Federal Ministry
for Economic Affairs
and Climate Action

2022 Federal Government Report on Energy Research

Research funding for the energy transition

bmwk.de

Cover picture: The team of scientists of the Fire Dragon research project has developed a new contact firing processes for highly efficient silicon solar cells. These processes are based, among other things, on innovative beam sources and inline quality control. The cover picture shows an industrial solar wafer entering a furnace.

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Content

Message of Greeting

Dear reader,

Innovations and technical progress are indispensable pillars of the energy transition and thus make a decisive contribution to independence from fossil fuel. Today's research secures sustainable, reliable and affordable options for tomorrow's climate-neutral energy supply. Energy research is therefore always also a strategic element of energy and climate policy.

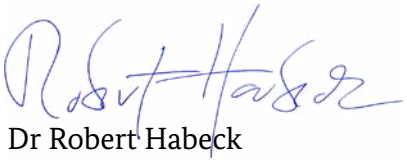
Behind the variety of projects presented in this report are passionate researchers who use their creativity and innovative spirit to produce new elements of a climate-neutral future every day. Each individual project is the expression of the desire and willingness to test a specific idea, a specific vision of the energy transition, and to try it out in competition with others. That is how research works; that is how progress works.

Our project funding creates the preconditions to rapidly advance the most promising ideas and innovations for a successful energy transition. As the time left for action and the bridges leading to an energy supply without fossil fuels are getting shorter, this sustainable innovation environment is of central importance.

In order to ensure that this crucial work continues to thrive, the Federal Government is providing funding for a wide range of research projects and cooperative work. Incipient ideas are nurtured towards applications in laboratories, and energy innovations are brought towards market maturity and tested in living labs.

It is clear that the Russian war of aggression against Ukraine is meaning that a priority is having to be placed on security of supply in the short term. But in the medium term, greater independence in energy policy and a climate-neutral energy supply are two sides of the same coin. The more Germany can rely on its own renewable energy sources, the more independently we can act to shape our future. Energy research prepares options precisely for this transformation.

In this report, the Federal Government provides an overview of the implementation of the 7th Energy Research Programme in 2021. I wish you an informative read!



Dr Robert Habeck

Federal Minister for Economic Affairs and Climate Action,
for the 2022 Federal Report on Energy Research

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

A climate-friendly, reliable and affordable energy supply can be achieved by means of a rigorous transformation of the energy system. Linking ecology and the economy lays the foundation for economic progress and the prosperity of our society. New and further developed technologies and concepts for a smartly balanced overall system are needed so that processes from generation to consumption can be managed in the most climate-neutral way possible. Green hydrogen (H_2) produced with electricity generated from renewable sources can contribute to this among others. The Federal Government is therefore using its 7th Energy Research Programme to fund technical and non-technical innovations and research for the energy transition along the entire value chain.

Energy research in Germany was affected last year by the great challenges of the COVID-19 pandemic. Nevertheless, it was possible to successfully continue research and development in the energy sector as in 2020 – in many cases thanks to massive efforts on the part of the stakeholders in commerce and science. Thanks to the flexibility of the project funding instrument research funding was able to support this work smoothly and without administrative delays. In view of the resilience of the energy research system, it was generally possible to cope with any pandemic-related issues affecting the research projects. On top of this, researchers receiving institutional funding benefited from a high degree of predictability.

The energy transition is an enormous transformation project. As a logical consequence of this, the number of research projects and the funding envelope for energy research have increased in defiance of the pandemic. Despite all the progress, the pace needs to be increased even further if we are to attain the ambitious climate targets that the Federal Government has set itself. Further to this, the ending of geostrategic dependencies on imports of fossil fuels is an important goal, and energy research is contributing to its attainment. Just as previous innovations form the basis of the current transformation processes, the research and development being done now is paving the way for medium- and long-term successes. The 7th Energy Research Programme, with its system-oriented approach, is a valuable component in the ongoing restructuring of the energy supply.

In terms of climate action, it is important for new technologies to find their way out of the laboratories and into commerce and society. The Federal Government has therefore placed a priority in the 7th Energy Research Programme on the expedited transfer of innovations into the energy sector and society, and has created new formats to support this approach. These include, for example, the Living Labs of 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).

1.1.2 Funding amounts

Through financial support, the Federal Government assists research activities by companies, research establishments, higher education institutions and other organisations with respect to new technologies and applications for the energy transition.

In 2021, the Federal Government invested €1.311 billion in energy research via the 7th Energy Research Programme. This marked an 8% rise in federal funding compared with the preceding year's figure of €1.216 billion. The Federal Government thus continued the positive trend of previous years in 2021: a constant increase in state investment in energy research. In fact, the rise since 2014 amounts to 55%. There has been an appreciable boost to the promotion of research into hydrogen technologies due to the Federal Government's National Hydrogen Strategy. The funding is provided across different fields of research.

€878.24 million went to specific research, development and demonstration projects of strategic significance for the long-term success of the energy transition in Germany. In 2021, the Federal Government provided funding towards 6,995 ongoing research projects (2020: 5,980 projects). 2,016 projects were newly approved (2020: 1,590 projects). A further €314.42 million went towards institutional funding for energy research by the Helmholtz Association of German Research Centres.

The bulk of the research, development and demonstration of energy and efficiency technologies is carried out by companies. They contribute equity totalling €744 million in the field of project funding alone.

1.1.3 Evaluation and review of the results

Evaluations and performance reviews are valuable instruments to verify the efficient and effective use of tax revenues for funding measures. They make it possible to draw conclusions and feed these into the financial, administrative, strategic and substantive design of future measures. Under the Federal Budget Code (section 7), the Federal Government has an obligation to undertake performance reviews of all the measures implemented. Evaluations support performance reviews and are carried out by external third parties.

An ongoing evaluation of the 7th Energy Research Programme was prepared in 2020 relating to the funding for applied energy research in line with the rules on state aid. It began in 2021. It covers the funding measures of the Federal Ministry for Economic Affairs and Climate Action (BMWK) in accordance with the funding announcement for applied non-nuclear research under the 7th Energy Research Programme "Innovations for the Energy Transition". The evaluation analyses the effectiveness of the funding formats in terms of the goals of the 7th Energy Research Programme, and considers the economic viability and the impact of the funding on the various target groups.

Figure 1: Overview of funding in 2021 in the 7th Energy Research Programme (Data cf. Table 1, p. 90)

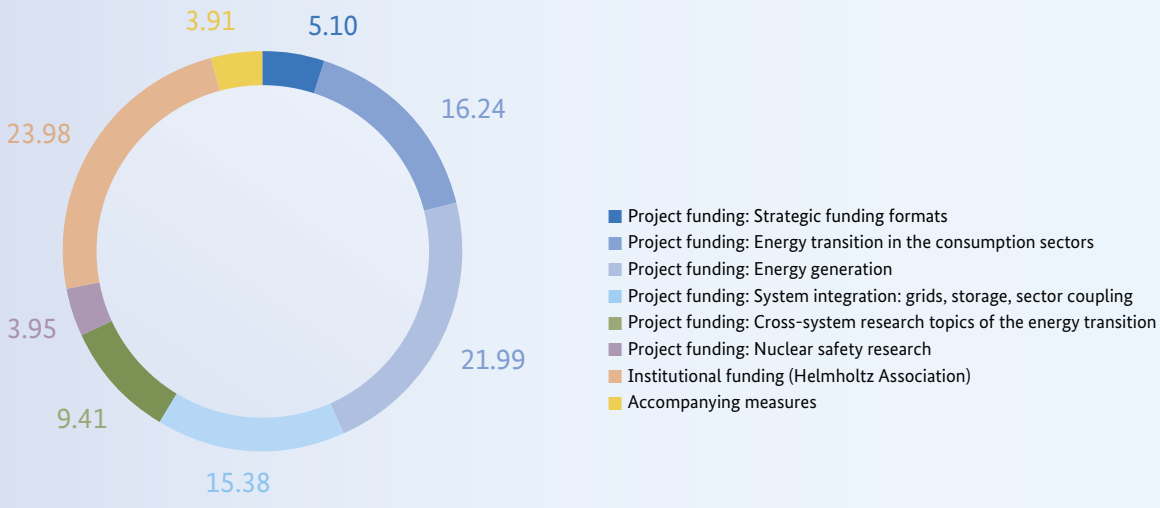
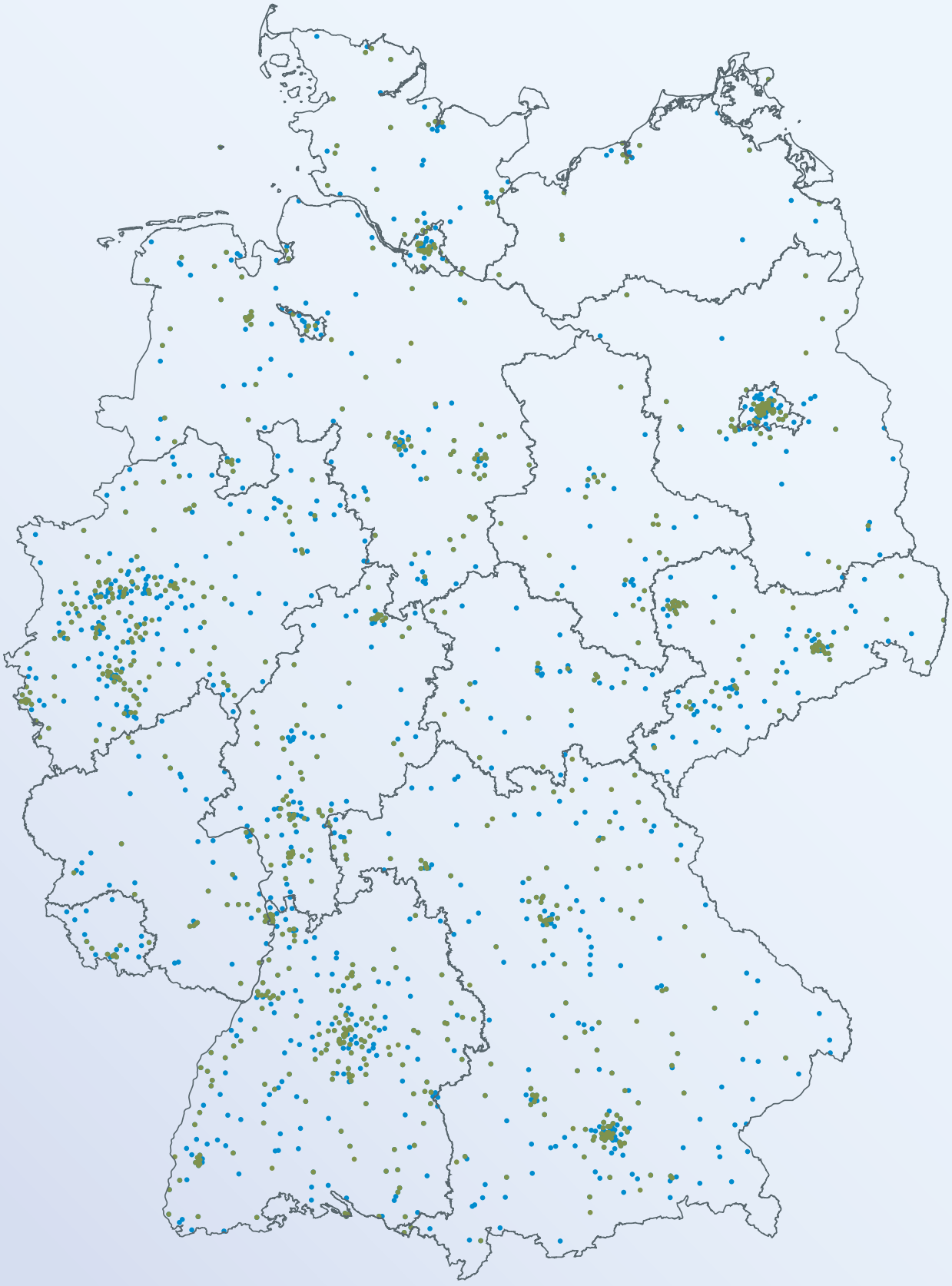


Figure 2: Overview of the ongoing (blue) and newly approved (green) projects of non-nuclear energy research in Germany



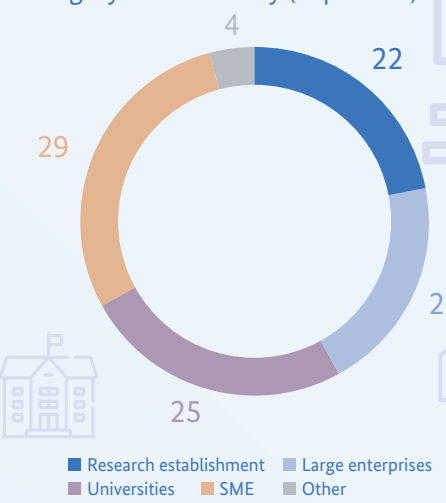
Source: GeoBasis-DE / BKG 2021 (data altered) / Geodata of the BKG for addresses of the implementing bodies from the BMBF profi-database / Projektträger Jülich

Figure 3: Energy research funding at a glance

€1.311 billion

total funding in the 7th Energy Research Programme in 2021 (preceding year: €1.216 billion)

Breakdown of funding by category of beneficiary (in percent)



In 2021, the Federation approved

2,016 new projects

(preceding year: 1,590)

55 percent

rise in funding compared to 2014 and 8 percent rise compared to 2020

The Federal Government funded **6,995** projects in the 7th Energy Research Programme in 2021 (preceding year: 5,980)

€277 million

funding for SMEs for energy research projects newly appropriated in 2021*

€744.4 million

own funding from companies towards newly approved research and development projects in 2021 (non-nuclear energy research)

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 a joint programme of the Federal Ministries for Economic Affairs and Climate Action (BMWK), Education and Research (BMBF), Food and Agriculture (BMEL) and, since the new government took up office in December 2021, also the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). The lead responsibility and the fundamental programmatic orientation of energy research policy rests with the Federal Ministry for Economic Affairs and Climate Action. When designing the funding measures, the Federal Government takes an interministerial, subject-oriented approach and aims to generate synergies from the cooperation.

The Energy Research Programme covers the entire innovation cycle – from basic research to the testing of new or further developed technologies on the brink of a market rollout. The project funding is oriented to the Technology Readiness Level (TRL) system. Here, the technologies are placed on a scale from 1 to 9 in line with the TRL which the project aims to attain.

The Federal Ministry of Education and Research primarily funds application-oriented basic research projects that aim at TRLs 1 to 3 and lay the foundation for future innovations, supporting young scientists, academic exchange and scientific cooperation at EU and international level. The Federal Ministry for Economic Affairs and Climate Action follows on from this by providing funding for applied research and development (TRLs 3 to 7) and for the Living Labs for the Energy Transition, which extend to TRL 9, and also gives backing to multilateral research cooperation. In the field of the use of biomass for energy purposes (cf. Chapter 2 Project funding, p. 17), the Federal Ministry of Food and Agriculture supplements the funding for applied research. Based on the instruction of the Federal Chancellor of 8 December 2021 regarding the structure of portfolios, responsibility for project funding for nuclear safety and disposal research has passed from the Federal Ministry for Economic Affairs and Climate Action to the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection.

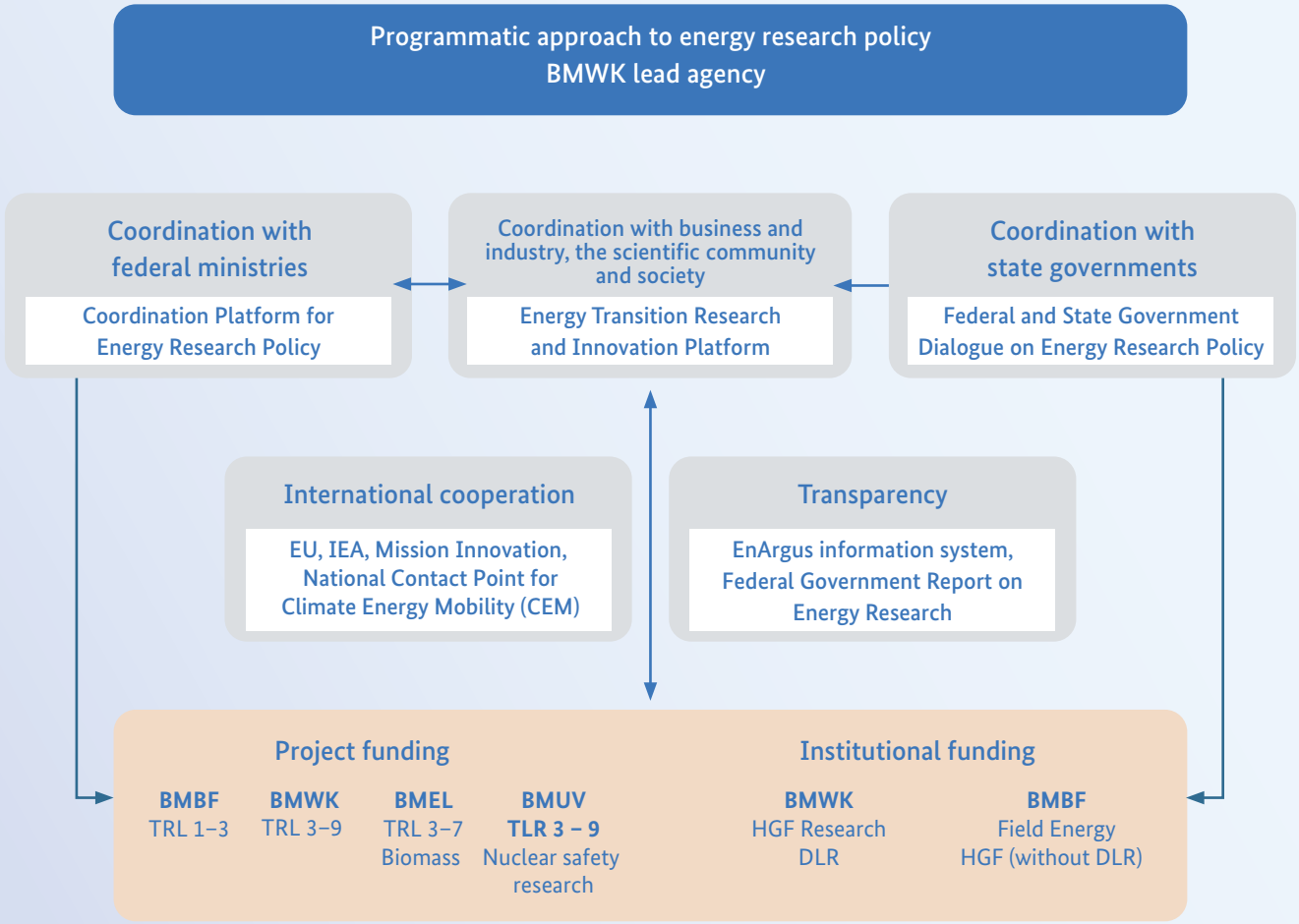
The updated project funding programme entitled "Research funding for nuclear safety" has been in place since the beginning of 2021. It takes account of the latest developments in the national and international context, and addresses the central issues arising for research funding in Germany. One of the main challenges is to develop skills and young experts in the field of nuclear safety (cf. Chapter 2.6 Nuclear safety research, p. 63).

In the area of institutional funding, the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Climate Action are jointly responsible for the strategic orientation of energy research by the Helmholtz Association. Further to this, 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 the institutional funding of the Helmholtz Centres (except for the DLR) (cf. Chapter 3 Institutional energy research, p. 70).

The transformation of the energy supply system in the course of the energy transition is a task for society as a whole, and the combined effect of all measures and instruments is crucial to its success. The Federal Government therefore relies on close cooperation between all the federal ministries directly involved in the Energy Research Programme, as well as the inclusion of all the other ministries and agencies, which have energy-related mandates and responsibilities. Not least of these are the

Federal Ministry for Digital and Transport (BMDV), responsible for mobility and transport, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), responsible for fleet targets, fuels, renewable energy products including sustainable renewable fuels, and the Federal Ministry for Housing, Urban Development and Building (BMWSB), for issues relating to the building sector.

Figure 4: Institutional setup for energy research



The Federal Government looks to the strengths of the multi-level system in order to achieve successful research funding. This means that, in the system of political decision-making structures, the funding and coordination of energy research in Germany takes place both at Länder and federal level, and also in European and international cooperation. This will require close dialogue with all the relevant political institutions. 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. 75).

1.2.2 Networking at national level

Public acceptance of the individual components of the energy transition is crucial for the transformation of the economy and society, as is the interplay of all the stakeholders involved. Dialogue and networking are therefore important elements of energy research. This applies within the scientific community, and for the dialogue with the energy industry, the institutions of society, and policy-makers. Only in this way will it be possible to bring together the many components of energy research for a successful energy transition.

Research and Innovation Platform (R&I Platform)

The Research and Innovation 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 serves to communicate current developments, to facilitate dialogue on new approaches for forward-looking strategies, and to bring together research and practical applications in the energy sector. The R&I platform thus provides an overarching structure for the energy research networks of the Federal Ministry for Economic Affairs and Climate Action, bringing them together and coordinating them. The 2021 annual meeting of the platform took place on 20 April. The virtual meeting focused on the implementation of the Federal Government's National Hydrogen Strategy, the funding strategies for the Living Labsfor the Energy Transition of the Federal Ministry for Economic Affairs and Climate Action and the Kopernikus projects of the Federal Ministry of Education and Research.

As the lead ministry for the energy transition, the Federal Ministry for Economic Affairs and Climate

Action is engaged in a regular exchange on energy research issues with the 16 Länder governments. The tenth Federation-Länder meeting on energy research took place on 22 April 2021.

Energy research networks

The nine energy research networks (www.forschungsnetzwerke-energie.de) are open to all interested parties and represent the broad spectrum of the research community. They cover bioenergy, construction for the energy transition, energy systems analysis, renewable energy, flexible energy conversion, industry and commerce, electricity grids, start-ups, and hydrogen.

The networks support an interdisciplinary dialogue between all the stakeholders. The Federal Ministry for Economic Affairs and Climate Action therefore promotes the platforms as important intermediaries between experts, commercial and societal interfaces. The members organise their work themselves in working groups. One major task is to develop ways to transfer research findings into practice. Further to this, the members provide assessments and recommendations on the strategic further development of energy research and on specific research agendas.

Many activities include 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 addition, together with the foundation "Stiftung Jugend forscht e.V.", a conference was held in March 2021 on careers in the energy sector for former participants in the competitions for young researchers organised by the foundation. In total, the energy research networks held 44 events in 2021.

The hydrogen research network is part of the Federal Government's National Hydrogen Strategy. In 2021, the 1,500-plus active members drafted expert recommendations on the need for research in the establishment of a hydrogen economy, and presented them to the Federal Ministry for Economic Affairs and Climate Action in September 2021. In June 2021, the bioenergy research network published comments on hydrogen made from and with biomass. The research network covering construction for the energy transition set up a working group on geothermal energy in 2021. This means that central areas of research and applications of the energy transition are mapped in active structures.

Academies' "Energy Systems of the Future" project

The Academies' "Energy Systems of the Future" (ESYS) project pools the expertise of the German academies of science. Funded by the Federal Ministry of Education and Research, the initiative by acatech, the German Academy of Sciences Leopoldina and the Union of the Academies provide impulses for the debate on the challenges and opportunities of the German energy transition. In the ESYS project, more than 120 experts are developing options for action to implement a secure, affordable and sustainable energy supply. This led to the drafting of proposals and comments in 2021 for a debate on the climate-friendly expansion of photovoltaics and wind energy and on the resilience of digitalised energy systems.

1.2.3 Research for the innovative leaps of tomorrow

The energy transition is a long-term task. Basic research is therefore just as important as supporting the transfer of innovation, market preparation and the application of technologies with a high level of maturity. Basic research lays the foundation for the innovations of tomorrow and beyond. The funding by the Federal Ministry of Education and Research is therefore consistently oriented to linking basic research with the challenges of industry, thereby accelerating the process from research idea to marketable innovation. The Kopernikus projects

on the energy transition are good examples of this. The projects are long-term, lasting up to ten years. Across three funding phases, innovations are prepared in key areas of the energy transition, from theory and conceptual design to validation and large-scale demonstration.

A further example of this approach is the project entitled "Hydrogen and beyond – Thin-film catalysts for sustainable chemistry with renewable electricity" (CatLab). This entails the establishment of a unique research platform, which unites catalyst research and thin-film technologies with measuring methods during operation (operando analysis). The aim is to develop novel thin-film catalysts for the production and transport of hydrogen-based chemical energy carriers. The project builds a bridge between basic research and industry – companies in the chemical industry are on board from the outset.

1.2.4 From research to practical use

The core objective of research funding is to support scientists in the development, research and testing of innovative technologies and applications in areas in which market forces alone are insufficient. This takes place by means of broad funding along the entire value chain of the energy system and along all the developmental stages. The intention is to create a wide range of solutions for the challenges of the energy transition so that the climate targets can be attained efficiently.

One criterion for success here is that innovations to transform the energy system can quickly emerge from the research laboratories and test stations and enter the market. The Federal Government's 7th Energy Research Programme is therefore consistently oriented to rapidly putting research findings into practice in the energy industry and to turning them into marketable applications. In this way, research funding in the energy sector makes an important contribution towards modernising the energy supply, to strengthening the German and European economy, and to safeguarding industry, jobs and value creation. At the same time, Germany is thus supporting international climate action, not least via the export of technologies and solutions developed here with the help of tax-payers' money.

1.2.5 Transparency and communications

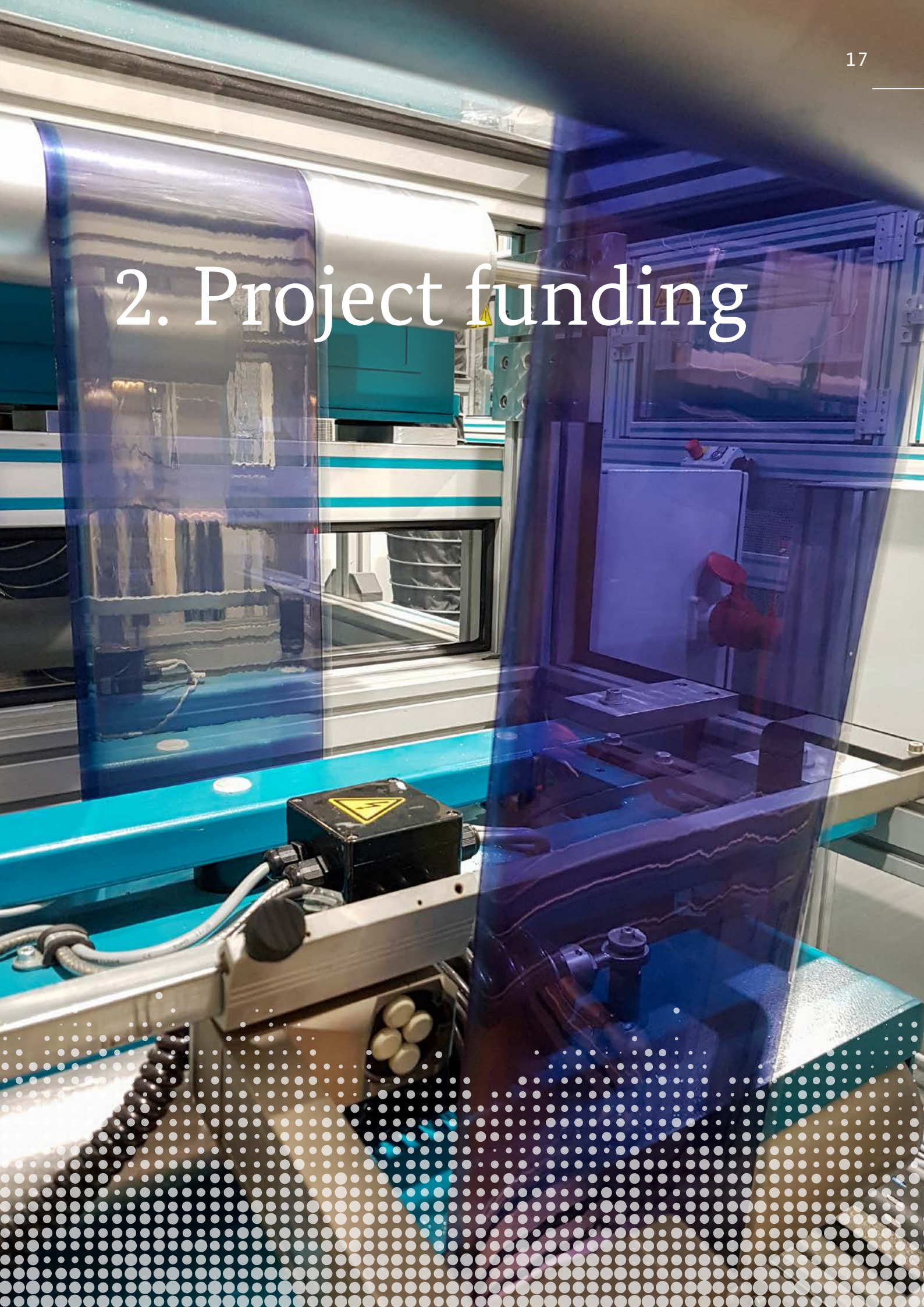
Transparent communication of energy research policy to all groups, and particularly the general public, is an important element of the 7th Energy Research Programme. This is because we need to work together if we are to feed the innovations from the research community into the energy system.

For this reason, the Federal Government provides information via a host of channels to the business and science communities, as well as to the public, about current progress, developmental trends, open research questions and successes and challenges on the road to a climate-friendly restructuring of the energy infrastructure.

The Federal Ministry for Economic Affairs and Climate Action's central website on energy research (www.energieforschung.de) offers comprehensive information about the goals, structures and core issues of energy research policy and current funding. Four specialised portals on specific issues of energy research deliver an in-depth insight into project funding and research projects. The portals host content on the research priorities of energy-optimised buildings and neighbourhoods, electricity generation, energy transition in industry, and energy systems.

EnArgus (www.enargus.de), the central information system for energy research funding, provides an overview of energy research projects funded by the Federation. The figures for project funding cited in the Federal Report on Energy Research are set out in a transparent manner on EnArgus. Also, the website provides information about technologies and specialist energy technology vocabulary.

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 by the Federal Ministry for Economic Affairs and Climate Action in the 7th Energy Research Programme. Targeted support is given to projects which systematically trial 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 regulatory sandboxes contribute to the success of the energy transition by paving the way for new technologies and new value creation.

A total of ten Living Labs have now been launched, six of them in 2021. The 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 "sector coupling and hydrogen technologies":

- H_2-Wyhlen
- Northern Germany Regulatory Sandbox
- Bad Lauchstädt Energy Park
- H_2Stahl
- WESTKÜSTE100

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

- Large heat pumps in district heating networks
- Darmstadt Energy Laboratory for Technologies in Application (DELTA)
- Wilhelmsburg Integrated Heat Transition IW3
- TransUrbanNRW
- SmartQuart – smart energy neighbourhoods

The project Trans4Real won the competition for ideas to explore the transfer of science for the hydrogen Living Labs. The consortium headed by the Forschungsstelle für Energiewirtschaft (FfE) in Munich started work in April 2021. The experts will undertake an overarching synthesis of results, network the Living Labs with one another, and derive learning experiences and options for action. The scientific 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.

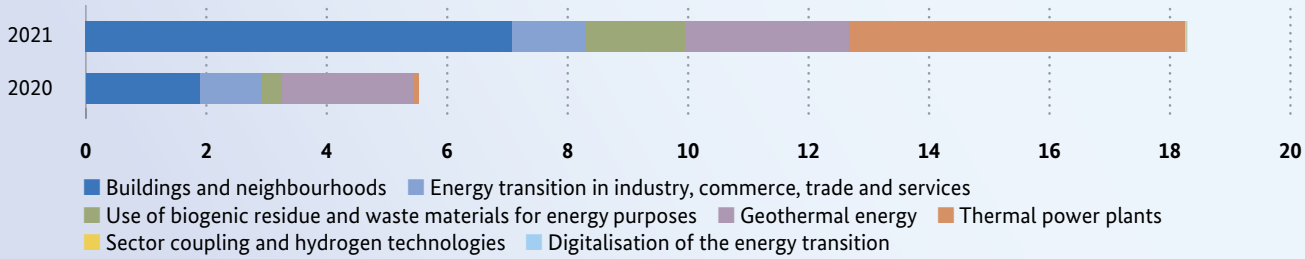
The Living Labs for the energy-optimised neighbourhoods will be supported by the accompanying "energy transition construction" research and will benefit in particular from Module III "Neighbourhood" of the accompanying research, headed by the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT.

The Federal Ministry for Economic Affairs and Climate Action has used the experience gained in the first implementation phase to develop the funding format for the Living Labs for the Energy Transition, consolidating them as a key pillar of energy research. The new funding concept was published in July 2021. Taking a subject-neutral approach, it addresses all fields of applied energy research in the 7th Energy Research Programme. The core aim of the systematically designed projects has to consist of progress on the energy transition and a contribution to climate neutrality. Moreover, the Living Labs for the Energy Transition must be able to demonstrate direct reductions in greenhouse gas emissions. In the concept, the Federal Ministry for Economic Affairs and Climate Action emphasises the high practicality of the funding format. The Federal Ministry for Economic Affairs and Climate Action plans to give appropriate support to future Living Labs for the Energy Transition by providing up to €15 million per partner, and €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 €18.29 million in funding for 147 ongoing projects in 2021. Also, the ministry appropriated approximately €216.23 million in funding for 87 new research projects in this period (cf. figure 5).

Figure 5: Funding for Living Labs of the Energy Transition in € million
(Data cf. Table 2, p. 90)



PROJECT ABSTRACT

Northern Germany Living Lab –
Energy Transition Alliance for Innovations and Effective Climate Action

The project partners are working on new approaches to climate neutrality. In this way, they aim to provide an economic stimulus to industry in northern Germany. The aim of the collaborative project is to trial how carbon emissions in the region can be cut by 75% by 2035. The work planned in the project period aims to save 350,000 to 500,000 tonnes of CO_2 per year. To this end, areas of production and life with high energy consumption levels are to be decarbonised – particularly in industry, but also in the heat supply and the mobility sector. Eight electrolysers with 42 megawatts of hydrogen generation capacity will contribute towards this. They are to foster a shift in industrial processes away from fossil energy sources across to hydrogen and its derivatives. Also, three projects which enable 700 gigawatt-hours of waste heat to be used per year are to be implemented. In the mobility sector, several hydrogen fuelling stations and more than 200 vehicles are to be tested in various use scenarios. The large-scale approach enables the project to serve as a supra-regional pilot for hydrogen-based sector coupling in Germany and Europe.

Hydrogen is to be used as a sustainable fuel for vehicles in the model region of the North German Living Lab.

Beneficiaries: Hamburg University of Applied Sciences and 17 other partners
Funding ID: 03EWR007A-V
Appropriated funding: €52.3 million
Project duration: 2021 – 2026
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

DELTA – *Darmstadt Energy Laboratory for Technologies in Application*

The DELTA Living Lab for the Energy Transition aims to show how a typical medium-sized town can be supplied reliably and cheaply with energy en route to climate neutrality. It uses greater efficiency, locally available energy resources, and networked energy flows. The experts are studying the internal efficiency of individual residential and industrial neighbourhoods and their energy-related interactions, including with the municipal infrastructure such as the tram system's direct current grid. Central components include the use of industrial waste heat and the electrolysis of hydrogen in a residential area. Also, residential buildings are being studied in terms not only of their useful life, but also of the carbon footprint of construction, upgrading and dismantling. The linking of urban energy sources and sinks into grids and storage facilities for heat, electricity, gas and hydrogen in the context of sector coupling can conserve conventional energy sources. This approach aims to reduce energy needs, displace fossil energy sources, and save at least 14,000 tonnes of CO_2 each year on a permanent basis. The people in Darmstadt are also playing their part in the transition to climate neutrality. They are benefiting from new possibilities for shared use of goods whose production is energy-intensive (e.g. eScooters) and environmentally friendly public and individual mobility.

DELTA is trialling the urban energy transition with interactive energy-optimised neighbourhoods.

Beneficiaries: Technical University of Darmstadt and 11 other partners
Funding ID: 03EWR002A-P
Appropriated funding: €40.1 million
Project description on EnArgus:

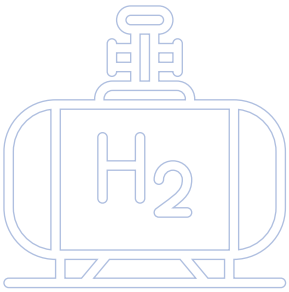
MORE DETAILS

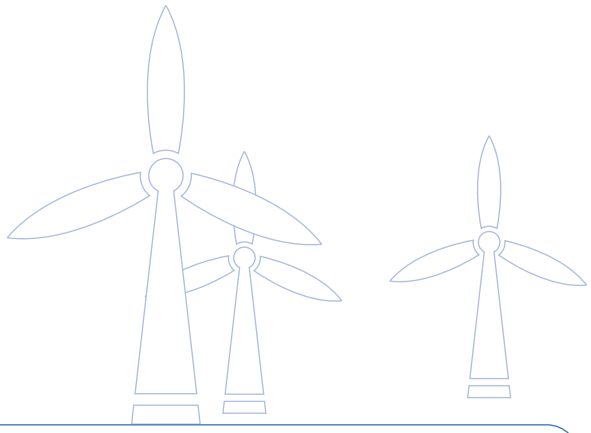
2.1.2 Hydrogen flagship projects – Technologies for industrial-scale hydrogen solutions

The hydrogen flagship projects of the Federal Ministry of Education and Research were launched in spring 2021. The hydrogen flagship projects form one of the ministry's largest research initiatives for the energy transition. They are an outcome of the "Hydrogen Republic of Germany" competition for ideas. The industry-led flagship projects involve more than 200 partners from science and commerce, and are doing practical research into three central fields of hydrogen innovation. H_2Giga is devoted to the series manufacturing and upscaling of electrolysers; H_2Mare is researching offshore hydrogen generation; and TransHyDE is working on ways to transport hydrogen.

Project funding

In the focal field of hydrogen flagship projects, the Federal Ministry of Education and Research provided approximately €48.64 million in funding for 326 ongoing projects in 2021. Also, the ministry appropriated approximately €688.48 million in funding for 328 new research projects in this period (cf. figure 6).





PROJECT ABSTRACT

H_2Mare – *Offshore production of green hydrogen*

H_2Mare studies how green hydrogen can be produced at sea without a grid connection and using offshore installations. Also, it is testing the offshore production of hydrogen derivatives via power-to-X processes. The production of green hydrogen at sea without any connection to the local electricity grid benefits from the fact that offshore wind turbines generate more electricity and do so on a more constant basis than onshore turbines. Moreover, the direct coupling of wind turbine and electrolyser can cut the hydrogen production costs and reduce the burden on the local electricity grid.

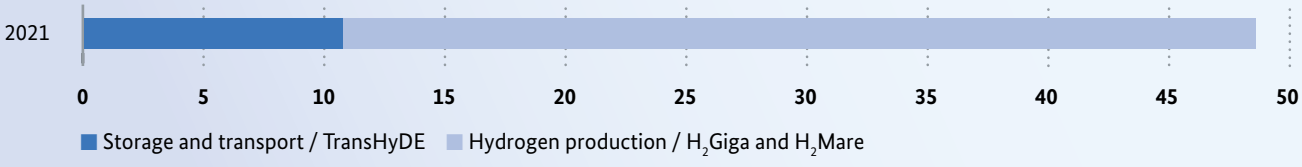
In addition to offshore hydrogen production, H_2Mare also aims to study the offshore production of the power-to-X products methane, methanol, ammonia and synthetic fuels (eFuels). To this end, H_2Mare is also conducting research into sea water electrolysis, high-temperature electrolysis and the extraction of CO_2 and nitrogen from the atmosphere and the sea. Further to this, answers to questions about safety and potential environmental impacts are to be drawn up, along with life cycle analyses and technology assessments.

The partners in the H_2Mare flagship project want to produce hydrogen on the high seas.

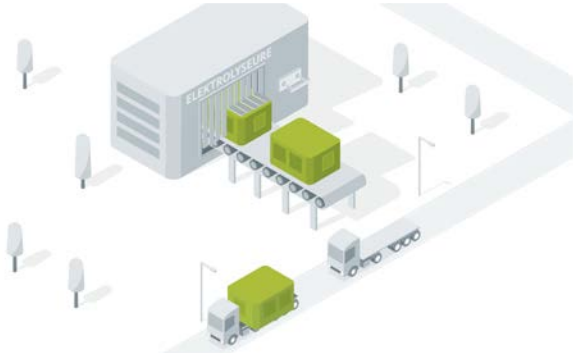
Beneficiaries: 32 partners in four groups with 45 projects
Funding ID: 03HY300A-03HY303P
Appropriated funding: €104.5 million
Project duration: 2021 – 2025
Project description on EnArgus:

MORE DETAILS

Figure 6: Funding for hydrogen flagship projects in € million
(Data cf. Table 2, p. 90)



PROJECT ABSTRACT



The H_2Giga flagship project wants to enable serial manufacturing of electrolysers for hydrogen production.

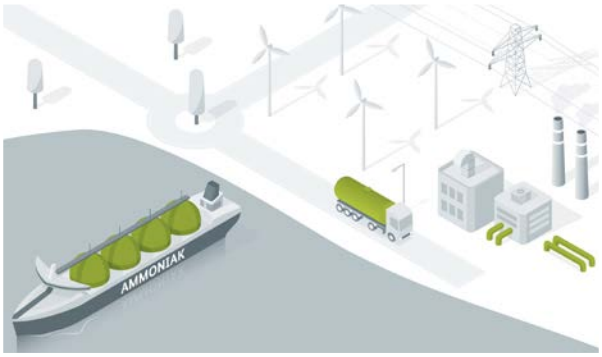
H_2Giga – *Serial manufacture and scaling up of electrolysers*

H_2Giga aims to provide technologies for the serial production of electrolysers. This is because large capacities of efficient, robust and cheap electrolysers are needed to meet Germany's need for green hydrogen. High-performance electrolysers are already on the market – but most of the manufacturing process is by hand. This is time-consuming and expensive.
In response, established electrolyser manufacturers, component suppliers and research establishments are working in the H_2Giga projects to prepare three existing electrolysis technologies for the conveyor belt and upscaling: PEM electrolysis (PEM = Proton Exchange Membrane), alkaline electrolysis (AEL) and high-temperature electrolysis (HTEL). Research is also to take place into developing highly efficient anion exchange membrane (AEM) electrolysis without the use of noble metals.

Beneficiaries: so far 115 partners in 27 groups, with 178 projects
Funding ID: 03HY101A-03HY127B
Appropriated funding: Committed so far: €449.2 million, further projects still at initial stage.
Up to €500 million in total is available.
Project duration: 2021 – 2025
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT



The TransHyDE flagship project wants to develop hydrogen transport infrastructure.

TransHyDE – *Development of transport technol ogies for green hydrogen*

TransHyDE assesses and tests hydrogen transport solutions: the hydrogen economy will not work without the necessary transport infrastructure. At present, however, there is a lack of clarity about which solution is best suited to which case, and on what scale it should be deployed. For this reason, the flagship project is progressing various transport possibilities in a technology-neutral way: transport in high-pressure vessels, liquefied transport, transport in existing and new gas pipelines, and the transport of hydrogen in ammonia or liquid organic hydrogen carriers (LOHCs).
The flagship project is launching its own roadmap process so that all of these technologies can become part of the overall energy system as soon as possible. TransHyDE is also working on potential standards and safety characteristics of hydrogen transport technologies (materials and sensors), as well as a systemic framework for a future hydrogen infrastructure.

Beneficiaries: 84 partners in ten groups and 105 projects
Funding ID: 03HY200A-03HY209Z
Appropriated funding: €134.8 million
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

Buildings account for roughly 35% of final energy consumption in Germany. Two thirds of this is consumed in residential buildings, and one third in non-residential buildings; the bulk of the energy is used for heating rooms. This shows that the decarbonisation of the building sector is crucial for the attainment of the climate targets. The revision of the Federal Climate Change Act in 2021 lowered the target value for admissible residual emissions from the building sector in 2030, and it now stands at 67 million tonnes of CO_2 equivalents. The Federal Government is aiming to substantially boost the proportion of heat generated from renewable sources. This can only be achieved in the buildings and neighbourhood sector if the retrofitting rate is stepped up significantly and the supply of heat and cold is decarbonised.

Funding priorities and scientific advances

The guiding principle for the funding is energy-optimised and climate-neutral buildings and neighbourhoods of the future. This refers both to the production and operation, and to the modernisation and dismantling of buildings. In addition to digital concepts, an important role is also played by innovative materials, e.g. from regenerative raw materials. Researchers are working on modernisation concepts in which the building stock is surveyed digitally, optimised in terms of energy, and via prefabrication is improved with little effort on-site.

A renewable, grid-based, decentralised supply of heat and cold, as well as storage facilities in buildings and neighbourhoods, form another research priority. In the restructuring and expansion of the supply networks, the teams of scientists are developing smart digital solutions to boost the share of renewable energy. In order to be able to provide local and district heating in an energy-efficient way, they are developing solutions for smart energy management with modern pipeline systems.

DELTA (cf. project description, p. 20) and GWP are two more Living Labs for the energy transition in the field of buildings and neighbourhoods. The aim of GWP is to deploy large-scale heat pumps to make use of waste heat, natural heat sources and renewable energy in district heating systems.

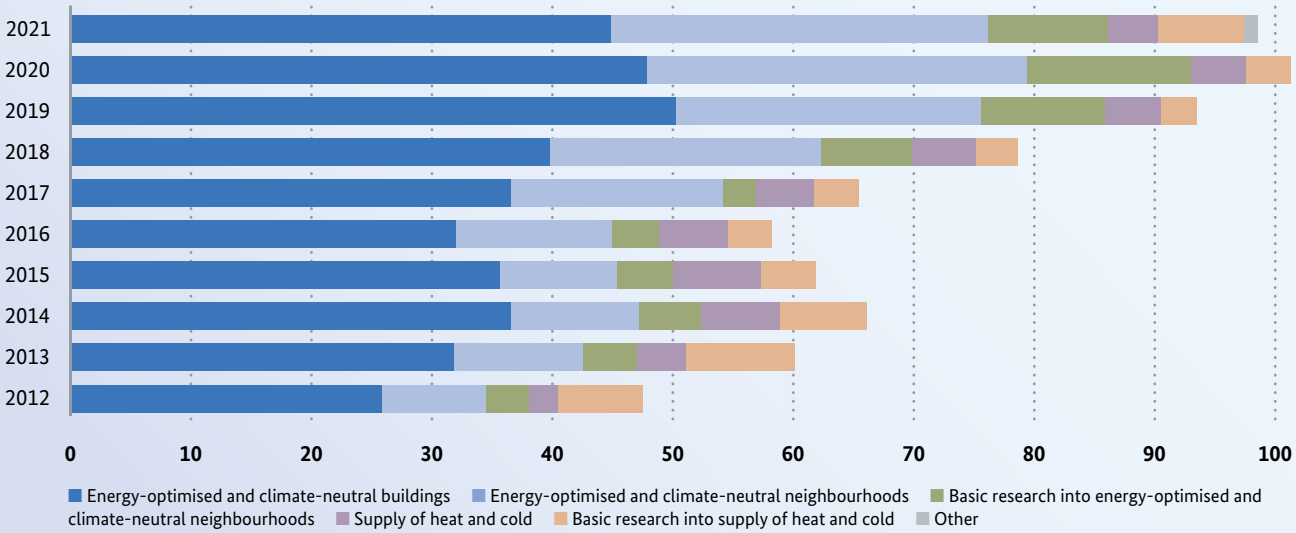
The Federal Ministry of Education and Research is funding cities and municipalities doing research into innovative energy systems en route to sustainable development. The collaborative project entitled “Wärmewende Nordwest” (heat transition north-west) aims to research the practicalities of various facets of the digitalisation of the transition in the heating sector in buildings and neighbourhoods in the region around Oldenburg and Bremen and to demonstrate their interactions. The project is also developing a digital heat transition platform and providing training for specialists (cf. project description, p. 25).

Working together, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research are promoting several flagship projects in urban areas under the initiative entitled “Solar Construction – Energy-efficient Cities”. This includes concepts for the introduction of a climate-neutral energy supply for the transformation of existing neighbourhoods, and projects focusing on the use of locally manufactured green hydrogen as a local energy storage solution. Aspects of sustainable mobility in the urban area are also covered by the funding of the Research Ministry. For example, a project for the practical implementation of a tool to control urban logistics was launched in 2021.

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 €98.57 million in funding for 1,043 ongoing projects in 2020. In addition, the ministries appropriated approximately €117.27 million in funding for 235 new research projects in 2020 (cf. figure 7).

Figure 7: Funding for energy in buildings and neighbourhoods in € million
(Data cf. Table 3, p. 91)



PROJECT ABSTRACT

DZWi – *Digital twin of heat production systems to pave the way for the development of low-emission energy technology for buildings*

The project aims to cut the time taken to develop energy technology equipment for buildings and to optimise its operation in practice. To this end, the researchers are initially developing digital twins of various energy conversion systems. In the project, these are heat pumps and fuel cells. All the key components of the equipment are presented in a real-time simulation. This gives the researchers a nearly exact description of the static and dynamic behaviour of the equipment. The numerical results are compared online with field data and analysed. An open source platform is to be created which other users can freely access and add further products and their digital twins. In this way, building energy technology can be monitored and optimised over its entire product lifecycle. The equipment operator is automatically informed online about equipment errors, can remedy these, and can keep optimising the equipment. An interface with the energy supplier is also possible. This enables the suppliers to plan further ahead and thus, for example, to improve the load on the low-voltage grid.

Digital twins enable monitoring and optimising energy technology equipment for buildings throughout the product lifecycle.

Beneficiaries: Dresden Technical University and three other partners
Funding ID: 03EN1022A-D
Appropriated funding: €1.7 million
Project duration: 2020 – 2023
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

Heat transition north-west – *Digitalisation to implement the heat transition and multi-value applications for buildings, campuses, neighbourhoods and municipalities in the north-west*

The heat transition is a central pillar of the energy transition. As we work to reduce the consumption of energy for heat, digitalisation plays an important role alongside the modernisation of buildings. The heat transition north-west project is studying how the heat transition can be digitalised in the region around Oldenburg and Bremen. Smart meter infrastructure is to register and optimise the heat requirements of buildings, neighbourhoods, commerce and industry. Smart electricity, water and gas meters are linked to a communications network. The construction physics experimental campus shows how buildings can be fully digitalised. A second experimental campus is researching sector coupling using innovative equipment to generate heat and cold. Heat transition north-west is also working on transformation strategies for urban district and local heating supply systems, taking the city of Bremen as an example, and on a concept for climate-friendly heat supply in municipalities. The project integrates the fields of research in a digital heat transition platform and provides training for specialists. This is the first project to embrace the entire heat transition. The findings are to be transferred to other regions and technologies.

The Northwest Heat Transition project wants to digitalise the heat transition in the region around Oldenburg and Bremen.

Beneficiaries: OFFIS e.V. – Institute for Information Technology and 20 other partners
Funding ID: 03SF0624A-U
Appropriated funding: €16.3 million
Project duration: 2020 – 2025
Project description on EnArgus:

MORE DETAILS

2.2.2 Energy efficiency in industry, commerce, trade and services

Germany's economy is driven by its private sector. Energy is consumed not only by traditional large-scale industrial operations – such as steel production or chemicals – but also in numerous small and medium-sized enterprises across the whole economy. In figures: around a third of Germany's final energy consumption takes place in industry, and it dropped by around 2% in year-on-year terms in 2020. Commerce, services and trade account for roughly 15% of final energy consumption. The aim of the research funding is to support the transformation to climate-neutral production without jeopardising economic performance.

Funding priorities and scientific advances

The industrial sector continues to depend heavily on fossil fuels. Energy research is therefore endeavouring to convert processes to alternative energy sources, and particularly to renewable ones. As a consequence, more and more facilities are being electrified, and this is making electricity the second leading source of energy. However, it is crucial to cut energy consumption by making use of further potential for efficiency. A central issue for research promotion is the continued use of industrial waste heat to supply other processes and to heat residential or business premises; the development of low-cost technologies to store and transport the heat can make this an attractive commercial proposition.

The issue of hydrogen is also playing an increasingly prominent role in industry: several research projects on this were launched in 2021. These include OptiLBO and BrEEGa under the umbrella of the Hydrogen Technology Campaign (cf. Chapter 2.4.3 Sector coupling and hydrogen, p. 48) and the H_2Stahl Living Lab for the Energy Transition.

In industry, commerce, trade and services, researchers are not just optimising and developing individual pieces of equipment or components of machines, but are embracing entire value chains. This approach avoids displacement effects and ensures that energy is saved and carbon dioxide emissions are reduced throughout the system.

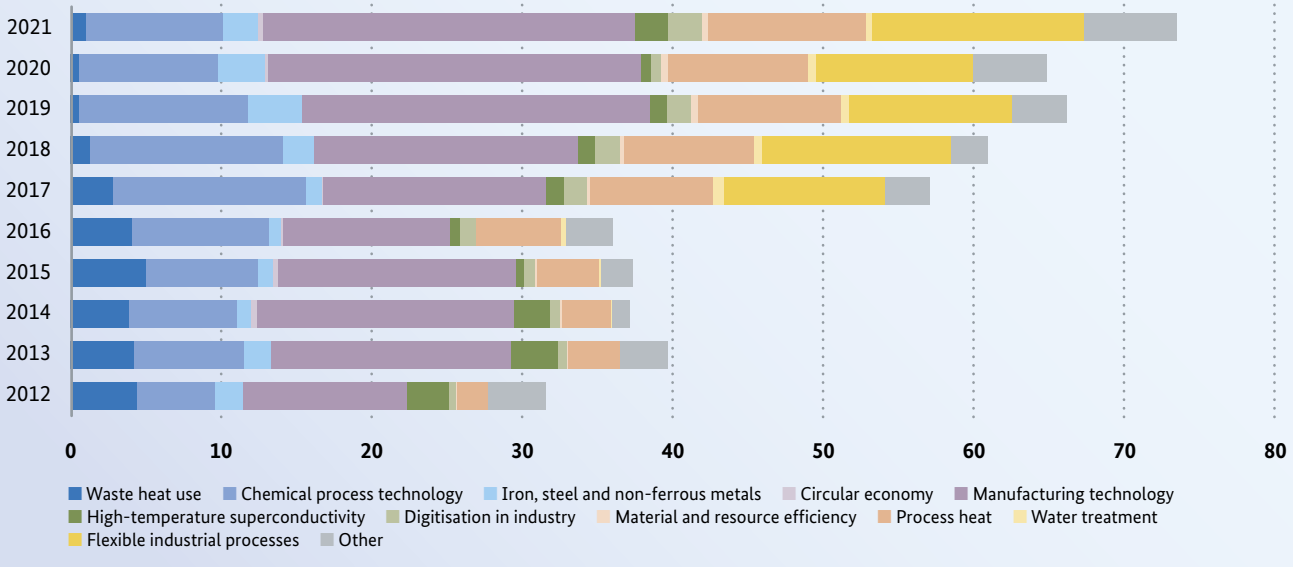
The research topics in the field of industry include waste heat and industrial heat storage units, chemical process technology, the CO_2 circular economy, iron and steel, manufacturing technology, high-temperature superconductivity, artificial intelligence and sensor technology, material and resource efficiency, tribology (friction, lubrication, wear-and-tear), heating and cooling technologies, and water technologies.

The SynErgie Kopernikus project for the energy transition funded by the Federal Ministry of Education and Research focuses on the future problem of feeding in rising amounts of intermittent renewable energy. In particular, the project is to put energy-intensive industry (paper, glass, metal and others) in a position to adapt energy demand to the available supply. To this end, various tools have been developed to identify, characterise and evaluate energy flexibility mechanisms. The energy-flexible model region of Augsburg is to trial the flexibilisation of energy demand in an interplay.

Project funding

In the field of industry, commerce, trade and services, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €73.49 million in funding for 720 ongoing projects in 2021. In this period, the ministries also appropriated approximately €93.68 million to fund 184 new research projects (cf. figure 8).

Figure 8: Funding for energy efficiency in industry, commerce, trade and services in € million
(Data cf. Table 3, p. 91)

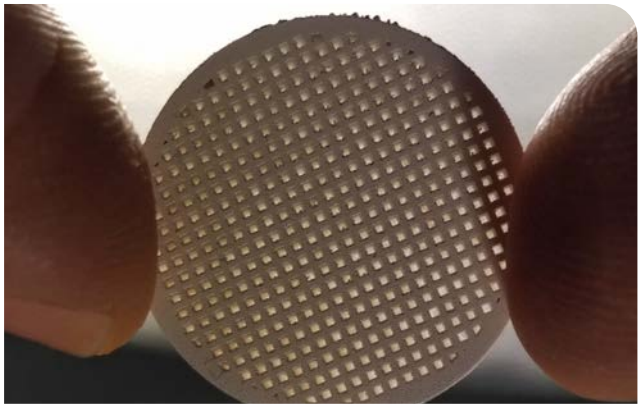


PROJECT ABSTRACT

AMAZING – *Additive Manufacturing for Zero-emission Innovative Green Chemistry*

Ethylene and propylene are basic materials for various plastics. They are produced from benzine, naphtha or gases like ethane via steam cracking. The needed temperatures of up to 850 Celsius are produced by fossil energy sources in a tube furnace. This means that the manufacture of the basic material is particularly energy-intensive and entails very high carbon emissions.

In the German-Dutch research project AMAZING, researchers wantish to make the process more efficient and, in a second step, simultaneously produce hydrogen. The focus is on a reactor for which ceramic membranes will be made by additive manufacturing. The catalytic function of the membranes cuts the necessary reaction temperature in the process. This makes it possible to use electricity – especially from renewable energy – to heat the reactor. In theory, in this way around 5.2 Terawatts of energy and almost four million tonnes of CO_2 can be saved at Germany's steam crackers. Furthermore, the new type of membrane can separate the hydrogen which arises as a side-product in cracking and thus enable it to be used. In this way, AMAZING is combining two processes, which open up great potential for efficiency, also in other parts of industry.



Magnesium oxide membrane carrier produced by 3D screen printing

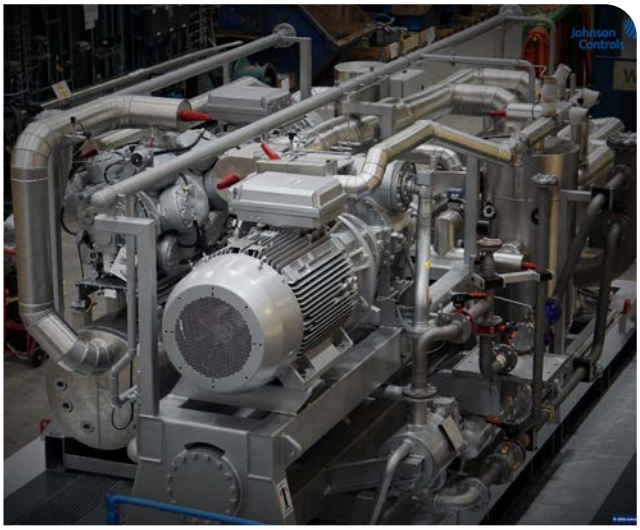
Beneficiaries: Forschungszentrum Jülich GmbH – Institute of Energy and Climate Research (IEK) – Materials Synthesis and Processing (IEK-1) and two other partners
Funding ID: 03EN2052A-C
Appropriated funding: €1.2 million
Project duration: 2020 – 2024
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

FernWP – *Supply of district heating and process heat from heat pumps as a substitute for coal combustion*

The phase-out of the use of coal to generate electricity affects all sorts of sectors, including the supply of district heating. This is because coal-fired power plants not only generate electricity, but also make a major contribution towards the supply of district heating – around 40 Terawatt-hours each year. Going forward, large-scale heat pumps are considered to be a lower-emission and more efficient solution. Heat pumps are already in widespread use in single-family and two-family houses, but district heating imposes far higher requirements on output and the temperature level of the equipment. This is the focus of the FernWP project: its team is developing an optimised heat pump and is studying how alternative sources of heat at power plant sites and the existing infrastructure can be involved. In order to be able to supply industrial process heat in future as well, the project partners are also adapting the technology for even higher temperatures. A dialogue platform for planners and investors created by the research project is to provide information about the technology and the policy environment.



The project partners are developing large heat pumps for district heating which not only attain particularly high temperatures, but also use available low-temperature sources at power station sites.

Beneficiaries: Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems IEG and Fraunhofer Institute for Solar Energy Systems ISE with four partners
Funding ID: 03EN4015A-E
Appropriated funding: €4.5 million
Project duration: 2021 – 2025
Project description on EnArgus:

MORE DETAILS

2.2.3 Interfaces between energy research and mobility and transport

In 2021, the proportion of energy covered by renewable sources in the transport sector rose from 5.6% (2019) to 7.5%. The reasons were a higher share of biofuel and growing numbers of vehicles with electric drivetrains. Further innovative solutions in passenger and freight transport are necessary in order to intensify the decarbonisation of the transport sector, on long and short routes, on road, rail, water and in the air.

Funding priorities and scientific advances

In a decarbonised energy system (in line with the national and European climate targets), the direct use of renewable electricity in electrical vehicle powertrains is generally the most energy efficient and economic option by far. Thanks to its efficiency, electric mobility can transfer the success in decarbonising the electricity sector to the world of transport. For this reason, the Federal Ministry for Economic Affairs and Climate Action is providing funding under the 7th Energy Research Programme towards work on sustainable battery-powered electric mobility along the value chain from the raw materials to production and use, and on to the

follow-up use and recycling of batteries. To this end, teams of researchers are developing low-cost rechargeable batteries with a high energy density and long lifetime. Charging points that can serve the grid are frequently elements of cross-sectoral projects. Electric mobility is also possible on the basis of hydrogen-based fuel cell propulsion. The disadvantage of the lower efficiency compared with batteries due to conversion losses can be partly offset by other aspects like the fact that hydrogen is easier to store. In stationary usage, fuel cells produce electricity and heat efficiently, and if the hydrogen is green, the production is climate-neutral. Other major research topics in both fields are environmental compatibility, resilient value chains, more flexible production processes, and recyclability.

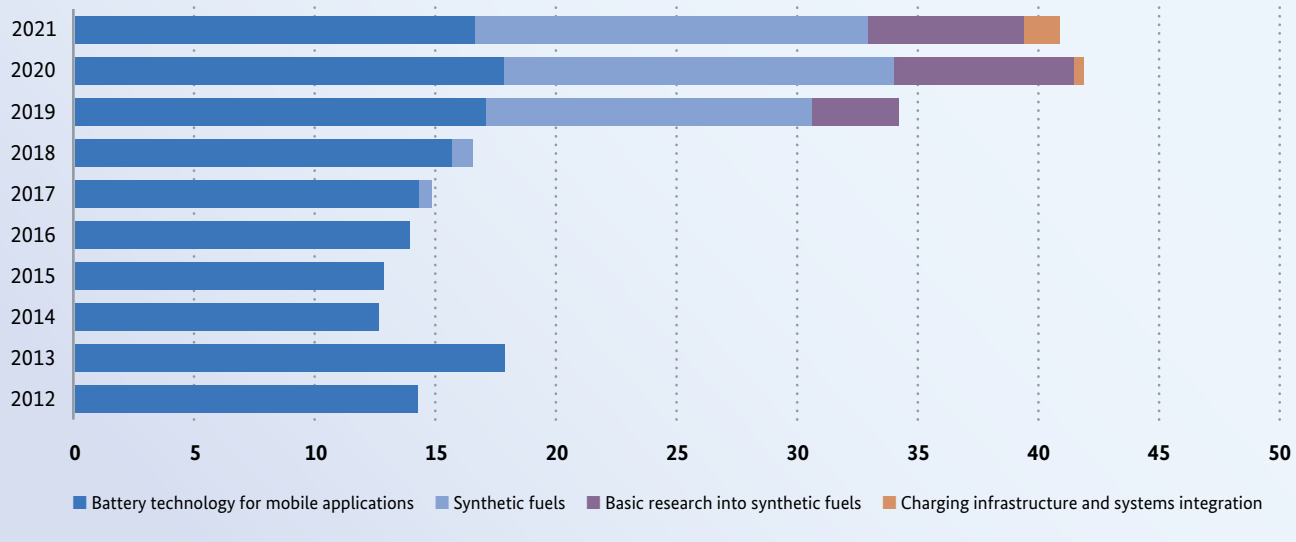
Hydrogen is regarded as a bridge-builder for the transport transition, since it permits sector coupling between the electricity sector and transport. Green hydrogen can be produced both from water via electrolysis using renewable electricity, and from biomass via thermochemical processes. In further steps, the hydrogen can be used to produce liquid or gaseous fuels. The Ministry's approach of providing systemic and also market-oriented funding is not only helping to develop solutions to make the transport sector more energy-efficient, climate and environmentally compatible, but is also helping to harness new, regenerative energy sources, thereby reducing dependence on fossil fuels.

The Federal Ministry for Economic Affairs and Climate Action is funding synthetic, electricity-based fuels via the "Energy transition in the transport sector" initiative, along with the accompanying BEniVer research, which is producing a roadmap with further options for the sector. The Federal Ministry of Education and Research is also funding these fuels, via the NAMOSYN measure. Thanks to cooperation with BEniVer, the NAMOSYN findings also feed into the roadmap.

Project funding

In the field of 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 €40.85 million in funding for 326 ongoing projects in 2021. In 2021, the ministries also appropriated approximately €27.76 million to fund 51 new research projects (cf. figure 9).

Figure 9: Funding for energy research into mobility and transport in € million
(Data cf. Table 3, p. 91)



PROJECT ABSTRACT

The GO3 team has developed a low-cost and lower-cobalt generation of lithium-ion cells for mild hybrid vehicles.

GO3 – *High-energy lithium batteries for automotive applications*

The 48-volt hybridisation of vehicles cuts fuel consumption by up to 15%. However, it also imposes particular demands on the batteries used in the 48-volt system: much more frequent charging and depletion en route, little space in the vehicle, and no external charging. In the GO3 research project, Bosch and CATL specified and developed a new low-cost and lower-cobalt generation of lithium-ion cells, which are designed precisely for this usage. Initially, the research teams worked on materials with high stability and storage capability, and also on a long-life and reliable battery system which continues to offer full capacity even at higher operating temperatures. The results of the project showed that the cells and the battery system are suited to use in mild-hybrid vehicles. Series production commenced in China in 2019, and since the end of 2021 the second generation of 48-volt batteries has been produced in the Bosch facility in Eisenach. Bosch expects that in 2025 nearly one in three new vehicles in Europe will be 48-volt hybrid.

Beneficiaries: Robert Bosch GmbH and three other partners
Funding ID: 03ETE002A-D
Appropriated funding: €10.3 million
Project duration: 2017 – 2021
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

SOFC Units – *Solid oxide fuel cell systems for stationary applications*

Solid oxide fuel cells (SOFCs) are quiet and highly efficient energy converters for electricity and heat and can serve as small, distributed power stations in urban areas, industry and commerce, to supply electricity to computer centres, or to boost the electric charging infrastructure. Also, they are "hydrogen ready" – they can be operated flexibly on the basis of hydrogen, biogas or natural gas. Their electrical efficiency is higher than 60%; when used also to generate heat, their overall efficiency exceeds 85%. In the context of prototype manufacturing, Bosch has been able to trial innovative thin ceramic-on-steel coatings for fuel cells, which work without expensive raw materials like platinum. This dramatically reduces the operating temperature, and thus increases the lifetime. The establishment of pilot installations has enabled the company to develop new fuel cell systems and test them in practical operation – for this, the development team needed to optimise the system and connect the facilities digitally. More than 50 pilot installations are now in operation across Germany; series manufacturing is to follow in 2024. Stationary fuel cell systems support the transformation of the energy market towards climate neutrality.

Beneficiary: Robert Bosch GmbH
Funding ID: 03ETB021
Appropriated funding: €5.1 million
Project duration: 2019 – 2022
Project description on EnArgus:

MORE DETAILS

2.3 Energy generation

2.3.1 Photovoltaics

With a view to the energy transition, the Federal Government wants to attain climate neutrality in Germany by 2045. As the restructuring of the energy supply advances, photovoltaics (PV) continues to play a key technological role. In its expansion path, the Federal Government has agreed on a substantial new build of PV installations. The target is 200 gigawatts by 2030. To this end, bureaucratic barriers are to be removed and innovative fields of application like floating PV and agrivoltaics are to be strengthened. Here, research funding is in particular targeting application-oriented developments to shape a successful energy transition, whilst also strengthening basic research as a foundation for future innovations.

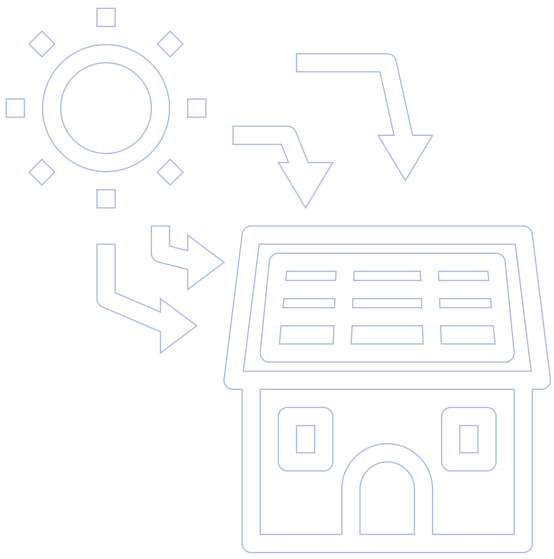
Funding priorities and scientific advances

In 2021, experts from a host of disciplines came together in a new working group on "Accompanying PV research" within the Renewable Energy Research Network. By offering qualified accompanying research, they intend to optimise research funding in the field of PV in both strategic and economic policy terms. To this end, the group has started by selecting three topics: securing the electricity supply from PV and corresponding business models, technical and socio-economic considerations and analyses, participation and public acceptance, as well as agrivoltaics.

The funding is currently focusing on PV in the built environment. Whilst a focus in the past has been on PV integrated into the building, i.e. the installation of solar modules as an integral part of a building envelope, the built environment offers a field of application that extends further. This is because the participants do not only focus on the "usual solutions" – roofs and facades – but also on all sorts of other structures like noise barriers and shelters over public squares and railway stations. If these surfaces are developed for PV not only in terms of technology, commercial and energy-related aspects, but also in terms of design, they will fit into the future urban and non-urban setting.

In addition to this field, research is also focusing more on floating PV and agrivoltaics. There are ideas to place more solar modules on water surfaces and in agriculture – in the latter case, on sites, which will be used simultaneously to produce crops and electricity.

From the technical point of view, it is also important to keep developing all the components of PV installations. These include, for example, the solar inverter, where the aim is to achieve further improvements in quality, in order to attain longer lifetimes and optimised operation of PV installations.

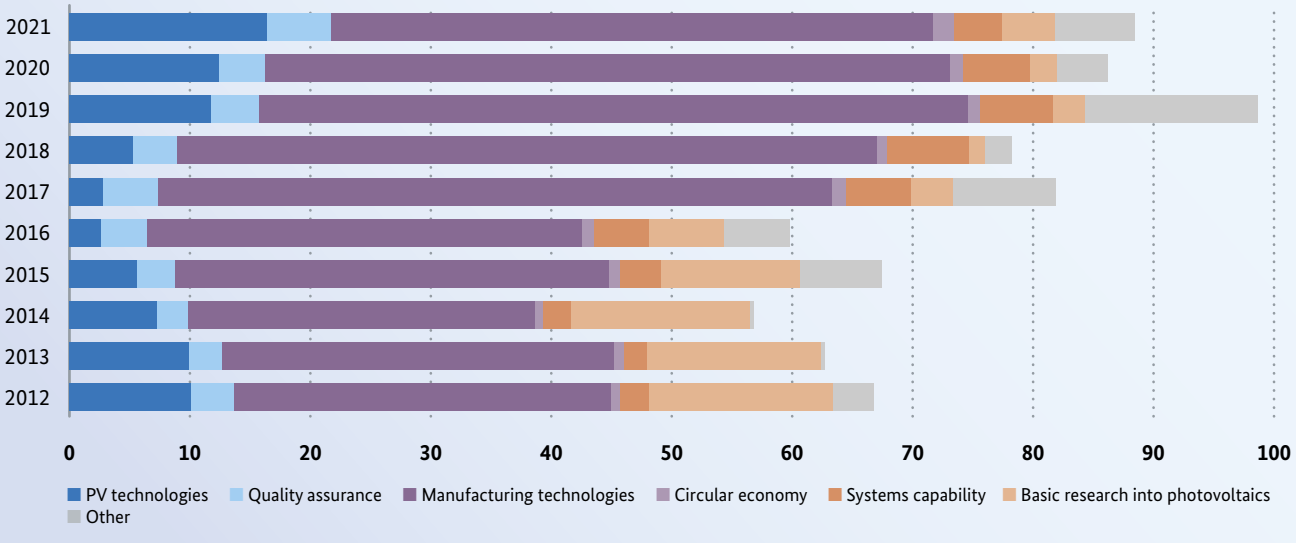


In the context of basic research, the Federal Ministry of Education and Research is funding projects on technologies with which the highest degrees of power generation efficiency can be attained, such as the dynamic field of perovskite- and silicon-based tandem and triple solar cells, as in the MeSa-Zuma project (cf. project description, p. 33). Also, work is continuing on the development of demonstrators for direct solar hydrogen production. A further focus is on the development of methods, e.g. operando studies at subatomic level in solar cells and other thin-film growth processes.

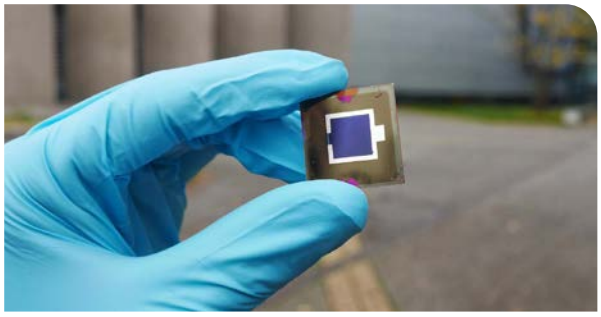
Project funding

In the field of photovoltaics, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €88.39 million in funding for 487 ongoing projects in 2021. In 2021, the ministries also appropriated approximately €64.23 million to fund 105 new research projects (cf. figure 10).

Figure 10: Funding for photovoltaics in € million
(Data cf. Table 4, p. 92)



PROJECT ABSTRACT



The world record cell (in front of the BESSY II electron storage ring) is of the usual size for research purposes: a surface area of around one cm^2.

MeSa-Zuma – *Development of highly efficient tandem solar cells offering long-term stability*

Boosting the efficiency of solar cells can contribute to further increasing the proportion of electricity from solar energy. For this reason, PV research is continuing to develop the materials used. Most of the potential of pure silicon PV has been exhausted. In response to this, the focus has shifted in recent years to the class of metal halide perovskites, since – in combination with silicon – they can massively boost efficiency in "tandem" solar cells. The MeSa-Zuma group of young scientists funded by the Federal Ministry of Education and Research has studied perovskite thin-films and, working together with other researchers, attained a new efficiency record of 29.8% in 2021 – close to the 30% mark aimed at by the research community. This record has been officially verified and entered into the NREL Chart. The follow-up project PEROWIN was launched in August 2021, focusing on new process and characterisation methods for the realisation of highly-efficient tandem solar cells.

Beneficiaries: Helmholtz Centre Berlin and two other partners
Funding ID: 03SF0540
Appropriated funding: €1.4 million
Project duration: 2016 – 2021
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

Large solar power stations account for two thirds of installed PV around the world.

PV-Kraftwerk2025 – *Innovations for the next generation of PV power stations: new component parts, system solutions and inverters for a cheap electricity supply that serves the grid*

Large solar power stations account for around two thirds of the new PV installations being built around the world. They can deliver output of up to 500 megawatts. In order to attain the objectives of the energy transition and to continue supporting the expansion of renewable energy, these PV power stations will in future have to be able to perform all of the grid services that are currently delivered by conventional power stations. The team of scientists in the PV-Kraftwerk2025 project is preparing the next generation of PV power stations so that the installations can help to serve both system stability and the security of supply of the electricity network: for example, when fluctuations between supply and demand need to be balanced in the grid. Components required for this include innovative semiconductor components for power electronics, battery storage integrated into the power station, and an optimised system concept. The project partners' research findings and the planned transition to serial production will help new PV power stations to operate more economically and will enable costs of solar power to be reduced further.

Beneficiaries: SMA Solar Technology AG and five other partners
Funding ID: 0324211A-F
Appropriated funding: €5.5 million
Project duration: 2017 – 2021
Project description on EnArgus:

MORE DETAILS

2.3.2 Wind power

The use of wind energy is crucial for the successful realisation of the energy transition in Germany. Despite comparatively poor wind conditions, it made the largest contribution towards power generated from renewable sources in 2021. In comparison with the preceding windy year, electricity generation from wind did drop by around 14% to 132 terawatt-hours (TWh). But even in this rather poor year for wind, wind energy was again the leading source of energy in the German electricity mix, ahead of lignite. Roughly three quarters of wind energy was generated by onshore wind turbines, and one quarter by offshore turbines.

In 2021, the new build of onshore wind energy was relatively modest, at around 1.7 megawatts of capacity – even though more installations were constructed than in 2020. At the end of 2021, installed onshore wind capacity in Germany amounted to around 56.1 megawatts. This represented an increase of 3% in capacity from the preceding year.

No new offshore turbines were connected to the grid in 2021. Overall, therefore, installed capacity remained unchanged at around 7.8 megawatts.

Funding priorities and scientific advances

The aim of the research funding is to achieve further cuts in the cost of wind energy and to enhance the reliability and lifetime of the installations.

In addition to the location of the turbines, the technology used in the installations determines the costs of generating the power. Components of the installation like the tower, gears, generator and power electronics can make substantial contributions towards cutting costs and boosting reliability. A holistic installation design is particularly important: Right from the design phase, attention should be paid to the effort needed for the manufacture, erection, operation, dismantling and recycling, and how the installations can be integrated into the electricity grid. Also, they need to be operated flexibly and smartly.

Windy and easily accessible onshore sites are becoming rarer, so that the rollout of wind energy is increasingly taking place at sites offering less favourable conditions. It is therefore essential to use suitable procedures to select potentially favourable sites, and then to investigate them using economic methods over a lengthy period.

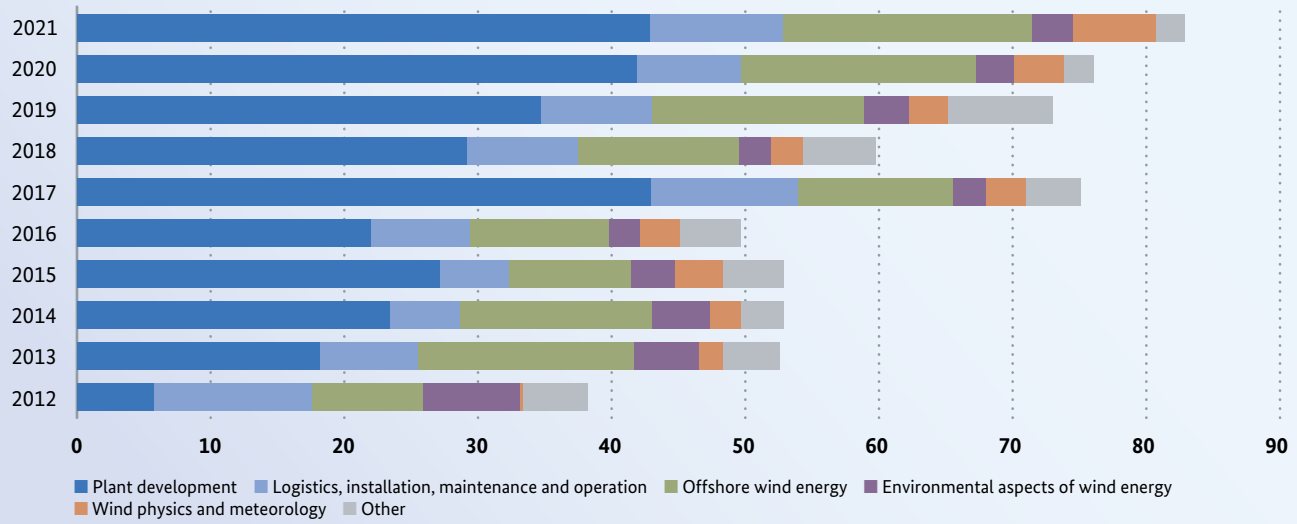
As modern wind turbines increase in size, more and more components are reaching the limits of their load-bearing capacities. New materials, e.g. to reduce weight, are therefore crucial for efficient and low-cost installation construction and operation.

Logistics and maintenance pose great challenges for offshore wind farms. The availability of the turbines is key to their economic efficiency, since offshore wind turbines are very complex and expensive to access in the event that they malfunction. For this reason, innovative grid connection and logistics concepts are important, and these must take account of the availability of installations, transport of staff and materials, and pooling, operation and maintenance concepts.

Project funding

In the field of wind energy, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Research and Education provided approximately €82.87 million in funding for 472 ongoing projects in 2021. In 2021, the ministries also appropriated approximately €43.90 million to fund 84 new research projects (cf. figure 11).

Figure 11: Funding for wind energy in € million (Data cf. Table 4, p. 92)



PROJECT ABSTRACT

WERAN plus – *Interaction of wind turbines and terrestrial navigation/radar plus*

Rotating beacons are navigation devices for air traffic, which can suffer interference from wind turbines. In order to avoid these problems, wind turbines are frequently not allowed to be erected in the vicinity of rotating beacons.
In the WERAN research project, the Physikalisch-Technische Bundesanstalt (PTB) and its project partners studied the scientific basis to assess the interaction and developed a new measurement technology and simulation methods. In the current WERAN plus follow-up project, researchers are now working on new forecasting methods to enable a realistic assessment of potential interference from wind turbines on rotating beacons in advance. This applies both to DVOR (Doppler Very High Frequency Omnidirectional Radio Range) and conventional VOR navigation equipment.
The new forecasting method will make it possible to decide on construction applications more quickly and more precisely in future. It will permit clear scientifically and legally robust forecasts of the interference effect of planned wind farms. The improved forecasting tool has already been used in practice:

An octocopter equipped with measuring technology collects measurements at various heights and distances around a wind turbine.

since 1 June 2020, the approval assessment has included a new formula for calculations. This enabled additional wind turbines with a total capacity of around 700 megawatts to be approved in the vicinity of rotating beacons last year.

Beneficiaries: Physikalisch-Technische Bundesanstalt (PTB) and three other partners
Funding ID: 0324252A-D
Appropriated funding: €1.3 million
Project duration: 2018 – 2023
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

InGROW – *Innovative foundation system for repowering of offshore wind turbines*

Offshore wind turbines are designed for a lifetime of 20 to 25 years. After that, they can only remain in operation if the most intensively used components are examined and, if there are defects or weaknesses, are replaced. This is difficult if not impossible in the case of underwater components in particular.
The Fraunhofer Institute for Wind Energy Systems IWES has developed an alternative for offshore wind farms: repowering that makes use of the existing components of the installation. In the case of onshore repowering, wind farm operators replace old installations with new, more powerful ones. Offshore, too, the advantages are obvious: the sites are already known, so that there is no need for sophisticated investigations. A grid connection is also already in place. If, in addition, a previously installed monopile foundation – pillars rammed deep into the seabed – can still be used, further substantial costs can be saved. However, new wind turbines tend to be heavier than the old ones. This means that the foundations must be able to cope with greater stress.
In the InGrow research project, the team has developed a foundation concept, which reinforces existing monopiles (by means of jacket structures on suction buckets), thus permitting repowering to take place without all the foundations needing to be replaced.
The Fraunhofer Institute for Wind Energy Systems has registered an international patent for this innovative concept.

Fraunhofer IWES has developed an innovative process to use existing foundations of offshore wind turbines for repowering.

Beneficiary: Fraunhofer Institute for Wind Energy Systems (IWES)
Funding ID: 03EE3003
Appropriated funding: €550,000
Project duration: 2019 – 2021
Project description on EnArgus:

MORE DETAILS

2.3.3 Bioenergy

Biomass used for energy makes an important contribution towards the attainment of Germany's ambitious targets for the expansion of the use of renewable energy. Bioenergy can be used in all the consumption sectors (heat, electricity, transport), and is thus the most versatile of the renewable forms of energy. Its availability does not depend on the weather or season, and it can be easily stored. This makes it an indispensable source of energy alongside the intermittent energy from wind and solar power. Bioenergy already accounts for a large proportion of the renewable energy used in the heat and transport sectors. At the same time, the research funding can further optimise the sustainable use of the various types of biomass in a way that fits the system.

Funding priorities and scientific advances

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 permit efficient, economic and above all sustainable use of bioenergy. For example, the ministry funds practical solutions that can serve as

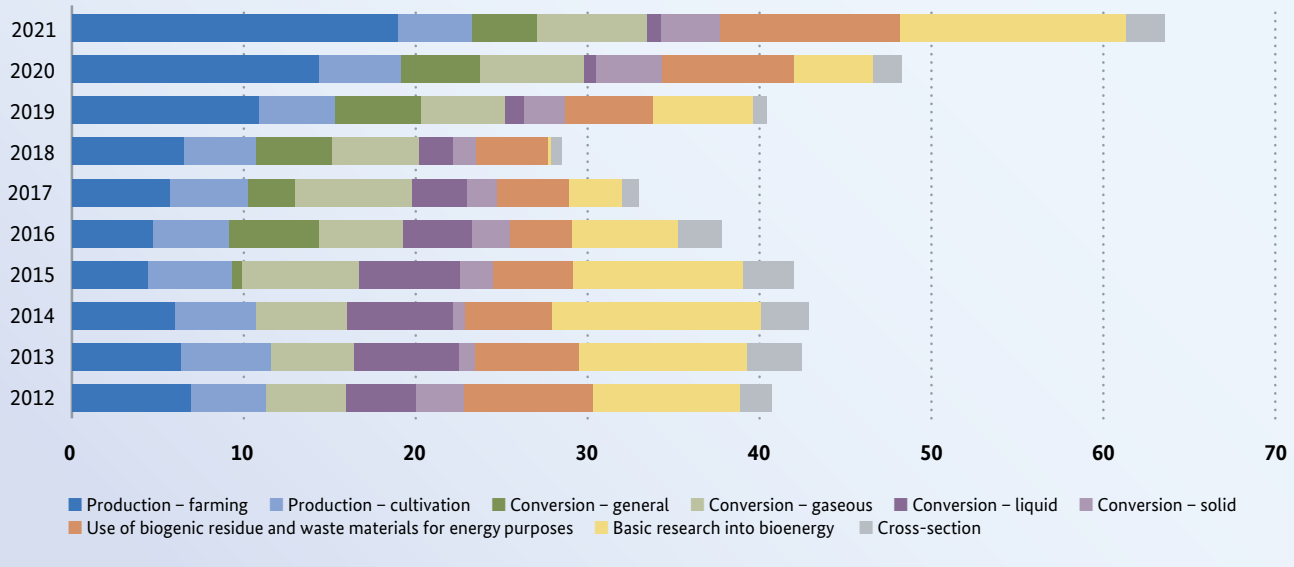
demonstration and pilot projects, which support the flexible generation of electricity and heat from biomass, provide biofuel and use biogenic residues and waste. Further aspects include system integration, sector coupling, digitalisation and the successful combination of installations and concepts for the use of renewable energy.

Since 2021, the focus has also included projects for biogenic hydrogen generation, which are also being funded by the Hydrogen Technology Campaign. 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 Deutsches Biomasseforschungszentrum gemeinnützige GmbH. Active dialogue between the researchers is also facilitated by the Bioenergy Research Network.

In the bioenergy priority, the Federal Ministry of Education and Research is giving funding not least towards projects, which aim to deploy fuels generated from renewable sources in the mobility sector. For example, the probioLNG collaborative project is developing a process chain to provide liquid biomethane as a fuel for agricultural machinery. In the context of cooperation with African countries, the ministry is funding projects to tackle the problem of uncontrolled waste disposal by using waste to generate bioenergy. The Waste2Energy project in Ghana, for example, uses green solar energy and various decomposition processes to transform waste into energy in a hybrid PV-biogas-pyrolysis plant.

The Federal Ministry of Food and Agriculture is funding research projects in the field of bioenergy via the Renewable Raw Materials funding programme, which is managed by the FNR (Agency for Renewable Resources) and has an annual budget totalling around €85 million. The priority areas include sustainable material flow management to give production and processing facilities the optimal supply of biogenic resources, the development of concepts for sustainable generation and use of renewable raw materials, paying particular atten-

Figure 12: Funding for bioenergy in € million
(Data cf. Table 4, p. 92)



tion to water as a resource, and the distributed generation of recyclable material in aquatic systems, e.g. with algae, cyanobacteria or aquatic plants to broaden the base of raw materials. In particular, use can be made of the expertise of the German Biomass Research Centre (DBFZ).

Project funding

As part of its key focus on bioenergy, in 2021, the Federal Government provided around €63.72 million to fund a total of 762 ongoing projects. In 2021, the ministries also appropriated approximately €47.10 million to fund 195 new research projects (cf. figure X12).

PROJECT ABSTRACT

WeMetBio – *Needs-based storage of intermittent renewable (wind) energy by integrating biological methanisation in the trickle-bed process in an energy association in Schleswig-Holstein*

The energy transition is one of the Federal Government's most ambitious climate policy goals. In order to attain this goal, it is necessary to progress the expansion of renewable energy. In the production of solar power from PV installations or power generation from wind turbines, the problem arises that the generation of renewable electricity depends on the availability of the sun and the wind. If renewable energies are to become a mainstay of the energy supply, it must become possible to store them. Here, bioenergy offers the advantage that it is available throughout the day and the year, and can easily be stored in the form of biogas. Coupling the various renewable energy sources is therefore a key precondition for a successful energy transition. Also, many biogas plants and wind turbines will lose their entitlement in the coming years to the remuneration anchored in the Renewable Energy Sources Act (RES Act). Many operators are facing the challenge of developing economic post-RES Act concepts for existing installations.

The WeMetBio project, funded by the Federal Ministry of Food and Agriculture, addresses this situation. The aim of the feasibility study was to integrate biomethanisation in the trickle bed process into an energy association consisting of a biogas plant and a post-RES Act wind turbine at a specific site. In this way, use is to be made of surplus electricity that has not so far been used, along with CO_2, thus preventing the dismantling of post-RES Act wind turbines. The study finds that a storage of wind energy in the form of power-to-gas methane can be implemented in various rural areas.

In the WeMetBio project, the integration of an innovative pilot plant for biomethanisation in the trickle-bed process in an energy association of biogas/biomethane plants, wind turbines and methane feed-in into the gas grid in Schleswig-Holstein is being trialled.

Beneficiaries: Brandenburg University of Technology Cottbus-Senftenberg and Flensburg University of Applied Sciences
Funding ID: 2219NR134, 2219NR401
Appropriated funding: €190,000
Project duration: 2020 – 2021
Project description on EnArgus:

MORE DETAILS

2.3.4 Geothermal energy

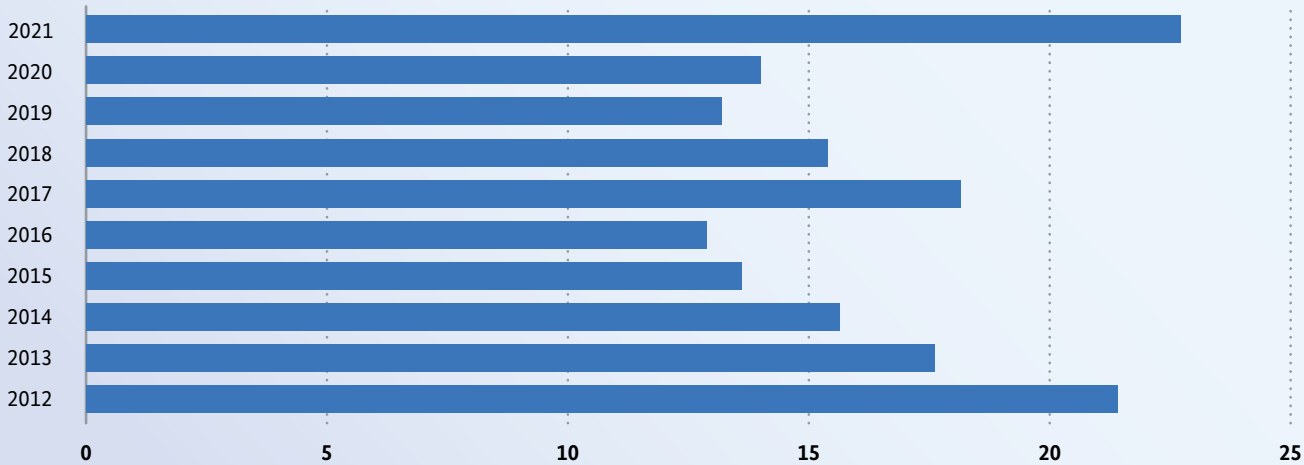
Geothermal energy is a reliable source of energy. Currently available technologies mean that hydrothermal geothermal energy is an economically viable heat source on the German market. In contrast, it is rarely used to generate electricity. For this reason, geothermal energy is mainly used to supply households, neighbourhoods and companies with heat and cold. The municipal utility Stadtwerke München for example is planning to supply most of Munich's district heating with heat from geothermal sources by 2040. In the field of deep geothermal energy, the German Geothermal Association (BVG) says that roughly 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 – e.g. 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 by the Federal Ministry for Economic Affairs and Climate Action in the 7th Energy Research Programme are to help make geothermal heat rapidly deployable, to reduce the costs and risks in the development and use of geothermal energy, and to boost the awareness and public acceptance of geothermal energy. The transfer of new technologies into practice is to be accelerated, with a special focus on demonstration and pilot projects.

Project funding

In the field of geothermal energy, the Federal Ministry for Economic Affairs and Climate Action provided approximately €22.71 million in funding for 111 ongoing projects in 2021. In addition, the ministry appropriated approximately €19.47 million in funding for 25 new research projects in 2021 (cf. figure 13).

Funding for geothermal energy in € million
(Data cf. Table 4, p. 92)



PROJECT ABSTRACT

HuKmeN – *Heating and cooling in a single network: a new type of machine makes the construction of large geothermal energy collectors to use near-to-surface geothermal energy more economically viable and more reliable*

Geothermal energy collectors are tubing systems laid in the ground, which remove heat from or supply heat to the ground at shallow depths. They make an important contribution towards the heat transition as renewable sources of heat and cold for the heating and cooling of buildings via heat pumps and passive cooling, and as heat storage facilities.

In the past, it has been necessary to move large amounts of earth for the collector. This has caused high costs and excluded many potential sites as sources of heat. Technologies and processes are therefore needed to make large-scale collectors less soil-invasive and thus cheaper. To this end, researchers at Dresden Technical University and their partner Doppelacker developed a new type of machine to lay geothermal collectors with little digging in the preceding KollWeb project. The "collector weaver" is being tested in practice in the current research project. The aim is to test its capacity, reliability and smooth integration into the assembly process. The findings are to create the preconditions for the cheap, reliable and climate-friendly provision of renewable heat and cold via scalable geothermal energy collectors.

The collector weaver is tested in practice in a test field.

Beneficiaries: Dresden Technical University and Doppelacker GmbH (subcontractor and associated partner)
Funding ID: 03EE4028
Appropriated funding: €4.9 million
Project duration: 2021 – 2025
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 technologies to boost the capacity of the installations and to develop new sites. Research is also being done 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 €0.93 million in funding for eight ongoing projects in 2021 (cf. figure 14).

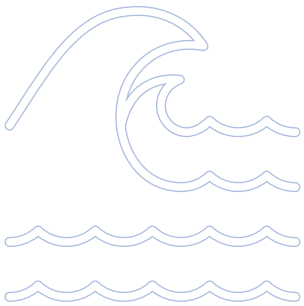
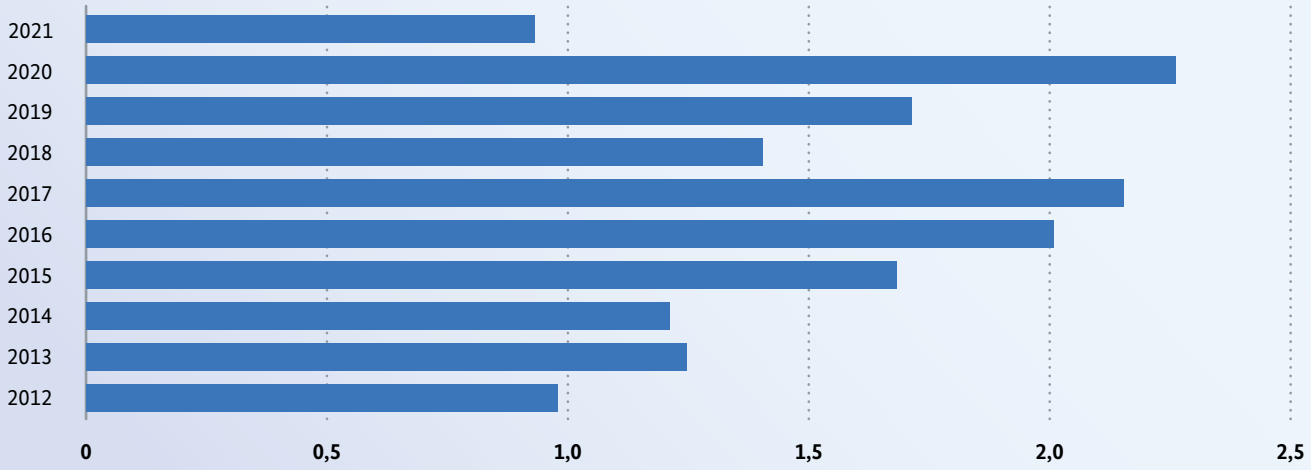


Figure 14: Funding for hydropower and marine energy in € million
(Data cf. Table 4, p. 92)



2.3.6 Thermal power plants

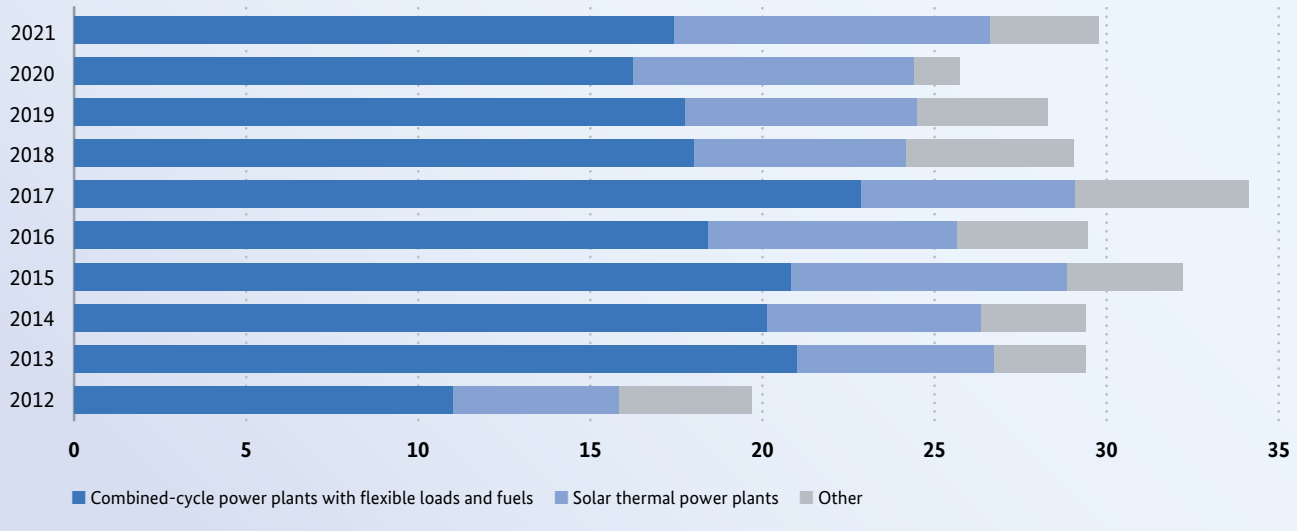
Thermal power plants continue to play a decisive role in the conversion of the energy system. Going forward, they are to be operated not with coal or natural gas, but with non-fossil fuels like hydrogen or supercritical carbon dioxide. Supercritical CO_2 has the density of a liquid and the viscosity of a gas. This state arises at around 31 C and a pressure of 74 bar.

Funding priorities and scientific advances

Turbo machinery technology is at the heart of conventional power stations. Turbines are needed as central components of power-to-X-to-power technologies to generate electricity from renewable energy sources. If for example surplus green electricity is converted for storage into gases (power-to-gas), to liquid fuels (power-to-liquid) and basic chemicals (power-to-chemicals), turbines can reconvert the converted electricity as needed. In future, thermal power stations are to be run on non-fossil fuels. Since these impose different demands on the operation of the power station than fossil fuels, it is necessary to research appropriate materials, components and process technologies.

Solar-thermal power stations are increasingly being used in regions with strong direct solar radiation, such as in southern Europe or North Africa. If thermal storage facilities are integrated into these power stations, they can provide the electricity generated from the sun as needed, even when the sun is not shining. The aim of the research into solar-thermal power stations is to develop concepts and pilot projects to study and optimise the interaction of different renewable energy technologies with electricity and heat storage. Here, a decisive role is played by alternative heat carriers, such as salt or silicon rather than thermal oil. They can attain higher efficiency levels and thus cut electricity costs.

Figure 15: Funding for thermal power stations in € million
(Data cf. Table 4, p. 92)



Project funding

In the field of thermal power plants, the Federal Ministry for Economic Affairs and Climate Action provided approximately €29.77 million in funding for 360 ongoing projects in 2021. In addition, the ministry appropriated approximately €39.12 million in funding for 74 new research projects in 2021 (cf. figure 15).

PROJECT ABSTRACT

High Performance Solar 2 (HPS2) – *Demonstration of a solar-thermal parabolic trough and steam generation system based on molten salt as a heat carrier*

An international team of researchers is working in a test facility in Évora, Portugal, on the operation of a solar-thermal parabolic trough using molten salt rather than thermal oil. The project is headed by the German Aerospace Center. The comparatively low procurement costs and the higher maximum temperature to which the salt can be heated are arguments in favour of the use of molten salt. This results in higher efficiencies in the power station. Also, more energy can be kept in the heat storage facility for the production of electricity at night.

Commercial solar power stations already use large tanks of molten salt to store heat. However, such power stations currently use a two-circuit system, with synthetic oil in the collector field and molten salt in the storage system. The HPS2 team of scientists is now studying the use of salt in practice as a medium to transport and store heat. This would mean that only one circuit would be needed in future. The investment and operating costs could be reduced, significantly lowering the costs of controllable, storable and renewable electricity.

Bird's-eye view of HPS2 research facility: parabolic trough mirrors (top left), covered drainage store (bottom left), steel structure with storage tanks and steam generation system (bottom), office and control station containers (centre)

Beneficiaries: German Aerospace Center and two other partners
Funding ID: 0324097A-C
Appropriated funding: €4.6 million
Project duration: 2016 – 2022
Project description on EnArgus:

MORE DETAILS

2.4 System integration

2.4.1 Electricity grids

The electricity grid is the backbone of the energy transition. However, the shift to generation from renewable sources is creating challenges for the grid. Electricity is being transported over increasing distances – in the extreme case from generation on the windy coasts to consumption in the densely populated west and south. Also, the transmission and distribution grids need to be designed to cope with rising distributed and local feed-in of electricity, as well as new large consumers like electric vehicles and heat pumps. Grid operation must bear in mind that the generation of electricity from renewable energy depends on the weather, and thus fluctuates. It is crucial to keep studying possible risks to health so that the expansion of the power grid can be accepted by society.

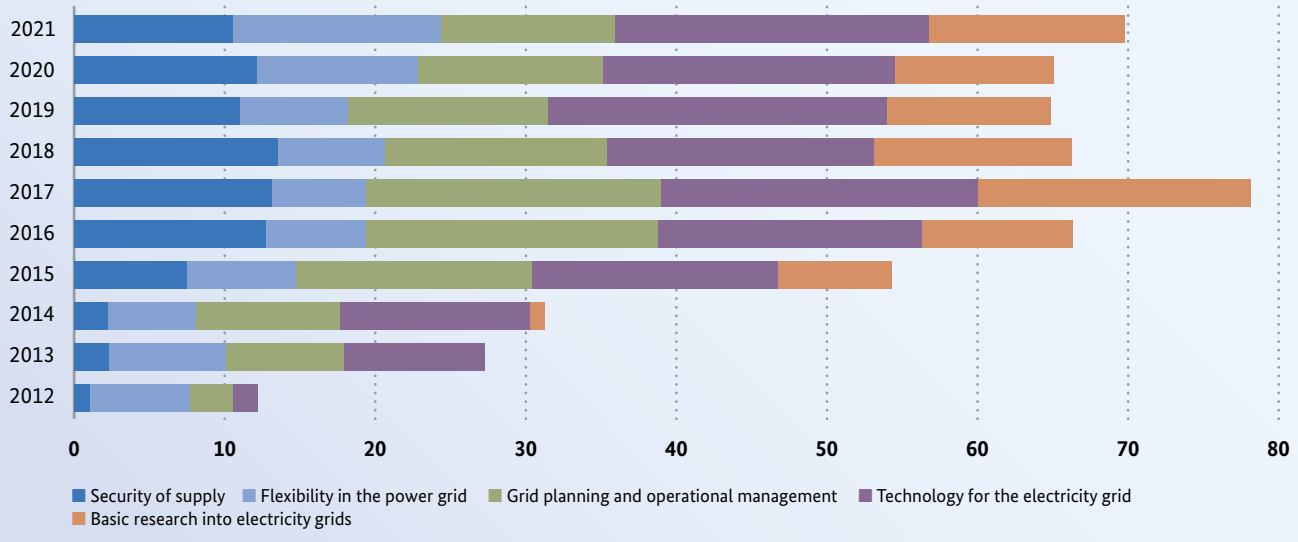
Funding priorities and scientific advances

The research goals address various levels. For example, it is necessary to improve components like power converters, underground cables, overhead lines and switches. The Federal Ministry for Economic Affairs and Climate Action is also providing funding for experts to be able to reliably integrate the distributed supply structures across all voltage levels and sectors (electricity, heat, transport). Furthermore, the beneficiaries of the funding are developing emergency concepts, e.g. for blackouts. Another research priority is automation, digitalisation and information technology. The advances help to make the energy system more efficient via better control and also to maintain or improve the level of security.

In 2021, the Federal Ministry for Economic Affairs and Climate Action concluded the "Smart Energy Showcases – Digital Agenda for the Energy Transition (SINTEG)" funding programme. The project partners developed model solutions for the digital energy supply of the future in practical trials. The programme was a measure of the Federal Ministry for Economic Affairs and Climate Action to promote innovation outside the Energy Research Programme.

The Federal Ministry of Education and Research also funds holistic and forward-looking solutions

Figure 16: Funding for electricity grids in € million
(Data cf. Table 5, p. 93)



for the electricity grid of the future. For example, the ENSURE Kopernikus project aims to test innovative technologies in practice or via computer-aided simulation. Additionally, tests will be carried out on how electricity grids can respond flexibly to the feed-in of renewable energy and how electricity can flow from the grid to electric vehicles without large losses. ENSURE is studying the exchange of energy reserves between subgrids and their smart integration. A digital transformer station is to show how electricity flows can be controlled automatically in future.

Project funding

In the field of electricity grids, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €69.75 million in funding for 556 ongoing projects in 2021. In this period, the ministries also appropriated approximately €54.75 million to fund 100 new research projects (cf. figure 16).

PROJECT ABSTRACT

SPANNeND – *Digital coordination of voltage using reactive power between grid operators*

The transformation of the energy system into distributed generation also signifies a shift for grid coordination and operation towards decentralised operations. A new Redispatch 2.0 process is responding to this shift. However, the process is primarily designed for active power. The reactive power generated locally in transport has not yet been explicitly covered by the coordination process. This is despite the fact that reactive power ensures that the grid voltage remains stable and the active power can be distributed securely. The challenge is that reactive power behaves in a very non-linear way, and can only be generated and used on a relatively local basis.
The SPANNeND project team therefore aims to develop a uniform, robust and interoperable method to reliably integrate potential reactive power from the distribution grid into the transmission grid management systems. The use of reactive power is intended to optimise the scale of redispatch and to maintain the stability and security of the grids. The reactive power flexibility available to the transmission system operators is to be offered uniformly via the redispatch platform and thus to ensure optimal (minimal) dosage of the necessary redispatch measures. The work is intended to boost the plannability of grid operation, enhance the security and stability of the system, and

Voltage coordination using reactive power

reduce the costs of redispatch and congestion management.
On the basis of preliminary work relating to the optimisation (Q-OPF) and provision of reactive power, the team of researchers aims to develop standardised methods, including implementation guidelines, and to trial them at the participating distribution system operators in field tests.

Beneficiaries: emsys grid services GmbH and five other partners
Funding ID: 03EI4040A-F
Appropriated funding: €1.9 million
Project duration: 2022 – 2024
Project description on EnArgus:

MORE DETAILS

2.4.2 Electricity storage

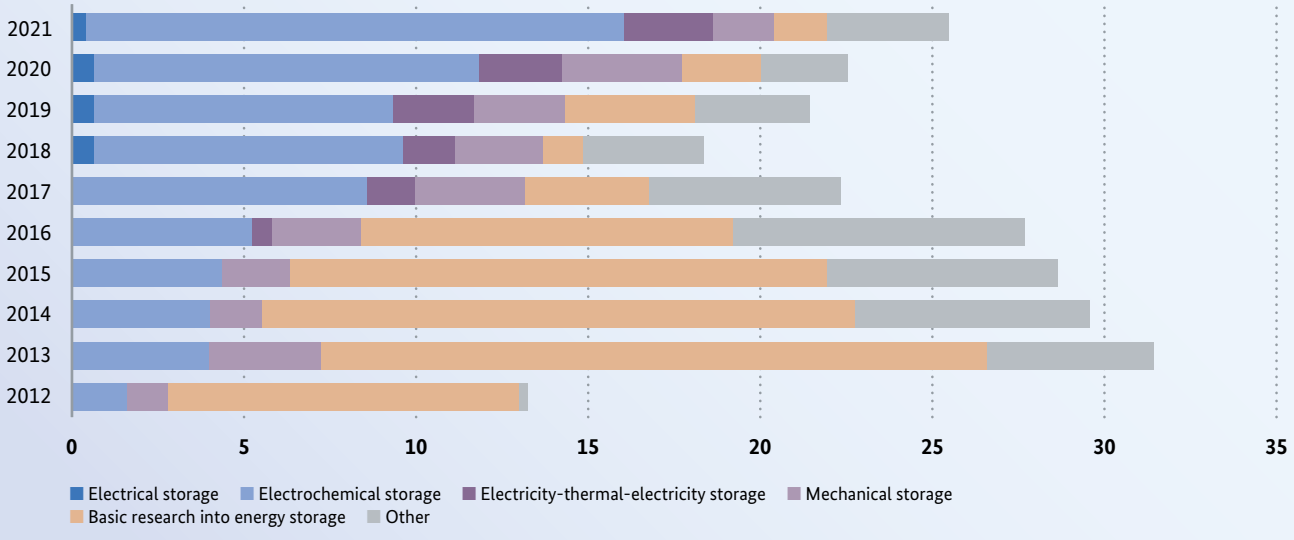
Electricity storage will play an important role in the energy system of the future. It helps to decouple the current demand for electrical energy from its generation. Power storage – with a storage duration from seconds to minutes, and a high ratio of output to storage capacity – can cope with peak loads of up to 18 megawatts. In this way, electricity storage stabilises the grid and improves security of supply. Displacement storage helps to keep the balance within a day, e.g. in order to boost the in-house consumption of electricity from a PV installation. This means that it would not be necessary to curtail wind turbines in windy weather because grid capacity is insufficient. Long-term storage is only charged and discharged a few times a year; it helps to offset long-term drops in renewable energy. Also, storage is an important link in sector coupling, integrating electricity, heat and transport and making the energy system more efficient.

Funding priorities and scientific advances

The aim of ongoing research and development is to cut the cost of storage and to improve its technical characteristics. Also, when there is sharp growth in storage capacity, questions of availability of the resources needed for its manufacture arise, along with the related environmental impact. It is therefore necessary to reduce dependency on critical raw materials in line with the Federal Government's National Raw Materials Strategy. The environmental footprint of the storage facilities is also to be improved over their entire lifecycle.

In Germany's key sectors, batteries represent an increasing part of value creation. The various electrical and electro-chemical storage technologies are at the focus of the Federal Ministry for Economic Affairs and Climate Action's funding, in order to initiate investments and to become independent of imports in this forward-looking field.

Figure 17: Funding for electricity storage in € million
(Data cf. Table 5, p. 93)



Here, electro-chemical storage technologies can be used in various rechargeable batteries (including redox-flow and high-temperature batteries) and supercapacitors ("supercaps"). The economic goal is to pool and strengthen technical excellence for the battery cell in Germany and to establish large-scale production across Europe on the basis of research and innovation. To this end, the Federal Ministry for Economic Affairs and Climate Action called for battery research proposals in March 2021. The initiative supports the establishment of a battery value chain, which is currently taking place in the context of two IPCEI projects. IPCEI stands for "Important Project of Common European Interest". Further to this, the Federal Ministry for Economic Affairs and Climate Action funds mechanical storage systems (compressed air and gas, pumped and flywheel storage systems) and high-temperature heat storage systems for electricity storage (Carnot batteries).

The funding of the Federal Ministry of Education and Research focuses on next-generation battery technologies like metal-air, solid state and new types of redox flow batteries. The focus is on material-related issues, including novel combinations of materials. For example, the Franco-German project MOLIBE (cf. project description, cf. project abstract on the right) is working on metal- and liquid-free organic lithium-ion batteries for sustainable and safe electricity storage. Further projects are investigating concepts for particularly low-cost rechargeable zinc-ion batteries and iron redox flow systems as prospective stationary electricity storage units.

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 €25.47 million in funding for 228 ongoing projects in 2021. In addition, the ministries appropriated approximately €19.09 million in funding for 48 new research projects in 2021 (cf. figure 17).

PROJECT ABSTRACT

Lithium-ion batteries are regarded as the most promising technology for reversible energy storage.

MOLIBE – *Metal- and liquid-free organic lithium-ion batteries for sustainable and safe electricity storage*

Efficient energy storage is essential for a successful energy transition. Lithium-ion batteries permit highly efficient reversible energy storage, and have become established as the standard solution for electric mobility. However, high costs and persistent safety aspects still stand in the way of universal deployment. The high costs arise not least from necessary materials like cobalt, nickel and, of course, lithium. The safety concerns relate to the flammability and the lack of stability of the liquid electrolytes. The Franco-German research project entitled MOLIBE is therefore developing entirely solid, metal-free rechargeable batteries based on organic active materials and polymer electrolyte systems. The researchers achieved a first major success in 2021: they produced organic full cells, which remain stable over several hundred cycles, but still contain lithium ions. One of the two half cells developed is actually stable over 5,000 cycles. The efficient and sustainable synthesis process for the active materials is an important element of a potential commercialisation of the technology.

Beneficiaries: Karlsruhe Institute of Technology and five other partners
Funding ID: 03SF0583A+B
Appropriated funding: €400,000
Project duration: 2019 – 2023
Project description on EnArgus:

MORE DETAILS

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. So far, it has proved difficult to make the sectors of industry, transport and heat climate-neutral. Sector coupling can help to decarbonise these sectors too. Green hydrogen – made from renewable electricity via electrolysis – is regarded as a key element here. It can be used as a feedstock for steel production and in the chemical industry. In the transport sector, it can defossilise aviation, maritime shipping and parts of heavy-duty road haulage through direct deployment in vehicles with fuel cells or as a component of synthetic fuels – e.g. for shipping and aviation.

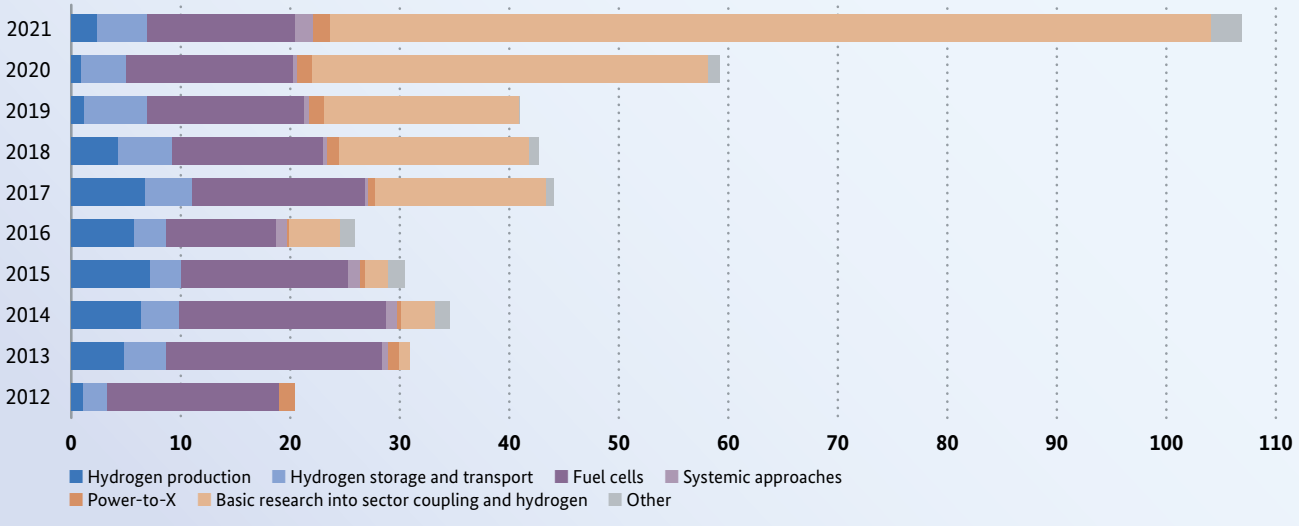
Funding priorities and scientific advances

In 2020, Germany anchored its goals for the launch of a hydrogen economy in its National Hydrogen Strategy. The Strategy provides a coherent framework for action on future production, transport and use of hydrogen, and lays the foundation for the market ramp-up. Green hydrogen technologies offer enormous opportunities for climate change mitigation, forward-looking jobs and new value creation – especially for the export industry. In 2021, the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Climate Action set up large-scale research initiatives to leverage these opportunities. The platform for the national and international market ramp-up is being put in place by a host of individual applied energy research projects. These became visible in 2021 in particular in the context of the "Hydrogen Technology Campaign" call for proposals.

Initial basic research projects into green hydrogen have also commenced – they are studying tomorrow's key enabling technologies along the entire hydrogen value chain. The initial findings of the H_2Atlas study have highlighted the great potential of the Sub-Saharan region to generate and export green hydrogen. The Federal Ministry of Education and Research has set up the International Master's Programme in Energy and Green Hydrogen (IMPEGH) to build up local expertise and train local experts (cf. project description, p. 49).

At European level, the market ramp-up is being driven by Important Projects of Common European Interest (IPCEIs) for hydrogen technologies

Figure 18: Funding for sector coupling and hydrogen in € million
(Data cf. Table 5, p. 93)



and systems (cf. Chapter 5.1 Federal Government innovation promotion beyond the Energy Research Programme, p. 84). The Economic Affairs and Transport Ministries are broadening the funding available via the Hydrogen Technology Campaign. It addresses new groups of beneficiaries, encouraging them to expand their efforts to develop hydrogen production and its use in industrial processes, storage and transport via gas grids. The campaign is backed by system analysis work for a global hydrogen economy.

Together, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research are funding the H2-Kompass collaborative project (cf. project highlight in Chapter 2.5.1 Energy systems analysis, p. 52), which is to draw up the foundations for a German hydrogen roadmap.

In view of the direct political significance of hydrogen as an energy carrier for the energy transition, strategically outstanding projects in this research field are being funded in the context of the Living Labs for the Energy Transition of the Federal Ministry for Economic Affairs and Climate Action and the hydrogen flagship projects of the Federal Ministry of Education and Research (cf. Chapter 2.1 Strategic funding formats: Living Labs for the Energy Transition and flagship projects on hydrogen, p. 18).

Project funding

In the field of sector coupling and hydrogen technologies, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €106.47 million in funding for 396 ongoing projects in 2021. In 2021, the ministries also appropriated approximately €220.99 million to fund 223 new research projects (cf. figure 18).

PROJECT ABSTRACT

GSP Green H2 – *International Master's Programme in Energy and Green Hydrogen*

Sub-Saharan Africa offers great potential to generate hydrogen from solar and wind energy – more than is needed locally. Exports, e.g. to Germany, could have many positive economic effects for the development of the region. New technologies, and also sufficient local expertise, are needed for the generation and use of green hydrogen. Capacity building is therefore necessary to train local experts. The International Master's Programme in Energy and Green Hydrogen is initially to offer two courses training a total of 120 students from all 15 countries of the Economic Community of West African States (ECOWAS) in green hydrogen. The two-year course is offered at four West African universities. The students will spend one semester and write their final dissertation in Germany. The master's programme covers the entire green hydrogen value chain – from production to storage and use.

The master programme aims to train young specialists in Africa in green hydrogen

Beneficiaries: West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) and two other partners
Funding ID: 03SF0626A-C
Appropriated funding: €16.2 million
Project duration: 2021 – 2025
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

OptiLBO – *Energy-efficient and carbon-neutral steel production via the use of additive manufacturing and smart control in the electric arc furnace*

The steel sector has a long tradition in Germany and provides a basic material for various branches of industry. Both primary and secondary steel making emit large quantities of CO_2 due to the processes used. In the secondary route, steel scrap is smelted in the electric arc furnace and new steel produced. The energy needed for the smelting is mainly delivered in the form of electricity, supported by gas-fired burners. The team of the OptiLBO research project is now developing an innovative combustion system for this. Using improved technology and intelligent control, this is to cut the current level of gas consumption by up to 25%. That equates to around five gigawatt-hours of saved energy, and 900 tonnes less carbon emissions, per year. Also, the combustion system is to be able to make partial or full use of (renewable) hydrogen instead of natural gas, creating expectations of even greater savings. For this reason, the researchers are studying how hydrogen affects the smelting process, both on its own and as part of a mixed gas. OptiLBO is the first research project to be funded by the Hydrogen Technology Campaign.

Researchers want to make steel production more sustainably using hydrogen.

Beneficiaries: Gas- und Wärme-Institut Essen (GWI) and three other partners
Funding ID: 03EN2069A-D
Appropriated funding: €2.6 million
Project duration: 2021 – 2025
Project description on EnArgus:

MORE DETAILS

2.5 Cross-system research topics

2.5.1 Energy systems analysis

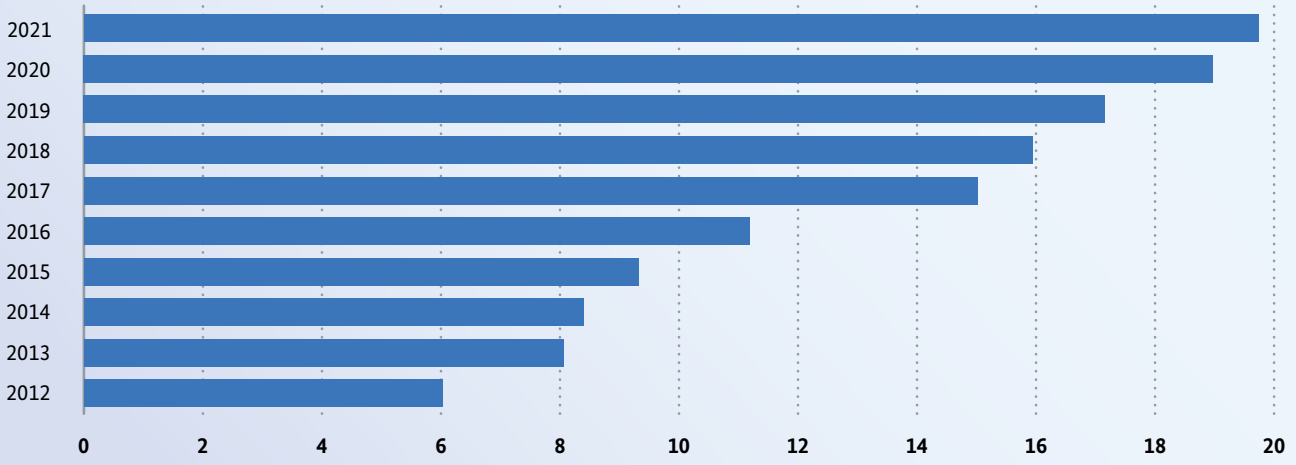
Energy systems analyses help stakeholders in government, commerce and society by providing a quantitative basis for decisions, e.g. regarding the operation and management of energy infrastructure. They supply models for municipal, regional, national and international energy systems and map energy systems of individual companies or buildings.

Funding priorities and scientific advances

Open science is becoming more and more prominent in the field of systems analysis. The Federal Ministry for Economic Affairs and Climate Action believes that open science has the potential to improve the transfer of knowledge and the efficiency of research and has therefore commissioned Project Management Jülich to obtain an overarching view from the system analysis research community. The outcome of the survey was published in July 2021 and fed into the development of the ministry's strategy on open science in systems analysis. In the context of the annual meeting of the systems analysis research network in May 2021, discussions were held with representatives of industry and consultants about how the transfer of findings could be expanded and users of systems analysis could become more involved. The results will feed into the development of the funding priority and the networking.

The MODEX projects completed their research work in December 2021. Within the thematic association, six collaborative teams of 39 partners carried out model experiments into current systems analysis issues for 40 models over the last three years. MODEX aims to compare the methodologies of the increasingly complex models of energy systems analysis. Also, five project associations were launched regarding system analysis questions as part of the Hydrogen Technology Campaign in 2021.

Figure 19: Funding for energy system analysis in € million
(Data cf. Table 6, p. 94)



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 €19.74 million in funding for 224 ongoing projects in 2021. In addition, the ministries appropriated approximately €21.48 million in funding for 49 new research projects in 2021 (cf. figure 19).

PROJECT ABSTRACT

H2-Kompass – *Tool to create a roadmap for a German hydrogen economy*

Hydrogen will play an outstanding role in the energy supply in future. For this to happen, innovations are needed which enable the necessary ramp-up of the hydrogen economy to take place. The Federal Government's National Hydrogen Strategy therefore envisages a roadmap to provide a long-term framework for German research and innovation policy along the entire hydrogen value chain. The H2-Kompass project, which is funded jointly by the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research, therefore produces and assesses options for action and application scenarios for hydrogen, thus providing a well-founded basis for the development of the hydrogen roadmap. The work gives equal consideration to economic, technological, environmental and social aspects. In addition to a meta-analysis of existing studies and a dialogue with interest groups, H2-Kompass will bring together in an atlas the numerous activities and stakeholders in hydrogen research and the hydrogen economy.

The H2-Kompass project wants to show the way to a climate-friendly hydrogen economy.

Beneficiaries: acatech – Deutsche Akademie der Technikwissenschaften e.V. and DECHEMA – Gesellschaft für Chemische Technik und Biotechnologie e.V.
Funding ID: 03EWT002A+B
Appropriated funding: €4.3 million
Project duration: 2021 – 2023
Project description on EnArgus:

MORE DETAILS

2.5.2 Digitalisation of the energy transition

Whether electricity grids or buildings, residential neighbourhoods and factories – digitalisation affects all aspects of energy research. Innovative information and communication technologies (ICTs) therefore play a key role in an energy-efficient and flexible energy system.

Funding priorities and scientific advances

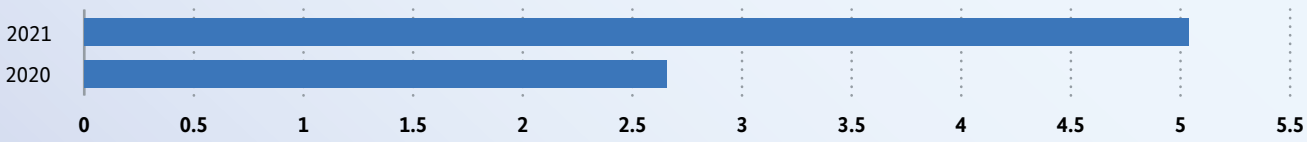
The Federal Ministry for Economic Affairs and Climate Action's call for proposals entitled "Communication Technologies for the Energy Industry" targets consortia doing research into ICT in the energy sector. This delivers a better inclusion of renewable energy, sector coupling and energy efficiency. The Federal Ministry for Economic Affairs and Climate Action has published the DigENet I call for proposals in order to incentivise the further development of smart meter gateways (SMGWs). This focuses on the networking of generation, storage and consumption via SMGW communication platforms, the drawing up of concepts for the flexibilisation of generation and consumption, the facilitation of participation in the energy system, and the improvement of data products and value-added services.

The Federal Ministry of Education and Research is also promoting digitalisation as a horizontal issue in application-oriented basic research – e.g. in projects to model complex energy systems or to develop digital marketplaces for local energy trading and services relating to energy measures in buildings, and to improve the presentation of energy-related data for planners and the population via augmented reality. The Wärmewende Nordwest (heat transition north-west) collaborative project is currently digitalising the heat transition in the region around Bremen and Oldenburg (cf. also project description, p. 25).

Project funding

In the field of digitalisation of the energy transition, the Federal Ministry for Economic Affairs and Climate Action and the Federal Ministry of Education and Research provided approximately €5.06 million in funding for 44 ongoing projects in 2021. Also, the ministries appropriated new projects in this research field in the context of the Living Labs for the Energy Transition (cf. figure 20).

Figure 20: Funding for the digitalisation of the energy transition in € million
(Data cf. Table 6, p. 94)

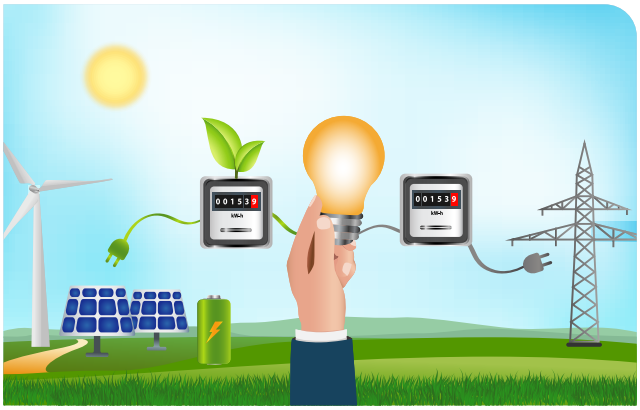


PROJECT ABSTRACT

DiMA-Grids – *Digital business models with self-determined users for smart distribution grids*

The project aims to progress the digitalisation of the energy transition. The project partners are studying how prosumers, i.e. consumers who both produce and consume electricity, can be activated. These might be households or small businesses which have, for example, installed PV equipment. These final customers are to be given the opportunity to provide surplus electricity, or "flexibility" via an internet platform, thus making it available to the distribution system operator. This approach means that surplus electricity can be passed on in the energy system and used elsewhere.

To this end, the team is studying economic, technical and regulatory issues with a view to developing new digital business models. The implementation of these models requires a flexible, automatically controlled electricity grid (a smart grid). So the partners are also working on the transformation of the distribution grid into a modern digital system. Building on this, they are studying how new business models can be implemented in line with the needs of the energy industry and in conformity with data protection rules, maintaining people's right to dispose of their own information.



As prosumers, consumers play an active part in the energy market, e.g. by feeding in electricity from the solar panels on their own roof.

Beneficiaries: Fraunhofer Institute for Systems and Innovation Research (ISI) and five other partners
Funding ID: 03EI6038A-F
Appropriated funding: €1.2 million
Project duration: 2021 – 2023
Project description on EnArgus:

MORE DETAILS

2.5.3 Resource efficiency in the context of the energy transition

In addition to the integration of renewable energy, a sustainable energy transition also embraces the macroeconomic demand for raw materials and resources. Energy research into resource efficiency in the context of the energy transition combines the securing of raw materials and resources specific to the energy transition with general ideas about material and resource efficiency and the circular economy. In this way, there is to be a lasting fall in primary energy demand and energy-related carbon emissions.

Funding priorities and scientific advances

In January 2021, the Federal Ministry for Economic Affairs and Climate Action held an expert workshop on the research area and published a first call. The ministry's focus was on interdisciplinary projects with a cross-system and cross-technology approach and a high level of corporate participation in order to ensure that the results are subsequently transferred into practice. On the basis of the call, ten collaborative projects were newly approved in 2021, and three others prepared. 20 companies, both SMEs and large firms, and research establishments are involved in the approved projects. Research is going into, for example, a more energy-efficient circular economy for critical raw materials, comparisons of battery systems for electric mobility, digital solutions for industrial products in a circular economy, more resource-conserving recycling of polycarbonate waste, and concepts to retain the material value of petrochemical products. In June 2021 SUMATRA was the first project to be launched in this research area.

Project funding

In the field of resource efficiency in the context of the energy transition, the Federal Ministry for Economic Affairs and Climate Action provided approximately €0.07 million in funding for four ongoing projects in 2021. In addition, the ministry appropriated approximately €10.66 million in funding for 43 new research projects in 2021 (cf. figure 21).

Figure 21: Funding for resource efficiency in the context of the energy transition in € million
(Data cf. Table 6, p. 94)

PROJECT ABSTRACT

SUMATRA – *More sustainable LED lighting systems – from recycling back to use*

Modern LEDs have facilitated great advances in the energy efficiency of lighting systems. Nevertheless, there is still potential to optimise the use and recycling of the resources used. The SUMATRA team aims to help establish a circular economy in the lighting sector. The consortium brings together Trilux (a lighting manufacturer), Interseroh (experts for recycling), Osram (manufacturer of LED and light control systems) and researchers into environmental footprints at the Fraunhofer IZM.

Modern LED lighting is used in the Futurium Berlin – the House of Futures. The SUMATRA project is thinking LED lighting a step further ahead.

The experts want to make LED systems more sustainable by optimising the product design and by designing new use concepts. The replacement of fluorescent tubes by LEDs can thus reduce energy-related carbon emissions. Sparing use is to be made of materials subject to limited availability, and particular use is to be made of resources with a small environmental impact. To this end, the team intends to develop the design of lighting systems from the perspective of the last stage of the life cycle (recycling/re-use). Building on a life cycle analysis and a sustainability strategy, they aim to orient "future luminaire design" entirely to re-usability and recyclability so that the individual parts and components of LED lights can be used over a 25-year period. If the work is successful, ideas for best practices are to be generated for the further development of the circular economy in the lighting industry and also other sectors.

Beneficiaries: TRILUX GmbH & Co. KG and three other partners
Funding ID: 03EI5001A-D
Appropriated funding: €540,000
Project duration: 2021 – 2023
Project description on EnArgus:

MORE DETAILS

2.5.4 CO_2 technologies

Since it is not possible to prevent the creation of carbon dioxide in some industrial processes, researchers are seeking ways to capture CO_2 and either store it (carbon capture and storage, CCS) or use it as a feedstock for new products (carbon capture and utilisation, CCU).

Funding priorities and scientific advances

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

For instance, in the context of the P2X Kopernikus project, the Federal Ministry of Education and Research is funding the further development of installations to capture CO_2 from the atmosphere

and use it as a feedstock for synthetic fuels. The Carbon2Chem project is developing a CCU approach for a steel work and transferring this to further sources of emissions. In the CO_2-WIN funding measure, funding goes to projects in the field of CCU offering an application in the energy sector. These include the projects entitled Bio-UGS, for the biological conversion of CO_2 into methane in underground storage sites, and CO_2SimO, in which the same conversion is studied in photo-electrochemical terms. The "artificial leaf" approach in the DEPECOR project is particularly innovative; here, the conversion of CO_2 into long-chain hydrocarbons via artificial photosynthesis is being studied. In the CO_2-LiPriSek project, the focus is on the recycling of lithium from old batteries via carbonatisation, enabling materials to be retained that are battery-grade and can replace primary lithium carbonate.

The Federal Ministry for Economic Affairs and Climate Action funds application-oriented technologies to enable closed carbon cycles to be established on the market in the near future. This was particularly visible in 2021 in the call for bids for funding for carbon capture and utilisation in the basic materials industry. The research funding is also to help ensure that German firms and research establishments play a pioneering role in these export-related technologies.

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 €32.87 million in funding for 102 ongoing projects in 2021. In 2021, the ministries also appropriatedapproximately €25.34 million to fund 48 new research projects (cf. figure 22).

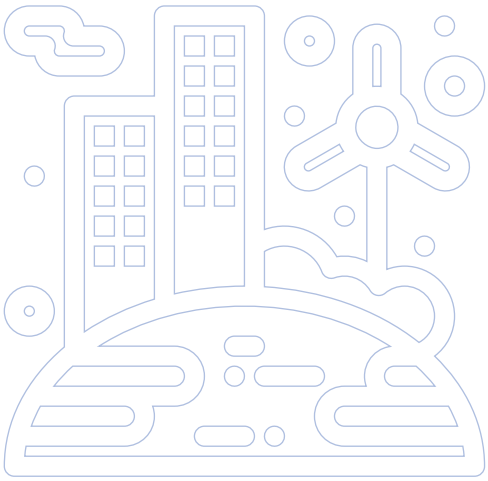
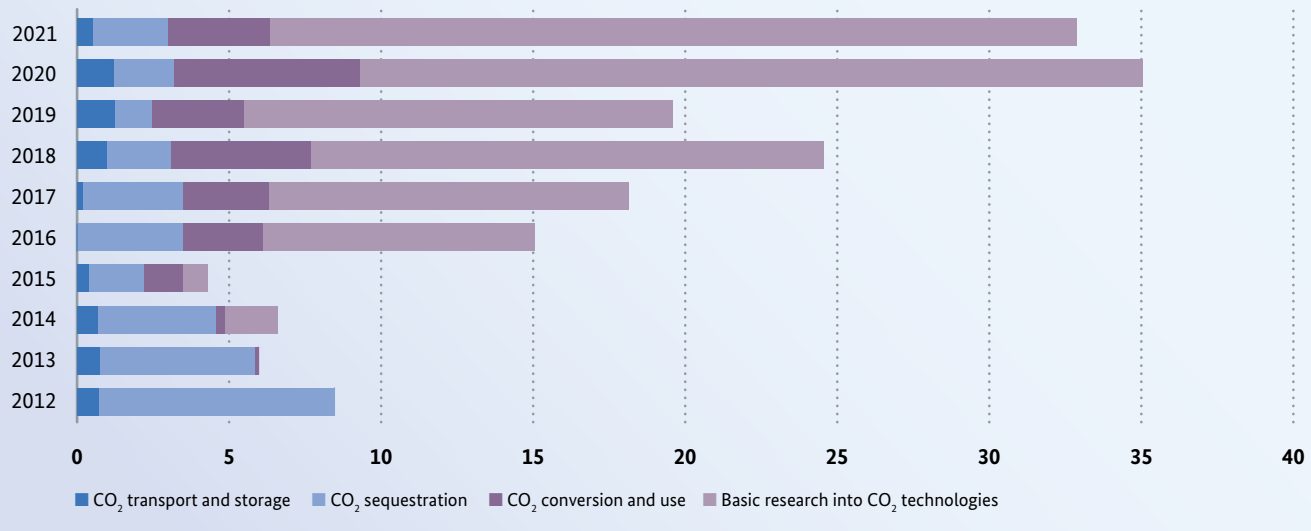


Figure 22: Funding for CO_2 technologies in € million
(Data cf. Table 6, p. 94)



PROJECT ABSTRACT

ACT-AC²OCem – *Acceleration of the market launch of CO_2 capture in cement production via the use of oxyfuel technology*

Cement is an important material for the construction sector around the world. However, its production process creates large amounts of carbon dioxide. In the AC²OCem research project, teams from the research and industrial communities in five European countries are working on oxyfuel technology to enable cement works to emit virtually no CO_2. In the oxyfuel process, the combustion process to make bricks is initiated not with air, but with pure oxygen. As a result, the CO_2 arising in the course of burning and conversion of limestone into lime can be used, without expensive further processing, as a high-grade raw material – e.g. for polymers and basic chemicals.

In AC²OCem, the research work is focusing for example on how the first-generation oxyfuel technology can be used in existing cement works. Beyond this, research is being done into second-generation oxyfuel technology for new cement works. Not least, a novel combustion concept is being tested in a pilot plant, including a specifically developed oxyfuel furnace.

500 kilowatt test facility of IFK at Stuttgart University

Beneficiaries: Stuttgart University and three other national and seven international partners
Funding ID: 03EE5024A-D
Appropriated funding: €1.7 million
Project duration: 2019 – 2023
Project description on EnArgus:

MORE DETAILS

2.5.5 Energy transition and society

The energy transition and climate action are initiated, supported and implemented by society, commerce, and individuals. Consumers become market-shaping prosumers and energy communities; new business fields emerge and replace a centralised energy supply. Social aspects are therefore becoming increasingly relevant for energy research.

Funding priorities and scientific advances

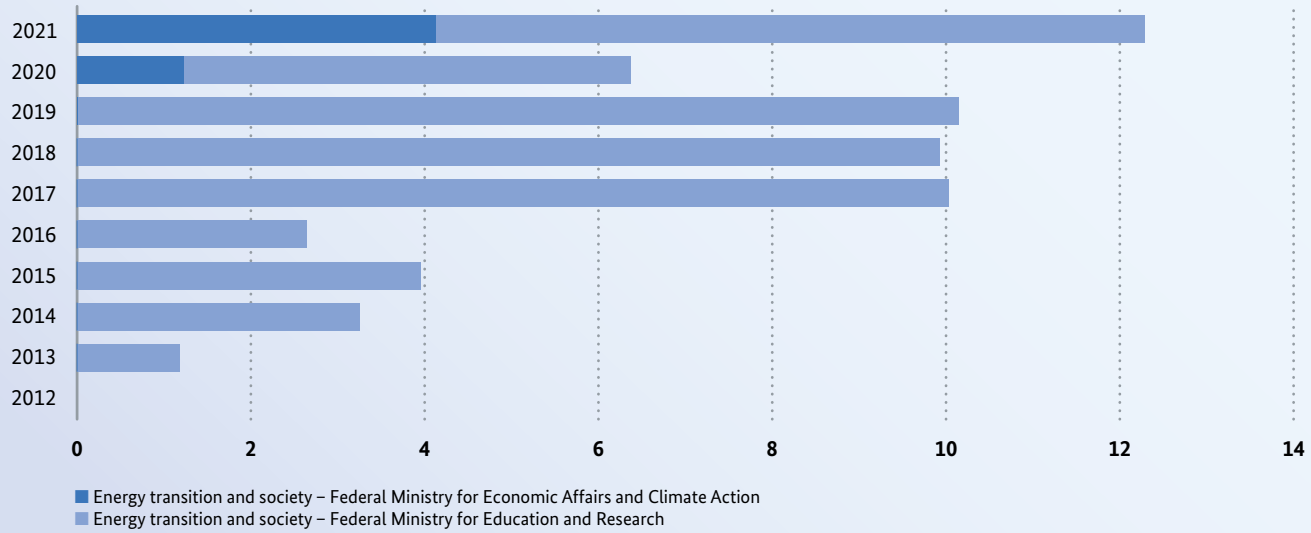
The second "Energy transition and society" call for proposals of the Federal Ministry for Economic Affairs and Climate Action led to the launch of 33 projects in 2021. For instance, in one of the projects experts are studying how new structures of work impact on energy, health and commercial aspects compared with the traditional world of work, and what energy conservation is possible in transport and offices. Other projects cover simulation, visualisation and communication forms, opportunities and risks of digitalisation, or opportunities for financial participation by municipalities, cooperatives and the public in energy transition measures, and public acceptance and participation. The Federal Ministry for Economic Affairs and Climate Action aims to address unresolved research issues in further calls.

The Federal Ministry of Education and Research's funding addresses societal aspects in Germany's regions which are facing a massive transformation in the course of the phase-out of coal. The projects of the initiative "scientific support and accompaniment of transformation in Lusatia" are working proactively on structural change in the region. Also, the Federal Ministry of Education and Research launched the Helmholtz hydrogen economy cluster (HC-H2) in 2021. Like the iNew 2.0 project (cf. project description p. 60), HC-H2 is also to shape structural change in the Rhineland mining district via science-based innovations and demonstration projects. The WissKommEnergiewende collaborative project aims to familiarise the public throughout Germany with core issues of the energy transition in an exhibition (cf. project description, p. 61).

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 €4.12 million in funding for 107 ongoing projects in 2021. In 2021, the ministries also appropriated approximately €8.93 million to fund 41 new research projects (cf. figure 23).

Figure 23: Funding for energy transition and society in € million
(Data cf. Table 6, p. 94)



PROJECT ABSTRACT

Dialogbrücken – *Local power grid expansion: the role of municipalities as bridges for dialogue between national planning and local protest*

The expansion of the transmission grids is considered to be a bottleneck of the energy transition. Many people see it as an intervention in their local environment without any local benefit. Local protests and resistance frequently delay the expansion. This is making it more difficult to integrate renewable energy sources into the energy system. The partners in the project funded by the Federal Ministry for Economic Affairs and Climate Action have analysed the way municipalities understand their role as key players in involving the public in the expansion of the power grid. The goal: to ascertain how cities, towns and rural districts act with regard to the restructuring and expansion of the energy system. To do this, the consortium identified the conditions and factors that influence the actions of municipalities in their function as dialogue bridges between national planning and local sentiment. Building on this, the experts derived recommendations and potential solutions to strengthen the

Municipalities play an important role as intermediaries in the dialogue between planners and the public.

role of municipalities as key players for the energy transition. The team based its work on reflection and dialogue between the parties involved in the expansion of the power grid, who formed an advisory board to accompany the project. This dialogue is to be continued on a long-term basis and is to increase understanding and cooperation between multipliers.

Beneficiaries: German Institute for Urban Affairs and Ruhr University Bochum
Funding ID: 03EI5207A+B
Appropriated funding: €290,000
Project duration: 2020 – 2022
Project description on EnArgus:

MORE DETAILS

iNEW 2.0 – *Incubator for sustainable electrochemical value chain*

The decision to phase out coal-fired power generation has been taken. Alongside the expansion of renewable energy to cover electricity demand, there is also the question of the future of Germany's coal-mining areas – and particularly the regional labour markets. iNEW 2.0, a project funded by the Federal Ministry of Education and Research, is therefore focusing on the successful transition of the Rhineland lignite-mining area into a forward-looking district of sustainable economic activity. The researchers want to develop new types of electrolysis processes for use in sustainable power-to-X value chains. Power-to-X is a key enabling technology for sector coupling and predestined for the establishment of a carbon circular economy in order to shape structural change and to pave the way to a successful climate-neutral post-coal era. The P2X approach creates the possibility for climate-neutral industrial processes using renewable electricity and regenerative resources based on CO_2. In this way, a climate-damaging gas becomes a sustainable raw mate-


The iNew 2.0 project aims to help shape the transition of the Rhineland lignite-mining area into a forward-looking area of sustainable economic activity.

rial. iNEW 2.0 also aims to secure existing jobs in energy-intensive industries via the transition to climate-compatible power-to-X technologies, whilst also creating new jobs in the development of technology and in plant construction.

Beneficiaries: Research Centre Jülich and two other partners
Funding ID: 03SF0627A-C
Appropriated funding: €23 million
Project duration: 2021 – 2024
Project description on EnArgus:

MORE DETAILS

PROJECT ABSTRACT

WissKommEnergiewende (Communication of energy transition science) – *An exhibition project on German energy research*

Researchers have been working for many years on technologies and concepts to shape the energy transition. Much of this work is market-ready, other parts are still in their infancy. The success of the energy transition will depend not only on science – it will also be crucial for the public to support it. The WissKommEnergiewende project therefore aims to familiarise the public with the core issues of the energy transition and at the same time to study how best to communicate the scientific aspects of energy issues. To do this, it is developing an exhibition linking participatory elements with research into the impact. The project promotes dialogue and discussion: it collects opinions, questions, requests and ideas about the energy transition from the public. This provides input for the exhibition itself, whilst also being analysed in accompanying research and serving as the basis for future public relations work in the energy and climate field. The WissKommEnergiewende consortium uniquely brings project partners from the scientific community together with exhibition spaces and communication experts. The exhibition is to launch in August 2022.

The WissKommEnergiewende project is developing an exhibition combining participatory elements with impact research.

Beneficiaries: DECHEMA Gesellschaft für Chemische Technik und Biotechnologie and six other partners
Funding ID: 03SF0625A-H
Appropriated funding: €7.6 million
Project duration: 2021 – 2024
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. Not least, there is a need for innovative materials. The Federal Ministry of Education and Research has therefore placed a focus on the development of innovations in materials in basic research.

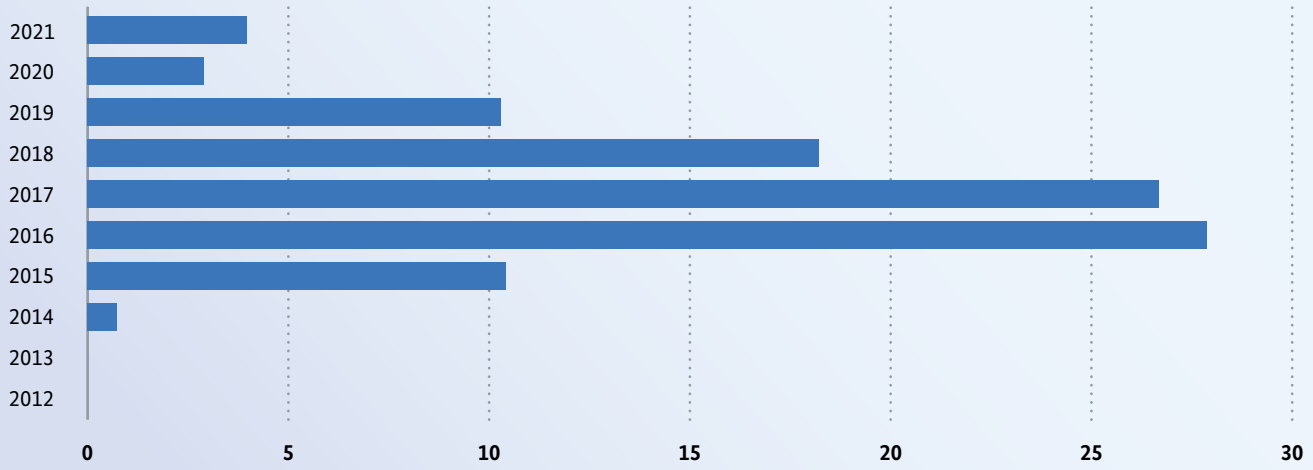
Funding priorities and scientific advances

In 2021, the material research projects covered a wide range – e.g. the development of new materials for optimising PEM fuel cells, electrochemical energy storage systems and wind turbines, promising high-performance materials for photovoltaics, as well as innovative materials for gas turbines. The PSUMEA-3 project, for example, researches fluorine-free membranes and electrodes for fuel cells and electrolysis (cf. project description, p. 62). The MeSa-Zuma project even set a new efficiency record in tandem solar cells from the development of novel materials in 2021 (cf. project description, Chapter 2.2.1, Photovoltaics, p 33).

Project funding

In the field of materials research for the energy transition, the Federal Ministry of Education and Research provided approximately €3.96 million in funding for seven ongoing projects in 2021 (cf. figure 24).

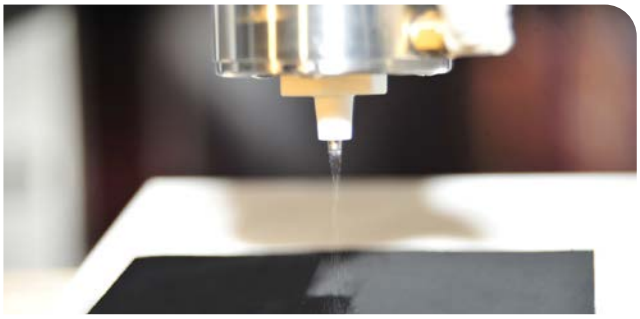
Figure 24: Funding for material research for the energy transition in € million
(Data cf. Table 6, p. 94)



PROJECT ABSTRACT

PSUMEA-3 – *Fluorine-free membrane electrode units for PEM fuel cells and water electrolysers*

The decarbonisation of the transport sector and thus the electrification of mobility is an important aspect of the energy transition. In the passenger car sector, electric vehicles will dominate urban traffic in the medium term. In aviation and maritime transport, and parts of heavy-duty road haulage, in contrast, the focus is shifting more to the hydrogen-fuelled fuel cells and synthetic fuels, due to the greater ranges. However, fuel cell technology needs to become more efficient before it enters widespread use. An important aspect here is the materials used, particularly in the polymer membrane, the heart of the PEM fuel cell. For this reason, the PSUMEA-2 project has developed a new type of membrane which is cheaper than the membranes established on the market but which can match their performance density and efficiency. The technology dispenses with environmentally harmful fluorine. The PSUMEA-3 project follows on seamlessly from the previous project. The researchers have improved the membrane with the help of partners from industry and science. The fluorine-free fuel cell components developed in the project define a new state of the art, some of which is higher than the conventional technologies and is also much more environmentally friendly.



Direct membrane deposition on electrode structures using ultrasound spray coating

Beneficiaries: Max Planck Society and three other partners
Funding ID: 03EK3045A-D
Appropriated funding: €1.4 million
Project duration: 2018 – 2021
Project description on EnArgus:

MORE DETAILS

2.6 Nuclear safety research

In January 2021, the Federal Ministry for Economic Affairs and Climate Action published the project funding programme "Research funding for nuclear safety" in order to flesh out the research policy requirements of the 7th Energy Research Programme and the Federal Government's concept on the development of skills and young scientists for nuclear safety. The programme's research priorities address current challenges in nuclear safety in the fields of reactor safety research, extended intermediate storage and treatment of highly radioactive waste, final disposal and overarching horizontal issues.

2.6.1 Reactor safety research

A key task for those conducting research on the safety of nuclear energy is to use R&D to make nuclear power plants ever safer, both in Germany and abroad and to promote skills development and young scientists in the area of nuclear safety in Germany.

Funding priorities and scientific advances

The thematic priorities of reactor safety research cover the remaining post-operational and residual operational phase application cases in Germany as well as technical safety issues for the installations in

Figure 25a: Funding for nuclear safety research 2012 – 2020 in € million
(Data cf. Table 7a, p. 95)

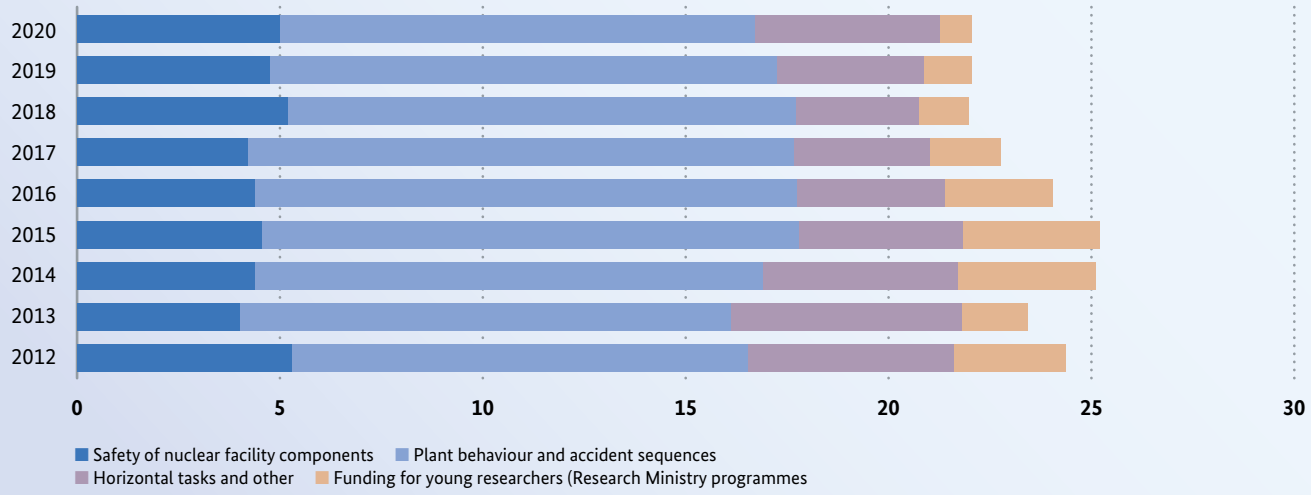
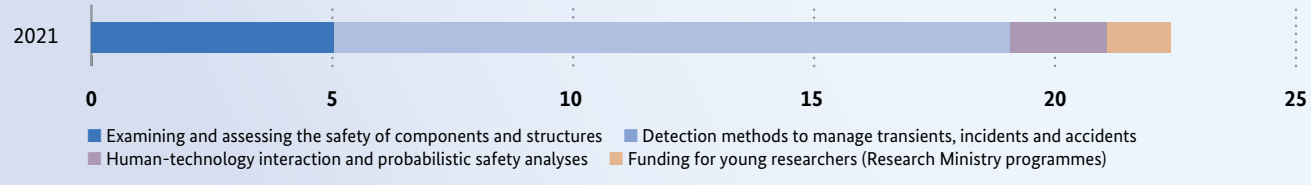


Figure 25b: Funding for nuclear safety research in 2021 in € million
(Data cf. Table 7b, p. 95)



operation or under development abroad. The focus of the safety-related research is increasingly on new reactors and plant designs. Research is being done into the safety of components and structures, into verification processes for the handling of transients, incidents and accidents, and into interactions between humans and technology and probabilistic safety analyses.

The involvement of German research work in international activities is of great significance here, and is strengthened for example by involvement in outstanding multilateral research projects of the OECD/NEA. In 2021, Germany participated in 15 of these projects.

Project funding

Project funding in the field of nuclear safety research is provided by the Federal Ministry for Economic Affairs and Climate Action, and is supplemented by a Federal Ministry of Education and Research programme which supports young scientists. The Federal Ministry for Economic Affairs and Climate Action provided approximately €21.08 million in funding for 141 ongoing projects in 2021. The Federal Ministry of Education and Research provided €1.32 million for 12 projects, including €6.07 million for eight projects. In addition to this, the Federal Ministry for Economic Affairs and Climate Action appropriated approximately €21.90 million in funding for 30 new research projects in the same year (cf. figure 25a, b).

PROJECT ABSTRACT

THAI-VI-Programm – *Experimental research on hydrogen and fission product behaviour in incidents and accidents in reactor containments*

Simulation programmes analyse and evaluate incidents and accidents in containment vessels of nuclear power plants, validated by means of high-grade experimental data. The THAI test facility (THAI: Thermohydraulics, Hydrogen, Aerosols, Iodine) generates these data from technical-scale experiments. They are used intensively in German and international nuclear safety research, with the funding being provided by international partners.

In the sixth phase of the THAI programme, experiments were carried out into the behaviour of flammable gases, thermohydraulics, the behaviour of fission products and the physics of hydraulic seals. The data from the trials formed the basis for an international benchmark for simulation programmes and have fed into multinational nuclear safety initiatives. The ongoing development of the test facility means that not only hydrogen but also scenarios with carbon monoxide can be studied on a technical scale.

The approx. 10m high THAI test facility consists of two test containers which can used flexibly, separately or together, to study phenomena in safety containment in nuclear power plants.

Beneficiary: Becker Technologies GmbH
Funding ID: 1501594
Appropriated funding: €3.9 million
Project duration: 2019 – 2021
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.

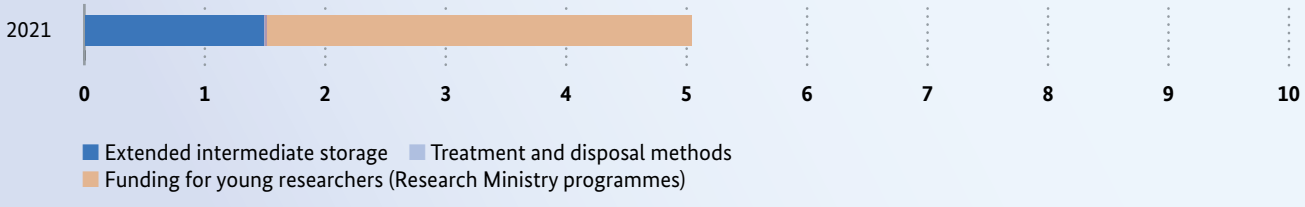
Funding priorities and scientific advances

The studies focus on the state of the stored highly radioactive waste and the containers, the effects of storage on the ability to transport and handle them, and the protective effect of the structures over the extended lifetimes. In order to optimally prepare the waste for final disposal, basic scientific knowledge of potential treatment and conditioning options is being drawn up for the time after intermediate storage. At the same time, developments in waste disposal abroad are being observed, and alternative or supplementary waste management and disposal methods studied, so that these can be assessed for potential use in Germany. In 2021, two projects to encourage young scientists were successfully completed, with experimental investigations into the integrity of fuel element cladding tubes and new assessment methods developed for this. The involvement in international research activities was also stepped up, for example via the launch of a study by German and international researchers into the treatment of highly radioactive waste.

Project funding

In the field of extended intermediate storage and treatment of highly radioactive waste, the Federal Ministry for Economic Affairs and Climate Action provided approximately €1.57 million in funding for 15 ongoing projects in 2021. The Federal Ministry of Education and Research provided €3.64 million across 33 projects in support for young scientists doing research into waste disposal. Of this, four new projects were approved by the Federal Ministry of Education and Research in 2021, with funding of €1.99 million. In addition to this, the Federal Ministry for Economic Affairs and Climate Action appropriated approximately €1.31 million in funding for 74 new research projects in the same year (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. 95)



PROJECT ABSTRACT

iCross – *Integrity of nuclear waste repository systems – cross-scale system understanding and analysis (subproject A-E)*

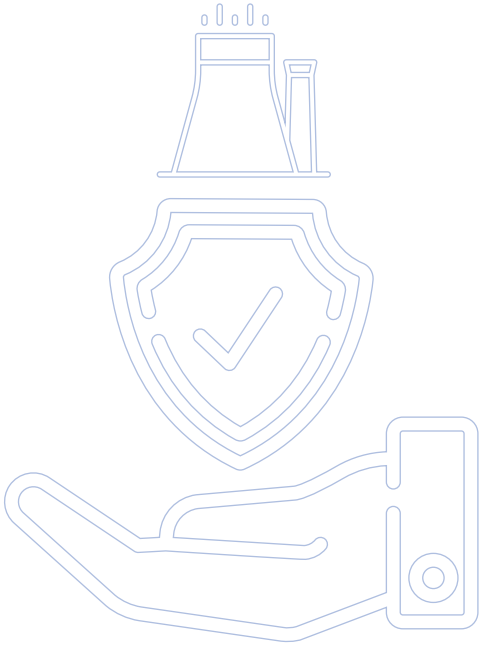
The iCross interdisciplinary project pools in a single project research and development expertise in the Helmholtz Association in the field of nuclear, geo-, biosciences and environmental simulations. Processes which are not yet fully understood are being studied, assessed and described, from molecular level to the regional scale. The aim is to conduct targeted laboratory experiments, to derive parameters, and to describe relevant processes on a cross-scale basis using advanced simulation methods (upscaling). The validation of the simulations takes place by means of experiment, including in underground laboratories. One special feature of the collaborative project is the involvement, funded by the Federal Ministry of Education and Research, of the Helmholtz centres as new partners in the international research programme in the Mont-Terri underground laboratory in Switzerland (Mt-Terri-Project), where a new experimental tunnel has been built with German assistance.

Further participation in experiments is envisaged at the Grimsel rock laboratory (crystalline rock). The work is thus concentrated on host rock formations which had not previously been a focus of German repository research. An important focus is placed on the involvement and networking of young scientists.

Holistic view of safe repository systems for nuclear waste

Beneficiaries: Research Centre Jülich and four other partners
Funding ID: 02NUK053A-E
Appropriated funding: €7.5 million (of which 50% is from federal project funding and 50% from programme-oriented research funding of the Helmholtz Association)
Project duration: 2018 – 2022
Project description on EnArgus:

MORE DETAILS



2.6.3 Repository research

The task of repository research is to provide and develop the scientific basis for the safe final disposal of radioactive waste, largely deriving from the operation of nuclear power plants, which is to cease at the end of 2022 as Germany phases out nuclear power.

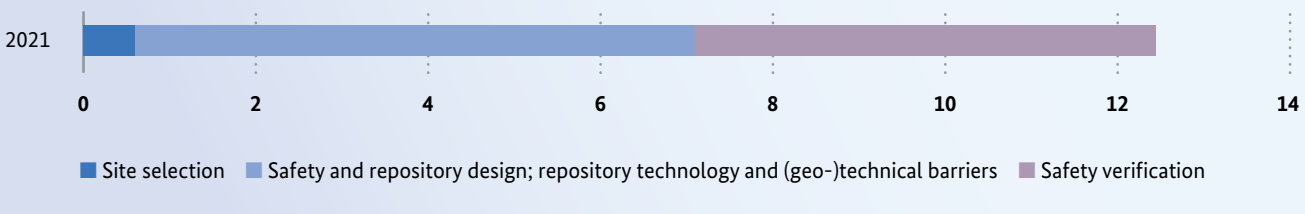
Funding priorities and scientific advances

Research covers questions of site selection, safety and repository designs, and the verification of safety. The funding priorities are the generation of experimental data in both field and laboratory tests, the further development of the methodology and the tools for the safety case, the study of the effectiveness of the barrier system including monitoring, the development of transport and storage technology designs, and scenario development for accompanying process management. The research field is rounded off by projects into socio-technical issues. New findings are also being arrived at in the international context via the integration of the work into the international project landscape. For example, in 2021 Germany participated in two new projects in the context of scientific and technical cooperation with international partners. This facilitated studies at specific sites and the acquisition of system-specific expertise. New cooperation projects began in 2021 with Swedish research establishments on final disposal in crystalline rock. Despite the pandemic, cooperation continued with both the United States and with China.

Project funding

The project funding provided by the Federal Ministry for Economic Affairs and Climate Action is complemented by the research funding provided by the Federal Ministry of Education and Research. The latter supports young scientists, thereby maintaining skills. In the field of final repositories, supplemented by the research into horizontal issues, the Federal Ministry for Economic Affairs and Climate Action provided approximately €16.22 million in funding for 115 ongoing projects in 2021. In addition, the ministry appropriated approximately €8.8 million in funding for 21 new research projects in 2021 (cf. figure 27)

Figure 27: Funding for research into repositories in € million
(Data cf. Table 7b, p. 95)



PROJECT ABSTRACT

Discussions involving the interested public in research activities

TRANSENS – *Transdisciplinary research on the disposal of high-level radioactive waste in Germany Research to improve the quality and resilience of the socio-technical design of the disposal path*

The TRANSENS project is the first one in Germany to engage in transdisciplinary research into the disposal of radioactive waste. Interested citizens are included in research activities of teams of scientists in order to promote the transfer of knowledge, learning processes, critical capabilities and mutual understanding. The research takes place in thematic corridors located at the interface between scientific and technical research on the one hand, and social science and humanities research on the other. The work examines the contribution that can be made by transdisciplinary research to understanding socio-technical processes relating to nuclear waste disposal, and thus to improving the quality and resilience of the German disposal approach and the scientific and technical foundations for a final repository.

Beneficiaries: Institute of Disposal Research of Technical University of Clausthal and nine other partners
Funding ID: 02E11849A-J
Appropriated funding: €14.78 million
(of which 75% is from federal project funding and 25% from the Volkswagen Foundation)
Project duration: 2019 – 2024
Project description on EnArgus:

MORE DETAILS

2.6.4 Radiation research

During the reporting year 2021, the Federal Ministry of Education and Research continued to support collaborative research and projects on radiation research under its funding guidelines for nuclear safety research and radiation research and the 7th Energy Research Programme.

Funding priorities and scientific advances

The Federal Ministry of Education and Research funds projects on radiobiological, radiation medicine, epidemiological and radioecological questions in the field of 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 continues to require expertise in the above-mentioned areas in public authorities, industry, research and medicine. Via these projects, the Federal Ministry of Education and Research supported approximately 150 junior researchers during their training in 2021, which means that this funding priority was able to make a substantial contribution to the formation and retention of expertise in the field of radiation research in Germany. The research conducted as part of the projects resulted in numerous publications in high-ranking and highly renowned scientific journals. The collaborative research was dedicated to highly relevant social and highly topical scientific issues. Some of the projects contributed with their research findings to the success of the National Decade Against Cancer. Overall, radiation research supplies the scientific basis to assess the risk deriving from radiation for health, and the benefit for technical and medical advances.

Project funding

In the field of radiation research, the Federal Ministry of Education and Research provided approximately €8.69 million in funding for 56 ongoing projects in 2021. In addition, the ministry appropriatedapproximately €1.29 million in funding for five new research projects in 2021 (cf. figure 28).

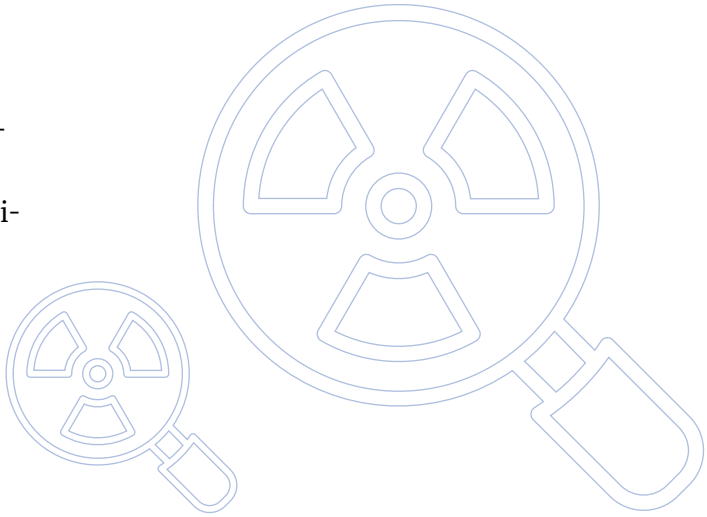
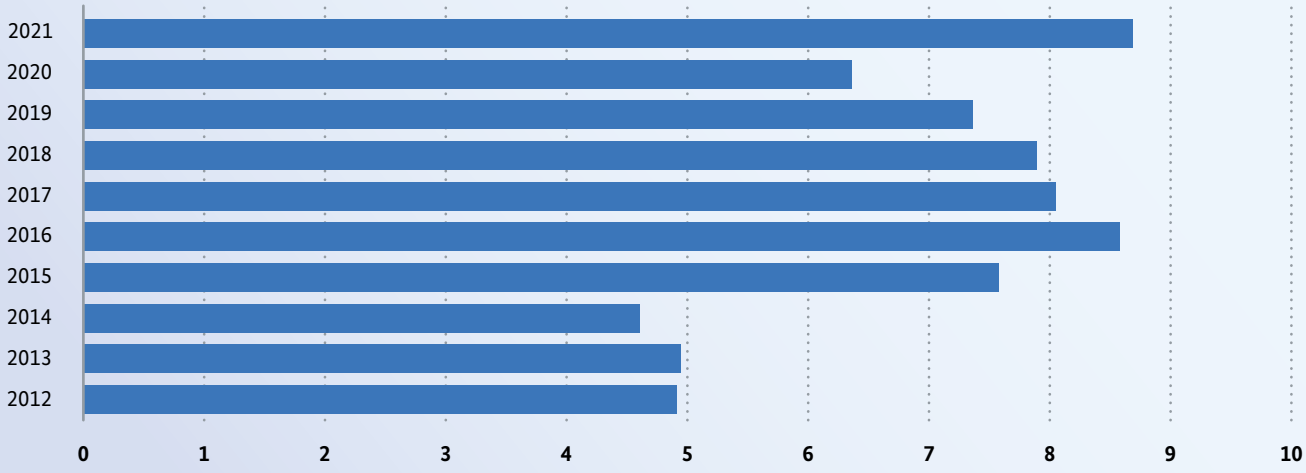
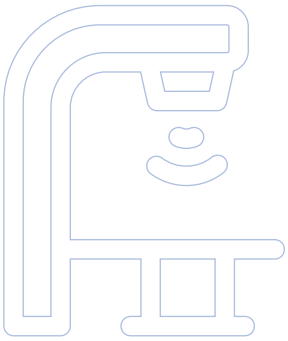


Figure 28: Funding for radiation research in € million (Data cf. Table 7b, p. 95)





3. Institutional energy research

3. Institutional energy research

Institutionally-funded research institutions make a major contribution to energy research in Germany. The Research Field "Energy" at the Helmholtz Association of German Research Centres (HGF) is an explicit part of the 7th Energy Research Programme, since it can be categorised as energy research due to its programme-based funding. In contrast, it is much less easy to categorise institutionally funded thematically-related research work by other research organisations such as the Fraunhofer Society, the Leibniz Association or the Max Planck Society, even though it is equally significant for energy research in Germany. Nevertheless, both basic and applied work by the afore-mentioned institutions and research findings from cross-cutting areas like material research also advance energy research.

Since 2021, the Research Field "Energy" has continued its research for the energy transition in new programmatic structures within the framework of the fourth period of programme-oriented funding (POF IV). The centres involved in the Research Field "Energy" in POF IV are the German Aerospace Center (DLR), the Research Centre Jülich (FZJ), the Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and the Karlsruhe Institute of Technology (KIT). The Max Planck Institute for Plasma Physics (IPP) is an associated scientific centre. The Research Field "Energy" tackles the challenges posed by the restructuring of the energy system by setting scientific priorities in four programmes.

The "energy system design" programme pursues a holistic approach. It pools expertise in system analysis, social science and economics relating to the design of the energy systems of the future. In addition to the analysis of energy systems, a focus is also placed on their digitalisation and the development of system technologies. Examples include the following activities:

- Establishment and operation of research infrastructure in the laboratories "Energy Lab 2.0" (Karlsruhe Institute of Technology), "Living Lab Energy Campus" (Research Centre Jülich) and "NESTEC" (DLR Institute of Networked Energy Systems).
- Forward-looking tools, such as freely available software solutions, data and benchmarks, have been made available to the public and researchers around the world via the Helmholtz Energy Computing Initiative (HECI).
- In order to be able to undertake a detailed analysis of the coupling of electricity and gas grids, suitable modelling and simulation approaches were developed jointly by the Helmholtz Centres, DLR, FZJ and KIT. Here, a role is also played by the use of hydrogen.
- Deployment of the Electrical Data Recorder (E.DR) developed at KIT in a worldwide measurement campaign. The data were archived and analysed at KIT and FZJ. Series of measurements, analysis software, equipment design and findings were published as an open database in Nature Communications.
- Identification of public perception of the bioeconomy in a computer-aided textual analysis of German newspaper articles. The findings show a discrepancy between the understanding of the bioeconomy between the public and the expert scientific community.

In the "Materials and Technologies for the Energy Transition" (MTET) programme, scientists take an interdisciplinary approach to materials and technologies for energy generation, conversion and storage as well as for energy and resource efficiency. These are some highlights from the MTET programme:

- Sustainable carbon-neutral fuels are an important element of the energy transition in areas that are difficult to electrify. The Future Fuels DLR project flagged up the significant reduction in the impact on the climate from aircraft using sustainable aviation fuel. Also, solar-based man-

ufacturing processes and novel patented hydrogen-optimised combustion concepts were developed.
- The KIT's bioliq® pilot plant demonstrated the concept of manufacturing green fuels from residual biomass with a high level of technological maturity in the "ReFuels" collaborative project.
- The use of liquid sodium as a heat carrier for concentrator power plants results in higher efficiency. As part of the SOMMER measurement campaign, output densities of up to four megawatts per square metre were achieved, and the results were highly stable.
- Perovskite/silicon tandem solar cells (cf. description of the world record PV cell of the HZB, p. 74).
- Highly detailed simulation methods were developed at the DLR which take account of structural and material-specific characteristics of battery electrodes. In combination with high-resolution analysis at the HZB and corresponding electrochemical characterisation, this was used to create a validated platform for the virtual design of battery materials which permits optimisation of the output and lifetime of novel batteries.
- A coupled system of large-area PV modules with direct hydrogen generation was set up and operated at FZJ. With a hydrogen generation efficiency rate of a little over 10%, more than 245,000 litres of hydrogen were produced in one year.
- For the first time, the gap was closed between highly brilliant X-ray examinations and the actual operation of catalytic converters for synthetic fuels under industrial conditions. A commercial catalyst for the generation of fuels was studied in realistic conditions.
- SOC Stack and System (cf. description of the high-temperature solid oxide converter (SOC) in reversible 9,000 hour operation to generate hydrogen and produce electricity from it (DLR and FZJ), p. 74).

The "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 the fusion research coordinated and funded at European level. Here are some highlights from the research done under the Fusion Programme:

- The IPP has made the hybrid scenario with magnetic pumping into a strong candidate for a stationary Tokamak scenario. Tokamak is the type of plant that has been most studied so far, and uses fusion with the help of magnetic confinement. The magnetic pumping works like a dynamo, and shifts the magnetic flow outside. This increases the central safety factor – a yardstick for the twisting of the magnetic field lines, and thus crucial for plasma stability – to the value of 1. This has two positive effects. Firstly, the central sawtooth instability is avoided. Secondly, via this route, power can be operated outside the centre, coupled with better efficiency of the centre due to the higher temperature. Through parameter variations in the ASDEX Upgrade, the "Axialsymmetric Divertor Experiment", it was possible to confirm that the driving of the magnetic pumping is scaled with the plasma pressure, and the deployment threshold depends on the electricity profile in the centre.
- Laser-based surface diagnostics is being developed and tested for in-situ monitoring of the in-vessel tritium inventory of the ITER test fusion reactor. Deposits of radioactive tritium in beryllium layers on tungsten in the inner divertor (device in the reactor to remove helium-4 and impurities) have been identified by experiments at the European JET fusion experiment. On top of these, there is modelling of JET and ITER as the key contribution to tritium retention. At FZJ, the study of beryllium layers with defined deuterium content on tungsten substrates using laser-induced desorption showed that, as the energy input increases due to laser pulses at the millisecond level, the deposited deuterium is entirely released and can be detected by quadrupol mass spectroscopy.

The "Nuclear Waste Management, Safety and Radiation Research" (NUSAFE) carries out key research work on intermediate and final storage, the dismantling of nuclear power plants, the safety of nuclear reactors, and radiation research. Here are some highlights from the research done under the NUSAFE Programme:

- In the context of the international nuclear material monitoring activities, the first officially available microparticle reference materials were certified for quality control. Also, a NUSAFE partner was officially qualified for the provision and supply of microparticle reference materials. Further to this, studies using X-rays were able to deliver new findings about the ageing process of uranium oxide particles following their production. These findings permit the first conclusions about appropriate storage conditions and the lifetime of the reference particles.
- The completion of a tailored open-source simulation platform permits the study of important processes in safety containers. Good results are achieved regarding prediction quality, scalability and numeric efficiency.

Figures 29a and b show the funding deployed in the Research Field "Energy".

Figure 29a: Funding for institutional energy research 2014 – 2020 in € million
(Data cf. Table 8, p. 96)

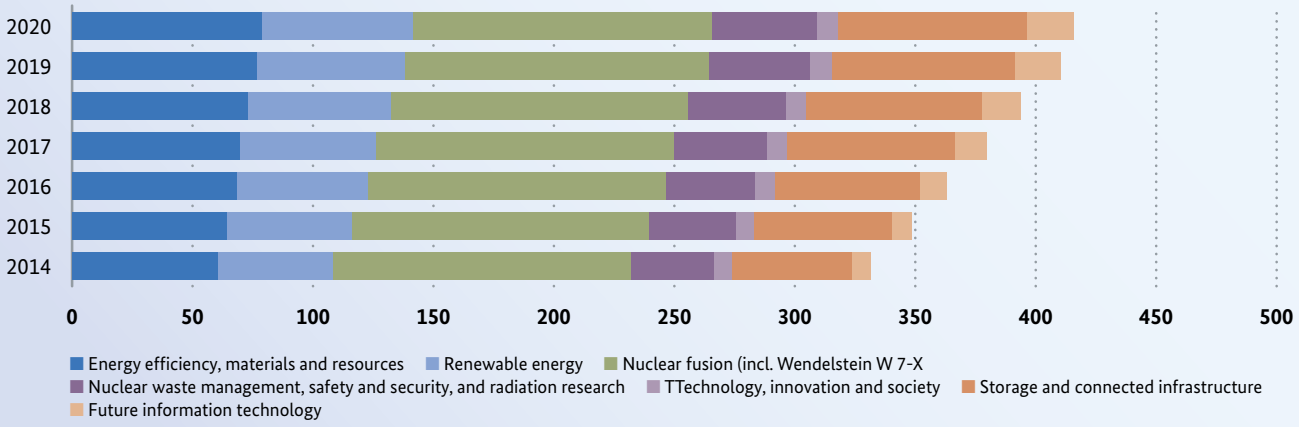
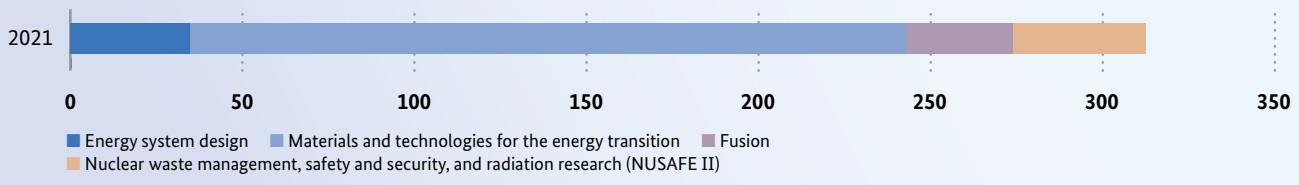


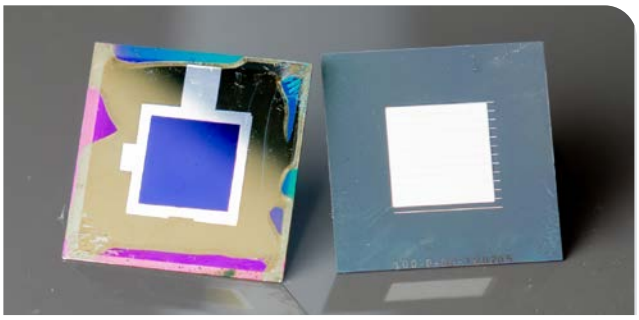
Figure 29b: Funding for institutional energy research from 2021 in € million
(Data cf. Table 8, p. 96)



PROJECT ABSTRACT

Perovskite/silicon tandem solar cells – *Improvements in optics deliver a world record PV cell*

Today's solar modules consist mainly of silicon. The combination of silicon with the more recent class of perovskite materials to form tandem cells has improved efficiency in recent years.
A further major step towards efficiency of 30% and more has now been achieved by a team at HZB through improvements in optics. With the aid of computer simulations, the best possible nanotexture for the silicon surface was identified. Improvements on the back of the cell optimised the inclusion of infrared light in the silicon absorber.
The new perovskite-silicon tandem solar cell was certified at a world record efficiency rate of 29.8% by Fraunhofer ISE CalLab, and registered on the renowned NREL efficiency chart.



The perovskite-silicon tandem cell is based on two innovations: a nano-textured front (left) and a back with dielectric mirror (right).

Participating Helmholtz centres: Helmholtz-Zentrum Berlin für Materialien und Energie
Participating programmes: Renewable energy (RE, PoF III) / Materials and technologies for the energy transition (MTET, PoF IV)

rSOC – *reversible high-temperature stack and system Proven in reversible 9,000 hour operation – SOC stack and system*

High-temperature solid oxide converters (SOCs) make it possible both to generate hydrogen using electricity from electrolysis, and also to do the reverse, operated as a fuel cell which generates electricity from hydrogen as needed. Here, the same cell stack can be used at a very high degree of efficiency for both processes.

Stack module for rSOC system

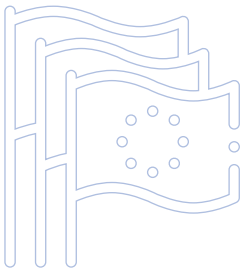
A 30 level stack was tested and measured at DLR alternately in the fuel cell and electrolysis mode for more than 9,000 operating hours and with more than 300 model switches in long-term operation. The lowest degradation rates seen internationally were attained for the reversible SOFC/SOEC operation (electrolysis: 0.25%/1,000 hours, fuel cell: 0.52%/1,000 hours).

A Jülich add-on structure was operated reversibly for more than 9,000 hours. For the first time, it was possible to demonstrate fuel gas use of more than 99%. Special operational management of the fuel gases made it possible to attain a comparatively high level of electrical efficiency of 62.7%, at a fuel cell output of 5.4 kilowatts direct current (0.5 amps per square centimetre).

Participating Helmholtz centres: German Aerospace Center (DLR), Research Centre Jülich (FZJ)
Participating programmes: Storage and connected infrastructure (SCI, PoF III)/Materials and technologies for the energy transition (MTET, PoF IV)

MORE DETAILS

4. European and international cooperation



4.1 European networking in energy research

Germany is actively involved in wide-ranging European research, innovation and networking activities in the field of energy. The strategic policy framework is provided by the European Green Deal, which aims at a modern, resource-efficient and competitive economy with no net greenhouse gas emissions by 2050.

Research and innovation are crucial for the transition to a stable and resilient energy system based on renewable energy. A particular contribution here is made by the European Strategic Energy Technology Plan (SET Plan), which promotes cooperation between EU countries, companies and research establishments, coordinates national research and adapts the availability of renewable energy resources.

The co-funded Clean Energy Transition Partnership (CETP) implements the funding measures in the context of the Horizon Europe research and innovation programme. Corresponding calls are being published by the participating countries from 2022. The CETP pools national and regional resources in order to overcome fragmentation in Europe's energy research. In its strategic research and innovation agenda, it focuses not least on the development of clean, affordable energy generation and conversion technology, the development of a climate-neutral, flexible and robust energy system, as well as storage technology and its integration into the energy system.

Germany is also involved in the co-funded partnership "Driving Urban Transitions to a Sustainable Future" (DUT). The DUT addresses global urban challenges via an integrational approach in order to offer solutions via cross-border coordinated research to the decision-makers in municipalities, companies and society. In addition to joint calls for proposals, the partnership will develop a European research and innovation centre for urban affairs and thus also contribute to the mission for climate-neutral and smart cities.

As an institutionalised public-private partnership on hydrogen, the Clean Hydrogen Joint Undertaking (CHJU) succeeded the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) in November 2021. It is intended to accelerate the improvement of clean hydrogen technologies along the entire value chain and will contribute to the goals of the European Hydrogen Strategy. In the coming seven years, up to €1 billion will be provided in Horizon Europe, supplemented by a further €1 billion from the private sector.

As proposed by Germany, an initiative on green hydrogen was launched in the context of the re-orientation of the European Research Area. The ERA Pilot on Green Hydrogen is developing a European research and innovation agenda for the competitiveness of green hydrogen.

Also, Germany is a leader in the initiation of Important Projects of Common European Interest (IPCEIs) for hydrogen (cf. Chapter 5.1 Federal Government innovation promotion beyond the Energy Research Programme, p. 84).

4.2 EU Research Framework Programme (Horizon Europe)

Horizon Europe is the ninth European framework programme for research and innovation (2021–2027) and, with a total budget of €95.5 billion, one of the EU's most important instruments to strengthen the European Research Area and to promote innovation and technology.

It makes a contribution towards attaining the UN Sustainable Development Goals and strengthens the competitiveness and growth of the EU, whilst also combating climate change. Horizon Europe facilitates cooperation between the business and research communities in the EU. Further to this, it strengthens the impact of research and innovation with a view to the development and implementation of EU policies and the tackling of global challenges.

Horizon Europe brings together research and innovation promotion in the energy sector in Cluster 5 – Climate, Energy and Mobility. 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 the first climate-neutral continent by 2050. This includes the transition to greenhouse gas neutrality of the energy and mobility sector by 2050 at the latest, whilst also boosting competitiveness, resilience and benefits to society.

The funding measures and activities of the work programmes thus aim to support implementation of the Paris Climate Agreement, the European Green Deal, the European Economic Recovery Plan and other EU priorities in the areas of climate, energy and mobility.

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

German applicants successful in the field of energy in Horizon 2020

Final figures for the preceding Horizon 2020 programme were presented in 2021. In the programme area of safe, clean and efficient energy, applicants from Germany were very well represented in collaborative projects. In the programming period from 2014 to 2020, roughly €4.281 billion in funding was provided for a total of 900 collaborative projects. Germany participated in 562 of these projects, with a total of 1,273 project participants. This means that actors from Germany were to be found in 62.4% of all collaborative projects in the energy sector of Horizon 2020, playing the responsible role of coordinator in 122 of these projects (figure 30). In total, German project participants were able to obtain approx. €557 million in funding. This places Germany in first place, ahead of Spain, France and Italy, with 13% of the total appropriated funding in this programme area (figure 31).

Figure 30: Number of beneficiaries by country in core area of energy research in Horizon 2020 (2014 – 2020)

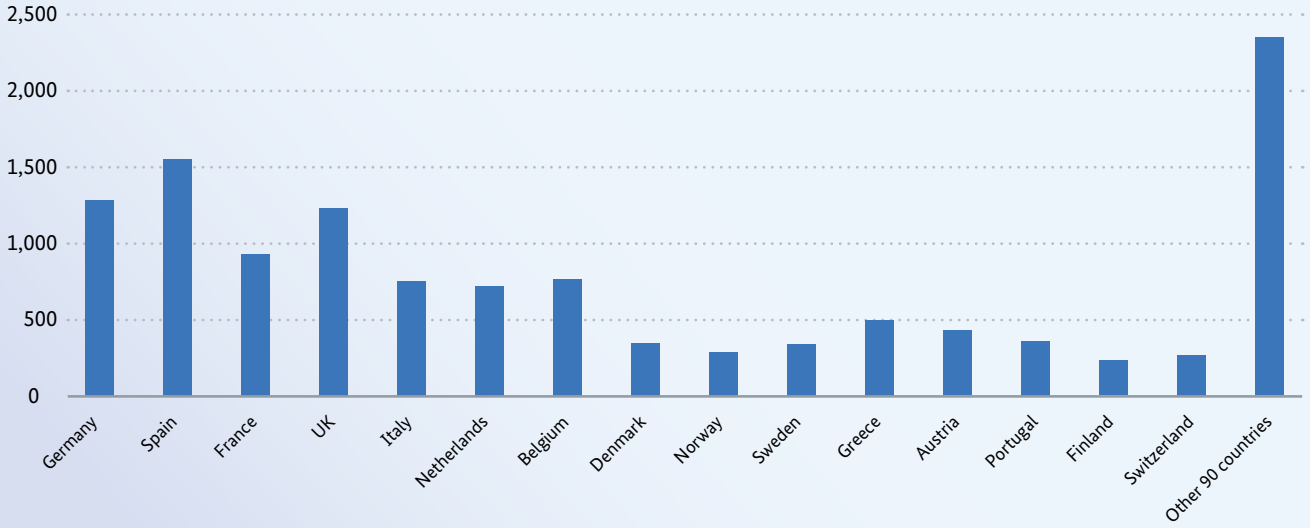
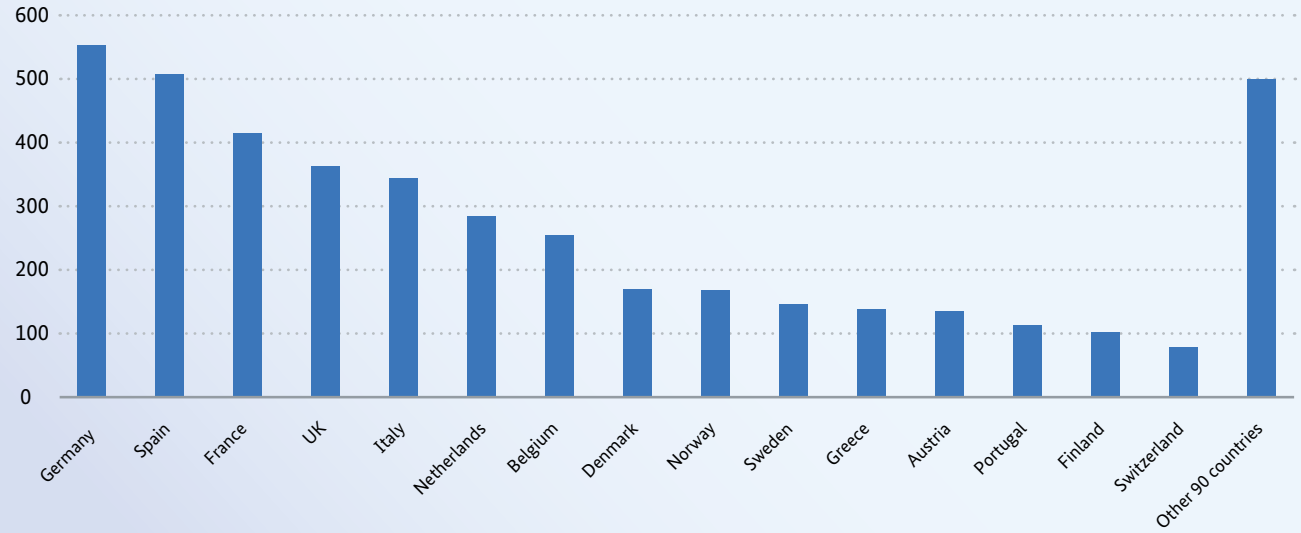


Figure 31: Breakdown of funding by country in core area of energy research in Horizon 2020 (2014 – 2020)



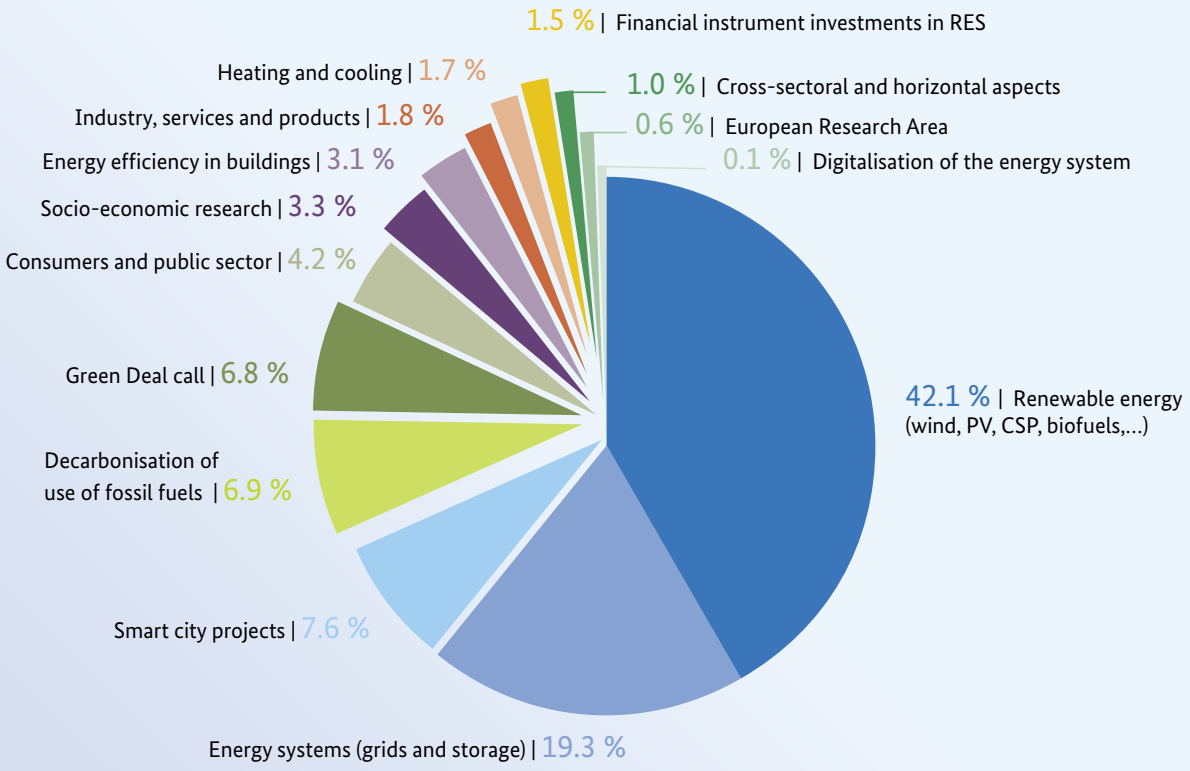
Priorities for energy research in Horizon 2020

More than 50% of the project participation of beneficiaries from Germany was concentrated on the fields of renewable energy and energy systems. 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 these fields of technology: renewable energy at 42.1% and energy systems (grids and storage) at 19.3%. These are followed by smart city projects (7.6%) and collaborative projects on decarbonisation in the use of fossil fuels (6.9%).

Hydrogen-related topics are not included in the diagram, since they were funded in the public-private partnership on Fuel Cells and Hydrogen (cf. Chapter 4.1 European networking in energy research, p. 76). In this programme area, Germany is involved in 107 or 80% of all collaborative projects. There were 278 German project participants (18.4% of all participants), who acquired around €160 million in funding. That equates to 25% of the total funding amount in the programming period.

Further energy-related topics such as material research outside the programme area of safe, clean and efficient energy are not included in this evaluation.

Figure 32: Breakdown of funding by topic in core area of energy research in Horizon 2020 (2014 – 2020)



4.3 International cooperation

Alongside the comprehensive European cooperation on energy research, the Federal Government also prioritises international cooperation in global organisations and initiatives.

International Energy Agency (IEA)

The International Energy Agency (IEA) is an independent organisation within the Organisation for Economic Co-operation and Development (OECD), and is devoted to international cooperation in the energy sector. Its focus in the field of technology and innovation lies on R&D, demonstration and the dissemination of sustainable technologies. The IEA unites 30 member states, including the Federal Republic of Germany under the auspices of the Federal Ministry for Economic Affairs and Climate Action, and eight associated partner states.

The energy research activities are coordinated by the Committee on Energy Research and Technology (CERT). The CERT has working parties and multilateral technology initiatives, known as Technology Collaboration Programmes (TCPs) covering the entire spectrum of energy technology.

Cooperation in the field of energy research takes place in these TCPs. The TCPs implement the IEA's technology programme, which is designed to help build a sustainable, safe and affordable global energy supply system. In addition to the IEA members, interested partner countries can also take part. Within the TCPs, research establishments and private-sector companies can work together in all fields of non-nuclear research and on fusion (via Euratom) on a cross-border basis. Germany is currently involved in 23 of the total of 38 ongoing TCPs. In 2021, Germany joined the C3E TCP, which aims to strengthen the role of women in the energy sector.

Mission Innovation

The intergovernmental initiative entitled Mission Innovation (http://mission-innovation.net) promotes the development, expansion and availability of clean, low cost energy technologies and solutions around the world. This is to be achieved via increased public investment and private-sector involvement. In addition, Mission Innovation aims to raise awareness of the potential offered by energy innovations.

Mission Innovation has 23 members – 22 countries and the European Commission – and was founded in 2015 at the 21st UNFCCC Conference of the Parties (COP21). In June 2021, the sixth ministerial meeting (MI-6) launched the second phase, triggering three new innovation missions. At COP26 in November 2021, four more missions were presented, aiming to expedite the development of clean technologies for cities, industry, carbon capture and climate-friendly fuels, chemicals and materials.

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 is involved in a variety of missions. Firstly, Germany, represented by the Federal Ministry for Economic Affairs and Climate Action, is a member of the Clean Hydrogen Mission. This 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. Further to this, the Federal Government is on board the Green Powered Future Mission. This is intended to enable electricity grids in different regions and climatic zones to effectively integrate up to 100% fluctuating renewable energy by

2030 into their generation mix, and also to maintain a cost-efficient, secure and resilient system. Also, the Helmholtz Association is participating in the Materials for Energy Innovation Platform, which aims to speed up the development of new materials for renewable energy technologies.

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 bilateral level in the field of energy research.

Bilateral cooperation in application-oriented basic research

The Federal Ministry of Education and Research is strengthening European cooperation on energy research via bilateral cooperation (2+2 projects). Since 2018, the Ministry has joined forces with the French Agence Nationale de la Recherche (ANR) to promote research cooperation on highly innovative solutions for an efficient, affordable and environmentally friendly energy supply which take an overarching approach to several sectors (energy, transport, industry and residential). In addition to technical aspects, a systemic approach is also being taken to economic and social challenges of the energy transition. Aspects of cooperation in the field of energy are regularly discussed in high-level bilateral meetings between the German and French Research Ministries.

Also, 2021 saw the completion of a large proportion of the eight German-Greek research associations on the subjects of “energy-saving technologies”, “technologies to generate and store renewable energy”, “smart grids”, “reduction of the harmful environment and climate-related effects of energy generation from conventional energy carriers”, and “scientific and technological support for public energy policy”. Alongside a high degree of innovation, the selected projects were also characterised by a high level of practical relevance for greater sustainability and more security in Europe’s energy supply. On the basis of this good experience in German-Greek cooperation, there are plans to expand it going forward via a further bilateral funding measure. This idea was fleshed out in the form of a joint declaration of intent in Athens on 20 July 2021 and signed by Deputy Minister Dimas and the then Parliamentary State Secretary Rachel. The focus is once again on renewable energy.

Green hydrogen agenda process

The Federal Ministry of Education and Research initiated a Member-State-led agenda process on research and innovation for green hydrogen during the German EU Council Presidency, and confirmed it in the context of Council conclusions on the new European Research Area. In 2021, urgent research and innovation questions were identified in a public pan-European dialogue process. The results were collated in a Strategic Research and Innovation Agenda for the European Research Area (SRIA), and published on 18 March 2022. There are plans to discuss ways to implement the SRIA findings at a hybrid conference of experts in Berlin on 16 – 17 May 2022, together with experts from EU Member States.

Framework announcement: “International cooperation on green hydrogen”

The framework announcement launched in March 2021 progresses networking of German stakeholders with international partners in research projects along the entire hydrogen value chain. It serves as a

basis for the design of tailored funding concepts for green hydrogen.

Canada is an important partner in the field of international hydrogen cooperation, particularly as a potential supplier of green hydrogen to Germany. In 2021, an announcement of funding for joint projects involving science and business was launched with Canada's National Research Council. Also, ten joint networking projects have been funded in cooperation with the Natural Sciences and Engineering Research Council (NSERC) since October 2021.

International green hydrogen future laboratory

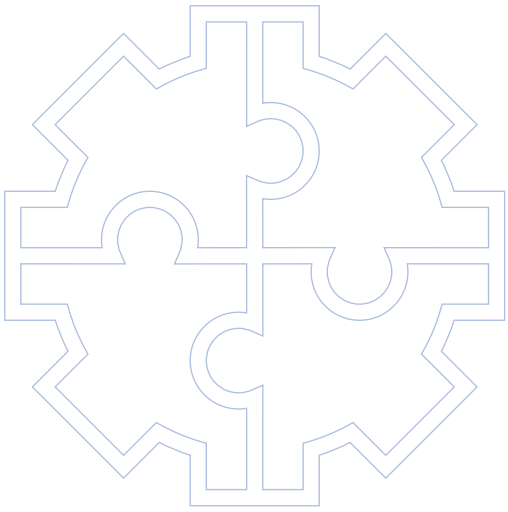
The international green hydrogen future laboratory funded by the Federal Ministry of Education and Research entitled "REDEFINE Hydrogen Economy (H2E)" started its research work at the Technical University of Munich on 1 December 2021. It is devoted to the environmentally friendly production of green hydrogen via novel technologies like high-temperature electrolysis, the innovative gasification of biomass, and the synthesis of basic chemicals and energy carriers. Scientists from 13 countries (Australia, Brazil, Canada, Germany, Italy, Lithuania, Netherlands, Poland, Portugal, Sweden, Switzerland, United Kingdom and United States) are working in the laboratory.

Partnership with Africa on renewable energy

The Federal Ministry of Education and Research is participating with €2 million in the five-year programme co-financed by the European Commission entitled "Long term European African Partnership on Renewable Energy" (LEAP-RE). LEAP-RE aims to help build a long-term partnership between Europe and Africa in the field of research and innovation. The first call for proposals in 2021 was addressed to stakeholders from science, business and society with research and development projects along the entire renewable energy value chain.

Cooperation with the Western Balkan countries

In the context of the technology-neutral call for proposals to promote research and development projects between Germany and the Western Balkan countries (WBC 2019), the Federal Ministry of Education and Research has been funding the NOVATRODES project since May 2021. In this project, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM has been working with Belgrade University in Serbia to develop innovative coated porous electrodes for the large-scale production of hydrogen.



5. Other energy-related research activities

5.1 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

Embedded in the National Hydrogen Strategy, the IPCEI on hydrogen was launched in December 2020 during the German presidency of the European Council by the Federal Ministry for Economic Affairs and Climate Action along with 22 EU Member States and Norway. On 28 May 2021, 62 large German projects were selected for the notification process. These include projects for facilities with electrolysis output of more than two gigawatts for the production of green hydrogen, innovative steel and chemical industry projects, and infrastructure and mobility projects. In this way, the market ramp-up of hydrogen technologies and systems is to be supported in the context of Important Projects of Common European Interest (IPCEIs). 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.

With more than €8 billion in federal and Länder funding, the IPCEI on hydrogen is the largest European project of its type so far; in Germany alone, it is to leverage €33 billion in investment along the entire hydrogen value chain.

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

The transport sector can 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 analyses, 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.

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. Since 2019, FEN has been operating the first research grid for medium-voltage direct current in the megawatt class on the campus of RWTH Aachen University.

Mobility2Grid is researching the energy transition and electric mobility in connected urban areas on the EUREF Campus in Berlin. Other examples of the research work are a virtual power station and battery storage of electric vehicles which serves the grid.

Living Labs Europe Competition (LLEC)

In the context of Germany's presidency of the European Council in 2020, the Federal Ministry for Economic Affairs and Climate Action introduced an initiative for an EU-wide competition format for the climate-neutral transformation of urban areas. Competitions are an attractive format with which to address broad groups across society. They are exciting, document outstanding achievements and offer a context to transform research ideas into practice more quickly. The Living Labs Europe Competition (LLEC) (https://www.ptj.de/living-labs) aims to produce neighbourhood transformations for climate-neutral neighbourhoods in the end-use sector. By awarding prizes to outstanding concepts at various points in the transformation, it creates publicity, flags up best cases and brings about processes of change for more inclusive, aesthetic and sustainable neighbourhoods.

The proposal fed in 2021 into a dialogue with the European Commission on potential cooperation with New European Bauhaus. In this initiative, the European Commission aims to fund projects which combine sustainability and aesthetics in the public arena. At working level, LLEC was anchored in the new Driving Urban Transition partnership (DUTP) as a central element of the exploitation strategy. The DUTP aims to progress the urban transformation as part of European research promotion programmes.

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 together on an interdepartmental basis in the National Hydrogen and Fuel Cell Technology Innovation Programme. 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 via the promotion of the procurement of hydrogen applications in the mobility sector. The aim of the NIP is to improve technological maturity and competitiveness via cost reduction.

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. In two ongoing funding measures, the focus of the research and development is both on the optimisation of individual production steps and processes and on their integration into the overall process to manufacture renewable fuel. Two further funding measures were published in 2022 to reduce further barriers to investment in generating installations through to the market ramp-up of these fuels.

Research programme "Radiation protection in the expansion of the power grid"

In order to further reduce scientific uncertainty about potential health effects in the field of magnetic fields associated with the expansion of the power grid, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection has designed the research programme "Radiation protection in the expansion of the power grid". This programme covers more than 40 individual projects and is being implemented in parallel to the expansion of the power grid. More than 10 individual projects have already been completed.

5.2 Research funding by the Länder

Since 2008, Project Management Jülich (PtJ) has undertaken an annual survey of the 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, for the 2020 financial year, total related Länder spending amounted to €387.4 million, with project funding accounting for €209.9 million and institutional funding accounting for €177.5 million.

The focus of the research policy is on promoting technology in the field of system integration and cross-system research issues, with funding totalling €142.6 million. Here, sector coupling is coming more to the fore than has been the case in previous years, and research work on energy storage technology (€54.7 million), hydrogen technology (€36.1 million), and fuel cells (€20.7 million) has also been expanded, some of it very considerably. Whilst Baden-Württemberg plays a leading role in the fields of energy storage (€16.9 million) and hydrogen (€14.1 million), Lower Saxony is heading the field in fuel cell research (nearly €7.6 million). The financial support for research into electricity grids stands at €9.1 million, just below the preceding year's level, and Lower Saxony again ranks first, investing €2.1 million.

The interactions between coupled energy sectors will be studied in the context of the overarching research discipline "energy system analysis", and will be considered on the basis of valid medium-term and long-term scenarios. The increasing complexity of the energy supply creates a need for comprehensive holistic system modelling; this is also reflected in the remarkable funding levels (€22 million) provided by the Länder. North Rhine-Westphalia is providing the largest contribution, €7.8 million.

In the direct year-on-year comparison, research funding for regenerative energy almost doubled to a total of €125.8 million. Here, the highest amount of financial support is going towards research into solar thermal/PV with spending of €36.1 million, the largest share coming from Bavaria (approx. €15 million). The research funding from the Länder has also been intensified in the field of wind energy (€24.8 million); due to its geography, Lower Saxony is investing far more than the other Länder, at €19.5 million). €22 million was provided in funding for bioenergy technology, similar to the previous year's level. Bavaria in particular is pressing ahead with this technology (€13.9 million).

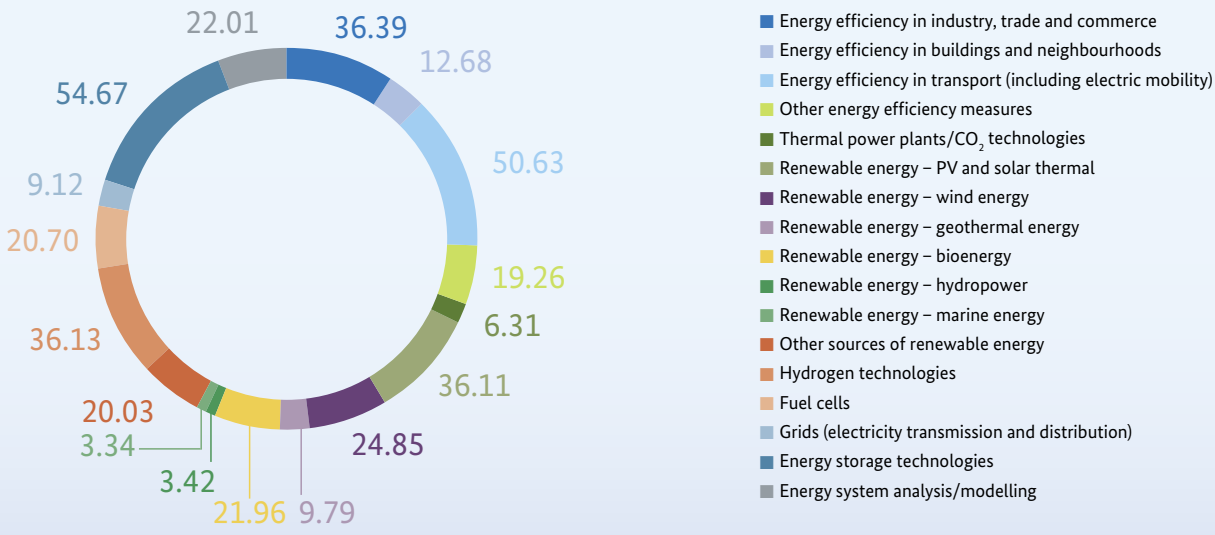
Geothermal energy (€9.8 million) has also seen a large rise in the level of funding; Lower Saxony is making use of its geological preconditions for research into this field (€5.8 million).

Research activities in the niche area of hydropower (funding of €3.4 million) aim solely to increase the capacity of existing installations. The topic of marine energy (€3.4 million) mainly covers the development of turbines and converters; here, Lower Saxony is providing €3 million.

In the funding area of thermal power plants/CO_2 technologies, the research activities in 2020 totalled €6.3 million, of which the highest amount (€3.3 million) was provided by North Rhine-Westphalia, a centre of the power station sector.

Another key pillar in German energy research is funding measures to boost energy efficiency in the consumption sectors; the Länder are providing a total of €118.9 million towards this. As in previous years, energy efficiency in transport, which also covers the expansion of electric mobility, is the main focus of technology-specific spending, at €50.6 million. Particular mention should be made in this regard of the comprehensive spending on research by the car-making state of Baden-Württemberg (€19 million). The Länder earmarked €12.7 million in funding for research into energy efficiency in buildings and neighbourhoods, with Hesse contributing €4.2 million. Research into energy efficiency in the industrial sector, trade and commerce was also funded by the Länder (€36.4 million in total), especially Berlin, where the main focus of the funding was on this type of research (€8 million).

Figure 33: Spending by the Länder on non-nuclear energy research by funding topic in line with IEA technology classification from 2018 (Data cf. Table 12, p. 99)



With funding totalling €87.9 million, Lower Saxony spends most on energy research promotion, followed by Baden-Württemberg (€78.7 million), Bavaria (€76.5 million), North Rhine-Westphalia (€43.8 million) and Saxony (€28.5 million). The scale of research funding in Hamburg (€16.9 million), Hesse (€16.2 million) and Schleswig-Holstein (€9.3 million) is also extremely impressive.

With their funding of more than €387 million in total for non-nuclear energy research, the Länder are making a major contribution to the national energy transition processes and to the achievement of the energy policy goals postulated by the Federal Government.

Alongside all other Länder reports published to this date, the more detailed version of the report on "Funding for non-nuclear energy research by the Länder in 2020" [in German] can be accessed on the above-mentioned website of Project Management Jülich (PtJ).

Figure 34: Spending of Länder on non-nuclear energy research by Land 2014-2020 in € million
(Data cf. Table 10, p. 98)

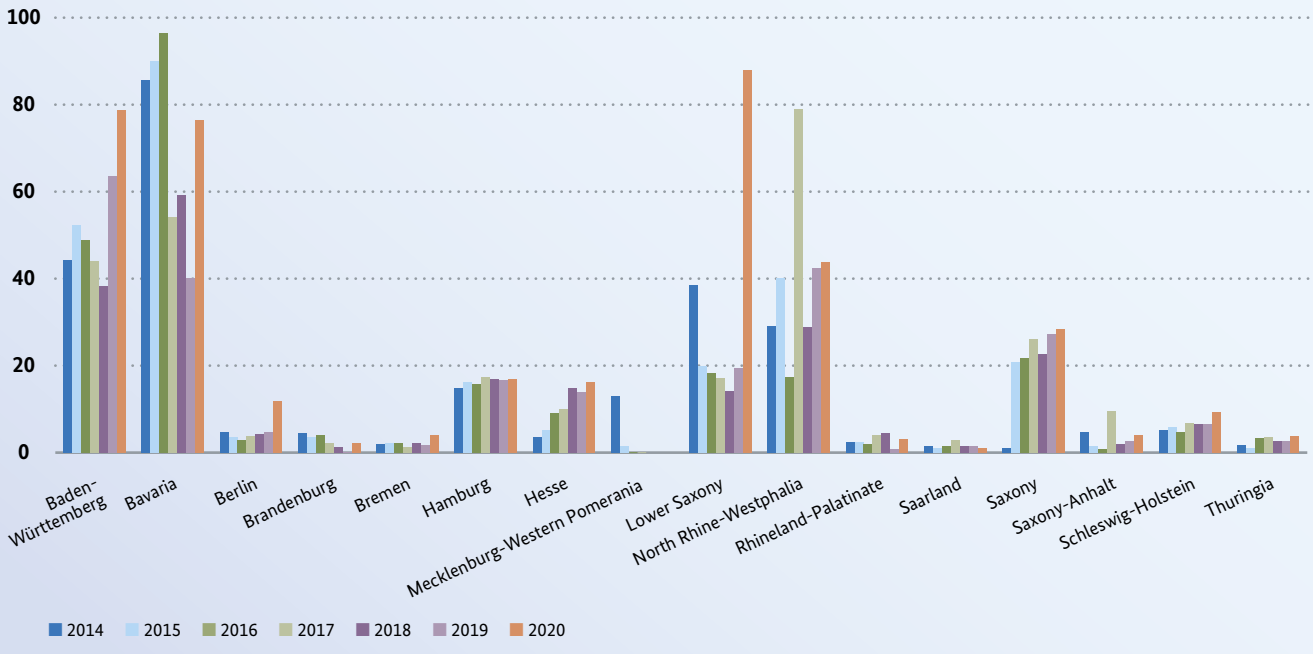
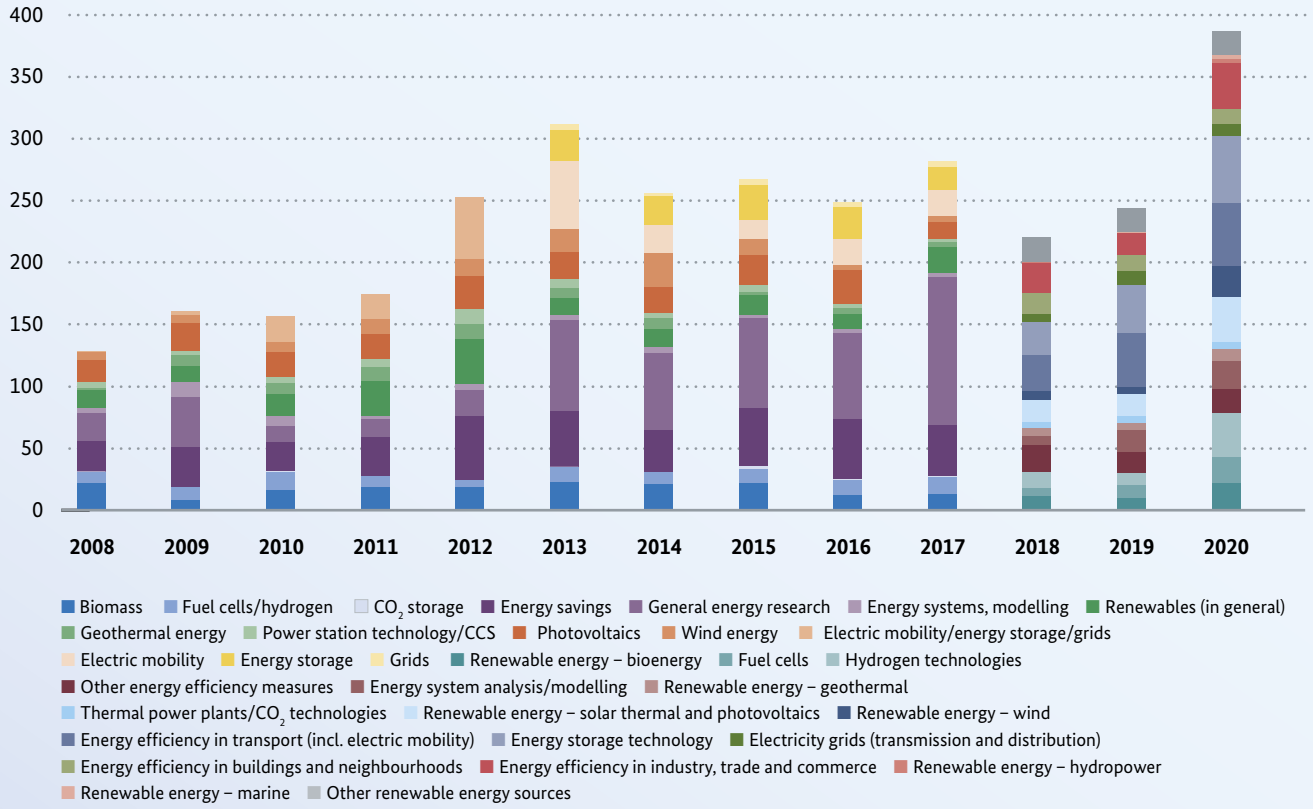


Figure 35: Spending of Länder on non-nuclear energy research by funding topic 2008-2020 in € million

(Data cf. Table 11 – 12, p. 98/99)



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
Project funding	**487.65**	**525.44**	**536.28**	**659.45**	**635.25**	**703.66**	**750.59**	**945.17**
Strategic funding formats						–	5.53	66.93
Energy transition in the consumption sectors	115.89	112.04	108.08	137.28	156.04	193.92	208.03	212.92
Energy generation	198.95	209.86	191.67	244.49	212.36	255.36	252.60	288.39
System integration: grids, storage, sector coupling	95.22	113.30	119.79	144.44	127.15	127.11	146.61	201.69
Cross-system research topics of the energy transition	34.29	44.49	71.01	86.12	92.22	78.31	91.61	123.42
Nuclear safety research	43.29	45.74	45.73	47.13	47.48	48.98	46.21	51.82
Institutional funding (Helmholtz Association)	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**	**415.78**	**314.42**
Accompanying measures	**28.14**	**34.72**	**35.03**	**28.20**	**25.76**	**34.47**	**49.63**	**51.38**
Total	**847.39**	**908.85**	**934.12**	**1,067.28**	**1,054.75**	**1,148.42**	**1,216.00**	**1,310.97**

Table 2 | Disbursements of project funding in the area “Strategic funding formats: Regulatory Sandboxes for the Energy Transition and hydrogen flagship projects”

Funding topic	Actual outlays in € million			Number of projects		Total funding in € million
	2019	2020	2021	ongoing in 2021	new in 2021	appropriated in 2021
Regulatory Sandboxes for the Energy Transition	**–**	**5.53**	**18.29**	**147**	**87**	**216.23**
Energy-optimised and climate-neutral buildings	–	0.14	1.22	5	–	–
Energy-optimised and climate-neutral neighbourhoods	–	1.70	5.06	47	17	41.61
Supply of heat and cold	–	0.06	0.80	17	12	21.31
Energy transition in industry, commerce, trade and services	–	–	–	3	3	37.13
Use of biogenic residue and waste materials for energy purposes	–	1.01	1.22	5	–	–
Geothermal energy	–	0.35	1.66	7	–	–
Thermal power plants	–	2.17	2.72	2	–	–
Hydrogen production	–	0.11	5.04	49	33	93.85
Systemic approaches	–	–	0.54	8	8	7.59
Digitisation in the energy transition	–	–	0.04	4	14	14.74
Hydrogen flagship projects	**–**	**–**	**48.64**	**326**	**328**	**688.48**
Storage and transport / TransHyDE	–	–	10.71	105	105	134.76
Hydrogen production / H_2Giga and H_2Mare	–	–	37.93	221	223	553.72
Total	**–**	**5.53**	**66.93**	**473**	**415**	**904.71**

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
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	ongoing in 2021	new in 2021	appropriated in 2021
Energy transition in buildings and neighbourhoods	**47.52**	**60.11**	**66.11**	**61.85**	**58.21**	**65.38**	**78.63**	**93.51**	**101.27**	**98.57**	**1.043**	**235**	**117.27**
Energy-optimised and climate-neutral buildings	25.83	31.82	36.55	35.64	32.00	36.57	39.78	50.24	47.86	44.90	539	102	31.12
Energy-optimised and climate-neutral neighbourhoods	8.60	10.67	10.59	9.65	12.94	17.57	22.52	25.35	31.51	31.24	291	70	38.68
Basic research into energy-optimised and climate-neutral neighbourhoods	3.63	4.49	5.19	4.65	3.88	2.73	7.50	10.22	13.63	9.92	79	20	11.21
Thermal energy storage	2.38	4.15	6.51	7.33	5.75	4.84	5.33	4.65	4.52	4.19	48	16	9.87
Supply of heat and cold	7.08	8.99	7.27	4.59	3.64	3.67	3.51	3.06	3.74	7.15	83	24	11.61
Basic research into supply of heat and cold	–	–	–	–	–	–	–	–	–	1.17	3	3	14.78
Other	–	–	–	–	–	–	–	–	–	–	–	–	–
Energy transition in industry, commerce, trade and services	**31.58**	**39.69**	**37.17**	**37.39**	**36.00**	**57.12**	**60.92**	**66.20**	**64.88**	**73.49**	**720**	**184**	**93.68**
Waste heat use	4.37	4.21	3.88	4.98	4.03	2.78	1.26	0.55	0.56	0.98	20	5	2.71
Chemical process technology	5.23	7.30	7.13	7.49	9.11	12.83	12.83	11.22	9.21	9.12	117	28	23.26
Iron, steel and non-ferrous metals	1.81	1.77	0.98	0.97	0.86	1.09	2.07	3.56	3.15	2.36	46	9	6.02
Circular economy	–	0.05	0.34	0.32	0.12	0.03	–	–	0.16	0.29	6	–	–
Manufacturing technology	10.93	15.93	17.13	15.82	11.09	14.82	17.49	23.19	24.80	24.75	265	65	26.57
High-temperature superconductivity	2.81	3.10	2.37	0.53	0.62	1.18	1.15	1.07	0.70	2.15	9	–	–
Industrial motors	–	–	–	–	–	–	–	–	–	–	–	–	–
Digitisation in industry	0.44	0.65	0.70	0.74	1.07	1.59	1.69	1.61	0.66	2.30	21	15	7.79
Material and resource efficiency	0.09	0.06	0.07	0.09	0.01	0.18	0.28	0.49	0.43	0.37	4	–	–
Process heat	2.02	3.41	3.29	4.14	5.65	8.15	8.58	9.45	9.36	10.51	90	31	15.71
Water treatment	–	–	0.04	0.18	0.35	0.72	0.58	0.57	0.51	0.41	9	–	–
Flexible industrial processes	–	–	–	–	–	10.70	12.54	10.80	10.43	14.05	58	2	1.10
Other	3.89	3.22	1.24	2.12	3.07	3.03	2.44	3.67	4.93	6.19	75	29	10.53
Energy transition in the transport sector	**14.22**	**17.83**	**12.61**	**12.80**	**13.87**	**14.78**	**16.49**	**34.21**	**41.87**	**40.85**	**326**	**51**	**22.76**
Battery technology for mobile applications	14.22	17.83	12.61	12.80	13.87	14.28	15.63	17.06	17.80	16.59	159	34	11.95
Synthetic fuels	–	–	–	–	–	0.50	0.86	13.51	16.19	16.29	111	11	7.49
Basic research into synthetic fuels	–	–	–	–	–	–	–	3.64	7.44	6.49	38	–	–
Charging infrastructure and systems integration	–	–	–	–	–	–	–	–	0.44	1.48	18	6	3.32
Other	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	**93.33**	**117.63**	**115.89**	**112.04**	**108.08**	**137.28**	**156.04**	**193.92**	**208.03**	**212.92**	**2,089**	**470**	**233.71**

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
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	ongoing in 2021	new in 2021	appropriated in 2021
Photovoltaics	**66.74**	**62.73**	**56.83**	**67.41**	**59.78**	**81.90**	**78.24**	**98.69**	**86.19**	**88.39**	**487**	**105**	**64.23**
PV technologies	10.11	9.88	7.22	5.64	2.65	2.75	5.24	11.75	12.40	16.40	73	19	11.60
Quality assurance	3.49	2.80	2.65	3.07	3.79	4.60	3.65	3.97	3.83	5.24	55	30	12.22
Manufacturing technologies	31.33	32.49	28.77	36.05	36.10	55.93	58.11	58.86	56.81	50.05	250	36	22.35
Circular economy	0.75	0.85	0.63	0.91	0.99	1.14	0.82	1.01	1.16	1.72	13	1	0.96
Systems capability	2.43	1.87	2.40	3.40	4.57	5.41	6.85	5.99	5.50	4.00	49	9	5.31
Basic research into photovoltaics	15.21	14.49	14.83	11.59	6.17	3.51	1.33	2.69	2.27	4.39	6	1	4.49
Other	3.41	0.34	0.34	6.75	5.51	8.56	2.24	14.41	4.23	6.60	41	9	7.30
Wind energy	**38.24**	**52.57**	**52.88**	**52.85**	**49.68**	**75.11**	**59.73**	**72.95**	**76.06**	**82.87**	**472**	**84**	**43.90**
Plant development	5.74	18.14	23.40	27.09	21.99	42.92	29.13	34.69	41.82	42.79	181	23	13.85
Logistics, installation, maintenance and operation	11.83	7.38	5.25	5.18	7.38	11.00	8.34	8.30	7.83	9.96	104	25	9.99
Offshore wind energy	8.30	16.09	14.34	9.19	10.45	11.56	12.03	15.88	17.61	18.67	90	18	13.60
Environmental aspects of wind energy	7.25	4.91	4.31	3.23	2.25	2.48	2.42	3.34	2.83	3.08	31	6	1.33
Wind physics and meteorology	0.21	1.78	2.34	3.63	3.03	3.06	2.33	2.96	3.70	6.18	46	8	4.56
Other	4.91	4.27	3.24	4.53	4.58	4.08	5.49	7.79	2.26	2.18	20	4	0.57
Bioenergy	**40.83**	**42.57**	**43.00**	**42.10**	**37.88**	**33.03**	**28.54**	**40.52**	**48.37**	**63.72**	**762**	**195**	**47.10**
Production – farming	6.91	6.31	5.98	4.43	4.69	5.70	6.52	10.86	14.39	18.97	243	78	19.10
Production – cultivation	4.43	5.25	4.77	4.92	4.49	4.58	4.20	4.44	4.78	4.35	57	17	4.51
Conversion – general	–	–	–	0.53	5.22	2.73	4.46	5.03	4.64	3.76	64	12	2.30
Conversion – gaseous	4.61	4.87	5.27	6.84	4.92	6.79	5.04	4.88	6.05	6.46	113	34	7.97
Conversion – liquid	4.11	6.12	6.19	5.92	3.97	3.21	1.98	1.12	0.68	0.78	8	1	0.28
Conversion – solid	2.78	0.94	0.73	1.92	2.23	1.77	1.34	2.43	3.85	3.49	41	3	0.83
Use of biogenic residue and waste materials for energy purposes	7.52	6.05	5.06	4.69	3.66	4.17	4.20	5.12	7.71	10.48	199	47	11.05
Basic research into bioenergy	8.61	9.81	12.16	9.89	6.17	3.13	0.22	5.83	4.63	13.13	11	–	–
Cross-section	1.86	3.22	2.85	2.97	2.53	0.94	0.59	0.80	1.65	2.29	26	3	1.05
Thermal power plants	**19.68**	**29.38**	**29.39**	**32.22**	**29.44**	**34.14**	**29.05**	**28.30**	**25.72**	**29.77**	**360**	**74**	**39.12**
Combined-cycle power plants with flexible loads and fuels	11.00	21.01	20.12	20.82	18.42	22.87	18.01	17.74	16.22	17.41	210	33	18.71
Solar thermal power plants	4.82	5.72	6.23	8.01	7.21	6.20	6.13	6.75	8.19	9.19	111	27	11.43
Other	3.87	2.66	3.04	3.39	3.81	5.07	4.90	3.80	1.31	3.17	39	14	8.98
Geothermal energy	**21.42**	**17.61**	**15.64**	**13.61**	**12.89**	**18.15**	**15.38**	**13.19**	**14.01**	**22.71**	**111**	**25**	**19.47**
Hydroelectric and marine power	**0.98**	**1.25**	**1.21**	**1.68**	**2.01**	**2.15**	**1.40**	**1.71**	**2.26**	**0.93**	**8**	**–**	**–**
Total	**187.89**	**206.10**	**198.95**	**209.86**	**191.67**	**244.49**	**212.36**	**255.36**	**252.60**	**288.39**	**2,200**	**483**	**213.83**

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
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	ongoing in 2021	new in 2021	appropriated in 2021
Electricity grids	**12.20**	**27.31**	**31.24**	**54.32**	**66.32**	**78.14**	**66.24**	**64.85**	**65.05**	**69.75**	**556**	**100**	**54.75**
Security of supply	1.04	2.32	2.23	7.50	12.75	13.10	13.51	11.02	12.11	10.52	78	14	8.23
Flexibility in the power grid	6.67	7.75	5.88	7.21	6.60	6.30	7.13	7.14	10.71	13.88	118	9	2.43
Grid planning and operational management	2.80	7.82	9.53	15.65	19.45	19.56	14.74	13.35	12.29	11.54	124	37	16.92
Technology for the electricity grid	1.69	9.42	12.64	16.39	17.52	21.07	17.71	22.50	19.36	20.83	193	38	18.29
Basic research into electricity grids	–	–	0.96	7.57	10.01	18.11	13.15	10.85	10.58	12.97	43	2	8.88
Other	–	–	–	–	–	–	–	–	–	–	–	–	–
Electricity storage	**13.23**	**31.43**	**29.57**	**28.63**	**27.69**	**22.35**	**18.37**	**21.43**	**22.53**	**25.47**	**228**	**48**	**19.09**
Electrical storage	-	-	-	-	-	0.02	0.61	0.63	0.63	0.39	15	6	1.60
Electrochemical storage	1.60	3.96	3.99	4.36	5.22	8.54	8.99	8.68	11.19	15.64	121	24	10.95
Electricity-thermal-electricity storage	–	–	–	–	0.58	1.39	1.54	2.36	2.42	2.60	6	–	–
Mechanical storage	1.19	3.26	1.53	1.97	2.60	3.19	2.53	2.65	3.48	1.76	20	5	1.78
Basic research into energy storage	10.20	19.37	17.21	15.61	10.79	3.60	1.17	3.77	2.30	1.56	21	–	–
Other	0.25	4.84	6.84	6.70	8.50	5.59	3.54	3.34	2.52	3.53	45	13	4.77
Sector coupling and hydrogen technologies	**20.33**	**30.85**	**34.41**	**30.35**	**25.77**	**43.95**	**42.53**	**40.82**	**59.02**	**106.47**	**396**	**223**	**220.99**
Hydrogen production	1.08	4.78	6.35	7.17	5.70	6.66	4.21	1.13	0.86	2.36	30	23	11.83
Hydrogen storage and transport	2.17	3.84	3.46	2.76	2.85	4.36	4.90	5.73	4.10	4.50	46	26	10.39
Fuel cells	15.64	19.58	18.82	15.23	10.04	15.67	13.81	14.31	15.17	13.48	121	62	29.74
Systemic approaches	–	0.62	0.96	1.12	0.99	0.32	0.33	0.46	0.43	1.60	9	2	1.19
Power-to-X	1.45	0.96	0.40	0.39	0.19	0.62	1.06	1.33	1.35	1.58	13	3	1.38
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	145	91	160.58
Other	–	–	1.39	1.58	1.37	0.79	0.85	0.08	1.13	2.83	32	16	5.89
Total	**45.76**	**89.60**	**95.22**	**113.30**	**119.79**	**144.44**	**127.15**	**127.11**	**146.61**	**201.69**	**1.180**	**371**	**294.83**

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
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	ongoing in 2021	new in 2021	appropriated in 2021
Energy system analysis	**6.02**	**8.06**	**8.39**	**9.32**	**11.18**	**15.01**	**15.94**	**17.16**	**18.97**	**19.74**	**224**	**49**	**21.48**
Digitisation in the energy transition	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**2.68**	**5.06**	**44**	**–**	**–**
Resource efficiency in the context of the energy transition	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**0.07**	**4**	**43**	**10.66**
CO_2 technologies	**8.47**	**5.97**	**6.60**	**4.28**	**15.06**	**18.15**	**24.58**	**19.57**	**35.05**	**32.87**	**102**	**48**	**25.34**
CO_2 transport and storage	0.72	0.74	0.67	0.38	–	0.18	0.96	1.23	1.22	0.49	10	6	1.77
CO_2 sequestration	7.75	5.12	3.90	1.80	3.46	3.30	2.11	1.23	1.95	2.48	29	17	5.46
CO_2 conversion and use	–	0.11	0.27	1.30	2.64	2.83	4.61	3.04	6.15	3.35	28	20	7.84
Basic research into CO_2 technologies	–	–	1.76	0.79	8.95	11.84	16.90	14.08	25.74	26.54	35	5	10.27
Collective industrial research programme cooperation	**–**	**–**	**–**	**–**	**0.05**	**2.52**	**4.22**	**5.47**	**4.90**	**5.71**	**47**	**8**	**3.90**
Energy transition and society	**–**	**1.18**	**3.25**	**3.95**	**2.64**	**10.02**	**9.93**	**10.15**	**6.37**	**12.28**	**107**	**41**	**8.93**
Energy transition and society – applied energy research	–	–	–	–	–	–	–	0.00	1.23	4.12	81	41	8.93
Basic research into energy transition and society	–	1.18	3.25	3.95	2.64	10.02	9.93	10.14	5.14	8.16	26	–	–
Materials research	**–**	**–**	**0.72**	**10.41**	**27.87**	**26.68**	**18.21**	**10.30**	**2.90**	**3.96**	**7**	**–**	**–**
Basic research into the energy-related use of the subsurface	**4.51**	**4.65**	**4.22**	**3.69**	**3.59**	**1.81**	**2.02**	**1.36**	**2.35**	**3.55**	**43**	**4**	**2.20**
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**	**88**	**4**	**18.91**
Other basic research	**20.95**	**16.99**	**10.07**	**10.84**	**9.96**	**11.64**	**15.22**	**10.42**	**6.64**	**15.70**	**18**	**8**	**10.59**
Total	**39.95**	**36.90**	**34.29**	**44.49**	**71.01**	**86.12**	**92.22**	**78.31**	**91.61**	**123.42**	**684**	**205**	**102.01**

Table 7a | Disbursements of project funding in the field 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 (Research Ministry programmes)	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 (Research Ministry programmes)	2.77	1.62	3.39	3.39	2.68	1.73	1.23	1.19	0.79
Radiation research (Research Ministry)	**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 field of "nuclear safety research" from 2021

Funding topic[1]		Number of projects		Total funding in € million
	2021	ongoing in 2021	new in 2021	appropriated in 2021
Reactor safety research	**22.39**	**153**	**38**	**27.97**
Examining and assessing the safety of components and structures	5.03	47	13	5.58
Detection methods to manage transients, incidents and accidents	14.04	78	16	15.32
Human-technology interaction and probabilistic safety analyses	2.01	16	1	0.99
Funding for young researchers (Research Ministry programmes)	1.32	12	8	6.07
Research into extended intermediate storage and the treatment of highly radioactive waste	**5.18**	**46**	**8**	**2.80**
Extended intermediate storage	1.52	11	1	0.46
Waste treatment and conditioning options for final disposal	–	–	–	–
Treatment and disposal methods	0.02	2	3	0.34
Funding for young researchers (Research Ministry programmes)	3.64	33	4	1.99
Repository research	**12.44**	**98**	**20**	**8.46**
Site selection	0.60	6	2	1.60
Safety and repository design; repository technology and (geo-)technical barriers	6.49	46	15	4.10
Safety verification	5.36	46	3	2.76
Funding for young researchers (Research Ministry programmes)	–	–	–	–
Research on cross-cutting issues	**3.12**	**16**	**1**	**0.34**
Knowledge and skills management	1.05	2	–	–
Socio-technical issues	1.82	12	–	–
Nuclear material monitoring (safeguards)	0.25	2	1	0.34
Funding for young researchers (Research Ministry programmes)	–	–	–	–
Radiation research (Research Ministry)	**8.69**	**56**	**5**	**1.29**
Total	**51.82**	**369**	**72**	**40.85**

1 Reorientation of funding from 2021

Table 8 | Institutional support

Funding topic	Actual outlays in € million							
	2014	2015	2016	2017	2018	2019	2020	2021
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 security, 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 connected infra-structure	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								**312.42**
Energy system design								34.60
Materials and technologies for the energy transition								208.09
Fusion								31.28
Nuclear waste management, safety and security, and radiation research (NUSAFE II)								38.46
Gesamt[1]	**331.60**	**348.69**	**362.81**	**379.63**	**393.75**	**410.29**	**415.78**	**314.42**

1 Note
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 Federation'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
Project funding and accompanying measures				**800.21**	**996.55**
0901 / 68601[3]	Federal Ministry for Economic Affairs and Climate Action	Innovation, technology and new mobility	Industrial research for companies		3.85
0903 / 68301	Federal Ministry for Economic Affairs and Climate Action	Energy and sustainability	Energy research	534.50	572.26
0903 / 68602	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	Regulatory Sandboxes for the Energy Transition		18.98
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 regenerative raw materials and to promote national projects of sustainable forest management & Grants to promote research, development and demonstration projects in the field of regenerative raw materials (investment)	37.83	42.11
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
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	10.68	14.32
3004 / 68542[3]	Federal Ministry of Education and Research	Research for innovation, high-tech strategy	Environmental technology, resources and georesearch		3.55
6092 / 68304	Federal Ministry for Economic Affairs and Climate Action	Energy and Climate Fund	Measures to develop electric mobility	14.64	15.37
6092 / 68502	Federal Ministry of Education and Research	Energy and Climate Fund	Application-oriented basic research into green hydrogen	29.42	99.79
6092 / 68616[3]	Federal Ministry for Economic Affairs and Climate Action	Energy and Climate Fund	Prevention and use of CO_2 in basic industries		0.11
6092 / 68626[4]	Federal Ministry for Economic Affairs and Climate Action	Energy and Climate Fund	Regulatory Sandboxes for the Energy Transition[5]	17.04	
6092 / 89203[3]	Federal Ministry for Economic Affairs and Climate Action	Energy and Climate Fund	Implementation of the National Hydrogen Strategy		0.01
6092 / 89304[3]	Federal Ministry for Economic Affairs and Climate Action	Energy and Climate Fund	Industrial manufacturing for mobile and stationary energy storage		–
Institutional funding (HGF)				**415.78**	**314.42**
0901 / 68531 & 0901 / 89431	Federal Ministry for Economic Affairs and Climate Action	Innovation, technology and new mobility	German Aerospace Center - operation & German Aerospace Center - investment	30.99	48.54
3004 / 68570 & 3004 / 89470	Federal Ministry of Education and Research	Research for innovation, high-tech strategy	HGF centres – operation & HGF centres – investment	384.79	265.88
Total				**1,216.00**	**1,310.97**

1 2021 federal budget or, where titles expire, last year of use
2 Responsibility in line with organisational decree of Federal Chancellor of 8 December 2021, where title expired, current responsible ministry is cited
3 New from 1 January 2021
4 Expired from 1 January 2021
5 Funding incl. existing funding stipulations for the regulatory sandboxes were moved from 2021 into federal budget chapter 0903 title 68301.

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

Ministry[1] topic	Actual outlays in € million 2020	2021
Federal Ministry for Economic Affairs and Climate Action	**597,18**	**659,14**
Project funding and accompanying measures	566.19	610.59
Institutional funding (German Aerospace Centre)	30.99	48.54
Federal Ministry of Food and Agriculture	**37.83**	**42.11**
Project funding and accompanying measures	37.83	42.11
Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection	**38.33**	**40.33**
Project funding and accompanying measures	38.33	40.33
Federal Ministry of Education and Research	**542.66**	**569.39**
Project funding and accompanying measures	157.87	303.51
Institutional funding (Helmholtz Association excl. German Aerospace Center)	384.79	265.88
Total	**1,216.00**	**1,310.97**

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 2014 – 2020 in € million

Land	Actual outlays in € million												
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
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
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
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
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
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
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
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
Mecklenburg-Western Pomerania	–	1.64	5.68	3.99	8.76	3.22	13.02	1.50	–	–	–	–	–
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
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
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
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
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
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
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
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
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**

Table 11 | Spending on non-nuclear energy research by Land by research 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 savings	24.86	32.19	23.74	31.66	51.35	45.58	34.73	46.10	49.27	42.00
General energy research	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 station 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[1], in 2018 – 2020 in € million

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

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