6th Priority Research Area

Climate and environmental protection, modern energy

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Power generation sector is the crucial industry shaping the socio-economic system. Protection of the environment and mitigating climate change are priorities for moving towards sustainable growth. In this respect, the Silesian University of Technology is active in a number research fields, where the main sub areas are:

1. POB6.1 Climate and environmental changes and reduction of air pollution
2. POB6.2 Water and wastewater management and environmental biotechnology
3. POB6.3 Circular economy
4. POB6.4 Renewable and alternative energy sources and prosumer energy
5. POB6.5 Innovative technologies and sustainable development
6. POB6.6 Education for sustainable development and shaping environmental awareness
7. POB6.7 Problems of degradation and revitalization of areas
8. POB6.8 Energy efficiency and energy management
9. POB6.9 Energy storage and hydrogen energy
10. POB6.10 Shaping the internal environment and intelligent buildings
11. POB6.11 Strategy for sustainable development of energy and gas energy

Energy sector is a dominant factor influencing global climate changes with significant impact on pollution of air, water, and soil.

One of the trends in research conducted within POB6 is the reduction of air pollution, in particular important in the context of smog problems in the cities. Scientists of the Silesian University of Technology investigate technologies allowing to reduce the emission of harmful compounds, identify their sources, and enabling intelligent monitoring of concentrations of specific chemical compounds and aerosols. They study their time-space distributions, also in relation to records reconstructed from geological archives such as trees, peat bogs and other land and sea sediments. Working in interdisciplinary, often international research teams, they reconstruct the natural changes in the climate and environment in the past, recorded in such archives over the last several hundred thousand years. In the last few hundred years they target the challenge of separating natural changes from anthropogenic influence. The scientists of the Silesian University of Technology are also exploring the interactions between atmospheric pollutants and the climate and human health, as well as the

processes of adaptation of urban areas and elements of the natural environment to climate change. Employees of the Silesian University of Technology investigate issues related to pollution and its impact on spheres other than the atmosphere of the Earth - the hydrosphere and lithosphere, in terms of identifying and marking toxic substances, determining their harmfulness and understanding the mechanisms of their spread, in order to develop methods of removing them from the environment. They analyse the processes of purification of the water-soil environment, develop methods of water and sewage treatment, and investigate the risks associated with the storage of industrial waste. In research works, scientists of the Silesian University of Technology use unmanned flying platforms to monitor and analyse the Earth's surface, including forest management.

SUT researchers have also deep knowledge and experience in the field of development of new technologies concerning enhancement of efficiency of coal-fired boilers, control the composition of the flue gases (easier capturing and storage of CO2), and reduction of harmful species emission. The scientists from Silesian University of Technology have extensive experience in the field of improving efficiency of the processes and reducing the emission of harmful compounds from the combustion of fossil fuels. Thanks to the extensive research carried out as part of one of the largest applied research projects, a number of pilot installations were created, that allows to study the possibility of emission reduction of harmful compounds to the atmosphere.

Researchers of the Silesian University of Technology study the land areas subjected to opencast and underground exploitation in the context of their influence on the environment, including gas emissions and the problems of post-industrial waste. They are actively exploring the stability of excavations and underground chambers in terms of their use by the landfill possibilities for post-industrial and hazardous waste, and for underground storage of gases and fuels. They are studying the interaction of post-mining- and energy waste with the environment, as well as their safe use, e.g. for land reclamation and the production of new building materials and supplies.

In the field of broadly understood civil engineering and architecture, scientists from the Silesian University of Technology conduct research on the interaction between building structures, including industrial ones, and the environment in which they are located. They're researching the foundations of building structures in difficult environmental and geotechnical conditions and the influence of tremors on ground-based and underground building structures. They optimize the energy efficiency of buildings, taking into account the architectural aspects of infrastructure. They conduct research on the future of civil engineering and architecture in the context of climate change, new social and technological challenges and the needs of human development. The engineering approach to the problems of climate and environmental changes is complemented by studies on the ethical, social and economic aspects of these changes.

Scientists of the Silesian University of Technology are developing methods of water and sewage treatment. Water is emerging as one of the single most important resources of Planet Earth for the prosperity of the economy and human life. However, freshwater resources have been increasingly polluted and depleted globally. The constant increase in water usage and climate change—such as altered weather-patterns (including droughts or floods), deforestation, and increased pollution—are the main driving forces for the rising global scarcity of water. The United Nations World Water Development Report stated that nearly 2/3 of the population will suffer from clean water scarcity by 2050.

Research taken by employees of the Silesian University of Technology in the field of water protection include the identification of emerging pollutants in the water environment and the development of technologies for their removal. These include a monitoring of the micropollutants concentration such as, xenoestrogens, PAHs, pesticides, pharmaceuticals, dyes and heavy metals in surface, underground, mine water bodies and rainwater as well as in elements of environmental infrastructure such as swimming pools, water supply networks, municipal and industrial wastewater treatment plants. Several scientific projects have been carried out to solve these important research topics. They resulted in a development of technologies and methods for removal of all mentioned pollutants. The most important achievements include the modification of Fenton's reagent for the treatment of poorly biodegradable wastewater, optimization of membrane processes and advanced oxidation processes for the removal of toxic organic micropollutants, preparation of membranes and sorbents from waste materials (sewage sludge, polystyrene waste) and nanostructured materials (graphene, nanosilver, carbon nanotubes), and the production of catalysts for oxidation reactions.

A newly identified, global and serious problem is the presence of microplastics in the aquatic environment. This important topic was taken up by the employees of the Silesian University of Technology within studies on the removal of microplastics from wastewater for different wastewater treatment technologies. In addition, the essence of these studies is to identify devices and processes that allow to minimize the concentration of microplastics in effluent.

The employees of the Silesian University of Technology were one of the few and the first in Poland to take up the subject related to the identification and removal of contaminants from swimming pool water that are not removed in classic pool water purification systems. The proposed purification methods include microfiltration, ultrafiltration, nanofiltration and reverse osmosis. The project results are updated on the project website https://www.facebook.com/PBU-Micropollutants-in-swimming-pool-water-102916601350352/.

Scientists of the Silesian University of Technology are developing new materials used in water purification processes. An important achievement for the photocatalysis process is the development of a semiconductor consisting of titanium dioxide and activated carbon. This approach guarantees a both degradation of contaminants and removal of the newly formed by-products of the oxidation of these pollutants.

Scientists from the Silesian University of Technology also proposed the use of several waste materials as sorbents for pollutants present in water. As for example, the use of sewage sludge, ash or straw. This solution makes it possible to use environmental waste difficult to manage as materials useful for environmental protection

Biotechnology is officially defined by the Organization for Economic Co-operation and Development (OECD) as the provision of goods and services using biological methods. At the same time, different colours of biotechnology were introduced, assigning them to specific areas of life:

1. green biotechnology, also called agrobiotechnology, concerns aspects related to agriculture, solutions used for food and non-food purposes;

2. white biotechnology is a biotechnology dealing with the use of various biological processes in industry, environmental protection and engineering;

3. red biotechnology covers the area of health care, in particular in the field of production of new biopharmaceuticals, development of genetic diagnostics, as well as gene therapy and xenotransplantology;

4. blue biotechnology is related to the general issues of water biotechnology;

5. purple biotechnology deals with legislation, the protection of intellectual property, as well as philosophical and ethical issues.

Under Subarea 6.2, research and projects will focus on white and blue biotechnology in the areas of researchers' interest and research. One of the examples of such projects is SNIT Project. The aim of this Project is to create an innovative Technology that will allow to achieve mainstream shortcut nitrification/denitrification via nitrite at municipal wastewater treatment plants (WWTPs). Achieving this objective will significantly reduce oxygen and organic carbon demand for the nitrogen removal process, improve effluent quality and increase digester gas production. This Technology also includes a development of separate reactors for sludge disintegration with nitrous acid to aim easy biodegradable organic carbon for denitrification process improvement, which is usually limited by organic carbon available in raw wastewater.

The overall objective of the other project (acronym SIREN), in line with the circular economy concept and sustainable development, is to integrate innovative processes into the traditionally operated municipal wastewater treatment systems to make a transition towards water resource recovery facilities. Specifically, innovative, cost-effective technologies will be developed with respect to the recovery of inherent resources, i.e. energy, nutrients and organic substances (humic acids) as well as generation of valuable products, i.e.

hydrogen and biopolymers. As a result, it is expected to enhance the biogas production by >10% and harvest >80% of nutrients.

The other project focused on circular economy and resource recovery challenge by deploying integrated bioprocessing is WasteValue project. This project is focused on the organic fraction recovery and nutrients from organic fraction of municipal solid waste, food waste and fish sludge in order to make maximal use of these waste and residues. These fractions will be used to formulate a substitute for A-1 jet fuel, natural gas and agriculture fertilizer.

Another line of research conducted by scientists in subarea 6.2 focuses on the topic of the effect of vacuum on bacteria. It is postulated to use vacuum in wastewater treatment, anaerobic digestion, sludge treatment, soil remediation and mining. As part of the research on the effect of vacuum on bacteria in activated sludge, it was found that the vacuum affects the disintegration of activated sludge flocs and also leads to the destruction of weak (or dead) bacterial cells. This increases the amount of active cells in the activated sludge.

Another group of research carried out by scientists in the field of biotechnology concerns the removal of synthetic dyes, which enter the environment in their original form and then undergo transformation in physical, chemical and biological processes used in wastewater treatment processes. Synthetic origin and complex aromatic structure make them more recalcitrant to biodegradation however, it has been shown that many species of microorganisms can effectively remove these contaminants. Studies on decolourization processes show significant potential of bacteria and fungi strains in the dyes decolorization. Application specially selected strains of bacteria allow to reach a great result of removal of dyes from different chemical groups, used as a single dye and their mixtures. Good results are obtained in case of usage of the pure bacteria cultures, but suitable composition of their mixture may accelerate the efficiency and rate of process. When using immobilized mycelium in the case of pure dyes in liquid cultures, 100% decolourization can be achieved within 96 hours. The situation is more complicated when removing mixtures. However, the current research confirms the possibility of removing some mixtures in over 90% in biological reactors even after 5 cycles of operation of such reactors. It can be observed that dyes removal is connected with the decrease of ecotoxicity of after process solutions to aquatic organisms.

The research conducted under sub-area 6.2 also uses the possibilities of artificial neural networks, inter alia, to determine the impact of distortions of input signals on the training process of the artificial neural network acting as a virtual sensor of nitrate nitrogen (V) concentration in one of the biological reactor tanks of a sewage treatment plant with activated sludge. in the activated sludge reactor.

Parallel to transformation of the energetic sector, the concept of the circular economy is introduced, which includes the use of combustion by-products in the construction industry using traditional and innovative building materials, such as geopolymers. Another example is the recovery of useful substances from electronic waste. At this point, reference should also be made to urban mining, i.e. a global trend in the circular economy. The term means the recovery of useful substances from human-used secondary raw materials which are in infrastructure, electronics, landfills and sewage treatment plants. The main directions of research conducted at the Silesian University of Technology are the processing of recovered substances for construction purposes and the production of sorbents and energy.

The research carried out under subarea 4, combining knowledge in the fields of physics (mechanics, optoelectronics), chemistry, mathematics, materials engineering and production technologies, is aimed primarily at improving the quality and lifestyle through effective production and use of electricity, taking into account environmental protection. This research is interdisciplinary and all the Departments of the Silesian University of Technology are involved in their implementation.

For years, research related to photovoltaics has been conducted continuously, as evidenced by numerous publications and research projects carried out. Non-toxic electrically conductive materials are sought on a large scale, in particular polymeric materials that can be used in optoelectric and photovoltaic systems. Using optical fiber techniques and integrated optics, the physicochemical properties of engineering materials potentially used in modern energy are investigated. The knowledge of conjugated polymers and doping of polymeric materials, semiconductor heterostructures in the context of their application in organic photovoltaic

cells, solar radiation concentrators, sensors and optoelectric devices is constantly being developed. Currently ongoing research includes 1st, 2nd and 3rd generation solar cells. Particular attention was paid to silicon solar cells with laser texture and antireflection thin films deposited by atomic layer deposition method(ALD), dye-sensitized solar cells with nanomaterials (nanotubes, graphene, nanowires, nanoparticles and solid polyelectrolytes) and polymer solar cells with newly developed conductive polymeric materials. Research on solar cells is developed in the direction of increasing the efficiency of cells and lowering production costs, as well as extending the possibilities of applications by integrating them with construction or developing flexible versions. Progress is made by improving connectors, contacts and geometric features of solar cells, methods of their surface treatment and the use of new engineering materials with unique properties. Hence the constant search for new materials and technological solutions that will allow to produce a highly efficient solar cell.

The Silesian University of Technology also conducts extensive work on wind and hydroelectric turbines, where e.g. geometric features of turbine blades are optimized in order to minimize their vibrations. In the area of interest of the Employees of the Silesian University of Technology there are also hybrid solar-wind micro power plants designed to power the electrical installation of single-family houses. The conducted research concerns power electronic converters used in wind and photovoltaic energy and their control algorithms, incl. algorithm of searching for the point of maximum power. In this regard, new solutions are developed for power electronic converters cooperating with renewable energy sources and energy storage, enabling the selection of optimal power to the energy needs of the recipient. In the case of power electronics solutions, the greatest emphasis is placed on ensuring the highest efficiency of solutions and the implementation of the widest possible functionality. Therefore, systems cooperating with single photovoltaic panels on one side and creating a chain at the outputs enabling cooperation with the grid converter were developed. Battery charging systems from photovoltaic panels with 2 independent inputs for cooperation with photovoltaic panels or converters for prosumer installations were also developed. This solution enables the charge/discharge energy storage, management of work load, reducing the flow of power from the network, the integration of renewable energy sources or even to reducing the impact on the domestic network of receivers. The works related to the selection of the optimal power (based on the power profiles at the point of connection to the grid) are aimed at minimizing installation costs and maximizing the return on investment.

Analyzes of the use of micro-CHP systems for the purposes of individual recipients are also conducted. Research focuses on the experimental and computational analysis of gas systems based on Stirling engines or fuel cells and their integration with photovoltaic installations and electricity storage within the building. The studies include an energy efficiency assessment as well as economic and environmental evaluation. Experimental and computational research on heat and electricity generation systems using solar parabolic concentrators is carried out. The works are aimed mainly at the intensification of heat reception by thermal oil flowing through the absorbers.

Analyzes of the configuration and structure of low-power steam and gas CHP plants (up to 1000 kW) are also carried out, which would be characterized by: high generation efficiency, the possibility of operation in a wide range of loads (from 10 to 100%), the possibility of using inexpensive and easily available machines and devices included in the system and the possibility of quick and inexpensive adaptation to work with alternative gaseous fuels or, above all, waste heat from various types of technological and industrial processes. Systems of this type can supply electricity and heat to small urban areas or production plants, in which there is also the possibility of using high-temperature process steam.

Research was also undertaken to develop guidelines and design recommendations for architects, which concern the consolidation of the currently dispersed theoretical and practical, interdisciplinary knowledge in the field of integration of alternative energy sources with the architecture of buildings, their form, body and facades (e.g. wind turbines or solar cells integrated with facades of buildings). Architectural solutions should support the installation of alternative energy sources on buildings in such a way as not to disturb the aesthetics of buildings, which is often the case nowadays (e.g. frames for photovoltaic panels protruding on the roofs, when the roof slopes are not properly oriented towards the directions of the world). With regard to enterprises, depending on the power consumption profile, research is conducted on the selection of power and type of energy sources (electricity and heat) and the control of the operation of individual sources depending on the external and internal conditions of the enterprise. With regard to residential buildings, research is being carried out on microcogeneration sources, electricity and heat cost accounting systems in multi-source systems.

In the field of broadly understood technologies, in particular aimed at application in environmental protection and energy, research is carried out on the improvement of fuel cells, e.g. by using new materials for their construction. These studies include the development of nanocatalysts, including the synthesis of metallic nanoparticles of a specific size, shape and chemical composition, and modification of the structure of the carbon support. The main barrier to the widespread use of catalysts is their limited resources and high price. This barrier can be overcome precisely thanks to the use of catalysts in the form of nanoparticles.

As part of the research carried out at the Silesian University of Technology, in order to increase the durability of catalysts used in fuel cells, the structure of the carbon support is modified and in place of the commonly used technical carbon black, carbon materials with a high degree of crystal structure order, resistant to electrochemical corrosion are introduced.

Research is also carried out on the conversion and use of CO2. Reducing greenhouse gas emissions, as well as the development of alternative clean energy, is becoming one of the most important challenges facing humanity, hence the ongoing research into the development of new nanocatalysts for use in the methanation process. These studies include the development of bimetallic nanocatalysts in a combination of nickel-noble metal (gold, platinum, palladium, etc.) with the use of carriers in the form of nickel foams and molecular mesh. The goal is to increase the efficiency of the methanation process, as well as to scale the technology to commercial applications.

Scientists from the Silesian University of Technology conduct research on the efficiency of the energy conversion process in reciprocating internal combustion engines powered by alternative fuels and gas biofuels. They focus in particular on: the combustion of hydrogen-enriched biogas, gas from biomass gasification, ammonia and pure hydrogen; optimization of energy indicators of internal combustion engines in connection with the minimization of harmful impact on the natural environment; testing and diagnostics of low-power cogeneration systems powered by natural gas, biogas and propane-butane mixture.

They also successfully deal with numerical CFD modeling of the pyrolysis and gasification reactor model, determining unknown quantities that characterize the process and carry out research on the process of solar biomass pyrolysis.

Research is conducted on matching energy sources for specific groups of recipients and simulating energy mixes with cost analysis. In addition to energy production, billing and management systems for small areas such as communities and housing cooperatives are also necessary. In this regard, billing systems are being developed for multi-source electricity and heat generation systems. Research and experiments related to energy management in both individual and collective prosumer micro infrastructures (virtual energy networks) are conducted. Solutions and reference technologies are developed for various groups of consumers / prosumers in the context of a variable energy price and the provision of system services in a distributed electricity market.

SUT staff has developed an original concept of thermoecology (thermodynamic-ecology cost) which gives an insight into the impact of a given process on the depletion of natural resources, using life cycle coupled with exergy analysis. This approach is unique not only on a national but also on a global scale, confirmed by numerous publications, e.g. on nuclear energy and systems for the integration of non-renewable and renewable technologies. This approach sheds new light on the optimization of industrial processes in terms of the limited access to natural resources.

SUT staff has proposed a topic named: Electronic devices supporting the holistic approach of energy efficiency of current technologies. Despite the fact that new technologies can be very effective in many areas, technologies known for many years are still being used. Currently designed devices that use the latest solutions can improve their energy efficiency. This may not only improve the efficiency of power supply and power control systems, but it also supports energy management techniques. In turn, the use of energy-saving technologies may lead to lower energy consumption. In order to optimize power supply and power control systems, dedicated measuring devices with model-based algorithms can be used. Sonochemical techniques are also an important part of the implemented technologies. In the case of energy management systems, machine-learning methods can be used for predicting energy consumption and optimal decision making. SUT participates in the project with one of the largest institutes in Europe - the Institute of Power Engineering

(IoPE) in Warsaw. The primary goal of the project realized jointly with IoPE is to design a method for solid fuel combustion intensification. The method must also ensure a flexibility of the power supply system. In this case, the flexibility is understood as a potential reduction in the fossil fuel consumption or combustion of fossil fuels of low quality, while at the same time, keeping sufficiently high efficiency of the power supply system and low emission of gaseous pollutants, even in the presence of varying demand for electricity. The project goals are currently realized in dedicated laboratories in IoPE, in Warsaw. The implemented technologies use the granted European Patent.

It is also worth mentioning the participation of scientists from the Silesian University of Technology in the implementation of the reclamation of post-industrial areas, including the revitalization of post-industrial architecture, coal and post-zinc spoil heaps, with the selection of appropriate technologies, social participation and environmental and historical education systems supported by online platforms, educational path boards and other infrastructure for outdoor education.

Water reservoirs contaminated with heavy metal compounds and residues of pesticides, pharmaceuticals and other organic compounds also require recultivation. One of the commonly used methods of water purification from this type of pollution is phytoremediation. Pesticides, as well as other compounds mentioned above, undergo numerous, both biotic and abiotic, transformations in the environment. As a result of these processes, degradation products claimed as more dangerous for the environment than parent compounds, are formed. Therefore, phytoremediation focused on effective removal of the parent compounds is an insufficient approach. Therefore, scientists of the Silesian University of Technology have undertaken research aimed at the development of phytoremediation conditions for the removal of both anthropogenic organic pollutants and their degradation products from water.

An increased share of renewable energy, particularly wind power and photovoltaics in an energy mix creates difficulties for the regional stability of the electricity grid on the supply side. Wind and solar generation both experience intermittency, a combination of regional meteorological uncontrolled variability and local unpredictability. A solution to this problem is energy storage. Accumulation of energy could be achieved by hydrogen generation and its possible further conversion into methane or methanol in Power-to-X technologies which are within the scope of research conducted at SUT. One of the benefits of this technology is the possibility of CO2 utilization generated by conventional fuel combustion. CO2 could be also captured from the process of biomass gasification as a “green” source of carbon. Basic research related to the process of hydrogen and CO2 synthesis into synthetic methane and methanol are currently being conducted under priority research areas. Research teams are making efforts to fund this scope of research through IPCEI calls in cooperation with companies and local authorities. Expertise of SUT researchers in technical risk assessment gives a possibility to analyze risks related to transport and storage of explosive gases such as methane and hydrogen and gases used as storage medium in CGES (Compressed Gases Energy Storage) technologies. One of the interesting activities which should help in the acquisition of research projects related to the priority research areas is establishment of the Fraunhofer Institute branch at SUT.

An idea which is currently being investigated is the possibility to use a post-mining infrastructure for energy storage. This concept is of crucial importance for coal regions in transition such as Upper Silesia where the decarbonisation process is taking place. Among many solutions, a concept of underground pumped storage hydropower where a lower reservoir is located in abandoned workings is being investigated. The other concept invented by SUT researchers considers a hybrid system where hydrogen (converted into synthethic methane) and compressed air is stored in an abandoned mine. This idea has been patented by SUT. Another patent application related to the concept of hybrid system where hydrogen and compressed CO2 are used as energy carriers is under processing. As stated by Inventors, this solution has a high application potential in urbanized regions where the need for industrial clusters integrating CO2 emitters with consumers of high energy needs is of utmost importance. This idea is of particular interest for the Upper Silesia region where the number of post-mining areas abandoned underground workings and shafts, will be increased dramatically in the next few years. This infrastructure could be converted into underground storage of hydrogen, methane, carbon dioxide and air. Actions related to this scope of priority research are within the research interest of employees of the Faculty of Energy and Environmental Engineering and the Faculty of Mining, Safety Engineering and Industrial Automation. The concept of a hybrid system of heat and compressed air storage intended particularly for post-mining shafts is the subject of EPO and Polish Patent Office application. The employees of the design

office of Energoprojekt Katowice SA joined the process of designing and developing the system. Teams working in the field of energy storage and hydrogen energy are actively participating in the submission of project proposals to the H2020 research fund and Polish-Norwegian research Fund. Other research fields are related to the distributed energy storage in prosumer systems based on electrochemical batteries working in hybrid systems using high voltage batteries.

A statistical person spends about 90% of the day in closed rooms, therefore shaping the indoor environment in buildings is of key importance. Thermal, acoustic and visual comfort, user safety, protection against noise and energy consumption by heating, ventilation and air conditioning systems are the main issues considered in this research field. Research into control devices, energy recovery devices and automatic systems allowing for optimal control of heat, comfort and climate in buildings is of great importance. Part of the research is carried out in cooperation with foreign universities, e.g. the task of developing a method for the assessment of occupants' exposure to CO_2 is carried out with the Technical University of Denmark included in the 151-200 rank place on the Academic Ranking of World Universities 2020 list.

The implementation of the sustainable growth strategy should, therefore, put special stress on the transformation of the traditional energy generation sector. The challenge is not only on the side of substitution of the traditional, based on combustion of fossil fuels systems, by renewables and increasing the efficiency of a single process, but the integration of all components into an efficient, targeted towards zero emission, system. Significant research conducted by employees of the Silesian University of Technology and related to modern energy should include works aimed at intensifying the use of the existing power system, including the modernization of existing generating units and construction of new ones. In addition, analyzes of the quality and reliability of electricity supplies are carried out. Equally important is research on the stability of the system and its optimization in the context of the development of the power system aimed at the integration of conventional and renewable energy sources. Scientists of the Silesian University of Technology in their research do not ignore economic and organizational issues that have a significant impact on the development of modern energy.

In order to effectively protect the natural environment and counteract the progressive human pressure, in addition to research and cooperation with the socio-economic environment, educational activities are also necessary. Due to the deteriorating environmental parameters, climate warming, water, soil and air pollution, education for sustainable development and shaping ecological awareness of all social groups becomes an important element of the university's impact on the environment, implemented as part of the third mission. Educational projects, seminars and workshops conducted by the university are addressed to various groups, ranging from primary and secondary school students to entrepreneurs, representatives of local government units, professionally active groups and seniors. The range of possible support tools in shaping responsible human behavior in the environment is very wide. It should be noted, however, that this is a long-term process that requires a holistic approach and activation of the activities of civil society, therefore the transfer of knowledge to the society and broad cooperation of universities with the environment are also important. The SUT already has enormously contributed to various aspects of the transformation of the energy system.

It should be stressed that SUT staff has already significant achievements in all these research areas, thus valuable results can be expected in the very near future. Another important feature of the carried out research is the parallel experimental and advanced computational techniques used. Developed mathematical models are very often used by researchers from around the world, as evidenced by the many cited scientific papers published in the top 10% journals in engineering, chemical engineering, computer science, mechanics, and thermodynamics.

The University of Technology has a rapidly developing network of several dozen research laboratories. The SUT staff through intensive contacts and joint research projects has developed a wide network of contacts including six universities from the top 20 institutions in the Shanghai list namely University of California, University of Cambridge, Massachusetts Institute of Technology, University of Oxford, Swiss Federal Institute of Technology Zurich (ETH), University College London and US National Lab Lawrence Livermore Laboratory. The biological part of the research is supported by equipment commissioned within a large 80 million project (Biofarma) within which one-third of the budget has been used for the bioenvironmental equipment. The structure of the investigations conducted in SUT is a balanced mixture of fundamental and

applied research. The University maintains close contacts with international and national corporations like ABB Corporate Research Center, General Electric, SGL Carbon, Tauron SA, Arcelor Mittal, Sumitomo FW, PKN ORLEN and numerous small and medium enterprises. Scientists cooperate with the Center for Climate and Environmental Protection and the Center for Prosumer Energy at the Silesian University of Technology. Researchers from SUT, coordinate or participate in research projects granted by European Union, i.e. Horizon 2020, projects focused on Polish-Norwegian cooperation, as well as from domestic funds.