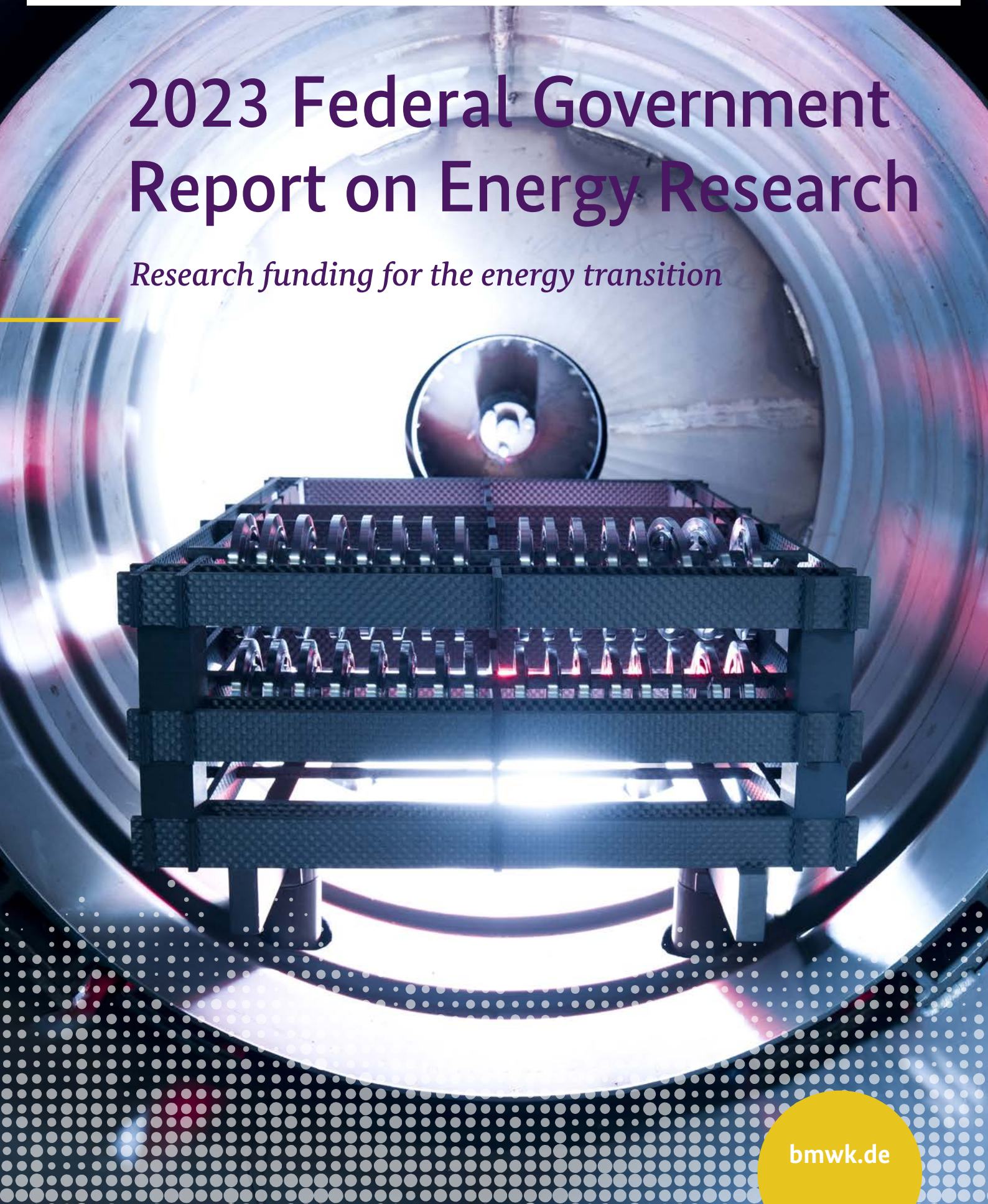
Federal Ministry
for Economic Affairs
and Climate Action

2023 Federal Government Report on Energy Research

Research funding for the energy transition



bmwk.de

Cover photo: If the entire system of a production facility is recorded, interconnected and and coordinated with each other, it significantly increases energy efficiency. The research team has already demonstrated with the ETA factory and the research project of the same research project of the same name (Funding 03ET1145A-F). In the follow-up project ETA in existing buildings (Funding 03EN2048A-I), the findings are now to be transferred and and adapted to existing productions. To the ETA factory also includes the hardening of components in the gas nitriding in the gas nitriding furnace, as can be seen on the cover picture.

MORE DETAILS MORE DETAILS

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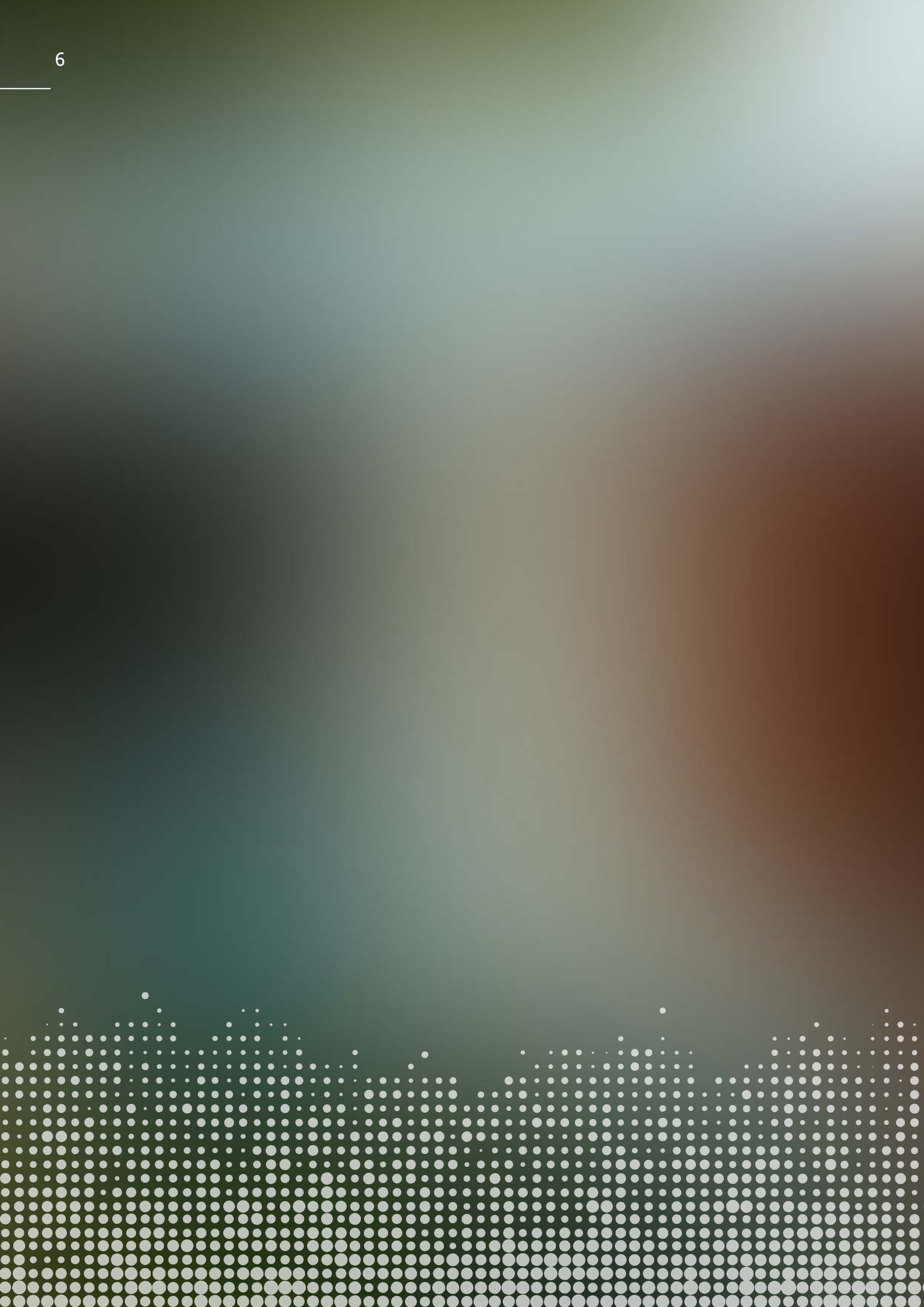
2023 Federal Government Report on Energy Research

Research funding for the energy transition

Contents



1. Research funding for the energy transition

1.1 The Federal Government's energy research programme

1.1.1 The Seventh Energy Research Programme of the Federal Government

The energy system is a highly complex structure consisting of a multitude of different elements. Climate change and, not least, the energy crisis caused by the war in Ukraine are exerting enormous pressure on the supply situation, making it all the more urgent to accelerate the transformation process of the energy transition. This is a challenge facing politics, business, science and society in equal measure.

Innovative ideas are what transform change into progress. It is therefore essential for the restructuring of the energy supply system that new solutions are created in cooperation with experts from research and development. Thereby Germany can become more climate-friendly, efficient and geostrategically less dependent on fossil energy imports – from generation right through to consumption.

The Federal Government's energy research programme is consistently geared towards the goals of the energy transition, i.e. reducing emissions, protecting resources, preserving biodiversity and developing and expanding technological sovereignty. The global challenges affecting domestic energy supply demand that climate protection and supply security be considered together more than ever, including in research funding. The Federal Government is therefore using the energy research programme to support the climate protection goals while at the same time focusing on tapping into more domestic renewable energy sources, researching and developing efficiency potentials and intelligently linking technologies within the framework of sector coupling.

Around 52% of energy consumption in Germany is used for heating and cooling with most of this heat still coming from fossil fuels. Therefore, innovations to rapidly expand novel heating and cooling technologies based on renewable energy are essential for climate-neutral supply. This will also make Germany less dependent on geopolitical developments that influence the price structures of fossil energy sources such as natural gas. Green hydrogen (H_2), which is produced using electricity from renewable energy plants, will also play an important role in the future energy system. To ensure that this succeeds, the Federal Government promotes the research, development and demonstration of technical and non-technical innovations along the entire value chain.

In the 7th Energy Research Programme, the Federal Government is taking a system-oriented approach that is focused on making research results available for practical application as quickly as possible. This also includes the Living Labs for the Energy Transition of the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the hydrogen flagship projects of the Federal Ministry of Education and Research (BMBF). Added to this is institutional funding, which guarantees researchers a high degree of certainty for their work.

1.1.2 Funding amounts

Through public funding from tax revenue, the Federal Government supports research and development activities by companies, research institutions, universities and other organisations with respect to new technologies and applications for the energy transition.

In 2022, the Federal Government invested €1.49 billion in funding within the 7th Energy Research Programme. This means that the ministries participating in the programme have once again increased their expenditure by 13% compared to the previous year. This highlights how important energy research is for anticipatory, climate-friendly energy policy and for maintaining supply security. In 2022, the focus was primarily on government research funding for hydrogen and sustainable heat supply.

The Federal Government invested €1.11 billion in project funding in 2022. It supported 7,365 ongoing research projects and approved 1,661 new projects. A further €319.85 million went towards institutional funding for energy research by the Helmholtz Association.

The research, development and demonstration of energy and efficiency technologies are primarily a task for the private sector. In the field of project funding, private companies have themselves invested a total of €390 million in innovative projects in 2022.

1.1.3 Evaluation and performance review

Evaluations and performance reviews are valuable instruments to verify the efficient and effective use of tax revenues for funding measures. Their findings are incorporated into the financial, administrative, strategic or substantive design of future measures. The Federal Government adheres to the Federal Budget Code (section 7) and conducts performance reviews of all the implemented measures. Evaluations by external third parties supplement and support these performance reviews.

An ongoing evaluation of the 7th Energy Research Programme was prepared in 2020 relating to funding for applied energy research. This was launched in 2021 and continued in 2022. It covers the funding measures of the Federal Ministry for Economic Affairs and Climate Action in accordance with the funding announcement for applied non-nuclear research under the 7th Energy Research Programme "Innovations for the Energy Transition" and analyzes the effectiveness and economic efficiency of the funding formats in terms of the goals of the 7th Energy Research Programme.

Figure 1: Overview of funding in 2022 in the 7th Energy Research Programme
(Data cf. Table 1, p. 101)

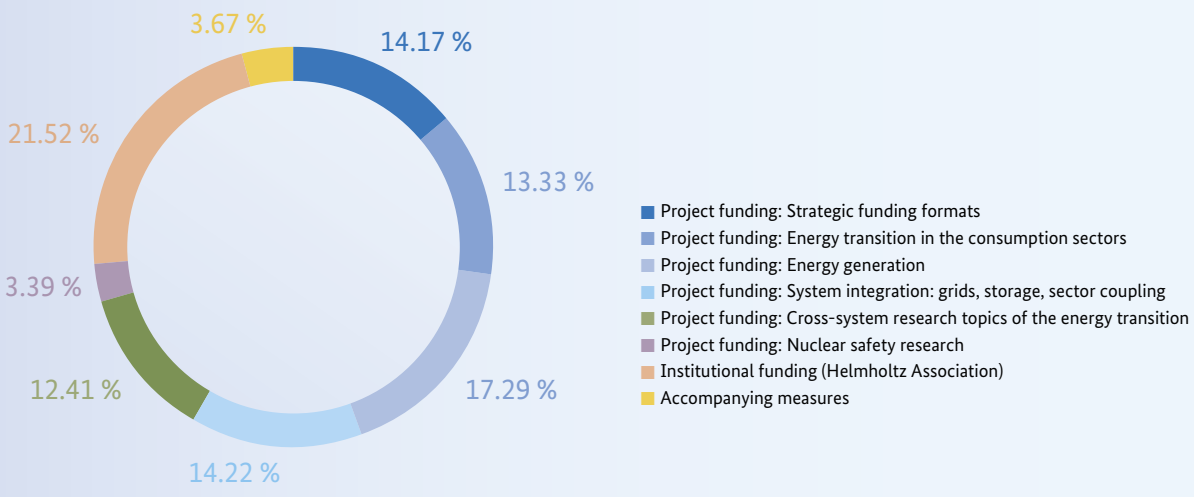
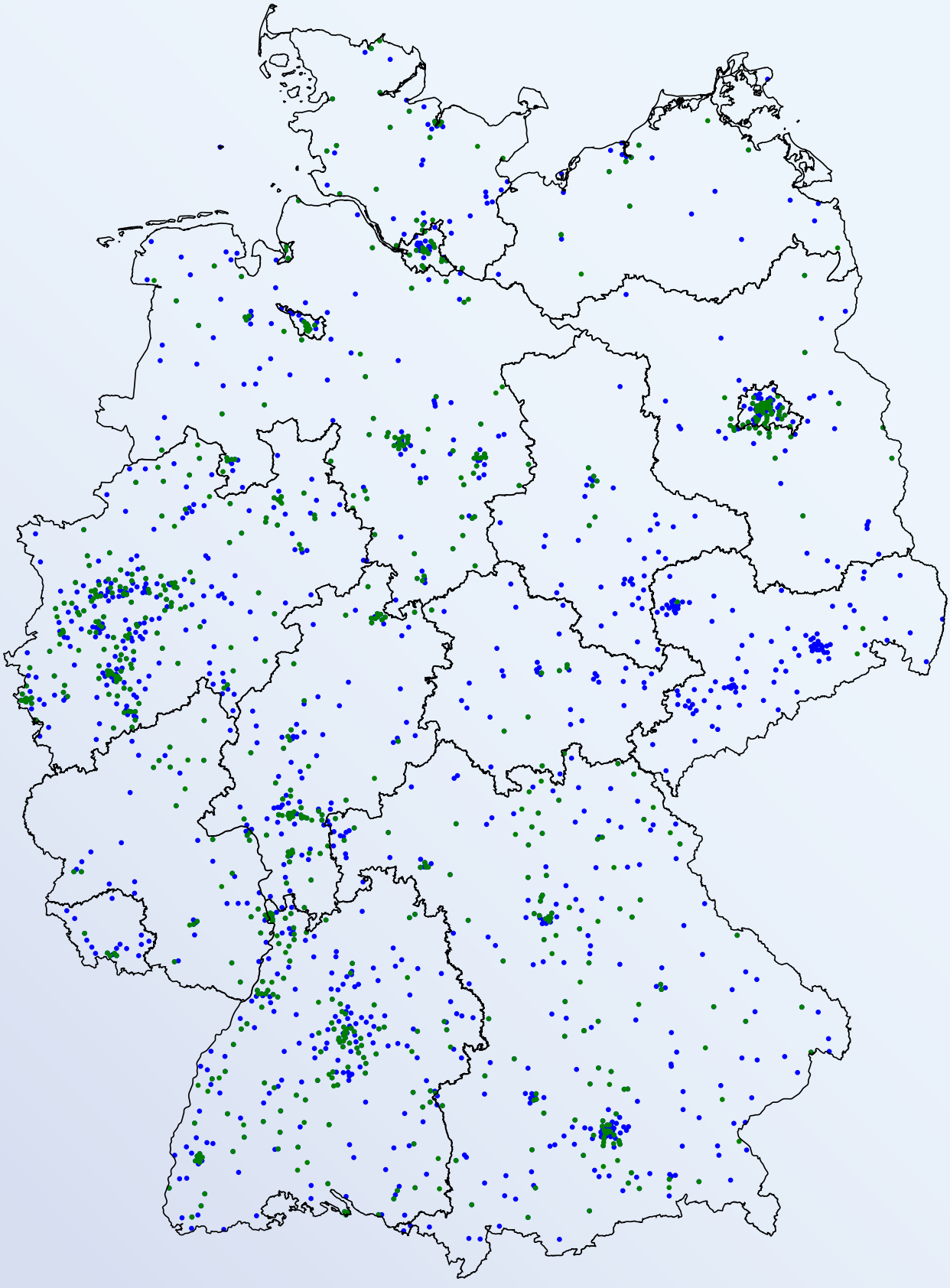


Figure 2: Overview of the ongoing (blue) and newly approved (green) projects of non-nuclear energy research in Germany

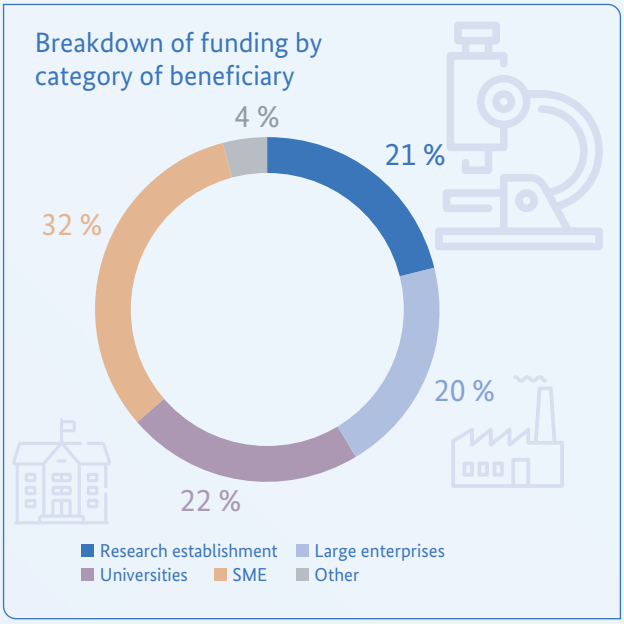


Source: GeoBasis-DE / BKG 2021 (data altered) / Geodata of the BKG for addresses of the implementing bodies from the BMBF profi-database / Projektträger Jülich

Figure 3: Energy research funding at a glance

€1.486 billion

total funding in the 7th Energy Research Programme in 2022 (preceding year: €1.311 billion)



In 2022, the Federation approved

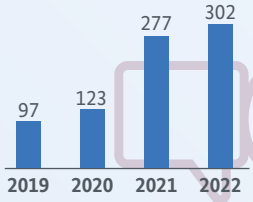
1,661 new projects

(preceding year: 2,016)

75 percent

rise in funding compared to 2014 and 13 percent rise compared to 2019

The Federal Government **funded** **7,365** projects in the 7th Energy Research Programme in 2022 (preceding year: 6,995)



€302 million

funding for SMEs for energy research projects newly appropriated in 2022* (non-nuclear energy research)

€390 million

own funding from companies towards newly approved research and development projects in 2021 (preceding year: €744 million)

473 ongoing projects in the context of strategic funding formats in the 7th Energy Research Programme

* based on German SME definition

1.2 Structures of energy research policy

1.2.1 Coordination of energy research funding and ministerial responsibilities

The Federal Government's 7th Energy Research Programme is an ambitious funding programme to promote innovation for the energy transition. With a cross-ministerial, technology-neutral approach, it covers the entire innovation cycle, from basic research to the testing of energy and efficiency technologies shortly before market launch.

The 7th Energy Research Programme is a joint programme of the Federal Ministries for Economic Affairs and Climate Action (BMWK), Education and Research (BMBF), Food and Agriculture (BMEL) as well as Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). The Federal Ministry for Economic Affairs and Climate Action is responsible for the programmatic orientation of German energy research policy.

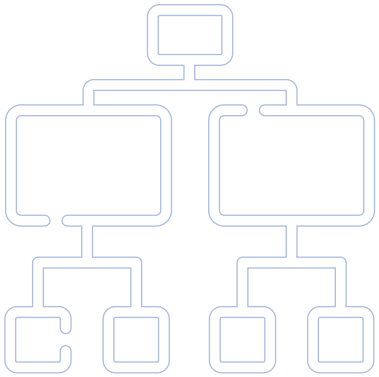
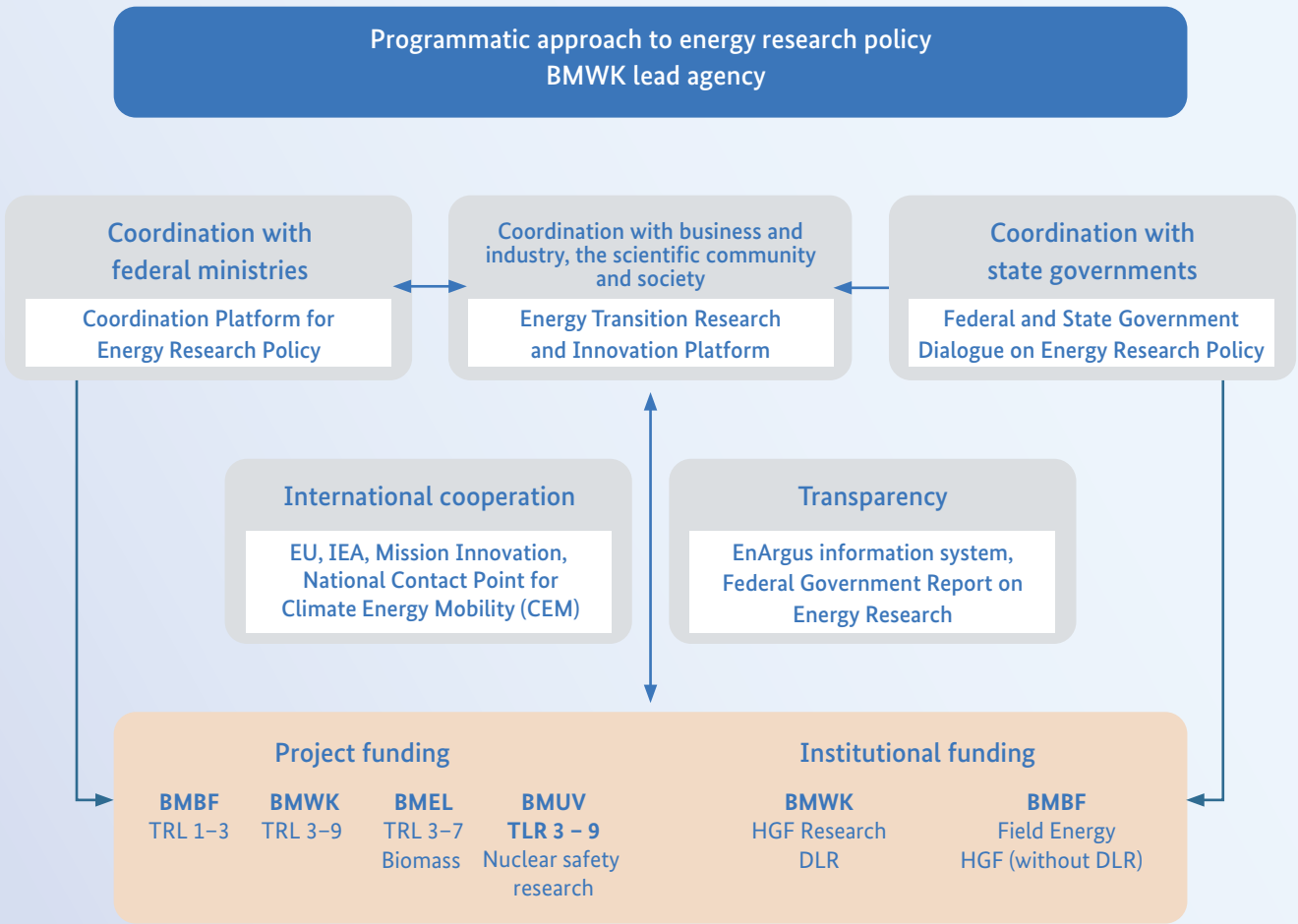


Figure 4: Institutional setup for energy research



In the field of project funding (cf. Chapter 2 Project funding, p. 17), the 7th Energy Research Programme is oriented towards the so-called Technology Readiness Level (TRL) system. For each funded project, the technologies that are being researched or further developed are rated on a scale of 1 to 9 according to the intended level of scientific and technical maturity. The Federal Ministry of Education and Research funds application-oriented basic research projects that aim to reach a TRL of 1 to 3. These projects pave the way for future innovations. The ministry also supports young scientists, academic exchanges and scientific cooperation at EU level and with international partners. Funding from the Federal Ministry for Economic Affairs and Climate Action follows on from this by providing funding for application-oriented research and development (TRLs 3 to 7). The ministry also supports the Living Labs for the Energy Transition, which extend to TRL 9, and multilateral research cooperation. The Federal Ministry of Food and Agriculture is responsible for funding applied research in bioenergy. This is supplemented by research funding provided by the Federal Ministry for Economic Affairs and Climate Action for the use of biomass for energy purposes. The Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection is responsible for funding nuclear safety research. Within the scope of institutional funding, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research are jointly responsible for the strategic orientation of energy research by the Helmholtz Association. In addition, the Federal Ministry for Economic Affairs and Climate Action is responsible for the institutional funding of the German Aerospace Center (DLR) while the Federal Ministry of Education and Research is responsible for institutional funding of the Helmholtz Centres (except for the DLR) (cf. Chapter 3 Institutional funding, p. 76).

The energy transition and climate protection are tasks for society as a whole. The Federal Government therefore relies on close cooperation between all the federal ministries directly involved in the Energy Research Programme. In addition, all other ministries and authorities with energy-related tasks and areas of responsibility are on board, such as the Federal Ministry for Digital and Transport (BMDV) which is responsible for mobility and transport. The Federal Republic of Germany also relies on the strengths of the multi-level system in order to achieve successful research funding. This

means that the funding and coordination of energy research in Germany takes place both at Länder and federal level, and also in cooperation with European and international partners. Here, the Federal Ministry for Economic Affairs and Climate Action represents the Federal Republic of Germany in European and international bodies with regard to this policy field (cf. Chapter 4 European and international cooperation, p. 85).

1.2.2 Networking at national level

Energy supply security and a climate-friendly energy system are major national tasks. Digitisation is taking hold of almost all areas of our economy and society. Technology-neutral energy research is paving the way here while intensive exchange between all stakeholders through networking and dialogue platforms is an important prerequisite for generating innovations for the future.

Research and Innovation Platform (R&I Platform)

The Research and Innovation Platform (R&I Platform) for the energy transition of the Federal Ministry for Economic Affairs and Climate Action is a forum for dialogue relating to energy research between federal and Länder policy-makers, scientists, the business community, associations and civil society. It facilitates exchange on current developments in funding policy and research as well as on new approaches for forward-looking strategies, and it brings together research and practical applications in the energy sector. The platform thus provides an overarching structure for the energy research networks of the BMWK, bringing them together and coordinating them.

In addition to the R&I Platform, the Federal Ministry for Economic Affairs and Climate Action, as the lead ministry for the energy transition, is engaged in a regular exchange on the most important energy research issues with the 16 Länder governments.

Energy research networks

The members of the nine energy research networks (www.forschungsnetzwerke-energie.de) of the Federal Ministry for Economic Affairs and Climate Action represent the broad spectrum of the scientific community around research for the energy transition. The networks are open to all interested experts and cover bioenergy, buildings and neighbourhoods, energy system analysis, renewable energy, flexible energy conversion, industry and commerce, electricity grids, startups and hydrogen.

The networks support an interdisciplinary dialogue between all stakeholders in energy research and serve as interfaces for experts, business and society. They are funded by the Federal Ministry for Economic Affairs and Climate Action and have around 3,700 active members who organise their own work in working groups. One major task of the energy research networks is to develop ways to transfer research findings into practice. The networks should also support a cross-sectoral and cross-technology dialogue as a central element of a networked energy research community. For example, the research networks have offered overarching webinars on research into public acceptance and a series of workshops on communicating science. In 2022, the energy research networks held a total of 53 events, including annual meetings of the individual networks, working group meetings and workshops. In addition, publications have been produced by the experts of the networks, including statements and methodology manuals. In 2022, the successful cooperation with the “Jugend forscht e. V.” foundation was also continued.

Academies’ “Energy Systems of the Future” project

The Academies’ “Energy Systems of the Future” project pools the expertise of the German academies of science. Funded by the Federal Ministry of Education and Research, the initiative by acatech, the Leopoldina and the Union of Academies of Sciences and Humanities generates momentum for

the debate on the challenges and opportunities of the energy transition in Germany. In the ESYS project, more than 120 experts are developing options for implementing a safe, affordable and sustainable energy system. In 2022, for instance, options for importing green hydrogen to Germany by 2030 were analysed with a particular focus on developing transport routes, Länder assessments and realisation requirements, while the effects of the Ukraine war on energy supply in Europe were also examined.

1.2.3 Research for the innovative leaps of tomorrow

Global developments over the past year, especially concerns about energy supply security in Germany and climate change, show that the innovation process towards supply entirely from renewable energy must be accelerated significantly. Basic research is the starting point, paving the way for disruptive innovations that can be developed to market maturity through further research funding.

The funding for research and development by the Federal Ministry of Education and Research is consistently geared towards a medium and long-term realisation horizon. The aim is to provide new technologies that make complete climate neutrality possible. Funding by the Federal Ministry of Education and Research also ensures that these innovations are quickly implemented, thus closing technology gaps. The Kopernikus projects are a good example of this and are set to enter the final demonstration and transfer phase next year.

This innovation pipeline is also being pursued to develop a hydrogen economy – in basic research, through large-scale transfer projects in the hydrogen flagship projects and through international research and innovation partnerships. Added to this is the expansion of energy research capacity, among other things through the Helmholtz Hydrogen Cluster in the Rhenish mining region.

1.2.4 From research to practical use

The research, development and demonstration of energy and efficiency technologies are primarily carried out by companies, so that energy research is largely the task of the private sector. However, the Federal Government's Energy Research Programme provides an incentive under funding policy for this important work. The Federal Government therefore supports the research and development of climate-friendly innovations for the energy transition along the entire value chain of the energy supply system – always with a focus

on making efficient technologies and applications quickly available for the market and making research results usable in practice. By funding research, the Federal Government is also strengthening Germany and Europe's position as a business location in international competition. This is achieved by supporting research to build and maintain a modern energy infrastructure and by facilitating attractive export opportunities for domestic companies through the development of innovative technologies and solutions.

1.2.5 Transparency and communications

Transparency is a valuable asset when implementing political measures. Open communication of the goals and progress of energy research policy to the general public, researchers and end users is thus an important element of the Federal Government's energy research programme. Using a wide range of formats, the Federal Government provides extensive information on progress, development trends, open research questions and challenges on the road towards climate-friendly transformation and the preservation of a resilient energy infrastructure.

The Federal Ministry for Economic Affairs and Climate Action's central website on applied energy research www.energieforschung.de, provides information on funding goals and structures as well as current funding opportunities. Four specialised portals also deliver information about project funding success and concrete research results from the many projects. These offers are implemented by Project Management Jülich on behalf of the ministry.

EnArgus (www.enargus.de) the central information system for energy research funding, provides a transparent overview of research projects in the energy sector funded by the Federal Government. The website also provides information about technologies and technical terms. In addition, the figures for project funding cited in the Federal Report on Energy Research are set out in a transparent manner on EnArgus.

2. Project funding

2.1 Strategic funding formats

2.1.1 Living Labs for the Energy Transition

The Living Labs for the Energy Transition are a measure anchored in the 7th Energy Research Programme by the Federal Ministry for Economic Affairs and Climate Action. Targeted support is given to projects which systematically test innovations and research findings in a real-life environment and on an industrial scale. These projects make it possible to speed up the transfer of technology and innovation by closing the gap between research and practice in the energy sector: they are the dress rehearsal for the market launch. In this way, the Living labs contribute to the success of the energy transition by paving the way for new technologies and new value creation.

A total of eleven projects are up and running under the JenErgieReal Living Labs for the Energy Transition, which was launched in 2022. All of these projects emerged from the first competition for ideas held in 2019 by the Federal Ministry for Economic Affairs and Climate Action.

Living Labs for the Energy Transition, in the field of "energy-optimised neighbourhoods":

- JenErgieReal
- Large-scale heat pumps in district heating networks (GWP)
- Darmstadt Energy Laboratory for Technologies in Application (DELTA)
- Wilhelmsburg Integrated Heat Transition (IW3)
- TransUrban.NRW
- SmartQuart – smart energy neighbourhoods

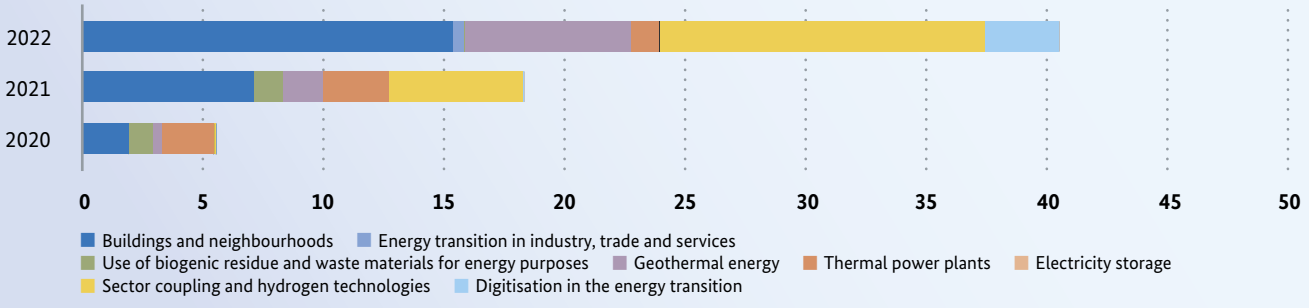
Living Labs for the Energy Transition in the field of "sector coupling and hydrogen technologies":

- H2-Wyhlen
- North German Living Lab (NRL)
- Bad Lauchstädt Energy Park
- H2Stahl
- WESTKÜSTE100

Important milestones were achieved in the Living Labs in 2022. In the GWP project, for instance, work began on the construction of a large-scale heat pump at the Mannheim site. In the hydrogen neighbourhood in the SmartQuart Living Labs, the hydrogen pipes are being laid and in the H2-Wyhlen project, the contract for the planned electrolysis plant has been awarded. The technical centre of the TransUrban.NRW Living Labs was inaugurated at the Herne site where a 5th generation energy system is to be created.

The Living Labs for the Energy Transition in the field of sector coupling and hydrogen technologies are supported by the Trans4Real project. The insights from the Living Labs will be used by Trans4Real to help build up a sustainable hydrogen economy in Germany and to integrate the gas into the energy system of the future.

Figure 5: Funding for Living Labs of the Energy Transition in € million
(Data cf. Table 2, p. 101)



The Living Labs for the Energy Transition that focus on energy-optimised neighbourhoods are supported by the accompanying "energy transition construction" research (in particular, Module III "Neighbourhood") headed by the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT.

The funding format for the Living Labs for the Energy Transition takes a subject-neutral approach, addressing all areas of applied energy research from the 7th Energy Research Programme. The core aim of the systematically designed projects is to bring the energy transition forward and to contribute towards climate neutrality. The Living Labs for the Energy Transition must therefore be able to demonstrate direct reductions in greenhouse gases that take effect while the project is still running. In the concept, the Federal Ministry for Economic Affairs and Climate Action emphasises the high practicality of the funding format. The ministry plans to support future Living Labs for the Energy Transition by providing up to €15 million in funding per partner, and a maximum of €25 million in funding for the overall project.

Project funding

In the focal field of Living Labs for the Energy Transition, the Federal Ministry for Economic Affairs and Climate Action provided approximately €40.50 million in funding for 189 ongoing projects in 2022. The ministry also appropriated approximately €59.91 million in funding for 40 new research projects in this period (cf. figure 5).

PROJECT ABSTRACT

Trans4ReaL – *Transfer research for the Living Labs for the Energy Transition on sector coupling and hydrogen technologies*

Trans4ReaL is the scientific accompanying and transfer project for the Living Labs for the Energy Transition in the field of hydrogen technologies and sector coupling. In this project, scientists are performing interdisciplinary investigations into their results and learning experiences with the aim of making them usable across the board. Their work focuses not only on the technologies used and their integration into the energy system, but also on the hydrogen market ramp-up with the resulting business models. Last but not least, the project is examining how Living Labs are embedded in the regulatory, social and international environment. The concepts of the individual projects take root at different points of the hydrogen value chain and feature different levels of integration in the energy system. Trans4ReaL therefore does not rely on direct comparisons, but looks at topics that are highly relevant to all the projects – such as approval procedures for electrolysers or the European Commission's proposals regarding criteria for hydrogen from renewable sources.

The Trans4ReaL project accompanies the Living Labs of the Energy Transition in order to make the findings as broadly usuable as possible.

At the beginning of 2023, the research team presented first results and recommendations for action for the ramp-up of a hydrogen economy. (in German only)

Beneficiaries: Forschungsstelle für Energiewirtschaft and six other partners
Funding ID: 03EWT001A-G
Appropriated Funding ID: €7 million
Project duration: 2021 – 2026
Project description on EnArgus:

MORE DETAILS

2.1.2 Hydrogen flagship projects – Technologies for industrial-scale hydrogen solutions

Hydrogen is a versatile energy carrier and basic material, an important energy store and an essential element of sector coupling. In the long term, the only way to reduce certain CO_2 emission sources, such as processes in the steel or cement industry, will be to use low greenhouse gas (GHG) hydrogen. It is therefore an essential building block of a successful energy transition. However, sufficient quantities of hydrogen and a reliable infrastructure must be available for it to be used on an industrial scale. That is why the Federal Government's National Hydrogen Strategy is committed to making hydrogen competitive and establishing it as an alternative energy carrier.

Funding priorities and scientific advances

With the hydrogen flagship projects, the Federal Ministry of Education and Research launched a central initiative in 2021 to ramp up a hydrogen economy. The three flagship projects are the result of a competition of ideas in which science, business and civil society were invited to submit ideas for large-scale hydrogen projects. Up until 2025, the projects will research the series production and scale up of electrolysers (H_2Giga), hydrogen production at sea (H_2Mare) as well as hydrogen storage and transport technologies (TransHyDE).

In the H_2Giga project, established electrolyser manufacturers, suppliers and research institutions are taking existing electrolysis technologies to the next level where they are to be scaled up and prepared for industrial production. In addition, highly efficient electrolysis without precious metals and using anion exchange membranes is to be optimised. Cross-cutting projects on new materials, digitisation, manufacturing technologies, recycling and system integration also ensure innovative capacity for future technology generations.

The H_2-Mare flagship project aims to generate green hydrogen and other offshore power-to-X products, i.e. on the high seas where electricity can be produced in larger quantities and more regular than on the mainland. The direct connection between wind turbine and electrolyser can help to reduce costs as well as relieve the local electricity grid. In addition, the project partners are working on technologies to use seawater directly for electrolysis – without the desalination step required up to now.

To ensure that the hydrogen economy can rely on a secure storage and transport infrastructure, the TransHyDE flagship project is testing and evaluating various technologies. This involves transporting hydrogen in high-pressure containers, in liquid form, in gas pipelines and bound in ammonia or the carrier medium LOHC (liquid organic hydrogen carriers). In addition, the researchers are developing requirements for the systemic framework.

In some first publications, TransHyDE shed light on how refineries could become climate neutral and how the existing gas infrastructure would have to be redesigned to secure national supply. Gaps and barriers in the current legal framework, especially for green hydrogen, have also been identified.

Project funding

In the focal field of hydrogen flagship projects, the Federal Ministry of Education and Research provided approximately €170.14 million in funding for 335 ongoing projects in 2022. In addition, approximately €25.47 million in funding was appropriated for twelve new research projects (cf. figure 6).

PROJECT ABSTRACT

TransHyDE-GET H2 – *A sub-project of Meter-Q Solutions GmbH on infrastructural and operational aspects of hydrogen network construction or conversion of natural gas transport pipelines to hydrogen*

The TransHyDE-GET H2 project is paving the way for publicly accessible long-distance hydrogen pipelines. Researchers are investigating which techniques are suitable for maintaining long-distance pipelines or how certain materials tolerate hydrogen. Another focus is the development of valid quality and quantity measurement of hydrogen. This is an important prerequisite for transporting hydrogen between producers, transporters and consumers.

Headed by Meter-Q Solutions GmbH, scientists have developed a nano-gas chromatograph for this purpose which enables the quality of one hundred percent hydrogen to be measured at a certified level. The MGC^{hydrogen} measuring device examines hydrogen in a pipeline during operation for impurities in the ppm range. An application was recently submitted for official calibration approval for the new measuring device. Once approved, the device developed in the TransHyDE project GET H2 could become the first system for billing one hundred percent hydrogen.

TransHyDE-GET presented a H2 transport and storage structure for green hydrogen at the leading international trade fair for the process industry ACHEMA.

Beneficiaries: DVGW, MeterQ Solutions GmbH and eight other partners
Funding ID: 03HY207A-H
Appropriated funding: €11.6 million
Project duration: 2021 – 2025
Project description on EnArgus:

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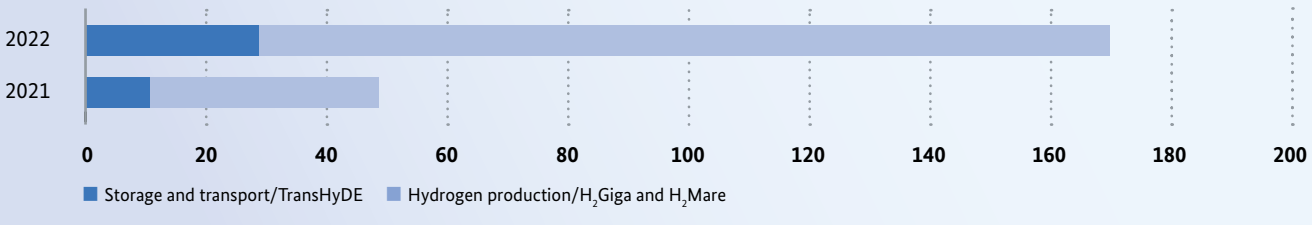
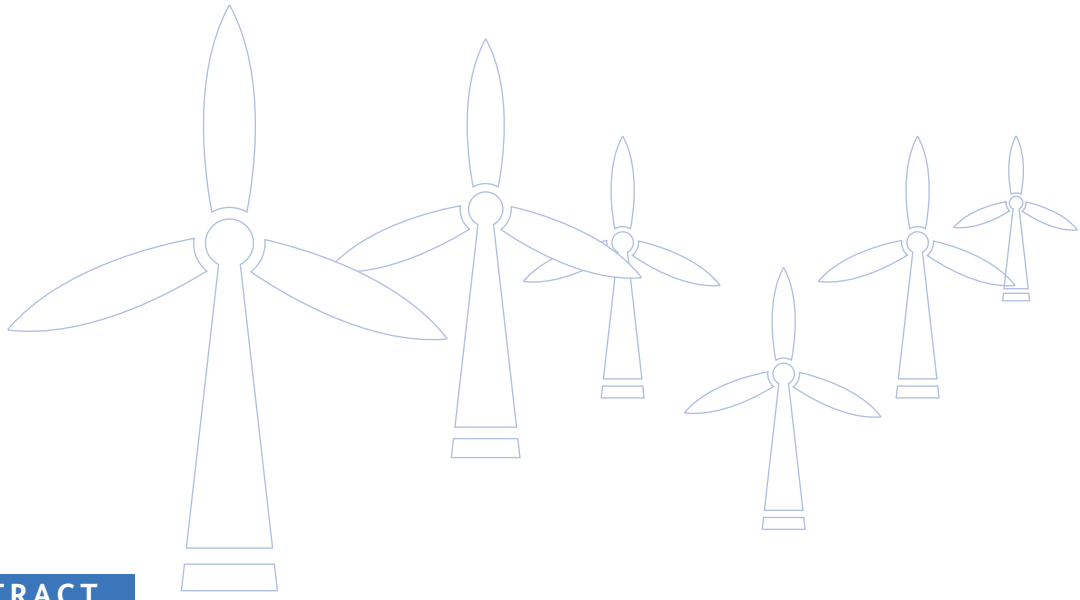
Figure 6: Funding for hydrogen flagship projects in € million
(Data cf. Table 2, p. 101)





PROJECT ABSTRACT

H2Mare: PtX-Wind – *Offshore power-to-X processes*

In the H2Mare project PtX-Wind, the offshore production of power-to-X products such as methanol, synthetic fuels, methane or ammonia is being tested. In addition to water, this also requires carbon dioxide and nitrogen which are extracted locally from the air or the sea. The project also focuses on steam electrolysis and seawater electrolysis for hydrogen production.

In a first step, the researchers worked on the modular process containers to test the production of synthetic fuels before they are used at sea. In this way, it was possible to configure the system planned for the offshore test platform, made up of these modular process containers, at Energy Lab 2.0. The system comprises a direct air capture system that extracts carbon from carbon dioxide in the air, solid oxide electrolysis and a Fischer-Tropsch synthesis system with an integrated product up-grade that produces kerosene from CO_2, electricity and water.

All the system components are to be set up on a floating test platform. Following operation at Energy Lab 2.0, the modular process containers will first be tested again in the safe harbour before being set up offshore.

In the flagship hydrogen project H2Mare, research is being conducted into the offshore production of green hydrogen and other power-to-x products.

Beneficiaries: Karlsruher Institut für Technologie and 17 other partners
Funding ID: 03HY302
Appropriated funding: €38.8 million
Project duration: 2021 – 2025
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

H_2Giga DERIEL – *De-risking PEM-elektrolyser*

The network is part of the H_2Giga technology platform for series production and scaling up of electrolysers. DERIEL supports the development of new pressurised PEM electrolysers by creating a fundamental understanding of the degradation, failure and interface mechanisms at all technical levels. For this purpose, electrolyser modules with a real output of one megawatt are set up in test beds and examined in operation. At the same time, researchers subject material samples from electrolyser operation to various analytical methods and test them on a laboratory scale. Numerical models help to identify the relevant load parameters. The data and models come together in a digital twin, making it possible to predict service life, develop optimum operating strategies and select future materials.

Scientists are also investigating the recycling of the electrodes containing precious metals, addressing the intermediate storage of hydrogen and simulating system integration of the electrolyser. This creates the basis for the optimum electrolyser design and a long service life as a prerequisite for efficient and economical production of green hydrogen.

In the H2Giga DERIEL project, electrolyser modules are being built on a real scale of one megawatt in test stands.

Beneficiaries: Siemens Energy Global and eight other partners
Funding ID: 03HY122A-I
Appropriated funding: €98 million (including €77 million Forschungszentrum Jülich)
Project duration: 2021 – 2025
Project description on EnArgus:

MORE DETAILS

2.2 Energy transition in the consumption sectors

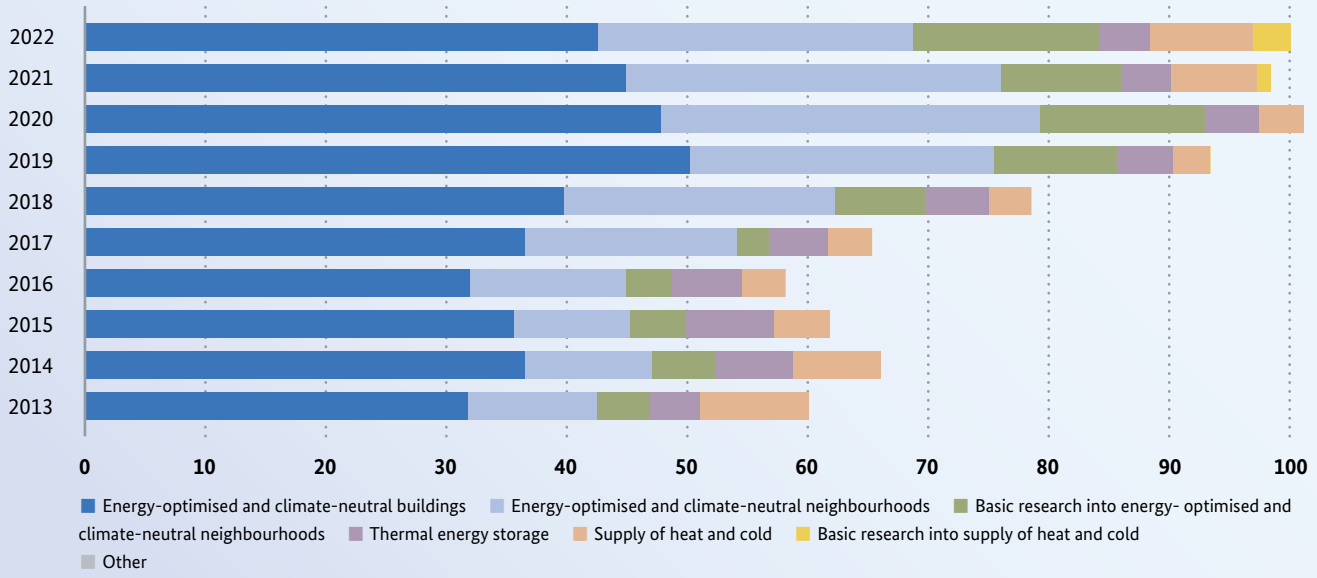
2.2.1 Energy in buildings and neighbourhoods

The building sector is responsible for about 40% of CO_2 emissions nationwide. A large part of these emissions are caused by burning fossil fuels, especially natural gas. Stepping up the rate at which buildings are renovated and decarbonising heating and cooling supply are the only way to ensure that buildings and neighbourhoods can be supplied and operated in a climate-neutral manner in the medium to long term. The Federal Climate Protection Act foresees limiting emissions to a maximum of 67 million tonnes of CO_2 equivalents by 2030. Switching to sustainable heating systems and district heating supply based on renewable energy are two important starting points for this.

Funding priorities and scientific advances

The aim of funding is to research renewable and energy-efficient energy supply systems for new construction and refurbishment and to test these systems in practice. Funding is available for solutions that are adapted to the location but can also be transferred. Developing innovative materials and intelligent renovation methods for buildings and neighbourhoods are other important priorities.

Figure 7: Funding for energy in buildings and neighbourhoods in € million
(Data cf. Table 3, p. 102)



This includes the automated monitoring of structural conditions as well as innovative and systemically designed energy supply solutions. Funded energy systems use on-site renewable energy, include storage and distribution systems and develop smart control and regulation technology to provide cooling, heating and electricity according to demand.

The Solar Decathlon Europe competition, funded by the Federal Ministry for Economic Affairs and Climate Action, was held in Germany for the first time in 2022. In Wuppertal, a German team came out tops against 15 international competitors. Teams of students competed by developing and implementing ideas for climate-friendly building stock in cities. In addition, JenErgieReal was launched in Jena as the sixth Living Labs for the Energy Transition in the field of buildings and neighbourhoods. The aim here is to demonstrate how energy generators, storage and consumers can be smartly linked in the local energy system.

In 2022, the Federal Ministry of Education and Research continued activities already underway in the field of buildings and neighbourhoods. The joint project “Climate-resilient urban-rural cooperation”, which was funded by the Ministry as part of its “City of the Future” flagship initiative, has now entered its final implementation phase. The project has brought together the scientific community, municipalities and practical partners from North Hesse to jointly develop strategies for sustainable bioenergy use at municipal or regional level. The implementation phase now focuses on construction measures, consolidation of the cooperative collaboration between municipalities and the district and a possible transfer of the previously developed strategies.

Project funding

In the field of energy in buildings and neighbourhoods, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €100.16 million in funding for 1,041 ongoing projects in 2022. The ministries also appropriated approximately €83.35 million in funding for 212 new research projects (cf. figure 7).

PROJECT ABSTRACT

SolaresBauen: LowEx-Bestand – *LowEx concepts for heat supply in existing multi-family buildings*

Around half of all homes in Germany are located in apartment buildings. Many of them were built before the first Thermal Insulation Ordinance (1979) and have a high heat demand. The aim of the project is to integrate and optimise energy-efficient and climate-friendly LowEx systems for existing apartment buildings. Together with companies from the heating industry, the researchers have developed new solutions for efficient use of heat pumps, heat transfer systems and ventilation systems for refurbished apartment buildings. These systems were implemented in demonstration projects with partners from the housing industry and then tested in the field. The integration of innovative heat pump systems was one priority and the researchers showed, for instance, that heat pumps, also combined with fossil systems such as a gas condensing boiler, can also make a significant contribution to heat supply. In all of the simulated system combinations considered, aggregated CO_2 equivalent savings of more than 50% were achieved (compared to a gas condensing boiler) over the service life and while operating economically.

Integrating and optimising energy-efficient and climate-friendly LowEx systems for apartment buildings in existing buildings: This is the goal of the LowEx-Bestand project.

Beneficiaries: Albert Ludwigs University of Freiburg and four other partners
Funding ID: 03SBE0001 A-E
Appropriated funding: €4.4 million
Project duration: 2016 – 2022
Project description on EnArgus:

MORE DETAILS

SPECIAL

Research for the heat transition

Accelerating the energy transition with climate-neutral heating and cooling

A climate-neutral heating and cooling sector is essential for the goals of the energy transition.

Heating and cooling account for around 52% of energy consumption in Germany – around half of this is used for heating rooms and more than a third for process heating. Most of this energy is still generated using fossil fuels. For this reason, the Federal Government is planning a more rapid expansion of heating and cooling supply from renewable energy sources. This is where energy research can help by delivering urgently needed innovations and by bringing novel technologies that are not yet established on the market into widespread use.

Heat sources and demand in buildings and neighbourhoods differ in terms of temperature level, availability or usability while regional characteristics and different types of grids have their own specific requirements. Low-temperature grids could serve as a particularly efficient heat source for different buildings and temperature requirements, for instance, when combined with heat pumps. Looking to the future, the optimisation and integration of heat pumps will become even more important in the building sector. Technologies for energy saving or smart control are also needed here, as too are heating networks and storage systems. A systematic approach is now needed in order to bring them together. In existing buildings, refurbishment offers considerable potential for savings. The digital infrastructure in complex heating systems must also be optimised, for instance, in operational management, diagnostics or evaluation. Innovative materials and the reduction of “grey energy” used to produce materials are further important priorities.

In industry, the lion's share of thermal energy is used for process heat. More than a third of this at temperatures of over 1,000 degrees Celsius. While defossilisation at low temperature levels is conceivable using standard solutions already available, suitable approaches still have to be developed for higher temperatures on a case by case basis. Production processes, for instance, need to be more efficient or new processes need to be researched, bioenergy sources (especially biogenic residual and waste materials) or large-scale heat pumps need to be integrated and, in addition, the electrification of processes that have so far been dependent on fossil fuels needs to be examined. The (waste) heat generated by industrial processes is also moving further into focus as this can be used on-site as process heat or made available to businesses or neighbourhoods via heat grids. In particular, low waste heat temperatures and heat cascades offer enormous potential for domestic, climate-friendly energy throughout Germany.

Geothermal energy is also important as a baseload heat source. With the help of large underground storage volumes, this energy could make a systemic contribution to seasonal long-term storage and thus also help to achieve greater supply security.

In October 2022, the Federal Ministry for Economic Affairs and Climate Action published the call for applications for "Climate-neutral heating and cooling" which is to help further accelerate the above-mentioned activities. The so-called micro-projects are new in the funding call and will be used to prepare classic funded projects or carry out final development steps shortly before market launch.

Sustainable and diversified heat supply is indispensable given the current scarcity of fossil natural gas. In six flagship projects funded by the Federal Ministry of Education and Research, partners from science, business, civil society and politics are researching how the energy transition can be implemented in cities and municipalities based on the example of a neighbourhood. As we work to reduce the consumption of energy for heating buildings, digitisation plays an important role alongside the modernisation of buildings. Therefore, smart electricity, water and gas meters will be connected to a communication network, providing a digital heat transition platform. Research funding that involves large industrial heat producers close to neighbourhoods will bridge the gap between buildings and industry. Research is now underway to identify how waste heat from steel production can contribute to the defossilisation of heating and cooling supply in urban environments.

2.2.2 Energy efficiency in industry, commerce, trade and services

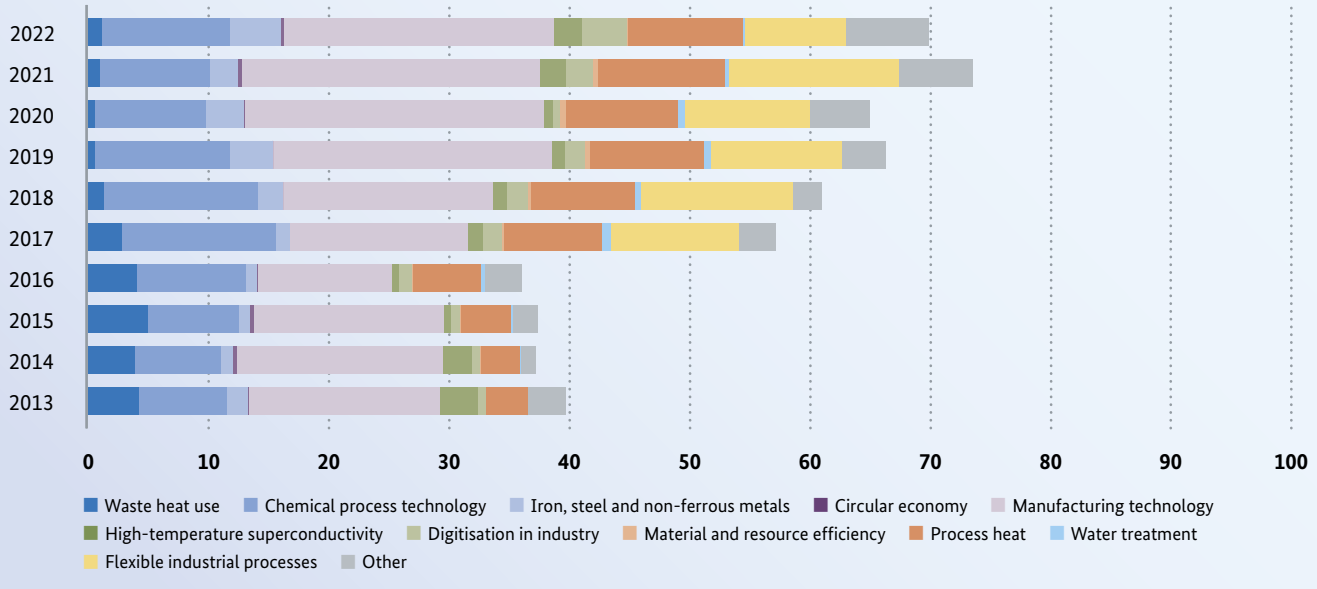
The four sectors of industry, commerce, trade and services together account for almost 45% of energy consumption with the commerce, trade and services sectors primarily using this energy for heating rooms and for electricity. In industry, process heat and mechanical energy account for the largest share of energy. In recent years, economic growth and improved energy efficiency have largely increased parallel, which is why consumption levels have remained almost constant. In 2020, the Covid-19 pandemic and, in 2022, energy price increases slowed down production and temporarily reduced energy consumption.

Funding priorities and scientific advances

Natural gas is still the most important energy source in industry, especially in energy-intensive industries. To decarbonise this sector, heat supply must be switched to climate-neutral alternatives. The aim is to further electrify plants and processes, replace natural gas with hydrogen, optimise heating and cooling technologies and make waste heat usable at all temperature levels. To this end, the Federal Ministry for Economic Affairs and Climate Action published a call for funding for climate-neutral heating and cooling in autumn 2022 (cf. Research for the heat transition, p. 26). Research projects that use hydrogen in the industrial sector have once again also been launched under the Hydrogen Technology Offensive (cf. Chapter 2.4.3 Sector coupling and hydrogen, p. 51). Research is also focused on increasing the energy efficiency of mechanical energy as well as technologies for material and resource-efficient handling of energy-intensive raw materials and recyclables, which will permanently remove further burdens from the energy system. In May 2022, the Congress on Energy Efficiency Research for Industry and Commerce brought together experts from research, industry and politics, providing them with an opportunity to report on successful market launches of research results in the past and to exchange views on the latest efficiency technologies and future funding needs.

The Kopernikus project for the energy transition SynErgie addresses the feeding in of rising amounts of intermittent renewable energy. The research

Figure 8: Funding for energy efficiency in industry, commerce, trade and services in € million
(Data cf. Table 3, p. 102)



results are to enable energy-intensive industry (paper, glass, metal and others) to significantly synchronise their energy demand with volatile energy supply. To this end, various digital tools have been developed to identify, characterise and evaluate energy flexibility mechanisms. This is precisely what is happening in the model region of Augsburg where stakeholders are testing the flexibilisation of energy demand (cf. Highlight project, p. 30).

The Kopernikus project is now focused on implementing and demonstrating the potential for energy flexibility. In addition to technical solutions for avoiding CO_2 emissions, this includes concepts for increasing the efficiency of the electricity market design, which must be adapted to changing system requirements. This would reduce costs and minimise redispatch as volatility increases. These are interventions into the generation capacity of power plants that aim to protect line sections against congestion.

Project funding

In the field of energy efficiency in industry, commerce, trade and services, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €69.30 million in funding for 770 ongoing projects in 2022. The ministries also appropriated approximately €66.18 million in funding for 152 new research projects (cf. figure 8).

PROJECT ABSTRACT

HT heat pump – *Development of a high-temperature heat pump for temperatures up to 160 degrees Celsius based on a refrigeration cycle process with solution circulation*

Much of the heat needed in sectors such as the chemical, food and paper industries, but also for district heating, is required at a high temperature level of between 100 and 160 degrees Celsius. This is currently obtained to a large extent from fossil fuels. Researchers in the HT heat pump project have now developed a compression heat pump with a solution circuit that can reach a temperature range of 160 degrees Celsius, so that it is considered a high-temperature heat pump. The refrigerant used is an ammonia-water mixture with good thermodynamic properties and no global warming potential and is therefore climate-neutral. The project team tested a demonstrator of this high-temperature heat pump at Stadtwerke Neuburg and continued to optimise it after the end of the project. The system upgrades the engine cooling heat of a combined heat and power plant, thus feeding a hot water grid with a temperature of up to 140 degrees Celsius. With a heating capacity of around one megawatt, the high-temperature heat pump meets industrial requirements and could also be used in other areas of application in the future. Two similar plants – with temperatures of around 85 and 120 degrees Celsius respectively – have already been realised or are in production in Lemgo and Münster.

In the HT heat pump project, researchers have developed a compression heat pump with a solution circuit.

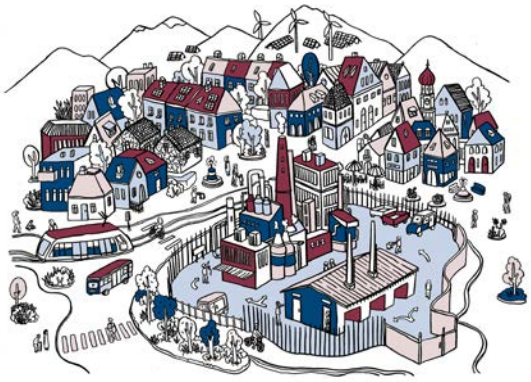
Beneficiaries: AGO AG Energie + Anlagen
Funding ID: 03ET1588A
Appropriated funding: €483,000
Project duration: 2018 – 2022
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

SynErgie – *Successful testing of the energy synchronisation platform in the energy flexible model region of Augsburg*

As part of the Kopernikus projects, SynErgie aims to create all the necessary technical and market conditions in line with legal and social aspects by 2026 so that energy demand by German industry can be effectively synchronised with volatile energy supply. If industry succeeds in flexibly and consciously increasing or decreasing its electricity demand within a very short time, this could significantly relieve Germany's electricity grid.



In the Energy Flexible Model Region Augsburg, 38 partners have joined forces to offer energy flexibility as a service.

Since 2016, SynErgie has been demonstrating how this can be achieved in the energy flexible model region of Augsburg where 38 partners from business, science and civil society joined forces to demonstrate for the first time how energy flexibility can be offered, sold and used as a service. The technical basis for this is a digital energy synchronisation platform that controls and monitors energy distribution and provides services for the assessment, provision and marketing of energy flexibility. Test operations prove that demand-side energy flexibility can be implemented regionally with the involvement of all relevant stakeholders and that the technical prerequisites for buying and selling energy flexibility are in place.

Beneficiaries: University of Stuttgart and 57 other partners
Funding ID: 03SFK3A0-2 - 03SFK3Z2-2
Appropriated funding: €37.5 million
Project duration: 2019 – 2023
Project description on EnArgus:

MORE DETAILS

2.2.3 Interfaces between energy research and mobility and transport

The use of renewable energy in the transport sector barely increased last year. Hydrogen plays a minor role and the share of biofuels has remained about the same compared to the previous year. The only exception was the use of electricity from renewable energy which increased by about 15%. In order to reach the climate targets set, further innovative solutions are needed in private and heavy-duty transport, on long and short routes, on road, rail, water and in the air.

Funding priorities and scientific advances

In a decarbonised energy system, the direct use of electricity from renewable energy in electric vehicle powertrains is generally the most energy-efficient and economical option. For this reason, the Federal Ministry for Economic Affairs and Climate Action is funding work on sustainable battery-powered electric mobility along the entire value chain. To this end, teams of researchers are developing low-cost rechargeable batteries with high energy density and a long lifetime while also addressing the industrialisation of manufacturing

and recycling at the end of service life. Grid-serving charging points are practical examples of sector coupling in projects.

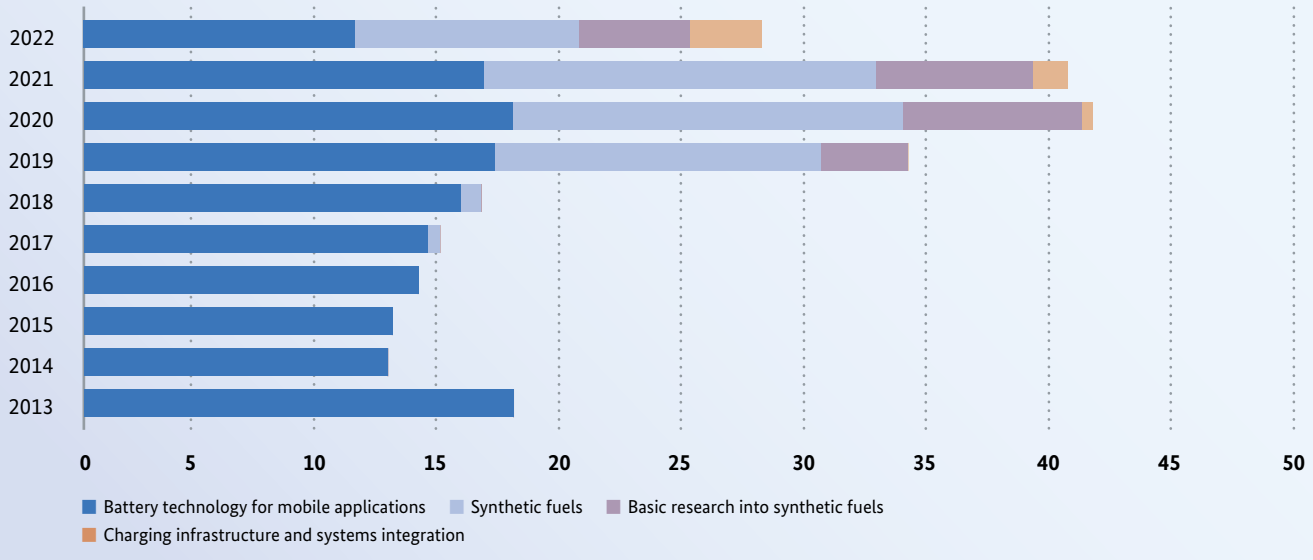
Hydrogen is another building block for the decarbonisation of transport that also enables sector coupling between the electricity industry and transport. Green hydrogen can be produced both from water via electrolysis using renewable electricity and from biomass via thermochemical processes. This can be used directly, for instance, in fuel cell powertrains. What's more, liquid or gaseous fuels can be produced as so-called derivatives via further process steps, and then used to replace fossil fuels. The Federal Ministry for Economic Affairs and Climate Action is funding research for electricity-based fuels, also for shipping and aviation, which are difficult to electrify, among other things with the "Energy transition in the transport sector" initiative. The accompanying BEniVer research project is preparing a roadmap with further options for action for the sector. BEniVer also organised a status conference in 2022 at which experts discussed how synthetic fuels are contributing towards the energy transition.

The Federal Ministry of Education and Research is funding research and development projects on sustainable and renewable fuels within the scope of various funding measures. These include both the production and use of fuels in fuel cells, combustion engines or turbines, as well as systemic analysis regarding their interactions with the rest of the energy system. The projects address both the production of fuels from electricity from renewable energy and carbon dioxide, industrial waste gases or biomass.

Project funding

At the interface between energy research and mobility and transport, the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Climate Action provided approximately €28.16 million in funding for 284 ongoing projects in 2022. The ministries also appropriated approximately €20.29 million in funding for 30 new research projects (cf. figure 9).

Figure 9: Funding for energy research into mobility and transport in € million
(Data cf. Table 3, p. 102)



PROJECT ABSTRACT

Electricity-based paraffin is to contribute to decarbonising the aviation sector in the future.

KEROSyN100 – *Development and demonstration of a dynamic, efficient and scalable process chain for electricity-based kerosene*

Synthetic kerosene based on electricity from renewable energy sources can help to reduce greenhouse gas emissions in aviation. In the KEROSyN100 research project, six project partners from industry and research have now been working on bringing electricity-based kerosene closer to market launch. To this end, the consortium developed a concept for the first power-to-liquid plant for the production of synthetic kerosene using the methanol route. Among other things, the team considered possible integration into a conventional oil refinery and into the energy system. The focus is on the exclusive use of electricity from renewable energy sources for the future production of climate-friendly kerosene. Based on the concept, a demonstration plant is to be built at the Heide refinery in Schleswig-Holstein in a follow-up project. The researchers have also developed proposals for suitable regulatory frameworks for synthetic fuels for aviation.

Beneficiaries: University of Bremen and five other partners
Funding ID: 03EIV051A-G
Appropriated funding: €4.4 million
Project duration: 2018 – 2022
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

NAMOSYN shows: Low blends of certain synthetic fuels are possible without engine adjustments.

NAMOSYN – *Sustainable mobility from synthetic fuels*

Researchers in the NAMOSYN project are investigating synthetic fuels based on C1 oxygenates, namely all steps of the process chain from production to combustion in the engine. In addition to reducing CO_2 emissions, these fuels are particularly clean, boasting very low particulate emissions. NAMOSYN is funded within the framework of the 2030 Climate Action Programme.

The researchers presented their findings in a final brochure, showing that the engines would have to be retrofitted for C1 oxygenates to be used as a pure fuel in existing vehicles. This is a considerable hurdle. However, if only a small proportion of the conventional fuel is replaced with C1 oxigenates, for instance, 5 to 15% by volume, the vehicles would not have to be retrofitted. In addition, these synthetic fuels in blends with high proportions or as a pure fuel represent an interesting option for closed fleets once the engines have been technically adapted.

Beneficiaries: Dechema and 32 other partners
Funding ID: 03SF0566A-V0
Appropriated funding: €24.9 million
Project duration: 2019 – 2023
Project description on EnArgus:

MORE DETAILS

2.3 Energy generation

2.3.1 Photovoltaics

In April 2022, the Federal Ministry for Economic Affairs and Climate Action published comprehensive draft legislation that fleshes out the implementation of the Federal Government's climate protection goals, takes account of climate change and the urgent need for autonomy in the energy sector. A key point in the draft is the almost complete generation of electricity from renewable energy by 2035 in which photovoltaics will continue to play a key role. In order to achieve these goals, the production of photovoltaic systems is to be strengthened once again in addition to annual expansion plans and the reduction of red tape. This will boost Germany's current but dwindling international technology leadership in order to support the expansion targets. After all, many photovoltaic innovations still come from Germany, also thanks to intensive research funding.

Funding priorities and scientific advances

In order to achieve the aforementioned goals, the current research and funding priorities cover the following priorities: support in rebuilding national production along the entire value chain through industrial mass production projects, photovoltaic systems as safe and reliable components for energy supply (the StRiLeb call for funding, for instance, addresses the reliability and service life of the required inverters) and the integration of photovoltaics for decentralised energy generation for dual use of suitable areas (for instance, integrated into the building envelope, on water surfaces and in agriculture or through photovoltaic modules integrated into the transport sector).

The available space is, however, limited and in order to make optimum use of this, research and industry are increasingly focusing on the development of high-efficiency solar cells. One promising approach is presovskite tandem solar cells where a perovskite cell is built onto a slightly modified, conventional silicon cell. In the past decade, teams of scientists have been able to increase the efficiency of these tandem cells from below 10 to over 30% – well above the efficiency of simple silicon cells. Almost all of the record efficiencies were achieved by funded institutes or companies in Germany – a unique international selling point. Researchers are currently working on both durability and industrial scaling as well as the realisation of mass production of these cells. First manufacturers in Germany expect a market launch in the coming years.

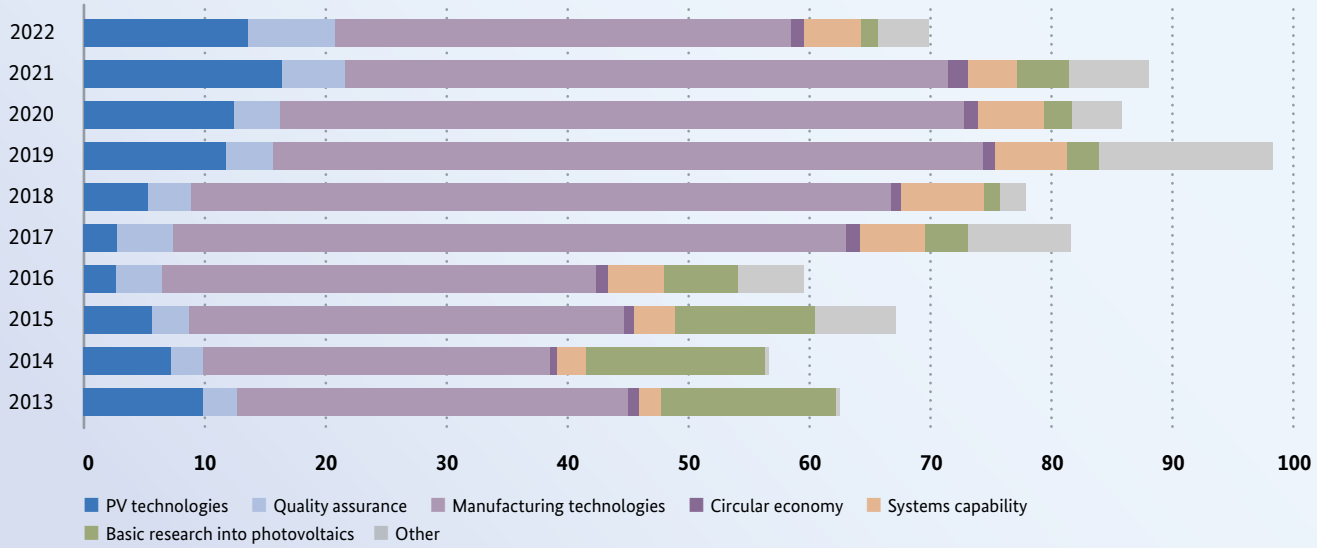
One of the funding priorities of the Federal Ministry of Education and Research is the direct coupling of solar cells with an electrolyser to store sunlight in the form of hydrogen. However, this means developing solar cells that not only achieve maximum efficiency, but also deliver sufficient voltage and current. Here, too, efforts are being made to adapt the water splitting components to the climatic boundary conditions on-site in order to enable the most efficient, direct solar hydrogen production.

Analysing and optimising solar cells and the associated infrastructure play a major role not only in Germany, but also on the African continent. The funding provided by the Federal Ministry of Education and Research focuses on many different areas, including yield analysis of photovoltaics for food production, energy supply and electric mobility.

Project funding

In the field of photovoltaics, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €70.14 million in funding for 478 ongoing projects in 2022. The ministries also appropriated approximately €61.64 million in funding for 105 new research projects (cf. figure 10).

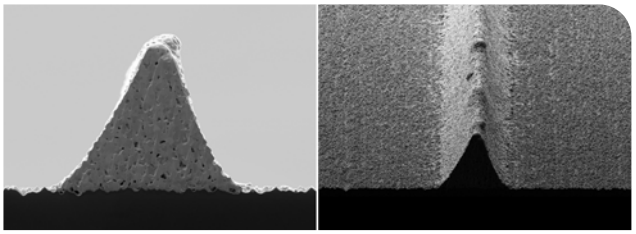
Figure 10: Funding for photovoltaics in € million
(Data cf. Table 4, p. 103)



PROJECT ABSTRACT

INNOMET – *Development of innovative printing technologies for the fine-line metallisation of Si solar cells*

The most widely produced solar cells in the world are made of silicon. In an effort to increase the efficiency of solar cells, teams of scientists are researching new technologies and optimising processes – as in the INNOMET project.



Using innovative stencils, the Innomet science teams have succeeded in printing cross-sectionally triangular contacts on crystalline solar cells.

The results of this research show promising approaches to realising the next generation of silicon solar cells. Among other things, the researchers have developed innovative printing processes and new printing stencils based on thin, structured glass foils that can be used to print fine-line contacts with a triangular cross-section on crystalline solar cells. Thereby, the geometry of the contacts is ideal for avoiding reflection losses, thus increasing the efficiency of the cell. Using glass foils also means that the technology can be used to specifically adapt the structures to the application. In addition, the team of scientists investigated multi-nozzle dispenser printing, a contactless printing process that could in the future replace the widely used screen printing. This process enables a higher throughput in the production of silicon solar cells while reducing silver consumption for the contacts.

Beneficiaries: LPKF Laser & Electronics AG and two other partners
Funding ID: 0324308A-C
Appropriated funding: €980,000
Project duration: 2018 – 2022
Project description on EnArgus:

MORE DETAILS

2.3.2 Wind power

Wind power is a key component of an energy supply system based on renewable energy. In 2022, wind power once again made the biggest contribution to electricity supply from renewable energy sources. In the overall electricity mix, it remains Germany's most important energy source at 25.9%, ahead of lignite. Together, onshore and offshore plants produced just over 125 billion kilowatt hours of electricity, around 10% more than the previous year.

The addition of newly installed turbines again increased slightly compared to the previous year. The net capacity connected to the grid from wind power has increased by around 2.5 gigawatts, i.e. around 850 megawatts more than in 2021. New offshore wind turbines accounted for 342 megawatts.

Funding priorities and scientific advances

The projects funded by the Federal Ministry for Economic Affairs and Climate Action are geared to achieve further cuts in cost of electricity from wind power. This also means increasing the reliability and lifetime of the installations. The results of wind power research should also help to accelerate the implementation of the energy transition by identifying and removing existing obstacles.

Against this background, issues such as acceptance by the general public play an important role as does the subject of wind physics: a better understanding of wind as a resource will enable this energy source to be used in the best possible way. This knowledge is in turn incorporated into the technology development and the search for locations. Both aspects are decisive for electricity generation costs. Larger and more powerful turbines, improvements to rotor blades, tower, drive train and generator, for instance, can reduce costs and boost reliability. As components become bigger, they also need to be lighter and more sustainable, for instance, by using new, readily available materials. The installations should be designed with sustainability in mind from the outset, i.e. the effort required for production, construction, operation as well as for dismantling and recycling should already be taken into account in the design phase. Consideration should also be given to how the systems can be integrated into the electricity grid.

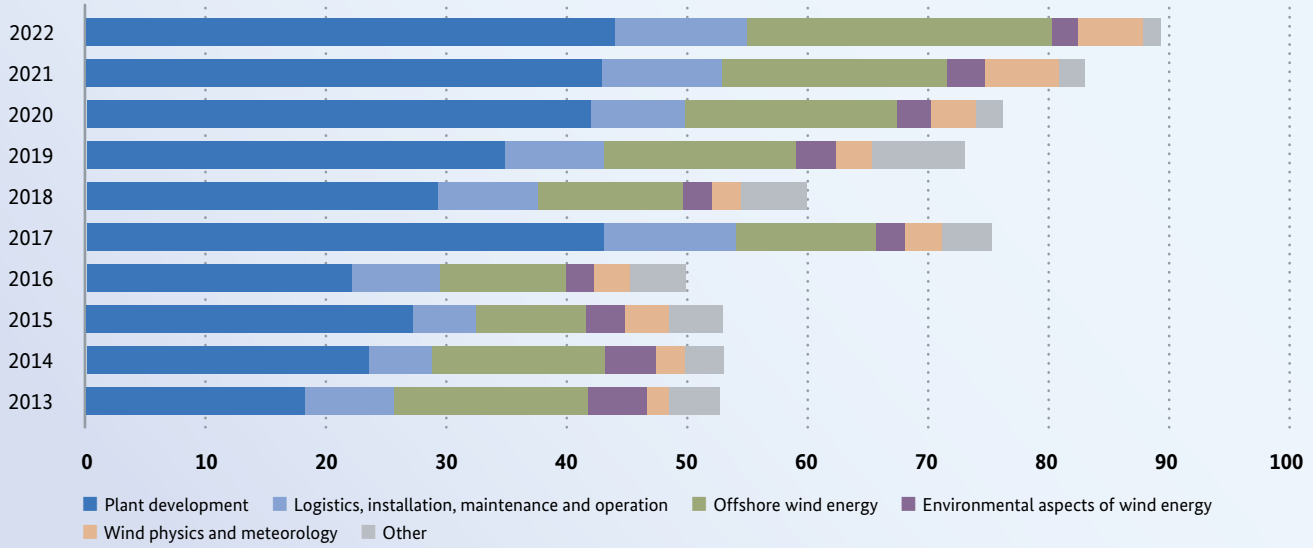
Logistics and maintenance are crucial, especially for offshore wind farms which are difficult to reach, so that repair and downtime costs are correspondingly high. Innovative grid connection and logistics concepts are therefore important and must take into account the availability of the installations, the transport of people and material, as well as issues related to operation and maintenance. So-called pooling is another aspect and refers to specialised tools or emergency vehicles or vessels being shared by several companies.

The Federal Ministry of Education and Research is funding research into how hydrogen can be produced from seawater by integrating water electrolysis into offshore wind turbines. As the wind energy is used directly for electrolysis, the turbine does not have to be connected to the power grid, thus cutting infrastructure costs. If the electricity grid and electrolysis are decoupled from each other, this reduces the burden on public grid structures. In addition to offshore hydrogen production, the focus is also on how downstream products such as methanol or ammonia can be produced offshore (cf. Chapter 2.1.2. Hydrogen flagship projects, p. 20 and the H2Mare highlight project, p. 22).

Project funding

In the field of wind power, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €89.19 million in funding for 469 ongoing projects in 2022. The ministries also appropriated approximately €59.75 million in funding for 97 new research projects (cf. figure 11).

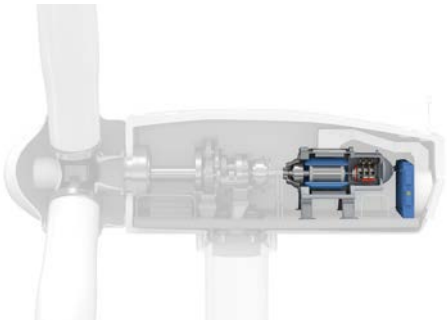
Figure 11: Funding for wind energy in € million (Data cf. Table 4, p. 103)



PROJECT ABSTRACT

HiL-GridCoP – *Hardware-in-the-loop testing of the electrical grid compatibility of multi-megawatt wind turbines with high-speed generator systems*

In order to verify the grid compatibility of new wind turbines, manufacturers require test certificates that demonstrate compliance with today's laws, standards and guidelines. Up to now, this involved expensive and lengthy certification tests in the field. Fraunhofer Institute for Wind Energy Systems (IWES), together with wind turbine manufacturers Nordex, Vestas and, initially, Senvion, developed a test rig that realistically replicates the electrical properties of wind turbines in the laboratory. Testing is carried out on a minimum system of the future installation, consisting of inverter, generator, transformer and main controller. The rest of the system is simulated in real time using special hardware and software in the HiL process, which stands for "hardware-in-the-loop". This research work also focussed on accurately mapping the installation's operational torque and speed data. The new test procedure saves time and money – different wind and grid conditions can be simulated directly and reproduced as required. New, high-performance installations and components can thus be brought to market faster, driving the energy transition forward.



In the HiL GridCoP test stand, the minimum system of a wind turbine is tested: Converter, generator, transformer and main control.

Beneficiaries: Fraunhofer Institute for Wind Energy Systems IWES and three other partners
Funding ID: 0324170A-D
Appropriated funding: €8.7 million
Project duration: 2017 – 2022
Project description on EnArgus:

MORE DETAILS

2.3.3 Bioenergy

Bioenergy currently accounts for around two-thirds and thus the largest share of renewable energy in Germany. It is therefore an important and indispensable component of the energy transition. Current research funding in the field of bioenergy includes research and development projects that scientifically address the supply of residual and waste materials, sustainable biomass cultivation, and the production of electricity, heat and fuel from biomass and its integration into existing energy systems.

More than 89% of all heat supply from renewable energy is currently generated by biomass alone. The contribution by bioenergy is also an important part of electricity generation from renewable energy, accounting for around 19% (cf. Renewable Energy in Figures, German Environment Agency), essentially through the use of biogas and biomethane. Thanks to its storage capabilities and flexible application options, biomass contributes to regional and sustainable energy supply and can thus make an important contribution towards the energy transition.

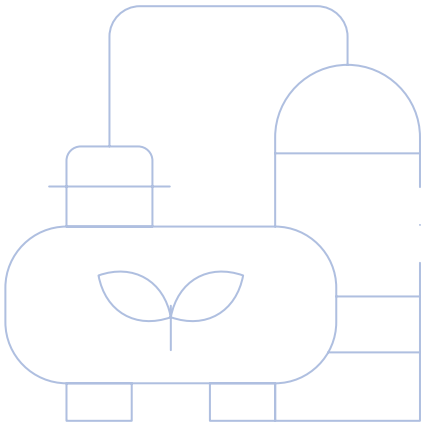
Funding priorities and scientific advances

Energy research by the Federal Ministry of Food and Agriculture includes research, development and demonstration projects on the use of waste and by-products as well as renewable raw materials from agriculture and forestry for energy purposes. The research projects are funded through the Renewable Raw Materials funding programme, which is managed by the FNR (Agency for Renewable Resources). The priority areas include the sustainable provision of biogenic resources, the development of innovative conversion processes, the reduction of environmental impacts and greenhouse gas emissions and the integration of bioenergy into the energy system in conjunction with sector coupling, increasing the efficiency of the use of scarce resources and maximising their contribution to the success of the energy transition.

Funding by the Federal Ministry of Education and Research will shed light on the conversion of biogenic residues into ultrapure, climate-neutral biohydrogen. In addition to selecting suitable residue materials, the focus here is on a stable, continuous, economical and scalable separation of hydrogen from thermochemically produced synthesis gas.

In the funding priority “Use of biogenic residue and waste materials for energy purposes” of the 7th Energy Research Programme, the Federal Ministry for Economic Affairs and Climate Action is focusing on the development and testing of forward-looking technologies and process optimisations which are to enable efficient, economic and above all sustainable use of bioenergy. The funding provided by the ministry focuses on practical solutions that can serve as demonstration and pilot projects which support the flexible generation of electricity and heat from biomass, provide biofuel and use biogenic residues and waste. In addition to system integration, sector coupling and digitisation, projects for biogenic hydrogen production are also attracting attention. In the heat sector, the search is on for solutions to decarbonise high-temperature processes. In the low-temperature sector, the focus is on finding solutions for heating buildings or neighbourhoods as well as heat grids, approaches for coupling two or more different energy systems (for hybrid or multibrid systems) in the interaction between electricity, heat and mobility. This also involves the practical demonstration of carbon capture as well as the necessary application and utilisation options with BECCUS (bioenergy with carbon capture and storage or utilisation).

The funding goes to traditional research establishments and also to small and medium-sized companies aiming to bring innovative technologies to the

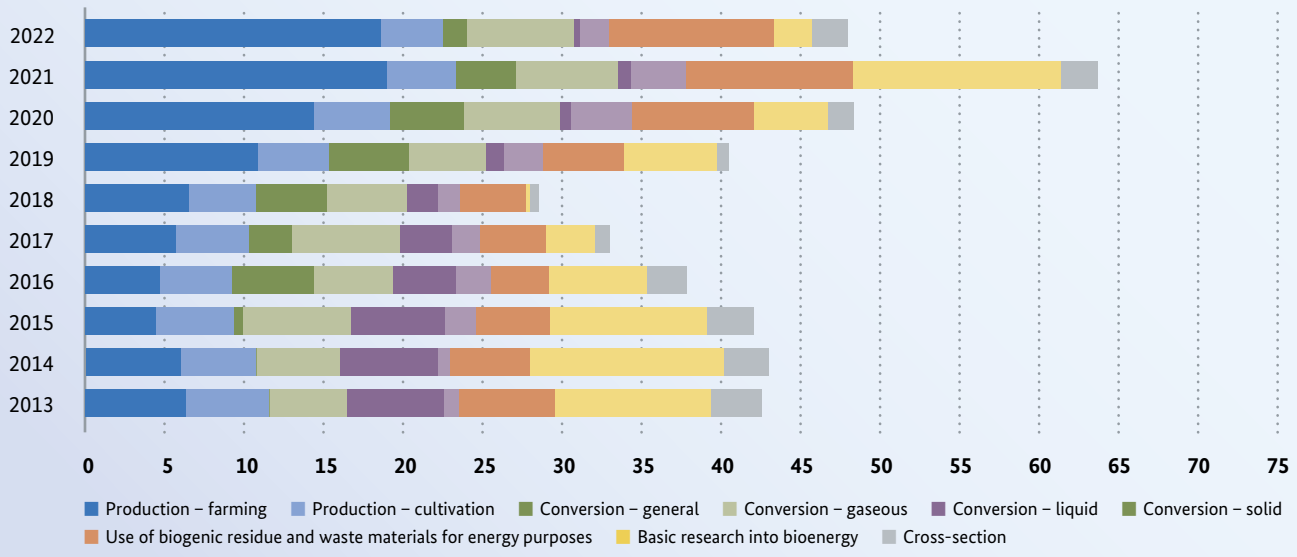


market. With a view to networking and knowledge transfer, the funding priority is being supported by DBFZ – Deutsches Biomasseforschungszentrum gemeinnützige GmbH. Active dialogue between the researchers is also facilitated by the Bioenergy Research Network.

Project funding

As part of its key focus on bioenergy, the Federal Government provided around €48 million to fund a total of 739 ongoing projects in 2022. The Federal Government also appropriated approximately €34.21 million in funding for 131 new research projects (cf. figure 12).

Figure 12: Funding for bioenergy in € million
(Data cf. Table 4, p. 103)



PROJECT ABSTRACT

NETFLEX – *Collaborative project: Development of a self-learning control system for integrating biogas plants into grids with a high proportion of intermittent electricity generation*

With the expansion of renewable energy, bottlenecks are expected for distribution grids. The solutions used up to now, such as load balancing, peak load capping, grid expansion and the use of electricity storage, require extensive planning and are cost-intensive. One alternative is controllable, decentralised electricity generation by biogas plants adapted to the needs of the distribution grids. For this purpose, a biogas plant control system was developed to produce electricity according to demand and to avoid local grid overloads. Depending on the application, this can be used to create schedules for operating biogas CHP plants based on the needs of the electricity market, heat demand and the distribution grid. The control system developed allows electricity generation from biogas plants to be additionally adapted to diurnal fluctuations in photovoltaic feed-in profiles – both at short notice and in a self-learning manner, thus enabling higher feed-in rates for surrounding photovoltaic plants. For this purpose, weather forecasts from models and advanced nowcasting methods are continuously integrated into the control system. This project promotes the integration of biogas plants as a system component of smart energy grids.

In the NETFLEX research project, researchers have developed a biogas plant control system to produce electricity according to demand and avoid local grid overload.

Beneficiaries: Ingolstadt University of Applied Sciences – Institute for New Energy Systems, Ludwig-Maximilians-Universität München – Faculty of Physics – Chair of Experimental Meteorology and Burghart GmbH & Co. KG
Funding ID: 22400318, 22405217, 22400418
Appropriated funding: €560,000
Project duration: 2018 – 2022
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

EmissionPredictor – *Collaborative project: Prediction and reduction of pollutant emissions in biomass combustion using intelligent controllers*

The formation of gaseous emissions of carbon monoxide and nitrogen oxides in a biomass furnace was described in this project using numerical simulation, thus enabling online optimisation of combustion control. First, pollutant formation models were integrated into numerical simulation tools and the emission prediction for transient furnace operating modes was validated. In addition, control mechanisms based on statistical and self-learning methods were designed for biomass CHP plants for the first time, thus achieving online combustion optimisation during operation with fluctuating fuel properties. These approaches were combined into an emission control system and tested in a CHP plant. The control system acts as an additional computer in the control room, providing the operator with enhanced information about current operating parameters and suggesting active control interventions. The control system developed can help to reduce pollutant emissions and to increase the use of agricultural residues.

Researchers in the EmissionPredictor project have, among other things, developed an emission control system and tested it in a CHP plant.

Beneficiaries: Friedrich-Alexander-Universität Erlangen-Nürnberg – Chair of Energy Process Engineering, aixprocess GmbH and Heizkraftwerk Altenstadt GmbH & Co. KG
Funding ID: 22040318, 22039218, 2219NR006
Appropriated funding: €420,000
Project duration: 2019 – 2022
Project description on EnArgus:

MORE DETAILS

2.3.4 Geothermal energy

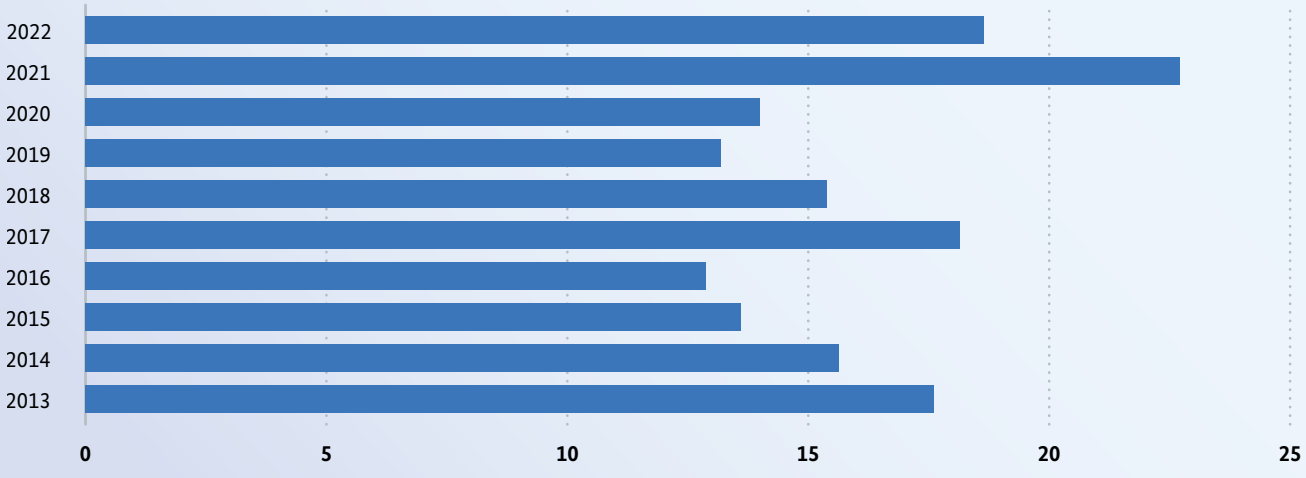
Geothermal energy is a reliable source of energy. With the technologies currently available, hydrothermal geothermal energy is an economically viable heat source on the German market. In contrast, it is rarely used to generate electricity. For this reason, geothermal energy is mainly used to supply households, neighbourhoods and companies with heat and cold. Municipal utility Stadtwerke München, for instance, is planning to supply most of its district heating networks with heat from geothermal sources by 2040. In the field of deep geothermal energy, the German Geothermal Association (BVG) says that more than 40 heating and power stations and combined heat and power plants with a heat capacity of around 350 megawatts and an electrical capacity of nearly 50 megawatts are in operation in Germany. In the field of near-surface geothermal energy, around 440,000 facilities have been installed – for instance, geothermal probes or collectors in conjunction with heat pumps – with a heat capacity of roughly 4,400 megawatts.

In strategic terms, the use of geothermal energy for the supply of heat and cold and the storage of heat is to be further expanded in Germany. Research projects funded under the 7th Energy Research Programme are to help make geothermal heat rapidly deployable, reduce the costs and risks in development and use, and boost awareness and public acceptance of geothermal energy. The transfer of new technologies into practical application is to be accelerated by focusing particularly on demonstration and pilot projects. In order to better exploit the potential of geothermal energy for the heat transition, the Federal Ministry for Economic Affairs and Climate Action has also identified further concrete measures in a key issues paper. As a result of the accompanying consultation process, at least 100 additional geothermal projects are to be initiated by 2030.

Project funding

In the field of geothermal energy, the Federal Ministry for Economic Affairs and Climate Action provided approximately €18.64 million in funding for 110 ongoing projects in 2022. The ministry also appropriated approximately €20.69 million in funding for 22 new research projects (cf. figure 13).

Figure 13: Funding for geothermal energy in € million
(Data cf. Table 4, p. 103)

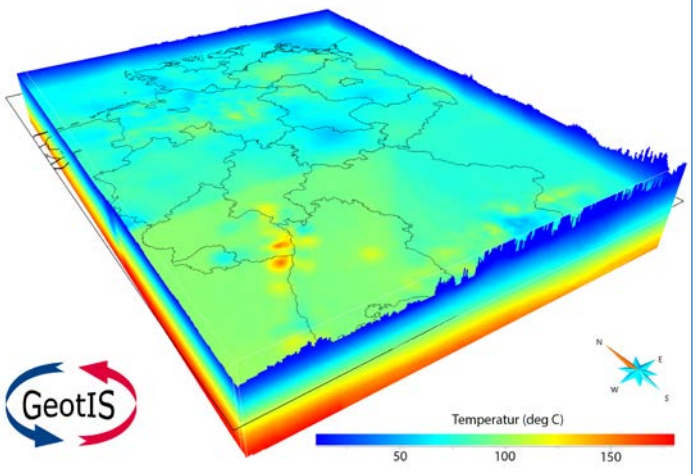


PROJECT ABSTRACT

WärmeGut und Warm-Up – *Uniform nationwide geoinformation on near-surface geothermal energy in Germany and a criteria catalogue for the selection of exploration measures and sites for medium-depth geothermal energy*

Geothermal energy can contribute significantly to the supply of climate-neutral heat. Tapping unused geothermal potential is the goal of research projects funded under the "Geothermal energy for the heat transition" campaign by the Federal Ministry for Economic Affairs and Climate Action. In order to make more comprehensive use of near-surface geothermal energy in Germany, researchers in the WärmeGut project, coordinated by LIAG (Leibniz Institute for Applied Geophysics), are standardising existing geological data from the Länder and integrating it into the GeotIS geothermal information system. Traffic light maps are used to show the utilisation potential of near-surface geothermal energy throughout Germany. By matching the geothermal potential with heat demand densities, the teams of researchers will enable ecologically compatible increases in efficiency and economic expansion paths for geothermal energy.

Researchers in the Warm-Up project, coordinated by the Federal Institute for Geosciences and Natural Resources (BGR), are developing criteria for the scientifically valid selection and evaluation of exploration measures and sites for medium-depth geothermal energy. Exploration sites should offer promising geological and infrastructural conditions. Using the elaborated, nationally valid criteria, hydrothermal projects with high prospects of success are identified and investigated, and development and utilisation concepts are drawn up.



In GeotIS, researchers standardise geological data and integrate it into a geothermal information system.

WärmeGut
Beneficiaries: Leibniz Institute for Applied Geophysics (LIAG) and three other partners
Funding ID: 03EE4046A-D
Appropriated funding: €13.8 million
Project duration: 2022 – 2025
Project description on EnArgus:

MORE DETAILS

Warm-Up
Beneficiaries: Federal Institute for Geosciences and Natural Resources (BGR) and three other partners
Funding ID: 03EE4049A-D
Appropriated funding: €2.8 million
Project duration: 2022 – 2026
Project description on EnArgus:

MORE DETAILS

2.3.5 Hydropower and marine energy

Hydropower covers roughly 3% of Germany's electricity generation. It has a crucial advantage over wind and solar energy: hydropower is largely unaffected by the weather and is thus continuously available. However, almost all of the suitable sites for current technologies have been exhausted. Researchers are therefore aiming to use innovative technologies to boost the capacity of existing installations and to develop new sites. Research is also underway into how hydropower can help to improve the response to fluctuating energy demand. In the field of marine energy, funding is going towards the development and demonstration of marine current turbines and wave energy converters.

Project funding

In the field of hydropower and marine energy, the Federal Ministry for Economic Affairs and Climate Action provided approximately €0.31 million in funding for four ongoing projects in 2022. The ministry also appropriated approximately €1.33 million in funding for three new research projects (cf. figure 14).

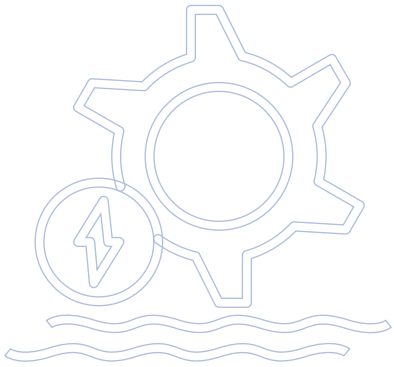
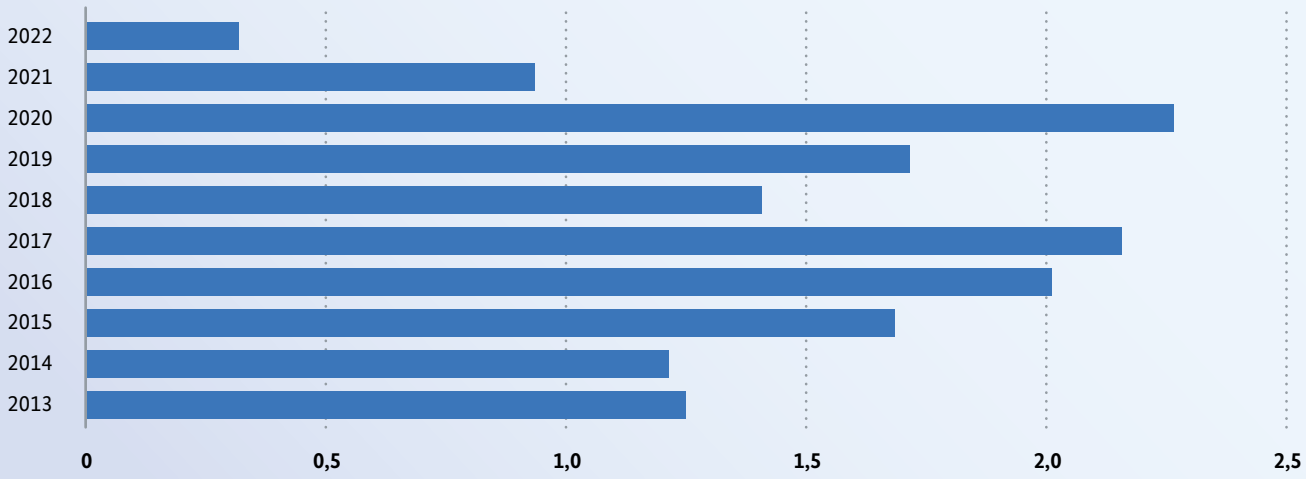


Figure 14: Funding for hydropower and marine energy in € million
(Data cf. Table 4, p. 103)



2.3.6 Thermal power plants

Moving away from fossil fuels towards synthetic gases such as hydrogen or other alternative fuels is expected to enable thermal power plants to operate efficiently and with low emissions during the energy transition. In addition, these power plants must produce electricity quickly and reliably when the sun is not shining or the wind is not blowing.

Funding priorities and scientific advances

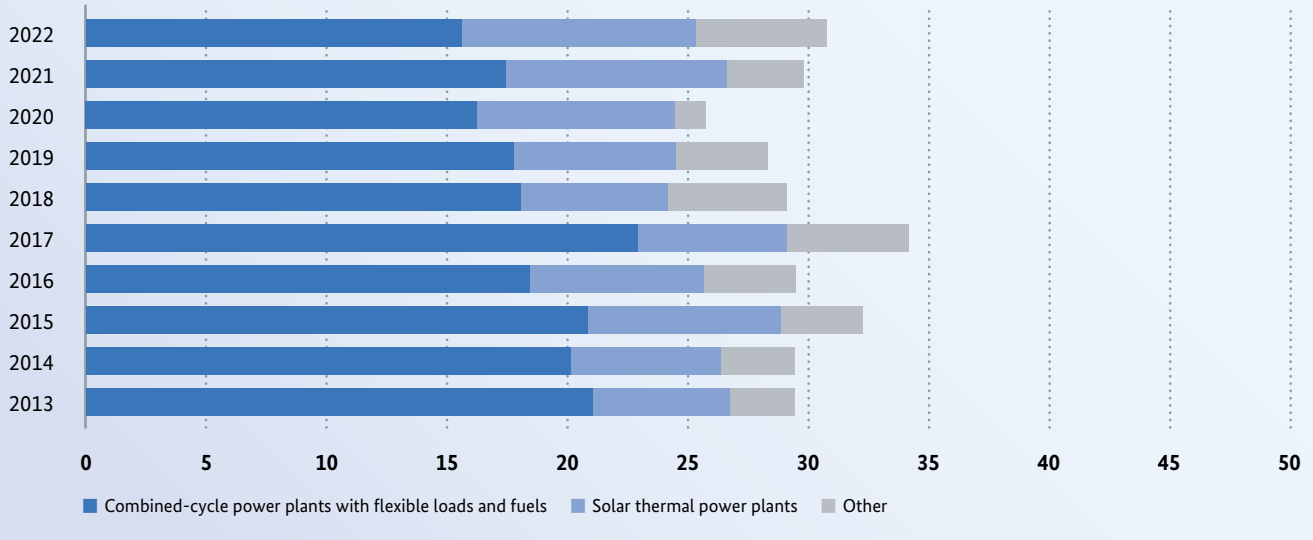
The use of alternative fuels poses major challenges for gas turbines. The combustion characteristics of these fuels differ from those of natural gas with a view to temperature, flame speed or ignition delay time. This means that combustion systems must be made fit for the next generation of gas turbines. Adapted plant concepts and operating processes are needed, also for power-to-x-to-power processes, while the materials used also need to be optimised. The reason for this is that turbine components are increasingly exposed to strong changes in load and temperature due to the increasingly flexible operation of power plants.

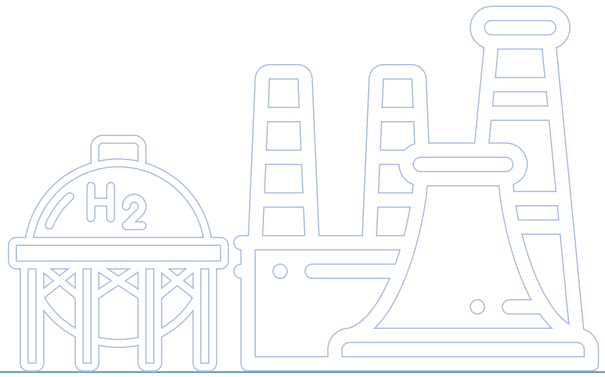
Solar thermal power plants, on the other hand, use concentrated solar energy to produce electricity. This form of electricity generation will become even more important in countries like Spain, Morocco or the United Arab Emirates with many hours of sunshine. Although Germany only has demonstration plants for research purposes, the country's considerable expertise in plant and mechanical engineering is to be further strengthened for export – for instance, with research work on new heat transfer media such as liquid salt or receiver technology.

Project funding

In the field of thermal power plants, the Federal Ministry for Economic Affairs and Energy provided approximately €30.72 million in funding for 356 ongoing projects in 2022. The ministry also appropriated approximately €41.65 million in funding for 86 new research projects (cf. figure 15).

Figure 15: Funding for thermal power stations in € million
(Data cf. Table 4, p. 103)



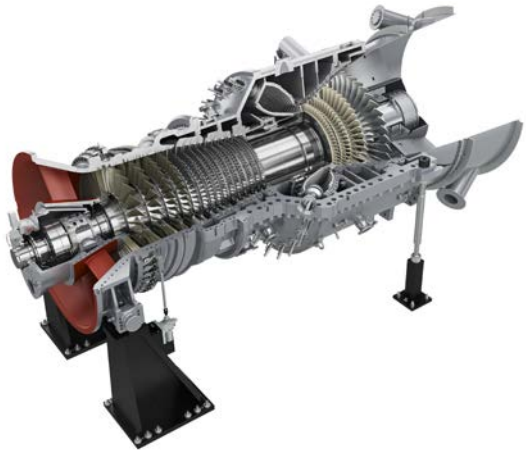


PROJECT ABSTRACT

4FH2Max – *Optimisation of the existing combustion system of the Siemens Energy Gas Turbine 4000F for safe operation with a hydrogen blend of >50% vol. to reduce CO_2 emissions*

In principle, the fuel composition in stationary gas turbines can be shifted from pure natural gas towards hydrogen. However, since there are considerable differences in the combustion properties of hydrogen and natural gas, adding hydrogen places high demands on the burner. As the blend of hydrogen in the fuel gas increases, this influences decisive combustion parameters such as flame speed, flame length and local heat release. The effect of hydrogen in the fuel gas is to be analysed in the 4FH2Max project using laser-optical measurement methods. The results will help to optimise hydrogen-enabled gas turbine burners.

The Siemens Energy SGT5/6-4000F gas turbine is used in over 350 turbine systems worldwide. The goal of the team of researchers working in the 4FH2Max project is to develop the burner in such a way that it will be possible to operate the gas turbine with a hydrogen blend of more than 50% with the same power output. The solution is to be fully compatible with the installed 4000F fleet so that operators will be able to retrofit the necessary adaptations to the gas turbine at a comparatively low cost, but will also be able to use them in new plants.



In the 4FH2Max project, laser-optical measurement methods are used, among other things, to analyse the effect of hydrogen in the fuel gas.

Beneficiaries: Siemens Energy Global and the German Aerospace Center – Institute of Propulsion Technology
Funding ID: 03EE5119A+B
Appropriated funding: €2.6 million
Project duration: 2022 – 2026
Project description on EnArgus:

MORE DETAILS

2.4 System integration

2.4.1 Electricity grids

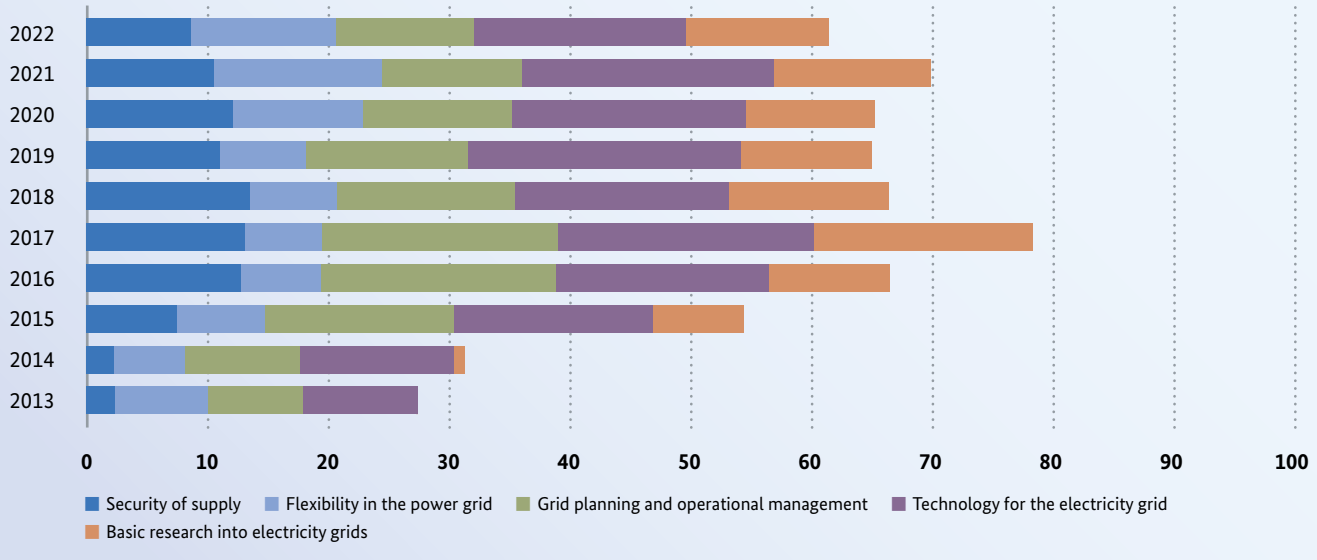
As part of the energy transition, the energy system is not only being converted from fossil to renewable energy sources, the infrastructure itself also needs to be adapted. Where electricity was once transported over short distances from large power plants to the surrounding industrial companies and private households, it now has to travel longer distances from the generation plant to the socket. One reason for the necessary expansion of grid capacities is that energy is mainly generated in wind farms on the North Sea coast and at sea and brought from there to the densely populated and high-consumption urban centres in western and southern Germany. Another reason is that power lines are no longer one-way streets like they used to be. Instead, they can be compared to busy multi-lane motorways. That's because more and more consumers are becoming electricity producers themselves and feeding in energy via photovoltaic systems on roofs, for instance, so that the energy system is developing into a finely meshed network with countless points that must be optimally and flexibly linked and coordinated with each other. This is based on the principle that the grid should be optimised before it is reinforced, and reinforced before it is expanded.

Funding priorities and scientific advances

In order to strengthen research for a sustainable energy system, the Federal Ministry for Economic Affairs and Climate Action published a call for funding for power converters in 2022. The Power Converter Lifetime (StRiLeb) call for applications aims to support collaborative projects in which experts research the causes of power converter failures, extend the lifetime of power converter systems and improve the operational management of renewable energy plants with higher resilience.

The Federal Ministry of Education and Research is continuing its successful funding of holistic interdisciplinary and transdisciplinary approaches. The Kopernikus project ENSURE, for instance, is researching building blocks for changed, more decentralised energy supply as part of the energy transition up until 2045. The social, economic, ecological and political framework conditions are also

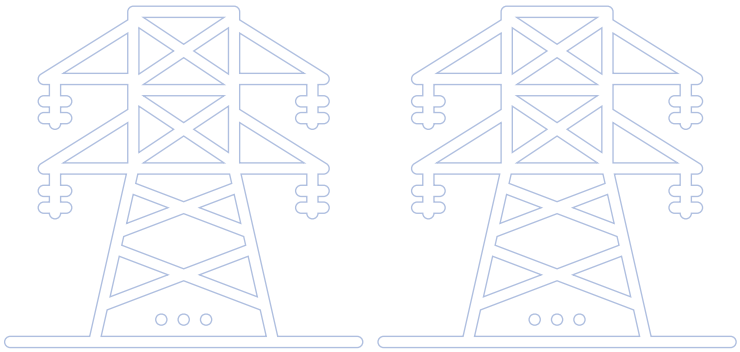
Figure 16: Funding for electricity grids in € million
(Data cf. Table 5, p. 104)



continuously considered. The technical priority is on future grid structures, taking into account digitisation, sector coupling and high power availability for new use cases such as electric mobility. The Flexible Electrical Networks (FEN) research campus aims to use DC technologies for an energy supply with a high share of decentralised and renewable energy sources. The HYPOWER project is exploring ways in which large-scale electrolysis can be integrated into the electricity grid.

Project funding

In the field of power grids, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €61.28 million in funding for 568 ongoing projects in 2022. The ministries also appropriated approximately €56.77 million in funding for 130 new research projects (cf. figure 16).



PROJECT ABSTRACT

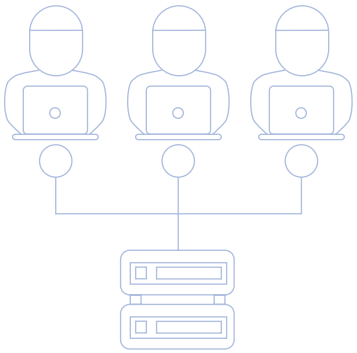
RegEnZell – *Cross-cell regionalisation of energy supply through operation-optimised sector coupling*

Optimising the distribution grid in terms of operation and sector coupling was the goal pursued by the project team in two energy cells in the neighbouring towns of Kirchheimbolanden and Alzey in Rhineland-Palatinate. To achieve this, the experts examined the cells' energy flows and improved intercellular interaction. At the same time, the team looked at ways to increase the use of regional green electricity. One of the requirements was the intelligent use of flexibilities in real operation. Secondly, the researchers simulated how residual power in the energy cells, i.e. the load that has to be drawn from the upstream grid, can be reduced. A central approach here was to convert surplus electricity from renewable energy into synthetic methane for local energy supply. In real experiments, this power-to-gas process also proved to be well suited for fast and flexible responses to load changes. In other words, if more renewable energy plants were included in the future, this potential could be multiplied, according to the experts, and the renewable methane produced could be integrated into the grid and marketed.

During the field test in the Alzey energy cell, green electricity from wind energy was also included (symbolic image).

Beneficiaries: EWR Netz and three other partners
Funding ID: 0350062A-D
Appropriated funding: €2.2 million
Project duration: 2019 – 2022
Project description on EnArgus:

MORE DETAILS



PROJECT ABSTRACT

BEAUTIFUL – *Stress-optimised work design for critical infrastructure network control centres – cognitive ergonomics, assistance systems and control centre simulators*

Staff in the network control centres of distribution grid operators are responsible for the reliable operation of the electricity and gas grids. However, as sector coupling and decentralised energy systems increase, so too does the amount of relevant process information that control centre staff must take into account in grid operation management. The aim of the BEAUTIFUL project is to optimise working conditions for control centre staff in such a way that they remain capable of acting as the amount of information increases. In a first step, control room simulators are being developed to realistically map various operating situations, as well as ergonomic assistance systems to enable critical decisions to be made safely. These will then be tested under real conditions using the example of energy supply in regional distribution networks.

Thereby, network control centres can be supplemented by socio-technical systems in the increasingly networked energy system while providing a load-optimised work design for control centre staff in critical infrastructures.

The control centre staff processes information for the electricity and gas supply.

Beneficiaries: Fraunhofer Institute for Applied Information Technology (FIT) and nine other partners
Funding ID: 03SF0694A-I
Appropriated funding: €7 million
Project duration: 2023 – 2025
Project description on EnArgus:

MORE DETAILS

2.4.2 Electricity storage

Whether large or small, mechanical or chemical, underground or above ground, electricity storage technologies are all used to decouple electricity consumption from the place and time of generation. This makes them essential building blocks of the future energy system which relies on green electricity. As the share of green electricity in the energy system steadily increases, it is also becoming more and more challenging to store the growing, fluctuating amount of electricity generated from renewable energy sources. High-performance and cost-effective electricity storage systems are therefore needed – with high energy density, long service life and operational reliability. In recent years, the criteria for sustainable production and the recyclability of critical raw materials have also become more important. Dependencies on certain raw materials have to be reduced, for instance, by recycling the cell materials used and increasing their durability.

Funding priorities and scientific advances

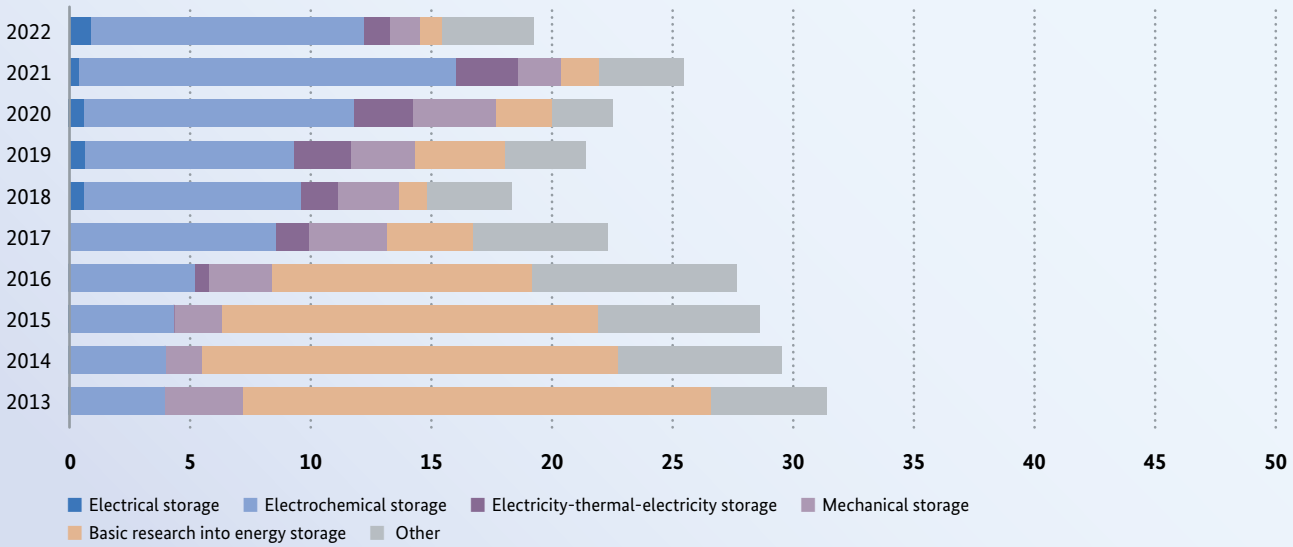
The focus is on promoting stationary electricity storage systems. To support research teams, the Federal Ministry for Economic Affairs and Climate Action published the call for funding for "Innovative Materials for Optimised System Integration of Stationary Electricity Storage Systems (IMSES)" in 2022. With this call, the ministry addressed experts working on cell and battery system enhancements while special consideration is to be given to the following aspects: resource and raw material availability, for instance, in the case of a large-scale rollout of electricity storage systems, climate neutrality and environmental friendliness of materials ("green chemistry"), material, cell and battery recycling, material and operational safety, cost reduction at component and storage level, ageing processes and synergy potential for mobile electricity storage systems. In this way, the call for funding serves the ministry's goal of meeting the growing demand for stationary energy storage systems in the electricity grid and improving their use in relation to the energy system. This allows possible potentials to be leveraged, for instance, by networking the elements and components even more and thus enabling better interaction between them. It is therefore particularly important that the (distribution) grid operators in question actively participate and that the requirements of end consumers are taken into account.

In addition to optimising lithium-ion batteries, the Federal Ministry for Economic Affairs and Climate Action sees a great need for research into new types of batteries in light of the efforts to achieve energy independence. The goals pursued are long-lasting stationary batteries, the avoidance of critical raw materials and a significant reduction in costs. With an initiative for Franco-German research cooperation, the Federal Ministry of Education and Research is funding a highly innovative polymer battery or a zinc-manganese dioxide battery concept that has achieved a breakthrough with a particularly powerful and stable manganese dioxide electrode. The "World Storage" innovation competition launched by the Federal Ministry of Education and Research is initiating the development of a particularly cost-effective zinc-ion-based home storage system.

Project funding

In the field of electricity storage, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €19.28 million in funding for 192 ongoing projects in 2022. The ministries also appropriated approximately €12.57 million in funding for 18 new research projects (cf. figure 17).

Figure 17: Funding for electricity storage in € million
(Data cf. Table 5, p. 104)



PROJECT ABSTRACT

HyReK – *Hybrid Regel Kraftwerk 2.0 – Development, optimisation and validation of a sector-coupling hybrid storage system for the provision of primary balancing power*

A functioning electricity system needs flexible balancing energy that compensates for fluctuations in the grid by being fed in or withdrawn as a reserve when needed. At present, balancing energy is mainly provided by fossil-fuelled power plants. Once these plants have been shut down, new solutions will be needed. This was what motivated the research team to use a hybrid balancing power plant to increase the flexibility of energy output and thus stabilise the power grid. The experts explored how to optimise the operation of a power plant in Bremen, which had been expanded to include a large-scale battery and a power-to-heat plant. To achieve this, they looked not only at the individual power plant components of electricity storage, heat storage and electric boiler, but also at the interaction of the entire system. According to the project partners, their model could help replace conventional power plants with new technologies in the future. To ensure the economic und sustainable operation of these plants, the research team also analysed ecological, economic and social issues relating to the new type of power plant and drew up recommendations that rank the chances of implementation in Germany in economic terms.


The battery storage system helps to optimise the operation of the Bremen-Hastedt hybrid power plant.

Beneficiaries: swb Erzeugung AG & Co. KG and two other partners
Funding ID: 03ET6147A-C
Appropriated funding: €2.5 million
Project duration: 2020 – 2022
Project description on EnArgus:

MORE DETAILS

INFO

Research and development in the field of battery cells and systems

Mobile and stationary energy storage systems are crucial for the successful transformation of energy and mobility systems. In the case of electric mobility, in particular, the battery system will account for a larger share of future value creation. Research funding by the Federal Ministry for Economic Affairs and Climate Action focuses on the various electrical and electrochemical storage systems (rechargeable batteries as well as supercapacitors) in order to trigger investments in this key industry in Europe, reduce the use of raw materials and energy in battery cell production, technically advance battery recycling and eliminate dependence on imports in these future fields.

The economic goal is to pool and strengthen excellence in battery cell technology, its production and recycling in Germany and to establish large-scale production across Europe on the basis of research and innovation. In addition to the initiative to establish a battery value chain within the framework of two European IPCEI projects ("Important Projects of Common European Interest"), the Federal Ministry for Economic Affairs and Climate Action also published a call for funding for battery research under the 7th Energy Research Programme which complements and supports the two IPCEIs. Within the scope of this call for funding, measures in the field of sustainability and digitisation are prioritised, with funding focused on innovative and application-oriented solutions for efficient material and energy use in the entire battery value-added cycle as well as on second-use and recycling concepts. Other priorities are research and development projects in the fields of battery testing, certification, Industry 4.0 and applications of next-generation battery cells. The overarching goal is to establish a sustainable, resource-conserving circular economy for high-quality and competitive battery production in Germany.

2.4.3 Sector coupling and hydrogen

In the course of the energy transition, it is important to introduce regenerative energy carriers across the entire energy system. Hydrogen produced from renewable energy can decarbonise sectors such as industry, transport and heat which are otherwise difficult to make climate neutral. Hydrogen is regarded as a key element here as it can be used as a feedstock for steel production and in the chemical industry. In the transport sector, it can be used in vehicles with fuel cell drives or as a component of synthetic fuels, for instance, for air travel. In a networked energy system, it can be used as a storage medium for renewable energy.

Funding priorities and scientific advances

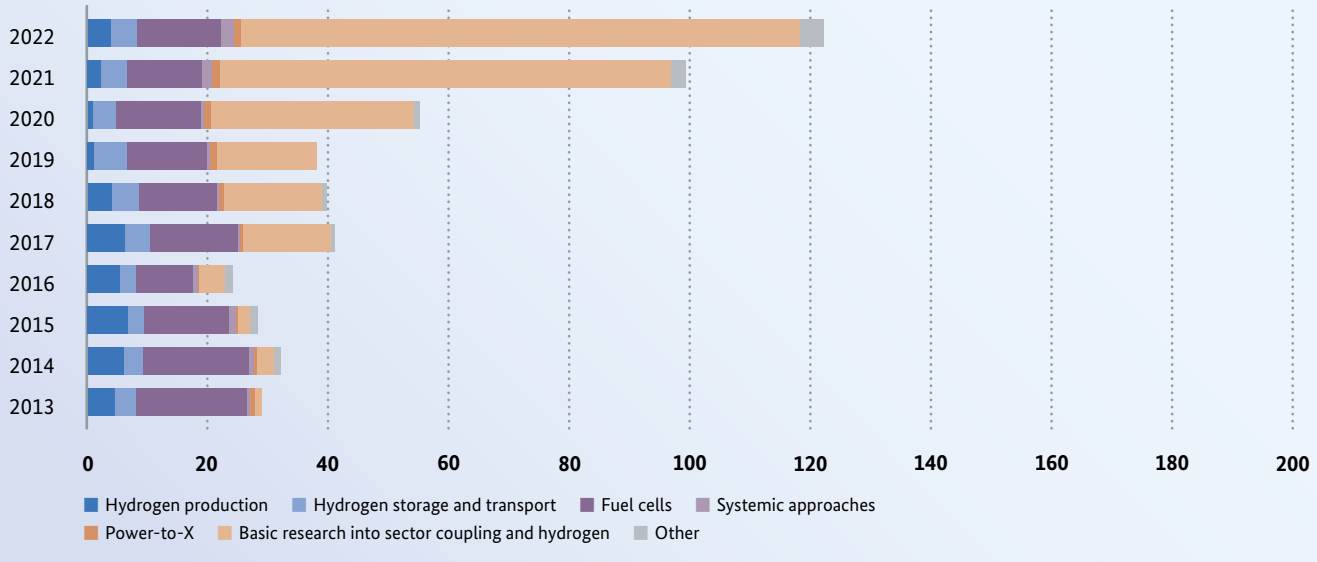
The Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research are funding research and development on a wide range of topics along the hydrogen value chain. These topics also reflect the priorities of the National Hydrogen Strategy, i.e. the hydrogen flagship projects, basic research into green hydrogen and applied energy research within the framework of the hydrogen technology offensive and the Living Labs for the Energy Transition in the field of hydrogen.

In the context of hydrogen technologies, the funding provided by the Federal Ministry for Economic Affairs and Climate Action for application-oriented research focuses on wide range of sustainable jobs, new potential for added value and a global market

worth billions. The Federal Government's National Hydrogen Strategy adopted in June 2020 as the cornerstone for the market ramp-up provides a coherent framework for the future production, transport and use of hydrogen. Within this framework, the Federal Ministry for Economic Affairs and Climate Action is promoting research and development that supports these goals. In addition, the *"Important Projects of Common European Interests" (IPCEIs)* for hydrogen technologies and systems at European level and the International Hydrogen Projects at global level are driving the market ramp-up (cf. Chapter 5.2 Innovation funding by the Federal Government beyond the Energy Research Programme, p. 98). With the Hydrogen Technology Offensive, the Federal Ministry for Economic Affairs and Climate Action is also addressing companies and research groups, encouraging them to expand their efforts to develop hydrogen production and its use in industrial processes, storage and transport in gas grids, on roads and rail. The campaign is being supported by systems analysis oriented to a global hydrogen economy. In addition, the interdepartmental Hydrogen Research Network, which is coordinated by the Federal Ministry for Economic Affairs and Climate Action, fosters exchange between experts from industry, universities and research institutes on the production, storage, distribution and cross-sectoral use of hydrogen. In 2022, the research network presented a detailed version of the expert recommendation published the previous year by the network. The need for research and development in the field of hydrogen innovations up to 2025 outlined in the recommendation was reaffirmed at the Hydrogen Dialogue jointly conducted in October 2022 with the Hydrogen Compass (German: H2-KOMPASS) project. This project, which is jointly funded by the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research, is developing the basis for a German hydrogen roadmap.

The Federal Ministry of Education and Research is supporting the ramp-up of hydrogen in the field of basic research, focusing on hydrogen pipeline projects. In addition, the Kopernikus project P2X is developing new production routes for the chemical and primary industries using hydrogen produced with renewable energy. P2X has made progress in hydrogen production and in the development of fuels, plastics and glass production. In the SEKO project, researchers are investigating the intelligent

Figure 18: Funding for sector coupling and hydrogen in € million
(Data cf. Table 5, p. 104)



linking of electricity, transport, heating and cooling using the example of a research infrastructure with real components and relying heavily on ICT.

In addition to CO_2 from industrial sources, the Carbon2Chem project also uses hydrogen from renewable energy to produce chemical feedstock. The project thus contributes to sector coupling (cf. Chapter 2.5.4 CO_2 technologies, p. 62). The hyBit project is building a hydrogen economy in Bremen's industrial port and addressing interaction between hydrogen production, industry, mobility, logistics and urban structures (cf. highlight project, p. 54). The WAVE-H2 industrial research platform is integrating the generation, distribution and storage of hydrogen with its use in flexible industrial production processes that can be operated either with electricity or with hydrogen. These results will not only enable the industry to reduce its CO_2 emissions, but will also stabilise the power grid.

In basic research, both technological innovations and system studies are helping to promote sector coupling with hydrogen.

Project funding

In the field of sector coupling and hydrogen, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €130.83 million in funding for 552 ongoing projects in 2022. The ministries also appropriated approximately €187.20 million in funding for 191 new research projects (cf. figure 18).

PROJECT ABSTRACT

OffsH2ore – *Offshore hydrogen production using offshore wind energy in an island mode configuration*

Hydrogen produced with electricity from renewable energy is to become a mainstay in the decarbonisation of the energy system. One option for hydrogen production in this country is at sea with the help of offshore wind power and this is precisely what the partners of the project OffsH2ore investigated. While keeping both technical and economic interests in mind, they explored the best way to produce hydrogen at sea and bring it to land by ship. The starting point was a fictitious offshore wind farm in the North Sea connected to an electrolysis platform that can produce green hydrogen with a ship delivering this to the coast. In addition to the challenges of offshore operating conditions, the experts analysed issues of storage, transport and logistics, operation and maintenance of offshore facilities, as well as regulatory aspects. The biggest challenge was that green hydrogen has not yet been produced at sea. The recommendations by the research team could serve as a model solution for the development of pilot and large-scale projects.

Producing hydrogen at sea and transporting it on land: The OffsH2ore project partners have investigated how this could be achieved in a technically and economically optimal way.

Beneficiaries: PNE AG and four other partners
Funding ID: 03EI3031A, C-F
Appropriated funding: €2 million
Project duration: 2020 – 2022
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

hyBit – *Hydrogen for Bremen's industrial transformation. A first boost to the development of a hydrogen economy in northern Germany*

As part of the hyBit project, an exemplary study is being conducted in Bremen's industrial port to identify how a sustainable hydrogen economy can be developed and integrated into the energy and economic system of both the region and the entire country. Research is underway into the necessary hydrogen transformation around the Bremen steelworks – both across sectors and with regard to interactions at different socio-technical, economic, ecological and regulatory levels. Since the transformation of the individual sectors requires complex, cost-intensive and long-term decisions, interactions and synergies must be identified in order to perfectly align these decisions with each other and to avoid mutual obstruction. The central element is a digital transformation platform that maps interactions at different levels and at the same time serves as a monitoring tool. If the transformation process in hyBit is researched, prepared and accompanied in an interdisciplinary manner, the transition to a hydrogen economy in Bremen can be successful for society as a whole and also serve as an example for other locations.

The development of a hydrogen economy is being tested in Bremen's industrial port.

Beneficiaries: University of Bremen and 16 other partners
Funding ID: 03SF0687A-S
Appropriated funding: €29.8 million
Project duration: 2022 – 2026
Project description on EnArgus:

MORE DETAILS

SPECIAL

Hydrogen research

The importance of research into hydrogen technologies and sector coupling for the energy transition

Already today, companies and research institutions in Germany are already leading the field with a host of developments in hydrogen technologies and sector coupling – also thanks to long-term and reliable research funding by the federal and Länder governments. There are still a number of hurdles to be overcome before the potential of this future technology can be exploited for sustainable energy supply. At present, generation, storage and transport technologies and the necessary infrastructure are still too expensive to be competitive with fossil energy sources. Swift action is now needed at all political levels. Research, development and innovation along the entire value chain can further reduce costs, make the technologies used more durable and efficient, and thus accelerate the market ramp-up of a hydrogen economy. Research and development work is also needed to build import infrastructure.

Against this background, the Federal Government adopted the National Hydrogen Strategy in June 2020. This strategy outlines how Germany can use hydrogen in industry, transport and the energy system to stay competitive, achieve climate protection goals, open up new markets and create economic potential. Using a systemic approach, hydrogen production, transport, distribution and use are considered holistically – also at an international level.

The focus is always on building bridges from research to application and implementation on an industrial scale. To this end, the Living Labs for the Energy Transition were established at research level as a new funding pillar of energy research. They are intended to accelerate the transfer of innovation in key technologies – above all in the hydrogen sector – and to help the technologies reach market maturity much faster than before. In addition, the Federal Government relies on proven funding formats such as collaborative projects with strong partners from industry and academia. In particular, the long lead times from research to practical application make it indispensable to strengthen and accelerate application-oriented energy research with regard to the increasingly urgent issues of climate protection. Funding is also provided for the implementation of technologies "Made in Germany" abroad in order to pave the way for an import structure for green hydrogen.

The 7th Energy Research Programme also strengthens pre-competitive cooperation between academia and industry in application-oriented basic research. The Carbon2Chem and Kopernikus flagship projects demonstrate how cutting-edge science and innovative companies can successfully cooperate. Basic research projects on green hydrogen are securing the innovation pipeline for the next generation of technology. Hydrogen is an educational topic and the hydrogen economy needs skilled workers. This is being supported by new horizons for cooperation between education and research as well as initiatives in the field of vocational training.

2.5 Cross-system research topics

2.5.1 Energy systems analysis

Systems analysis research provides a valuable basis for planning a robust, affordable and environmentally friendly energy policy and an anticipatory climate policy. In light of recent developments in the energy industry, security of supply needs to be rethought and reassessed. Models and analysis provide an indispensable knowledge base for decision-makers.

Funding priorities and scientific advances

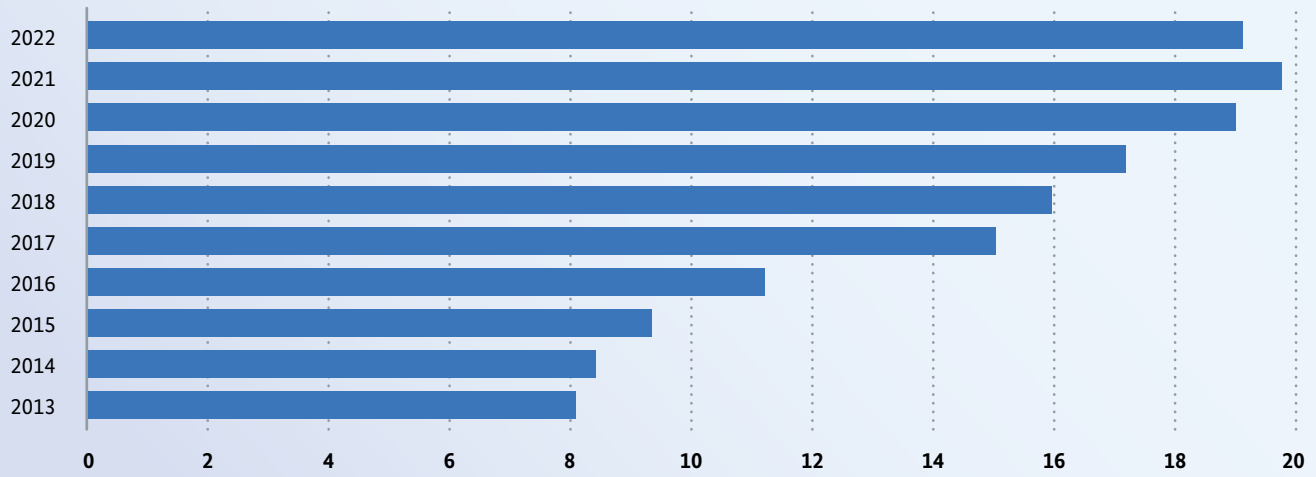
In November, the Federal Ministry for Economic Affairs and Climate Action published a key issues paper on Open Science in systems analysis as part of its open science strategy for research. The collective term includes openly accessible data (open data), openly licensed programme codes (open source) and free access to scientific publications (open access). An effective open science approach enables the transparent comparison of systems analysis models, thus facilitating improved energy supply planning. Around 150 experts from the Systems Analysis Research Network were involved in the development of this strategy.

Another focus of research funding by the Federal Ministry for Economic Affairs and Climate Action is the transfer of systems analysis work to practical application in the energy industry. This means, model calculations, scenario analysis and techno-economic studies need to be better used by the energy sector. This is to be achieved by involving companies more in the research network and in research projects, for instance, on advisory boards.

Project funding

In the field of energy systems analysis, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €19.09 million in funding for 213 ongoing projects in 2022. The ministries also appropriated approximately €21.37 million in funding for 53 new research projects (cf. figure 19).

Figure 19: Funding for energy system analysis in € million
(Data cf. Table 6, p. 105)



PROJECT ABSTRACT

METIS – *Development of new interdisciplinary methodological and analytical procedures for implementing the complexity of the energy transition in energy system models*

The team of researchers in this project pursued the goal of developing cross-sectoral models in order to map the increasing complexity of the energy system more accurately than before. With each day that passes, the energy system is becoming more complex due to the expansion of renewable energy, the coupling of electricity, heat, transport and industry as well as digitisation. Today's models must take this into account in order to provide politics, business and society with scientifically sound assessments for the energy transition. At the same time, the applications should continue to be understandable and solvable within reasonable computer time. For this purpose, methods to reduce complexity and optimisation algorithms have been developed. The modelling tools were used on the high-performance computers at Forschungszentrum Jülich to analyse energy supply variants. The researchers have made the software tools developed available as open source software. The models and tools are already being used in new research projects and, in part, in other energy system models investigating developments in the German and European energy systems up to the year 2050.

METIS researchers have also had supercomputers working, such as JUWELS at Forschungszentrum Jülich.

Beneficiaries: Forschungszentrum Jülich and two other partners
Funding ID: 03ET4064A-C
Appropriated funding: €1.8 million
Project duration: 2018 – 2022
Project description on EnArgus:

MORE DETAILS

2.5.2 Digitisation of the energy transition

The energy transition is rightly considered to be Germany's largest transformation project. At the same time, it is also a highly complex IT project that is part of the necessary digital transformation of the energy industry. After all, software controls today's energy infrastructure, digital applications support sector coupling and smart IT solutions enable greater energy efficiency.

Funding priorities and scientific advances

In the field of digitisation research, the Federal Ministry for Economic Affairs and the Federal Ministry of Education and Research are funding projects to develop information and communication technologies for energy supply, new business models and services, to optimise industrial processes with the help of IT solutions and to develop security and resilience concepts.

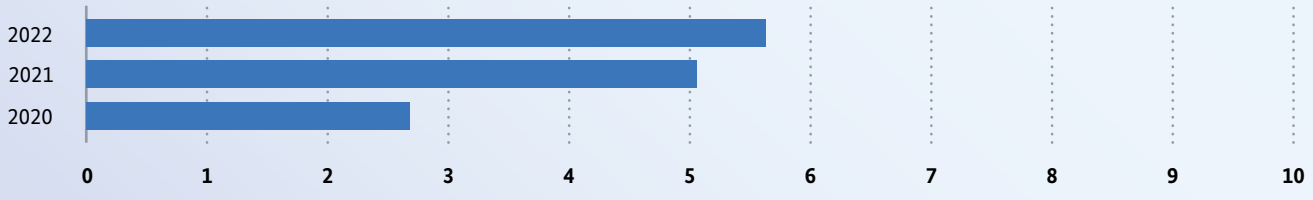
In July 2022, the Federal Ministry for Economic Affairs and Climate Action published the second call for funding for the development and application of the smart meter gateway communication platform for the digitisation of energy grids (DigENet II). The ministry is using this measure to step up the further digitisation of the energy transition. The aim is to equip as many smart metering points as possible with smart meter gateways and to run as many applications relevant for energy users as possible via these gateways. Due to the increased risk of cyber attacks on critical infrastructures such as energy supply as a result of current global political crises, smart meter gateways have become even more important as secure communication platforms.

Digitisation is also an important driver in basic research into new materials for future energy supply. Simulations can help to significantly shorten development cycles, for instance, of new catalysts for hydrogen production (cf. project highlight CatLab, p. 68).

Project funding

In the field of digitisation of the energy transition, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €5.63 million in funding for 97 ongoing projects in 2022. The ministries also appropriated approximately €15.13 million in funding for 56 new research projects (cf. figure 20).

Figure 20: Funding for the digitalisation of the energy transition in € million
(Data cf. Table 6, p. 105)



PROJECT ABSTRACT

HC-H2 – *Helmholtz Cluster for a Sustainable and Infrastructure-Compatible Hydrogen Economy*

New innovative hydrogen technologies are being developed and demonstrated on a large scale in the Helmholtz Cluster. The stakeholders are working to show that the ideas for a climate-neutral energy economy of the future work on an industrial scale. Focusing on technologies that make hydrogen economically storable and transportable, liquid organic hydrogen carriers are to be developed to help establish a sustainable hydrogen economy in the Rhenish mining region.

The cluster consists of two pillars: an H2 Innovation Centre as a research facility of the Helmholtz Association at the Jülich site and an H2 Demonstration Region as a network of stakeholders from industry, science and municipalities in the Rhenish mining region.

The launch project responsible for the overarching organisation and networking has been up and running since 2021. Funding is also provided for an office and the establishment of a laboratory infrastructure. In the first demonstration project, Multi-SOFC, electricity and heat supply is being tested at

New innovative hydrogen technologies are being developed in the Helmholtz Cluster.

Erkelenz hospital using a solid oxide fuel cell (SOFC). What's new here is that the SOFC is being supplied with hydrogen from liquid organic hydrogen carriers (LOHCs).

Beneficiaries: Forschungszentrum Jülich GmbH and other partners from the Rhenish mining region
Funding ID: 03SF0629, 03SF0701
Appropriated funding: €860 million, of which approx. €100 million for project funding
Project duration: 2021 – 2038
Project description on EnArgus:

MORE DETAILS MORE DETAILS

2.5.3 Resource efficiency in the context of the energy transition

Replacing energy-intensive materials, using fewer rare raw materials and preserving the value of products for as long as possible: for the energy transition to be a success, it is crucial that we use existing resources more sparingly and consume less.

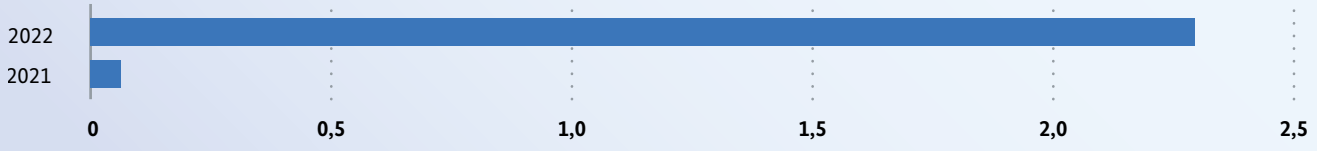
Funding priorities and scientific advances

In 2022, the Federal Ministry for Economic Affairs and Climate Action published a call for funding on resource efficiency. This underpins the ministry's commitment to supporting interdisciplinary projects with a cross-system approach. The goal is to sustainably reduce primary energy demand and energy-related carbon dioxide emissions. The focus is on reusing goods for the same purpose before reusing them for a different purpose. The funded projects include projects in which experts prepare, develop and test energy services or business models in the sense of a circular economy. Examples include balancing instruments in conjunction with greenhouse gas emissions and the economic, sociological and ecological impacts of recyclable products. In addition, research teams in the funded projects are exploring how energy-intensive or critical raw materials and materials can be replaced by more readily available or secondary raw materials. Concepts and solutions are also being developed in the projects that provide information on remaining waste flows, data on material flows and on the nature of products and components.

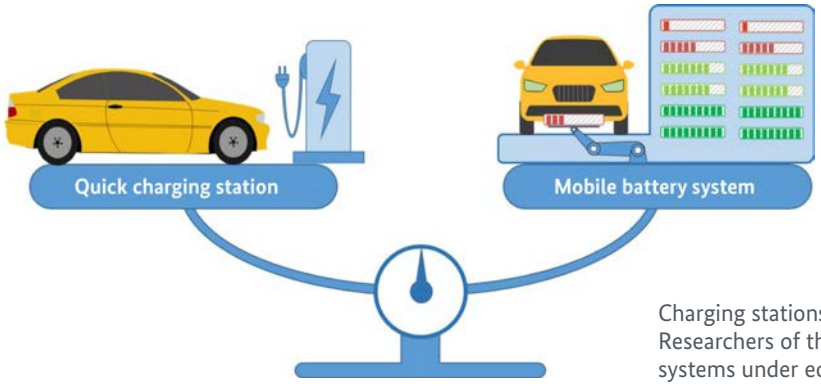
Project funding

In the field of resource efficiency for the energy transition, the Federal Ministry for Economic Affairs and Climate Action provided approximately €2.29 million in funding for 55 ongoing projects in 2022. The ministry also approved approximately €6.38 million in funding for 25 new research projects (cf. figure 21).

Figure 21: Funding for resource efficiency in the context of the energy transition in € million
(Data cf. Table 6, p. 105)



PROJECT ABSTRACT



Charging stations or the use of mobile battery systems: Researchers of the KreislaufAkkus project are comparing both systems under economic, ecological and technical aspects.

KreislaufAkkus – *Efficiency and circular economy potentials of battery systems in electric mobility*

In the KreislaufAkkus project, a research team is comparing the fully integrated battery systems widely used for electric cars, including the charging point infrastructure, with a swappable battery system at electric charging stations or with modular exchange concepts. The focus here is on ecological impact, resource intensity, recycling properties, impact on the energy system and economic efficiency. In addition to technology and infrastructure, business models, framework conditions as well as social and acceptance issues are being researched in an interdisciplinary manner. The most promising services and business models are then subjected to an in-depth analysis of the technical implications with the team examining the effects on vehicle construction as well as on the charging infrastructure. In this way, the team aims to provide urgently needed foundations for further strategic discussions. Based on the results, stakeholders can make trend-setting strategic decisions at an early stage, which will have far-reaching consequences from both an economic and ecological point of view. Several vehicle manufacturers, energy companies and associations are participating in the project as associated partners.

Beneficiaries: RWTH Aachen University and Institute for Ecological Economy Research (IÖW)
Funding ID: 03EI5006A+B
Appropriated funding: €500,000
Project duration: 2022 – 2024
Project description on EnArgus:

MORE DETAILS

2.5.4 CO_2 technologies

CO_2 technologies have considerable potential to reduce emissions, especially for industries where the production of carbon dioxide (CO_2) is unavoidable. Two approaches are being pursued here: carbon capture and storage (CCS) and carbon capture and usage (CCU).

Funding priorities and scientific advances

The Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research are funding research and development for a range of technological approaches to capture, store, transport and re-use CO_2 as a feedstock.

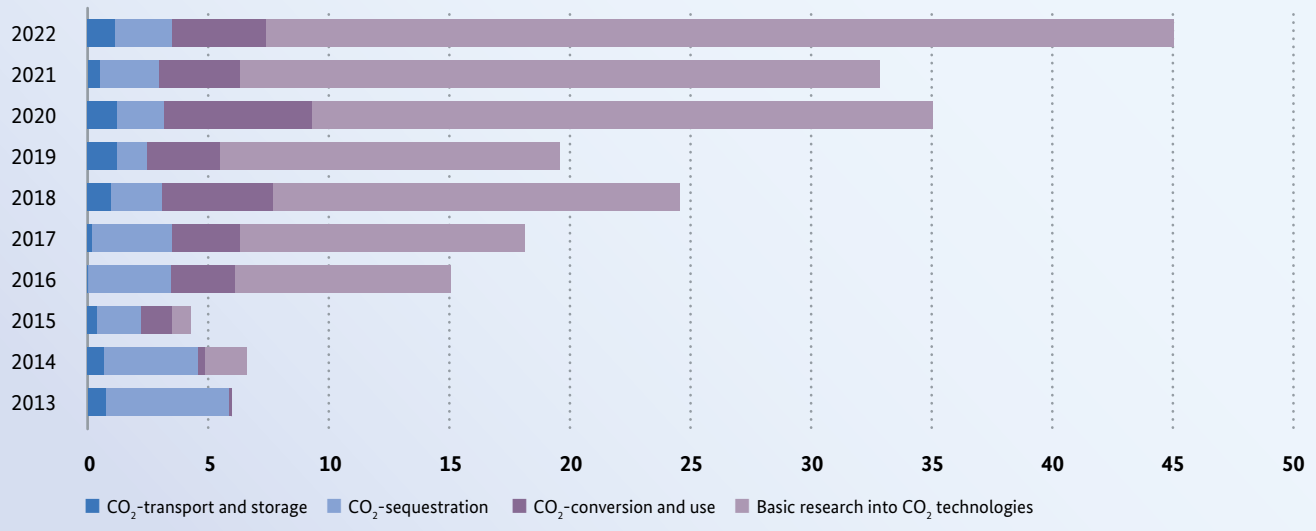
The Federal Ministry for Economic Affairs and Climate Action promotes application-oriented research projects. In some industrial processes, such as lime and cement production, CO_2 emissions are difficult or even impossible to avoid and this is where CCU and CCS technologies are needed. The capture, recycling and, if necessary, storage of CO_2 are creating important carbon cycles. Captured CO_2, for instance, can be used in the chemical industry as a component for basic materials or synthetic fuels.

The Carbon2Chem project funded by the Federal Ministry of Education and Research is successfully converting blast-furnace gases from steel production into input products for fuel, plastic or fertilizers. In this project, the blast-furnace gases are purified and finally converted into methanol, for instance, using hydrogen generated with electricity from renewable energy. Among other things, this can be used as a feedstock in the chemical industry.

Project funding

In the field of CO_2 technologies, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €45.09 million in funding for 143 ongoing projects in 2022. The ministries also approved approximately €13.76 million in funding for 40 new research projects (cf. figure 22).

Figure 22: Funding for CO_2 technologies in € million
(Data cf. Table 6, p. 105)

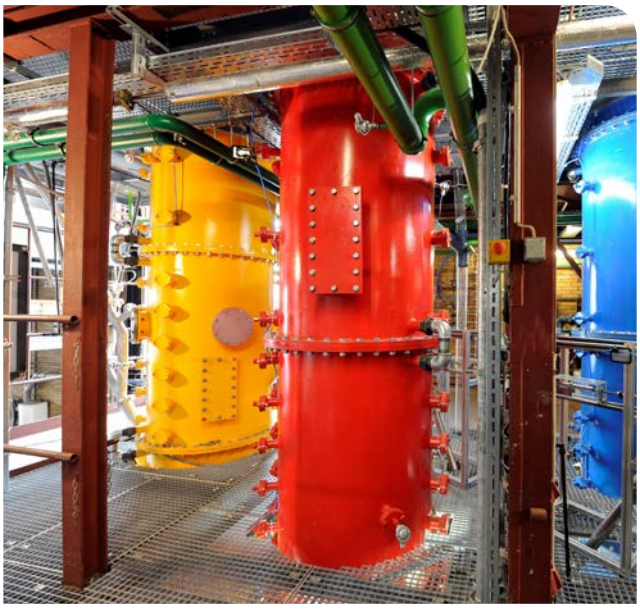


PROJECT ABSTRACT

NuCa – *Sustainable and low CO_2 waste treatment*

Waste-to-energy plants, or WtE plants for short, use waste to generate electricity or heat. Unlike landfills, waste incineration plants can recycle CO_2 for new products. Different processes are used to burn waste and the researchers in the NuCa project are optimising two of these: oxy-fuel and oxy-SEG gasification. Both of these thermal processes enable the capture of CO_2. While the oxy-SEG process converts waste materials into a synthesis gas in a fluidised bed gasification process, the oxy-fuel process uses oxygen to capture CO_2 as a valuable material in the combustion process. This process could be implemented as a retrofit measure on existing waste incineration plants.

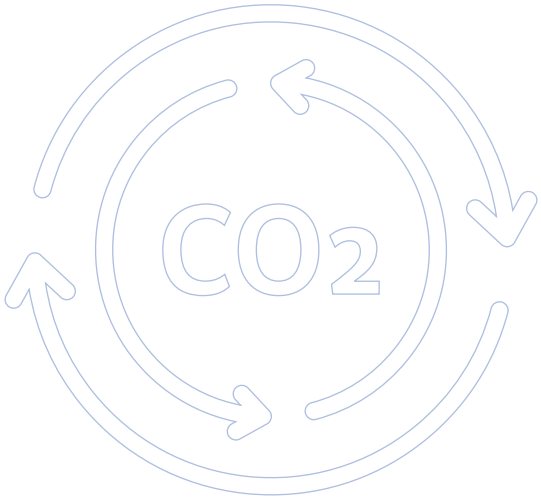
In addition to the analysis and optimisations being carried out by the team of researchers in the NuCa project, there are also plans to demonstrate the oxy-fuel and oxy-SEG gasification processes in 200-kWth pilot plants. In addition, the researchers are in close contact with colleagues working on a comparable research project in Norway.



In the NuCa project, researchers are optimising two thermal processes for capturing CO_2 in waste incineration processes.

Beneficiaries: Institute of Combustion and Power Plant Technology – IFK, University of Stuttgart and REMONDIS GmbH & Co. KG
Funding ID: 0324342A+B
Appropriated funding: €1.4 million
Project duration: 2018 – 2022
Project description on EnArgus:

MORE DETAILS



PROJECT ABSTRACT

Carbon2Chem L-0 – *System integration*

The Carbon2Chem project uses process gases from the primary industry to produce chemical feedstock. The aim of the L-0 sub-project is to link the results regarding possible sources of CO_2, gas purification and processing as well as various chemical syntheses with theoretical methods in order to create climate-friendly production networks that are economically competitive. A specially developed platform for distributed CO simulations enables detailed systemic analysis of process concepts for different products and carbon sources. The processes investigated are validated by comparing the test results obtained with real gases from steel production at the Duisburg-based Carbon2Chem Technical Centre. The Carbon2Chem L-0 project provides economic and environmental system assessments as a basis for sustainable technology options in industry and their implementation on an industrial scale. As a next step, researchers in the L-0 sub-project are working out the technical and economic framework conditions for first-time implementation of the Carbon2Chem concept on an industrial scale.

Experimental campaigns are being conducted at the Carbon2Chem® pilot plant in Duisburg to validate the robustness of the technology.

Beneficiaries: thyssenkrupp and 4 other partners
Funding ID: 03EW0004A-E
Appropriated funding: €29.5 million
Project duration: 2020 – 2024
Project description on EnArgus:

MORE DETAILS

2.5.5 Energy transition and society

The energy transition is more than a technological and economic transformation – it is a collective achievement of society, involving the general public, administration, (energy) industry and politics. Many actors take on multiple roles, for instance, as energy consumers and prosumers. Research in this field looks at the conflicts of interests and aims pursed by the groups and levels involved (municipal, regional, national) and develops solutions.

Funding priorities and scientific advances

In February, the Federal Ministry for Economic Affairs and Climate Action published a call for funding to support projects that develop societal issues in conjunction with cross-system and cross-technology aspects. The focus is also on interdisciplinary projects that examine the social framework conditions of the energy transition with a view to their technical, economic, social, institutional and legal dimensions. This also includes socio-economic research into social needs in regions of structural change. Other priorities in the call for funding included simulation, visualisation and communication strategies with social participation as well as positive narratives of a successful energy transition. Targeted research communication is also shifting closer to the focus of research. There are also projects that research and promote particularly successful forms of cooperation between institutional and other social actors and also specifically address young generations in order to transfer these findings to other areas of action in the energy transition.

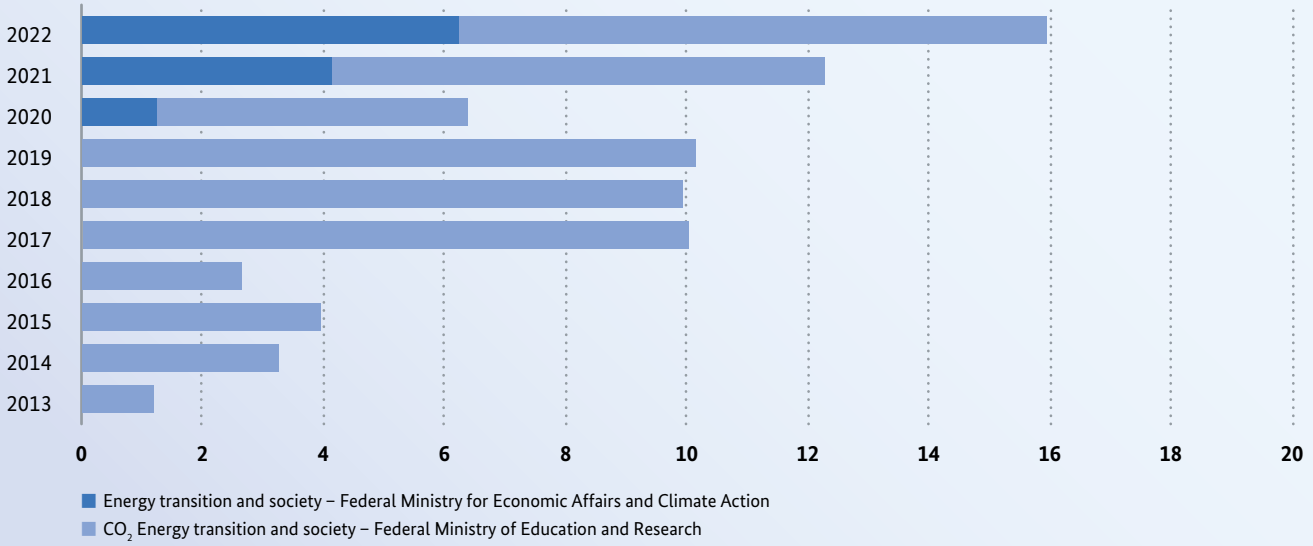
Since 2020, the Ariadne Kopernikus project funded by the Federal Ministry of Education and Research has been developing various decarbonisation scenarios and examining policy instruments in a systemic perspective in order to identify their potential effectiveness in achieving climate goals.

Together with stakeholders from politics, the energy transition and society, the project is identifying useful strategies and measures for the energy transition and determining their acceptance among citizens. One priority here is to integrate the German energy transition into a European framework. In 2022, the project adapted various focal points of its work in response to the new overall global situation caused by the Ukraine war and the energy price explosion. The team of researchers in the Ariadne project addressed, among other things, the effectiveness of relief measures and the compatibility of climate protection and energy sovereignty. In addition, social aspects are being examined in research projects on mobility, the urban energy transition and structural change in the wake of the phase-out of coal-fired power generation. The projects of the initiative “scientific support and accompaniment of transformation in Lusatia” are thus working proactively on structural change in the region.

Project funding

In the field of the energy transition and society, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €15.95 million in funding for 131 ongoing projects in 2022. The ministries also approved approximately €9.63 million in funding for 40 new research projects (cf. figure 23).

Figure 23: Funding for energy transition and society in € million
(Data cf. Table 6, p. 105)



PROJECT ABSTRACT

Akzept – *Effects of self-supply and membership in citizen energy societies on social inequality and their impact on the social acceptance of the energy transition*

The analysis of the Akzept science team proves: Financial participation and acceptance of the energy transition are connected.

The research team investigated how financial participation helps to achieve greater widespread social acceptance of the energy transition. The idea behind this being that while many people support the energy transition itself in surveys, they oppose the construction of wind farms and power lines on the ground. Due to this contradiction, the experts explored the extent to which citizens approve local projects more frequently when they benefit financially from them. They analysed what happens when citizens belong to an energy cooperative, participate in wind farms and wind energy funds or generate renewable electricity themselves, for instance, using a solar system. The team tested different forms of acceptance: general acceptance of the energy transition, passive acceptance of negative consequences, such as higher energy costs, local acceptance of wind and solar power farms close to residential areas, and active support of the energy transition, for instance, through energy-saving behaviour in everyday life or participation in citizens' initiatives. The results confirm that financial participation and acceptance are related. In order to advance the energy transition, the experts therefore recommend more opportunities for participation without great administrative effort and without risk.

Beneficiaries: Fraunhofer Institute for Systems and Innovation Research ISI and Women Engage for a Common Future
Funding ID: 03EI5210A+B
Appropriated funding: €190,000
Project duration: 2020 – 2022
Project description on EnArgus:

MORE DETAILS

2.5.6 Materials research for the energy transition

If the energy transition is to succeed, existing technologies need to be developed further and made more efficient. Innovative materials are an important part of this, which is why the Federal Ministry of Education and Research is funding innovations in materials in basic research.

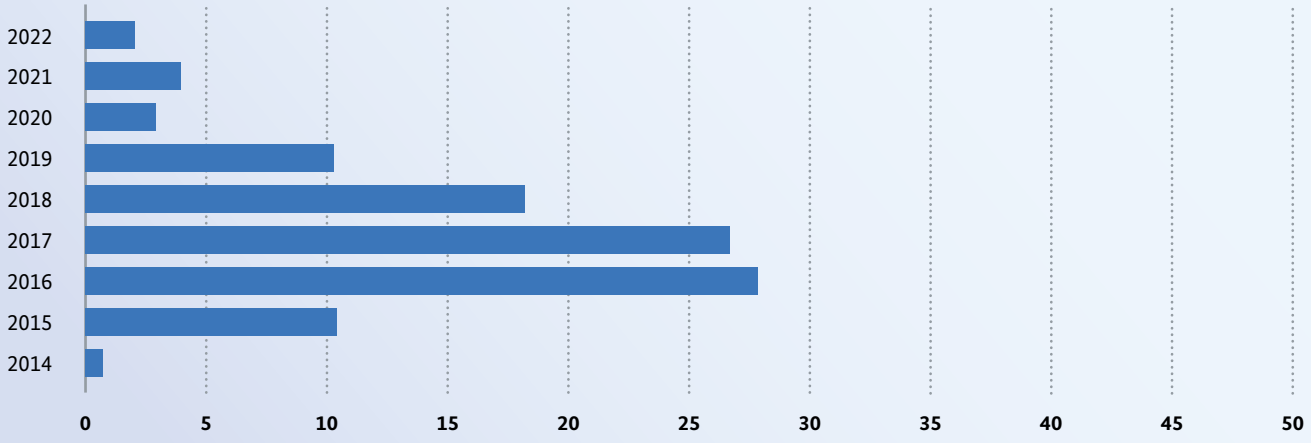
Funding priorities and scientific advances

In 2022, the materials research projects covered a wide range of areas. Young scientists, for instance, are investigating the problem of white etching cracks, i.e. cracks in the microstructure of wind turbine gearbox bearings, and these findings have already been taken up by the industry. Another junior research group is working on nanostructured carbon materials for electrochemical energy storage that are sustainably produced by mechanochemistry. Another project is exploring customised material systems for electrochemical energy systems and their production in a roll-to-roll process.

Project funding

In the field of materials research for the energy transition, the Federal Ministry of Education and Research provided approximately €2.05 million in funding for three ongoing projects in 2022 (cf. figure 24). In addition, materials research also plays a central role in the ministry's research funding outside the funding priority, for instance, for the CatLab research platform.

Figure 24: Funding for material research for the energy transition in € million
(Data cf. Table 6, p. 105)



PROJECT ABSTRACT

CatLab – *Catalysis Laboratory – Hydrogen and beyond: Thin film catalysts for sustainable chemistry with renewable energy*

In order to achieve extensive greenhouse gas neutrality for Germany by 2050, all generation and consumption sectors within the energy system will need to be thoroughly restructured. Helmholtz Zentrum Berlin, Fritz Haber Institute of the Max Planck Society and the Max Planck Institute for Chemical Energy Conversion are pooling their expertise to create the unique CatLab research platform. At the Berlin Adlershof site, scientists are developing novel, customised catalysts based on thin film technology. These catalysts are needed for the production and conversion of transportable and storable hydrogen-based chemical energy carriers and synthetic fuels. They are to be prepared in the project for use on an industrial scale. The work packages range from catalytic reactions to layer systems and operando analysis to digital catalysis. A separate work package to support young researchers underpins this interdisciplinary approach. First results show that thin film catalysts have significantly better properties than conventional powder-based industrial catalysts.

In Berlin-Adlershof, researchers are developing customised catalysts based on thin-film technology.

Beneficiaries: Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) and two institutes of the Max Planck Society
Funding ID: 03EW0015A+B
Appropriated funding: €58.8 million
Project duration: 2020 – 2025
Project description on EnArgus:

MORE DETAILS

2.6 Nuclear safety research

2.6.1 Reactor safety research

The task of reactor safety research in the 7th Energy Research Programme was to deepen knowledge of the safety of power and research reactors both in Germany and abroad and to advance the state of the art in science and technology. Another focus was on promoting the development of skills and young scientists in the area of nuclear safety in Germany.

Funding priorities and scientific advances

The knowledge gained in reactor safety research concerns the safety not only of power reactors but also of research reactors. Reactor safety research has a strong international orientation so that funding is provided for safety research projects on reactors operated or under development abroad. Safety aspects of new reactors and plant concepts were also the subject of research. Research is underway into the safety of components and structures, into transients, incidents and accidents, and into interactions between humans, technology and organisation as well as into probabilistic safety analysis.

The involvement of German research work in international activities is of great significance here and was strengthened by involvement in outstanding multilateral research projects or by support for international cooperation.

A key objective of funding was also to sustainably strengthen skills and the development of young scientists in the area of nuclear and, in particular, reactor safety. To this end, the Nanu initiative for

Figure 25a: Funding for nuclear safety research 2021 – 2022 in € million
(Data cf. Table 7b, p. 106)

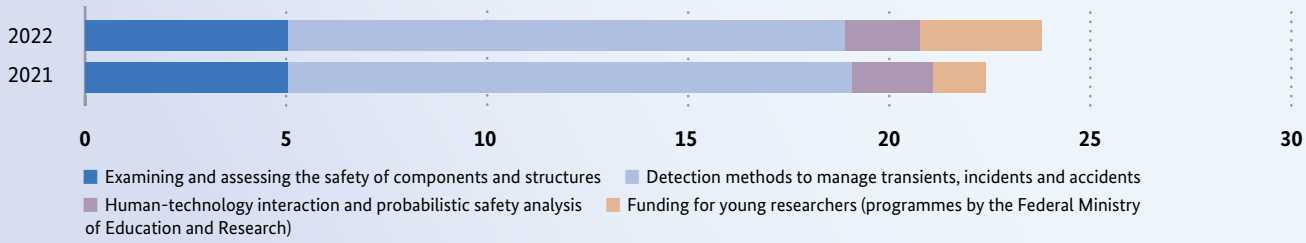
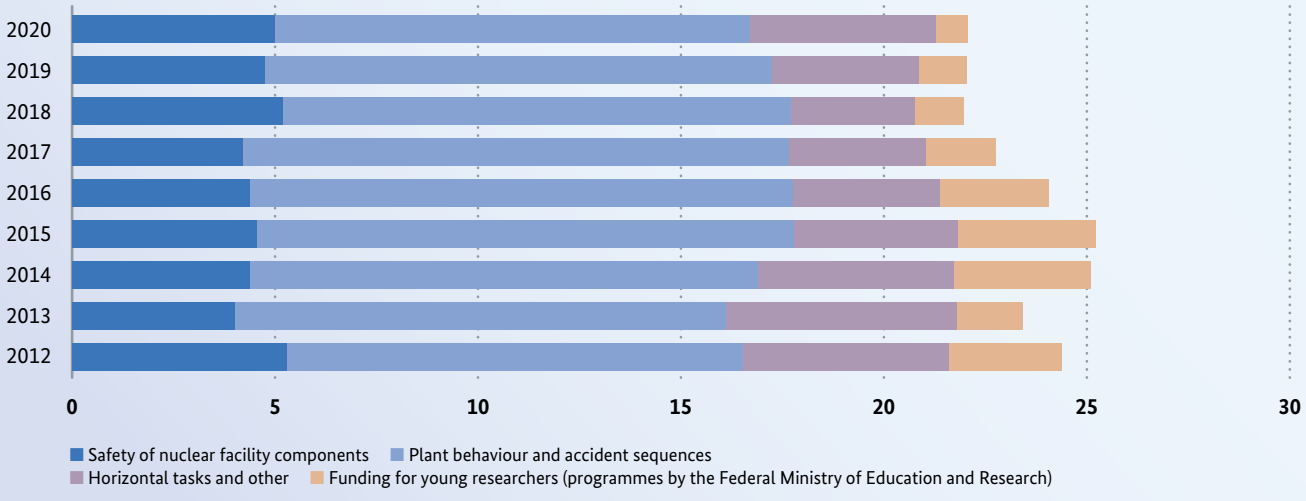


Figure 25b: Funding for nuclear safety research 2012 – 2020 in € million
(Data cf. Table 7a, p. 106)



the promotion of junior research groups at universities has been launched with one group each at the University of Stuttgart (SiFeKo) and the Technical University of Dresden (RIMANUS). In concerted action with Nanu, a junior research group in reactor safety research (iCFD4NS, Universität der Bundeswehr) was also approved through the "NukSiFutur" announcement by the Federal Ministry of Education and Research.

Project funding

Project funding in the field of nuclear safety research in 2022 was provided by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, and is supplemented by a Federal Ministry of Education and Research programme which supports young scientists. During this period, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection provided approximately €20.77 million in funding for 141 ongoing projects and approved funding of approximately €15.96 million for 21 new research projects. The Federal Ministry of Education and Research provided funding of approximately €3.03 million for 15 projects in addition to €4.25 million for three new projects (cf. figure 25a, b).

PROJECT ABSTRACT

MISHA – *Modelling of innovative micro modular reactors with potassium filled heat pipes with the nuclear computational chain of GRS*

At international level, the US and the UK, among others, are developing new reactor concepts, such as Micro Modular Reactors (MMRs). The power plants, which are about the size of a container, are to be transported by truck or plane to their place of use, for instance, to remote settlements or to disaster areas with no electricity or heat supply. The first prototypes should be in use before the end of this decade.

A new feature of these MMRs is the use of heat pipes in which heat from the reactor core is transferred without a pump to a turbine-compressor system (similar to an exhaust gas turbocharger in a car) to generate electricity. The reactor and the heat pipes are filled at the manufacturer's site, then brought to the place of use and collected from there again after use.

The aim of the interdisciplinary collaboration project MISHA is to build up the expertise needed to assess the safety of these new reactor concepts through experiments and validations. This will also enable the assessment of accidents, for instance, during transport, and disruptions to operations. The Federal Ministry of Education and Research is funding this nuclear safety research project to train the experts of tomorrow and to strengthen scientific and technical skills.

Trials of the Misha research project are underway at the heat pipe test stand at the University of Stuttgart.

Beneficiaries: University of Stuttgart and Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH
Funding ID: 02NUK074A-B
Appropriated funding: €2.4 million
Project duration: 2022 – 2026
Project description on EnArgus:

MORE DETAILS

2.6.2 Research into extended intermediate storage and the treatment of highly radioactive waste

This research area aims to develop the scientific basis and insights into the intermediate storage of highly radioactive waste, as this storage will probably be needed for an extended period, as well as the treatment of the waste through to final disposal. It also aims to promote the development of skills and young scientists in this field in Germany.

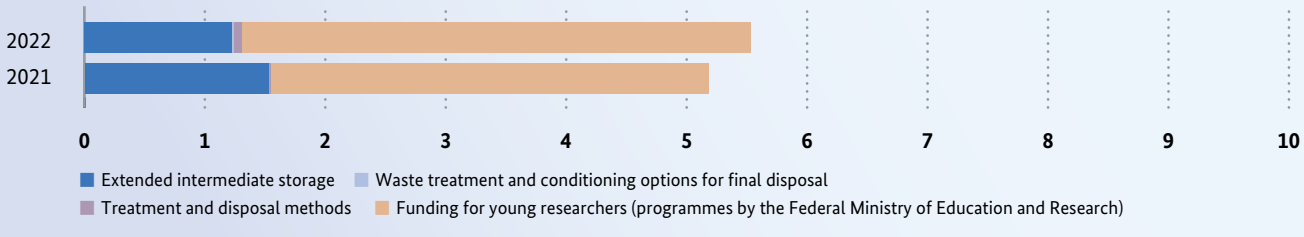
Funding priorities and scientific advances

This research focuses on the state of the highly radioactive waste and containers stored, the effects of storage on their transport and handling capability, the protective effect of the structures over the extended lifetimes, and the (further) development of methods for assessing the safety of the interim storage facilities and the stored inventories. For this purpose, it is often possible to draw on findings from reactor safety research. For example, research is currently being carried out in several projects (such as ProCast and MCGUSS) on new methods for analysing container material behaviour. In order to optimally prepare the waste for final disposal, basic scientific knowledge of potential treatment and conditioning options is also being drawn up for the time after intermediate storage. In addition, developments abroad are being observed that could potentially impact the disposal of highly radioactive waste in Germany or in nearby foreign countries. Promoting young researchers and the development of skills are top priorities for waste management research and are strongly supported. A current example is the recently launched junior research group RIMANUS. Funded by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, this group is also working on monitoring procedures for extended interim storage. Thanks to the one-time announcement by the Federal Ministry of Education and Research of funding for the “NukSiFutur” junior research groups, the TecRad project at the Helmholtz Centre Dresden-Rossendorf was also initiated this year.

Project funding

Project funding in the field of extended interim storage and for the treatment of highly radioactive waste in 2022 was provided by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, and is supplemented by a Federal Ministry of Education and Research programme which supports young scientists. During this period, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection provided approximately €1.31 million in funding for 15 ongoing projects and approved funding of approximately €2.43 million for four new research projects. The Federal Ministry of Education and Research provided approximately €4.22 million in funding for 29 projects. This included three new projects with €3.71 million in funding (cf. figure 26).

Figure 26: Funding for research into extended intermediate storage and treatment of highly radioactive waste in € million (Data cf. Table 7b, p. 106)



2.6.3 Repository research

The task of repository research is to provide and develop the scientific, technical and socio-technical basis for the safe final disposal of radioactive waste. In doing so, it is guided by the specifications of the safety requirements and the Repository Site Selection Act. At the same time, expertise in this field is being secured and expanded.

Funding priorities and scientific advances

Thanks to the new project funding approved in 2022, a special focus is now being placed on research and development in the areas of safety verification, site selection and repository concepts, in addition to ongoing research into the effectiveness of the barrier system, container development, monitoring, safeguards and cross-cutting issues. The new projects are specifically dedicated to developing the understanding of the processes taking place in the respective repository system and their interactions, as well as developing process-describing models by generating reliable experimental data and its modelling.

Research in the previously mentioned fields is carried out in an international context by integrating the work into the international project landscape. This includes conducting experiments in the European underground laboratories (Grimsel, Äspö, Mont Terri), participation in international task forces and networks on specific topics, membership in OECD/NEA clubs and participation in the European Joint Programme EURAD.

Involving young scientists in this research work will also help considerably to secure and expand expertise in nuclear waste management in Germany far into the future.

Project funding

The project funding provided by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection is complemented by research funding provided by the Federal Ministry of Education and Research. The latter supports young scientists, thereby maintaining and promoting skills. In the field of final repositories, supplemented by the research into horizontal issues, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection provided approximately €13 million in funding for 117 ongoing projects in 2022. The ministry also approved approximately €12.8 million in funding for 22 new research projects (cf. figure 27a, b).

Figure 27a: Funding for research into repositories in € million
(Data cf. Table 7b, p. 106)

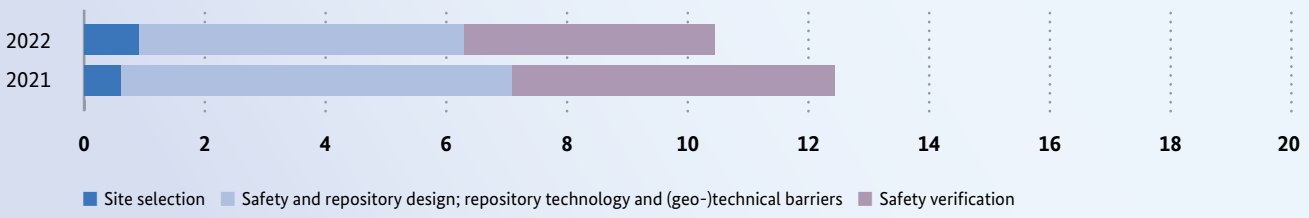
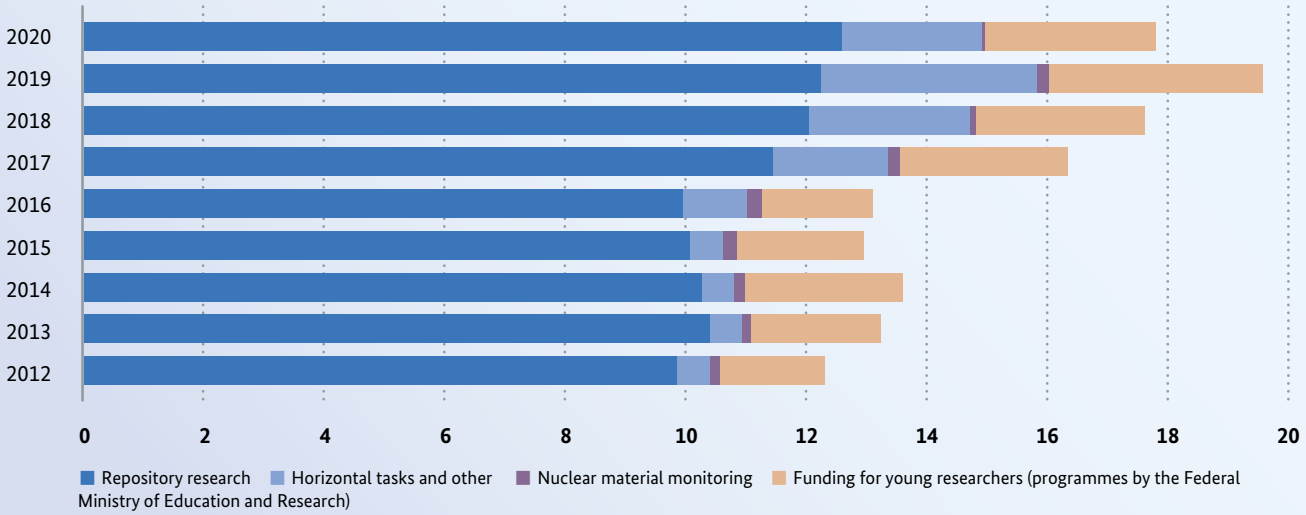


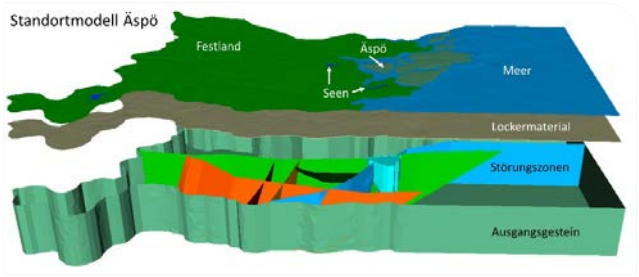
Figure 27b: Funding for Nuclear waste repository and disposal research in € million 2012 – 2020 (Data cf. Table 7a, p. 106)



PROJECT ABSTRACT

HYMNE – *Hydrogeological modelling on a regional scale*

Assessing the long-term safety of a radioactive waste repository requires a comprehensive understanding of the system and a tried and tested set of powerful tools. The HYMNE project is currently developing such a set of tools that can describe the processes that are relevant for transport through the host rock or through the overlying geological formations. High-accuracy models with acceptable computer times are now possible thanks to the application of state-of-the-art numerical methods that enable the effective use of high-performance computers. On the one hand, using the d³f++ code developed here density-driven groundwater flow can be simulated in areas with a complex hydrogeological structure, even on a regional scale. On the other hand, the transport of radionuclides and other pollutants in groundwater can be calculated with all interactions relevant for repository safety.



Hydrogeological model of the use case Äspö Site Descriptive Model

Beneficiaries: Gesellschaft für Anlagen und Reaktorsicherheit (GRS) gGmbH and Johann Wolfgang Goethe University Frankfurt
Funding ID: 02E11809 A und B
Appropriated funding: €2.13 million
Project duration: 2019 – 2022
Project description on EnArgus:

MORE DETAILS

2.6.4 Radiation research

During the 2022 reporting year, the Federal Ministry of Education and Research provided funding through its funding guideline for nuclear safety research and radiation research under the 7th Energy Research Programme and through the guideline for funding junior research groups from the natural sciences and engineering: "Creative Young Researchers for Nuclear Safety, Radiation and Decommissioning Research (NukSiFutur)" continues to support alliances and projects on radiation research.

Funding priorities and scientific advances

The Federal Ministry of Education and Research funds projects on issues of radiobiology, radiation physics, epidemiology and radioecological in application-oriented basic research. This serves to further develop science and technology, thereby making a substantial contribution to building, developing and maintaining scientific and technical competence. Germany still needs expertise in the above-mentioned areas in public authorities, industry, research and medicine. Within the scope of these projects, the Federal Ministry of Education and Research supported a total of approximately 150 young researchers during their training in 2022, which means that this funding priority was able to make a substantial contribution to the formation and retention of expertise in radiation research in Germany. In particular, the newly added focus of material-relevant radiation research was strengthened, creating the basis for socially explosive as well as scientifically highly relevant areas of application, such as radiological emergency preparedness. In its entirety, radiation research provides the scientific basis for assessing the health risks posed by radiation as well as the benefits for technical and medical progress. The "NukSiFutur" announcement made it possible to establish the TOGETHER junior research group at Friedrich-Alexander-Universität Erlangen-Nürnberg which is researching the immunological effects of radiation.

Project funding

In the field of radiation research, the Federal Ministry of Education and Research provided approximately €6.98 million in funding for 52 ongoing projects in 2022. The ministry also approved approximately €7.45 million in funding for ten new research projects (including two junior research groups) in 2022 (cf. figure 28a, b).

Figure 28a: Funding for radiation research (Federal Ministry of Education and Research) in € million (Data cf. Table 7b, p. 106)

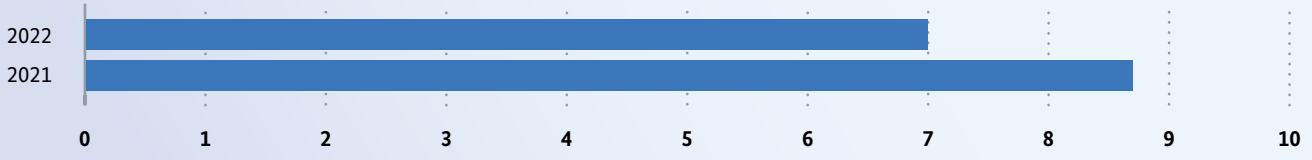
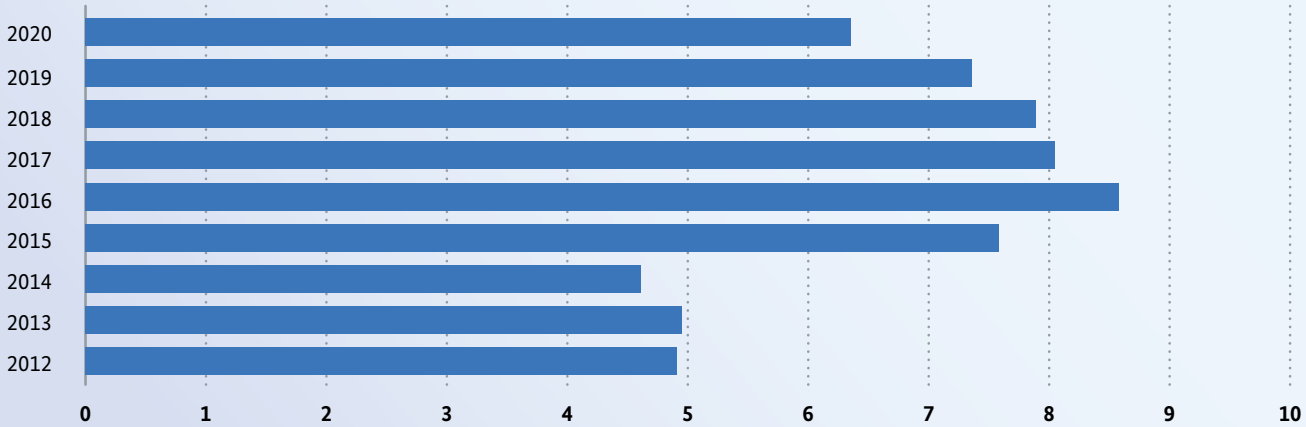
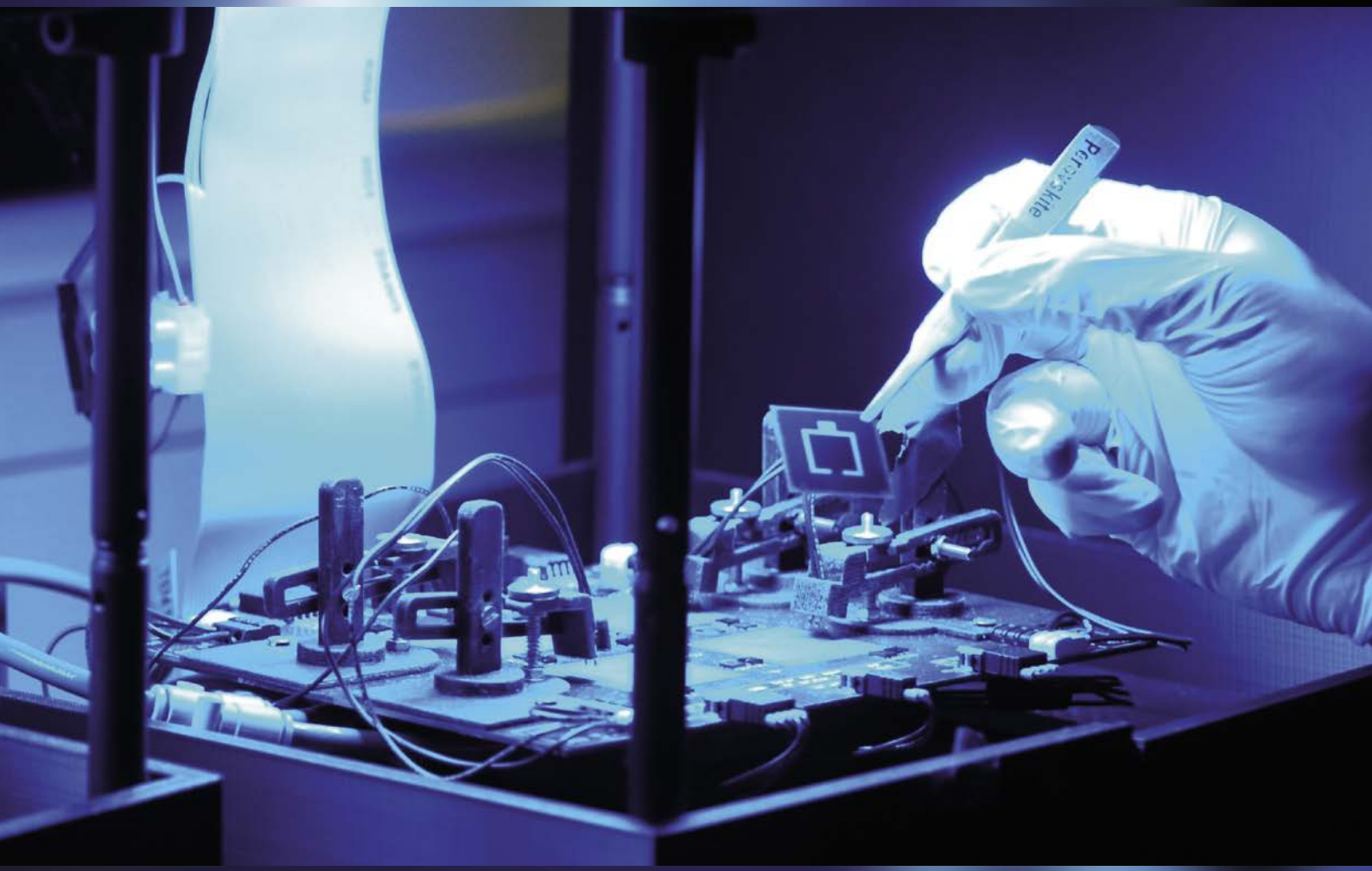


Figure 28b: Funding for radiation research (Federal Ministry of Education and Research) in € million (Data cf. Table 7a, p. 106)



3. Institutional energy research



3.1 Energy research by the Helmholtz Association

With research from basics to application, Helmholtz Energy is creating the scientific prerequisites for climate-neutral energy supply that is both economically and socially sustainable. In interdisciplinary programmes, the energy researchers are developing viable solutions for the energy transition in Germany and for the sustainable restructuring of energy supply.

To this end, their activities focus on researching and developing innovative conversion, distribution and storage technologies. Taking into account all relevant energy conversion chains and future-proof technological options, Helmholtz Energy is developing holistic, cross-sectoral concepts and solutions for an energy system of the future.

Since 2021, Helmholtz Energy has continued its research for the energy transition with a scientific focus on four programmes within the framework of the fourth period of programme-oriented funding (POF IV):

The "energy system design" programme uses a holistic approach to research in order to build a sustainable energy system. In addition to the analysis of energy systems, a focus is also placed on their digitisation and the development of system technologies.

The "Materials and Technologies for the Energy Transition" programme is dedicated to developing new technologies along the entire value chain – from the exploration and extraction of raw materials and the development of high-performance materials to the generation, conversion, storage and distribution and application of complementary energy sources such as electricity, biomass and hydrogen.

As part of European coordinated and funded fusion research, the "Fusion" programme researches and develops the physical and technical foundations for the design and construction of fusion power plants.

The "Nuclear Waste Management, Safety and Radiation Research" programme deals with the essential issues of interim and final storage of radioactive waste, dismantling of nuclear facilities, safety of nuclear reactors and radiation protection. As part of the complete scaling down of radiation research at the renowned Helmholtz Munich (HMGU), 12 employees of the former Institute for Radiation Protection were taken over by the Federal Office for Radiation Protection (BfS).

The centres involved in energy research in POF IV are the German Aerospace Center (DLR), Forschungszentrum Jülich (FZJ), Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and Karlsruhe Institute of Technology (KIT), with the Max Planck Institute for Plasma Physics (IPP) as a scientifically associated centre.

Selected highlights from Helmholtz Energy's research:

- A solar tower fuel plant for the production of sustainable kerosene (cf. DLR's SUN-to-LIQUID project profile on p. 80).

- Helmholtz Energy occupies a leading position worldwide in the research and development of future highly efficient, cost-effective and sustainable photovoltaic technologies. A key target system is tandem solar cells based on crystalline silicon combined with novel wide bandgap semiconductors from the metal-halide perovskite class. This is being impressively demonstrated by three research highlights in the field of perovskite solar cells:

  - **A wiki for perovskite solar cell research:** An international team of experts has collected data on metal halide perovskite solar cells from more than 15,000 publications and developed a database with visualisation options and analysis tools. The database is open source and provides an overview of the rapidly growing knowledge as well as the open questions in this exciting class of materials.

- **Perovskite solar cell with ultra-long durability:** Researchers from the Helmholtz Institute Erlangen-Nuremberg of Forschungszentrum Jülich have presented a variant of the perovskite solar cell that stands out for its special stability. In tests at elevated temperature and light exposure over 1,450 hours of operation, the perovskite-based cell retained 99 per cent of its initial efficiency.

- **World's first perovskite/perovskite tandem solar module:** Innovative material sciences and process know-how were combined at KIT, enabling the development of a technology for the production of the first perovskite/perovskite tandem solar modules manufactured entirely using industrially scalable methods, with efficiencies of up to 19.1% and a low scaling loss of less than 5% (rel.).

- In an effort to increase resource efficiency in the metal industry, scientists at the Helmholtz Institute Freiberg for Resource Technology (HIF) at the HZDR have identified the potential for optimisation in recycling different types of alloys by using unique new sorting techniques (camera/sensor systems). The innovative techniques enable separation of alloys by type and thus high quality recyclates. This paves the way for a sustainable circular economy as contemplated in the Green Deal, CO_2 can be reduced and supply security for metal raw materials can be significantly increased.

- The Helmholtz Hydrogen Cluster HC-H2 is to generate momentum for developing the Rhenish mining region into a future-oriented hydrogen model region. One year after its launch, the currently largest German hydrogen infrastructure project coordinated by Forschungszentrum Jülich celebrated its opening in September 2022 at Brainergy Park Jülich.

- The HyReK 2.0 project provides important findings on the operation and design of an innovative primary balancing power supply using a combination of battery storage and district heat extraction. The DLR conducted research into operating strategies, battery ageing, use cases and system-related environmental impacts, and the results of this research have increased the system benefits thanks to intelligent operation management, raising the concept to a high level of technical maturity and providing an important building block for decarbonised electricity grid system services.

- Fluctuations in electricity consumption are an essential element in planning future energy systems. KIT researchers analysed high-resolution consumption data from households and have proposed a new load model that should make the planning and operation of electricity grids more stable and cost efficient. In addition to understanding consumption, grid expansion is essential for a successful energy transition. Contrary to expectations, however, some new lines can lead to grids becoming unstable rather than more stable. This phenomenon, referred to as the Braess paradox, was simulated for the first time in detail for electricity grids by an international team that included KIT researchers. They then demonstrated it on a larger scale and developed a prediction tool that supports grid operators in their decisions.

- The Wendelstein 7-X stellarator at IPP has reached its full operational capability and, with significantly improved equipment, scientific experiments began again in autumn 2022. In a few years, high-power plasma discharges lasting up to 30 minutes will be demonstrated at the fusion facility.

Turnaround in energy supply security

As a direct response to the Russian war of aggression against Ukraine, Helmholtz Energy has developed four energy security initiatives. Backed by €25 million in funding from the non-appropriated Pact funds, these initiatives will accelerate the development of technologies to market maturity within three to five years and thus contribute to the turnaround.

The four initiatives at a glance:

- Accelerated transfer of the next generation of solar cells to mass production (HZB, FZJ, KIT)
- Geo technologies for a turnaround in energy supply in Germany (KIT, GFZ)
- Helmholtz platform for the design of robust energy systems and raw material supply (KIT, FZJ, (DLR associated))
- Securing raw materials through flexible and sustainable closure of material cycles (HZDR, KIT)

Figure 29a: Funding for institutional energy research 2021 – 2022 in € million
(Data cf. Table 8, p. 107)

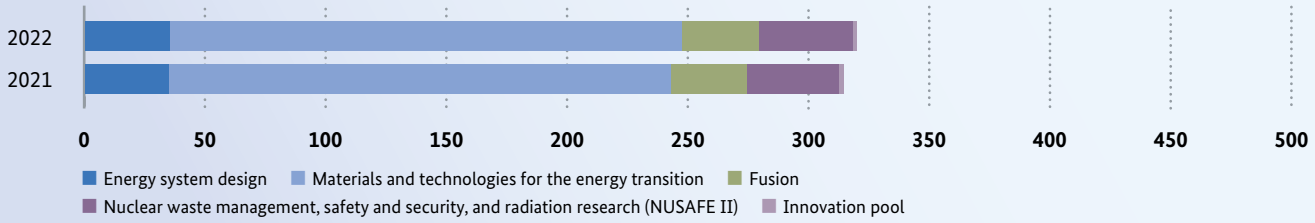
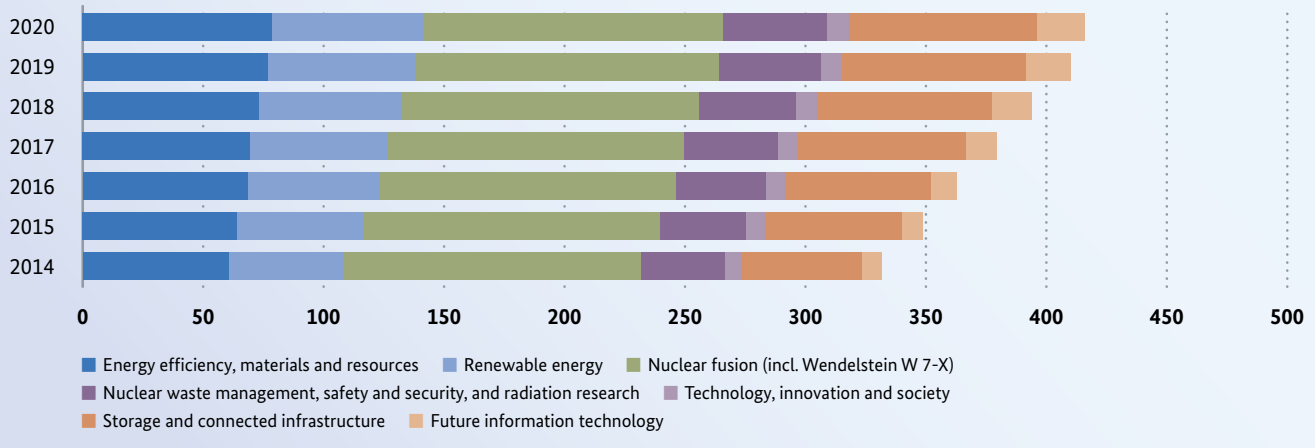


Figure 29b: Funding for institutional energy research 2014 – 2020 in € million
(Data cf. Table 8, p. 107)



PROJECT ABSTRACT

SUN-to-LIQUID – *Solar tower fuel plant for the production of sustainable kerosene*

At a solar tower plant in Spain, researchers from the German Aerospace Center (DLR), together with partners, successfully demonstrated a solar thermochemical process for producing synthetic kerosene using water and CO_2. A solar mirror field consisting of 169 heliostats collects solar radiation and reflects it to a receiver in the solar tower. The concentrated heat energy starts a thermochemical cycle in the installed reactor, which splits water and CO_2 to produce a gas mixture of hydrogen and carbon monoxide. In a further step, this synthesis gas is used as the basis for synthetic kerosene. With a solar-to-syngas energy conversion efficiency of 4.1%, the process is a technological milestone towards the industrial production of sustainable aviation fuels.

The solar tower plant at IMDEA Energía near Madrid: Here, researchers have successfully demonstrated how synthetic paraffin can be produced from water and CO_2.

Participating Helmholtz centre: German Aerospace Center (DLR)
Participating programme: Materials and technologies for the energy transition (MTET)

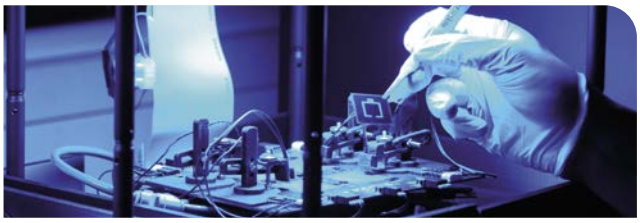
MORE DETAILS

Accelerated transfer of the next generation of solar cells to mass production Tandem solar cells *a technology of the future*

In order to create the basis for a climate-neutral circular economy, photovoltaics and wind energy need to be expanded on an enormous scale. These two renewable energy sources have the highest technical implementation potential and the lowest cost level worldwide, in the EU and Germany. If the necessary expansion of solar energy is to succeed, a new generation of photovoltaics will be needed. We are aiming for an innovative tandem technology that offers more than 30% efficiency, a high degree of stability and a competitive cost and environmental profile, and is significantly more efficient and cost-effective than the silicon-based PV technology that currently dominates the market. To achieve this, the innovative tandem technology must be rapidly developed to market maturity over the next five years.

Objectives

- Adaptation of existing silicon cell processes for optimal and effective tandem integration
- Development of industrially scalable sputtering processes for highly efficient and large-area perovskite silicon tandem solar cells
- Investigation of the stability of large-area tandem solar cells
- Expansion of analytics for better and accelerated understanding of solar cell properties
- Development of tandem solar cells with better circular recycling properties



Innovative tandem solar cells are to contribute to a further increase in the share of electricity from renewable energies.

Overview:

- Helmholtz-Zentrum Berlin für Materialien und Energie (HZB)
- Forschungszentrum Jülich (FZJ)
- Karlsruhe Institute of Technology (KIT)

PROJECT ABSTRACT

Securing raw materials through flexible and sustainable closure of material cycles

German and European industries are dependent on imports for many raw materials. Switching to renewable energy increases this dependency and energy demand, since renewable energy systems require significantly more raw materials per unit of energy produced than fossil fuels. Therefore, domestic raw material sources need to be developed while the energy demand of raw material supply must be reduced and made more flexible. This is where the project comes in with its development of new recycling processes, since the recovery of raw materials requires significantly less energy than their primary extraction. The greatest challenge lies in the complexity and variability of these raw material sources with many different raw materials occurring in mixed, ever new structures so that they can only be recovered by processes that flexibly address the specifics of the respective material source. Energy-efficient recovery calls for efficient mechanical pre-separation of the material streams. At the same time, material streams that have not been completely separated must be recovered for re-use. We have set ourselves the goal of developing new recycling technologies over the next two to three years that will help to sustainably close material cycles.

In order to become more independent of raw material imports, it is necessary to develop new recycling technologies for material cycles.

Objectives

- Further development of processing technology to improve product purity, plant throughput and flexibility
- Construction of two pilot-scale demonstration plants
- Application of a multiphase measurement technique to characterise material streams
- Development of active load management to increase flexibility of operations

Overview:

- Helmholtz-Centre Dresden-Rossendorf (HZDR)
- Karlsruhe Institute of Technology (KIT)

PROJECT ABSTRACT

RESUR – *Helmholtz platform for the design of robust energy systems and raw material supply*

The energy system of the future will be largely determined by renewable energy. A faster and better transformation towards climate neutrality means greater independence from fossil fuel imports.

The complexity of this transformation poses enormous challenges. The RESUR platform provides (co) simulations and analysis that allow energy suppliers and decision-makers to examine complex interrelationships in advance, such as “re-bundling”, i.e. the joint consideration of electricity generation and electricity grids of different operators and grid levels with simultaneous consideration of the progressive coupling of electricity and gas grids. RESUR aims to provide short-term, proactive and reactive decision-making information, especially on current events. RESUR is to be operated on a long-term basis and the model toolbox is to be adapted to new challenges in constant dialogue with policy-makers and industry partners.

In the RESUR project, researchers are developing a toolbox that enables energy suppliers, among others, to analyse and evaluate complex interrelationships.

Objectives

- Bottom-up models for the electricity and gas sector to assess security of supply and the robustness of transport grids
- Models and tools for co-simulation of heat, electricity and gas
- Provision of a meta-database and toolbox for analysing and evaluating options for action by business, society and politics in the event of disruptive events in energy and commodity markets

Overview:

- Karlsruhe Institute of Technology (KIT)
- Forschungszentrum Jülich (FZJ)
- German Aerospace Center (DLR) – associated

PROJECT ABSTRACT

Geotechnologies for a turnaround in energy supply in Germany – GEOZeit – *Energy and material storage in the deep underground*

The deep underground offers enormous potential both for decarbonising heat supply and for the ever-growing need for energy storage. In order to exploit this potential, researchers are developing solutions for the environmentally sound use of deep geothermal energy and geo-based energy and material storage. This calls for the expansion of geological pore storage facilities for heat and energy-relevant gases in the TWh range and a market ramp-up of geothermal technologies. With the help of the DeepStor 1 and 2 research wells and the conversion of the Ketzin pilot site for hydrogen storage, researchers are developing new storage technologies that will make sustainable use of depleted hydrocarbon reservoirs, thus providing a short-term solution to today's energy storage issue. The objectives listed below are to be achieved within the next two to three years.

Objectives

- Validation of the technical feasibility of storage technologies in depleted hydrocarbon reservoirs via the DeepStor research infrastructure at KIT
- Evaluating and ensuring stable reservoir properties to prepare an H_2 demonstrator in the saline aquifer to implement cyclic and safe loading and unloading operations
- Development of geo-based solutions for hydrothermal aquifers to meet base and intermediate loads
- Upscaling of underground storage on a technical scale
- Development of solutions in co-design and with a Citizen Science project

Overview

- Karlsruhe Institute of Technology (KIT)
- Helmholtz Centre Potsdam – German Research Centre for Geosciences (GFZ)

3.2 Fusion research

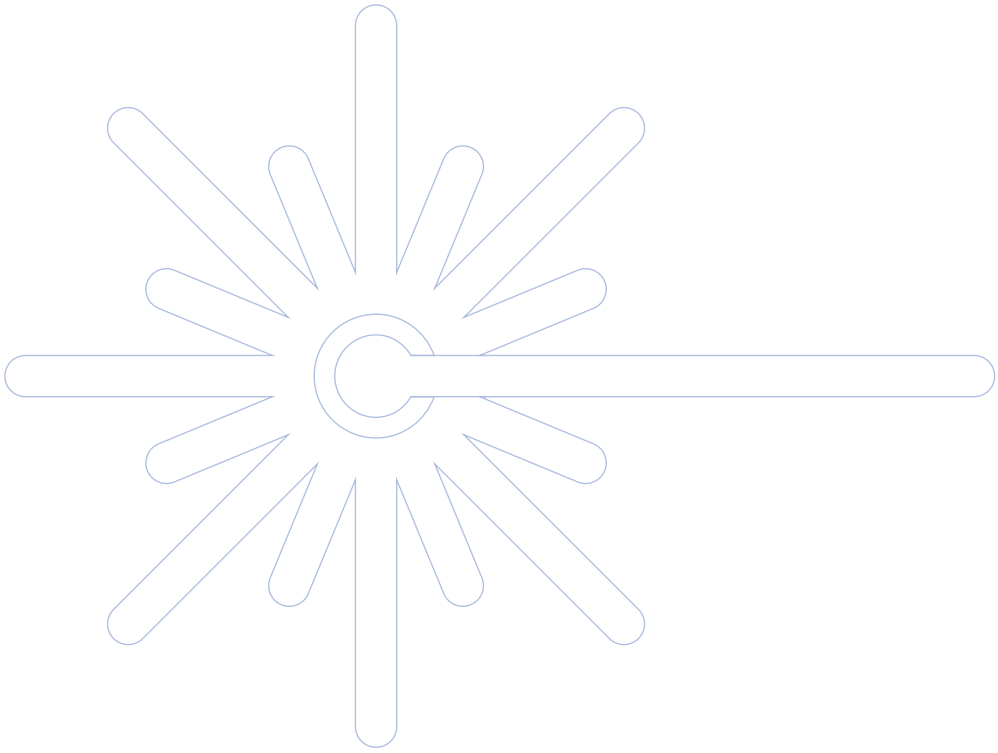
The "Fusion" (FUSION) programme is researching and developing the physical and technical foundations for the design and construction of a fusion power plant. It forms part of fusion research coordinated and funded at European level.

Highlights from research under the FUSION programme

Following two successful initial experimental phases, the Wendelstein 7-X fusion plant has been further expanded. The final step, which upgrades the machine to demonstrate plasma pulses lasting up to 30 minutes at higher heating power, was completed at the beginning of 2022, marking final completion of Wendelstein 7-X. Water-cooled inner cladding and the new centrepiece, a water-cooled divertor, complete the system. The scientists now have a total of 70 measuring systems at their disposal. Now that expansion is complete, the performance parameters that are important for a fusion power plant can be increased further and it is possible to demonstrate that stellarators can operate reliably in continuous operation. To mark the occasion, the Federal Minister of Education and Research, Bettina Stark-Watzinger, together with Bettina Martin, Minister of Science, Culture, Federal and European Affairs of the Federal State of Mecklenburg-Vorpommern, visited the ceremony at Max Planck Institute for Plasma Physics (IPP) in Greifswald on 9 August 2022.

Current activities by the Federal Ministry of Education and Research in the field of fusion

At the end of May 2022, an expert discussion on fusion technologies was held at the Federal Ministry of Education and Research in Bonn with representatives from science and industry. Based on the results of the meeting, the Federal Ministry of Education and Research decided to take a closer look at the field of inertial fusion, which has not been extensively researched in Germany so far, especially laser fusion, which is a variant of inertial fusion. For this purpose, a commission made up of seven international experts in the field of inertial fusion was set up and between December 2022 and May 2023 they prepared a memorandum on inertial fusion that focuses on laser fusion and its technological maturity. The memorandum contains an evaluative statement and, more importantly, provides information on where Germany's strengths and weaknesses lie in the field of inertial fusion, especially laser fusion.



4. European and international cooperation

4.1 European networking in energy research

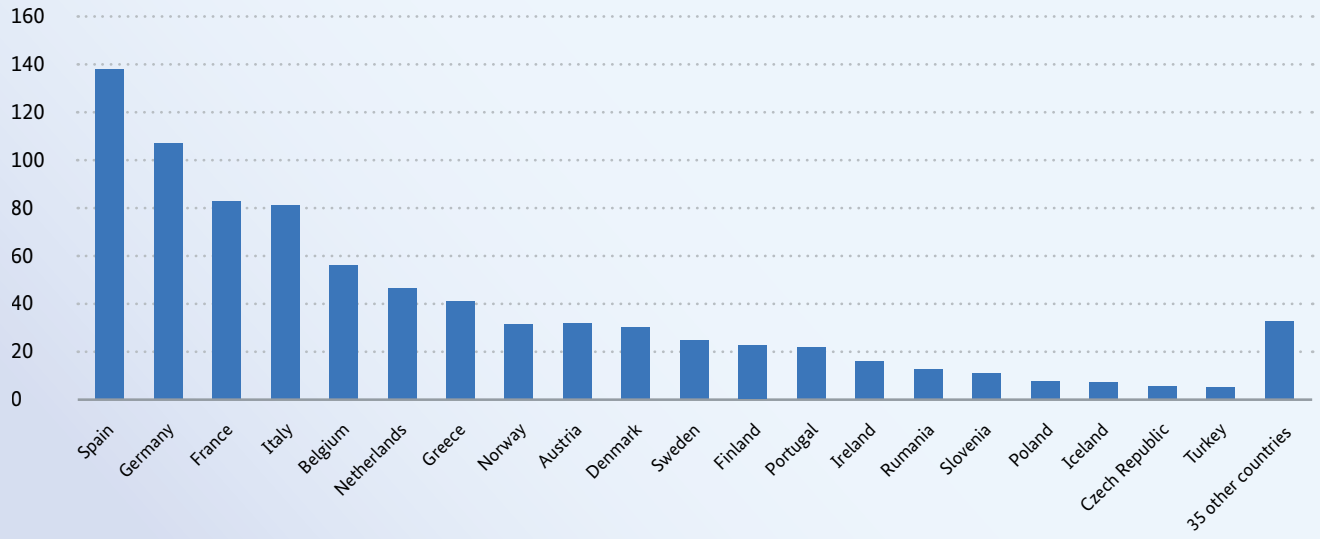
For more than 20 years now, Germany has been involved in the development of the European Research Area to promote networking and cooperation between European research and science systems. This initiative has laid an important foundation for improving Europe's competitiveness.

Under Germany's presidency of the European Council, the European Research Area was realigned in 2020 and linked to the adoption of the EU Framework Programme Horizon Europe in 2021. Since 2022, the "Pact for Research and Innovation in Europe" has provided the basis for cooperation in the European Research Area. This Pact aims to mobilise EU, national and regional resources by prioritising public spending on research and development. It also creates conditions for greater private investment in research and innovation while supporting the main objectives of the European Growth Strategy for 2030, i.e. the green and digital transformation.

Through its activities in the European Strategic Energy Technology Plan (SET-Plan), Germany is networked in the energy sector with the member states, industry and stakeholders via the research and innovation strategies and programmes. The current revision of the SET-Plan is part of the implementation measures of the European Research Area. The objectives and targets of the SET-Plan need to be adapted to the EU's current energy policies and challenges (Green Deal, Fit for 55 package, REPowerEU Communication).

The implementation of the SET-Plan strategy is supported by the Clean Energy Transition Partnership (CETPartnership) that is co-financed by the EU. The aim is to facilitate the joint planning and implementation of research activities and the development of technological innovations for the energy transition. The Federal Government has promised around €80 million in funding from the 7th Energy Research Programme for the partnership's annual funding calls (joint calls) until 2027.

Figure 30: Allocation of EU funding by country in the energy sector of Cluster 5 in 2021
in € million



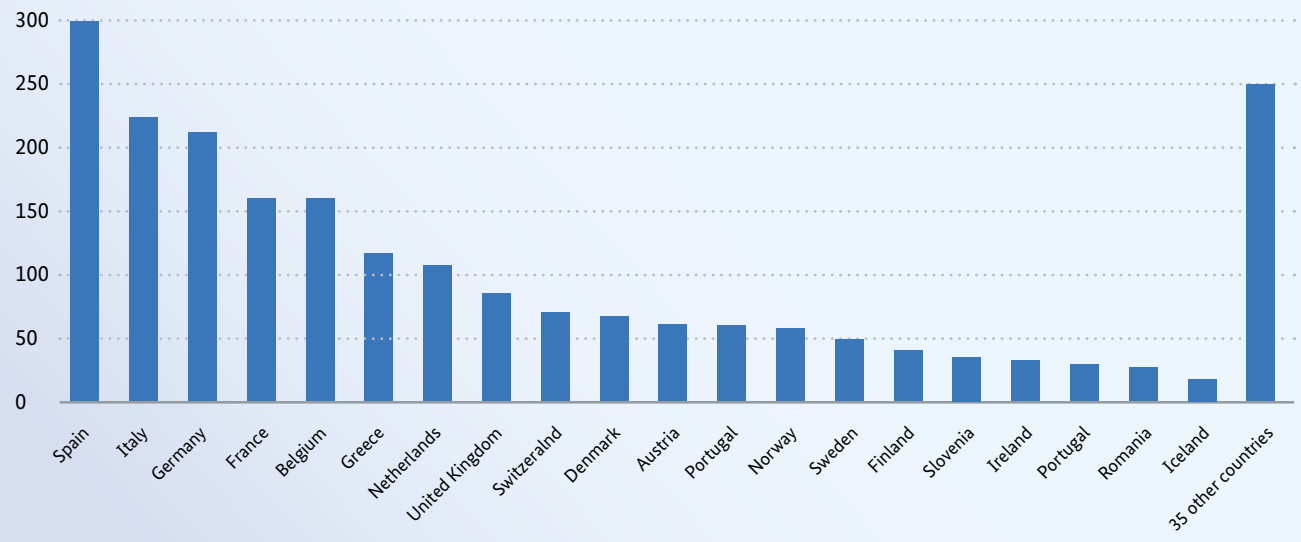
In addition, further regional funding from Germany is available from Saxony and North Rhine-Westphalia, which are also participating in the partnership. A total of around 50 partners with national and regional funding programmes from over 30 countries are involved in the CETPartnership. Their intention is to provide funding of around €210 million for the first two joint calls in 2022 and 2023.

In addition to the CETPartnership, Germany is also involved in the Driving Urban Transitions to a Sustainable Future Partnership (DUTP). In a first joint call for funding in 2022 with 26 participating countries and a funding budget of around €90 million, transnational research and innovation projects will be supported that address urban challenges and support cities in their transition to a more sustainable economy and way of functioning. The challenges are divided into three subject areas: Positive Energy Districts (PED), 15-minute City (15mC) and Circular Urban Economies (CUE).

Germany is also participating in Important Projects of Common European Interest (IPCEIs) for hydrogen at European level and is providing more than €8 billion in funding to support major research, demonstration and implementation projects.

Within the framework of international cooperation, Germany is involved in various other European and non-European funding measures.

Figure 31: Number of project participants by country in the energy sector of Cluster 5 in 2021



4.2 EU Research Framework Programme (Horizon Europe)

Horizon Europe is the European Union's key funding programme for research and innovation with a budget of €95.5 billion. The programme facilitates European and international collaboration and strengthens the impact of research and innovation in developing, supporting and implementing EU policies while addressing global challenges. It tackles climate change, helps to achieve the UN's Sustainable Development Goals, strengthens the European Research Area and boosts the EU's competitiveness and growth.

The core of energy research is grouped in Cluster 5 – Climate, Energy and Mobility – with a total budget of €15.3 million. The overarching goal of this cluster is to accelerate the green and digital transition and the related transformation of commerce, industry and society in order to make Europe climate neutral by 2050. Cluster 5 supports the EU's strategic objectives in the field of energy through activities geared to more efficient, secure, sustainable and competitive energy supply, distribution and use. This includes numerous topics, such as innovations in the field of renewable energy, new solutions for smart grids and energy systems, innovative storage solutions or climate-neutral building stock.

The focus is currently on the REPowerEU plan as a strategic response to the war in Ukraine and aims to reduce the EU's dependence on fossil fuels through renewable energy and electrification. The European Commission announced in its Communication an additional investment of €200 million for the Clean Hydrogen Partnership under Horizon Europe, marking the continuation of the institutionalised public-private partnership FCH 2 JU. The aim of this partnership is to accelerate the development and deployment of the European value chain for clean hydrogen technologies, thereby promoting the implementation of the EU hydrogen strategy.

In 2021, calls were already issued in Cluster 5 for a total of 54 energy-related funding topics, with envisaged funding of around €826 million. The first projects were launched in the second and third quarters of 2022.

German applicants successful in the field of energy in Horizon Europe

Final figures for the Horizon Europe programme were presented in 2021.[1] In the energy sector of Cluster 5 – Climate, Energy and Mobility – applicants from Germany were involved to an above-average extent in collaborative projects. In 2021, roughly €800 million in funding was provided for a total of 137 collaborative projects. Germany participated in 97 of these projects, with a total of 195 project participants. This means that stakeholders from Germany were to be found in 70.8% of all collaborative projects in the energy sector of Horizon Europe, playing the responsible role of coordinator in eleven of these projects (figure 31). In total, German project participants were able to obtain approx. €106 million in funding. This places Germany in second place after Spain and ahead of France and Italy, with 14% of the total approved funding in this programme area (figure 30).

1 At the time of publication (June 2023), reliable figures are only available for the Horizon Europe programme for the year 2021.

Priorities for energy research in Horizon Europe

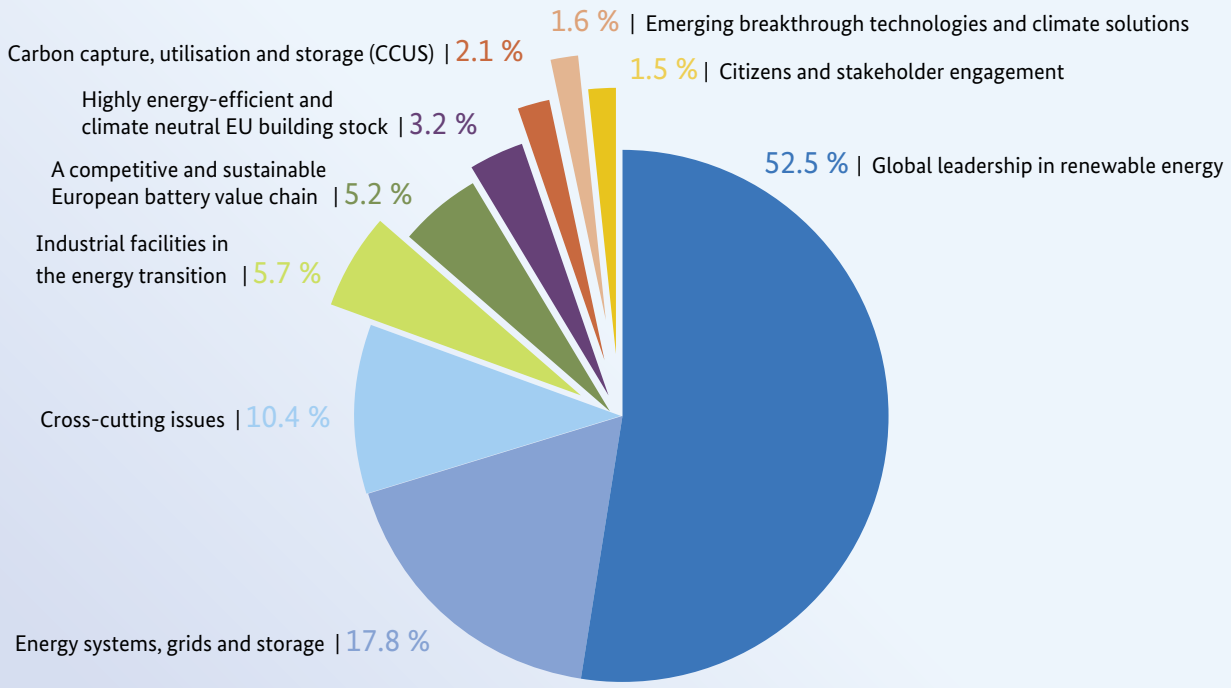
More than 49.7% of project participation by beneficiaries from Germany focused on renewable energy (global leadership in renewable energy). This takes into account both applied research and demonstration projects for renewable energy, such as wind, solar, photovoltaic, geothermal, water and marine technologies, as well as bioenergy and biofuels. This is also reflected in the breakdown of the funding received by thematic area (figure 32). A clear focus is placed on research and demonstration projects in the fields of renewable energy at 52.5% and energy systems, grids and storage at 17.8%. This is followed by cross-cutting issues accounting for 10.4%, industrial facilities in the energy transition 5.7%, batteries 5.2%, energy efficiency in buildings 3.2%, carbon capture, utilisation and storage (CCUS) 2.1%, breakthrough technologies for climate change 1.6% and citizen and stakeholder engagement 1.5%.

Topics with a focus on hydrogen technologies and innovations are not listed in the figure since these are funded within the Clean Hydrogen public-private partnership. There was no funding call in this programme area in 2021. Further energy-related topics such as materials research outside the programme area of Cluster 5 – Climate, Energy and Mobility – are not included in this evaluation.

Euratom programme

The overall objective of the Euratom Research and Training programme is research and training activities in the nuclear field on the basis of the Euratom Treaty (EAEC Treaty). The continuous improvement of nuclear safety, supply and disposal safety and radiation protection are the top priorities here. The programme complements the EU's Horizon Europe framework programme for research and innovation. It currently has an initial term of five

Figure 32: Thematic priorities by funding volume of German participation in the energy sector of Cluster 5 in 2021



years (2021 to 2025) and a budget of around €1.38 billion. Most of the research and innovation will be carried out through co-funded European partnerships.

One example is the new European Partnership for Radiation Protection Research PIANOFORTE which was launched in June 2022 with the aim of improving radiation protection further. During the five-year duration of the partnership, PIANOFORTE will fund research across four thematic priorities through three open programme rounds (open calls):

- Improving radiation protection of patients during the application of ionising radiation in medicine
- Better understanding of individual radiosensitivity
- Exploring mechanisms of action in chronic radiation exposure in the low dose range
- Improving preparedness for nuclear and radiological crises, societal resilience and post-incident management

In this way, the partnership also supports the objectives of the European Union such as

- the fight against cancer (Europe's Beating Cancer Plan),
- improving disaster preparedness and resilience in such situations (implementation of the Sendai Framework for Disaster Risk Reduction).

PIANOFORTE brings together 58 partners from 22 EU countries as well as the UK and Norway. A total of €46 million in funding is available to implement the programme.

4.3 International cooperation

The Federal Government is involved in energy research not only in European but also in globally active organisations and initiatives.

International Energy Agency (IEA)

The International Energy Agency (IEA) is an independent organisation within the Organization for Economic Co-operation and Development (OECD) and is devoted to strengthening international cooperation on energy policy, technical and economic issues. The IEA has 31 member states, including the Federal Republic of Germany under the auspices of the Federal Ministry for Economic Affairs and Climate Action, and eleven associated partner states.

All overarching research and development activities and strategic tasks in the field of energy technologies are coordinated by the Committee on Energy Research and Technology (CERT). The goals of energy research policy are implemented in concrete terms through the transnational Technology Collaboration Programmes (TCPs). Germany is involved in 24 of the 39 ongoing TCPs. In 2022, the Federal Republic of Germany joined the TCP on Fluidized Bed Conversion which focuses on the use of fluidized bed processes in power plant technology.

Mission Innovation (MI)

Mission Innovation (MI) promotes the development and expansion of clean, cost-efficient energy technologies and solutions around the world. To achieve this, the intergovernmental initiative relies heavily on higher public and private sector investment.

MI was established in 2015 at the 21st UNFCCC Conference of the Parties (COP21) and currently comprises 23 states and the European Commission. In 2021, seven innovation missions were presented at the sixth ministerial meeting (MI-6) and the 26th

UNFCCC Conference of the Parties (COP26). At the seventh ministerial meeting (Mi-7) in 2022, the members set national innovation pathways, committing themselves to implement over 220 demonstration projects to accelerate the energy transition by 2030. The seven Innovation Missions:

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

The Federal Government, represented by the Federal Ministry for Economic Affairs and Climate Action, is involved in four missions. The Clean Hydrogen Mission aims to cut the price of clean hydrogen to below US$2 per kilogram by 2030 and supports the establishment of a global hydrogen economy. With the Green Powered Future Mission, power grids around the world are to be able to integrate up to 100% fluctuating renewable energy by 2030. Funding is provided in the Net-Zero Industries Mission for innovations to decarbonise energy-intensive industry while the Zero-Emission Shipping Mission aims to demonstrate economically viable, zero-emission vessels by 2030.

International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

The IPHE is an association of 22 partners consisting of 21 member countries and the European Commission.

Its mission is to support and promote the commercialisation of hydrogen and fuel cell technologies. To this end, the IPHE pools together and coordinates the international activities of different sectors and departments. The Federal Government has been involved in this global forum since it was established.

4.4 International research initiatives

The Federal Government is also cooperating with other countries at both bilateral and multilateral level in the field of energy research.

German-Dutch promotion of electrochemical materials and processes for green hydrogen and green chemistry

In October 2022, the Federal Ministry for Economic Affairs and Climate Action, the Federal Ministry of Education and Research and the Dutch Research Council NWO published a joint funding call for “Electrochemical materials and processes for green hydrogen and green chemistry” (ECCM). The call is geared to German-Dutch cooperation projects along the entire innovation chain of green hydrogen and green chemistry, from basic research to industrial application involving end users. The bilateral projects are to pool the competencies of both countries in order to develop highly innovative and practical solutions and processes for green hydrogen and green chemistry. The call for applications covers five areas: electrolysis (including hydrogen storage and power-to-X technologies), electrosynthesis, materials and catalysis, design and manufacturing processes for electrolysis systems, as well as system design and integration.

Cooperation with France on sustainable energy supply for Europe

At an initiative by the Federal Ministry of Education and Research and the French Ministry of Research, nine research projects have been working on solutions for efficient, affordable and environmentally friendly energy supply since the end of 2019. The projects explore battery technologies, innovations for electricity grids and energy markets, the production of gases and chemicals from electricity from renewable energy, as well as fuel cells and private household energy supply with hydrogen.

European Green Hydrogen Research Agenda (SRIA)

The agenda process on green hydrogen, a pilot initiative of the European Research Area coordinated by the Federal Ministry of Education and Research, paved the way for the Strategic Research and Innovation Agenda (SRIA) launched in March 2022. This agenda addresses the most important research questions at European level and the results of this work were presented and explored further at an international conference held in May 2022. The issue of the hydrogen future of ports was addressed in more detail in a workshop with participants from several North Sea countries.

Partnership with Africa on renewable energy

The five-year *Long-Term European African Partnership on Renewable Energy (LEAP-RE)* programme, co-funded by the European Commission, is building a long-term partnership between Europe and Africa on renewable energy research and innovation. German researchers are involved in eight of the 13 projects selected for the first call in 2021 and the Federal Ministry of Education and Research is contributing €2 million in funding. Funding has already been pledged for the projects set to start in 2023.

The Federal Ministry of Education and Research is also funding several projects in West African countries on renewable energy and green hydrogen. In Ghana, for instance, the Waste2Energy project is looking into how waste can be converted into energy and fertiliser while researchers in Togo are setting up a large biogas laboratory. In Nigeria, greenhouses are being powered by photovoltaics which is also helping to dry crops there to increase their shelf life.

The Green Hydrogen Potential Atlas in Africa contains data-based forecasts of where green hydrogen can best be produced in Africa. The specialists of tomorrow are being trained in the *International Master Program in Energy and Green Hydrogen*.

German-Namibian cooperation agreement on green hydrogen

Namibia is one of the most promising countries when it comes to the production of green hydrogen and its derivatives, such as methane, ammonia or methanol, and the country aims to export green hydrogen before 2025. In 2021, the Federal Ministry of Education and Research reached an agreement with the Namibian government on German-Namibian cooperation. In addition to a National Hydrogen Strategy, which was presented at the 27th UN Climate Change Conference in Egypt, the Federal Ministry of Education and Research is also funding pilot projects and a scholarship programme to train and qualify local experts in Namibia. The first pilot project, *Daures Green Hydrogen Village*, was launched at the end of 2022.

Australia

As part of the strategic hydrogen partnership being established by Germany and Australia, a German-Australian consortium from science and industry conducted the *HySupply* feasibility study to first identify the regulatory, technical and economic barriers that hinder the establishment of a green hydrogen supply chain from Australia to Germany. The Federal Ministry of Education and Research and ARENA (*Australian Renewable Energy Agency*) then published the German-Australian funding call: HyGATE – *German-Australian Hydrogen Innovation and Technology Incubator*. Demonstration and pilot projects are underway along the entire value chain to prepare a German-Australian hydrogen supply chain. *HyGATE* implements two fundamental goals of the National Hydrogen Strategy: on the one hand, the import of sustainable energy sources and, on the other, the export of climate protection technologies “Made in Germany”. The Federal Ministry of Education and Research is providing €50 million and *ARENA* AU$50 million for the HyGATE initiative. Four German-Australian projects are set to begin their work in 2023.

PROJECT ABSTRACT

CARE-O-SENE – *Catalyst research for sustainable aviation fuels (green aviation fuel)*

The technology for converting sustainable energy into liquid energy carriers (Power-to-Liquids, PtLs) is the key to sustainable decarbonisation of sectors such as aviation. With the help of PtLs, sustainable aviation fuels (SAFs) are produced using green hydrogen, carbon dioxide and the important Fischer-Tropsch-(FT) process. Processes that are highly efficient and cost effective are crucial for long-term viability of SAF-technologies. The aim of this project is the accelerated and knowledge-based development of FT-catalysts for the highly efficient and sustainable production of SAFs in the quantities needed for the transformation of the aviation sector.

Leading partners from science and industry are taking promising, existing catalysts one step further, giving them clear economic and ecological advantages over today's standard thanks to higher activity, selectivity and lifetime. They are also developing completely new catalyst concepts that could revolutionise FT catalysts in the future. These developments are being tested in South Africa at Sasol and in Germany under real conditions.

The catalyst research is being tested in South Africa at Sasol and in Germany under real conditions.

Beneficiaries: Helmholtz-Centre Berlin for Materials and Energy together with Sasol and four other partners from Germany and South Africa
Funding ID: 03SF0673
Appropriated funding: €29.9 million
Project duration: 2022 – 2025
Project description on EnArgus:

MORE DETAILS

5. Other energy-related funding activities

5.1 Research funding by the Länder

Since 2008, Project Management Jülich (PtJ) has undertaken an annual survey of spending by the Länder on non-nuclear energy research on behalf of the Federal Ministry for Economic Affairs and Climate Action.

According to the latest survey, total related spending by the Länder amounted to €430.6 in 2021, with project funding accounting for €252.9 million and institutional funding for €177.86 million.

As in the previous year, the highest priority in 2021 was once again given to funding in the field of system integration and cross-system research topics. This funding is the mainstay of the energy research policy of the Länder. As interdependencies between the energy sectors increase, energy policy is focusing more on coupling these sectors, with the Länder providing a total of €186.2 million in funding for this purpose. Funding in the area of hydrogen technologies (€97.6 million) deserves special mention here as this formed the focus of technology research in 2021 and is currently the most significant instrument for sector coupling with Lower Saxony (€39.2 million) and Bavaria (€19.7 million) making the biggest contributions.

The growing importance of energy storage technologies for decentralised energy supply is also reflected in high expenditure by the Länder (€42.3 million): Lower Saxony (€13.3 million) and North Rhine-Westphalia (€8.8 million) were the frontrunners here in 2021. Funding for the research and development of reliable electricity grids, however, was only slightly higher than the previous year's €9.9 million, with Lower Saxony (€2.8 million) and Hamburg (€1.9 million) making the largest contributions. Funding for fuel cell technologies in 2021 was slightly lower, totalling €18.4 million. Lower Saxony and Baden-Württemberg made the largest contributions to this research area, accounting for €6.7 million and €5.3 million, respectively.

The research area of energy system analysis and modelling studies interaction between conventional and new energy technologies. The growing complexity of energy supply structures is reflected in the volume of expenditure by the Länder on topics like these (€18 million). North Rhine-Westphalia made the most significant contribution to research with €7.8 million.

Research funding in the area of energy generation totalled €125.8 million, the same level as the previous year. As in previous years, the Länder invested the lion's share of funding, i.e. €28.2 million, in the research field of solar thermal and photovoltaics. Baden-Württemberg, Lower Saxony (each with €6.6 million) and North Rhine-Westphalia (€5.6 million) made the biggest contributions. The Länder supported research in the field of wind energy with a total of €18.5 million in funding. Due to their geographic location, the northern states of Lower Saxony (€8.9 million), Bremen (€2.6 million) and Mecklenburg-Vorpommern (€2 million) made the biggest financial contributions. Technology funding for bioenergy totalled €13.7 million, with Lower Saxony (€5 million) and Bavaria (€4.6 million) leading the way in this research topic.

Research efforts on the part of the Länder in the field of geothermal energy were stepped up with funding totalling €10.2 million. As in previous years, Lower Saxony made the biggest contribution, investing €6 million. In contrast, not least due to growing ecological demands, only a small number of Länder are still conducting research in the field of hydropower (€5.1 million), with Lower Saxony spending the most in 2021 with €3.9 million. Funding for the niche area of marine energy, which is also only being researched in three Länder, totalled €2.9 million in 2021, with Lower Saxony alone contributing €2.5 million. Research activities by the Länder in the area of thermal power plants/ CO_2 technologies amounted to €6.6 million. North Rhine-Westphalia, home to many power plants, provided €1.7 million in funding.

The cross-technology research area "Energy Transition in the Consumption Sectors", which encompasses all measures to save energy and boost efficiency, received €116.6 million in funding from the Länder in 2021. As in previous years, energy efficiency in transport, which also covers the expansion of electric mobility, was the main technological focus with funding totalling €55.7 million. Baden-Württemberg, traditionally home to the automotive industry, provided €21 million of this funding. In 2021, the Länder supported research into energy efficiency in industry, trade and commerce with a total of €35.9 million in funding: first and foremost Bavaria (€11.5 million), followed by Lower Saxony (€10.5 million) and Saxony (€8.2 million). Länder funding for research into energy efficiency in buildings and neighbourhoods was down slightly at €9.7 million, with Bavaria making the highest contribution of €1.9 million.

Totalling €135.6 million, the financial contribution to energy research funding in Lower Saxony was clearly higher than in the other Länder, followed by Bavaria (€71 million) and Baden-Württemberg (€68 million) in second and third place, respectively. In addition, North Rhine-Westphalia (€37.9 million), Saxony (€28.5 million), Bremen (€17.3 million) and Hamburg (€17.1 million) as well as Mecklenburg-Vorpommern (€14.8 million) also provided substantial funding this purpose in 2021.

Alongside other Länder reports published to this date, the full version of the report on "Funding for non-nuclear energy research by the Länder in 2021" [in German] can be accessed on the website of Project Management Jülich (PtJ).

Figure 33: Spending of Länder on non-nuclear energy research by Land 2014-2021
in € million

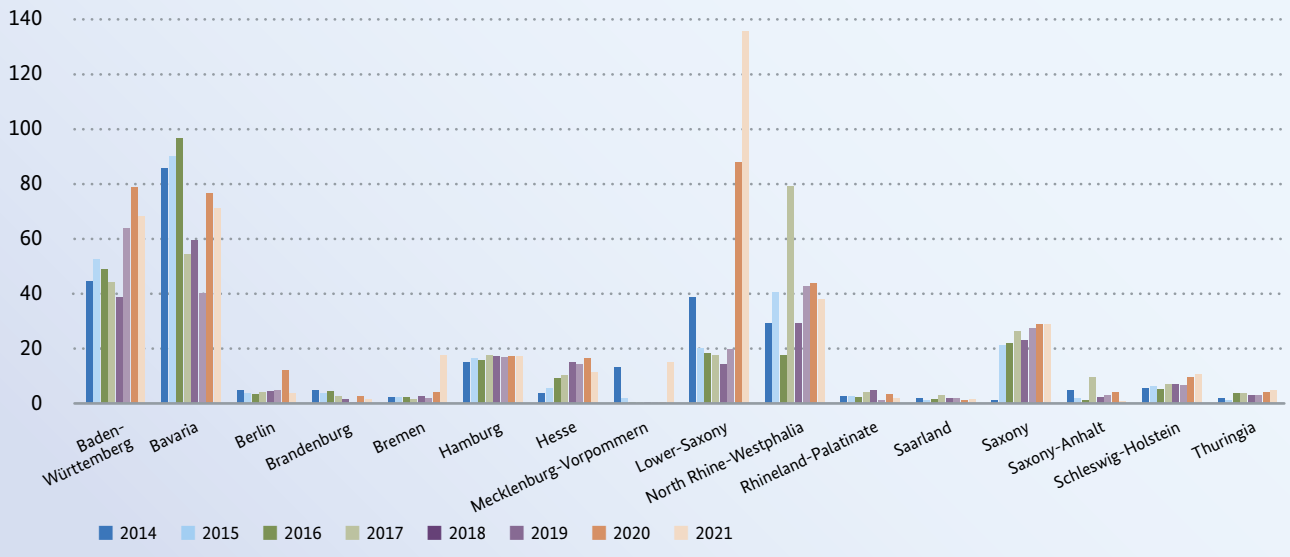


Figure 34: Spending of Länder on non-nuclear energy research by funding topic 2008-2021 in € million

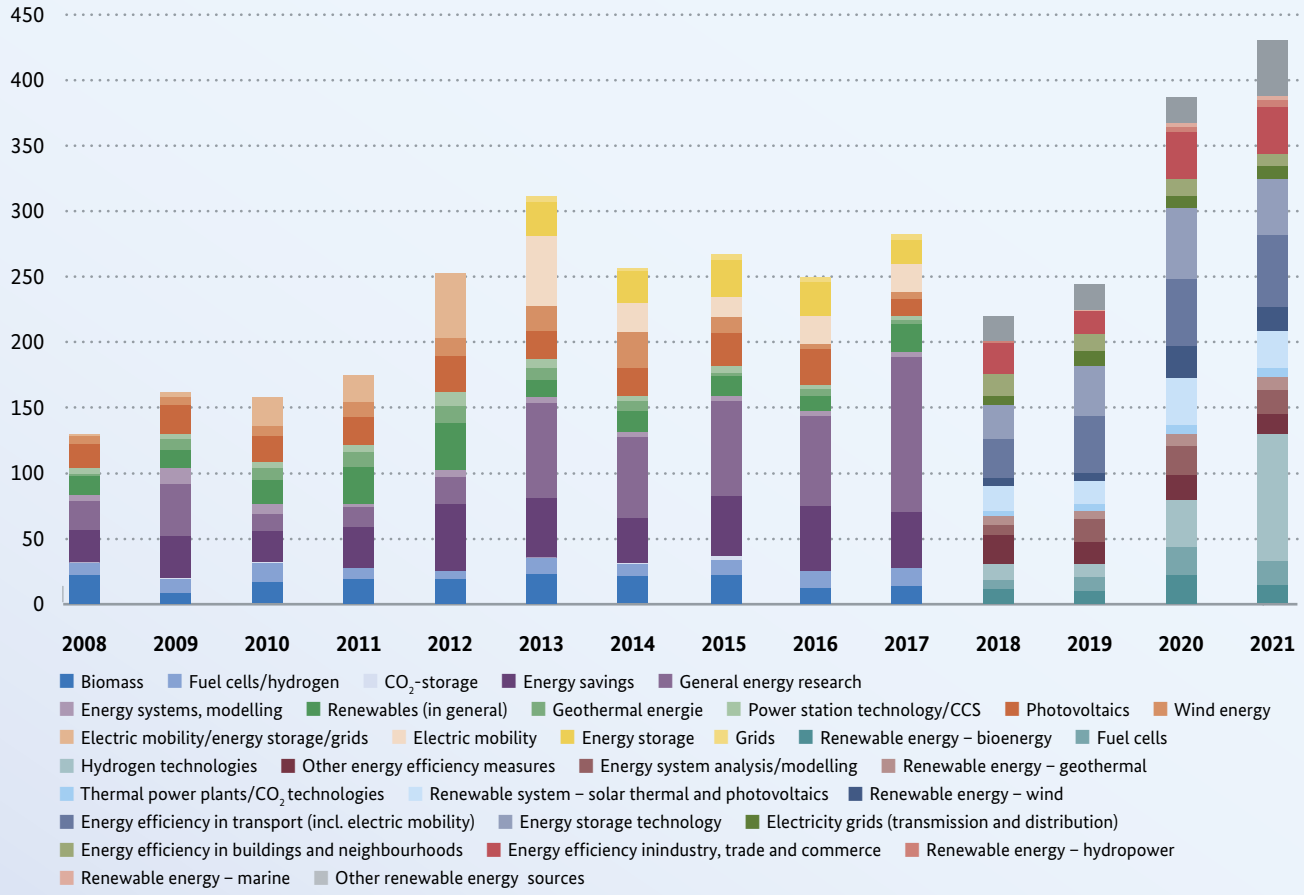
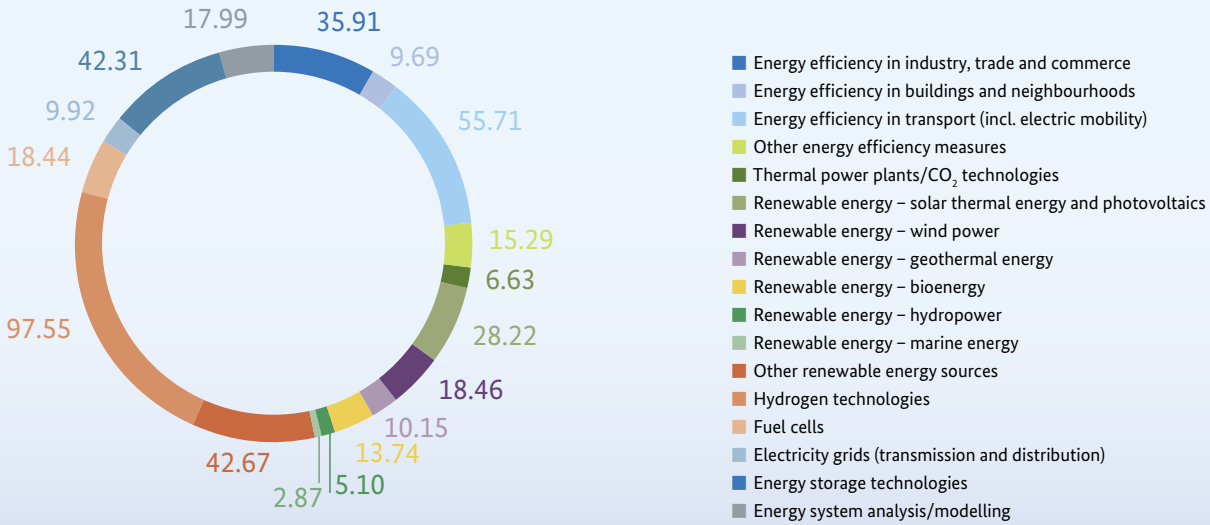


Figure 35: Spending by the Länder on non-nuclear energy research by funding topic in line with IEA technology classification from 2021 in € million



5.2 Federal Government innovation promotion beyond the Energy Research Programme

The Federal Government also funds measures to promote innovation in the field of energy outside the 7th Energy Research Programme.

IPCEI on hydrogen – Important Projects of Common European Interest (IPCEIs) for hydrogen technologies and systems

As part of funding under the Important Projects of Common European Interest (IPCEI) funding initiative, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Digital and Transport, together with 22 EU Member States and Norway, launched the IPCEI on hydrogen in 2022 during Germany's presidency of the European Council. 62 major German projects were selected the following year to enter the notification process. These include projects for facilities with electrolysis output of more than 2 gigawatts for the production of green hydrogen, innovative steel and chemical industry projects, as well as infrastructure and mobility projects.

Backed by funding from the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry for Digital and Transport, the IPCEI is to provide a significant boost to the European Single Market via joint investments by cooperating European countries, strengthening growth, employment, innovative capacities and global competitiveness throughout Europe. In Germany, the IPCEI is embedded in the National Hydrogen Strategy and thus aims to support the market ramp-up of hydrogen technologies and systems.

In 2022, an important milestone was reached with the approval of the Hy4Chem and SALCOS projects. As the first major German industrial projects under the IPCEI hydrogen initiative, they form the basis for the hydrogen economy in Germany. In addition, the European Commission approved two further projects selected by the Federal Ministry for Economic Affairs and Climate Action for research into stationary fuel cell systems and the series production of electrolysers. In addition, approvals have also been granted for two projects selected by the Federal Ministry for Digital and Transport.

Research Campus – public-private partnership for innovation

In the Research Campus funding initiative, the Federal Ministry of Education and Research is funding two energy-related research campuses: flexible electrical grids (FEN) and Mobility2Grid.

FEN is studying how energy can be distributed in a highly flexible manner with the aid of direct current grids and is developing pioneering applications. This research includes aspects on grid components, the operation of hybrid AC/DC grids, as well as digitisation, socio-economics and standardisation. Since 2019, FEN has been operating the very first research grid for medium-voltage direct current in the megawatt class on the campus of RWTH Aachen University.

Mobility2Grid, which is located on the EUREF Campus in Berlin, is researching the energy transition and electric mobility in connected urban areas, focusing on grid integration, autonomous charging or electrification of depots as well as new networked forms of mobility in the overall context of the city. This research extends beyond the EUREF Campus to four other sites in Berlin, so that technical and economic concepts are being developed to aggregate sites and then examined in a regulatory sandbox. Both research campuses are in the second main phase of funding.

Leading-edge technologies for the energy transition within the framework of industrial collective research

As part of programme cooperation between the 7th Energy Research Programme and industrial collective research, the Federal Ministry for Economic Affairs and Climate Action has been funding various projects related to the energy transition since 2016. The "Leading-edge Technologies for SMEs" defined in the Guideline for Industrial Collective Research of 10 August 2017 provides the basis for linking the two programmes. Industrial collective research focuses on bridging the gap between basic research and commercial application to create innovations that specifically strengthen the competitiveness of small and medium-sized enterprises.

The Federal Ministry for Economic Affairs and Climate Action also issued a funding announcement in August 2022 calling for applications. A total of four flagship projects were approved and will now receive a total of around €4.3 million in funding: "Energy-activated steel solutions for climate-positive buildings", "Urban wind turbines with high-performance steel rotor blades", "Resource-saving, current-conducting connections for the energy transition (ampere-clinch)" and "Development of an energy-efficient oxygen separation process using ceramic pellets".

Overall funding concept for renewable fuels of the Federal Ministry for Digital and Transport

The mobility and fuel strategy (MKS) set up an intermodal information and orientation basis for the energy transition in transport in 2013. Building on this, the 2030 Climate Action Programme has taken up the issue of renewable fuels to reduce greenhouse gas emissions in transport, providing funding on a technology-neutral basis both to the further development of electricity-based synthetic fuels (eFuels) and advanced biofuels from waste and residues and to their market entry/ramp-up. The importance of renewable fuels, and particularly of eFuels, for a climate-neutral transport sector was also underscored in the Federal Government's coalition agreement.

The overall funding concept for renewable fuels of the Federal Ministry for Digital and Transport addresses this issue and provides a four-pillar funding programme which takes a technology-neutral and intermodal approach to the entire spectrum of the (further) development of eFuels and advanced fuels through to their generation and market ramp-up. Research and development are focused on two ongoing funding measures, i.e. the funding guideline "Development of Renewable Fuels" and the funding of a modular technology platform for PtL fuels with a research and demonstration strand on a semi-industrial scale. The aim here is to optimise the individual production steps and processes and to integrate them fully to produce renewable fuels. Two further funding measures were published in 2023 to reduce further barriers to investment in generating installations through to the market ramp-up of these fuels.

Greater use of the potential deployment of renewable energy in transport and infrastructure

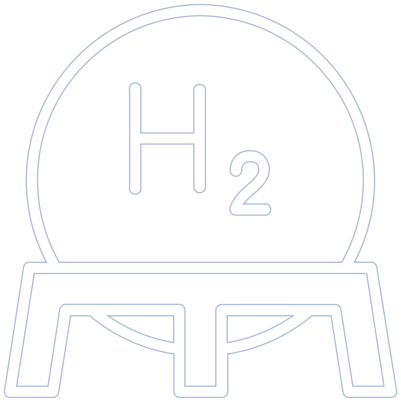
The transport sector must make a substantial contribution towards cutting greenhouse gas emissions in order to attain climate targets. Intermodal transport research in the network of experts of the Federal Ministry for Digital and Transport makes a valuable contribution towards this.

In the ministry's network of experts, six leading departmental research establishments (Federal Highway Research Institute, Federal Institute of Hydrology, Federal Maritime and Hydrographic Agency, Deutscher Wetterdienst, Federal Railway Authority/German Centre for Rail Traffic Research, Federal Institute for Waterway Engineering and Research) and a specialist agency (Federal Office for Goods Transport) of the ministry are pooling their expertise and researching specific issues of particular political relevance in strategically important fields on an intermodal basis, led by the vision

"Making the transport system resilient and environmentally friendly". Thematic area 5 "Renewable energy" in the network of experts takes an intermodal approach to the development of renewable energy for transport and infrastructure (e.g. via estimates of potential for PV and, going forward, geothermal energy installations alongside federal transport infrastructure) and the identification of potential savings. The scientists are also focusing here on new systems, e.g. self-supplying (railway) bridges or road surfaces and noise barriers with integrated PV. In addition to the technical analysis, proposed solutions are also being drawn up to reduce organisational and legal barriers to the mutual exchange of renewable energy between the modes of transport and between public and private facilities.

National Innovation Programme on Hydrogen and Fuel Cell Technology (NIP) in the Federal Ministry for Digital and Transport

Since 2007, the promotion of research and development to launch hydrogen as an energy carrier has been pooled across ministries in the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP). The current funding guidelines of the Federal Ministry for Digital and Transport for the second phase of the NIP from 2016 – 2026 focus not only on promoting research and development but also on market activation by promoting the procurement of hydrogen applications in the mobility sector. The aim of the NIP is to improve the technological maturity and competitiveness of hydrogen technologies for the transport sector through lower costs and standardisation.



6. Tables

6.1 Funding in the 7th Energy Research Programme of the Federal Government

Table 1 | Overview of topics in the Energy Research Programme of the Federal Government

Topic	Actual outlays in € million								
	2014	2015	2016	2017	2018	2019	2020	2021	2022
Project funding	**487.65**	**525.44**	**536.28**	**659.45**	**635.25**	**703.66**	**750.59**	**945.17**	**1,111.98**
Strategic funding formats						–	5.53	66.93	210.65
Energy transition in the consumption sectors	115.89	112.04	108.08	137.28	156.04	193.92	208.03	212.92	198.11
Energy generation	198.95	209.86	191.67	244.49	212.36	255.36	252.60	288.39	257.01
System integration: grids, storage, sector coupling	95.22	113.30	119.79	144.44	127.15	127.11	146.61	201.69	211.39
Cross-system research topics of the energy transition	34.29	44.49	71.01	86.12	92.22	78.31	91.61	123.42	184.43
Nuclear safety research	43.29	45.74	45.73	47.13	47.48	48.98	46.21	51.82	50.39
Institutional funding (Helmholtz Association)	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**	**415.78**	**314.42**	**319.85**
Accompanying measures	**28.14**	**34.72**	**35.03**	**28.20**	**25.76**	**34.47**	**50.16**	**51.38**	**54.53**
Total	**847.39**	**908.85**	**934.12**	**1,067.28**	**1,054.75**	**1,148.42**	**1,216.53**	**1,310.97**	**1,486.36**

Table 2 | Disbursements of project funding in the area of "Strategic funding formats: Living Labs for the Energy Transition and hydrogen flagship projects"

Funding topic	Actual outlays in € million				Number of projects		Total funding in € million
	2019	2020	2021	2022	ongoing in 2022	new in 2022	new appropriated in 2022
Living Labs for the Energy Transition	**–**	**5.53**	**18.29**	**40.50**	**189**	**40**	**59.91**
Energy-optimised and climate-neutral buildings	–	0.14	1.22	1.31	5	–	–
Energy-optimised and climate-neutral neighbourhoods	–	1.70	5.06	8.69	47	–	–
Supply of heat and cold	–	0.06	0.80	5.33	16	–	–
Energy transition in industry, commerce, trade and services	–	–	–	0.46	3	–	–
Use of biogenic residue and waste materials for energy purposes	–	1.01	1.22	0.05	3	–	–
Geothermal energy	–	0.35	1.66	6.87	11	5	2.85
Thermal power plants	–	2.17	2.72	1.20	2	–	–
Electricity storage	–	–	–	0.00	12	12	20.56
Hydrogen production	–	0.11	5.04	11.63	49	4	28.36
Fuel cells	–	–	–	-	4	4	2.18
Systemic approaches	–	–	0.54	1.89	23	15	5.96
Digitisation in the energy transition	–	–	0.04	3.05	14	–	–
Hydrogen flagship projects	**–**	**–**	**48.64**	**170.14**	**335**	**12**	**25.47**
Storage and transport/TransHyDE	–	–	10.71	28.72	106	4	1.26
Hydrogen production/H_2Giga and H_2Mare	–	–	37.93	141.43	229	8	24.21
Total	**–**	**5.53**	**66.93**	**210.65**	**524**	**52**	**85.38**

Table 3 | Disbursements of project funding in the area of "energy transition in the consumption sectors"

Funding topic	Actual outlays in € million										number of projects		Total funding in € million
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	ongoing in 2022	new in in 2022	appropriated in in 2022
Energy transition in buildings and neighbourhoods	**60.11**	**66.11**	**61.85**	**58.21**	**65.38**	**78.63**	**93.51**	**101.27**	**98.57**	**100.16**	**1.041**	**212**	**83.35**
Energy-optimised and climate-neutral buildings	31.82	36.55	35.64	32.00	36.57	39.78	50.24	47.86	44.90	42.60	518	104	36.42
Energy-optimised and climate-neutral neighbourhoods	10.67	10.59	9.65	12.94	17.57	22.52	25.35	31.51	31.24	26.20	291	58	29.74
Basic research into energy-optimised and climate-neutral neighbourhoods	4.49	5.19	4.65	3.88	2.73	7.50	10.22	13.63	9.92	15.53	78	3	0.48
Thermal energy storage	4.15	6.51	7.33	5.75	4.84	5.33	4.65	4.52	4.19	4.17	44	12	5.26
Supply of heat and cold	8.99	7.27	4.59	3.64	3.67	3.51	3.06	3.74	7.15	8.56	107	35	11.45
Basic research into supply of heat and cold	-	-	-	-	-	-	-	-	1.17	3.09	3	-	-
Energy transition in industry, commerce, trade and services	**39.69**	**37.17**	**37.39**	**36.00**	**57.12**	**60.92**	**66.20**	**64.88**	**73.49**	**69.80**	**770**	**152**	**66.18**
Waste heat use	4.21	3.88	4.98	4.03	2.78	1.26	0.55	0.56	0.98	1.11	22	6	1.86
Chemical process technology	7.30	7.13	7.49	9.11	12.83	12.83	11.22	9.21	9.12	10.64	115	21	9.85
Iron, steel and non-ferrous metals	1.77	0.98	0.97	0.86	1.09	2.07	3.56	3.15	2.36	4.25	49	13	4.51
Circular economy	0.05	0.34	0.32	0.12	0.03	-	-	0.16	0.29	0.29	6	-	-
Manufacturing technology	15.93	17.13	15.82	11.09	14.82	17.49	23.19	24.80	24.75	22.40	286	47	15.56
High-temperature superconductivity	3.10	2.37	0.53	0.62	1.18	1.15	1.07	0.70	2.15	2.33	12	3	1.58
Industrial motors	-	-	-	-	-	-	-	-	-	-	-	-	-
Digitisation in industry	0.65	0.70	0.74	1.07	1.59	1.69	1.61	0.66	2.30	3.70	32	16	5.51
Material and resource efficiency	0.06	0.07	0.09	0.01	0.18	0.28	0.49	0.43	0.37	0.15	4	-	-
Process heat	3.41	3.29	4.14	5.65	8.15	8.58	9.45	9.36	10.51	9.49	104	25	16.63
Water treatment	-	0.04	0.18	0.35	0.72	0.58	0.57	0.51	0.41	0.20	14	5	1.67
Flexible industrial processes	-	-	-	-	10.70	12.54	10.80	10.43	14.05	8.37	58	-	-
Other	3.22	1.24	2.12	3.07	3.03	2.44	3.67	4.93	6.19	6.89	68	16	9.01
Energy transition in the transport sector	**17.83**	**12.61**	**12.80**	**13.87**	**14.78**	**16.49**	**34.21**	**41.87**	**40.85**	**28.16**	**284**	**30**	**20.29**
Battery technology for mobile applications	17.83	12.61	12.80	13.87	14.28	15.63	17.06	17.80	16.59	11.25	142	24	12.65
Synthetic fuels	-	-	-	-	0.50	0.86	13.51	16.19	16.29	9.28	87	3	6.90
Basic research into synthetic fuels	-	-	-	-	-	-	3.64	7.44	6.49	4.61	38	-	-
Charging infrastructure and systems integration	-	-	-	-	-	-	-	0.44	1.48	3.02	17	3	0.75
Total	**117.63**	**115.89**	**112.04**	**108.08**	**137.28**	**156.04**	**193.92**	**208.03**	**212.92**	**198.11**	**2.095**	**394**	**169.82**

Table 4 | Disbursements of project funding in the area of "energy generation"

Funding topic	Actual outlays in € million										number of projects		Total funding in € million
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	ongoing in 2022	new in in 2022	appropriated in in 2022
Photovoltaics	**62.73**	**56.83**	**67.41**	**59.78**	**81.90**	**78.24**	**98.69**	**86.19**	**88.39**	**70.14**	**478**	**105**	**61.64**
PV technologies	9.88	7.22	5.64	2.65	2.75	5.24	11.75	12.40	16.40	13.55	81	35	22.01
Quality assurance	2.80	2.65	3.07	3.79	4.60	3.65	3.97	3.83	5.24	7.25	76	21	10.07
Manufacturing technologies	32.49	28.77	36.05	36.10	55.93	58.11	58.86	56.81	50.05	37.90	223	38	24.92
Circular economy	0.85	0.63	0.91	0.99	1.14	0.82	1.01	1.16	1.72	1.05	12	-	-
Systems capability	1.87	2.40	3.40	4.57	5.41	6.85	5.99	5.50	4.00	4.79	44	9	2.76
Basic research into photovoltaics	14.49	14.83	11.59	6.17	3.51	1.33	2.69	2.27	4.39	1.34	6	-	-
Other	0.34	0.34	6.75	5.51	8.56	2.24	14.41	4.23	6.60	4.27	36	2	1.88
Wind energy	**52.57**	**52.88**	**52.85**	**49.68**	**75.11**	**59.73**	**72.95**	**76.06**	**82.87**	**89.19**	**469**	**97**	**59.75**
Plant development	18.14	23.40	27.09	21.99	42.92	29.13	34.69	41.82	42.79	43.85	163	47	33.63
Logistics, installation, maintenance and operation	7.38	5.25	5.18	7.38	11.00	8.34	8.30	7.83	9.96	10.97	136	35	15.08
Offshore wind energy	16.09	14.34	9.19	10.45	11.56	12.03	15.88	17.61	18.67	25.31	80	8	6.06
Environmental aspects of wind energy	4.91	4.31	3.23	2.25	2.48	2.42	3.34	2.83	3.08	2.13	31	4	2.08
Wind physics and meteorology	1.78	2.34	3.63	3.03	3.06	2.33	2.96	3.70	6.18	5.45	40	2	1.96
Other	4.27	3.24	4.53	4.58	4.08	5.49	7.79	2.26	2.18	1.48	19	1	0.93
Bioenergy	**42.57**	**43.00**	**42.10**	**37.88**	**33.03**	**28.54**	**40.52**	**48.37**	**63.72**	**48.00**	**739**	**131**	**34.21**
Production – farming	6.31	5.98	4.43	4.69	5.70	6.52	10.86	14.39	18.97	18.59	237	19	9.44
Production – cultivation	5.25	4.77	4.92	4.49	4.58	4.20	4.44	4.78	4.35	3.90	54	6	1.02
Conversion – general	-	-	0.53	5.22	2.73	4.46	5.03	4.64	3.76	1.53	51	-	-
Conversion – gaseous	4.87	5.27	6.84	4.92	6.79	5.04	4.88	6.05	6.46	6.72	101	19	4.19
Conversion – liquid	6.12	6.19	5.92	3.97	3.21	1.98	1.12	0.68	0.78	0.39	6	1	0.03
Conversion – solid	0.94	0.73	1.92	2.23	1.77	1.34	2.43	3.85	3.49	1.83	47	19	3.84
Use of biogenic residue and waste materials for energy purposes	6.05	5.06	4.69	3.66	4.17	4.20	5.12	7.71	10.48	10.39	197	59	12.53
Basic research into bioenergy	9.81	12.16	9.89	6.17	3.13	0.22	5.83	4.63	13.13	2.37	11	-	-
Cross-section	3.22	2.85	2.97	2.53	0.94	0.59	0.80	1.65	2.29	2.28	35	8	3.16
Thermal power plants	**29.38**	**29.39**	**32.22**	**29.44**	**34.14**	**29.05**	**28.30**	**25.72**	**29.77**	**30.72**	**356**	**86**	**41.65**
Combined-cycle power plants with flexible loads and fuels	21.01	20.12	20.82	18.42	22.87	18.01	17.74	16.22	17.41	15.59	208	57	30.48
Solar thermal power plants	5.72	6.23	8.01	7.21	6.20	6.13	6.75	8.19	9.19	9.71	108	28	11.04
Other	2.66	3.04	3.39	3.81	5.07	4.90	3.80	1.31	3.17	5.43	40	1	0.13
Geothermal energy	**17.61**	**15.64**	**13.61**	**12.89**	**18.15**	**15.38**	**13.19**	**14.01**	**22.71**	**18.64**	**110**	**22**	**20.69**
Hydroelectric and marine power	**1.25**	**1.21**	**1.68**	**2.01**	**2.15**	**1.40**	**1.71**	**2.26**	**0.93**	**0.31**	**4**	**3**	**1.33**
Total	**206.10**	**198.95**	**209.86**	**191.67**	**244.49**	**212.36**	**255.36**	**252.60**	**288.39**	**257.01**	**2.156**	**444**	**219.27**

Table 5 | Disbursements of project funding in the area of "system integration: grids, storage, sector coupling"

Funding topic	Actual outlays in € million										number of projects		Total funding in € million
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	ongoing in 2022	new in in 2022	appropriated in in 2022
Power grids	**27.31**	**31.24**	**54.32**	**66.32**	**78.14**	**66.24**	**64.85**	**65.05**	**69.75**	**61.28**	**568**	**130**	**56.77**
Supply security	2.32	2.23	7.50	12.75	13.10	13.51	11.02	12.11	10.52	8.67	76	18	8.65
Flexibility in the power grid	7.75	5.88	7.21	6.60	6.30	7.13	7.14	10.71	13.88	11.90	123	13	5.01
Grid planning and operational management	7.82	9.53	15.65	19.45	19.56	14.74	13.35	12.29	11.54	11.43	136	40	17.07
Technology for the electricity grid	9.42	12.64	16.39	17.52	21.07	17.71	22.50	19.36	20.83	17.50	190	49	19.10
Basic research into electricity grids	-	0.96	7.57	10.01	18.11	13.15	10.85	10.58	12.97	11.78	43	10	6.94
Energy storage	**31.43**	**29.57**	**28.63**	**27.69**	**22.35**	**18.37**	**21.43**	**22.53**	**25.47**	**19.28**	**192**	**18**	**12.57**
Electrical storage	-	-	-	-	0.02	0.61	0.63	0.63	0.39	0.89	9	-	-
Electrochemical storage	3.96	3.99	4.36	5.22	8.54	8.99	8.68	11.19	15.64	11.32	103	-	-
Electricity-heat-electricity storage	-	-	-	0.58	1.39	1.54	2.36	2.42	2.60	1.12	5	-	-
Mechanical accumulators	3.26	1.53	1.97	2.60	3.19	2.53	2.65	3.48	1.76	1.24	13	2	3.62
Basic research into energy storage	19.37	17.21	15.61	10.79	3.60	1.17	3.77	2.30	1.56	0.88	13	4	4.87
Other	4.84	6.84	6.70	8.50	5.59	3.54	3.34	2.52	3.53	3.83	49	12	4.08
Sector coupling and hydrogen technologies	**30.85**	**34.41**	**30.35**	**25.77**	**43.95**	**42.53**	**40.82**	**59.02**	**106.47**	**130.83**	**552**	**191**	**187.20**
Hydrogen production	4.78	6.35	7.17	5.70	6.66	4.21	1.13	0.86	2.36	4.06	41	19	11.48
Hydrogen storage and transport	3.84	3.46	2.76	2.85	4.36	4.90	5.73	4.10	4.50	4.74	74	38	19.64
Fuel cells	19.58	18.82	15.23	10.04	15.67	13.81	14.31	15.17	13.48	14.81	109	4	3.14
Systemic approaches	0.62	0.96	1.12	0.99	0.32	0.33	0.46	0.43	1.60	2.41	12	6	1.94
Power-to-X	0.96	0.40	0.39	0.19	0.62	1.06	1.33	1.35	1.58	1.11	11	-	-
Basic research into sector coupling and hydrogen	1.08	3.04	2.10	4.63	15.53	17.36	17.78	35.99	80.12	99.54	238	83	134.18
Other	-	1.39	1.58	1.37	0.79	0.85	0.08	1.13	2.83	4.16	67	41	16.81
Total	**89.60**	**95.22**	**113.30**	**119.79**	**144.44**	**127.15**	**127.11**	**146.61**	**201.69**	**211.39**	**1,312**	**339**	**256.54**

Table 6 | Disbursements of project funding in the area of "cross-system research topics of the energy transition"

Funding topic	Actual outlays in € million										number of projects		Total funding in € million
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	ongoing in 2022	new in in 2022	appropriated in in 2022
Energy system analysis	**8.06**	**8.39**	**9.32**	**11.18**	**15.01**	**15.94**	**17.16**	**18.97**	**19.74**	**19.09**	**213**	**53**	**21.37**
Digitalisation in the energy transition		**-**	**-**	**-**	**-**	**-**	**-**	**2.68**	**5.06**	**5.63**	**97**	**56**	**15.13**
Resource efficiency in the context of the energy transition		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.07**	**2.29**	**55**	**25**	**6.38**
CO_2 technologies	**5.97**	**6.60**	**4.28**	**15.06**	**18.15**	**24.58**	**19.57**	**35.05**	**32.87**	**45.09**	**143**	**40**	**13.76**
CO_2 transport and storage	0.74	0.67	0.38	-	0.18	0.96	1.23	1.22	0.49	1.14	8	-	-
CO_2 sequestration	5.12	3.90	1.80	3.46	3.30	2.11	1.23	1.95	2.48	2.36	38	10	4.93
CO_2 conversion and use	0.11	0.27	1.30	2.64	2.83	4.61	3.04	6.15	3.35	3.88	57	24	7.43
Basic research into CO_2 technologies	-	1.76	0.79	8.95	11.84	16.90	14.08	25.74	26.54	37.71	40	6	1.41
Industrial collective research programme cooperation			**-**	**0.05**	**2.52**	**4.22**	**5.47**	**4.90**	**5.71**	**4.64**	**34**	**11**	**4.35**
Energy transition and society	**1.18**	**3.25**	**3.95**	**2.64**	**10.02**	**9.93**	**10.15**	**6.37**	**12.28**	**15.95**	**131**	**40**	**9.63**
Energy transition and society – applied energy research		-	-	-	-	-	0.00	1.23	4.12	6.23	105	40	9.63
Energy transition and society – basic research	1.18	3.25	3.95	2.64	10.02	9.93	10.14	5.14	8.16	9.72	26	-	-
Materials research	**-**	**0.72**	**10.41**	**27.87**	**26.68**	**18.21**	**10.30**	**2.90**	**3.96**	**2.05**	**3**	**-**	**-**
Basic research into energy-related use of the subsurface	**4.65**	**4.22**	**3.69**	**3.59**	**1.81**	**2.02**	**1.36**	**2.35**	**3.55**	**14.88**	**122**	**39**	**21.87**
Technology-neutral funding with an international focus	**0.05**	**1.03**	**2.00**	**0.65**	**0.28**	**2.11**	**3.88**	**11.73**	**24.46**	**60.00**	**96**	**25**	**78.03**
Other basic research	**16.99**	**10.07**	**10.84**	**9.96**	**11.64**	**15.22**	**10.42**	**6.64**	**15.70**	**11.57**	**17**	**-**	**-**
Accompanying funding for IPCEI battery cell research										**3.24**	**11**	**79**	**76.58**
Total	**36.90**	**34.29**	**44.49**	**71.01**	**86.12**	**92.22**	**78.31**	**91.61**	**123.42**	**184.43**	**922**	**368**	**247.09**

Table 7a | Disbursements of project funding in the area of "nuclear safety research" until 2020

Funding topic[1]	Actual outlays in € million								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nuclear waste repository and disposal research	**12.30**	**13.23**	**13.58**	**12.95**	**13.09**	**16.33**	**17.61**	**19.57**	**17.79**
Repository research	9.84	10.39	10.25	10.06	9.94	11.43	12.02	12.23	12.58
Horizontal tasks and other	0.54	0.53	0.53	0.54	1.06	1.90	2.69	3.57	2.31
Nuclear material monitoring	0.18	0.15	0.19	0.24	0.26	0.21	0.09	0.22	0.05
Funding for young researchers (measures by the Federal Ministry of Education and Research)	1.74	2.17	2.61	2.11	1.83	2.78	2.81	3.54	2.85
Reactor safety research	**24.38**	**23.43**	**25.10**	**25.22**	**24.06**	**22.76**	**21.98**	**22.05**	**22.06**
Safety of nuclear facility components	5.28	4.01	4.38	4.55	4.38	4.20	5.19	4.75	4.98
Plant behaviour and accident sequences	11.25	12.09	12.51	13.22	13.37	13.46	12.52	12.47	11.72
Horizontal tasks and other	5.08	5.72	4.81	4.05	3.63	3.37	3.04	3.63	4.56
Funding for young researchers (measures by the Federal Ministry of Education and Research)	2.77	1.62	3.39	3.39	2.68	1.73	1.23	1.19	0.79
Radiation research (Federal Ministry of Education and Research)	**4.91**	**4.95**	**4.61**	**7.58**	**8.58**	**8.05**	**7.89**	**7.36**	**6.36**
Total	**41.59**	**41.61**	**43.29**	**45.74**	**45.73**	**47.13**	**47.48**	**48.98**	**46.21**

1 Reorientation of funding from 2021

Table 7b | Disbursements of project funding in the area of "nuclear safety research" from 2021

Funding topic	number of projects				Total funding in € million
	2021	2022	ongoing in 2022	new in 2022	appropriated in 2022
Reactor safety research	**22.39**	**23.80**	**156**	**24**	**20.21**
Examining and assessing the safety of components and structures	5.03	5.03	53	8	5.74
Detection methods to manage transients, incidents and accidents	14.04	13.88	73	12	9.80
Human-technology interaction and probabilistic safety analysis	2.01	1.86	15	1	0.42
Funding for young researchers (measures by the Federal Ministry of Education and Research)	1.32	3.03	15	3	4.25
Research into extended intermediate storage and the treatment of highly radioactive waste	**5.18**	**5.53**	**44**	**7**	**6.05**
Extended intermediate storage	1.52	1.22	10	2	1.27
Waste treatment and conditioning options for final disposal	-	0.02	1	1	0.22
Treatment and disposal methods	0.02	0.07	4	1	0.85
Funding for young researchers (measures by the Federal Ministry of Education and Research)	3.64	4.22	29	3	3.71
Repository research	**12.44**	**10.46**	**88**	**22**	**12.86**
Site selection	0.60	0.90	4	6	2.62
Safety and repository design; repository technology and (geo-)technical barriers	6.49	5.38	40	5	1.87
Safety verification	5.36	4.17	44	11	8.36
Funding for young researchers (measures by the Federal Ministry of Education and Research)	-	-	-	-	-
Research on cross-cutting issues	**3.12**	**3.63**	**16**	**1**	**0.08**
Knowledge and skills management	1.05	1.26	4	1	0.08
Socio-technical issues	1.82	2.37	10	-	-
Nuclear material monitoring (safeguards)	0.25	-	2	-	-
Funding for young researchers (measures by the Federal Ministry of Education and Research)	-	-	-	-	-
Radiation research (Federal Ministry of Education and Research)	**8.69**	**6.98**	**52**	**10**	**7.45**
Total	**51.82**	**50.39**	**356**	**64**	**46.65**

Table 8 | Institutional support

Funding topic	Actual outlays in € million								
	2014	2015	2016	2017	2018	2019	2020	2021	2022
PoF III	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**	**415.78**		
Energy efficiency, materials and resources	60.49	64.12	68.43	69.45	73.00	76.67	78.60		
Renewable energy	47.84	51.91	54.37	56.73	59.09	61.51	62.94		
Nuclear fusion (incl. Wendelstein W 7-X)	123.51	123.51	123.51	123.51	123.51	126.00	78.23		
Nuclear waste management, safety and radiation research	34.62	35.76	37.27	38.84	40.47	42.16	19.63		
Technology, innovation and society	7.11	7.65	7.95	8.25	8.54	8.84	9.00		
Storage and networked infrastructures	49.93	57.12	60.47	69.61	72.86	76.21	43.32		
Future information technology	8.11	8.62	10.81	13.24	16.28	18.90	124.07		
PoF IV								**314.42**	**319.85**
Energy system design								34.60	34.89
Materials and technologies for the energy transition								208.09	212.13
Fusion								31.28	32.03
Nuclear waste management, safety and radiation research (NUSAFE II)								38.46	38.81
Total[1]	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**	**415.78**	**314.42**	**319.85**

1 The total for 2021 does not correspond to the total of individual items. The total includes an extra €2 million for an overarching innovation pool.

Table 9a | Overview of the Federal Government's energy research programme by chapter and title in the federal budget

Topic Chapter/Title[1]	Responsible Ministry[2]	Chapter heading[1]	Title heading[1]	Actual outlays in € million 2020	2021	2022
Project funding and accompanying measures				**800.75**	**996.55**	**1.166.51**
0903/68301	Federal Ministry for Economic Affairs and Climate Action	Energy and sustainability	Energy research	535.03	572.61	530.94
0901/68601[3]	Federal Ministry for Economic Affairs and Climate Action	Innovation, technology and new mobility	Industrial research for companies		3.85	4.28
0903/68602[7]	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection	Energy and sustainability	Safety research for nuclear facilities	38.33	40.33	
0903/68608[3]	Federal Ministry for Economic Affairs and Climate Action	Energy and sustainability	Living Labs for the Energy Transition[6]		18.64	43.66
0904/89602[8]	Federal Ministry of Education and Research	Opportunities of globalisation	Hydrogen strategy, foreign Trade – international cooperation on hydrogen			7.28
1005/68611 & 1005/89311	Federal Ministry of Food and Agriculture	Sustainability, research and innovation	Grants to promote research, development and demonstration projects in the field of renewable raw materials and to promote national projects in sustainable forest management & grants to promote research, development and demonstration projects in the field of renewable raw materials (investments)	37.83	42.11	35.17
1605/54401[6]	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection	Nuclear safety and radiation protection	Research, investigations. etc.			38.33
3004/68541	Federal Ministry of Education and Research	Research for innovation, high-tech strategy	Energy technologies and efficient energy use, green hydrogen – research and development projects	117.77	185.84	201.61
3004/68541	Federal Ministry of Education and Research	Research for innovation, high-tech strategy	Funding young researchers in nuclear safety research	10.68	14.32	14.93
3004/68542[3]	Federal Ministry of Education and Research	Research for innovation, high-tech strategy	Environmental technologies, resources and geo-research		3.55	14.88
6092/68304	Federal Ministry for Economic Affairs and Climate Action	Climate and transformation fund	Measures to develop electric mobility	14.64	15.37	14.34
6092/68502	Federal Ministry of Education and Research	Climate and transformation fund	Application-oriented basic research – green hydrogen	29.42	99.79	245.92
6092/68616[3]	Federal Ministry for Economic Affairs and Climate Action	Climate and transformation fund	CO_2 avoidance and use in primary industries		0.11	2.83
6092/68618 & 6092/68621[7]	Federal Ministry of Food and Agriculture	Climate and transformation fund	Grants to promote measures for the use of farm manure for energy purposes and for emission reduction in farm manure management & grants to promote measures to protect peat soils and reduce peat use			1.82
6092/68626[4]	Federal Ministry for Economic Affairs and Climate Action	Energy and Climate Fund[5]	Living Labs for the Energy Transition[6]	17.04		
6092/89203[3]	Federal Ministry for Economic Affairs and Climate Action	Climate and transformation fund	Implementation of the National Hydrogen Strategy		0.01	7.29
6092/89304[3]	Federal Ministry for Economic Affairs and Climate Action	Climate and transformation fund	Industrial manufacturing for mobile and stationary energy storage systems		0.00	3.24
Institutional Funding (Helmholtz Association)				**415.78**	**314.42**	**319.85**
0901/68531 & 0901/89431	Federal Ministry for Economic Affairs and Climate Action	Innovation, technology and new mobility	German Aerospace Center e. V. – operation & German Aerospace Center e. V. – investment	30.99	48.54	49.62
3004/68570 & 3004/89470	Federal Ministry of Education and Research	Research for innovation, high-tech strategy	Helmholtz centres – operation & Helmholtz centres – investment	384.79	265.88	270.24
Total				**1,216.53**	**1,310.97**	**1,486.36**

1 2022 federal budget or, where titles expire, last year of use
2 Responsibility in line with the organisational decree of the Federal Chancellor of 8 December 2021; where title expired, the ministry currently responsible is cited
3 New from 1 January 2021
4 Expired from 1 January 2021
5 In 2020 still referred to as the "Energy and Climate Fund", from 22 July 2022 "Climate and Transformation Fund".
6 Funding incl. existing funding stipulations for the Living Labs were moved from 2021 into federal budget chapter 0903 title 68608.
7 Responsibility transferred from the Federal Ministry of Economic Affairs and Climate Action to the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, implemented in the federal budget as of 2022
8 New from 1 January 2022

Table 9b | Overview of the Federation's Energy Research Programme by ministry

Ministry[1] Topic	Actual outlays in € million 2020	 2021	 2022
Federal Ministry for Economic Affairs and Climate Action	**597.71**	**659.14**	**656.19**
Project funding and accompanying measures	566.72	610.59	606.57
Institutional funding (German Aerospace Centre)	30.99	48.54	49.62
Federal Ministry of Food and Agriculture	**37.83**	**42.11**	**36.99**
Project funding and accompanying measures	37.83	42.11	36.99
Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection	**38.33**	**40.33**	**38.33**
Project funding and accompanying measures	38.33	40.33	38.33
Federal Ministry of Education and Research	**542.66**	**569.39**	**754.85**
Project funding and accompanying measures	157.87	303.51	484.61
Institutional funding (Helmholtz Association excl. German Aerospace Center)	384.79	265.88	270.24
Total	**1,216.53**	**1,310.97**	**1,486.36**

1 Responsibility in line with organisational decree of Federal Chancellor of 8 December 2021, where title expired, current responsible ministry is cited

6.2 Funding for energy research by the Länder

Table 10 | Spending on non-nuclear energy research by Land in 2008 – 2021

Land	Actual outlays in € million													
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Baden-Württemberg	11.54	26.83	15.10	23.12	24.77	35.55	44.37	52.22	48.77	44.10	38.30	63.62	78.66	67.98
Bavaria	16.67	14.14	22.64	32.28	88.13	114.82	85.61	89.98	96.34	54.15	59.26	40.05	76.49	71.01
Berlin	3.87	15.53	4.73	2.10	3.03	0.88	4.70	3.63	2.94	3.89	4.36	4.62	11.86	3.48
Brandenburg	11.34	4.65	4.37	5.81	4.03	7.86	4.40	3.54	4.05	2.20	1.22	0.19	2.24	1.39
Bremen	2.71	2.42	2.78	3.61	2.71	3.46	1.99	2.08	2.10	1.35	2.22	1.75	3.94	17.30
Hamburg	1.15	1.56	0.61	1.27	2.01	15.76	14.91	16.12	15.64	17.29	16.81	16.63	16.87	17.11
Hesse	7.02	5.77	9.10	8.12	12.57	9.63	3.48	5.17	9.11	9.95	14.93	13.96	16.22	11.14
Mecklenburg-Vorpommern	-	1.64	5.68	3.99	8.76	3.22	13.02	1.50	-	-	-	-	-	14.77
Lower Saxony	15.74	24.60	26.36	30.53	32.82	33.00	38.57	19.78	18.21	17.15	14.22	19.40	87.86	135.62
North Rhine-Westphalia	31.52	22.68	31.80	26.55	37.27	28.52	28.99	40.14	17.24	79.08	28.84	42.34	43.76	37.90
Rhineland-Palatinate	2.43	2.76	2.40	2.79	2.10	2.43	2.37	2.51	1.95	4.00	4.39	0.90	3.05	1.64
Saarland	0.95	1.17	0.51	1.12	0.87	0.75	1.56	0.98	1.42	2.77	1.53	1.52	1.06	1.28
Saxony	14.18	29.26	17.42	23.60	24.88	44.06	1.01	20.89	21.78	26.04	22.66	27.29	28.46	28.54
Saxony-Anhalt	2.51	3.83	7.81	6.04	3.43	4.11	4.62	1.53	0.89	9.45	1.94	2.71	3.94	6.52
Schleswig-Holstein	4.12	3.54	3.10	2.08	1.83	4.28	5.15	5.97	4.76	6.76	6.65	6.44	9.28	10.38
Thuringia	3.10	0.78	2.68	1.36	3.55	3.40	1.81	0.95	3.42	3.50	2.70	2.68	3.69	4.57
Total	**128.87**	**161.14**	**157.11**	**174.39**	**252.78**	**311.74**	**256.56**	**266.99**	**248.63**	**281.68**	**220.04**	**244.12**	**387.37**	**430.64**

Table 11 | Spending on non-nuclear energy research by funding topic in 2008 – 2017[1] in € million

Funding topic	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biomass	21.48	7.79	15.90	18.73	18.71	22.44	20.56	21.53	11.78	13.05
Fuel cells/hydrogen	9.47	10.86	15.14	8.11	5.40	12.29	9.82	11.46	12.83	13.73
CO_2 storage	-	0.11	0.24	0.07	0.21	–	0.02	2.77	0.02	0.20
Energy saving	24.86	32.19	23.74	31.66	51.35	45.58	34.73	46.10	49.27	42.00
Energy research in general	22.21	40.20	12.97	14.96	21.01	72.81	61.73	73.03	69.02	118.87
Energy systems, modelling	4.48	12.02	7.87	2.46	5.37	4.53	4.33	3.13	3.33	3.35
Renewables in general	14.45	13.38	18.09	28.28	35.83	13.50	15.34	15.96	11.94	21.61
Geothermal energy	1.27	8.41	8.86	11.27	12.52	8.43	8.09	2.09	4.70	3.53
Power plant technology/CCS	5.09	3.87	4.84	6.09	11.35	7.12	4.25	5.52	3.78	2.68
Photovoltaics	18.12	22.17	19.62	20.84	26.95	21.85	21.31	24.81	27.34	13.19
Wind energy	5.89	6.12	8.26	11.61	14.48	18.60	27.29	12.25	3.97	4.93
Electric mobility/ energy storage/grids	1.55	4.02	21.58	20.31	49.61					
Electric mobility						54.19	22.54	15.88	20.73	21.43
Energy storage						25.84	24.16	28.12	26.34	18.32
Grids						4.58	2.40	4.33	3.60	4.81
Total	**128.87**	**161.14**	**157.11**	**174.39**	**252.78**	**311.74**	**256.56**	**266.99**	**248.63**	**281.68**

1 Continued from 2018 with different classification, cf. Table 12

Table 12 | Spending on non-nuclear energy research by Land by research topic according to the IEA technology classification[1] from 2018

Group number[1]	Funding topic	Actual outlays in € million			
		2018	2019	2020	2021
11	Energy efficiency in industry, trade and commerce	24.04	17.00	36.39	13.74
12	Energy efficiency in buildings and neighbourhoods	16.97	13.62	12.68	18.44
13	Energy efficiency in transport (incl. Electric mobility)	29.39	43.72	50.63	97.55
14	Other energy efficiency measures	22.10	16.55	19.26	15.29
2	Thermal power plants/CO_2 technologies	4.40	5.63	6.31	17.99
31	Renewable energy – solar thermal and PV	18.39	17.49	36.11	10.15
32	Renewable energy – wind energy	6.82	5.64	24.85	6.63
33	Renewable energy – marine energy	0.40	0.36	3.34	28.22
34	Renewable energy – bioenergy	10.86	9.54	21.96	18.46
35	Renewable energy – geothermal energy	6.55	5.74	9.79	55.71
36	Renewable energy – hydropower	0.95	0.44	3.42	42.31
37	Other renewable energy sources	19.48	19.92	20.03	9.92
51	Hydrogen technologies	12.94	9.92	36.13	9.69
52	Fuel cells	6.49	10.47	20.70	35.91
62	Power grids (electricity transmission and distribution)	6.43	11.06	9.12	5.10
63	Energy storage technologies	26.42	38.85	54.67	2.87
71	Energy system analysis/modelling	7.39	18.18	22.01	42.67
	Total	**220.04**	**244.12**	**387.37**	**430.64**

1 IEA-technology classification, cf. https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2#documentation