climate-neutral urban neighbourhoods. The funding format for living labs will be designed to keep pace with local social developments. The challenges in regions affected by structural adjustment and declining population numbers differ from those faced in growing, populous cities. The living labs for the energy transition will develop, try out and propagate integral solutions. They must be cross-cutting projects whose objectives are understood and endorsed by the local population to arrive at the necessary basic consensus for the successful transfer from research to application.

These solutions can only be successfully implemented in close partnership with businesses seeking to introduce innovative energy technologies and schemes onto the market but also with local actors who are familiar with the challenges in the region or neighbourhood. Added to this are scientific institutions that prepare the transfer of research findings and accompany the implementation of the living lab scientifically. The participation of small and medium-sized enterprises (SMEs) and startups will play a major role in this.

As a new pillar of energy research, the living labs will be carried out in phases. Ensuing measures, especially for possible adjustments to the regulatory framework, will be taken step by step, taking account of the experience gained and the rapidly developing boundary conditions.

Living labs for the energy transition are a new funding format, but they will in part draw on experience gained from previous funding initiatives conducted in energy research, such as SINTEG, Solar Construction/Energy-Efficient Towns and the Kopernikus projects geared to basic research. The Kopernikus projects will in parallel be developed further and focussed on key solution options for the energy transition.

3.2 Startups: New actors in the energy transition

In its project funding, the Federal Government's 7th Energy Research Programme will adopt a partnership approach: The scientific creativity of research institutes and higher education institutions, the innovative power of SMEs and the infrastructure and experience of large-scale enterprises will complement each other in collaborative projects with integral tasks that encompass the whole chain from basic research to research nearing application to commercialisation. Despite the many favourable outcomes of these cooperative partnerships in the past, the pace of innovation must be speeded up for a successful energy transition. Cooperation with startup enterprises will play a pivotal role here, because it will generate new ideas and can improve innovation transfer.

To bring about substantial market innovations, the increasing complexity of the energy system and industry demands entrepreneurial abilities, such as adaptability and enthusiasm for experimentation. Non-technological innovations will also play a major role in the digitisation of energy supply and the development of innovative business models can also make a contribution to this.

Startups are also important as innovation drivers in this connection. By helping to find novel technological solutions and developing new markets with innovative and sometimes unconventional products, services and business models, they will give a major impetus to the energy transition. They are often engaged in cross-technology fields of research, such as sector coupling or digitisation, but also deal with socio-economic issues and try out innovative developments and findings in a practical environment. This is why the new funding format of living labs is of special interest for startups: It will enable them to test their newly developed, frequently almost market-ready products in an adaptable framework.

Startups operate with a strong focus and impetus under pressure to succeed from their investors. To date, however, the classical tools and mechanisms of project funding have hardly been tailored at all to these actors. Without the closer involvement of startups, energy research will be deprived of a major innovation driver. The Federal Government will therefore aim to address startups better with new, appropriate funding formats and step up their participation in all thematic clusters of energy research. For this, it will successively dismantle current barriers, on the one hand by enlarging the contents of the programme to include non-technological innovations (business models, new services) with a bearing on technological innovations and on the other by reforming and speeding up administrative procedures with a number of new elements, such as specific startup advice, the possibility of a "Fast Track" (accelerated application procedures), by means of new, more adaptable project designs and prize formats along with the new networking platform, Energy Research Network Startups.

3.3 Exchange and networking: Energy Transition Research and Innovation Platform and Energy Research Networks

With the participation of all relevant ministries at federal and state level, the Energy Transition Research and Innovation Platform (R&I Platform) groups high-level actors from policymaking, science, business, industry and civil society for the joint discussion and assessment of current developments and research strategies. The project Energy Systems of the Future (ESYS) of the German Academies of Sciences focuses on basic research. It also contributes its findings and will be upgraded. This way, the R&I Platform integrates all three pillars of energy research, from basic to applied to near-market research in living labs.

The Energy Transition Research and Innovation Platform is provided with expert support from Energy Research Networks. The approximately 3,500 members of these open expert networks generate networking gains to assure the quality of research findings and guarantee continuous advances in knowledge and transfer into practice.

The increasing complexity of our energy system makes it more difficult to ascertain the best technology and instrument mix for the energy transition. Exchange among experts with complementary operational, strategic, technical and methodological expertise can find answers to this. Energy Research Networks aim to bring these experts from research and business and industry together around diverse thematic issues and to facilitate exchange of experience in a transparent, open setup. This liaises and consolidates important relationships among the actors, some culminating in joint research projects, and also expedites the transfer of major findings from research to practice. The research networks afford scope for largely self-organised procedures among their members, supplemented with joint events, webinars and opinion polls (*forschungsnetzwerke-energie.de*).

The energy transition involves a growing number and diversity of actors that influence future energy supply. Its success will depend on whether a balance of interests can be struck and basic consensus reached in competition among the different stakeholders. This is also a task for energy research policy. Energy Research Networks will be able meet this need by linking the researcher community closely with policymaking procedures and giving it easy access to these. Ministerial advisory committees assist every research network and support the exchange and transfer of findings to specialist policymaking. Moreover, the members of research networks can also take part in and contribute proposals for planning energy research policy, including, for example, the identification of new trends and research requirements and expert input into broad-based consultative procedures for the present Energy Research Programme.

Vibrant research networks will continue to bring together all actors with their different interests and facilitate cooperation and social dialogue. A special task in the coming years will be to upgrade the strategies of the current research networks and expand their capacities for specific, selected priority issues. Assistance will also be given for cross-cutting themes, such as digitisation, energy storage and sector coupling. Major actors that can perform a multiplier function in the energy transition will be integrated more into the research networks, startups, for example. Accompanying scientific research projects in research networks will pool research findings and further improve their practical application.

3.4 Research communication

Besides research funding, research communication is a key task of federal energy research policy, especially reporting on future trends and research contents and expediting the practical application of research findings. Another aim is to ensure transparency in the allocation of funds. Suitable formats and instruments for exchange and dissemination of information are developed and made accessible to the public.

EnArgus is the central information system for energy research funding (enargus.de). The web-based portal documents over 24,000 research projects in the energy sector and also provides information on various energy topics, technologies and technical terms. This database makes a decisive contribution to transparency in energy research funding, accounts for the efficient application of funds in the various projects and enables analyses to be made for the future direction of funding policy. Based on this, the Federal Government prepares its annual Federal Energy Research Report, which informs the public and parliament about its funding activities in energy research. Both instruments will be upgraded in the years ahead. For example, the EnArgus database will be enlarged to include additional activities of innovation promotion at federal and state level.

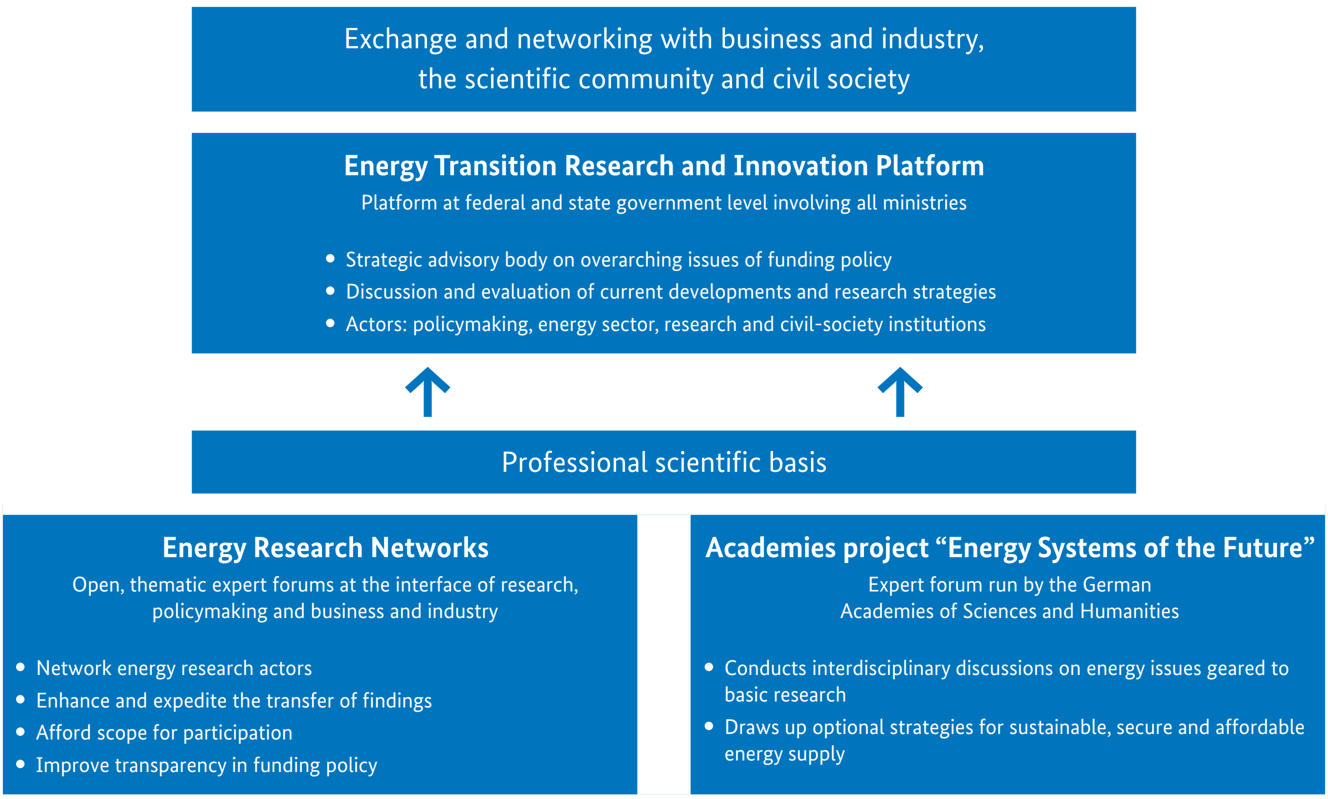
In view of the broad societal consensus on the value of promoting energy research, it is important to fully inform the public on pressing research issues and progress and setbacks in research projects. The Federal Government has set up a central web portal (*energieforschung.de*) for this, with a diverse range of information for different target groups. Alongside sound information on everything to do with energy research, it also provides access to research portals on various priority issues and reports on special research initiatives. Ranging from energy transition issues in transport, construction and industry to renewables, pro-active knowledge transfer with competent, reliable information on energy research will contribute to preparing for the commercial application of research findings at an early stage.

The website, *fona.de*, is a multi-media source of information on additional activities in energy and sustainability research. It informs a specialist readership, science journalists and the interested public on the contents of various measures and the findings of the three FONA (Research for Sustainable Development) flagship initiatives, Transformation of the Energy System, Green Economy and the City of the Future.

Information on energy research is also disseminated in social media. Besides making especially the younger generation aware of this important issue for their future, these information channels provide opportunities for direct exchange and will therefore be developed further.

As part of its open access strategy, the Federal Government supports the free availability and use of scientific findings, because the outcomes of publicly-financed research projects are intended to be of general public benefit. With its 7th Energy Research Programme, it therefore advocates mainstreaming open access even more in energy research.

Figure 7: Exchange and networking



4. Project funding

4.1 Energy transition in consumption sectors

4.1.1 Buildings and neighbourhoods

Energy-sector relevance and strategic goals of R&D

Buildings account for about 35% of final energy consumption in Germany, 90% of which is used for heating. The investment cycles for buildings and their technical service systems are as a rule very long, lasting in some cases over 30 years. Today's investment decisions will therefore have a direct effect on the building stock in 2050, the year that the Federal Government aims to achieve near climate-neutral buildings (Energy Efficiency Strategy for Buildings of November 2015). New and refurbished buildings must therefore already be generally compatible with the energy-policy targets for 2050 today, based on economically efficient and reliable technical solutions that also cater for the diversity of existing buildings. Putting research findings into practice faster is essential for the rapid commercialisation of innovations. This is why conducting demonstration projects is of particular importance for putting the technology but also the coordination of operations on the construction site to the practical test. These demonstration projects should go beyond trade and company boundaries. Virtually climate-neutral buildings can already be built today with the smart use of components already available on the market but not yet in broad use. Further efforts in research and development are, however, also needed to improve the commercial viability of innovative solutions, because for one thing climate-neutrality in existing buildings and urban neighbourhoods is difficult to achieve without innovations and for another the energy performance of buildings can also be improved beyond climate neutrality (e.g. energy-plus houses).

Energy research in buildings and neighbourhoods must take account of the needs of users, because there is no advantage for energy efficiency and climate protection, if buildings do not adequately perform their intended purpose or efficiency technologies are available but cannot be put to commercial use. This highlights issues such as the impact on rent pricing, affordable construction prices, comfort or also user data privacy. Issues of acceptance must also be taken into account in all research activities. When developing technologies and concepts, consideration must be given to whether they are not just technically feasible but are also worthwhile from the user perspective. Acceptance research can devise methods, such as participatory approaches, that explain complex transformation processes to those concerned and facilitate dialogue where there is a possible conflict of aims.

Alongside the development of individual building service technologies and integrated renewable generators, the systemic interaction of buildings with each other and with the energy infrastructure is playing a growing role. This applies for both high-density urban neighbourhoods, where efficiency gains can be made through joint or networked supply systems, but also rural regions, in which the decentral use of local and temporarily available renewable energies can ease the burden on the distribution grid. In the course of sector coupling, buildings and neighbourhoods will in future have to interact more with the power and also transport system, because linking the building infrastructure with energy supply in the transport sector, using vehicles as storage units for locally produced renewable energies, for example, can contribute to improving the climate footprint and energy efficiency. The increase in localised supply systems and linking the power, transport and heating sectors, including mobility at neighbourhood level, calls for an enormous improvement in the responsiveness of on-grid energy supply. The attendant complexity due to volatile inputs and outputs will require far-reaching digital networking and demand responsiveness to ensure a secure supply. To be successful, a systemic approach will need both components and systems to be able to communicate with each other independent of manufacturer and they will have to be as standardised as possible.

Systemic solutions at building or neighbourhood level must also take the issue of 'grey energy' into account, i.e. the energy and greenhouse gas equivalents embodied in building-materials, as in the course of the general decline in energy demand, the energy consumption and greenhouse gas emissions related to the production, dismantling and recycling of building-materials and building service technologies take up a larger share. Lifecycle analyses are helpful and necessary to gain a clear picture of the various contributions of structural and technical plant life phases for different technological solutions. Aspects of resource and space efficiency also need to be taken into consideration.

Because an increasing number of people in Germany live and work in towns, urban neighbourhoods are a major focus of energy research. The requirements the Federal Government places on future energy-efficient neighbourhoods call for a sweeping transformation process that needs to include energy, sustainability and resource challenges, but also social factors, such as the living environment, new ways of living and working, demography, urban-suburban relationships and sustainable mobility in planning and construction procedures – also architectural identity and the preservation of historical monuments.

This integral approach sees neighbourhood energy design as part of an overall urban development strategy. Assistance will therefore be made available for developing and testing integral systemic and innovative initiatives for climate-neutral development at neighbourhood level. The conversion of the energy supply infrastructure will play an important role: It must be brought into line with the gradual retrofitting of supplied buildings. Various actors must be involved in the different phases of development, such as companies, investors, municipal utilities and local authorities. Living labs, which also permit of longer operational periods, are an appropriate format for putting this approach into practice.

The Federal Government also promotes research and development for technologies with a specific bearing on energy in the construction sector outside the Energy Research Programme, e.g. in building research as part of the Efficiency House Plus initiative. As an element of building policy, it supports energy-efficient, sustainable construction with future viability and the prompt translation of research findings into practice. With needs-based, practice-centred, interdisciplinary and transdisciplinary research, the initiative, City of the Future, under the framework programme, Research for Sustainable Development (FONA), contributes to meeting the challenges of increasingly urbanised life. In addition, hydrogen and fuel cell technologies are attested great potential in the transport sector, which is why research activities on specific applications for this are promoted by The Ministry of Transport and Digital Infrastructure.

Strategically important R&D topics

The buildings and neighbourhoods sector comprises a broad range of R&D topics. Innovations in building and other materials and upgrades in construction components and technical building services pave the way for locally adapted, integrated concepts with the aim of bringing the generation, distribution, storage and use of thermal and electrical energy into alignment.

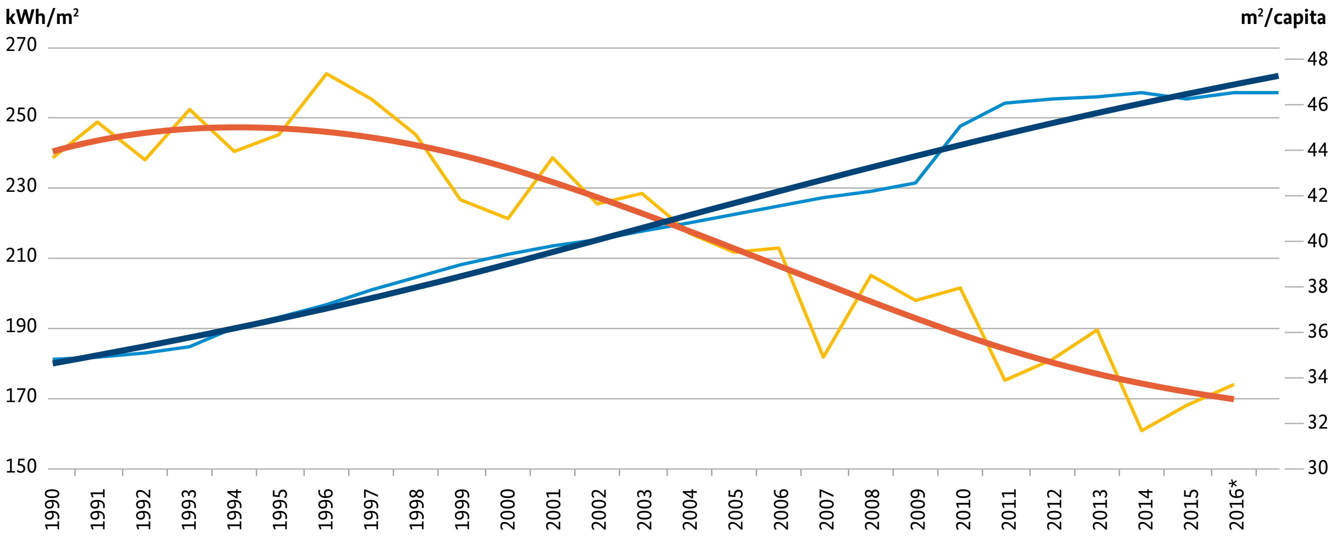
Technical building services and innovative materials

Major research topics here are upgrading and applying innovative thermal storage technologies, accessing renewable energy sources and ambient heat, more efficient and integrated technical building services and sustainable or even adaptive thermal insulation. The aim is to make necessary progress in these sectors with technological innovations, but above all materials research. Innovations in technical building service equipment and passive building components can also contribute to raising energy efficiency, while taking account of aspects of economic and resource efficiency. This also applies for the improvement of production technologies and the energy-performance and economic assessment of technologies. Research must also be conducted into integral dismantling, recycling and disposal strategies. Thorough lifecycle analyses at building level will assess the prospects of success for the strategies developed throughout all use phases.

Integration of renewable energies

In future, the entire shell of a building will be able to be more adaptable and active, respond to environmental influences, integrate technical building services and convert and store energy. Building-integrated photovoltaics (BIPV) and solar thermal power along with coupled photovoltaic thermal hybrid installations will play a major role in this. New architectural scope will also emerge that ought to be put to consistent use for the benefit of residents. Additional synergies can be harnessed in neighbourhoods in the course of integrating renewable energies. Their increased integration in buildings and neighbourhoods can also contribute to improving supply security.

Figure 8.1: Final residential energy consumption of private households and trends in living space: Final energy consumption per square metre and year and living space per household



Final energy consumption** kWh/m²

Trend line (final energy consumption** kWh/m²

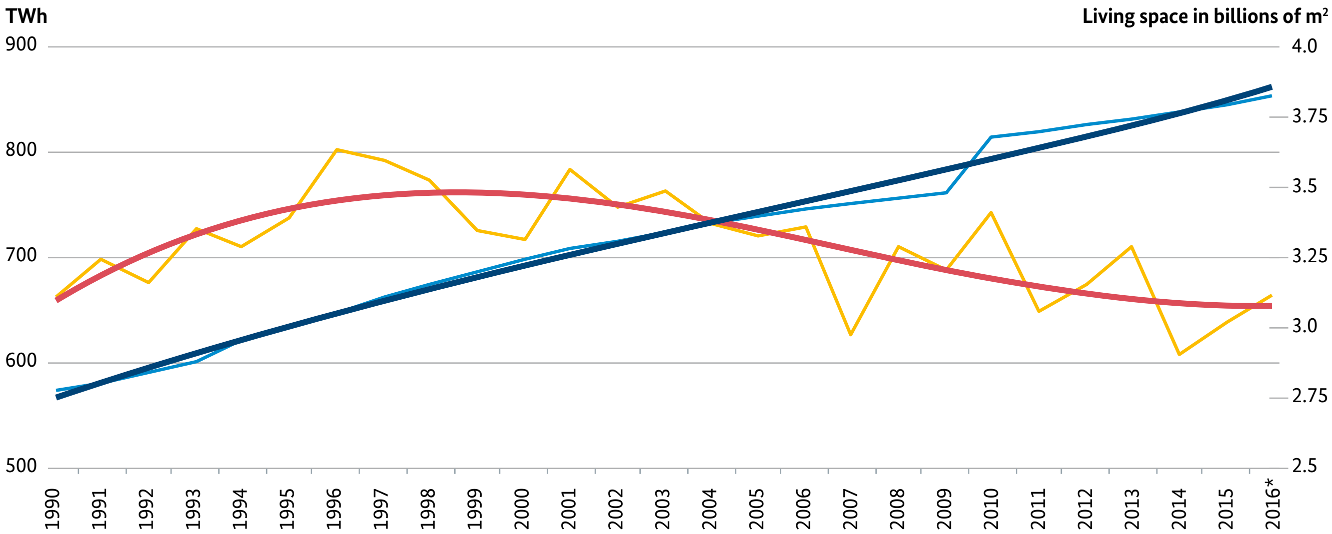
Living space in m²/capita

Trend line (living space m²/capita)

* Energy data for 2016 are preliminary. ** Data on final energy consumption are not temperature-adjusted.

Source: Federal Statistical Office (housing data) and Working Group on Energy Balances (energy data)

Figure 8.2: Final residential energy consumption of private households and trends in living space: Total final energy consumption and total living space



Final energy consumption** kWh/m²

Trend line (final energy consumption** TWh)

Total living space in billions of m²

Trend line (living space in billions of m²)

* Energy data for 2016 are preliminary. ** Data on final energy consumption are not temperature-adjusted.

Source: Federal Statistical Office (housing data) and Working Group on Energy Balances (energy data)

Heat and cold supply

In heat, cold and power supply for buildings and neighbourhoods, novel concepts can create technical solutions that enable users to respond adaptably to the erratic supply of renewable energies. Sector coupling in heat and cold supply can raise responsiveness. Amalgamating larger building complexes or neighbourhoods will generate synergies for greater efficiency and sustainability, but will also increase complexity. A promising option are innovative, integral low-exergy schemes for renewable, on-grid, decentral heat and cold supply. They will enable the simple use of renewable energy and waste heat and make the electricity system responsive. A major foundation for this is the development of efficient and commercially viable heat and cold storage facilities and upgrading these for use in local energy supply. Other major research topics are linking heat supply systems with geothermal energy, solar thermal power, bioenergy, ambient and waste heat and also the smart combination of heat sources and heat sinks, through digital networking, for example.

Closer networking with the electricity sector (see Section 4.3.3) can mobilise synergies in the heating/cooling sector. As the most adaptable source of energy, electricity should be put to the most efficient possible use in the heating sector and generated with no impact on climate to meet the climate protection targets. Thanks to the availability of the fundamental technologies, combining electricity and heat already makes a significant contribution to a stable energy system today. Innovative concepts for information and communication technologies (ICT) and smart control technology need further development to contribute to efficient integral solutions in buildings and neighbourhoods. Research is needed in heat pumps to cope with new temperature levels, raise efficiency more and reduce costs, e.g. through improved production processes.

Thermal storage facilities

As thermal storage facilities are a key element for energy system integration and responsiveness, they are also a broad-based, cross-cutting topic of energy research. By integrating storage units in buildings, neighbourhoods and industry (see Section 4.1.2), use can be made of volatile yields from locally available sources, thus saving on primary energy and improving supply security. The main goals of research in thermal energy storage are therefore cost-reduction, higher efficiency in energy conversion, improved reliability and security as well as the faster integration of storage technologies into the energy system, including large-scale heat accumulators. For this, researchers must investigate innovative storage materials, identify new storage designs and develop the most suitable components and the most cost-effective production processes. Account must also be taken of the combination or reciprocal effects of power storage (see Section 4.3.2) and these must be designed to support the network or system.

Stationary fuel cells and co-generation plants

Stationary fuel cells will be deployed in particular in buildings and neighbourhoods. Through the high-efficiency and low-pollutant conversion of fuels with high gravimetric energy density, such as hydrogen or (transitionally) natural gas, into electrical and thermal energy, this has the potential to make a major contribution to the energy transition. Consideration must also be given in this connection to the use of surplus electricity for hydrogen production in reversible fuel cells or electrolysers (see Section 4.3.3) or special applications, such as off-grid power supply.

After decades of research, fuel cell technology has now attained technological maturity. The persistent excessive costs compared with performance and service life are, however, proving to be a hindrance to broad market introduction. Besides initiatives towards the next generation of efficient and cost-effective technologies, new manufacturing processes for large unit numbers can contribute to improving their commercial viability.

Research and development in this sector will focus on two types of fuel cell, polymer electrolyte (PEFC) and solid oxide (SOFC) fuel cells, attaching equal priority to subsequent use in stationary or mobile applications. The aims are raising capacity, reliability and lifespan under typical (flexible) operating conditions, cutting costs for key and system components, improving system integration and upgrading operating strategies. To be able to reduce costs further, high-throughput production technologies also need to be developed (industrialisation of production). Investigations into the recycling or substitution of costlier or limited raw and operating materials and lifecycle studies will pave the way for improving the overall energy balance. This will be flanked by promoting materials research and conceptual development for future technology generations.

Demonstration projects, field tests and possibly living labs will help prepare future generations of fuel cells for commercialisation. This is also a way to provide in-depth validation of the market maturity of existing systems, by also including additional determinants, such as operational management strategies and quality assurance. Another step towards propagating fuel cells is the scientific preparation of internationally accepted and validated norms and standards for their components.

Combined heat and power (CHP) installations will make up an integral component of efficient and climate-friendly energy supply. Deployed locally in buildings and neighbourhoods, they can reach particularly high total energy efficiency rates. As in energy-efficient buildings the heat demand declines relative to electricity consumption, combined heat and power stations with a high electricity yield will play a more important role, which is the reason for the high expectations attached to the use of fuel cell technology in co-generators. Besides this, micro gas turbines are also an important research topic, especially in combination with fuel cell technology. The prime concern here is with their fuel and load flexibility and their smart integration into energy supply for buildings and neighbourhoods (see also Section 4.2.6).

Digital planning, construction – and living

The extensive use of digital options in planning refurbishment and construction measures for housing and non-residential buildings and their management is a key task of the energy transition. This also includes devising planning aids. Digitising planning along the construction industry supply chain calls for renewed efforts on the part of practical research. More research activities are needed for upgrading connectable building information modelling (BIM) and energy performance aspects as part of digitisation processes to ensure on the one hand that innovative digital tools developed in research are also adopted in practice and on the other that energy efficiency estimates are incorporated into BIM programmes and procedures. For long-term commercial success, open interfaces need to be defined that are freely accessible to stakeholders. Operational energy performance can be improved faster with digital and user-friendly diagnostic tools.

Digital technologies have long been part of the home environment, but how far these can contribute to improving energy efficiency (smart building) is often still an open question. The growing potential of ICT in the building sector should not cause IT security and data protection issues to be overlooked.

Digital technologies are also becoming increasingly important for neighbourhood development. Research should therefore be conducted into smart neighbourhood approaches, taking account of data protection, ICT security and the use of big data methods. The methods then devised for the integral auditing and rationalisation of energy performance in neighbourhoods and the simulation and modelling of refurbishment paths will also be developed and tested.

Although digital construction is not a primary issue in energy efficiency, the scope and potential afforded here also have a bearing on energy research, for example, raising the cost-effectiveness of new and renovated buildings with very ambitious energy performance standards by using 3D printing, automated surveying (including drone technology) and serial construction methods in combination with digital planning and industrial production.

Research transfer for the energy transition in neighbourhoods

Neighbourhoods are particularly suitable environments for carrying out large-scale demonstration projects (see Section 3.1), because ideally they encompass all the structural and instrumental facets needed to exemplify the implementation of the energy transition over a relatively small territory. Economic structural adjustment has an influence, just as typical regional features of building culture, urban planning and demography do. Demonstration projects at neighbourhood level are at an appropriate scale to gain an overall view and put the complexity of networking energy and heat supply, system integration and mobility service delivery up to and including social processes and needs into a manageable perspective. They also raise awareness of complex, long-term planning and approval procedures and can in addition point to practicable and acceptable prospects and implementation pathways towards climate-neutral and energy-efficient neighbourhoods that integrate renewables and afford a high quality of life.

These projects reach people where they live: to succeed, it is important for the transfer process to take account of data protection and the private sphere, user-friendliness and comfort. Research on probable user behaviour is also of high relevance: this entails successfully addressing the actors, methods for pooling competencies and the needs-based strategic realignment of institutions and their organisation (institutional design).

The involvement of all actors, sectors and buildings at neighbourhood level is essential for interdisciplinary cooperation and mutual learning processes and for arriving at a common understanding of research. Besides sustainable transfer, the aim of demonstration projects, such as model or transformation projects or living labs, is to show how systemic schemes can maximise energy performance at neighbourhood level. They will look at integral solution approaches for different, but transferable urban or rural types of neighbourhood – with the following priorities:

- Neighbourhoods in the process of structural adjustment
- Neighbourhoods and sector coupling
- Neighbourhoods undergoing demographic change
- Synergies for residential neighbourhoods and production estates
- Planning, implementing and monitoring innovative supply concepts
- Energy transition business models for minimising market and implementation constraints

Institutional set up of R&D funding

The Federal Government has amalgamated the funding of research, development and demonstration measures for energy-efficient buildings and neighbourhoods in the research initiative, ENERGIEWENDEBAUEN (Energy transition construction). In addition to ongoing calls for proposals and specialist portals, this also includes its own research network. The purpose is not only to cluster topics, but also to network the many different actors involved in energy efficiency and renewable energies in buildings and neighbourhoods. This open expert platform synchronises research activities and discusses findings from research with practitioners. Along with the established formats, such as manuals, guidelines, electronic planning aids, workshops and specialist events and conventions, the thematic working groups of the Research Network ENERGIEWENDEBAUEN will be deployed even more in future as an instrument for imparting knowledge to specific target groups and accelerating transfer. Close collaboration is envisaged with other networks for cross-cutting issues.

The ENERGIEWENDEBAUEN accompanying scientific research project makes a central contribution to the overall research initiative. This accompanying scientific research documents and evaluates work programmes and discusses the outcomes of research and demonstration projects with all stakeholders and compiles these so that they can be mainstreamed into planning and decision-making practice. A key success factor is imparting knowledge to interested parties via user-friendly knowledge management and exchange of experience to cater for the very complex funding recipient landscape. Relevant actors are also involved as part of participatory procedures.

Along with research, development and demonstration projects, near-market model and pilot projects are also promoted in the buildings and neighbourhoods sector (EnEff.Gebäude.2050). These demonstrate broad-impact (technological and non-technological) solutions for climate-neutral buildings and neighbourhoods with a flagship function to expedite market introduction or broad application. Owing to the close user involvement in this field of research, it is also particularly suitable for innovative and participatory formats, such as challenges, special innovation spaces and living labs.

At national level, research and development in fuel cell technology falls under the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP 2016 – 2026), which is aimed at market preparation. Under this framework, interministerial and interprogrammatic research initiatives will be expanded further, supported by a closer linkage of actors with the Energy Research Networks.

International networking will also be expanded further on the basis of current cooperation formats. International research collaborations are possible under a memorandum of understanding in place since 2013 on cooperation in research, development and demonstration for smart, energy-efficient cities of the future in Germany, Austria and Switzerland (D-A-CH).

Regular cooperation takes places in three working groups of the European SET-Plan – Positive Energy Districts 2025, Smart Solutions for Energy Consumers and Energy Efficiency in Buildings – with a focus on New Materials and Technologies and Heating and Cooling for Buildings. R&D aspects in the SET-Plan working groups on individual building service technologies are addressed under the Energy Research Programme. Germany is also represented at international level in the IEA technology collaboration programmes, Energy in Buildings and Communities and Solar Heating and Cooling and also takes part under Mission Innovation in the Affordable Heating and Cooling of Buildings Innovation Challenge.

4.1.2 Industry, commerce, trade and services

Energy-sector relevance and strategic goals of R&D funding

Alongside transport and households, the industry, commerce, trade and services (ICTS) sectors have long been the largest energy consumers in Germany. Energy consumption is, however, on the decline. Industry accounts for about 30% of final energy consumption in Germany, two-thirds of which in the form of process heat. Besides the industrial focus on highly specialised materials and processes, the main reasons for this are innovative technological developments in industrial energy efficiency, which can only be achieved with ongoing research and development. It is therefore a crucial instrument for keeping industry and commerce competitive, also in the long term.

When identifying effective measures for reducing energy demand, account also needs to be taken of the way these sectors are organised. In energy-intensive sectors, a few individual plants have a large impact on the energy balance. Broad sections of the business landscape in Germany are, however, made up of small and medium-sized enterprises (SMEs), each of which only makes a small contribution to the energy balance and also has limited research capabilities at its disposal. The job of research funding is therefore to expedite initiatives for the requisite technological developments by assisting particularly innovative and enterprising companies – supported by top-calibre research institutions. Networking sectors can ensure that the findings gained are disseminated and implemented on a broad basis.

After petroleum, coal and gas, electricity is the most important source of energy in the ICTS sectors and its share in the industrial energy mix is successively growing, due to the substitution of fossil fuels for supplying thermal and mechanical energy, but electricity demand is also rising due to the progressive automation and digitisation of industrial processes. Over the last few decades, the ratio of on-site generators in industry to total power supply has been on the decline and increasingly replaced by external supply from public power-stations and renewable energy input.

These developments are the response of industry to alterations in power supply. In connection with the long-term changes in the electricity mix, the industrial carbon footprint will be improved by reducing fossil fuel use. At the same time, this poses new challenges, such as the flexible use of volatile electricity input from renewables. The key to meeting the climate targets in industry and commerce lies, however, in raising energy efficiency across the whole range of issues, taking account of the energy balance along the entire lifecycle of products – from raw material extraction to processing, manufacturing and energy consumption during service life up to subsequent disposal or recycling. Far greater use of renewables is also expected in the production of process heat.

Partly for commercial reasons, many measures to raise energy efficiency have already been carried out in the industry and commerce sectors. So far, it has been possible to partly offset higher costs due to stricter environmental requirements, higher energy prices or also specific customer demands through energy-efficiency measures and the integration of renewable energies. Additional potential for efficiency gains can be harnessed by enlarging the scope of activities from isolated individual processes to include inter-technology efficiency strategies and also directing attention to increasing the flexibility of the energy system.

The rapid expansion of computer and data capacities over recent decades and the resulting miniaturisation, modularisation and lower prices have made information technology into an effective development instrument. Initially in separate applications (as an offline instrument), this expedited research along tried and tested paths. Brand new possibilities were also added, such as in combination with simulation or additive manufacturing. With the advent of the systematic data networking of electronic components in recent years, digitisation (also online) has entered the world of process control and rationalisation and given fresh impetus to energy saving and responsiveness. The attendant increase in linkage and mutual dependencies, however, places the responsibility on digitisation in industry and commerce for ensuring the reliability and security of processes and ruling out adverse effects, including the instability of the energy system.

Achieving the envisaged transformation towards low-carbon industrial processes as part of the energy transition calls for extensive research and technological development. Research funding will contribute to mitigating the associated economic risks. The increased know-how can permanently enhance the position of local industry on international markets.

Research will pursue the following programmatic goals for this:

- Intersectoral reduction of energy input with innovative and efficient processes and process technologies
- Rationalisation of sectoral energy efficiency in current industrial processes
- Efficient use of secondary forms of energy and substitution of fossil fuels with renewables
- Consistent harnessing of energy-efficiency potential in industrial cross-cutting technologies, flexibilisation of industrial processes for their integration into the energy system

Strategically important R&D topics

In the industry and commerce sectors, greenhouse gas emissions due to energy use and processes can be abated in all kinds of ways (e.g. through higher efficiency). Promising research initiatives already underway can bring about innovations in energy-intensive sectors, but can also have large, broad impacts by harnessing aggregate smaller-scale efficiency potential. Energy research looks at both the energy-efficient redesign of pre-established processes and the development of new materials and related manufacturing methods. These must, however, serve the foremost purpose of meeting the target of extensive greenhouse-gas neutrality by 2050.

Energy-intensive primary industries

Industrial sectors with high energy throughput, such as steel and iron, building materials, glass, chemicals and paper manufacture, have an inherent, keen, commercial self-interest in planning their processes for energy efficiency. More research is needed for long-term demonstration projects with a signal effect for subsequent pilot facilities, but their implementation entails considerable R&D risks due to the requisite plant size.

Proceeding from large-scale processes, the chemicals industry has gone over to harnessing energy efficiency in processes with diminishing material throughput. Major concerns for the future are the modularisation of plants and processes, the substitution of batch with continuous modes of production and shortening process chains. As the basic chemicals industry has been largely based so far on fossil resources – crude oil and natural gas – the technical resource base must in future shift to renewable sources. Along with the renewable synthesis of major raw materials, the requisite power-to-chemicals process will afford additional prospects for industrial energy storage (see Section 4.3.3).

Thanks to increased electricity from renewable sources, the electrification of industry, especially in process heat supply, can prove to be an effective measure for CO_2 avoidance. The associated adjustments call for more research activities to maintain process quality and reliability. Current technical capabilities for flexibilisation in industry must be upgraded for this so as to be able to respond to frequent or rapid load variations in the power grid and thus integrate industrial plants into the energy system for grid support. Investigations must also be conducted here on the interaction between frequent, rapid load fluctuations and the repercussions on installations and critical components.

Specific industry measures over a broad cross-section of the industry and commerce sectors

Besides large-scale industrial consumers, the second pillar of industrial energy efficiency consists in the broad cross-section of the sectors (especially SMEs). Due to the many actors, e.g. in the SME segment, there is an equally large number of different technologies and applications. They will be assisted by a technology-neutral funding research policy that actively addresses research needs and context and combines these into strategic thematic clusters. Whereas individual processes have been the object of efficiency research in the past, the present trend is now directed towards looking at process interrelations to harness additional efficiency potential. Some examples of relevant topics are listed below:

Current complex research questions in the thematic cluster of manufacturing technology will be solved by an interdisciplinary interaction among the relevant fields of expertise, such as mechanical engineering, lightweight construction and additive manufacturing, electrical engineering, information technology and business management.

As a prototype in energy technology, high-temperature superconductivity (HTSC) has proven that compared with conventional methods energy performance advantages can be gained both in industrial high-current applications and with components in the power grid, without having to sacrifice reliability. In addition to optimal and replicable HTSC conductor manufacturing processes, a multi-year demonstration and evaluation of the main operational features are needed for future market development.

Research and development for new climate-friendly and resource-efficient processes will play a pivotal role for preparing energy-intensive industries, such as steel and chemicals, for future climate protection requirements and preserve their competitiveness in the process. There is large innovation potential in the smart combination of processes, such as using metallurgical gases in steel production as raw material for the chemicals industry. As an alternative to using exhaust gases, hydrogen generated from renewable energies can be applied in (the steel) industry to avoid CO_2 emissions.

Another ambitious goal on the way towards a low-carbon industrial sector is the establishment of a sustainable circular economy. Besides planned waste avoidance, energy research will focus on the reusability of valuable waste materials, installations, components and appliances, especially converting waste flows into recyclable materials, because these require a multiplicity of energy-intensive processes today. Taking an integral energy-efficiency approach to all material flows aimed at higher industrial recycling rates, the necessary chemical, physical and material properties should be investigated and standardised for subsequent industrial use (see Section 4.4.3). These investigations will also include the energy-efficient treatment of raw water and as well as industrial and municipal wastewater.

Cross-cutting topics

Many project topics reappear in connection with applications in various industries or in processes of various scales. The aim of efficient research organisation is to amalgamate these into cross-cutting issues. Examples of cross-cutting topics are listed below:

Companies already make use of the possibilities provided by digitisation processes today. The highly individualised solutions developed have been identified as constraints on their widespread application. Especially due its affinity with mathematics and the abstract description of reality, information technology should be particularly suitable for providing general and broadly applicable solutions. Specific applications must be demonstrated on a broad basis and their technical and commercial advantages communicated in model projects to support their broad dissemination in the business landscape. Developing methodological competency in smaller enterprises as well will be a major development goal here.

Mechanical friction incurs energy losses in all moving parts and causes secondary energy consumption due to wear and tear. Involving close cooperation between basic physical-chemical research and the heavily application-driven development of materials and lubricants, the discipline of tribology is indicative of the increasing complexity and inter-industry networking in energy research.

Due to the multitude of sectors and processes involved, there are still hardly any overarching concepts in industrial process heat. Research therefore needs to find individual ways to reduce the requisite thermal energy while retaining product quality. Environment-friendly heat can also be supplied through solar energy or, to a limited extent, biomass. For higher temperatures, methods for integrating electricity and biomass and the utilisation of waste heat need to be upgraded. Alongside direct use via heat pumps, heating networks and heat storage in other processes, research will also look at conversion into electrical energy.

Organisation of R&D funding

This field of research addresses a diverse target group: from large-scale enterprises and SMEs to heavy industry and companies with moderate consumption to research institutions and engineering firms. It is important and expedient for project funding to address this multiplicity, because on the one hand financial assistance must be accessible to all research topics and on the other because similar questions can, however, recur at various scales and answers can be efficiently found through collaborative research. This will lay the foundation for initiatives and solutions with prospects for broad, practical application.

Manufacturing processes have already adapted in response to previous transformations of energy supply. For the energy transition in industry, however, there is still a need to demonstrate completed research and development findings in the pre-competitive phase. Unconventional, viable concepts for the future can be tried out in innovation spaces. To attain the energy transition goals, it is especially important to subsequently compile and apply the findings gained in an assisted company so that as many additional applications as possible are taken up in and outside the sector. Particular assistance will be given to transferring results as part of model projects based on a regional or sectoral structure.

Demonstration projects document for the first time the feasibility of new process designs on a large industrial scale. These are very important for taking the next step towards the commercialisation of new technologies, because upscaling usually necessitates renewed developments in production, special construction and installation. With their flagship effect, best-practice projects can publicise the findings and accelerate the market penetration of new high-efficiency technologies and processes. The analysis of commercial, legal and economic barriers and constraints for demand responsiveness will play a special role in demand response. Innovative ideas whose implementation requires regulatory reforms can possibly be tried out in systemically designed living labs (see Section 3.1). Civil society should be involved (e.g. via stakeholder dialogues) to raise awareness and gain social acceptance for demand responsiveness.

Besides research, development and demonstration projects, funding will be made available for near-market model projects for energy efficiency and renewable heat in industry and commerce assisted by accompanying scientific research projects. These will address the translation of research findings on innovative technologies and processes into operational practice. Through their flagship function as innovative best-practice projects, they will speed up the propagation and market penetration of high-efficiency technologies.

Accompanying scientific research projects evaluate the work programmes and outcomes of research, demonstration and model projects to be able to take rapid advantage of innovation opportunities. Based on analyses, courses of action will be recommended for targeted R&D and diffusion activities. Besides identifying major innovations, possibilities need to be investigated for transferring technologies to other fields of application.

The Energy Research Network Industry and Commerce was established in ICTS research to enable specific, needs-based research and keep funding measures efficient. In research fields on selected key or overarching topics, research activities are combined into long-term clusters. Each research field identifies relevant gaps and ranks these in order of priority, conducts coordinated research to gain additional findings and prepares these for translation into practice. The research network, however, also takes account of innovative, isolated individual topics that are not assigned to a defined key cluster, owing to the broad diversification and narrow specialisation in high-tech sectors. The overarching networking of various branches of industry is of special importance, as most key topics from individual fields of research affect many other fields of research, whose potential can only be fully harnessed through overarching cooperation.

4.1.3 Interfaces of energy research with mobility and transport

Energy-sector relevance and strategic goals of R&D funding

As transport accounts for 29% of final energy consumption in Germany, energy research focuses on the interfaces between the power and transport sectors as well. As part of sector coupling, for example, electricity from renewable energy sources can also be put to use in this sector, either directly, e.g. with battery electric mobility, or indirectly by producing synthetic fuels. This is why account must be taken of the repercussions of these developments in the transport system on the energy system. Trends in electromobility (and autonomous driving), for example, need to be catered for in the technological and conceptual development of distribution grids, but also when drawing up energy plans for neighbourhoods. The digitisation and networking of actors and innovative, multimodal mobility schemes and climate-friendly user behaviour and planning in the neighbourhood can contribute to rationalising overall energy consumption and facilitating progress in the electrification of transport. There are additional interfaces, for example, in bioenergy as a system integrator or in issues of transporting chemical energy sources for storing renewable energies. Research funding under the 7th Energy Research Programme will therefore engage at these interfaces and promote research and development in the energy system in line with developments in the transport sector. Programme measures with a direct bearing on mobility and transport will be closely coordinated with the Ministry of Transport to avoid overlaps and harness synergies. Energy research will take account of relevant outcomes from transport research activities under other federal programmes.

The mobility and transport sector is currently undergoing very rapid development. Digitisation and electrification and also sharing economy schemes will have an enormous influence on future mobility. Carsharing, autonomous and connected driving, intermodal travel routes, also including electric scooters and electrical bicycles, for instance, are just some examples of this trend. Their impacts on the energy system can hardly be estimated at present. Overall, the trend appears to be moving in the direction of greater transportation needs. Whether this will entail increased energy consumption depends on the development of energy efficiency in the overall system. The progressive electrification of the transport sector affords opportunities and poses challenges for the energy sector. As an efficiency technology, electromobility makes up a component of sustainable mobility and takes full advantage of its environmental and climate benefit in its use of renewable electricity. In addition, the vehicle-to-grid charging and discharging of battery vehicles can contribute to stabilising the power grid. Electromobility, however, places additional demands on the responsiveness of the energy system and resource efficiency. Renewed efforts will therefore also be needed in battery research for the long-term success of electromobility. Fuel cells also form part of electromobility.

As an alternative, new kinds of improved fuels (e.g. biofuels from waste substances and residues, fuels from renewable electrical energy, or solar fuels) can integrate renewables into the existing and expanding infrastructure (petrol stations, combustion engines). High standards will have to be placed here on the sustainability and the economic efficiency of production and supply. Synthetic fuels should be produced with renewable electricity (power-to-fuel) in installations that allow for system-supportive operation or do not affect the domestic power system (production of fuel from power abroad for reasons of cost).

The solar production (artificial photosynthesis) of chemical energy carriers (solar fuels) and other valuable substances from the practically unlimited resources of sunlight, water and constituents of air (CO_2 or nitrogen) can make major contributions in the medium term to the global energy transition and climate protection. This will afford Germany opportunities for the seasonal storage of renewable energies, supplying material and energy to the chemicals and primary industries, exporting high-quality plant technology and importing solar fuels and other valuable substances from regions with higher solar irradiation (particularly desert regions). Additional innovations and technological progress will be needed to grasp these opportunities. Closer coordination must be sought between basic research with broad thematic scope and industrial research.

Supplying drive power from alternative fuels requires far more renewable energy than direct use in an electromotor. The poorer energy efficiency needs to be considered, however, with regard to the superior storability of chemical energy carriers. Added to this is the global transportability and possibly lower overall system costs, because battery electric drives for aircraft or vessels, which have to take on board operating energy for thousands of kilometres, are technically hardly feasible. The respective ratios of synthetic fuels and battery electric mobility in the energy system of the future cannot be estimated today. The 7th Energy Research Programme therefore addresses both the production and use of alternative fuels and research and development on batteries and fuel cells for supplying operating power. Considerable research efforts are needed for all the technological options at the interface between the energy and transport sectors.

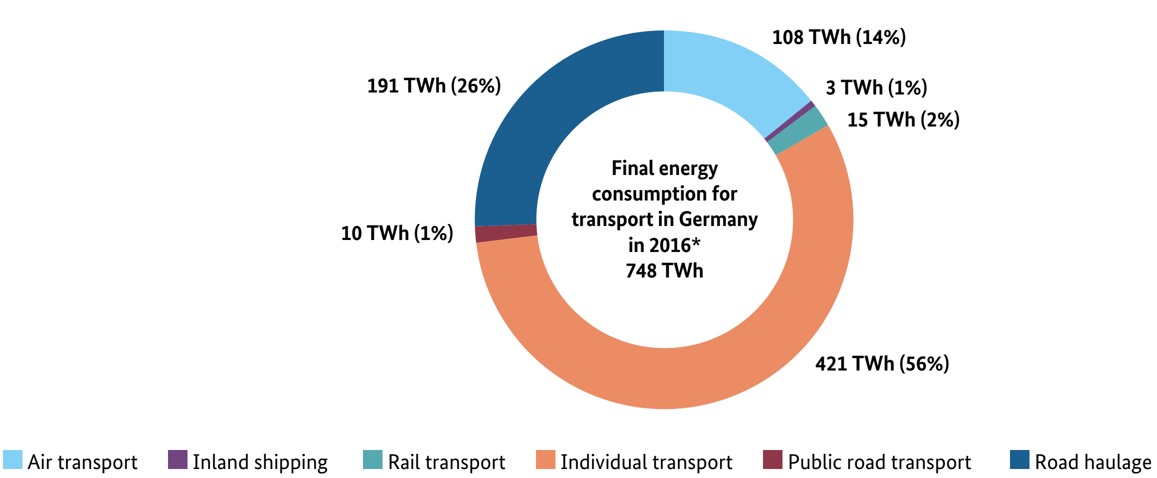
Strategically important R&D topics

In the energy economy, innovative storage systems, such as batteries, and their efficient assimilation into the energy system make up crucial components for the success of electromobility and its integration into the energy transition. For sustainable battery electric electromobility, research needs to look at the value chain from raw materials to the production and use to the reuse and recycling of batteries. The biggest challenge for batteries in electric vehicles is being able to cover longer distances and charge faster. The requisite technological developments have already been made in the conceptual design and production of battery cells. Greater importance is being attached to the expansion of recharging infrastructure with the related charging and load management technology. Added to this are smart battery management systems (BMS) in electric vehicles, power electronics, various charging technologies (e.g. inductive, i.e. wireless charging), progressive grid-supportive and battery-saving charging strategies and user-friendly access to charging facilities for electric and hybrid vehicles. Research and development in electromobility focuses on adapting road transport to sustainable energy supply, but other fields of application (e.g. agricultural machinery, commercial vehicles, vessels, aircraft, delivery drones) should also be taken into account.

Compared with battery vehicles, fuel cell vehicles can run over longer distances and be refuelled more quickly. The integration of fuel cells in mobile applications will concentrate on the operational management of the complete system including frost ignition, lifespan, efficiency and maintenance. Hybrid systems consisting of fuel cells, batteries and combustion engines will be developed for specific applications. A major prerequisite for commercialisation is setting up a nationwide infrastructure with hydrogen filling stations. The National Innovation Programme Hydrogen and Fuel Cell Technology supports investments for setting up a filling station infrastructure. Research will look at the related issues in the production, storage and transportation of hydrogen in connection with sector coupling.

In many cases, alternative fuel production requires the electrolytic production of hydrogen, but biogenic and solar generation pathways are also possible. A sustainable carbon source is needed for the production of most alternative fuels. Besides direct CO_2 capture from the air, various point sources can be considered. This gives rise to interfaces with

Figure 9: Final energy consumption for transport in Germany in 2016*



* preliminary data

Source: BMVI Statistical Handbook: Transport in figures, 2017/2018

Data exclude short sea shipping, because these were not compiled separately from the rest of maritime shipping; rail transport comprises inland sales for rail, underground and tramway transport; individual transport comprises road transport of persons with cars, motorcycles, mopeds, small mopeds and mokicks; public passenger transport is made up of road transport with coaches and buses; freight transport comprises road transport with heavy goods vehicles, articulated lorries and tractors, including other motor vehicles; inland shipping encompasses transport including port and coastal shipping.

forestry and agriculture and solid waste management (biomass as well as biogenic residues and waste substances for biofuels, use of CO_2 from biogas facilities, use of alternative fuels in agricultural machinery) and industry (use of CO_2 from industrial processes, application of alternative gases, including biomethane for CHPs and high-temperature heating processes). The different generation pathways should be subjected to technological-economic assessments, accounting for the lifecycle and entire value chain, particularly also for biofuels. Regulatory and social acceptance issues will have to be clarified when introducing alternative drive designs and fuels.

Artificial photosynthesis denotes the production of chemical energy carriers or other valuable substances using sunlight as the sole or main energy source. This encompasses many processes with different Technology Readiness Levels. Examples of relevant basic research topics are the development of biologically inspired light absorbers and highly effective catalysts, the genetic manipulation of bacteria and algae for the direct production of solar fuels and other valuable substances or the development of highly-integrated, photo-electrochemical cells based on semiconductors. The thematic diversity is very broad in basic research, which also makes sense with a view to the possible development of disruptive innovations. Artificial photosynthesis is no longer just a basic research issue. The indirect coupling of photovoltaics and electrolysis installations is already in the process of industrial development, for example. Thermochemical processes, certain bioreactors or some photo-electrochemical cells could attain market maturity in the medium term and are therefore relevant topics for industrial energy research.

Alongside research on individual questions to do with specific technologies, attention must be paid to the good scalability of developed technologies (in the terawatt range in 2050, for instance) as early on as possible. A short energy payback time is conducive to scalability. The materials used should be abundant and non-toxic. Recyclability must be applied as an important criterion in device development (see Section 4.4.3).

Organisation of R&D funding

Research at the interface between energy and transport technologies encompasses a broad thematic spectrum, ranging from the development of batteries and fuel cells to the biogenic and solar production of alternative fuels to electric-based processes. The 7th Energy Research Programme will also deal with the technological development needs of this interface in the research fields of buildings and neighbourhoods (see Section 4.1.1), bioenergy (see Section 4.2.3), power grids (see Section 4.3.1), electricity storage (see Section 4.3.2) and sector coupling as a major focus (see Section 4.3.3).

Investigating and testing production pathways for alternative fuels on an industrial scale, trying these fuels out in field tests and the pilot installation of an energy infrastructure will call for extensive research work. Connecting the conversion plants to the power grid will accord these a systemic role and make them eligible as a possible topic for energy-transition living labs (see Section 3.1). Energy and transport research must collaborate closely here.

The accompanying scientific research project for the funding initiative, Energy transition in the transport sector, will make a major contribution to results transfer. Based on research findings in the energy and transport sciences, it will draw up overriding trend analyses and strategies for future development to be able to respond even more precisely to research needs in future.

In many places throughout the world, intensive R&D work is being done on electromobility, including hydrogen and fuel cell technology as well the as solar, biogenic or electricity-based production of fuels. The SET-Plan and the EU funding programme, *Horizon 2020*, and its sequel, *Horizon Europe 2021 – 2027*, will in part pursue the goal of establishing battery cell production in Europe (TWG 7 on the battery sector, European Battery Alliance). European collaborations make sense for exchange and risk sharing in development needs for storage and stationary and mobile applications. There is a very pressing need for international cooperation in standardisation and interfaces.

The Converting Sunlight Innovation Challenge launched as part of Mission Innovation focuses on the issue of artificial photosynthesis. Owing to the global aspects inherent in this thematic cluster, this international collaboration is a priority of research funding *(Berlin Model)*. Cooperation with regions in the Global South can also be addressed as part of projects for scientific-technical collaboration (see Section 6.1.). At national level, networking and results transfer in this area will be stepped up under the auspices of the Energy Research Networks.

4.2 Power generation

4.2.1 Photovoltaics

Energy-sector relevance and strategic goals of R&D funding

In photovoltaics (PV), the sun's rays are directly converted to electrical energy using solar cells. Semiconducting materials are used here. Silicon is mainly used for this today, however, other materials are also used such as compound semiconductors or inorganic and organic thin-film systems. Photovoltaics help to reduce greenhouse gas emissions as they offer emissions-free technology, at least during their operation (no noise pollution, unpleasant odours, or harmful emissions). Thanks to their scalable, modular design, PV systems range in size from small plants to large power plants and can be flexibly deployed. They require little maintenance and, by being easily adapted to a very wide range of operating conditions, form a key component of the energy transition.

The goal of the Federal Government is to design energy production in a way that is secure, economical and environmentally sustainable, thereby making it as reliable as possible. Current studies have shown that the balanced use of photovoltaics and wind power is ideally suited to achieving this. Network variability caused by shifts in local solar radiation and wind speed is lessened by combining both technologies. These two sustainable technologies are therefore considered to be core elements of the energy transition. Photovoltaics are characterised by broad added value from the extraction and treatment of the raw materials and auxiliaries through the production of resources and components to installation, plant operation (incl. contracting or tenants' power models), network and storage aspects as well as recycling options. In this context, there is a wide range of possibilities for startups as well.

Since the 2000s, the photovoltaic market has been growing at an average rate of over 30% a year. An estimated 100 GW is expected to be added in 2018. Germany accounts for a large share of this growth with its leadership position in research and industrial implementation and rollout. The continuous development of production technology has been a major factor in reducing the cost of solar power in Germany from 50 cent/kWh in 2000 to below 6 cent/kWh today.

Ongoing research work is essential in order to consistently build on this high product quality while also developing advanced and innovative technologies and production techniques, and preserving the breadth of national added value, against a background of stiff international competition. The strategic goals of R&D funding must be adjusted to the dynamic and competitive environment and target the following aspects:

A competitive photovoltaics industry and a successful worldwide energy transition requires exploiting cost-saving potential across the entire value chain, while improving product quality. This means continuously improving efficiency and productivity, reducing the resources and space used, extending the service life and providing simpler recovery after use.

One of the main tasks here is to develop new materials and technologies until they are ready for production, while verifying their cost efficiency. In tandem with this, it is necessary to allow the development of industrial-capacity production (from the raw material through the solar cell and module up to the system) in order to exploit economies of scale, while taking account of resource efficiency and environmental sustainability.

Furthermore, various applications require tailored product solutions such as building-integrated photovoltaics (BIPV). In the long-term, these markets will make a greater contribution to the success of the energy transition because they offer huge potential for sector coupling with other disciplines such as building technology (including photovoltaic thermal collectors) or mobility. They make demands on the technology above and beyond a simple focus on electricity generation. There is also a continuing focus on the integration of photovoltaics into energy systems while preserving the quality of supply.

Strategically important R&D topics

Based on these strategic goals the following topics for funding can be identified:

- Photovoltaics engineering in Europe supplies an international group of customers with competitive industrial production facilities and highly-efficient processes such as laser processes or role-to-role techniques. Domestic companies need to continuously innovate to set themselves apart from the international competition in order to quickly achieve cost-savings potential by making technological developments to boost efficiency. Plant layout and service quality need to be improved through process controls, logistics and automation concepts. This can be achieved by using comprehensive monitoring, analysis and forecast technology through digitisation ('big data' analysis) and automation, as well as through self-monitoring and self-managing factories (Industry 4.0).

- Reliable energy supply also requires improving service life and quality assurance measures at the system level. This includes analyses of degradation mechanisms and the associated development of adjusted measurement and simulation techniques, as well as aspects of automated system maintenance.

- Further improvements in the economic viability are critical for the acceptance and industrial application of new technologies. Pilot trials with pre-industrial demonstration plants are therefore very important for the further development of processes from material to module, as well as for the associated process equipment. This requires a suitable industrial development platform.

- New photovoltaic materials are different from established technologies in terms of their manufacture and processing. For the most part, they can be flexibly produced and are cost-efficient in terms of their use of materials, manufacture and processing. However, some technologies still have shortcomings in terms of their service life or efficiency and therefore have different application areas than the familiar technologies. Their benefits for these specific applications, and their advantages, must be easily identifiable. For example, concepts for developing highly-efficient tandem solar cells based on crystalline silicon (e.g., in combination with perovskite semiconductors) or thin-film solar cells allow for further improvements in efficiency. Innovations that can be integrated into existing production techniques are particularly interesting.

- To cover energy consumption with regenerative energy, the integration into buildings of photovoltaic modules (BIPV) by incorporating innovative process technology with attractive architectural designs has huge significance for energy policy. BIPV is leading the way for related, tailored product solutions in other application areas such as vehicle-integrated photovoltaics (VIPV).

- At the system level, even closer coordination with grid operators is required when developing new markets. With respect to the photovoltaic system itself, there is a need for R&D in the photovoltaic yield forecast to reduce investment risk and safeguard electricity supply. This also affects new management and control systems. Account must be taken here of network repercussions and influence. This underlines that additional developments are required in systems technology by establishing a new generation of large photovoltaic power plants with network-friendly attributes for the grid. In addition to this, research will continue on an environmentally-friendly and secure electricity supply for microgrids (off-grid systems) and on additional areas of security of supply. The development of systems technology should also address the growing land-use conflicts as photovoltaic generation capacity is expanded further. For example, plant manufacturers and installers in this area can use innovations to increase domestic value-added, develop attractive solutions for export and help to strengthen the high level of acceptance of PV installation.

- Materials that are hazardous to health or the environment must be avoided during manufacturing as far as possible. Scarce resources must be conserved. Careful recycling after use makes photovoltaic systems more sustainable. At the same time, accompanying tests must be conducted to look at socioeconomic aspects as well as lifecycle analyses.

Organisation of R&D funding

The primary R&D need is in industry-oriented research with rapid economic implementation, preferably through joint research projects involving collaboration between companies (the photovoltaics industry, material and device manufacturers, photovoltaic systems technology providers), research institutions and universities. The Research Network Renewable Energies – Photovoltaics seeks to ensure the integration of the various actors and the successful transfer of research results. With regard to building-integrated photovoltaics and the integration of photovoltaics into the energy system, this will take place in conjunction with the ENERGIEWENDEBAUEN and Power Grids research networks.

Research funding will be considered for energy transition field testing to develop process facilities on an industrial scale.

The application of research funding in the photovoltaics area is tailored to activities in a European context, particularly with respect to the European Strategic Energy Technology Plan (SET-Plan) to strengthen European national economies by leveraging synergies. This provides for a 35% increase in efficiency in the established technologies by 2030 relative to 2015. The costs of key technologies are to be reduced by 50%, while products' service life and sustainability will be significantly improved. Furthermore, concepts for reducing installation costs and economies of scale in production will contribute to establishing strong renewed solar module production in and for Europe. Also in order to achieve the "zero-energy building", photovoltaics are expected to play a decisive role with regard to energy performance, cost reduction and aesthetics. In order to implement these goals, the prioritisation for the SET-Plan implementation plan will be taken into account for photovoltaics. Common strategic projects were defined in this plan: "PV for BIPV and similar applications", "Technologies for silicon solar cells and modules with higher quality", "New Technologies & Materials", "Operation and diagnosis of photovoltaic plants", "Manufacturing technologies" and "Cross-sectoral research at lower Technology Readiness Level (TRL)". Closer European research cooperation will be achieved, among other things, by participating in the European Research Area (ERA) – net activities and bilateral cooperation initiatives under the *Berlin Model*. The European cooperation initiatives are supplemented by a targeted exchange in the Technology Collaboration Programme of the International Energy Agency (IEA) on photovoltaic systems (PVPS).

4.2.2 Wind power

Energy-sector relevance and strategic goals of R&D funding

Wind power produced more than 105 terawatt hours of electricity in 2017 with an installed output of over 56 gigawatts (GW), which corresponds to an average output of around 12 GW[3]. Wind therefore accounted for over 16% of

3 The ratio between installed performance and average performance is described as the utilisation ratio.

Germany's gross electricity generation. The significantly higher capacity factor for offshore wind turbines means that plants installed in the North Sea and in the Baltic Sea contributed to over 17% of the energy, even though they only represent barely 10% of the installed output (5.4 GW). Tender outcomes for future wind power plants are trending towards falling levelised costs of electricity. The new and anticipated generations of turbines are showing a strong trend towards an increased capacity factor.

Since wind power has very low specific carbon dioxide emissions, with five to eight grams per kilowatt hour, it can make a particularly large contribution towards the Federal Government's goal of achieving a 55% reduction in emissions by 2030 compared with 1990 levels. This is another reason why a huge further expansion in wind power is required: new electrical applications such as 'electromobility' or heat pumps will bring additional electricity demand. The only way to meet this demand while achieving the greenhouse gas reductions sought is by using renewable energy.

In addition to the targets for reducing greenhouse gases, the wind sector is an important employer thanks to its strong competitive position and large share of exports. Furthermore, due to logistical challenges it is often based in economically underdeveloped regions. For example, knowledge gained in shipyards about the construction of major maritime structures can also be transferred to the production of offshore wind power plants. In the construction phase and, in particular, in the operational phase as well, wind power offers reliable jobs, providing new employment opportunities for a lot of people who are affected by the structural shift (see Cuxhaven Appeal 2.0, 2017)[4].

In order to continue to fulfil the triple energy policy imperative of reliable, affordable and environmentally friendly energy supply into the future, wind power needs to be expanded in a cost-effective, environmentally friendly way that is supported by the vast majority of the population. In the future, research funding will therefore continue to focus on contributions towards reducing costs and making wind power more reliable. This funding is intended to help to provide future plants that are even more powerful and reliable and that have a higher capacity factor. This will allow electricity to be provided at competitive prices, even in places that have been difficult to date. The acceptance of the addition of more capacity will be supported by appropriate participation processes and innovative technical solutions. The expectations of the broadest possible range of actors from the area of wind power in the consultation process on the 7th Energy Research Programme will only be met if there is ongoing research that is both high-level and broad-based. This can also be undertaken as part of an offshore test site, for instance. In the future, holistic considerations will play an even greater role in wind power research, particularly to avoid conflict between different interests, for example by ensuring the safety of aviation and maritime shipping.

Strategically important R&D topics

Overall, Germany still has sufficient onshore and offshore space available to further expand its wind power. However, it is becoming harder to find windy onshore sites that are easy to develop, which means that capacity increasingly has to be added on complex terrain. It is therefore essential that suitable methods be used to select good potential sites and that the sites then be investigated over an extended period of time using methods that are as inexpensive as possible. Improved algorithms can help here, as can cheaper investigative methods that render measuring masts redundant. With margins likely to fall, a careful farm layout is necessary – not only for future repowering projects – based on site data that has been harvested in the past, for example. The layout should take into account the extent to which the farm can show performance that supports the system. The energy yield, which was previously the primary focus, is thus supplemented with additional considerations. Onshore and offshore test sites can make important contributions here.

Since more and more wind turbines will face demolition in the future and the volume of materials that flow into wind power is consistently large, questions about demolition and reusability also need to be addressed. Ideally, materials for future generations of plants have already been chosen so that they can easily be recovered to a high standard. Lifecycle analyses allow the optimal balance to be continuously struck between the best possible reusability and robust, reliable plant design, in line with the latest technology.

4 The document is available online: https://www.mw.niedersachsen.de/download/122456/Cuxhavener_Appell_2.0_im_Wortlaut.pdf

In addition, there is an ongoing need for specific new developments and enhancements for all components, from the foundations to the blade tip. It is beyond dispute that only a holistic view allows for increased reliability and thereby also a reduction in the cost of the overall wind turbine system. For example, durable converters that can also assume tasks in support of the network are just as necessary as developments to reduce the performance-specific weight in the drivetrain – for instance by using new or improved materials or new generator/drive concepts. This allows the increase in the nacelle mass due to the increase in size to be attenuated. Thanks to the reduction in materials used, this leads to an increase in efficiency.

Greater reliability and a longer service life can also be achieved by minimising the loads that act on the wind turbine. A better understanding of the incoming wind can allow individual plants to better respond to changes in the wind field. The wake behind a wind turbine or behind a wind farm can give rise to greater loads or reduce yields. Wind farms must therefore be seen as a system. Consequently, research must look at the interplay between individual wind turbines or between wind farms. The rotor itself determines whether, and how efficiently, the wind can be converted to electrical energy. Particular attention will therefore also be paid to this component in future. For example, this will include methods to industrialise production or to reduce noise when a wind turbine is in operation. Noise reduction is not only a particular factor for securing approval for a plant, but also helps to ensure acceptance from local residents. In this context, funding focuses on the development of cheap and reliable technical methods for needs-oriented lighting or for bird- and bat-friendly operation.

In certain cases, such as for unconnected microgrids, small wind power plants can help to allow electricity to be reliably and affordably generated locally. There is thus a need to develop small wind power plants that can work with comparatively low as well as turbulent and fluctuating wind flows. In order to be able to develop sufficient good sites, it is vital to marry wind energy with other interests and public needs such as the protection of nature and the environment, wildlife conservation and aviation needs.

Compared with other sectors, there is relatively little standardisation of components and methods in the wind industry. Greater modularisation and the establishment of standards to reduce costs in many steps across the value chain can help here. This has already happened for installation to a large extent. Nevertheless, improved installation concepts can also make a further contribution to reducing costs here.

Organisation of R&D funding

Since wind power is set to account for an ever-increasing share of electricity generation – with electricity demand likely to rise overall – funding must also continue at a high level and with appropriate structures and content. This is supported through collaboration and exchange between the relevant actors in the Research Network Renewable Energies – Wind. The previous form of funding and associated priorities is to be supplemented with input from members. In the future, targeted cooperation with other research networks will primarily address cross-cutting issues such as the interplay between wind power and electricity grids. New collaborative formats for these disciplines, which have cooperated little in the past, can provide critical support for the continued development of this area of research. One possibility here is to conduct the research in living labs where joint approaches can also be undertaken outside of existing rules.

The expected continued growth in the size of wind turbines, particularly offshore, requires corresponding manufacturing and port facilities. Integration with the strategic goals for the maritime industry is advisable here. This affects existing manufacturing and logistics facilities, or those to be strengthened, for example.

As a cross-cutting task, the digitisation of almost all processes such as manufacturing, construction, operation or grid management offers huge potential to save and efficiently use the resources deployed. These possibilities can be profitably leveraged by interdisciplinary collaboration. The operating data generated by approximately 30,000 wind energy installations should provide further findings.

Close cooperation is also maintained with other countries both within and outside the EU, not least thanks to the strong export focus of plant manufacturers resident in Germany and through the now global supply chains for wind energy installations. This is the only way to efficiently tackle the challenges faced by all countries such as the secure operation of grids with a large share of wind power. In this way, climate- and region-specific solutions (e.g., “cold climate”, particular grid conditions) can also be developed and examined locally. Participation in appropriate IEA tasks will therefore continue and collaboration will be intensified at a European level. The content developed by the Offshore Wind Temporary Working Group in the SET-Plan Implementation Plan can also be implemented as part of the 7th Energy Research Programme with the *Berlin Model*. Among other things, this comprises the areas of operation and maintenance, industrialisation, lifecycle considerations, holistic optimisation and validation of corresponding models and tools, wind-power-specific system integration, mechanical and electrical component design.

4.2.3 Bioenergy

Energy-sector relevance and strategic goals of R&D funding

Biomass will contribute to energy production to a limited extent by 2050, mainly based on the energetic use of biogenic waste and manure, ferment and residual material. Power generation must be almost completely decarbonised by no later than 2050 and, given the pressure on land to produce food, the significance of the contribution that bioenergy from cultivated biomass can make will be limited. In contrast, the use of bioenergy from residual and waste materials will make an increasingly important contribution to cross-sectoral energy supply, thereby tapping the sustainably available potential.

Even today, bioenergy already contributes to climate-friendly power supply in the electricity, heating/cooling and mobility sectors. Around two-thirds of renewable energy in Germany comes from bioenergy. The demand for sources of high-density energy carriers in industry has opened up an application area for bioenergy to substitute fossil energy sources. Bioenergy is also developing its own economic sector. Furthermore, bioenergy is opening up additional areas of activity and sources of income for agriculture and forestry, thereby helping to strengthen rural areas. As far as possible, biogenic resources should only be used to produce energy at the end of a cascade system.

Based on these underlying conditions, the following objectives for research funding can be deduced: for example, bioenergy can support flexible electricity production or storage, offer ancillary services and contribute to the stability of the electricity grid. In the overall energy system of the future, it will assist the expansion of sector coupling and showcase its strengths in the transport sector and as bio-heat in the heating market.

Residual and waste material will increasingly be used to test and validate cheap, efficient, climate-friendly and sustainable bioenergy technologies and process concepts to generate electricity, heating as well as electricity and heating in combination, and also biofuels. Lifecycle analyses for existing technologies and use cases, or those that are in development, are an important focus of research to be able to quantify the contributions of bioenergy use to climate protection. In this context, the question arises as to how and for which applications limited biogenic energy sources can best be used. Where possible, the goal must be to achieve cascading and coupling.

Strategically important R&D topics

An important goal is to improve the system suitability and economy of bioenergy plants for the biochemical and thermo-chemical conversion of biomass by taking measures to improve efficiency and make systems more flexible. The goal here is to develop plant components and increase overall plant efficiency, for instance through coupled electricity and heating production. Further strategic tasks are aimed at new business models and moves towards a circular economy, including the efficient energetic utilization of cheap biogenic residual and waste materials.

In order to integrate bioenergy into the overall energy system, research activities will be undertaken to make bioenergy plants more flexible and more beneficial to the system, while also improving overall efficiency. In addition to the repowering of plants, this will also include a focus on the development of sustainable new and existing business models and ancillary services as well as the realisation of intelligent measurement, management and control technology to link up with other variable and storable energies – for example, using hybrid and multibrid systems. Overall, there is a need to develop cheap, efficient solutions to achieve a sharp reduction in emissions for sustainable bioenergy production.

The varied properties of biomass as either a gaseous, liquid or solid – but always storable and transportable – energy source must be used and further exploited during sector coupling. Due to biological processes in crop production, it is almost impossible to reduce emissions to zero when producing cultivated biomass. In contrast, the largely low-emissions use of bioenergy from residual and waste material will become increasingly important, thereby making an important contribution to cross-sectoral energy supply. In this context, work must continue on the development of flexible and efficient bioenergy plants here for sustainable energy production for electricity, heating and mobility, by taking account of the system integration of such plants and their potential for sector coupling. Examples for this include biomass-based CHP solutions, the interplay of biomass and renewable electricity in power-to-X applications and the provision of high-temperature process heating or cooling in the industrial sector. In addition, significant value is attached to the funding of technologies and systems for bioenergy production and use in order to further reduce greenhouse gas emissions.

In the medium term, biofuels will make an important contribution towards climate goals being reached in the transport area. Even in the years ahead, new drive concepts such as electromobility using batteries or fuel cells will not yet be available nationwide for road traffic or in shipping and aviation. Various research activities will be funded in order to further improve the use of liquid and gaseous biofuels. The extension of the spectrum and the valorisation of additional biogenic residual and waste materials in keeping with a high fuel quality will thus be examined in more detail. To this end, the primary utilisation areas in specific transport sectors must be identified, the production processes and plant components improved with respect to their energy, cost and climate efficiency and their interplay examined in biorefinery concepts, for example.

With respect to the goal of the climate-neutral housing stock, smart supply solutions and more efficient combustion techniques will become ever-more important. We will therefore need to develop high-energy, low-emission and economical optimisations of compact micro-combustion equipment and flexible fuel combustion equipment with biogenic fuels for heating supply for low-energy and passive houses as well as for neighbourhoods. Novel approaches need to be implemented for hybrid and multibrid systems and renewable heating and storage options in combination with bioenergy (see Section 4.1.1).

Integrated bioenergy requires the development of standardised and secure information, communication and control interfaces between the bioenergy plants and other power generation plants to serve the time-related, spatial and economic requirements of the energy supply system.

Cross-cutting aspects such as the ongoing development and application of appropriate measurement techniques and methods, sector-coupled energy system models, long-term strategies, sustainability analyses and lifecycle analyses or the scaling and standardisation of combustibles and fuels will also be funded.

Organisation of R&D funding

In addition to research and development projects, the primary focus is on procedural and process optimisations for demonstrations and pilots and a high level of participation from SMEs, in order to close the gap between research and the market.

As part of the Renewable Raw Materials funding programme, the Federal Government has implemented various research, development and demonstration projects to use renewable raw materials for energy. With the Deutsches Biomasseforschungszentrum (DBFZ) (German Biomass Research Centre), the BMEL (Federal Ministry for Food and Agriculture) has established a cross-departmental research institute. This institute develops technical solutions and concepts for the economically sustainable, ecologically harmless and socially compatible use and integration of biomass. The accompanying research for biomass use to generate energy is currently also performed by the DBFZ. You can find further information at *energetische-biomassenutzung.de*. The Research Network Bioenergy groups together the interchange of experience between science, industry and politics and develops recommended actions on the electricity market, heating market and transport.

Bioenergy research joins up with the Strategic Energy-Technology Plan (SET-Plan) and the Bioenergy and Renewable Fuels for Sustainable Transport (Bioenergie und Erneuerbare Kraftstoffe für einen nachhaltigen Transport) implementation plan (Action 8). It complements the EU's strategic targets in the area of research and innovation and funds the expansion of bioenergy in the electricity and heating market and in the transport sector. This seeks to achieve progress in terms of efficiency, a reduction in costs and ecological sustainability. It supplements the research funding of the European Commission in the fields of bioenergy in the "*Horizon 2020*" programme and in the follow-up programme "*Horizon Europe 2021 – 2027*". At the national level, bioenergy research is influenced, among other things, by the sustainability strategy, the biomass action plan, the bioeconomy research strategy and policy strategy, the charters for wood and by forestry strategy.

4.2.4 Geothermal

Energy-sector relevance and strategic goals of R&D funding

Various technologies can be used to exploit the earth's natural warmth to generate electricity and heating depending on the depth, geology and purpose. Ground-coupled heat pump systems are used where heating is exclusively being used for buildings. At neighbourhood level, underground boreholes are combined with heat exchangers or heat pumps and distribution networks. Germany needs deep boreholes for geothermal electricity generation and large-scale heating supply in order to reach sufficiently high-temperatures and heating flows to operate power plants and heating plants.

With the aid of research funding, numerous geothermal-specific technical problems relating to exploration, the operation of geothermal power plants (see also Section 4.2.6) and geothermal heating supply have been solved. Around 40 megawatts of electricity output has already been installed and heating utilisation has been expanded. Compared with electricity generation, geothermal heating utilisation has already been able to show its economic competitiveness compared with conventional heating generation. In the future, geothermal will therefore be able to substitute fossil fuels and make an important contribution to the energy transition and to CO_2 emissions reductions.

Since more than 50% of primary energy in Germany is used to generate heating, the expansion of geothermal heating and cooling production is a key strategic target to supply energy in the future that is ultra-efficient and based on renewable energy. The increasing use of geothermal as a local energy source also reduces dependence on fuel imports and promotes added value domestically.

For broad market penetration it is important to minimise the risks associated with the use of geothermal and to increase public acceptance through transparent communication of the opportunities and risks based on scientific findings. In addition, energy production costs must be reduced and geothermal storage applications expanded.

Strategically important R&D topics

R&D funding focuses on the following topics:

- Demonstration projects that implement innovative technological solutions that are easily transferable,
- The continued development of the technology under the aspects of cost reduction, increased efficiency, plant availability, automation and digitisation of geothermal in the electricity and heating area,
- Further development of heating and cooling storage underground,
- Development of the geological database for potential geothermal uses,
- Security aspects of methods and use cases,
- Research on the material use of extracted geothermal liquids,
- Modelling and simulation of geothermal systems to increase forecasting reliability and minimise financial risk.

Organisation of R&D funding

In addition to research institutions and companies, users such as energy suppliers and municipal utilities, in particular, will also be funded. Application-oriented research topics are to be accompanied here by targeted demonstration projects. The actors exchange knowledge in the Energy

Research Networks, particularly in the Research Network ENERGIEWENDEBAUEN due to the strong relationship with heating supply. In the future, the incorporation of users will become even more visible. Users are particularly well placed to carry the knowledge transfer into widespread use and to provide important feedback to researchers.

The Federal Government also supports international R&D cooperation, for instance through activities under the IEA as well as through the implementation of the SET-Plan and by participating in transnational funding instruments such as ERA-Nets. At the European level, the focus is on the implementation plan defined by the SET-Plan Temporary Working Group Deep Geothermal, which is to be implemented using national and European funding as well as through industrial investment.

The research and development of geothermal has strong connections to the research field of buildings and neighbourhoods, particularly in relation to the fields of seasonal thermal storage (e.g., aquifer storage), heat pump applications, LowEx systems and sector coupling (see Section 4.1.1 and 4.3.3). While the emphasis there is on the systemic context, the geothermal research area predominantly concentrates on technological development. There are also links to the research field of thermal power plants (see Section 4.2.6).

4.2.5 Hydropower and marine energy

Hydropower is a proven source of energy and the associated plant technology has been largely perfected. While technical innovations and the modernisation of existing plants can improve effectiveness, research funding for hydropower use pays particular attention to growing ecological requirements and seeks to design hydropower plants in a way that is environmentally sustainable.

Worldwide, the use of marine energy is still at the demonstration stage. The tidal range and the energy content in currents and waves, as well as thermal or salt gradients, can be used to generate electrical power. Due to the geographical conditions, power generation on German coasts is not particularly promising economically. However, domestic companies have the opportunity to develop export markets in regions with better conditions, e.g., a relatively constant, strong current pattern and wave climate, such as in the UK or France. There is a particular emphasis here on the development and demonstration of economically promising aggregates that are particularly robust under maritime conditions for the sustainable use of current and wave energy. In addition to innovative components for run-of-river systems, the Federal Government therefore provides appropriate funding for the development and demonstration of ocean current turbines and wave energy converters.

4.2.6 Thermal power plants

Energy-sector relevance and strategic goals of R&D funding

Even today, Germany's electricity generation infrastructure primarily consists of thermal power plants. These are power plants where heat from various energy sources is converted to electricity through gas and steam cycle processes: To date, these energy sources are generally coal, natural gas and nuclear energy. In the future, this will increasingly be achieved using waste, biomass, geothermal energy and heat from otherwise unusable renewable electricity. These power plants are generally characterised by a long service life and are an important part of the energy infrastructure. How existing energy infrastructure, including electricity grids that were expanded to accommodate major central power plants, can be harnessed using new technological solutions for the energy transition is therefore a pressing question for researchers. One possibility could be the use of existing sites for large and efficient electricity storage installations. There is a growing need for these when there is a rising share of fluctuating renewable energy in the energy system. In this way, existing power plants could also continue to contribute to a stable energy supply in the future. This would allow structural interruptions to be prevented or at least mitigated. However, this also necessitates extensive research on technologies and concepts for the climate- and environmentally-friendly use of existing structures. Large thermal energy storage facilities, high-temperature heat pumps and innovative process technology are key research topics here that can also make an important contribution for existing and new heating supply infrastructures.

Gas-fired power plants have huge potential for flexibility and can help to smooth out the fluctuating power generated by renewable energy installations. The gas network will face new tasks through sector coupling, for instance due to increasing proportions of hydrogen from renewable energies (see Section 4.3.3). For gas-fired power plants in particular, fuel and load flexibility are therefore key research objectives to be able to provide ancillary services.

Solar thermal power plants use concentrated solar energy as a source of heating. They only exist as demonstration plants in Germany due to the low direct solar radiation. However, climate protection and the corresponding transformation of energy supply are global challenges. In other parts of the world, the solar thermal use of solar radiation plays an important role. German companies and research institutions are world leaders in the field of solar thermal electricity generation. Germany therefore has considerable export potential in this area.

Strategically important R&D topics

New power plant processes

Taking account of the strategic goals, the key R&D topics in this area include:

- The adjustment of power plant processes for the long-term activation of the energy infrastructure, for instance through the development of new thermodynamic cycles or hybrid plant concepts,
- The integration of energy storage facilities into the power plant process, e.g., high-temperature heating stores, electricity-heat and electricity-heat-electricity stores or isentropic stores where renewable electricity is reversibly converted to heat and, where necessary, into mechanical energy (e.g., rotation),
- The development and the integration of suitable high-temperature heat pumps,
- Retrofit measures for integrating altered or new fuel compositions, e.g., the shared use or alternative use of hydrogen, waste and biogenic residual material, the integration of thermal storage facilities, measures to increase the effectiveness of various operating modes and the lowering of emissions,
- The use of new fuels and processes such as pure hydrogen and supercritical CO_2,
- Transferable technological processes and management concepts, internal power plant infrastructure and concepts for separating and using CO_2 in the context of burning waste and biogenic residual material, including the development and perfection of materials (e.g., CO_2 pipelines, CO_2 compressors, CO_2 separation processes),
- The combination of various process, storage and infrastructural developments.

Turbo-engines

Since electricity cannot currently be stored to a sufficient extent, consideration is being given to primarily using electricity that is generated during the integration of volatile renewable energy and that cannot be used directly for so-called power-to-X processes to produce hydrogen and fuel. Research funding is therefore focusing on making gas-fired power plants more flexible. This involves changes to the gas composition in favour of higher hydrogen content as well as the use of synthetic gaseous fuels from power-to-X plants for reconversion.

The following R&D topics arise with respect to fuel and load flexibility:

- Optimisation of the processes and systems and the service life of the overall plant and its components including thermodynamic and aerodynamic optimisations (increase in operating temperatures, optimisation of cooling systems),
- Improvement in the heat transfer (recuperation) and the combustion systems (burners and combustion chamber) and optimisation of ignition and flame stability,
- Material research and maintenance, repair and replacement measures to meet changed operating cycles, including corrosion testing due to changed fuel compositions, composite and ceramic materials and materials for turbines that are highly temperature-resistant,
- Retrofit measures to strengthen existing plants with respect to their fuel and operating flexibility, incl. CCU.

In general terms, the development of local, modular, mid-performance power plants is being advanced.

Gas-powered units are also coming into greater focus again as an alternative. The integration of local power plants, gas-powered units with renewable generation plants and energy storage facilities (virtual power plant) also plays a role. The modelling and simulation of systems, plants and components (Digital Twin) as well as sensors, data analysis and learning methods for management and optimising operations can also help to increase load and fuel flexibility.

Solar thermal power plants

In order to exploit the export opportunities in the area of solar thermal power plant technology, integration concepts must be developed for solar thermal power plants and heating storage facilities in conjunction with other renewable energy sources. The goal is to provide electricity and heating in a way that is planable and needs-oriented. This must be accompanied by further cost savings.

These general objectives give rise to key R&D topics such as:

- The development of concepts and pilot projects across all technologies and a cost-optimised concept for usage-oriented energy provision, for example in conjunction with photovoltaics, wind, biomass and biogas,
- The development of highly efficient and highly flexible solar thermal power plants,
- The provision of heat at medium and high-temperatures for solar cooling, local and district heating and industrial processes – including processes with the potential to produce synthetic fuels using thermochemical techniques (see Section 4.1.3),
- Techno-economical efficiency improvements: This includes comprehensive system optimisation and the examination of all core components (solar field, receiver, storage facilities, power station unit, etc.) including management, operation and maintenance as well as the use of innovative digital technologies with respect to cost minimisation, improved efficiency and reliability (CSP 4.0),
- Standardised development of measurement and testing procedures to ascertain the performance and service life of all systems and components.

Geothermal power plants

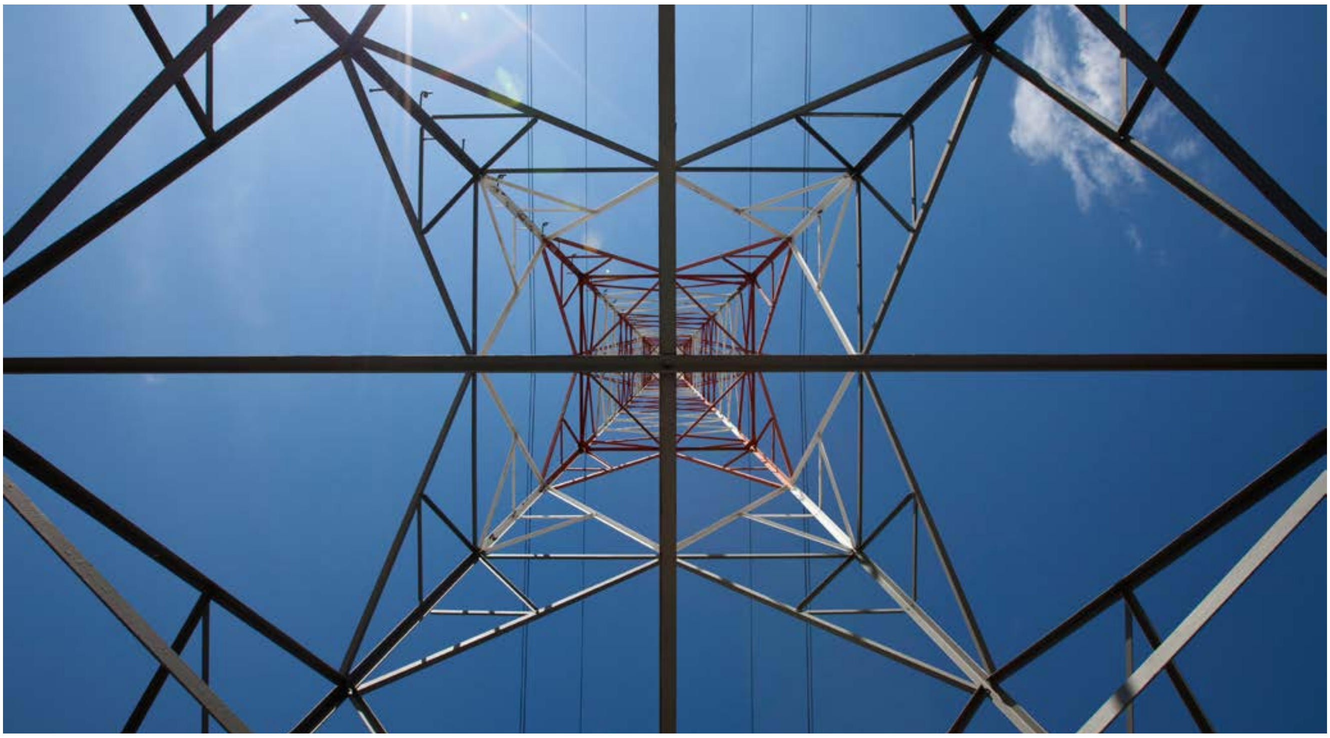
In addition to the direct use of geothermal heat, deep geothermal installations offer the opportunity to generate heat and produce electricity. Due to the temperatures of geothermal liquids of up to 180°C, to date only power plants with a secondary cycle such as ORC (Organic Rankine Cycle) plants and plants using the Kalina cycle process have been used in Germany.

There is a need for research, for example, with respect to the use of improved heat transfer installations, their components and media as well as improved cooling processes to increase efficiency and the associated increased profitability. Due to the increased corrosion arising in the circuits of the geothermal liquids required, there is also an additional need for materials research.

Organisation of R&D funding

At the national level, the themes and actors in the research area of thermal power plants are grouped together in the Flexible Energy Conversion Research Network. A theme-specific exchange of members is taking place in various working groups. In the future, it will be based even more heavily on the application-related results transfer and the handling of cross-cutting topics in cooperation with the working groups in other networks.

The Federal Government also participates in international R&D activities in this field. For the activities of the SET-Plan implementation plan on solar thermal power plants, participation was approved for the topics of Improved Central Receiver Molten Salt Technology, Parabolic Trough with Molten Salt and Parabolic Trough with Silicon Oil. Under Solar ERA-Net, The Federal Government is are also actively participating on all of the topics on solar-thermal power plant technology (Topic E-CSP low-cost and next-generation technologies) and in IEA working groups in the Technology Collaboration Programme (TCP) such as SolarPACES (Solar Power and Chemical Energy Systems).



4.3 System integration: Grids, energy storage, sector coupling

4.3.1 Electricity grids

Energy-sector relevance and strategic goals of R&D funding

Implementation of the key policy goals for the German energy system faces a significant task in better utilising and modernising electricity grids, and in expanding and converting those grids, in order to be able to economically exploit renewable energy even across sectoral boundaries. The expansion of renewable energy can mean that the distance between power generation and power consumption centres continues to grow (for instance, with offshore wind farms). The transfer of energy over large distances therefore remains important. On the other hand, however, the number of local supply structures will increase. At the same time, the trends towards the increasing electrification of mobility and heating provision will continue. This requires increasingly aligned operation between regional and nationwide electricity grid operators, generating plants and consumers, in order to continue to make the energy system more flexible. Thanks to research and development efforts, the integration and transformation of electricity grids into an open-technology, market-oriented system continues.

In developing and converting electricity grids, a high level of supply security combined with consistently good supply quality is one of the foundations for Germany's international competitiveness as an industrial and economic location. At the same time, the intention is to achieve a transition to an energy-efficient and environmentally sound energy supply. Digitisation presents both an opportunity and a challenge here. The goal is to obtain resilient electricity grids as a central component of a secure energy system.

Research and development is essential so that electricity grids can continue to meet these diverse requirements in the future. We must increasingly take account of the results from other areas of research here due to the increasing complexity and growing interdependencies in the system as a whole.

A key pillar of research funding here is the use of modern equipment and the continued development of that equipment, in order to improve both capacity utilisation and load capacity, as well security and stability. New materials and equipment allow compact, cost-efficient, durable and environmentally sustainable technologies to be used in the networks. These technologies support the integration of electricity, gas and heating grids, the combination of AC and DC networks and new forms of supply.

Furthermore, processes and technologies must be further developed to ensure flexible, safe and efficient grid operation. In this way, innovative methods and tools for grid operation and grid planning can enable, or facilitate, new forms of energy infrastructure and sector coupling. There is a focus here on grid control and grid protection, grid stability and system security as well as the system integration of renewable energies.

Tailored electricity grids for integrated regional energy systems are required for the efficient use of local and global resources. At the same time, their integration into national grid structures must be observed. In this way, concepts for sustainable local and regional renewable energy supply can be scaled over a wide area while also guaranteeing security and stability of supply.

The digital transformation of the electricity grid towards a smart energy system (smart grids) is also to be further supported and advanced through research and development. Systemically secure solutions to penetrate the electricity grid with information and communications technology (ICT) will allow access to a wide range of options for planning and operation, reduce costs for operation and planning and tailor the approaches to various voltage levels in a scalable way. In addition, this will facilitate sector coupling and the integration of renewable energies.

The German electricity grid is heavily integrated into the European network, so that the solutions developed through research help European climate targets to be met more quickly through coordinated action. Furthermore, research and development strengthen the competitiveness of European companies and research institutions in the international environment.

Strategically important R&D topics

The electricity grids research area covers a very broad spectrum of issues, due to the complexity of the overall system. The following R&D areas are particularly significant in the 7th Energy Research Programme:

Equipment and components

In order to increase the intake and transport capacity of the electricity grid, existing equipment is further developed and new equipment is prepared to improve system attributes such as grid stability. Innovative grid equipment contributes to secure and cost-efficient grid operation, while also allowing an increase in grid capacity and the availability and reliability of supply. In the future, converters will be an important component of the grid infrastructure for local power generation and bidirectional load flows. In order to ensure the grid compatibility of the converters, the research is addressing technologies to increase reliability and efficiency and to reduce the costs of components and of the overall system. The use of new materials also contributes to improved grid equipment, in order to reduce costs and increase reliability, for instance for underground cables, gas-insulated lines and control rooms, overhead circuits, new semiconductor materials for grid components and the use of superconductor technology.

Grid operation

New technologies in the grid make it possible to shift and expand the limits of previous system management, grid planning and grid protection. Nevertheless, in future local supply structures, the protection and control technology must ensure a secure grid condition at all times, while reliably identifying and dealing with faults. This means investigating new processes and components in order to continue to fulfil today's requirements in terms of selectivity, reliability and speed. Procedures are also required for emergency operation and system recovery incorporating distributed generators at different voltage levels. In addition to new, universal switching, protection and security concepts, this also requires adjustments to the network control technology and coordinated grid protection as well as restart strategies for the electricity grids.

The criteria for security and system stability must be examined here against the background of existing and future changes in the energy supply system. Potential instability must be researched and the analysis and simulation tools adjusted so that they can cope with the complexity of the system as a whole. These tools support the planning and operation of the network to safeguard interactions that serve the system, increase resilience and optimise the system.

In the future, a flexible, safe and efficient grid operation must include all generators and consumers across varying voltages and sectoral boundaries. New, optimised management concepts and equipment are required for all grid levels in order to provide flexibility and to manage that flexibility. It is particularly important to strengthen volatile renewable generators to achieve system-stabilising behaviour. This is because, with the loss of controllable conventional power plants, their stabilising effect on the electricity grid also disappears. Research concentrates on future uses such as the penetration of the electricity grid with electromobility, microgrids with a large proportion of renewable generators or the examination of collective dynamic phenomena. Providing flexibility in the grid demands better grid integration as well as appropriate management concepts to provide ancillary services. This affects the observability, evaluation and (automated) controllability of the overall system, for example through an automated survey of the system structure, dynamic and transient security analyses and forward-looking processes based on load forecasts and generation forecasts. Ultimately, in order to optimise the overall system it is also necessary to demonstrate and analyse the use of flexibility from the electricity grid in other sectors and power grids.

ICT in the electricity grid

The information technology integration into the electricity grid and with the energy system encompasses all grid levels and energy sectors. Urgent questions relate to the automated handling of network participants as well as automated solutions for management strategies, equipment and grid expansion planning. In addition, there is a need to continue with the ICT-based integration of technical operations, operational processes and business transactions. Where large volumes of data arise as part of the continuing digital transformation of the electricity grid, innovative solutions are required to store, process and evaluate this data. They should avoid the central consolidation and long-term storage of information collected nationwide on an ongoing basis.

The integration of information and energy systems means that there are increased demands in terms of ICT security and resilience. The stability of the electricity grid and thus of the entire energy system therefore no longer exclusively depends on its operating conditions and equipment. ICT is a new part of the equipment mix. IT security will therefore remain a key focus for research when planning and operating new technologies ('security by design'). Existing security procedures and measures as well as security-related technologies need to be continuously adapted to the latest science and technology.

Grid planning and new grid structures

The use of ICT, new equipment and more flexible operating concepts opens up the possibility of considering new structures for the energy system. Research therefore also considers distributed, cellular approaches, the integration of various different sectors, the meshing of AC and DC grids and planning methods covering multiple levels. For example, this should allow direct current grids and high-voltage direct current transmission technology to be integrated into existing supply systems. New technologies and concepts will be tested and test requirements will be adjusted and enhanced with appropriate testing procedures (e.g., hardware-in-the-loop).

Organisation of R&D funding

In the Research Network Power Grids, members exchange views across a broad range of topics including HVDC, system stability, digitisation and ICT, plant and converter technology and flexibilisation. Experts work in topic-specific groups to develop proposals on the strategic direction of research funding in this area and on major themes by making contributions on calls for proposals, funding notifications or competitions. Cross-cutting topics that must be considered in tandem with other networks are becoming more important.

The electricity grid represents one of the energy system's key infrastructures, the importance of which will continue to grow with increasing electrification, among other factors. Research and development in the area of electricity grids and the integration of renewable energies into the grid therefore have much in common with other research topics, such as the integration of photovoltaics and wind energy (see Section 4.2). In addition, the cross-sectoral exploitation of flexibility options requires common solutions from the areas of energy storage, heating networks and gas distribution systems (see Section 4.3.3). Intelligent coupling with the industrial sector is necessary to activate the flexibility potential to be found there (see Section 4.1.2). Links to the building sector and the heating sector also result in more flexibility in the German energy system and support grid-friendly load behaviour (see Section 4.1.1). The interface with the transport sector is evident, given the increasing integration of electromobility into the electricity grids (see Section 4.1.3). Last but not least, research in the area of electricity grids, and in particular grid planning and system management, is often systemic in nature and therefore has distinct interfaces with research questions related to energy system analysis (see Section 4.4.1). Electricity grids also play a key role in major systemic demonstration projects. A holistic approach and long-term collaboration between industry, science and civil society have proven to be successful in this context (through *Kopernikus projects* and the *SINTEG* funding programme, for example). Investigating innovative business models or operating concepts may require adjustments to the regulatory framework here (see Section 3.1).

This close link with neighbouring areas requires coordinated, comprehensive research activity. In the future, common funding appeals and research initiatives will underscore these links. The research networks will accompany and support cross-thematic research with joint events, workshops and discussion papers.

Under the SET-Plan, European research funding is coordinated in the field of electricity grids and the integration of renewable energies into the network in Action 4 of the implementation plan (increasing the resilience and security of the energy system). This measure is based on two programme goals: The optimisation of a European electricity grid and the development of integrated regional and local energy systems where electricity grids and the integration of renewable power generation in turn play a key role. The national funding projects in the 7th Energy Research Programme will contribute to both goals in the long term.

Germany continues to contribute to the reaching of these programme targets through a range of activities at the European level. In the area of project funding, instruments from the European research programme such as the ERA-Net Smart Energy Systems help to efficiently coordinate the funding from European countries in the field of intelligent networks and the network integration of renewable energies, taking account of energy stores and system-analytical aspects. Additionally, research initiatives will be launched with funding under the *Berlin Model* in conjunction with other countries. This model is particularly attractive for the effective handling of bi- and trilateral funding projects with partners from Germany's neighbouring countries. As well as direct research funding, Germany will also participate in the ongoing knowledge transfer with other European countries. As part of Mission Innovation, Germany will take part in the smart grids Innovation Challenge.

4.3.2 Electrical energy storage

Energy-sector relevance and strategic goals of R&D funding

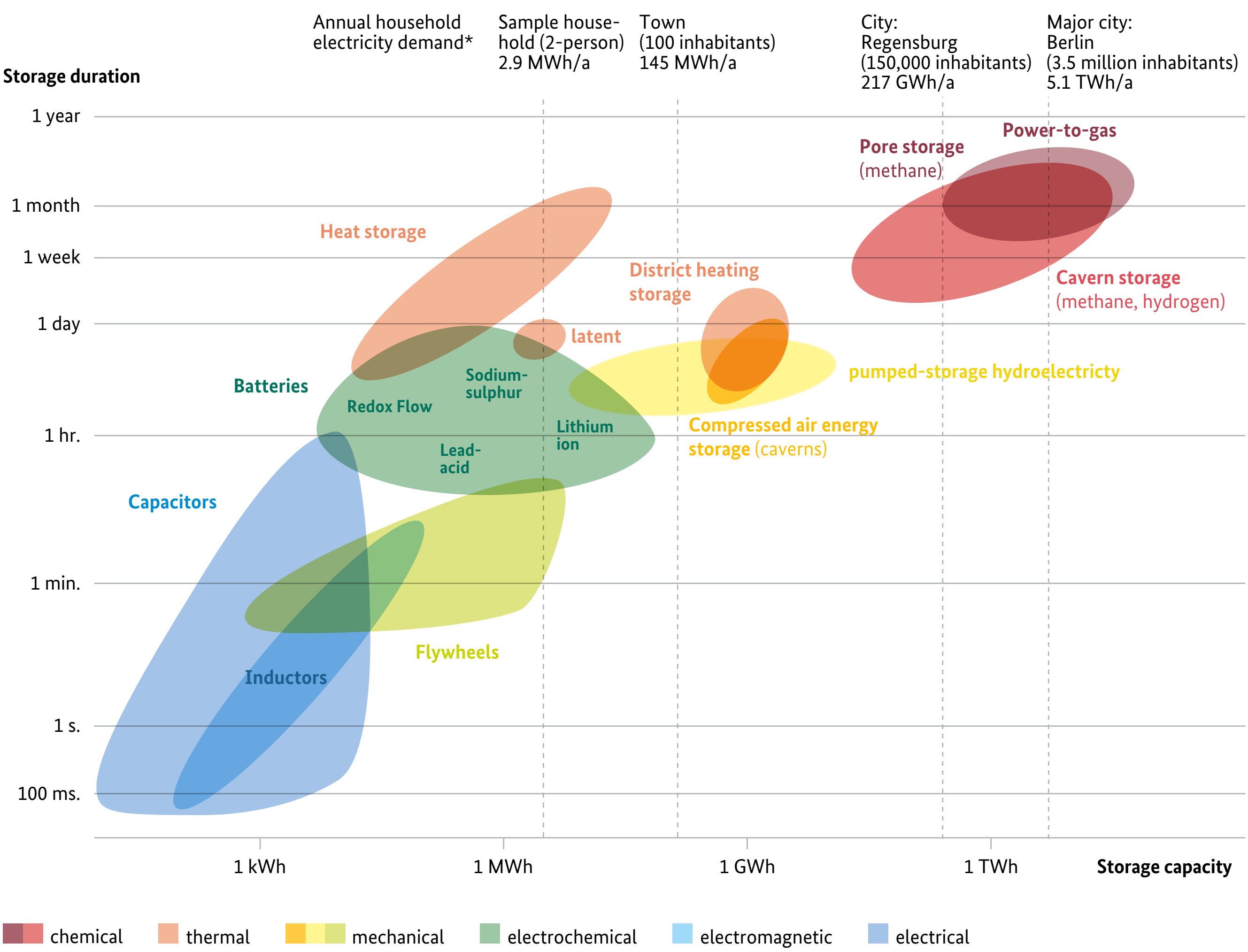
Electrical energy storage facilities are an important component in making the energy system of the future more flexible. They help to incorporate an additional share of renewable energy and contribute to ensuring security of supply, as they can respond quickly to fluctuations and stabilise the grid. Electrical energy storage facilities can be employed in a broad range of areas. In the public electricity grid they can provide ancillary services, while in electric vehicles they supply the drivetrain with electrical energy either on their own or in combination with a fuel cell. In buildings, neighbourhoods or industrial plants they help to increase self-consumption and contribute to energy management. In wind and solar farms, energy storage facilities can improve efficiency by allowing power to be fed with a time delay, and they can increase the generation of renewable energy by avoiding curtailment. These examples, as well as additional examples, support sector coupling, the integration of renewable energy and the efficiency of the energy system as a whole. This requires electricity storage facilities with specific optimised attributes (particularly performance, capacity, gravimetric or volumetric energy density, cycle stability, response times and costs), which are especially suitable for the relevant requirements and can take over short, medium-term and long-term storage tasks.

Starting points for improving the efficiency of electricity storage include, in addition to simple cost degression for storage elements and systems, improvements in quality and security as well as increasing standardisation to allow more widespread compatibility. Digitised, automated production technologies must be further developed and sustainability needs to be improved. Innovative electricity storage facilities and their environment must be optimally adjusted to specific applications and tested during operation, with the support of digitised management methods. Future market requirements can be met with new business models. They allow even companies from sectors outside of today's energy sector to provide new kinds of services. The regulatory environment for new business models should also be taken into account here.

Strategically important R&D topics

The technological spectrum of electricity storage comprises electrochemical storage (batteries, including redox-flow-batteries), electrical storage (compressed air and gas storage, pumped hydroelectric storage and flywheels) and high-temperature heat storage for electricity storage (see Section 4.2.6). Electricity storage research focuses in particular on different types of battery technology, since the battery is the central technical component at key points in the energy system. Research on the battery in the Energy Research Programme is extended along the value chain: On the one hand, application-specific questions on materials, cell chemistry and production are addressed. On the other hand, the incorporation of the battery into mobile and stationary applications is examined, through to the development of use cases and questions of standardisation. In this way, the 7th Energy Research Programme supplements other Federal Government programmes – such as those in relation to material research, the introduction of electromobility and its integration with the energy system or ICT technologies – and places the Federal Government's R&D funding for the battery as a key component of the energy transition in an overall strategic context. In addition to the

Figure 10: Energy stores by storage duration and storage capacity



* not including industry, trade, commerce and services; Electricity consumption per capita: 1.45 kWh/a
The coloured areas show the storage capacity and duration for facilities of different types of storage realised in Germany.

Source: Sterner und Stadler, Energiespeicher – Bedarf, Technologien, Integration, Springer 2014 technical prerequisites, greater efficiency is essential for the use of storage overall. R&D topics address the cost reductions that are required for this.

Materials and components

The development of innovative materials and storage media faces a broad range of requirements. In battery cells, for example, new materials should improve the technical attributes of batteries, making them cheap and easy to produce. At the same time, they must meet high safety standards and be environmentally friendly. The increased use of available and non-critical raw materials also reduces dependence on imports when manufacturing storage devices.

The necessity to develop materials ranges from the cell through the system or module to peripheral devices, as illustrated by the following examples: New materials give batteries for electromobility greater energy density and performance for longer ranges. Redox flow batteries require materials for high-performance, stable bipolar plates; flywheels require materials for magnets. In electrical storage, nanomaterials can maximise the electrode surface and thereby the capacitance. New working substances can open up new application options for compressed air and gas storage or pumped hydroelectric storage. With electrochemical storage devices, the development of fundamentally new cell chemistries is a very important research area. Research helps to exploit alternative materials and raw material sources (circular economy, see also Section 4.4.3) for lithium, lead, vanadium and cobalt, for example. Post-lithium batteries, especially metal-air batteries and solid batteries also play an important role.

Rapid, reliable measurement procedures are required to test the suitability of such materials at an early stage of development and to accelerate the development. Electricity stores, components, parts, systems and their peripheral equipment must be developed and optimised so that they suit the relevant application and operate safely and reliably. The key parameters are cost, overall efficiency, power density, storage capacity, response time, longevity, cycle stability and charging and discharging speed. Stable operation is required at both high and low temperatures.

Production

Production is the decisive technical step to produce a product, from the materials and components developed in the laboratory, which satisfies the features required in the storage application. The Federal Government has prepared an “Innovative Battery” action plan in order to implement the research results, by means of a cluster approach, into a large-scale battery cell production. Appropriate and digitised production concepts (“Industry 4.0”) must be established for this. These are designed to ensure consistently high quality by using rapid, reliable production-integrated testing procedures and measuring technology, as well as through uniform testing standards. Faulty batches are avoided thanks to increased reproducibility and the identification of errors at an early stage, thereby further reducing the energy expenditure for production. Production technology also offers huge potential to reduce costs, because automation and the reduction of components makes it cheaper to manufacture large numbers of units.

Digitisation offers opportunities for “production on demand”. Production on demand helps to boost the competitiveness of innovative products. This also enables the production of novel designs that have been individually adapted to customer requirements.

Standardisation

Currently it is very difficult to compare manufacturers’ figures for electrochemical storage in particular, as there are not enough accepted standard tests. In addition, there is a lack of international standards for external and internal interfaces (both ICT and electric performance interfaces) as well as a standardised description. The 7th Energy Research Programme is preparing additional standardisations through R&D work, thereby eliminating the barriers to system development and market launch.

Operation of stationary storage systems

The transfer of research to the market will be supported by the demonstration of electricity storage systems in specific applications. Technical feasibility and economical viability must be shown here. Processes and procedures as well as storage management concepts must be optimised, innovative business models tested and new application areas and site possibilities developed. Upscaling plants and components can make the operation of storage plants within the electricity grid or for energy management in neighbourhoods, for example, more economical. In this way, new applications can be examined that support the future energy system. New market actors can be won by using innovative methods to operate distributed storage systems. The optimisation potential for the regulatory provisions must also be factored into the analysis. After all, they are a key to the success of innovative business models.

In demonstration projects, the plant components must be tailored to each other in order to ensure efficient operation. This requires appropriate interfaces. Intelligent communication technologies and management systems manage the plant both technically and from a marketing strategy perspective. Monitoring systems must be developed for optimal technical operation and a high level of security.

Lifecycle and circular economy

Environmental sustainability and profitability must be analysed and optimised throughout the entire lifecycle. The production of batteries requires the use of raw materials that are not naturally found in Germany, or that are only found in small quantities. Suitable production methods use easily available materials that are as harmless as possible, thereby conserving resources.

Lifecycle costs of storage systems can be brought down by reducing their degradation, making the systems more durable. New reuse concepts for batteries ("second-life") also increase their useful life. Here, the reuse of components, storage systems and plants at the end of their service life is being researched, so that this can already be taken into account when technology is being developed.

The investigation of recycling methods at the end of their service life can improve batteries' environmental sustainability and reduce the strategic dependence on raw materials imports with respect to the use of energy storage. These 'circular economy' aspects must already be taken into account during manufacturing. The objective is to continue using components for as long as possible and to reclaim as much as possible of the raw materials.

Organisation of R&D funding

Both basic and applied research are required in order to improve electrical energy storage across the entire value chain, from material through components, systems and plants to peripheral devices. Demonstration projects, pilot plants, field tests and living labs are the instruments of the 7th Energy Research Programme, to examine the use of new storage technologies under near-real-world conditions. The relevant actors from research, industry, private households, local authorities, grid operators and marketing are included here.

Since electrical energy storage is a cross-cutting technology, there are links to other funding areas within the 7th Energy Research Programme: For the integration of energy storage systems into electricty grids (see Section 4.3.1), for storage systems for transport and mobility (see Section 4.1.3), thermal energy storage for converting electricity and for storage concepts for energy-efficient buildings and neighbourhoods (see Section 4.1.1), for the use of energy storage in industrial processes (see Section 4.1.2), for sector coupling (see Section 4.3.3) and for the connection of storage systems to wind and solar plants (see Section 4.2 and 4.2.2).

The 7th Energy Research Programme continues to fund technology-neutral innovation in the research field of electrical energy storage. This approach has also proven itself in the successful *Energy Storage Research Initiative* within the 6th Energy Research Programme. The results of the development work are discussed within the Energy Research Networks, so that the research field of electrical energy storage is strategically developed. The *Battery Forum Germany* continues to offer a platform, as part of the BMBF material research programme, for the strategic direction of battery research in Germany.

In the SET-Plan and in the "*Horizon 2020*" EU Research Programme and in the "*Horizon Europe 2021 – 2027*" follow-up programme, storage research is embedded into many different research areas (IG4/Stability of the electrical system; IG7/Battery sector). Here, one of the objectives is to establish battery cell production in Europe (TWG 7 on batteries, European Battery Alliance). European cooperation initiatives are useful for exchanging experience and spreading risk for storage development requirements. Also very urgent, even in the short-term, is an international collaboration on the subject of standardisation and interfaces.

4.3.3 Sector coupling

Energy-sector relevance and strategic goals of R&D funding

The energy transition has proceeded very differently in the electricity, heating and transport sectors to date. While considerable successes in the electricity sector were achieved for the integration of renewable energy, to date the integration in the heating and transport sectors has primarily succeeded through the limited use of biomass as expansion has continued. Sector coupling, in other words, the efficient use of electricity from renewable energy sources in the areas of heating and cooling as well as mobility and transport, can make an important contribution to implementing the energy transition in all sectors. Electricity can be used directly, for example for electromobility or with the use of heat pumps, as well as indirectly by generating chemical energy sources (such as hydrogen). Above all, sector coupling needs to lead to synergies compared with the separate expansion of energy infrastructures.

Sector coupling allows new flexibility options to be made available for the energy system, although with increased requirements in terms of the flexibility of the individual technologies, as well as in terms of information exchange and intelligent management. This is because, in a more closely integrated energy system, they must be able to respond flexibly to changes in the availability of renewable electricity. Furthermore, the conversion of renewable electricity into chemical energy sources enables the long-term storage of renewable energy. This increases the supply security. Technologies for sector coupling should be developed in such a way that they help to increase the stability of the energy system and reduce the costs of the energy transition.

Energy research can make a multitude of contributions here. This affects, on the one hand, the development of individual technologies such as heat pumps, bioenergy plants or electrical and thermal stores that must be prepared for flexible deployment in an energy system that will be digitally networked in the future. On the other hand, high-performance modelling tools and ultra-modern ICT methods should be developed for the concept development as well as for the planning and realisation of the sector coupling, while the regulatory framework must also be examined for optimisation potential. In addition, the corporate and social implications must also be taken into account.

Hydrogen as an energy source can assume a particular significance in the context of sector coupling. Hydrogen offers possible uses in central and local electricity generation, in vehicles, for the manufacturing of alternative fuels, gases and combustibles, for long-term storage and as a raw material for industrial (particularly chemical) processes. Where hydrogen is produced in a regenerative way (for instance, from renewable electricity in electrolysis plants), its use is associated with no, or very few, greenhouse gas emissions. Considering the huge export potential for hydrogen production technologies, the Federal Government intends to strengthen its domestic manufacturing base and expand the technology leadership position Germany has gained as far as possible. Funding for research and innovation is intended to significantly reduce the costs for renewable hydrogen.

Coupling the sectors and connecting the infrastructures can give rise to considerable flexibility potential. Subterranean geological formations and, potentially – once the technical and capacity possibilities have been examined – the gas network infrastructure, are available so that hydrogen can be used for the long-term storage of renewable energy. This also gives rise to new possibilities for the transport of renewable energy (for example, as an alternative offshore connection). A further possibility is the use of natural gas stores for hydrogen storage. Hydrogen can already be blended in with natural gas in pipelines and distribution networks to a certain extent. This opens up flexibility for the electricity grid. The gas network, which to date has been primarily used to supply natural gas for the electricity and heating market, could therefore take on a new role in the energy system in the future. If hydrogen were to be further converted to methane with CO_2 in power-to-gas plants, the gas network could also be fully used for the long-term storage of renewable energy. Nevertheless, this involves additional efficiency losses compared with simple electrolysis. Key research objectives are therefore to increase the energy efficiency of the conversion processes themselves, as well as the sensible use of the unavoidable waste heat generated by chemical conversion processes, in order to obtain a high level of system efficiency.

Strategically important R&D topics

Sector coupling in the context of the energy system

A holistically optimised energy supply in the future requires advance research work in the field of systems analysis (see Section 4.4.1). For example, a sufficiently precise mapping of the infrastructures requires comprehensive models and new tools and processes to allow national and regional strategies to be reliably and thoroughly planned. Robust system-analytical models allow the flexibility potential from sector coupling to be analysed and fully assessed. The systems analysis therefore supports the understanding of the technical, legal, economic and socio-economic relationships. In addition, operational and profitability analyses, lifecycle analyses incorporating recycling and techno-economic analyses and safety analyses are required.

Since the current regulatory framework must be adjusted in order to successfully implement the sector coupling, there is a significant need for research work here, which it may be possible to implement as part of the living labs for the energy transition (see Section 3.1). Energy infrastructures do not stop at Germany's borders. Sector coupling must therefore be devised and implemented at a European level.

Direct use of electricity in other sectors

In order to allow the direct use of renewable electricity in the area of mobility and transport, methods must be developed for the controlled charging and discharging of electric vehicles (vehicle-to-grid) and improved batteries. Further research topics relate to grid-friendly charging, innovative overhead line systems or efficient DC grids. Parallel, highly dynamic developments in the area of mobility and transport (e.g. autonomous driving, unmanned aerial vehicles (UAV), new mobility trends such as urban bicycle traffic or car-sharing) must also be considered when conducting research on sector coupling. In the area of heating and cooling supply, renewable electricity can be used either directly or by means of heat pumps (incl. air conditioning systems). In addition to research and the development of individual technologies, holistic concepts are required here for heating/cooling systems, particularly in the context of buildings and neighbourhoods.

Generation of hydrogen and other chemical energy sources from renewable electricity

In many cases, sector coupling requires the conversion of electrical energy into synthetic gases, alternative fuels or chemical raw materials (power-to-gas, -fuel/-liquids and -chemicals). The efficiency, flexibility and profitability of the related plants must be significantly improved. These technologies must be made available for various size ranges, including efficient paths for further conversion. Since carbon is also needed as a raw material to produce most synthetic fuels and combustibles, sector coupling is closely related to CO_2 technologies and the production of biogas. In addition to hydrogen, CO_2 has thus become an additional core element of sector coupling (see Section 4.4.4).

In most cases, these conversion processes begin with the production of hydrogen through electrolysis installations. The economical operation of such plants requires the optimisation of all processes for producing, storing, conditioning, transporting and converting hydrogen within a technically efficient, needs-oriented and comprehensive infrastructure. Aside from the costs, the key challenges relate to increasing the energy efficiency of the processes and the meaningful use of unavoidable waste heat. Technological options and design revisions with respect to concepts, system technologies, processes, peripheral devices, components and materials are just as much the subject of research as the remotely controlled, automated and system-friendly management within the electricity market. Research into the various electrolysis technologies, which is supported by long-term data, remains focused on performance, dynamics and flexibility, degradation and service life as well as scaling, efficiency and power density. Basic application-oriented research provides next-generation technologies and makes a significant contribution to reducing plant costs. Processes suitable for series production for large-scale electrolysers require optimised production processes. The standardisation of the processes and components supports their development.

As with its entire Energy Research Programme, for the sustainable production of hydrogen the Federal Government believes in technology neutrality. It therefore supports research into promising new paths, even outside a narrow definition of sector coupling, such as methane pyrolysis for the controlled, climate-neutral splitting of methane into hydrogen and elementary carbon, which is needed as a valuable raw material in the chemical industry. Furthermore, the production of hydrogen or other chemical energy sources by means of renewable energy in the Earth's sunbelt also opens up a global perspective (see Section 4.1.3).

Flagship projects with major electrolysis plants in urban areas and industrialised regions and decentralised plants for local consumers can examine the value chain in its entirety. The expansion to systemic projects that are closely connected to the energy market, for example as living labs, or building on Kopernikus projects, supports this need for research. This applies in particular to the system integration of hydrogen production, possible hydrogen pipeline networks, bringing water electrolysis to an industrial scale and digital integration throughout the energy industry. From an overall system perspective, salt caverns (cavern storage) and porous formations (pore storage) are particularly suitable for large-volume, long-term storage. However, they need further research. Investigations of the potential of geological formations, the layout of the required technical installations, as well as of questions relating to approval, construction and operation, as well as possible risks, are important foundations for the future achievement of real gigawatt electrolysis storage plants. Additional research questions relate to functioning permanent hydrogen stores and alternative, new types of storage such as organic fluids. The secure and user-friendly usability of hydrogen is a basic prerequisite for technological development. Research into acceptance and participation can help to identify and incorporate users' requirements and preferences at an early stage.

The reconversion of renewable generated hydrogen (or combustibles generated from it) provides an option for long-term electricity storage. Hybridisation with other energy storage facilities represents a considerable challenge here. They can be implemented with fuel cells or stationary combustion engines. Reversible fuel cell/electrolysis systems are an important research topic in this context. All of the materials used should be analysed by taking account of critical resources. They should be reduced in use as far as possible or substituted by using alternatives. Material research for existing infrastructure seeks to obtain higher hydrogen content. It is relevant for the expansion of the infrastructure and is described in the next section.

Linking the electricity and gas infrastructure

Linking the gas infrastructure to the electricity sector requires, among other things, the scientific development of integrated planning methods that can support the identification of optimal locations for power-to-gas plants, for example. In determining the capacity of gas pipelines to store hydrogen, it is necessary to examine the hydrogen compatibility of various elements in the gas network and connected devices. This also affects the tolerance of the gas pipelines at various pressure levels in terms of hydrogen-induced corrosion and diffusion. Particular attention must be paid here to the supply dynamic. With the development of processes to separate hydrogen from the gas flow, the gas network could assume additional tasks as part of the energy transition. Local and regional examination of the specific gas network infrastructures is important here, in order to open up additional hydrogen storage potential. To increase the potential hydrogen content in gas networks, research should take place into new pipeline and lining materials and their usability, for example. Since a change to the composition of the gas that is transported could have implications for the gas pipelines and valves, the methods for recognising damage in pipelines, for example, must also be adjusted.

Generally it must be borne in mind that the gas network is organised in a Europe-wide network. The growth in the market for liquefied gas and its suitability e.g. for ship and truck power units give rise to additional challenges that must be considered in the context of sector coupling. This affects, for example, optimal locations for liquefiers, fluctuations in gas compositions and the characterisation of combustion gases (Wobbe index) as well as their impact on gas network components, storage and end-customer plants and on safety aspects. Overall, there is therefore huge demand for the continued development of intelligent technologies for calculating and tracking calorific values.

Sector coupling from a user perspective

People play a central role for the success of the energy transition in the mobility and heating market. Concepts for sector coupling should be developed in such a way that the implementation suits their needs and desires. The behaviour of consumers and users must also be modelled in detail and taken into account when developing concepts for sector coupling. Research work on acceptance and participation formats can help to make transformation processes comprehensible and create fair general conditions. For the technology and concept development it should also be noted that the expansion or reorganisation of energy infrastructures must be arranged in a way that respects the interests of people locally.

Organisation of R&D funding

The further implementation of sector coupling requires comprehensive demonstration projects, in addition to the development of individual technologies (see Section 4.1.1, 4.1.2, 4.1.3, 4.2.3, 4.2.6, 4.3.1 and 4.3.1). The model linking of infrastructures can only be tested in projects of a systemic nature. The living labs of the energy transition (see Section 3.1) are particularly suitable here, because goods subject to duties as part of the technology testing (e.g., electricity, gases and fuels) are being used and produced. The test operation of corresponding plants may require regulatory exceptions. Overall, the subject of sector coupling has many points of contact with system analysis and socio-economic research (see Section 4.4.1 and 4.4.5) as well as with the inclusion of modern ICT (see Section 4.4.2.).

In the Research Network Power Grids, the role of sector coupling in stabilising the electricity grids is related to other methods of grid planning and grid operation. Bioenergy as a system integrator in the context of sector coupling is treated in the Research Network Bioenergy. The use of renewable energies in the area of heating/cooling is an important aspect in the Research Network ENERGIEWENDEBAUEN. Electrolysis is a central theme in the Research Network Flexible Energy Conversion. Based on the existing structures, the networking of actors with a focus on sector coupling is to be further intensified.

Since sector coupling is also discussed intensively outside Germany, it is a topic of the SET-Plan (IG 8/hydrogen based on renewable energy; IG 9/synthetic fuel) and of the European Commission's funding programmes. Since pilot projects of a systemic nature have substantial financing requirements and a cross-border examination of sector coupling will require new research content, the aim must be to achieve collaboration between the funding bodies under the SET-Plan and seek recourse to European Commission funding mechanisms. At European level, hydrogen technology is also found in the working programme of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). At an international level, the Hydrogen Innovation Challenge addresses this topic under 'Mission Innovation'.

4.4 Cross-system research topics for the energy transition

4.4.1 Energy system analysis

Energy-sector relevance and strategic goals of R&D funding

The energy transition means that the energy system is undergoing a period of radical change. Decentralised generation structures, fluctuating supply, sector coupling, digital integration and new mobility concepts require a rethink at many different levels. These developments are unfolding in a highly complex environment shaped by many underlying technical, economical, ecological, energy policy and societal conditions. In order to be able to take appropriate action here, industry, politics and society need to be guided by comprehensive fact-based knowledge with respect to the likely paths in which the energy system will develop and the potential effects of those paths.

This knowledge can be provided by system analysis. It provides policymakers, society and industry with scientifically sound decision-making support and courses of action to allow people, for example, to comprehensively assess the impact of introducing new technologies or the effects of market interventions in a timely manner. The development of new and existing system-analytical tools, methods and databases is therefore a core component of energy research policy. Energy system models form the key element of energy system analysis. These models contain quantitative representations of individual processes, sectors or even the entire energy system. They allow an analysis of the impact of the energy system's potential development paths or the interplay between existing and new energy technologies. In order to adequately represent the complexity of the future energy system, collaboration is needed between various different specialist disciplines from fields such as engineering, economics, applied mathematics, information technology, the social sciences and law.

A system-analytical model cannot, and is not intended to, produce forecasts in the sense of predictions of the future. With its multitude of changing underlying conditions, the energy system is much too complex for this. However, by identifying cause-effect relationships and specific effects, and by examining sensitivities, it is possible to make a better assessment of the potential impact of various options for the arrangement of the energy transition (scenarios). The number of possible development paths that can be generated with simulation models is so big that a manageable number of scenarios must be selected. It is possible to set a very wide range of analytical focal points here.

The validation of system-analytical models is therefore of key importance in ensuring that the instrument of scenario analyses is not discredited. There is therefore a huge need for transparency in the development of such system-analytical tools. Society and policymakers are entitled to scientifically sound assistance in their decision-making processes. The results of a system-analytical examination must be transparent, comprehensible and capable of being verified by third parties. Only in this way can they serve as an authoritative basis for making fundamental decisions on the future direction of the energy system.

The development of corresponding validation methods is therefore an important focus of research. This includes model comparisons, the reconciliation of simulation results with historical data series, the verification of general attributes such as internal consistency and limited parameter sensitivities or the checking of input data and parameter values.

The reduction of complexities while preserving the required level of detail in system-analytical models is a key challenge of system-analytical research. What aspects of reality need to be represented within system-analytical models depends on the relevant question. In the energy area in particular, the detailed mapping of the demand and producer side is critically important in order to be able to take account not only of economic factors, but also of other factors influencing actors' decision-making processes.

Strategically important R&D topics

The system analysis must examine the interplay and relationships between technological, regulatory and social questions and develop concepts for optimising the socio-technical energy system. As a research discipline, the system analysis must concentrate on the development of general methods and tools. Its typical application for system-analytical questions is the subject of studies and expert opinions that the Federal Government commissions in the context of its scientific consultation. Key research topics primarily include, aside from the actual methodology development, validation and transparency, model coupling possibilities as well as the strengthening of the international perspective and collaboration.

Methodology development

Ongoing methodology development is required in order to be able to cope with the increasing complexity of the energy system – such as the development of standardised interfaces – in order to be able to couple different models together (even across sectors). Their modular design offers the advantage of being better able to exchange the results that are achieved. Aside from this, new approaches must be developed for the sectors of the energy system that have been insufficiently represented to date. There is a particular focus here on intersectoral model approaches and the better integration of the heating and traffic sector into the energy system modelling. Reducing the computation time presents further scientific challenges (e.g., through the parallelisation of model runs). Model simplifications can be achieved through empirical approximation methods and the application of learning algorithms (machine learning, KI). It is also important to integrate modern statistical methods (for instance, in the context of big data).

The actors' decision-making behaviour in the energy system, which does not correspond to simple cost minimisation, is to be better captured in the future. Modern approaches to behavioural economics will therefore be taken more strongly into account. This also relates to socio-scientific research. Further development is needed with regard to improving methods for mapping market and diffusion barriers when introducing new technologies. The impact of the new underlying regulatory framework is also to be included to a greater extent.

System-analytical models are not only needed to examine future scenarios, but also to analyse previous developments. In a complex environment detailed feedback analysis is needed in order to be better able to assess measures' effect mechanisms.

Validation

Methods for validating models must be developed for specific applications, because the relevant models capture various sub-aspects of the energy system with varying degrees of success. The model comparison is a proven means for validation: Various models examine the same question using broadly the same choice of input data and scenarios.

Differences in the model results often give an indication of the different modes of operation and basic assumptions of the relevant models and can potentially indicate potential for improvement. Further research topics are the comparison of modelling results with historical data and the improvement of the model attributes through sensitivity analyses, in other words, examining the dependence of the results on changes in the chosen assumptions. The development of methods for verifying generally desirable model attributes such as internal consistency or low parameter sensitivity is also one of the key research topics.

The establishment of general quality assurance measures for publicly funded simulation models is a central requirement within the Energy Research Programme. This includes the appropriate documentation and publishing of assumptions, programmes, data and results, as well as the checking of input data and parameter values.

Transparency

The Federal Government will strengthen the comparability and transparency of energy-system-analytical modelling through an effective open source, open data and open access strategy, in order to ensure the verifiability of the possible courses of action that are deduced. In order to ensure that modelling results remain transparent even in the long term, the development of an integrated, open and systematic data infrastructure for system-analytical research projects will be supported.

International perspective

Energy-system-analytical research work must incorporate the international context to a greater extent, for instance through cooperation with European and international partners and the expansion of existing models to include European and international factors. This includes, for example, the potential of renewable energy in the form of chemical energy sources, which could be imported from other regions of the world in the future.

Organisation of R&D funding

Since the energy system analysis does not involve a direct technological development and the focus is on the methodical development of the system-analytical instruments, the actors are predominantly located in the university or extramural research environment. The Research Network Energy System Analysis provides formats that are used for scientific exchange and to work together on comprehensive projects. The network is open for the participation of companies in trade and industry that are developing their own energy-system-analytical tools.

As an interdisciplinary research field, system analysis has strong links to many technologically-oriented funding areas, particularly those of a systemic nature such as electricity grids (see Section 4.3.1), sector coupling (see Section 4.3.3), energy stores (see Section 4.3.2 and 4.1.1), consumption sectors (see Section 4.1), Kopernikus projects and the living labs of the energy transition (see Section 3.1).

4.4.2 Digitisation of the energy transition

Energy-sector relevance and strategic goals of R&D funding

The digitisation of the energy transition acts as an umbrella term for a large number of highly dynamic developments in the field of modern information and communication technologies (ICT) and their impact on the energy system. It can assume a key role in solving existing and future challenges from the decentralisation, added flexibility and efficient use of energy and resources and takes effect throughout the entire energy area in its various guises.

The comprehensive integration of information technology into all of the elements in the energy system will make it easier to manage the future energy supply, which will fluctuate and will be largely decentralised. However, at the same time it will make the system more complex and create further dependencies. As digitisation and automation continues to spread, the reliability and security of the energy system, which provides the foundation for Germany's prosperity and industrial productivity, must not be called into question. In this context, the multiplicity of technical systems, participating actors and regional peculiarities with respect to energy supply and demand presents particular challenges.

The implementation of the digitisation of the energy transition requires both the development of security concepts and concepts for the resilience of highly networked systems. This is intended to rule out faults in both the setting up and the operation of new systems, or limit their impact, so that they remain manageable. To achieve this, given the large volume of operational data arising, methods, concepts and IT tools must be developed for efficient data management, processing and analysis. This ensures the best possible use of fluctuating energy sources and much greater flexibility overall in the demand side in the energy system (households, industry, transport).

In the context of industrial applications, digitisation and automation allow the optimisation of production processes to increase energy and resource efficiency. This also affects the adjustment of energy plants to the relevant site conditions.

Strategically important R&D topics

Digitisation touches on almost all areas of energy research. With its possibilities for boosting flexibility and efficiency in the energy system, it offers many opportunities, but also challenges, giving rise to interdisciplinary requirements for research and development in various overarching fields. These include the following:

- Internet of Things (including smart grids, smart neighbourhoods, smart factories, autarkic sensors, automation and Industry 4.0),
- Big data analytics (methods for processing large volumes of data, applied e.g. in forecasts or in status monitoring),
- Artificial intelligence (e.g., machine learning applied from production to forecasts),
- ICT security and the resilience of the energy system (the robustness of digital infrastructures, systemic and networked risks), including with respect to protective measures for interfaces to other sectors and systems, e.g., the mobility area,
- Data handling, data protection, data usage rights and standardisation (adapted methods for data collection and data handling; development of standardised interfaces such as in the smart grid for grid-friendly management),
- Simulation methods (e.g., material screening, plant and process simulation, building and neighbourhood planning, digital twin),
- Human-machine interaction (e.g., augmented reality, automated illumination and temperature control, user-friendliness of digital technologies),
- Robotics (e.g., production, automated plant monitoring and maintenance),
- Open science (this is an umbrella term for open source, open access, and open data, for the purpose of higher transparency and reproducibility in the digital world),
- Innovative digital business models (e.g., using virtual power plants, digital platforms and marketplaces).

Due to the rapid development in the ICT area, research funding in the context of digitisation must be continuously adjusted to changed underlying conditions. In addition to the development of new digital products and processes, there is also a focus on the adaptation of energy technologies to developments in the ICT area (e.g., 5G, cloud computing, quantum computers or blockchain technology). The objective is to make upcoming developments, and those that are already established, usable for the energy transition.

Organisation of R&D funding

Digitisation is a cross-cutting topic of particular importance. It is present in all subareas of energy research and the corresponding research networks, but often in differing aspects and with a different emphasis. It is therefore addressed not in a separate Energy Research Network, but in all Energy Research Networks (see Section 3.3). Where innovative ideas for digitising the energy transition are difficult to realise given the difficult underlying regulatory framework, in individual cases the living labs for the energy transition (see Section 3.1) can contribute to proving new technologies and concepts.

4.4.3 Resource efficiency for the energy transition

Energy-sector relevance and strategic goals of R&D funding

The responsible use of natural resources is a key objective of the Federal Government. The energy transition contributes to this goal, as it replaces energy from fossil sources with renewable energy. This contribution is enabled, for example, by substantial investment in infrastructure for production plants for renewable energy and electricity grids, but also through sector coupling and the digitisation of the energy transition. However, new energy and storage technologies, the expansion of energy infrastructures and electromobility also have significant raw material and resource requirements and are significantly changing demand on the international raw materials market.

Research on the resources for the energy transition helps to protect strategic raw materials, and those of which there is limited availability, and to use them sustainably. This reduces the risk that the energy transition may become more expensive, and may endanger itself, because of rising raw materials prices or a scarcity of raw materials. The secure provision of raw materials and their energy-efficient use are indispensable both to the success of the energy transition and to the continuance of production, in order to ensure a high level of employment and continued economic growth in Germany as a site of industry and technology.

Finally, the energy transition comprises both aspects of material and resource efficiency in that, through research, materials that are particularly energy-intensive are substituted, used more sparingly or reused. Innovations in digitisation and automation can also make a huge contribution to resource efficiency in the energy sector and in industry.

The existing recycling rates on their own will not be enough to meet the future demand for raw materials following the energy transition. In addition, the strategic approach of the circular economy should therefore be researched, building on earlier closed-substance cycle models. The circular economy envisages preserving the value of products, material and resources within the economy for as long as possible and generating as little waste and as few emissions as possible. The reuse and further use of goods without a loss of quality is the core of the circular economy. Renewable energy should cover the accordingly reduced energy consumption.

At the same time, resource research for the energy transition responds to a priority future task arising from Germany's high-tech strategy. Furthermore, the EU has adopted the Circular Economy action plan with the goal of enabling green growth and the reindustrialisation of Europe.

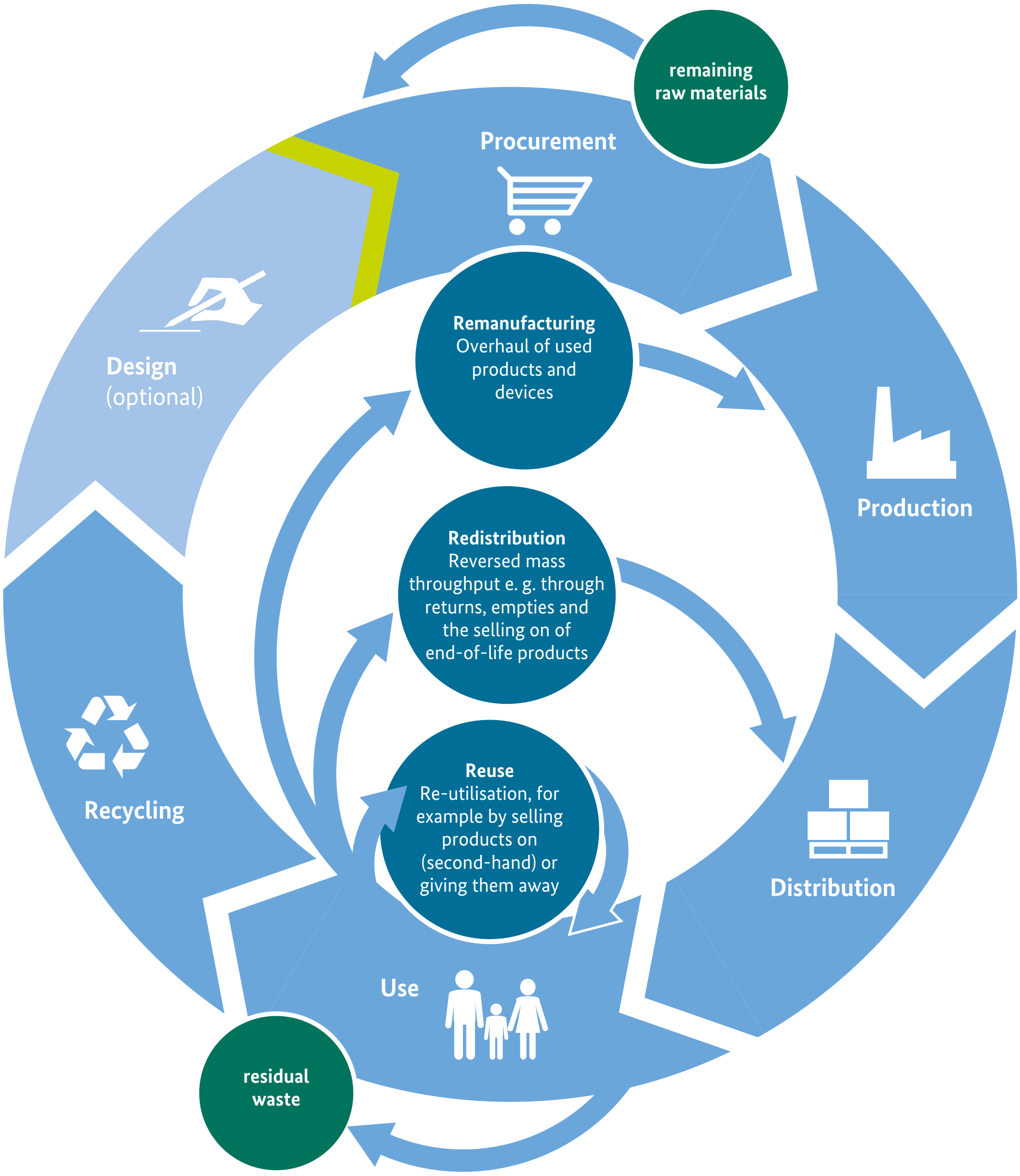
Energy research therefore contributes to the three central spheres of activity of safeguarding raw materials, achieving energy and resource efficiency and the circular economy.

Strategically important R&D topics

Above all, research is designed to address the substitution of the raw materials that are in greater demand following the energy transition with secondary raw materials or raw materials that are more available, while also increasing the efficiency of energy storage facilities (for instance, through lightweight design or raw material substitutions). Furthermore, research should provide the design basis for the generating plants, distribution plants and conversion plants of the energy transition, making it much easier to subsequently (re-) use the materials. The use of non-biogenic residual and waste materials to produce energy must also be improved, for example using gasification technologies. The rate of reclaimed raw materials from production plants for renewable energy (for example, for photovoltaic plants) is to be increased with the help of research, and the utilisation phase of energy technologies with limited resources is to be extended.

In the field of wind energy installation development, research seeks, for example, to reduce service life costs through more resource efficiency, the use of lightweight technologies and a holistic assessment of the installation design from the energy yield through the installation's service life to the removal/recycling of the components. Similarly, the goal with the development of photovoltaic modules is to reduce, or completely avoid, materials that have sometimes been used to date and that are hazardous to health (such as lead and cadmium), or scarce resources (such as indium). The focus for energy-optimised buildings and industrial products is on innovative lightweight technologies and on better removal and recycling capability. For the development of storage technologies, resource research concentrates on the substitution of scarce and expensive raw materials as well as their most efficient possible subsequent uses (second-life, second-use, re-use).

Figure 11: Circular economy model



Source: Project Management Jülich

Organisation of R&D funding

Energy research should be structured in such a way as to complement the ongoing activities of the BMBF framework programme Research for Sustainable Development (FONA), particularly here with respect to raw materials technologies, resource efficiency and recycling.

The circular economy is firmly embedded in the EU research programme "*Horizon 2020*" and in the follow-on programme "*Horizon Europe 2021–2027*", in the LIFE funding programme as well as additional funding programmes of the European Investment Bank (EIB) and the EU structural funds (e.g., INTERREG).

4.4.4 CO_2 technologies for the energy transition

Energy-sector relevance and strategic goals of R&D funding

CO_2 emissions are one of the primary drivers of anthropogenic climate change. In Germany, CO_2 emissions primarily arise in the context of the use of fossil energy sources such as coal, oil and gas. The reduction of energy-related CO_2 emissions is therefore a key energy policy objective. Energy research addresses this goal by increasing energy efficiency, integrating renewable energy into the energy system and developing alternative industrial processes that generate lower greenhouse gas emissions, or no emissions.

In the area of industrial processes, two mutually complementary strategies are pursued. On the one hand, an increase in energy efficiency thanks to the lower use of energy leads to a sustainable reduction in energy-related CO_2 emissions in the industrial sector (see Section 4.1.2). At the same time, technologies for closing the carbon cycle are being developed for certain industrial processes for which the formation of CO_2 is difficult or impossible to avoid. For example, CO_2 can be used in the chemical industry as the starting point for base materials (conversion to polymers, basic chemicals, etc.). It can also be used to produce liquid fuels and combustibles in the context of sector coupling (see Section 4.3.3). Closing the carbon cycle requires technologies for separating CO_2 from waste gases or the atmosphere. This can be achieved biologically (plant growth) or by using technical methods. CO_2 technologies for separating, transporting, storing and using CO_2 require more intensive research so that domestic companies and research institutions can assume a pioneering role in them, including for exporting the relevant technologies.

Strategically important R&D topics

The Federal Government has identified the following strategically important R&D topics to support the development of CO_2 technologies in the context of the energy transition through research funding:

- The development of low-CO_2 industrial processes,
- Scalable technological processes and economic concepts for CO_2 separation (e.g., using gas separation membranes) for industrial processes,
- The modification of new CO_2 separation technologies, installations and components, and those that have already been developed, for use in industrial CO_2 sources (e.g., production processes for the steel, cement and lime industry, waste incineration),
- Operating concepts and flexibility of CO_2 infrastructures and proposed tools for various areas of application,
- Robust processes and new, highly flexible catalysers for converting CO_2 into basic chemicals, incl. the demonstration of a complete CCU chain (CCU: Carbon Capture & Utilisation). This particularly relates to those processes that result in the immobilisation of CO_2, for example, in persistent materials and products, if necessary through mineral binding (enhanced weathering),
- Most of all, the chemical utilisation of CO_2 to manufacture basic chemicals requires research work on synthesis and catalyst developments in order to increase the reaction turnover and achieve high selectivity and stability in respect of contamination,
- CO_2 separation directly from the atmosphere using technical systems or through the permanent binding of the carbon contained in biomass,
- The direct utilisation of CO_2 (e.g., CO_2 as a working medium in ORC processes and in cooling units as well as air-conditioning units or as a heat transfer medium in borehole heat exchangers and geothermal applications),

- The direct electro-chemical conversion of CO_2 (e.g. co-electrolysis) into resources,
- Research into alternative CO_2 implementation processes (e.g., plasma-induced reduction),
- The initial development and further development of resources for various applications and components (e.g., pipelines, CO_2 compressors, CO_2 separation processes, co-electrolysis) as well as the development of transport alternatives to develop a comprehensive CO_2 infrastructure,
- The identification and development of sustainable technologies for closing the carbon cycle.

R&D funding structures

The development and operation of a complete CCU chain from CO_2 separation to sustainable CO_2 utilisation would also be possible as part of a living lab as well as in the Kopernikus projects. Particular attention must be paid here to the lifecycle analysis of the CO_2 that is utilised. Nationally, the Federal Government supports the Research Network Flexible Energy Conversion, which serves as an information and discussion platform for research-policy topics such as CO_2 technologies. The Federal Government continues to support international R&D activities, for instance by cooperating within ERA-Nets (e.g., ACT) in the European Framework Programme for Research.

4.4.5 Energy transition and society

Energy-sector relevance and strategic goals of R&D funding

Following the recommendation of the “Secure Energy Supply” ethics commission, the Federal Government has always understood, and implemented, the energy transition as being a joint effort for the future. The necessary changes can only happen through the participation of all of the societal players. For a transformation process such as the energy transition, a constructive social dialogue is critical.

For the implementation of the energy transition, aside from providing procedures and orientation knowledge through research, science also bears increasing responsibility for the transformation process itself. It can offer solutions, but it can also participate in the implementation in a supporting and advisory role, by jointly advancing suitable technical and social innovations with the state and civil society. Here, ethical questions must often also be considered with respect to the consequences of individual technologies or of the energy transition as a whole. At the same time, however, not all questions can be answered purely scientifically and objectively – science cannot replace societal dialogue and the democratic process.

Science should therefore strive to examine technological requirements and social needs in a transdisciplinary discussion and address technical consequences in a transparent manner. It can investigate possible solutions experimentally, in other words, under realistic conditions, and examine their social and economic impact. In interdisciplinary collaboration, science is asked to predict societal and institutional conflicts of objective. It should offer approaches and agendas that allow the energy transition to be implemented in a coordinated and effective manner. In addition, through its advisory services it can help the organisations of society and of the market, to develop regulatory and structural measures, business cases and market strategies that effectively support the market launch of innovations. This of course also includes science’s communication and transparency. The researchers undertake to act transparently and to engage in proactive publicity work when reporting on progress and setbacks. They should set out the relevance of their own work, but should also question it critically.

Strategically important R&D topics

Societal research into the energy transition must incorporate many different areas of activity.

The following topics and developments deserve particular consideration here:

- Data capture and the ascertainment of the underlying technical, social, economic and institutional framework, the estimation and assessment of the consequences of intervention and the investigation of business cases for corporations and companies plays an important role.
- New instruments for data processing, versatile and extensive amounts of data (big data) and data exchange in social media form another innovative tool that transcends disciplines for collating and presenting enabling

conditions as well as assessing possible consequences. Innovative digital instruments such as forms of simulation, visualisation and communication should be provided for the planning and participatory optimisation of energy transition measures.

- Resulting new forms of information and participation can provide significant support during collective planning, that incorporates society, and in identifying equitable, low-conflict and widely-accepted solutions. Ongoing scientific methodological development helps to design effective forms of participation that are adapted to the various different actor and user groups and to measure investment successes.

- Efficient, climate-friendly and resource-saving consumer goods and strategies for avoiding emissions, for the development of which scientific research makes a huge contribution, tend to resonate most successfully in citizens' consumer and usage behaviour when they can also offer them practical advantages. Behavioural economics experiments, living labs and model regions can usefully complement the proven methods, which are primarily based on model-based deductions and surveys. These make it possible to empirically and experimentally identify needs and acceptance barriers.

- The implementation of the energy transition requires market mechanisms and regulatory frameworks that allow the potential of innovative technologies and business models to be reached. Their investigation and design must take place in a comprehensive way to take account of the implications across sectoral boundaries.

- The Federal Government will support structural change in Germany's lignite mining regions and will ensure that there are concrete future prospects for the period after coal has been phased out. In this context, energy research requires a greater degree of socio-economic research in order to be better able to evaluate the anticipated consequences of particular measures.

R&D funding structures

The results of such fundamental investigations must be produced with the participation of all relevant actors and be conveyed in a way that is oriented to the target group. Studies, stakeholder workshops, guides and planning aids can support the subsequent planning and decision-making processes. This also includes the experimental investigation of energy transition measures in behavioural-economics experiments or accompanying investigations in living labs and model regions.

4.4.6 Materials research for the energy transition

Energy-sector relevance and strategic goals of R&D funding

Many advances in technology were historically driven by advances in materials research. Therefore, the energy transition depends on "energy materials" – new materials or variants of existing materials with substantially improved properties. This can be achieved, for instance, through functionalisation or structuring.

Materials research for the energy transition must also consider the huge range of fields of application in the areas of energy efficiency and power generation, electricity grids and energy storage, CO_2 technologies, as well as current production processes and technologies. The research and development carried out in the laboratory is supported by digital simulation and modelling technologies as well as measurement and testing technology. These help to accelerate the innovation process and enable certain methodologies to be carried out (e.g. a comprehensive material design screening). Further progress in standardisation should help in the manufacturing of new materials. In addition, it is necessary to create synergies between different technologies in comparable applications. These objectives can only be achieved through transdisciplinary research and international cooperation, where appropriate.

The energy transition has already begun, for which reason it is necessary to primarily answer those questions relating to material science which have high application potential, i.e. practical solutions. These must be flanked by proposals for transferring these into practice.

Strategically important R&D topics

Important general research fields in the area of materials research are:

- reducing the costs for energy materials,

- using economical, abundant materials and raw materials that are available at a reasonable cost, as well as recycling and resource efficiency (see Section 4.4.3);
- substituting materials that are rarely used nowadays, are harmful to the environment and involve energy--intensive manufacturing,
- developing production strategies that are more energy efficient and better suited to the materials used,
- gaining insight into the underlying mechanisms and reactions of chemical processes (particularly of the catalytic process).

There is a need for the following research in these fields of application:

- developing and improving materials to optimise energy production (in production plants) from renewable energy sources such as photovoltaics, solar energy, wind energy, geothermal energy and bioenergy,
- developing and improving materials for energy storage and energy transfer media such as new materials and concepts for high-performance battery systems, supercapacitors and fuel cell components, post-lithium-ion batteries, next generation thermal storage (large thermal storage capacities, isentropic energy storage), electrolysis, energy grids etc.,
- developing and improving materials and production processes to increase energy efficiency in industry with the aim of substituting energy-intensive processes whilst considering the overall energy balance,
- applications in the fields of mobility, buildings/neighbourhoods such as high-performance thermal insulation, transparent insulation systems, battery components, lightweight construction materials, heating and cooling management systems,
- developing and improving materials used to align the operations of fossil fuel power plants with the challenges of the energy transition. These include fibre-reinforced ceramics for gas turbine plants, high-temperature metals and coatings, materials with improved corrosion properties, as well as thermal and thermochemical energy storage in power plants.

These goals must be underpinned by advances in the relevant manufacturing and synthesis processes, the processing and handling steps, improving the recyclability of the materials developed, advances in simulation and modelling, measurement and testing technology, and in standardisation.

Organisation of R&D funding

Innovative materials are taking on a very important role in nearly all areas of technology relating to energy. They improve on existing technical solutions and tap into new functionalities. Materials research therefore provides a fundamental contribution to nearly all of the topics covered in the Energy Research Programme, particularly the energy transition in the consumption sectors (see Section 4.1), power generation (see Section 4.2), electrical energy storage (see Section 4.3.2), resource efficiency (see Section 4.4.3) and CO_2 technologies (see Section 4.4.4).

The Materials Roadmap, which expands on the Technology Roadmap developed within the scope of the SET-Plan, lists important research and innovation activities in the materials field which should drive forward energy technology development for the next 10 years. The Roadmap provides pragmatic guidelines for research and development activities in the area of materials used for power generation and is the basis for the research and innovation programme of the European Union and the programmes of the Member States.

Dealing with questions relating to material sciences in junior research groups has proved to be a promising funding measure and should therefore be continued. At the same time, it is essential that the (further-)developed materials and processes are transferred quickly into practice, e.g. with the help of lighthouse projects.

Materials research is a global topic of interest since its findings can be utilised universally. International cooperation is therefore being strengthened in the form of bilateral and multilateral research alliances where national measures are interlinked with the programmes in use in other EU Member States and non-EU countries. As part of Mission Innovation, the *Clean Energy Materials Innovation Challenge* is forging ahead with materials research for the energy transition.

4.5 Nuclear safety research

Energy-sector relevance and strategic goals of R&D funding

By the end of 2022, Germany will stop using nuclear energy to generate electricity. To ensure safe operation during the remaining time and in the following years of decommissioning operations, continued technical-scientific monitoring at the highest level is still essential, as is maintaining national expertise on this issue and its use in national and international bodies. This also includes having sufficient human resources.

Looking at the situation outside of Germany, nuclear power plants are continuing, and will continue in the foreseeable future, to supply electrical energy. Given that potential operational risks in other countries could cross borders and reach Germany, it is in the safety interests of Germany that its specialists can continue in the long term to follow developments in neighbouring countries relating to existing and planned power plants.

Furthermore, Germany will still be responsible for the safety of irradiated fuel elements and radioactive waste management for a period reaching far beyond the operation of German nuclear power plants. In the 18th legislative period the German government adopted measures to continue developing the legal, organisational and financial framework for nuclear waste management. These measures mean that German waste management research faces new challenges which go beyond existing research and development activities.

The Atomic Energy Act (AtG) ties the approval of a nuclear plant to safety regulations in line with the advancing state of science and technology. Government nuclear safety and waste management research plays a key role in the advancement of this science and technology. This applies for the operation, decommissioning and dismantling of nuclear power plants and research reactors, just as for the temporary storage and management of radioactive waste. There are also international obligations to the European Union (Euratom) and the International Atomic Energy Agency (IAEO) in the areas of nuclear safety and waste disposal.

Continued research funded by the government into nuclear safety and waste management is essential for preserving and extending technical-scientific expertise in the long term. This ensures that national and international safety and waste management concepts can continue to be independently tested, evaluated and developed further. It is vital to retain the expertise and specialist personnel responsible for the safety questions that must be answered for the operation and decommissioning of nuclear plants, for the interim and final disposal of waste, and for radiation protection and radiation research. This serves to ensure that Germany remains influential in the field of reactor safety in the long term and will guarantee the safety of waste management and the regulations on radiation protection in Europe and worldwide. This is also the aim of institutional and project-funded research that is independent from operator interests. This research includes funding projects that are directly aimed at junior colleagues. This project funding is in addition to the long-term institutional funding of the Helmholtz Association of German Research Centres (HGF) and these projects also have access to the experiment facilities and corresponding infrastructures available at the Helmholtz centres.

4.5.1 Reactor safety research

The funding measures of the Federal Government over the past decades have been key for ensuring that German reactors are recognised as amongst the safest in operation in the world. The findings of this kind of research have provided impetus on multiple occasions for further improvements to safety technology and safety culture both at home and abroad.

In light of the political decision made back in the year 1998 to end the use of nuclear energy for the generation of electricity, recommendations were provided by the Evaluation Committee for "Nuclear Reactor Safety and Waste Management Research", established by the Federal Government, on setting priorities and on the cooperation of research institutes. These resulted in the establishment of the Network for Competence in Nuclear Technology and the recommendations have been regularly updated since then. The last update by the Competence Network was carried out in the year 2013. Here significant modifications were made in light of the expedited phase-out of nuclear energy, triggered by the reactor disaster in the Japanese nuclear plant Fukushima-Daiichi.

Strategically important R&D topics

With these funding measures the Federal Government is pursuing the following complementary strategic objectives:

- ensuring the technical-scientific safety of the remaining German nuclear power plants and research reactors during power operation, including the decommissioning operations that will take place in the years that follow,
- retaining and increasing expertise relating to safety technology in order to evaluate and advance safety approaches of nuclear plants abroad, including new reactor concepts that are being developed internationally and have a different safety concept from the plants operated in Germany.
- employing methods and tools of reactor safety research to examine selected issues on the management of radioactive waste, particularly in connection with prolonged temporary storage (e.g. long-term behaviour of irradiated fuel elements and radioactive waste) and alternative waste management strategies, as well as strategies used in other countries (see Section 4.5.2),
- making a substantial contribution to build, advance and retain scientific-technical expertise and to support young researchers in the area of nuclear safety research in Germany.

Some of the key topics in reactor safety research that must be dealt with and which are also being pursued at international level (by Euratom, the OECD/NEA, for instance) are:

- realistic, detailed descriptions of the processes in the reactor core, in the cooling cycles and in the containment during power and decommissioning operations, as well as during incidents and accidents, identifying measures to contain even serious incidents,
- materials science investigations on structural materials, components and materials, especially on ageing and integrity, methods for material characterisation and non-destructive testing,
- methods of structural analysis for assessing the integrity of building structures and components,
- safety-relevant impacts of human activities and of organisation,
- probabilistic methods for improving tools that identify vulnerabilities in the power plant design and process management,
- safety issues relating to innovative safety systems and digital control systems.

4.5.2 Waste management and repository research

Repository research has been conducted in Germany for more than 50 years and has built up excellent, internationally renowned scientific expertise in Germany on the management of radioactive waste. Selecting a site for this waste in Germany and giving equal and unprejudiced consideration to all host rocks poses new challenges for nuclear waste management research. Besides final disposal in deep geological formations, waste management research also includes specific pre-emptive measures as well as studies on the effects of considerably longer temporary storage times on waste and containers that one can expect to see in future. This research also involves the final disposal of the radioactive waste as the last step. Besides direct final disposal in deep geological formations, it is necessary to assess alternative options for safe waste management and to test, where appropriate, their technical practicability.

The funding measures carried out by the Federal Government over the past decades have greatly contributed to creating a scientific-technical basis for future repository concepts and safety assessments. Germany has a well-funded scientific basis covering a comprehensive range of topics and is home to internationally renowned research institutes in the field of nuclear waste management. A contributing factor to this is the consistent observance of and active participation in relevant developments abroad within the context of international cooperation.

This independent, broad-based, national and international research and development activity ensures – as a kind of preventative research – the continual improvement of the scientific foundation that has been laid for the management of radioactive waste, and, thus, also the improvement of the state of the art in science and technology in Germany. This research takes place independently of the institutions involved in the processes of selecting sites for waste storage. The interdisciplinary exploration of the technical, social and procedural aspects of waste management helps to strengthen understanding of the complex interrelationships connected with the site selection processes and disposal strategies.

Strategically important R&D topics

The objectives and strategies of project funding for waste management research are presented in detail in the funding plan of the BMWi "Research into the management of radioactive waste". These are regularly reviewed and updated with the involvement of independent experts.

With these funding measures the Federal Government is pursuing the following complementary strategic objectives:

- laying the scientific-technical foundations for the realisation of a repository, especially for heat-generating radioactive waste,
- creating a broader, more solid knowledge base and foundation for decision-making through studies on alternative waste management strategies and on those options preferred abroad,
- developing the required methods and techniques for specific measures used in the preparation of final waste disposal, paying particular attention to the effects of longer temporary storage periods, e.g. on waste and containers. Developing also the methods and techniques required for the conception, construction, operation and decommissioning of a repository, and in parallel the continual development of the state of the art of science and technology.
- Making a substantial contribution to build, advance and retain scientific-technical expertise and to support young researchers in the area of nuclear waste management in Germany.

Some of the key topics in waste management research to be dealt with in future and which are also being pursued at international level (i.e. under the framework of Euratom, European Joint Programming; Implementing Geological Disposal of Radioactive Waste Technology Platform, IGD-TP; OECD/NEA) include:

- the instrumental and methodological development of the *safety case*;
- an in-depth analysis of system behaviour and development and of the technical feasibility and long-term behaviour of repository components,

- measures to ensure operational safety and to monitor the repository system and its surroundings,
- the effects of longer temporary storage periods on spent nuclear fuel, radioactive waste and its storage containers in relation to repository-appropriate conditioning and necessary transport,
- development of scientific foundations for site selection of the repository and studies on alternative waste management methods instead of direct disposal in a mine,
- consideration of socio-technical issues and taking into account interdisciplinary and transdisciplinary approaches, governance issues and the inclusion of interested members of the public and policy-makers,
- development of concepts, methods and techniques for the control of nuclear materials (Safeguards).

4.5.3 Radiation research

New requirements are to be fulfilled by radiation research as a result of amended political framework conditions reflected in the Repository Site Selection Act, prolonged temporary storage of radioactive waste, and the overall extended period it takes to identify suitable storage sites and safe final disposal.

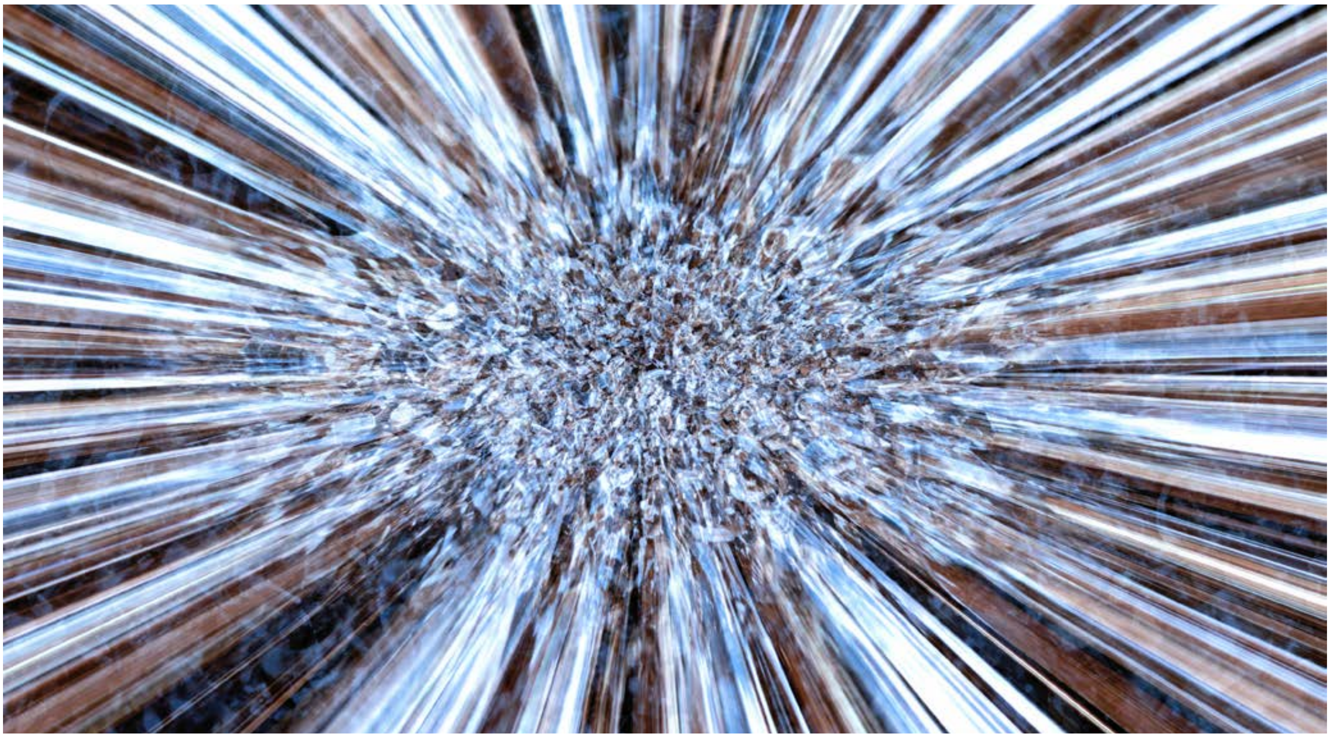
The studies carried out in this connection on the impact and consequences of low-level radiation exposure on humans and the environment are laying the foundations for an approach to radiation protection aligned with the latest developments in science and technology. Radiation research is of key importance for risk assessment and preventative protection not only in the areas of decommissioning nuclear stations and the disposal of their waste but also in the other areas of natural and man-made radiation exposure in everyday lives, e.g. through radon and UV radiation, during medical procedures or when flying.

At the centre of project funding on biological, biogeochemical, medical and radioecological aspects is, besides gaining scientific insight, a systematic focus on supporting junior researchers and maintaining competence in this area. The aim is to ensure that German radiation research covers a wide range of topics, has a high scientific performance and is internationally competitive. Research should also cover the higher demand for highly-qualified radiation protection experts in authorities and in industry that is predicted as a consequence of decommissioning and waste disposal activities. To this end, essential research issues affecting society as a whole are addressed through interdisciplinary and transdisciplinary research alliances, for instance on the effects of low doses of radiation.

This can build on the targeted funding of radiation research that has been carried out over the past decade. This has meant, for instance, that highly-competent research alliances could be established and new fields such as epidemiology, systems biology, radioimmunology and molecular targeting could be addressed.

Research topics of the future will be in the following areas in particular:

- *Radiation epidemiology and radiation risks*
- The aims of this research include exploring the mechanisms that lead to radiation-induced cancer, the identification of specific biomarkers to aid understanding of radiological impact models.
- *Radiation protection and dosimetry*
- Studying, recording and evaluating low-level radiation doses.
- *Radioecology*
- In-depth examination of the behaviour of radionuclides in the food chain and of specific transport routes, also of weathering of contaminated materials.
- *Radiobiology*
- Elucidating cellular and molecular mechanisms from which to derive new therapeutic approaches, where possible.



4.6 Guidelines for project funding

Project funding is aimed at businesses, research institutes and universities. Funding will be provided in the form of grants for research, development, innovation and demonstration projects, pilot projects and living labs. The benchmark for the allocation of state aid for research and development and innovation (R&D&I) is the TRL of the proposed project, the Technology Readiness Level at the end of the project. For projects obtaining funding under the 7th Energy Research Programme, the area of application-oriented basic research encompasses TRL 1-3, and TRL 3-7 for the area of applied energy research. Funding activities in the format of pilot projects and living lab projects can go up as far as TRL 8 and 9.

Project funding is an instrument for supporting thematically defined and temporary projects that carry a high risk and are of national interest. It will only be provided in cases where the market cannot produce the new technical developments on its own in the foreseeable future and in cases where interdisciplinary scientific studies are of particular public interest.

The project funding is often awarded in the form of collaborative research, where universities and research institutes work together in collaboration with companies pre-competitively.

Conditions

These guidelines should provide an initial overview of the general conditions for the granting of funding. Specific details on the funding arrangements are published in sector-specific funding guidelines and calls-for-proposals which ensure that the funds are used in the German national interest and in accordance with statutory and sector-specific regulations.

The 7th Energy Research Programme describes the eligible topics, formulates the main features of the funding policy and constitutes the basis for funding decisions.

Project funding for research, development and innovation in the field of energy is a competence of the Ministries concerned (BMWi, BMEL, BMBF), which each publish funding guidelines within their fields of competence. The federal ministries receive support throughout implementation from project management agencies:

On behalf of the competent ministry, the project management agencies review each project proposal and each funding application and check that it fits the profile of the programme, how innovative it is, its plausibility and feasibility, that the funding amount is appropriate as well as the level of expertise and financial standing of the applicant. They also assess the possible contribution that the project can make to achieving the political goals of the Energy Research Programme. Where suitable, expert appraisers and panels of experts are consulted. If these criteria are all sufficiently fulfilled, the proposed project can be recommended for funding. The final funding decision is made by the competent federal ministry (awarding authority) at its discretion within the limits of the funds available. There is no legal entitlement to this funding.

Those eligible to apply are companies producing in the European Economic Area – particularly SMEs –, universities, and non-university research institutes domiciled in Germany as well as other institutions and legal persons. Generally speaking, the project should be conducted and realised within the European Economic Area. Furthermore, applicants must generally bear a part of the project costs themselves and must demonstrate this when submitting the application.

Cross-departmental funding initiatives

As a specific contribution to achieving the political climate and energy objectives, the present Energy Research Programme of the Federal Government intends to strengthen system-oriented research approaches with cross-cutting issues in areas of relevance for the energy transition. To this end, research initiatives are being carried out across multiple ministries and programmes, for instance "Solar Construction/Energy Efficient Towns" or "Energy transition in the transport sector: sector coupling through the use of electricity-based fuels". Further funding projects with inter-departmental cooperation are possible.

The joint funding initiatives are characterised by a broad range of topics, high complexity and issues requiring intense cooperation between basic research, applied research and technological development to ensure successful implementation.

For this reason, each project is implemented by a central programme management concept. One element of this programme management is a common contact point. This contact point answers initial enquiries relating to funding and receives all project ideas. This structure also applies to comprehensive funding initiatives in the form of living labs and for specific funding groups such as startups.

Generally, the project proposals received are allocated to the relevant ministry and the relevant funds according to the outlined project themes. The formal applications are processed in the second stage of the process at the project management agency. This simplifies the process for the applicant and means that the danger of double funding can be avoided at an early stage.

Financial arrangements of project funding

Funding is awarded in the form of grants. Its legal basis is the Federal Budget Code (BHO) together with the General Administrative Regulation on the Federal Budget Code (VV BHO), in which the requirements and procedures are laid down. Furthermore, EU rules on state aid and the current version of the general block exemption regulation (EU) No. 651/2014 and the Union framework for State aid measures for research, development and innovation must be observed.

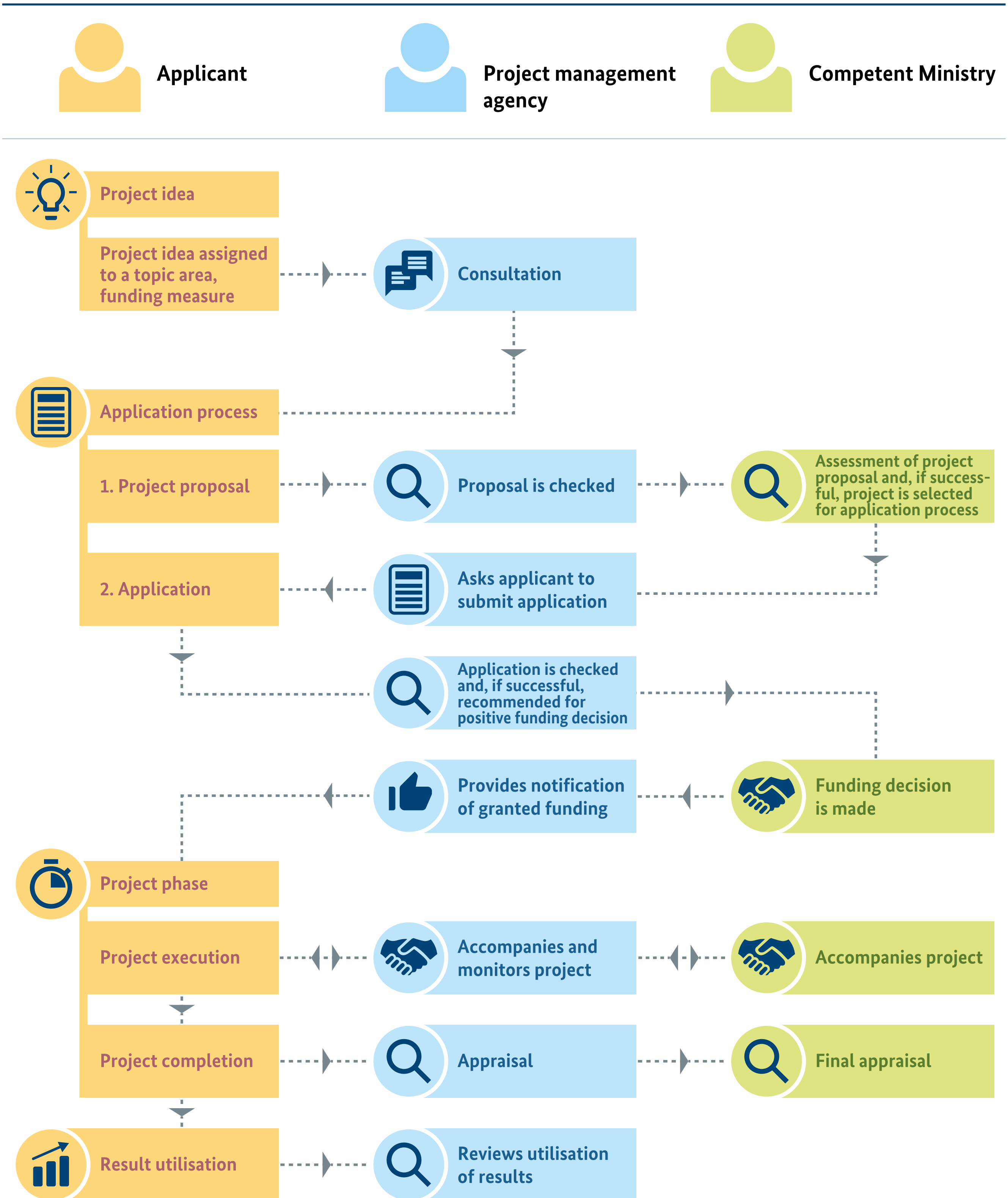
The grants are awarded in the form of partial funding for the co-financing, deficit financing, fixed-sum financing, or – in exceptional cases – full financing of a project.

For applicants from public institutions, the project costs generally serve as the basis for calculating the amount of funding. For commercial companies the project costs including overheads form the basis for funding.

The funding rates cannot exceed the maximum amount indicated in the general block exemption regulation and the Union framework for State aid measures for research, development and innovation of the European Commission. For example, in the case of application-oriented projects (which are the kind generally carried out by industrial companies) the funding rate is 50% of the costs. Universities can be supported with a funding rate of up to 100%.

Factors determining how high the funding rate may be are: regulations governing state aid law and, following the principle of making efficient and economical use of public funds, also the technical-scientific risk of the project, as well as the extent to which it is deemed to be in the national interest.

Figure 12: Steps of project funding



Source: Project Management Jülich

Project implementation

An important concern of the Federal Government is to provide detailed and competent advice to applicants on the funding possibilities available under the Energy Research Programme. One of the first contact points for this advice is with the project management agencies which are commissioned to implement and execute this research programme on behalf of the competent ministries.

The project management agencies supervise and accompany the projects with both technical and administrative support – starting with receipt of applications, then providing advice during the application stages, reviewing applications, making preparations for the funding decision, providing technical and administrative support for the project and project performance right the way through to utilisation of the project findings. The order of events for a successful project from the idea through to utilisation of the results is depicted in figure 12.

Utilisation of results

For a project to be successful, it must ensure the best possible utilisation of its results. The funding guidelines therefore require that during their application, candidates provide a plan containing a clear description of the utilisation of results that will later follow. The party executing the project must undertake to implement this utilisation plan. In return it receives the rights to exclusive use of the results. Nevertheless, it must ensure that for all research projects where commercial utilisation is expected, the results obtained are patent-protected. This is because it is in the interests of project funding that, where possible, new patentable findings are filed for patenting. For small and medium-sized companies and public research institutes, the costs associated with this process are eligible for funding. Furthermore, there is a general obligation to publish findings in the form of papers for conferences and/or the specialist press. The transfer of this knowledge into practice should also be supported in other ways, for instance through participation in the Energy Research Networks.

List of project management agencies

This list is subject to change over the programme duration since project management roles are generally awarded through a call for tender.

Energy technology incl. basic research

Project Management Jülich (PtJ) –
Division for Basic Energy Research (EGF)
Forschungszentrum Jülich GmbH
52425 Jülich
Tel.: 02461 61-3547, Fax: 02461 61-2880
PTJ-EGF-7EFP@fz-juelich.de, www.ptj.de

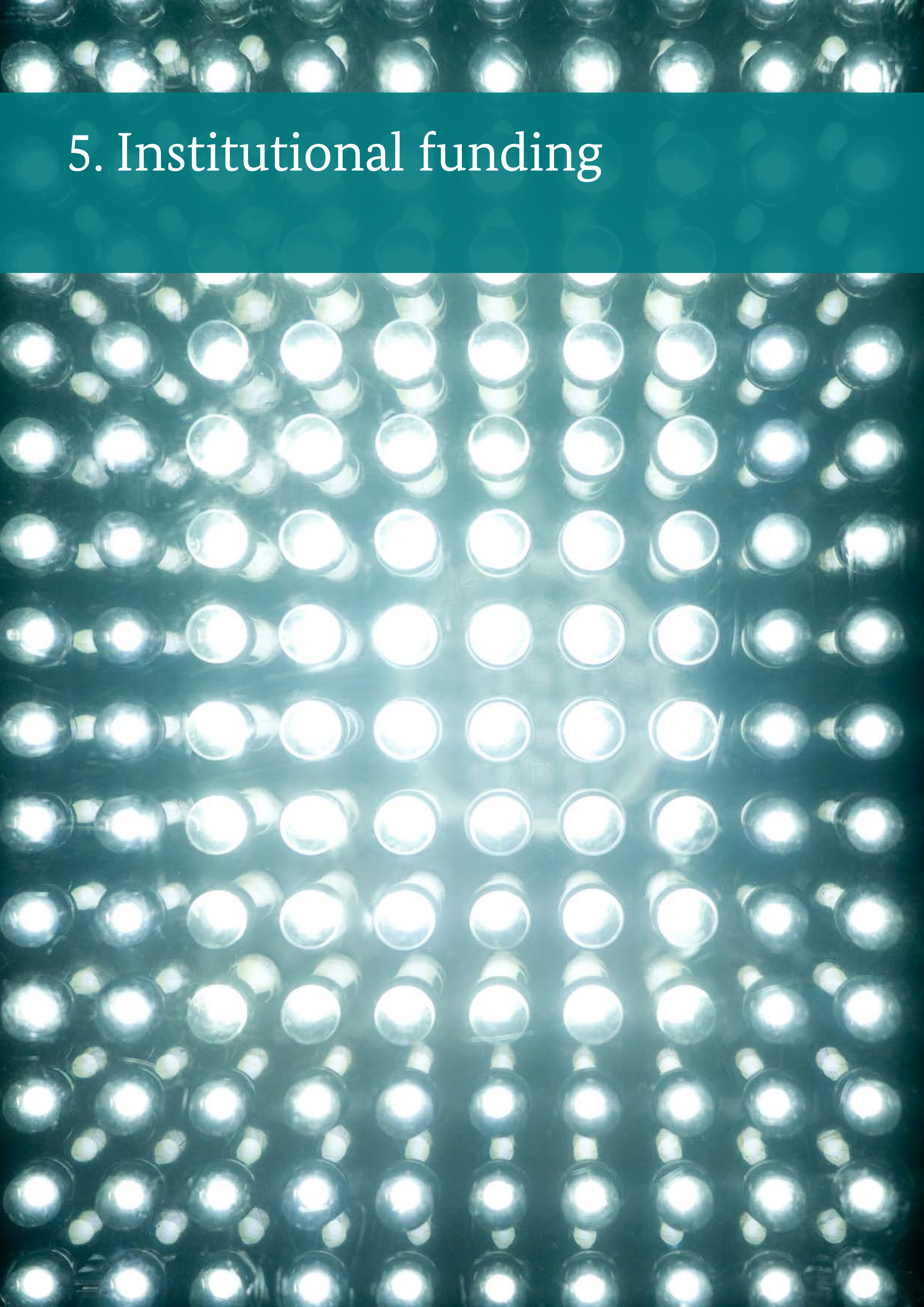
Project Management Jülich (PtJ) –
Division for Energy Systems (ESI, ESN, ESE)
Forschungszentrum Jülich GmbH
52425 Jülich
Tel.: 02461 61-1999, Fax: 02461 61-2690
PTJ-ESX-7EFP@fz-juelich.de, www.ptj.de

Nuclear safety research
Reactor safety research (BMWi)
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)
gGmbH – Project Management Division
P.O. Box 10 15 64, 50455 Cologne
Tel.: 0221 2068-720, Fax: 0221 2068-629
projekttraeger@grs.de, www.grs.de

Nuclear waste management research (BMWi),
Nuclear safety research and radiation research (BMBF)
Project management agency Karlsruhe (PTKA) –
Division for Water Technology and Waste Management
Karlsruher Institut für Technologie (KIT)
P.O. Box 3640, 76021 Karlsruhe
Tel.: 0721 608-25790, Fax: 0721 608-925790
info@ptka.kit.edu, www.ptka.kit.edu

Bioenergy
Agency for Renewable Resources (Fachagentur
Nachwachsende Rohstoffe e.V.)
Hofplatz 1, 18276 Gülzow
Tel.: 03843 6930-0, Fax: 03843 6930-102
info@fnr.de, www.fnr.de

5. Institutional funding



5.1 Helmholtz Association of German Research Centres

5.1.1 The HGF's research field energy

The Hermann von Helmholtz Association of German Research Centres (Hermann von Helmholtz-Gemeinschaft deutscher Forschungszentren e.V.), (HGF), differs from other institutionally funded research institutes in that its research work is embedded in programme-oriented funding (POF). This instrument pools the diverse resources of the various research centres and aligns these with the long-term research goals of the government and of society. In six research fields, including the research field energy, the HGF tackles important and urgent issues of society and the scientific and business communities with the aim of maintaining and improving the livelihood of the global population. Federal institutional funding for the energy research field of the HGF are assigned to the 7th Energy Research Programme. The Helmholtz Centres are financed 90% by the Federal Government, and 10% by the relevant Land in which the centre is located.

The transition (from the current third) to the fourth period of programme-oriented funding (POF-IV) is planned for 2021. At the beginning of 2018, the scientific work of the research field energy underwent a comprehensive scientific evaluation within the framework of POF-III. Similar assessments took place also in the other areas of research. In total around 600 internationally-renowned experts assessed the scientific work in the HGF in 32 on-site examinations. Performance was examined by international benchmarking and with regard to the POF-III programme. Together with the 7th Energy Research Programme, the evaluation reports resulting from these assessments form an important foundation for the development of political goals for HGF-driven energy research in the coming years. These goals and the programme evaluation reports also form the basis for the POF-IV programme proposals in the research field energy. The programme proposals are to undergo a strategic evaluation at the end of 2019. This, in turn, forms the basis for funding recommendations for the new POF period.

The 7th Energy Research Programme provides a framework and strategic foundation for these complex processes.

5.1.2 Content and structures of the research field energy

The HGF's research field energy addresses the great challenges facing energy policy (see Section 2). The aim of the scientific work carried out in the research field energy is to successfully implement the energy transition (nationally and globally) – regardless of whether this research be fundamental or application-oriented. There must be a clear link to applications also for basic research in the research field energy (application-oriented basic research).

With the exception of fusion research (see Section 5.1.3), which is not currently being addressed in project funding since this research tends to be long-term and focuses on basic aspects, institutionally-funded research in the research field energy of the HGF should be in line with the topics of project funding (see Section 4). The competences and infrastructures built under the framework of institutional funding can and should provide important contributions to the project funding of the Federal Government. Besides this, the scientists working in the research field energy are obliged to actively participate in the Energy Research Networks and to contribute to the continued networking activities of energy research.

In essence, the difference between this and project funding is that institutional funding aims to secure the competence and strategic positioning of the German research landscape in the long term. In contrast, temporary project funding has the flexibility to focus on current research requirements and above all sets the course for short and medium-term research policy. As a result, the HGF's research field energy has two unique characteristics: Firstly, it has large and long-term research infrastructures, secondly, it possesses systems expertise thanks to the range of expert opinions pooled into one programme structure. Thus, the research field energy is intended to especially address those scientific questions for which the HGF is particularly suited to thanks to the above-mentioned unique features and its other competencies.

Institutional funding is the appropriate method to finance major research infrastructures in the long run and to operate these sustainably. One primary task of the HGF Centres involved in the research field energy is consequently to develop and maintain these kinds of research infrastructures and to use these for their own research work. They should also make these resources available to external users from the scientific and industrial communities, and in doing so contribute significantly to strengthening Germany's position as a hub for science and industry. Thanks to these unique research infrastructures, the Helmholtz Centres are attractive partners for research institutes from all over the world. But also for the universities at regional and national level as well as for business and industry.

The funding agencies monitor the continued development of the research field energy and of the HGF as a whole. In future, this governing will take place within the framework of the new governance structure developed in 2017. At research field level there will be three governing bodies in future. The *Management Board* serves as a platform for communication, information and strategic matters for the centres involved in the research field energy. In the Research Field Platform, the centres and the funding agencies discuss and take decisions in consensus about tasks specific to that research field. A Strategic Advisory Council provides independent external scientific advice for the research programme. Procedures are designed to be consensus-based and therefore fit well into the long-term research approach of the research field energy of the HGF. Contrastingly, in project funding, new courses for research and energy policy can be set at short notice.

Even though institutional funding is supposed to be long-term, in a highly-dynamic international research system it requires suitable instruments to provide a degree of flexibility in order to react at short notice to new developments. Continual working, communication and "foresight" processes ensure that new challenges are recognised early even during ongoing phases of funding and that these are systematically transformed into new research topics and addressed using the flexibility instruments. Under the annual monitoring process, the international strategic advisory council of the research field energy discusses strategic and scientific development. It provides recommendations to the other governing bodies of the HGF, including the Research Field Platform and the Senate, to ensure dynamic development of the research portfolio.

Flexibility instruments for implementing these recommendations could be, for instance, launching strategically important future topics within the framework of funding from the Initiative and Networking Fund, the recruitment initiative for top international researchers, the establishment of Helmholtz Institutes on future key areas of research, as well as targeted reallocation of resources and scaling-back on topics of secondary importance.

5.1.3 Fusion research (high-temperature plasma research)

From the perspective of the Federal Government, the growing demand for energy is creating a need to explore a wide range of options for the future provision of energy. Given its excellent scientific know-how in fusion research, Germany has a global responsibility to advance understanding of high-temperature plasmas and fusion processes and to provide the world with access to this knowledge. The aim of research into the generation of fusion energy is to tap into a cost-effective energy source that does not rely on fossil fuels. Should this research make it into practice, this energy source will presumably only be available after the year 2050. Fusion research contributes directly to long-term, application-oriented basic research. Just as with other basic research activities, fusion research is carried out not least to advance knowledge.

Most of the funding for research into fusion is provided via the programme-oriented funding of the HGF. This programme involves the Max Planck Institute for Plasma Physics (IPP), the Karlsruhe Institute for Technology (KIT) and the Jülich Research Centre (FZJ). These research institutes dispose of outstanding scientific expertise in the international comparison. Large-scale equipment like the Tokamak ASDEX Upgrade and the Stellarator Wendelstein 7-X, both at IPP, and the High-temperature Helium Loop (HELOKA) and the testbed for superconductive components (TOSKA), both at KIT, mean that Germany can draw on infrastructure which is unmatched around the world.

The work done by IPP, KIT and FZJ is integrated into Euratom's European fusion research programme. The IPP coordinates the EUROfusion consortium, founded by 30 national fusion centres in 26 EU countries and Switzerland, which provides the new central structure for European fusion research. The IPP itself is one of the world's leading institutes.

At European level, Germany, as a member of Euratom along with all the other EU Member States, is funding the construction of the International Thermonuclear Experimental Reactor (ITER) in Cadarache (southern France). Euratom represents the EU in the ITER Council. It is one of the seven project partners alongside Japan, the USA, Russia, China, South Korea and India.

ITER is designed to produce a fusion plasma equivalent to around 500 megawatts, to deliver for the first time ever a ten-fold energy return on energy invested with respect to the energy needed to heat the plasma, and thus to demonstrate the feasibility of a controlled terrestrial generation of energy using fusion processes. The first fusion plasma is due to be ignited at the end of 2025. Full operation is due to begin ten years later. ITER is the interim step toward the first demonstration power plant DEMO, which feeds electricity into the grid. ITER will therefore test many technologies which were not needed in previous experimental facilities.

5.1.4 Transfer and communication

One of the mission goals of the HGF is the transfer of research results into industry and society. Scientific publications and comprehensible communications regarding scientific findings and research results help to fulfil this purpose. Further measures and structures are necessary, however, to systematise and accelerate the transfer of findings into practice. These include technology transfer points, close cooperation with industry and swift patent registration of R&D results. This transfer into practice can also be achieved by spin-offs and startups. What is key here is early training in entrepreneurial skills and the establishment of a scientific culture in which due attention is paid early on to the economic utilisation of research initiatives. In this connection, it is important that there is no stigma surrounding entrepreneurial failure. The possibility of failure is inherent to startups, just like in scientific experiments. Funding spin-offs with public resources requires a uniform and clear set of rules – both in the HGF and beyond. Since legal uncertainties not only tie up resources in the centres but also scare off potential investors.

Besides preparing results to be transferred into practice, a key task of research communication is to publish research content, including the successes and failures taking place within the scientific community. The aim is to provide information on the use of public funds allocated to research purposes. It must be communicated how relevant the work performed is for the societal challenges it addresses, and this must be scrutinised both internally and by industry, the government and the interested public.

Given its size and systems competence, the HGF's research field energy has a special role and responsibility when it comes to public dialogue on energy systems issues. An exchange of views should take place between the interested public, the scientific community, business and policy-makers based on valid information and scientific findings. This social discourse should not be limited to publicising energy research and its findings. Successful social discourse can be viewed as a kind of technology impact assessment, which complements the professional analysis of the impact of technological advancement from a variety of perspectives. Concerns, demands, criticism and ideas from society can thus be collected early on and taken into account in research and the development of technologies (see Section 4.4.5).

5.2 Other institutionally-funded research

In addition to the HGF there are various other scientific organisations in Germany which receive their basic funding from the federal and Land governments under joint federal/*Länder* research funding (Art. 91B German Basic Law). However, these organisations provide new insights in energy research outside of the Energy Research Programme. For instance, the percentage of energy research carried out within the institutional funding of the Fraunhofer Institute (FhG) or the Max Planck Society (MPG) is therefore not counted in the statistics for the budgetary overview of the 7th Energy Research Programme. Nevertheless, these other institutionally-funded institutions do form an important pillar of energy research in Germany. Their active participation in the Energy Research Networks is essential for successful networking activities which include the whole spectrum of energy research in Germany.

In the field of energy, the FhG focuses on the following priorities: sustainability, security and efficiency of energy supply, energy conversion, energy and resource efficiency and electromobility. Some institutes of its energy alliances, such as IWES, ISE, IBP, IEE and UMSICHT, are more closely involved than others in energy research. Energy research is also conducted at many other institutes. As the largest research organisation for application-oriented research in Europe, Fraunhofer participates as a partner for industry in many application-oriented collaborative projects within the Energy Research Programme.

The MPG focuses its energy research on the objectives of increasing energy efficiency, putting existing energy sources to better use, and tapping new energy sources. Particularly in application-oriented basic research it makes a considerable contribution to energy research, e.g. through the following institutes: MPICEC, MPI for Coal Research, Fritz-Haber-Institut, and MPIKG. Energy research also takes place in various institutes of the Leibniz Association, e.g. in the LIKAT, FIZ Karlsruhe and in the PIK. Furthermore, the academies of sciences, particularly Acatech and Leopoldina, also provide input for energy research and scientific expertise relating to the energy transition. For instance, in the form of the project ESYS. Additionally, there are other institutes which are partly funded by federal resources and focus on subdivisions of energy research, e.g. the ZSW and the DBFZ.

6. International Cooperation

6.1 Internationalisation strategy of research policy

Successful innovation resulting from research and development is an important objective for the Federal Government for strengthening international competitiveness and securing jobs. Increased international cooperation can help considerably to achieve this goal. International cooperation supports the implementation and compliance of the European and global climate protection goals and the transformation of energy systems agreed upon e.g. within the framework of the Paris Climate Change Conference (COP21) in 2015, the UN Sustainable Development Goals (Goal 7: affordable and clean energy) and the G7 process. The Federal Government is emphasising its commitment through its wide-ranging international engagement. In addition to bilateral and multi-lateral initiatives focusing on different topics, it is first and foremost supporting cooperation at European level in the EU Framework Programme on Research and Innovation and its participation in funding initiatives of the International Energy Agency (IEA).

Bilateral Cooperation

Increasingly, research and innovation processes are being integrated into global networks. To remain internationally competitive, increased cooperation between research stakeholders will be key. The Agreements on Scientific and Technological Cooperation can provide the basis for bilateral research activities (S&T). These framework agreements regulate issues from the financing of exchange programmes between researchers and students through to facilitating customs and visa procedures during cooperation activities. At the end of 2010, Germany had 48 S&T-agreements with governments all over the world. These agreements are regularly updated and adapted to current circumstances. In the upcoming years, bilateral partnerships with France, Greece, Australia and development partnerships with African countries will be the focus of German basic and systems research.

France

Together, Germany and France aim to strengthen the role of Europe in the fight against climate change and efforts to implement the energy transition. A key element of these efforts is the cooperation with the Agence Nationale de la Recherche in application-oriented basic research on grids and storage facilities. In 2+2 collaborative projects, German and French partners from the scientific and business communities are developing highly innovative, cross-sectoral and systemic solutions for the cost-effective, ecological and safe storage and distribution of energy in France, Germany and Europe. Furthermore, the project addresses ecological and social aspects, the specific economic, legal and societal features of the partner countries and the resulting implications for systemic innovations, as well as addressing measures to create networks.

Greece

Energy research is one of several pillars in research cooperation between Germany and Greece. Joint initiatives on e.g. efficient, stand-alone energy supply solutions, solar-thermal heating and cooling systems or building-integrated photovoltaics provide valuable impetus for sustainable systems solutions in the Mediterranean area. They also allow SMEs in Germany and Greece to tap into markets for innovative products.

Australia

The Federal Government intends to increase scientific and technological cooperation with Australia under their energy partnership.

Africa

Energy issues are a very important factor for economic and social development in Africa. It is very much in Germany's interest, particularly with regards to economic, security and migration policy, to help reduce disparities between levels of development and prosperity. The development of prosperity in Africa greatly depends on urbanisation and industrialisation, as well as a reliable electricity supply. Currently 75% of Africans (600 million people) have no access to an electricity supply. The Federal Government is actively involved in more than 15 African countries through the centres “WASCAL” (West African Science Service Centre for Climate Change and Adaptive Land Management) and “SASSCAL” (Southern African Science Service Centre for Climate Change and Adaptive Land Management). Building on these structures, the Federal Government will increase its involvement in Africa in the area of renewable energies. It will focus on the following strategically important R&D topics:

- collecting reliable data, analysing and estimating needs and potential,
- identifying and developing technical strategies and scenarios; focusing this research on local climate, ecological and social conditions,
- developing needs-based measures in coordination with stakeholders and decision-makers in the target countries,
- jointly developing training concepts.

6.2 European Cooperation

Energy Union and the European Strategic Energy Technology Plan (SET-Plan)

As part of the European Energy Union approach, the SET-Plan defines a strategic concept with a long-term agenda for coping with innovation bottlenecks from the research stages through to market introduction of innovative energy technologies. It pools the efforts of EU members and associated states in coordination with research stakeholders (represented by the European Energy Research Alliance, EERA) and industry (represented by European Technology and Innovation Platforms, ETIPs) with the participation of the European Commission. Within the framework of this SET-Plan, Germany is contributing to strategic projects (known as Key Actions) on non-nuclear energy topics. These topics are defined by working groups in technology-specific implementation plans. The topics include renewable energies, smart energy systems, energy efficiency and sustainable transport. These efforts are closely coordinated with the topics of the present 7th Energy Research Programme of the Federal Government and the European Framework Programme for Research (*Horizon 2020* and the follow-up programme *Horizon Europe 2021 – 2027*). Under the *Berlin Model*, national funding agencies define joint research projects on the basis of the SET-Plan. Research partners from the member states involved in these projects can each receive funding for this project from their own national funds.

German project partners can participate also in network initiatives such as EUREKA/EUROGIA and COST. Funding opportunities for the part of project work carried out by German partners can be verified following submission of an application in line with the usual national application procedure.

EU Framework Programme for Research

With a funding budget of just under EUR 80 billion, the European Framework Programme *Horizon 2020* (programme duration 2014 – 2020) is intended to strengthen the competitiveness of Europe internationally in research, development and innovation processes. In the area of *Secure, Clean and Efficient Energy*, around EUR 5.9 billion are budgeted for non-nuclear energy technologies. Until the year 2020, approximately a further EUR 2 billion will be provided here as funding for excellent project proposals. Under this framework the Federal Government is participating in shaping the content of the EU Framework Programme and is advocating the simplification and acceleration of funding procedures.

The overarching goals of European energy and climate policy are to decarbonise the economy and secure energy supply. Progress made in these areas will also make Europe more internationally competitive. Further increasing energy efficiency, widespread use of renewable energies and also the sustainable integration of these renewable energies into European energy systems are examples of topics and funding priorities which contribute significantly to this goal.

When developing the content of specific implementation measures, the EU Framework Programme follows very much the same line as the objectives of the SET-Plan. Here, the funding efforts at European and national level are efficiently pooled and the EU Energy Union policy is underpinned with a long-term agenda for coping with innovation bottlenecks. International cooperation is particularly encouraged. Using the instruments of the ERA (European Research Area), topic-specific collaborations, agreements and joint calls for tender at European level receive support and help with coordination.

As of 2021, the new 9th EU Framework Programme will continue the efforts made under *Horizon 2020* with a new focus.

6.3 International Organisations

International Cooperation within the International Energy Agency (IEA)

As an autonomous organisation of the OECD (Organisation for Economic Cooperation and Development), the IRA advises the governments of its 30 member states and international organisations on issues relating to the energy industry. It also offers a cooperation platform in the form of its Energy Technology Network (ETN) for research and the development of energy technologies. The Steering Committee of the ETN is the Committee on Energy Research and Technology, CERT. This group coordinates R&D activities at political level. It is supported in this role by specific recommendations from four Working Parties each dedicated to different topic areas. The Technology Collaboration Programmes are subordinate to the CERT and the Working Parties. These programmes represent the whole spectrum in energy technology and are the most important instrument for the implementation of international cooperation. Currently, Germany is active in 22 of the 38 TCPs and is contributing its national expertise to the international exchange of information.

Other international organisations

Besides the work carried out in the IEA, which covers the entire energy technology spectrum, there are other international organisations and bodies dedicated to selected aspects of technology development and special technologies. Particularly important organisations include the International Renewable Energy Agency, IRENA, the European Energy Research Alliance, EERA, the Association of European Renewable Energy Research, EUREC, the Carbon Sequestration Leadership Forum, CSLF and the International Partnership for Hydrogen and Fuel Cells in the Economy, IPHE. In 2009, during the Clean Energy Ministerial, CEM, which was an international initiative at energy ministry level, fora on various topics of energy technology were also established. Germany is active in these fora and contributes on topics such as smart grids and electric vehicles.

6.4 International cooperation in nuclear safety research

Research efficiency in Germany thrives on the opportunities created as a result of international cooperation and the scientific exchanges associated with this. Only by providing sound expertise (based on its own research and development) on safety technology at international level, can Germany maintain its influence in international safety discussions in the future and continue to represent its legitimate safety interests.

To this end, German research institutes are endorsed by the Federal Government to participate in activities e.g. of the European Union (Euratom), the International Atomic Energy Agency (IAEA), and of the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD). They are encouraged to contribute in consortia and working groups in which there is a strong focus on the mutual use of scientific findings and data and on long-term cooperation. This participation gives an insight into international developments and ensures that Germany can also exert influence.

The fact that German infrastructure and expertise on nuclear and scientific-technical topics is used in international networks and that Germany participates in international projects has its advantages. Germany can make use (at a shared cost) of internationally available test facilities and underground laboratories. Other benefits include the exchange of expertise and, it follows, more efficient safety and waste management research in Germany. This helps to maintain German security integrity.

6.5 Mission Innovation

In November 2015, on the side-lines of the Paris Climate Change Agreement (COP21), the initiative *Mission Innovation* was established, whose members now include 23 states and the European Union. The member states, including Germany, have committed to double public investment in research and development for clean energies within five years. During COP21, private creditors also came together to form the Breakthrough Energy Coalition, which supplements government efforts. There is also an intense exchange of expertise with the World Economic Forum, the IEA and the IRENA. Annual ministerial meetings help ensure that the topic of energy innovation and the need for a global energy transition remain a high political priority. Furthermore, various other activities take place within the framework of Mission Innovation, for instance eight innovation challenges on important areas of energy research, and the *MI Champions* initiative, which distinguishes outstanding individuals in the field of energy innovation.

Annexe

Glossary

This glossary contains terms for which there is no clear definition or a varying definition in common usage. Some terms have been taken from the EnArgus information portal (enargus.de). This website contains a wiki with many other terms.

Ancillary services: Ancillary services are additional services which ensure the grid can operate reliably and efficiently. When used in reference to the electricity grid, these services might concern operational management, frequency stability, voltage maintenance and re-establishing power generation.

Artificial Intelligence (AI): This refers to computer programmes and machines that possess abilities previously thought to have been exclusive to the biological brain (e.g. Go games, driving a car, recognising faces, translating different languages). It is possible to differentiate between weak and strong AI (intellectual capabilities on a par or superior to a human in single (weak) or all (strong) aspects). Weak AI is the type that is relevant for energy research funding.

Berlin Model: To provide funding for international cooperation in the form of collaborative projects with partners from several countries, under the Berlin Model each participating country funds the project partners from their own country. The Berlin Model is designed to implement the European Strategic Energy Technology Plan (SET-Plan) in an efficient, unbureaucratic manner.

Big data: are large unstructured data sets which are highly complex and variable. Big data can refer to all kinds of different data, such as sensor data collected by smart objects, data from social media users, financial data and energy consumption data. Ever increasing computing power and innovative data processing methods are necessary in order to process these large volumes of data.

Building Information Modelling (BIM): Stands for a method of digital planning in which the *Digital Twin* of a building is created. With the help of this digital model, the planning, construction and operation of the building can be optimised, and it is easier to react to altered requirements. The topic of *lifecycle assessment* can also be integrated into the process of BIM.

Blockchain: Blockchain technology (also distributed ledger technology) is a kind of accounting system which records transactions on a decentralised database structure whose complete content can be accessed by all parties involved. The transactions can be verified by the partners without them having to enter into direct exchange with each other or a third trusted party being involved. Many digital currencies, for instance, work on the basis of blockchain technology. What exactly is being recorded in this system is irrelevant in the blockchain principle, meaning that the idea could start being used also in other sectors of the economy (e.g. electricity trading).

Call for proposals: Calls for proposals and funding guidelines can be issued on the basis of the 7th Energy Research Programme. These are published in the Federal Gazette, they specify details of the funding procedures and can set focuses based on current developments in research and energy policy (see *Funding initiatives*).

CO_2 Closed-substance cycle: The CO_2 closed-substance cycle is intended to reduce CO_2 emissions by developing technologies to complete the carbon cycle in certain industrial processes where it is difficult or impossible to avoid production of CO_2. These might be technologies for e.g. capturing, transporting or storing CO_2 but can also be technologies for using CO_2 in the chemical industry to produce e.g. liquid fuels.

CCS: Carbon (dioxide) capture and storage: Technologies for capturing, transporting and storing CO_2 released during industrial processes.

CCU: Carbon (dioxide) capture and utilisation: Technologies for using CO_2 in applications in the chemical industry or to produce liquid fuels.

Circular economy: Describes the creation of a more circular-oriented economy where the aim is to preserve the value of products, substances and resources within the economy as long as possible and to produce as little waste as possible. The circular economy links closed-substance cycles, upcycling/recycling, energy efficiency and the sustainable use of resources with each other. The principles of the circular economy must be taken into consideration even during the stage of product design.

Closed-substance cycle: A closed-substance cycle describes an attempt to limit waste generation by prevention measures and reutilisation measures, as well as by placing unavoidable waste back into the economic cycle as a secondary raw material using professional treatment processes. The closed-substance cycle model is being developed further using the strategic approach of the *circular economy*.

Collaborative project: In a collaborative project, several legally independent partners work together on a common project with an agreed goal. To this end, they provide each other with all necessary information and rights for the duration of the project and regulate their cooperation and use of results in a cooperation agreement.

Conditioning (of nuclear energy): Conditioning transfers radioactive waste into a chemically-stable state, ensuring that this waste is packaged in line with requirements for transportation and/or final storage. Various methods are used to carry out this process.

Conditioning (electrolysis): The hydrogen produced as a result of various methods of water electrolysis requires conditioning. Different technical conditioning methods facilitate the necessary steps of gas drying and compressing the hydrogen for its use in storage, distribution and application. Gas conditioning is energy-intensive and of relevance for processing costs.

Decarbonisation: Restructuring economic systems to achieve a lower carbon turnover. The main aim of this is to replace activities and processes which release CO_2 into the atmosphere with low-emission alternatives.

Digital twins: are an important element in the digital representation and integration of production, operation and maintenance processes in an industrial context and form the basis of modelling software used in the construction of buildings and neighbourhoods. These may be digital models or a digital image of the real measurements taken from real system components. Digital twins can also be control modules which can be used to optimise and simulate not only industrial plants and their operation but also buildings and neighbourhoods.

Digitisation: refers to the digital revolution driven by digital technology and computers which has been changing nearly all aspects of life for several decades now. Correspondingly, the digitisation of the energy transition is the collective term for an array of highly dynamic developments in the area of modern information and communication technologies (ICT) and their applications and the effects of these on energy systems.

End-use energy: is the usable part of the primary energy (see *energy chain*) that is available to the consumer. This is calculated by subtracting the losses in energy incurred due to energy conversion and energy transport from the primary energy.

Energy chain: the successive conversion of energy from its original form, known as the primary energy, through to the energy service utilised by the consumer.

ERA-Net: In an ERA-Net, research funding organisations and programme agencies of several EU Member States form a partnership (consortium) on a specific topic. The aim is to strategically coordinate national programmes. To this end the consortium partners, supported by the EU, issue joint calls for tender for the funding of transnational research and innovation projects.

Funding initiatives: To address particular research topics and the challenges of the energy transition, or to implement specific formats of research funding, the Federal Government launches research initiatives at a given time. These can be implemented by individual or several ministries and are published in the form of a call for proposals. This gives the Federal Government the opportunity to react at short notice to current developments during the running period of the Energy Research Programme.

Funding guidelines: see Call for proposals.

Implementation Working Group: see *Temporary Working Group.*

Industry 4.0: is a concept describing manufacturing technology and logistics which are digitised and fully networked.

Layout: The designed positioning of something laid out or an intended spatial arrangement. For instance, the spatial arrangement of wind turbines on wind farms and installations in a factory.

Lifecycle assessment: A lifecycle assessment (also known as environmental balance or ecobalance) is a systematic analysis of the environmental impact of a product. A lifecycle assessment looks at all environmental impacts occurring during production, use and disposal of the product, as well as the upstream and downstream processes associated with these (e.g. the production of raw, auxiliary and operating materials).

Living labs: are large, systematically-constructed transversal projects spanning various topics, in which the interaction of different energy technologies is tested in real application settings. Living labs are based on innovative concepts for achieving objectives of energy and climate policy. A living lab may require adaptations to the regulatory framework. They always involve close scientific monitoring. Research focuses mainly on those issues, which cannot be investigated in the artificial conditions of a laboratory environment. The main objective of a living lab is to put innovations faster into practice.

LowEx: LowEx systems are used in heating with the intention of keeping the difference in temperature between the components of a heating system which are located in close proximity to one another as low as possible. This reduces exergy losses (see *power consumption*) through heat conduction and reduces the need for heat insulation.

Machine learning: Machine learning is a branch of *artificial intelligence*. Using databases, machine learning algorithms can independently recognise patterns, develop solutions and capabilities. Once developed, algorithms can successfully address a whole range of problems and objectives without the underlying algorithm having to be altered.

Meshing: In a mesh network, different network nodes are connected with each other. This means, for instance, that the start and end points of a radial network, in which nodes spread from one starting point to different end points, can be connected to each other via other nodes. The transmission grid is an example of an electricity grid with a high degree of meshing. In general, meshing lends the network redundant interconnections, which helps increase security of supply.

Multibrid systems: A concept for generating power and heat using a minimum of three different interconnected energy plants. Contrastingly, a hybrid system has just two interconnected plants.

Neighbourhood: In the context of energy research, a neighbourhood refers to a contiguous geographical residential environment, the next step up from the individual housing unit. In an urban environment this can be e.g. a block of flats or the direct surroundings of streets and squares which distinguish the place, in rural areas it could be a village or district.

Offshore: Is mainly used in the context of wind turbines and refers to the position of a wind turbine on the open seas.

Onshore: Is mainly used in the context of wind turbines and refers here to the position of a wind turbine in an inland location.

Open access: Open access means free access to scientific literature and other materials on the internet. Publishing a scientific document under open access conditions means that any person may read, download, save, link, print and use this document free-of-charge. Furthermore, other rights of use can be granted using free licences (e.g. free subsequent and continued use).

Open data: These data can be freely used, re-used and distributed by any person through the utilisation of open user rights. According to the Open Definition, the use of these open data may only be limited for the purposes of ensuring proof of origin by naming the source and guaranteeing the openness of the information contained in the data. However, this data may not contain any personal data or data which is subject to data protection requirements.

Open source: Open source software is a type of software whose source code is released to the public, is freely usable and is thus transparent and verifiable.

Peripheral equipment: Refers to all auxiliary components of a renewable or conventional power generation system such as the wiring, assembly system or chiller.

Plasma processes: Using a plasma, a very hot, reactive mixture composed of neutral and charged particles, for technical (e.g. cleaning, etching, coating) chemical (e.g. plasma-induced water splitting) and nuclear processes (nuclear fusion).

Post-li batteries: This collective term refers to battery technologies with a cytochemistry which provides higher energy density compared to the current cytochemistry of lithium-ion batteries. This kind of battery technology is needed, for instance, in mobile applications.

Power consumption: Just like power generation, power consumption is also a colloquial term. This refers to the conversion of usable energy (exergy) into ambient heat (exergy losses or entropy generation).

Power generation: In physics, power (or energy) is a conserved quantity, therefore it is not possible to generate power. The colloquial term power generation, however, describes the provision of usable energy, especially electrical energy, through energy conversion. For instance, the conversion of wind energy or solar energy into electricity is often referred to as power generation.

Power-to-chemicals: describes the use of renewable power to produce chemical energy sources or other energy-intensive chemical substances for use in the chemical industry.

Power-to-fuels: describes the use of renewable power to generate fuels for the combustion engines of e.g. cars, lorries, ships or aeroplanes.

Power-to-gas: a concept whereby electricity from renewable energies is first converted into hydrogen and then, where necessary, into methane via chemical synthesis and is then fed into the natural gas grid.

Power-to-heat: Refers to the conversion of power from renewables into heat. This is possible using heat pumps or electrical resistance heating and is usually carried out in combination with a thermal storage system to provide demand side flexibility.

Power-to-hydrogen: describes the conversion of renewable power into hydrogen by the process of electrolysis. The term is especially used to refer to when hydrogen is fed into the gas grid, reconverted into fuel cells, or used in hydrogen-powered logistics.

Power-to-liquids: Refers generally to the possibility of converting power into liquid energy sources (e.g. methanol, ethanol, kerosene, petrol, diesel and other chemical energy sources). In some ways, the term is therefore a synonym for power-to-fuels.

Power-to-X: The “X” can stand for “hydrogen”, “gas”, “liquids”, “fuels”, “chemicals” or “heat”. It refers to the conversion of renewable power into these substances and energy forms. This concept is an essential element of sector coupling.

Prosumer: In the energy industry, this coinage describes a consumer who is simultaneously a producer of energy, e.g. a home owner with photovoltaic panels installed on his/her roof.

Recycling: The term recycling encompasses many processes for reusing raw materials. A distinction should be made between product recycling and material recycling. Product recycling refers to the reprocessing of a product or a part of a product for the same (direct reuse) or another purpose (alternative use). Material recycling refers to the recirculation of the actual materials via mechanical, metallurgical or chemical processing.

Recuperation: An expression for the technical process of energy recovery (e.g. combustion plants with air preheating systems or regenerative braking in electric cars).

Refurbishment pathways: when referring to a building or neighbourhood, this term describes a fundamental decision on the time plan and specification of different renovation measures in order to fulfil a renovation objective. For the purpose of energy-efficiency improvements to buildings, refurbishment pathways involve decisions on the depth of renovation for individual renovation steps and the number of renovation steps resulting from this. Due to high investment costs and long periods of use, adjustments might have to be made with due regard to the maintenance costs.

Repowering: Refers to the replacement (of old parts) of power generation plants with new ones. This process typically serves to increase performance or efficiency. For instance, older wind turbines at an existing location may be replaced by larger, more efficient wind turbines.

Resilience: When a system does not completely breakdown in the case of a failure or partial system failure, but instead the main system services keep running.

Resource efficiency: Refers to the efficient use of technical, economic and natural resources. These resources can be material or immaterial goods. One example of increasing resource efficiency when it comes to raw materials is the process of recycling.

Seasonal energy storage: Refers to energy stores that store large amounts of energy over a minimum of several months and without significant energy losses. Examples include aquifer and groundwater storage fields for heat, as well as certain pumped storage power plants for electricity and chemical stores such as hydrogen and methane.

Second-life: "Second-life" and also "second-use" describes the use of used (traction) batteries in a second application. These applications can be different to the original application, e. g. switching from a mobile to a stationary battery.

Sector coupling: Refers to the efficient use of renewable power in the heating and cooling and transport sectors to reduce reliance on fossil fuels. Some examples are the production of synthetic fuels, heat pumps, and the electric engine of a vehicle. In a broader sense the term sector coupling also refers to processes and concepts which do not satisfy the above definition but whose purpose is still to interlink energy systems and prevent the production of greenhouse gases (e. g. power-to-chemicals, methane pyrolysis).

SET-Plan: The "Strategic Energy Technology Plan" (SET-Plan) is a strategic activity initiated by the EU and other participating states with the objective of making energy technologies competitive and involving the most important stakeholders in this process. This should help to prevent greenhouse gas emissions whilst taking into account the EU Climate and Energy Package. In the SET-Plan, specific measures are defined to implement the 2030 goals of the EU and the priorities of the Energy Union.

Smart grid: The conventional electricity grid becomes a smart grid if it is equipped with communication, measurement, control, regulation and automation technology as well as IT components. "Smart" therefore means that the grid status can be recorded in real-time and there are possibilities to control and regulate the different networks so that existing grid capacity can be used as fully as possible.

Smart building: A building which is both able to automatically respond to the needs and comfort requirements of the user thanks to sensor technology and intelligent control systems and also has interfaces which can flexibly interact with a *smart grid* (this concept is also called smart home). Since all technology in the household and all electrically-powered household devices are interlinked, a smart building can both provide extra convenience for the user and also contribute to saving energy and grid stabilisation. There are parallels to *Industry 4.0* in the technology used.

Sustainability: Sustainability is a principle whereby consumption of resources should not be higher than the amount of resources which can be regrown, regenerated or re-provided in future. In more general terms the word describes a way of acting which can be regarded as positive both in the long-term and from as many different perspectives as possible.

Synthetic fuels: Higher hydrocarbons and other chemical energy sources, which are produced using power-to-liquid or power-to-fuel plants. These fuels can be a supplement or replacement for fossil fuels (petrol, diesel, kerosene and others).

Technology neutrality: Funding is provided for research, development and demonstrations in technologies which can make a relevant contribution to reaching the Federal Government's energy and climate policy objectives. Funding is not generally limited to specific technologies but focuses are chosen under consideration of the innovation and market potential of the technology, as well as how relevant the technology is for achieving climate and energy goals.

Temporary Working Group: A group defined by the SET-Plan whose objective it is to draw up (and realise) implementation plans (IP) for each Key Action of the integrated SET-Plan. After the IPs were formulated, the most important stakeholders, including the SET-Plan states, European industry initiatives and research alliances, set up the Implementation Working Groups whose job it is to coordinate the realisation of the IPs. The process should be coordinated taking into consideration the national energy and climate plans.

Underlying regulatory conditions: Underlying regulatory conditions refer to all applicable laws and regulations which govern the economic activity in an economic sector.

List of abbreviations

AC	alternating current
ACT	Accelerating CCS Technologies (an ERA-Net)
BIM	building information modelling
BIPV	building-integrated photovoltaic
BMBF	Federal Ministry of Education and Research
BMEL	Federal Ministry of Food and Agriculture
BMS	battery management system
BMWi	Federal Ministry for Economic Affairs and Energy
CCS	carbon dioxide capture and storage
CCU	carbon dioxide capture and usage
CO_2	carbon dioxide
COP21	United Nations Framework Convention on Climate Change, 21st Conference of the Parties
CSP	concentrated solar power
D-A-CH	Germany, Austria and Switzerland
DBFZ	German Biomass Research Centre
DC	direct current
DLR	German Aerospace Center
EERA	European Energy Research Alliance
EIB	European Investment Bank
ERA-Net	European Research Area Network
ERA	European Research Area
ESYS	Academies' project "Energy Systems of the Future"
EU	European Union
EURATOM	European Atomic Agency
FIZ Karlsruhe	Leibniz Institute for Information Infrastructure
FONA	BMBF framework programme "Research for Sustainable Development"
FZJ	Jülich Research Centre
G7	Group of Seven (Germany, France, Italy, Japan, Canada, the United Kingdom and Northern Ireland, the United States of America)
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit
GW	gigawatt
GWh	gigawatt hour
HGF	Helmholtz Association of German Research Centres
Horizon 2020/ Horizon Europe	European Framework Programme for Research
HTSC	high-temperature superconductor
HVDC	high-voltage, direct current
IAEO	International Atomic Energy Agency
IBP	Fraunhofer Institute for Building Physics
ICT	information and communication technologies
IEA	International Energy Agency
IEE	Fraunhofer Institute for Energy Economics and Energy System Technology
IG	Implementation Group (formerly Temporary Working Group – TWG)
ICTS	industry and commerce, trade and services
IPP	Max Planck Institute for Plasma Physics
IRENA	International Renewable Energy Agency
ISE	Fraunhofer Institute for Solar Energy Systems
ITER	International Thermonuclear Experimental Reactor
IWES	Fraunhofer Institute for Wind Energy and Energy System Technology

KIT	Karlsruhe Institute for Technology
kWh	kilowatt hour
LIKAT	Leibnitz Institute for Catalysis
MI	Mission Innovation
MPG	Max Planck Society
MPI	Max Planck Institute
MPICEC	Max Planck Institute for Chemical Energy Conversion
MPIKG	Max Planck Institute of Colloids and Interfaces
OECD/NEA	Organisation for Economic Cooperation and Development/Nuclear Energy Agency
ORC	Organic Rankine Cycle
PIK	Potsdam Institute for Climate Impact Research
POF	Programme-Oriented Funding within the Helmholtz Association of German Research Centres
PtJ	Project Management Jülich
PV	photovoltaics
R&D	research and development
R&I	research and innovation
SET-Plan	European Strategic Energy Technology Plan
SINTEG	Smart energy showcases Digital agenda for the energy transition
SME	small and medium-sized enterprises
SOFC	solid oxide fuel cell
TCP	Technology Collaboration Programme
TWh	terawatt hour (one billion kWh)
TRL	Technology Readiness Level
TWG	Temporary Working Group (now Implementation Group – IG)
UMSICHT	Fraunhofer Institute for Environmental, Safety and Energy Technology
ZSW	Centre for Solar Energy and Hydrogen Research Baden-Württemberg

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