

**University of Belgrade**  
**Institute for Chemistry, Technology and Metallurgy (ICTM)**  
**National Institute of the Republic of Serbia**

*Based on Article 22 of the Statute of the University of Belgrade – Institute for Chemistry, Technology and Metallurgy – National Institute of the Republic of Serbia and the recommendations of the ICTM Scientific Council (decision number 534 from the meeting held on May 15, 2024), the Director of the Institute presents the following document:*

# ICTM Development Strategy

For 2024 – 2028



Director of ICTM

Dr Jasmina Stevanović

*ICTM expresses gratitude to the expert team of the Serbia Accelerating Innovation and Growth Entrepreneurship (SAIGE) project and consultants from the International Project Management Association (IPMA)-Serbia for their support during the preparation of this document.*

## CONTENT

<b>1. SUMMARY</b> .....	2
<b>2. Description of activities</b> .....	4
2.1 History .....	4
2.2 Current Status of ICTM.....	7
<b>3. Analysis of the external environment</b> .....	8
3.1 Analysis of the legislative framework/regulation.....	8
<b>4. Analysis of the institute</b> .....	10
4.1 Organization .....	10
4.1.1. Organization of Research.....	12
4.2 Infrastructure .....	18
4.3. Projects.....	20
4.3.1 International projects.....	20
4.3.2 National projects.....	22
4.4 Published papers .....	24
4.5 Collaboration.....	26
<b>5. Vision and mission</b> .....	27
5.1 Vision .....	27
5.2 Mission .....	28
5.3 Values .....	28
<b>6. Strategic areas of development and objectives</b> .....	28
6.1 Research areas .....	28
6.2. Key strategic objectives.....	30

## 1. SUMMARY

The Institute of Chemistry, Technology and Metallurgy (ICTM) is one of the *leading scientific institutions* in the Republic of Serbia. It serves as a reference point in the fields of *chemistry and related technologies* in the country. The Government of the Republic of Serbia has granted ICTM the status of a *National Institute of the Republic of Serbia*, making it one of only eight (out of sixty-eight) scientific institutes to receive this prestigious designation.

The Institute was founded in 1961 through the initiative of the Faculty of Natural Sciences and Mathematics, the Faculty of Technology and Metallurgy, and the Faculty of Pharmacy at the University of Belgrade. Since then, the Institute has grown and elevated its scientific reputation to a level recognized and acknowledged by the academic community. In 2001, ICTM became one of eleven Institutes admitted to be *members of the University of Belgrade*. Five other National institutes are also members of the University of Belgrade. ICTM is the only member of the University of Belgrade whose research spans the broad fields of chemistry, chemical technology, and chemical engineering.

In 2023, the Institute had 244 employees, of which 214 were research staff.

The strategic goal of ICTM is *to create cutting-edge achievements in the field of chemical sciences and related technologies and to acquire and disseminate knowledge for the benefit of society as a whole*. ICTM intends to reach this goal by conducting fundamental, developmental, and applied research while engaging in higher education and contributing to advancing and disseminating high technologies. ICTM is committed to achieving its strategic goal in a collaborative environment by partnering with leading scientific and educational institutions domestically and internationally. These partnerships include the founding faculties in Serbia and those with which the Institute shares common scientific themes, most notably, the Faculty of Chemistry, the Faculty of Physical Chemistry, the Faculty of Technology and Metallurgy, and the Faculty of Electrical Engineering.

ICTM has identified four strategic directions for development:

1. Increasing research excellence
2. Increasing research relevance (improving knowledge and technology transfer )
3. Broadening societal impact
4. Strengthening research capacities

Since its inception in 1961, ICTM has been nurturing the tradition of employing top experts who share the following values: (a) excellence in science and research, (b) promotion of knowledge and innovation as social values, (c) a culture of collaborative research, (d) encouragement to disseminate knowledge broadly, (e) fostering an entrepreneurial spirit, (f) socially responsible science, (g) diversity and inclusion, and (g) tradition of trustworthy partnerships.

In the coming period, the Institute will focus on the following research areas:

- A. Chemistry and Chemical Engineering
- B. Biotechnology

### C. Microelectronics and Microelectronic Technologies

This document (ICTM Development Strategy) has been drafted to serve as a guiding document to ensure systematic planning, implementation, and monitoring of the activities needed to accomplish the goals of the Strategy. The ICTM Strategy consists of the following segments:

- a) Description of activities
- b) Analysis of the external environment
- c) Analysis of the Institute
- d) Vision and mission of the Institute
- e) Strategic areas of development and objectives
- f) Action plan
- g) Monitoring and reporting system

Each segment is elaborated, explained, and analyzed throughout this document to make the strategy feasible and based on facts. Chapter 2 outlines the current organizational structure of the Institute and briefly describes the types of activities the Institute is involved in. It also provides a short history of the Institute, highlighting its significant accomplishments and drawbacks during the various phases of the Institute's existence. Chapter 3 analyzes the external environment of the ICTM, describes the legislative foundation for the Institute's operation, and lists a number of specific laws and regulations by which the Institute and its employees abide. Chapter 4 details current research, organizational structure, results achieved so far, a list of international and national projects, and an analysis of the type, total number, and project distribution by year. It also outlines the current infrastructure (space, equipment, and human resources) and identifies the critical needs for improving the existing infrastructure of the Institute. Chapter 5 presents the Vision and Mission of the Institute and the Values it upholds. Chapter 6 outlines projections for future development, including the research areas to be pursued, the strategic areas of advancement, the specific goals, and an Action plan for the future.

This strategy is designed for the five-year period from 2024 to 2028.

## 2. DESCRIPTION OF ACTIVITIES

The main activity of the Institute for Chemistry, Technology and Metallurgy (ICTM) – National Institute of the Republic of Serbia is research and development in chemistry and related technologies. The Institute carries out fundamental and applied research in chemistry, physical chemistry, geosciences, environmental science, materials and chemical technologies, electrical engineering, and environmental engineering. The most represented disciplines at the Institute are organic and inorganic chemistry, biochemistry, electrochemistry, catalysis, medicinal chemistry, analytical chemistry, environmental chemistry, theoretical chemistry, microbiology, ecology, materials science, chemical engineering, microelectronic and microsystem technologies, as well as nanotechnologies.

In addition to conducting and disseminating research, ICTM researchers participate in the implementation of master's and doctoral academic programs at the University of Belgrade and other Universities across Serbia, collaborate with related institutions of higher education, and organize seminars, lectures, and talks for the University audience and the general public, thus contributing in education in less-formal ways. These activities are supported by the Government and comply with the laws that govern the field of higher education and the system of science and research in the Republic of Serbia. As a member of the University of Belgrade, ICTM participates in governing the University through its elected members serving in the governing committees of the University.

Service to the scientific community is vital to the Institute's work. ICTM researchers organize national and international scientific conferences and lectures that promote and popularize science. A number of the Institute's researchers are engaged in the work of scientific societies and associations and the working bodies of Government.

### 2.1 HISTORY

The Institute of Chemistry, Technology and Metallurgy was founded in 1961 by the decision of the Executive Council of the People's Republic of Serbia. The decision was initiated by three faculties at the University of Belgrade (Faculty of Natural Sciences and Mathematics, Faculty of Technology and Metallurgy, and Faculty of Pharmacy) and fourteen companies from Serbia. Since then, ICTM has grown continually, following the tradition of the State Chemical Laboratory – an institution founded in 1859 by Prince Milos Obrenovic - and the Institute of Chemistry of the Serbian Academy of Sciences.

ICTM has passed through several phases throughout its history. We identified and analyzed six developmental periods:

- I. PHASE OF INTENSIVE GROWTH (1961–1973);
- II. PHASE OF CRISIS (1974–1981);
- III. PHASE OF REVITALIZATION (1982–1990);
- IV. PHASE OF CRISIS CAUSED BY WAR CONFLICTS IN FORMER YUGOSLAVIA (1990–2000);
- V. PHASE OF SYSTEMATIC (SYSTEMIC) ENCOURAGEMENT OF FUNDAMENTAL RESEARCH (2000–2022);
- VI. PHASE OF TRANSFORMATION (2022–).

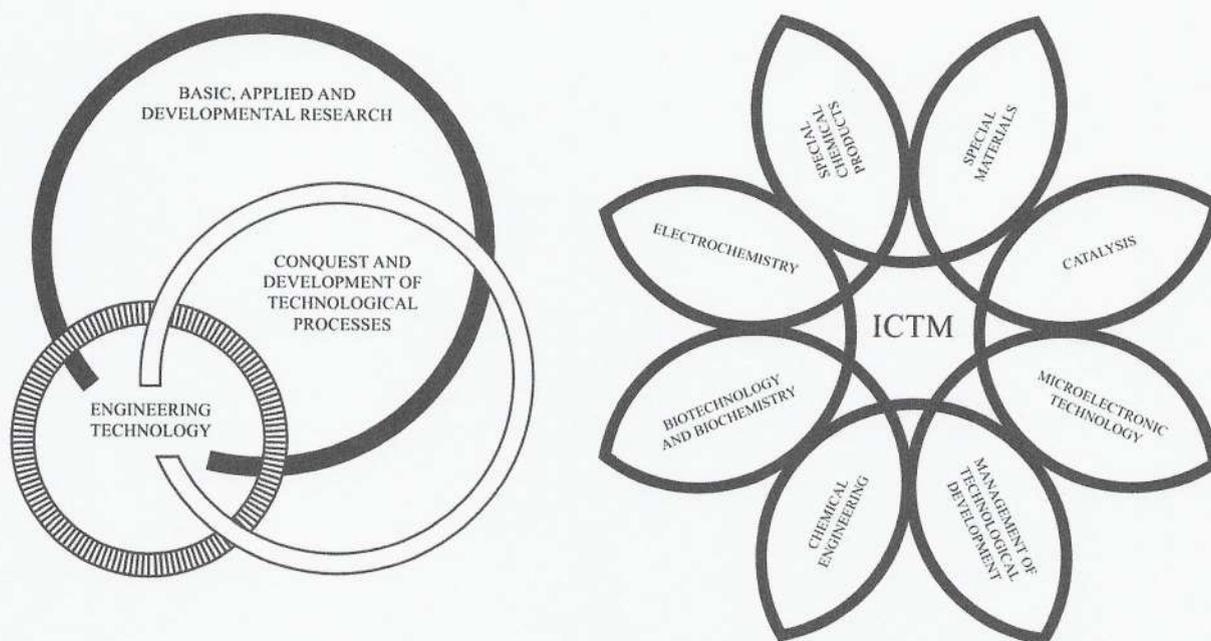


Figure 1. Overview of the organization of the main research areas and topics at the founding of ICTM (1961).

The basic premise for the formation of ICTM was to monitor and transfer scientific and technological innovations to our environment. The primary purpose of ICTM at the time was to initiate scientific research and development to support the country's efforts to develop its chemical industry and metallurgy. Even then, it was well understood that significant progress in chemical and metallurgical production could not be achieved without advanced and efficient research in the chemical sciences.

When ICTM was founded, its organizational structure was relatively simple. The Institute was comprised of a system of scientific research units whose work focused on different chemistry-related research areas. The Institute's research personnel specialized in chemical, physico-chemical, and metallurgical sciences and chemical engineering. ICTM researchers were sent to leading scientific institutions abroad, served as visiting scholars, and brought back home the knowledge and experience they gained abroad. In conjunction with growing and advancing its human resources, the Institute collected and concentrated relevant research equipment. It is worth noting that, at that time, the ICTM strategy recognized that fundamental research was critical to achieving success in applied research. It also emphasized that it was of vital importance to transfer knowledge and technology from academia to industry. As a consequence of such visionary planning, ICTM managed, even in its beginnings, to successfully produce results in fundamental and applied research in chemistry, chemical technology, materials, metallurgy, electronics, and microelectronic technology and, in doing so, promoted the science that resulted from them.

The first twelve years of the Institute are characterized as a PHASE OF INTENSIVE GROWTH. During this phase, ICTM grew its human resources and strengthened its organizational structure. In only twelve years, from 1961 to 1973, the number of employees increased from 46 to 402, while the number of researchers grew from 22 to 206. The employees comprised faculty from the University of Belgrade, about 40% of the research force, and ICTM employees alone. Most of the leaders of the research units were faculty. In conjunction with the significant strengthening of human resources, ICTM stabilized its organizational structure during this period.

Most notable research results of this period were achieved in the areas of organic chemistry and chemistry of natural products. ICTM researchers were pioneers and carriers of the advancement of these fields in the country. The fact that the research staff was educated in ways of well-known European

Universities created conditions for modern scientific research and laid the foundations for future advancement of chemistry in the country - most notably, that of organic chemistry.

The phase of crisis came when the Faculty of Technology and Metallurgy broke the foundation agreement and the new law -- Associated Labor Law (ZUR) was implemented into the scientific research units. The Law enabled the units to become independent from the integrated Institute; some left the ICTM system.

As the ZUR was abolished in 1982, the Institute entered a *period of revitalization*. The research staff was expanded, and the newly hired personnel managed to revive the Institute. The ICTM leaders perceived the direction in which the Institute should develop, predicted specific science and engineering activities to develop high technologies, set the guidelines for applied research, and directed it toward industrial development. The organizational structure of ICTM was successfully adapted to support these activities. This enabled ICTM to become an exemplary scientific research institute, typical of similar institutions abroad.

During this period, notable results in fundamental and applied research were achieved. New technologies and new materials emerged as a result of the research work at the Institute. These innovations were successfully transferred to appropriate industries or implemented into the Institute's micro-pilot plants. New products, new industrial procedures, new analytical methods, and semi-industrial and industrial syntheses were implemented in various factories and companies throughout Serbia. Such knowledge and technology transfer became much less pronounced in the following periods.

During the war conflicts in former Yugoslavia in the 1990s, ICTM continued to operate, albeit under challenging conditions. While the country's borders were narrowing, industrial production operated with a dramatically reduced capacity. The UN sanctions isolated the country both politically and economically. The inability to procure equipment and chemicals from abroad was accompanied by a severe labor outflow, further setting back the Institute's research potential. During this period, research was limited. The activities of the Institute partially focused on research and production of replacement products for the ones in short supply. Efforts were made to preserve the scientific potential and knowledge base needed in the post-war period.

After the political changes in the year 2000, the Government began to encourage and support fundamental research. When compared to the time when both fundamental and applied research were conducted at the Institute (period of intensive growth) -- the research at ICTM post 2000ths shifted more towards fundamental science themes. Basic sciences grants primarily funded the Institute. As a result, significant progress was made in fundamental science. Scientific publications in top-rated journals increased significantly at this time. The accomplishments of the Institute were recognized and rewarded by the Government in 2018 as the Institute was accredited and granted the status of a National Institute of the Republic of Serbia. Eight out of sixty-eight scientific institutes in the Republic of Serbia carry that title. This status is renewable and was renewed in 2022 for the next ten years.

Attempts at supporting applied research -- especially ones that would direct the Institute towards initiating and reviving industrial production were also underway. This initiative was, to an extent, complicated by the fact that there was (and still is) a lack of market for the services that ICTM can offer nationally. One of ICTM's goals in the coming period is to increase its visibility and become more recognizable for its services in the country and abroad.

In 2022, ICTM entered a new developmental phase, the PHASE OF TRANSFORMATION. The goal for the Institute during this period is to modernize in ways that align it with similar institutes in developed countries and to become a central institute within the new research, innovation, and entrepreneurial ecosystem of the Republic of Serbia.

## 2.2 CURRENT STATUS OF ICTM

ICTM comprises **six research Departments**: the Department of Chemistry, the Department of Electrochemistry, the Department of Catalysis and Chemical Engineering, the Department of Microelectronic Technologies, the Department of Materials and Metallurgy, and the Department of Ecology and Technoeconomics. **Centers of Excellence** were accredited in 2014 (the Center of Excellence for Microelectronic Technologies (Department of Microelectronic Technologies, as a separate organizational unit of ICTM) and in 2017 (the Center of Excellence for Environmental Chemistry and Engineering, involving researchers from two departments – the Department of Chemistry and the Department of Electrochemistry).

ICTM has **one accredited laboratory for chemical analysis**. Many years of experience in instrumental organic analysis place the Department for Chemistry with its certified laboratory among the world-renowned centers in this field.

ICTM is engaged in fundamental and applied research in the fields of organic chemistry, inorganic chemistry, physical chemistry, electrochemistry, biochemistry, biotechnology, chemistry of biomacromolecules, medicinal chemistry, environmental chemistry, chemistry of synthetic polymers, computational chemistry, and materials science. Applied research is particularly intense in chemical technologies, metallurgical engineering, technologies for developing adsorbents, catalysts, and other materials for special applications, and microelectronic and microsystem technologies, including sensors that are based on them.

From 2017 to 2023, ICTM participated in implementing 96 national and 61 international projects. Within these projects, ICTM researchers served as principal and participant investigators. The national projects included the programs financed by the Science Fund of the Republic of Serbia (Green Program of Cooperation between Science and Industry (4), program IDEAS (5), Program for Excellent Projects of Young Researchers and Scientists in the Early Stage of Career - PROMIS (4), Special research program on COVID-19 (1), program IDENTITIES (1), program PRISMA (8)), Innovation Fund of the Republic of Serbia (15), Fundamental research of the Ministry of Science and Technology of the Republic of Serbia (MNTRS) (28), Technological development of MNTRS (10), III MNTRS (10), Serbian Academy of Science and Arts (SANU/SASA) (3), collaboration between academia and industry (1), UNDP (2) and others (4). Completed international projects include Horizon Europe (4), Horizon 2020 (3), NATO (2), EUREKA! (3), DAAD (5), Diaspora (2), COST and other (25) and bilateral collaboration projects (24).

In 2023, the Institute formed an **International Cooperation and Project Office (ICPO)**. The primary purpose of the newly formed office is to improve the efficiency and success rate of ICTM investigators when applying to calls for national and international grants and to provide support to ICTM researchers while the grant is active. An Technology Transfer Body was formed to support further researchers' activities towards commercializing products resulting from their scientific and research work and encourage entrepreneurship and business collaboration.

Together with related institutions of higher education, the Institute actively participates in implementing master's and doctoral programs at various Universities across Serbia. It organizes student practice programs following the law governing the field of higher education and the system of science and research in the Republic of Serbia.

Outreach activities of the Institute include organizing courses, seminars, and other forms of training for personnel who work in industry and academia or conduct science in general.

### 3. ANALYSIS OF THE EXTERNAL ENVIRONMENT

#### 3.1 ANALYSIS OF THE LEGISLATIVE FRAMEWORK/REGULATION

Adopting this Strategy is governed by the legislative framework that defines how science and research are conducted in the Republic of Serbia. The operation of the Institute is legally governed by the Science and Research Law ("Official Gazette of the Republic of Serbia," No. 49/19), the Law on the Science Fund of the Republic of Serbia ("Official Gazette of the Republic of Serbia," No. 95/18) and the Innovation Law ("Official Gazette of the Republic of Serbia", No. 110/05, 18/10 and 55/13).

In addition to specific laws, the Institute follows guidelines provided by the Government of Serbia in the *Strategy for Scientific and Technological Development of the Republic of Serbia for the period from 2021 to 2025 -- "The Power of Knowledge."* This document envisages measures to strengthen institutions, researchers, and research teams within the scientific research and innovation system. Institutions of science and technological development desire to rise to an internationally recognizable level, to be able to solve problems comprehensively, and to be empowered to respond to societal challenges. Five specific objectives are defined to achieve the overall objectives of the National Strategy. These are: 1) to provide the necessary conditions for the dynamic advancement of science, technological development, and innovations, 2) to utilize the resources of the scientific research system more efficiently, 3) to foster the top quality of science and technological advancement while strengthening the competitive capacity of the industry, 4) to focus research on social challenges and priorities, and 5) to strengthen international cooperation.

The science and research system in the Republic of Serbia is regulated by the Science and Research Law ("Official Gazette of the Republic of Serbia," No. 49/19). This Law regulates how societal interests in science and research are planned and realized, ensures the quality and the development of scientific research, establishes the legal status of Institutes, provides procedures for founding and managing institutes as well as outlines the procedures for earning the research titles, explains ways in which institutions and other programs of general social interest are financed, provides guidelines for keeping records, and secures other issues of importance to the system of science and research. Based on Article 135 of the aforementioned law, a Contract for the Implementation and Financing of Scientific Research Work of Scientific Research Organizations for 2023 was concluded.

Article 3 of the Law on the Science Fund of the Republic of Serbia ("Official Gazette of the Republic of Serbia," No. 95/18) specifies that scientific research and development activities are implemented through scientific, technological, and development programs that fund projects aimed at achieving the goals outlined in the Strategy of Scientific and Technological Development of the Republic of Serbia. The Law explains project funding in ways that ensure the competitiveness and quality of results, enable efficient implementation of research, ensure that program and project results are open and available, attend to the development and integration of scientific personnel into international scientific and technological projects and systems, regulates the cooperation with the scientific diaspora and the business sector as well as the property rights related to research results, and provides directions for intellectual property protection, copyright, and data protection.

The Innovations Law ("Official Gazette of the Republic of Serbia," No. 110/05, 18/10, and 55/13) regulates the basic principles, goals, and organization of the application of scientific, technical, and technological knowledge and inventiveness in the function of improving the existing technical-technological

base and developing new and improved products, processes and services, as the promoter of the development of the Republic of Serbia.

In its work, the Institute applies the following laws and bylaws:

1. Science and Research Law ("Official Gazette of the Republic of Serbia," Nos. 793/2020, July 30, 2020)
2. Basics of Education System Law ("Official Gazette of the Republic of Serbia," Nos. 88/2017, 27/2018 – other law, 10/2019, 27/2018 – other law, 6/2020 and 129/2021)
3. Public Procurement Law ("Official Gazette of the Republic of Serbia," Nos. 91/2019)
4. Public Services Law ("Official Gazette of the Republic of Serbia," Nos. 42/91, 71/94, 79/2005 – Other Law, 81/2005 – Amended Act, 83/2005 Amended Other Laws and 83/2014 – Other Law)
5. Environmental Protection Law ("Official Gazette of the Republic of Serbia," Nos.135/2004, 36/2009, 36/2009 – other law, 72/2009 – other law, 43/2011 – decision of the Constitutional Court, 14/2016, 76/2018, 95/2018 – other law and 95/2018 – other law)
6. Obligations Law ("Official Gazette of the Republic of Serbia," Nos. 29/78, 39/85, 45/89 – decision of the Administrative Court and 57/89, "Official Gazette of the Federal Republic of Yugoslavia", Nos. 31/93, "Official Gazette of the Serbia and Montenegro," Nos. 1/2003 – Constitutional Charter and "Official Gazette of the Republic of Serbia," Nos. 18/2020)
7. Work Safety and Health at Work Law ("Official Gazette of the Republic of Serbia," Nos.35/2023)
8. Companies Act ("Official Gazette of the Republic of Serbia," Nos. 36/2011, 99/2011, 83/2014 – other law, 5/2015, 44/2018, 95/2018, 91/2019, and 109/2021)
9. Labor Law ("Official Gazette of the Republic of Serbia," Nos. 24/05, 61/05, 54/09, 32/13, 75/14, 13/17 – Decision of the Constitutional Court, 113/17 and 95/18 – authentic interpretation)
10. Waste Management Law ("Official Gazette of the Republic of Serbia," Nos., 36/2009, 88/2010, 14/2016, 95/2018 – other law and 35/2023)
11. Special Powers for More Efficient Protection of Intellectual Property Rights Law ("Official Gazette of the Republic of Serbia," Nos. 46/2006, 104/2009 – Other Laws and 129/2021)
12. Patent Law ("Official Gazette of the Republic of Serbia," Nos. 99/2011, 113/2017 – other Law, 95/2018, 66/2019 and 123/2021)
13. Code of Conduct in Scientific Research
14. Code of Professional Ethics of the University of Belgrade
15. Statute of the University of Belgrade
16. ICTM Statute
17. ICTM Labor Regulations, 407/1, of 28.04.2023.
18. Organization and systematization of ICTM activities regulations book, No. 407, 28.04.2023.
19. Workplace Risk Assessment and Work Environment Act, 524/30.03.2021.
20. Safety and Health at Work Rulebook, 376/18.04.2023.
21. Safety and Health at Work Training Program for Employees, 1476/06.11.2017.
22. Fire Protection Regulations, 340/04.04.2023.
23. Periodic assessment of the working environment from 01-647 NS 23.02.2021.
24. Certificate of Completion: Work Safety related to Gas Installations and Equipment Training, Dejan Vučetić 5997/2023 30.10.2023.
25. Appointment of the person responsible for waste management: Dr Ivana Jevtić 1070/10.11.2023.
26. Certificate of passing the exam for the Officer for Safety of Chemicals with Marko Jonovic SH.2019.1570
27. ICTM Gender Equality Plan for 2022-2024.

28. Rules of Procedure of the Scientific Council, 10.04.2024.
29. Intellectual Property Rulebook, 746/24.07.2023.
30. Open Science Ordinance, No. 217 of 05.03.2024.
31. Acquisition of Research and Scientific Titles Rulebook, "Official Gazette of the Republic of Serbia," no. 159/2020 and 14/2023

Given that the Center for Microelectronic Technologies conducts research and development of microelectronic chips, ICTM will also adapt to the regulations that the EU Chips Act will set.

## 4. ANALYSIS OF THE INSTITUTE

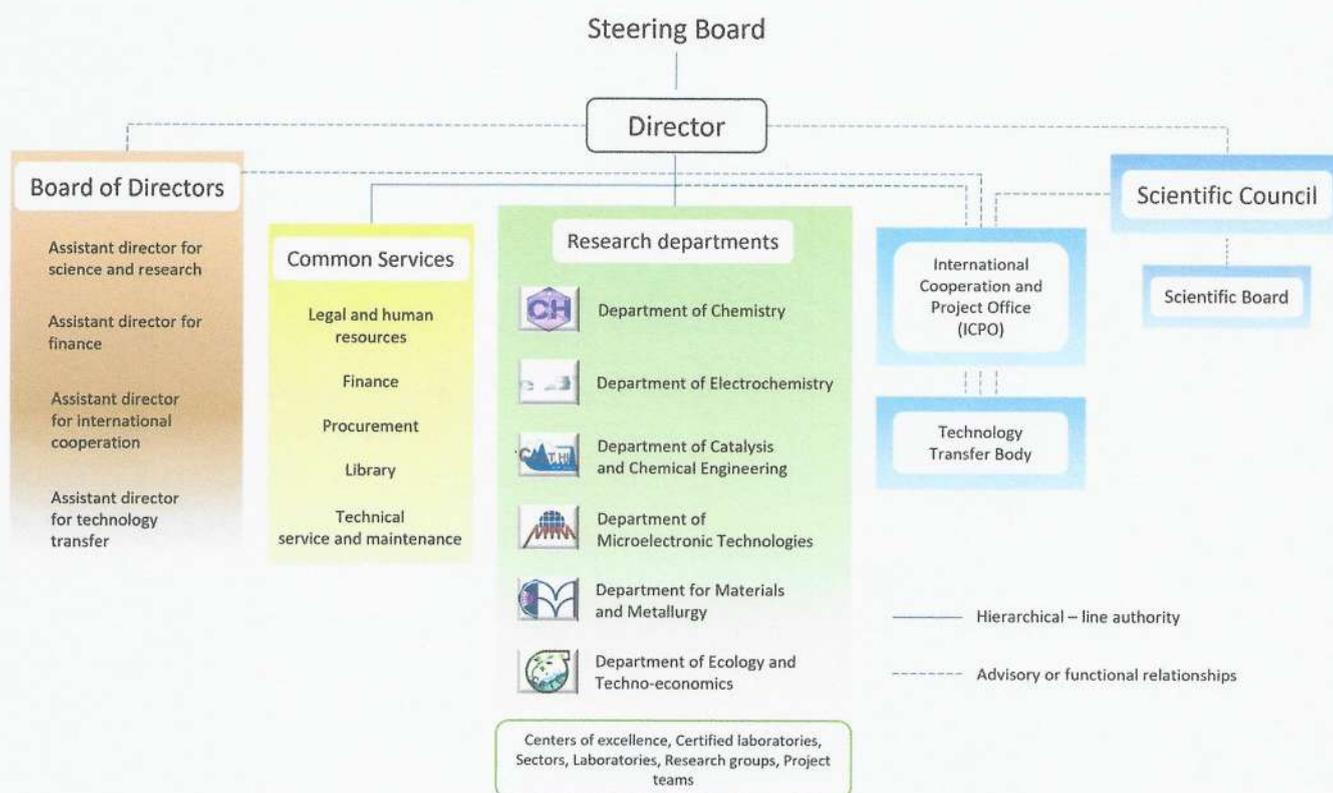
The Institute **conducts fundamental and applied research** in Natural sciences (chemistry, physical chemistry, biochemistry and biotechnology, geosciences, environmental sciences, and materials science) and engineering (chemical engineering and technology, electrical engineering, and environmental engineering). Activities are carried out in many disciplines, most notably in organic, inorganic, and analytical chemistry, medicinal chemistry, biochemistry, electrochemistry, chemical kinetics and catalysis, environmental chemistry, computational chemistry, microbiology, ecology, materials science, microelectronics, microsystems technologies, and chemical engineering.

In 2019, the Institute launched a repository of publications and research data (CeR: <https://cer.ihtm.bg.ac.rs/>) in compliance with the Open Science Platform of the Ministry of Science (<https://prosveta.gov.rs/wp-content/uploads/2018/07/Platforma-za-otvorenu-nauku.pdf>) and the Open Science Platform of the University of Belgrade ([https://bg.ac.rs/files/sr/vesti/Platforma\\_za\\_otvorenu\\_nauku\\_UB.pdf](https://bg.ac.rs/files/sr/vesti/Platforma_za_otvorenu_nauku_UB.pdf)). The repository aims to provide open access to publications and other project results from the Institute.

In addition to fundamental science research, ICTM conducts research and development activities to commercialize **products**. These activities are primarily focused on *providing services to external partners*. The Institute offers services for *the analysis of natural and synthetic organic compounds and the synthesis of organic, inorganic, and complex compounds*. It also develops catalysts and sensors for the detection of compounds and biomolecules. The Institute also *develops, designs, and produces sensors and measuring instruments for industry applications based on microelectronic and microsystem (MEMS) technologies*. The MEMS sensors are used to measure the physical parameters of industrial processes, detect chemical substances, biomolecules, and biological agents, environmental pollution parameters, monitor the body's physiological state, and control food safety. Microfluidic platforms and structures based on MEMS technologies for applications in chemistry, biochemistry, biology, and medicine are also developed, designed, and produced at the Institute.

### 4.1 ORGANIZATION

The following chart represents the current configuration and organization of the ICTM:



**Figure 2.** Organizational scheme of ICTM.

The Departments are led by the researchers appointed by the Director - Head of Departments. The Departments consist of research groups and laboratories that are either focused on common research areas or specialized in specific disciplines. At the same time, researchers within and between Departments are organized into less formal research groups and project teams. The personnel structure of the project teams varies periodically. Research groups and laboratories are formally and informally managed by more experienced researchers holding senior scientific titles or researchers who achieved particularly notable results in either fundamental or applied research (services and commercialization). Current project managers (principal investigators) organize and lead the project teams.

The Collegium consists of four Assistant Directors who have been chosen and appointed by the Director. The Scientific Council advises the ICTM Director when choosing the Assistant Directors. The Scientific Council consists of researchers with scientific titles who are elected by direct vote by researchers from their home departments. The Institute's legal documents define the number of members and the structure of the Council. The President of the Scientific Council and his/her Assistant are appointed from among the elected members at the first constitutive session. Their job is to manage the work of the Council.

The Scientific Board is an auxiliary body named and appointed by the Scientific Council. It consists of researchers holding the highest scientific title in the Institute -- the title of a Principal Research Fellow. The Scientific Board is managed by its President, while the legal documents of the Institute determine the number of members and the structure of the Scientific Board.

The Director manages the work, financial, and legal operations of the Institute and reports to the Board of Directors. The Director of the Institute and members of the Board of Directors are appointed in ways that follow the current Statute of the Institute and are in compliance with the legal regulations of the Republic of Serbia.

### 4.1.1. Organization of Research

Research work at the Institute is carried out within the framework of six Departments:

**The Department of Chemistry** is involved in fundamental and applied research in organic chemistry, biochemistry, biotechnology, the chemistry of biomacromolecules, synthetic and bio-polymers, environmental chemistry, inorganic chemistry, and computational chemistry. The Department of Chemistry is recognized internationally for its work in instrumental organic analysis – a field in which it has had many years of experience. The following research is carried out at the Department of Chemistry:

- *Organic synthesis, medical, bioorganic and chemistry of natural products:* synthetic transformations of natural products (derivatives of steroid compounds, monosaccharides, heterocyclic compounds, synthetic protein transformations), synthesis and design of biologically active substances (quorum sensing inhibitors, abiotic elicitors, heterocyclic compounds as signaling pathway modulators, thiazolidines, dopaminergic and serotonergic ligands, antimicrobial substances, cytotoxic and anticancer compounds, transition metal complexes with peptides, heterocyclic and other bio-relevant ligands, reversible protein stabilizers). Research in total and partial synthesis of natural products, method development for the synthesis of complex organic compounds, including asymmetric synthetic reactions and activation of the S-N bond, as well as development of new catalysts (organocatalysis, biocatalysis, and catalysis with complex compounds), synthesis and development of complex nanostructures and nanomolecular machines based on fullerene C<sub>60</sub> and other nanomaterials and testing of physicochemical properties, supramolecular interactions of synthesized products, and construction of nanoparticles of various derivatives suitable for the design of new materials and applications in bionanotechnology are also conducted.
- *Instrumental methods of analysis:* isolation and characterization of natural products and secondary metabolites from endemic plants, marine species, and microorganisms; isolation of organic compounds; determination of structure by advanced spectroscopic techniques; investigation of their biological activity and examination of structure-activity relationships, detailed chemotaxonomic research of importance for the broader region of the Balkan Peninsula; metabolomic testing of plants and fungi to study the effects of metabolic variations (caused by disease, environmental or genetic changes) on complex biological systems. Metabolomic examination of blood and tissue samples of patients suffering from psychiatric diseases and cancer to develop methods for early diagnosis and monitoring medical therapy's effects; development and improvement of analytical methods for identifying and characterizing toxic substances (long-lived organic pollutants, chemical weapons).
- *Theoretical chemistry and molecular modeling (computational chemistry)* – understanding of chemical problems using modern computational techniques, rational design and prediction of chemical systems with targeted properties (molecular magnets, catalysts, explosives, drugs, dyes); supramolecular approach to crystal packaging, its role in biological recognition and in binding to synthetic polymers; reaction mechanisms; computational spectroscopy; modeling of inorganic complexes, biomolecules and molecules of atmospheric or energetic significance dispersed within porous materials; correlation between electronic structure, (re)activity and properties of molecules. High-level quantum-mechanical calculations, density functional theory, semi-empirical methods, molecular dynamics, Monte Carlo simulations, docking, and database searches are used.
- *Biochemistry and biotechnology:* production of industrially important enzymes; development of methods for identifying the complexity of isoenzyme forms in mixtures of enzymes produced by microbes. Stabilization of enzymes by protein engineering techniques and/or chemical modification as well as immobilization on inert carriers; isolation and characterization of microorganisms; production

and characterization of microbial biologically active substances (antibiotics, polysaccharides, enzymes, biosurfactants); study and development of new infant formulas with unique properties concerning bifidogenic effect and antioxidant activity; bioremediation, biodegradation and biotransformation of substances from the environment; development of new biopolymer-based materials for use in the food industry and environmental protection; directed evolution of lignocellulite enzymes; investigation of the biological activity of small organic molecules and inorganic complexes with DNA and proteins.

- *Polymer chemistry*: synthesis of polymer nanocomposites based on silver nanoparticles, unmodified and modified nanoparticles, and various polymer matrices; synthesis of hyper-branched polyesters as well as cross-linked polyurethanes based on hyper-branched polyesters; synthesis, functionalization and characterization of non-magnetic and magnetic macroporous copolymers; synthesis and characterization of polymer nanocomposites; biocompatibility testing of polymeric materials.
- *Functional materials and biomaterials* – rational design, synthesis, and development of new multifunctional nano- and micro-composite materials, functionalized natural and synthetic macromolecular materials, and coordination compounds with optimal structural and functional properties having electrochemical, optical, and biological activity for applications in medicine and the chemical industry. Functions and activities of materials are studied for their analytical (electrochemical detection - sensors and biosensors), catalytic (photochemical and electro-degradation), environmental protection (for the remediation of natural and wastewater), antimicrobial (bactericidal, antifungal), and pharmacological (biocompatibility, anticancer drugs, drug delivery) properties; ecosystem protection by testing the effectiveness of control of the effects of natural and anthropogenic toxic and nutritious substances on food chains (ecotoxicological bioindicators); development of novel oxide materials with characteristic electrical, magnetic and optoelectric properties for applications as multiferroics, energy conversion and storage materials by studying the correlation between their macroscopic activity and the nanostructure of the material.
- *Development of new biological indices* based on micro- and macroalgae and new, innovative, and significantly improved methods (such as metabarcoding) of monitoring natural aquatic ecosystems (rivers and lakes) and their biodiversity.
- *Geochemistry and environmental chemistry* – investigating biogeochemical processes occurring at the surface and deeper layers of the Earth's crust using various geochemical analyses. Field, experimental, and laboratory work to establish the situation in various segments of the environment, including the study of the origin, distribution routes, biodegradation and bioaccumulation of pollutants, determination of the vulnerability of terrain to environmental changes, prevention of degradation processes, current climate change, risks to the environment and human health, determination of ecosystem services and proposing nature-inspired solutions; examination of sedimentary rocks of different geological ages, crude oil, coals, oil shales, soils, archaeological samples and artifacts, characterization of pyrolysis products and the possibility of using biochars.

**The Department of Electrochemistry** conducts research in electrochemistry and electrochemical engineering. Research themes include characterization of electrocatalytic materials, electroplating engineering, electrometallurgy, corrosion and corrosion protection, fuel cells, supercapacitors, electroanalysis of drugs and drug-related chemistries and electrochemical sensors as well as electrochemistry of polymeric, building materials and biocomposites. In this area, the following frameworks of work have been set:

- *Electrocatalysis* – development of catalysts for applications in low-temperature fuel cells and water electrolyzers, synthesis and characterization of stable catalysts for oxidation of small organic molecules, oxygen reduction, and oxygen evolution. Research on catalysts based on precious and transition metals

and oxides is carried out. The catalysts are studied in thin films, which serve as model systems for real catalysts, and as nanoparticles deposited on carbon, polymers, and composite materials of high surface areas. The research aims to obtain catalysts with superior characteristics to commercially available ones.

- *Electrochemical deposition and dissolution* of metals and alloys can occur from aqueous electrolytes, brine, and ionic liquids. New procedures for electrochemical deposition of technologically important metals (copper, silver, tin, and others) from aqueous electrolytes are being developed. Deposits with superior morphological, structural and mechanical characteristics are obtained. Processes are being devised that allow the production of metals and alloys in various forms, ranging from compact to highly developed surface area powders. New procedures for the electrochemical deposition of non-ferrous metals, rare earths, and their alloys – which enable the more successful recycling of these metals and alloys from waste products- have also been developed. Nano-multifunctional coatings on titanium obtained by electrochemical precipitation have biocompatible, osteoconductive, antimicrobial, and anti-inflammatory properties and are also being studied.
- *Batteries and supercapacitors* – synthesis, physicochemical and electrochemical characterization of composite particles with different core-shell structures to serve as electrocatalysts in alternative energy sources. The goal is first to obtain composite particles through the controlled synthesis of the core, then synthesize core-shell particles, and finally, to produce and test electrodes derived from these particles in a fuel cell.
- *Corrosion protection* – testing of various types of corrosion in structural materials using electrochemical and non-electrochemical methods. Testing of metallic and non-metallic inorganic and organic coatings, corrosion inhibitors and anodes for cathodic protection. Testing the protective effect of environmentally friendly corrosion inhibitors, including those based on the combination of lanthanides, organic inhibitors, commercial aluminum alloys, and steels. Electrochemical methods and morphological and structural characterization are studying the protection mechanism of these materials. Methods of computational chemistry further characterize the action mechanism of the inhibitors on the protected metal.
- *Other activities* include the synthesis and characterization of new composite, metal, refractory, ceramic, and building materials with properties improved in ways that meet modern industrial requirements of sustainable development; development of technological procedures for obtaining usable and environmentally friendly materials and products, using underutilized natural and technogenic mineral resources; synthesis and characterization of functional polymers and polymeric nanocomposites for new technologies for the production of biodegradable materials for food packaging and as drug carriers.

**The Department of Catalysis and Chemical Engineering** performs and studies the synthesis and characterization of materials for applications in catalysis, including catalysts, catalyst precursors, catalyst carriers, and adsorbents for a broad range of applications. Adsorption and catalytic phenomena, modeling of catalytic processes, fluid mechanics, and multiphase fluid-particle systems are also being studied at the CKHI. The Department is also engaged in the technology transfer from academia to industry.

Current research in the field of catalysis covers the following topics:

- *Heterogeneous catalysis* – development of new catalysts for hydrogenation of vegetable oils, production of biodiesel by transesterification, photocatalytic hydrogen production, oxidative and photocatalytic degradation of pollutants in water, and production of sensor materials for the detection of organic compounds in biological liquids.

- *Photocatalysis* – development of new nanostructured photocatalytic materials for applications in energy conversion and environmental protection; improvement and modification of existing catalysts for the conversion and storage of solar energy (hydrogen production by photocatalytic decomposition of water, artificial photosynthesis/photoreduction of CO<sub>2</sub>). Research of nanostructured, multifunctional catalysts based on polymer/metal oxide composites as catalysts in the photocatalytic degradation of organic pollutants in aqueous environment is also conducted. Insight into the mechanisms and kinetics of degradation reactions is obtained using quantum-mechanical calculations in complex reaction systems.
- *Electrocatalysis* – development of new electrode materials for electroanalysis and energy conversion applications. Activity, stability, and selectivity of electrode materials for medical applications, food control, and environmental protection are examined. Electrocatalytic processes such as oxygen evolution and reduction, hydrogen evolution, and methanol electrooxidation are investigated. The main focus of research is ways in which the electrocatalytic properties of the composite material depend on the electrochemically active surface, the surface of the catalyst support, and the synergy between the catalyst support and the electroactive component.
- *Enzyme catalysis* (in collaboration with the Department of Chemistry) – work aimed at producing safe and robust biocatalysts for use in various industries. The catalysts comprise enzymes immobilized on safe (benign, non-toxic), naturally occurring, or modified inorganic supports. Chemical, physical, morphological, structural, and textural characterizations of enzyme supports and immobilizates are performed. The resulting biocatalysts can be used repeatedly in continuous processes in various industries.
- *Modeling of catalytic processes* – due to the high level of complexity of physicochemical processes in the catalyzed reactions, often followed by complex dynamics and nonlinear kinetics. Research in this field demands sophisticated computational methods and modeling processes, as well as evaluation of mechanisms of reactions in which oscillatory changes in the concentration of intermediates occur during the processes.
- *Chemical engineering* – momentum, heat, and mass transfer in fluid-particle systems in co-current and counter-current flow, air and water purification, granulation/agglomeration, drying of suspensions and pastes, testing of rotating systems (rotating reactors, rotating-packed and fluidized bed reactors) to intensify mass and heat transfer in polymerization, distillation, extraction, and crystallization. Research also includes modeling and design of processes aimed at obtaining high-quality products, consuming little energy, and minimizing environmental impact while improving process efficiency.
- *Adsorption materials and adsorption phenomena* – development of nanostructured and hybrid materials based on smectite phyllosilicate and their application as adsorbents; development of multifunctional hybrid nanocomposites. Adsorption mechanisms of organic and inorganic adsorbates are studied.

**The Department of Microelectronic Technologies** performs basic and applied research in microelectronic, optoelectronic and microsystem technologies and materials, sensors and measuring instruments. The Department performs comprehensive research, starting from the theoretical investigation of phenomena, development and design, and finally, fabrication of sensor structures and components using microelectronic and microsystem technologies. The Department develops measurement methods and apparatus for the characterization of fabricated structures and components, optimizes design using mathematical models and computer simulations, develops electronic circuits for signal processing mechanical circuits, and produces measuring instruments based on sensors developed at the Department. Current research includes:

- *Development of miniaturized sensors for a wide range of applications.* These include graphene-based sensors for the detection of chemicals (gases) and monitoring of physical properties (air humidity, temperature, substrate stress, acoustic signals, physiological parameters); MEMS multi-sensor instrument for measuring aerodynamic pressure; miniaturized, simple, high sensitivity, high stability and high response speed, low-temperature, thick-film sensors, obtained by mechanochemical treatment of metal oxide powders; electrochemical air-humidity sensors, self-powered by an electrochemical reaction between water and the materials from which the sensor is fabricated; semiconductor detectors of ionizing radiation; a new generation of thermal MEMS sensors with thermocouples for the detection of single gases and the composition of binary gas mixtures; the ultimate goal is to produce a portable multifunctional measuring device that would be applied in industry, medicine and environmental protection; wide range microwave filters.
- *Microfluidic platforms based on MEMS technologies* – development, design and fabrication of devices for use in chemistry, biochemistry, biology, and medicine. Devices comprised of different combinations of microfluidic reactors, micromixers and microparticle separators are envisioned to be developed and fabricated. Optimization of microchannel dimensions and design parameters of integrated heaters in microfluidic reactors for the synthesis of nanoparticles is performed. Optimization and improvement of microfluidic reactors for photoredox functionalization aimed at obtaining biologically active derivatives. The validity of the trade-off between the cost of production and the reliability of the fabricated devices is being examined.
- *Dye-sensitized solar cells*, based on natural pigments to achieve the highest possible efficiency of solar energy conversion using relatively inexpensive and readily available materials. Optimization of existing cells by utilizing new materials, methods and procedures to expand the absorption range and increase efficiency.
- *Modeling of kinetics and dynamics of adsorption-desorption (AD) processes* in micro- and nanosensors and components and practical application of the developed models. Physical and chemical processes are being modeled, including the adsorption of heavy metals and hazardous materials (for bioremediation purposes), greenhouse gases, and volatile organic compounds in food chains. Artificial intelligence methods are used to model AD processes. Optical metasurfaces for application in refractometric biochemical sensors are investigated theoretically and experimentally.
- *Fabrication and characterization of materials for microelectronics applications* – electrochemically deposited **metal coatings** in various forms, including thin films, multilayer structures and metamaterials; structure optimization performed by software analysis and application of artificial neural network and multiparameter regression analysis. Characterization of structural, morphological and mechanical properties of synthesized materials. Synthesis, development and characterization of **new multifunctional polymeric materials and their nanocomposites** with good mechanical, thermal and surface properties for applications as coatings in medicine (study of antimicrobial properties, biocompatibility, ability to controllably release drugs, genes, antibiotics, and other medically important substances) as well as for applications in microelectronics. Testing the mechanical properties of polymeric materials by applying them directly to existing constructions using additive technologies aimed at improving the mechanical properties of polymeric materials by exposing them to various chemicals or heat. This research has also found its application in forensics.

**The Department of Materials and Metallurgy** is focused on developing modern metal, magnetic, ceramic, polymer, composite and nanostructured materials and multicomponent metal systems with different properties and functions. The research also includes mathematical modeling and simulation of chemical engineering processes and behavior of materials, their integration at the laboratory and industrial level,

and the development of green technologies, including ones utilized for reducing harmful emissions or recycling and increasing the energy efficiency of chemical processes.

More specifically, the research themes at the Department include:

- *Processing, characterization, thermodynamic analysis, and modeling* of metal systems and sintered materials with improved structural, mechanical, thermal and electrical properties and/or environmentally friendly materials for applications in electronics, electrical engineering, energy, and other fields.
- Development of *innovative methods of synthesis*. Materials of interest include nanocrystalline materials and nanoparticles based on magnetic Nd-Fe-B alloys, magnetic soft mixed metal containing Fe, and quasi-one-dimensional nanomaterials with magnetic and superparamagnetic properties. Surface modification and functionalization of such materials are also conducted.
- *Synthesis, characterization, development, and modeling* of composite/nanocomposite materials based on polymer or metal matrices of defined structure, porosity, magnetic, electrical, and mechanical properties.
- *Surface modification* and functionalization of woven and non-woven, polymer-composite textile membranes obtained by electrospinning aimed at improving their selectivity and mechanical, physical and chemical properties.
- Investigating possibilities of *organic sulfur removal from crude oil using polymer membranes* -- research aimed at reducing sulfur oxide emission during combustion of petroleum products.
- *Construction of membranes* comprised of polymer matrices and dispersed inorganic zeolite powders of different pore geometries and additives – research aimed at reducing the emission of harmful combustion products.
- Development of *performance testing devices* for membrane separation and a system for advanced osmosis.
- Development of a *universal mathematical model for membrane separation* and a hybrid mathematical model based on artificial intelligence.
- Design of a *device for efficient and continuous centrifugal-fluid-filtration* and modeling, simulation, integration, and optimization of filtration processes.
- Development of *recycling devices* for reuse of organic solvent waste from paints. The operational principle of such devices is based on distillation. Development of computer applications for assessment of the economic viability of recycling waste paints and other organic solvents.
- *Studies of energy efficiency* of chemical, petrochemical, food, pharmaceutical, and other industrial processes.
- *Testing of alternative renewable fuels* based on terpene feedstocks. Experimental determination of volumetric characteristics of multicomponent terpene mixtures at high pressures and temperatures and their modeling.
- Feasibility studies of *indirect electricity generation from waste heat* using the Organic Rankine Cycle.

**The Department of Ecology and Technoeconomics** is the most recently founded organizational unit of ICTM. The Department conducts applied research in environmental protection, focusing on the sustainable use of natural resources, climate change mitigation, and techno-economic analysis of production processes and services. Activities include applied research and development in environmental protection of water, air and soil, use of renewable resources and analysis of techno-economic aspects of production technologies. Areas of research include:

- Studies of the effectiveness of adsorption of pollutants (i.e., heavy metals, petroleum products, paints, pesticides, and other organic pollutants) from aquatic ecosystems and soils using various biomaterials.

- Modeling of experimental results using adsorption isotherms and kinetic models, calculation of thermodynamic and activation parameters, and modeling using diffusion models in batch and continuous systems.
- Synthesis and modification of biomaterials and their application for the removal of pollutants, as well as studies of biological processes for hydrogen production.
- Use of renewable, alternative, and new energy sources, as well as biofuels for environmental protection and mitigation of the effects of climate change. The ultimate goal of this work is to integrate these resources into existing energy systems following the concept of circular economy and cleaner production. Activities in the Department include laboratory testing, obtaining energy from biomass and other resources, and applying statistical methods and energy modeling.
- Detection and monitoring of organic pollutants in various media (water, air, soil) and following their migration in the environment using chemical and electrochemical detection techniques as well as the Geographic Information System (GIS);
- Strategic assessments of environmental impact, planning strategies and programs for remediation, studies of impacts of various investment projects on the environment, drafting plans to improve local communities' environmental protection, and consulting expertise in environmental protection.

The Government of the Republic of Serbia accredited two **Centers of Excellence** at ICTM: the **Center of Excellence for Environmental Chemistry and Engineering** and the **Center of Excellence for Microelectronic Technologies (Department of Microelectronic Technologies)**. Centers of Excellence are accredited based on the exceptional quality of their researchers and the unique impact these groups have on the advancement of science in the country.

Researchers from the Department of Chemistry and the Department of Electrochemistry participate in the Center of Excellence for Environmental Chemistry and Environmental Engineering work. Researchers in this Center study cause-and-effect relationships between pollutants and the environment, conduct studies of migrations, transformations, and interactions of pollutants in the environment (atmospheric aerosols, soils and river sediments), and perform risk assessments for the environment and wildlife. Quantum chemical calculations of stability factors of persistent organic pollutant molecules aimed at predicting their behavior in the environment are performed. The food chemistry of small molecules having potentially detrimental effects on human health is also of interest.

All researchers from the Department of Microelectronic Technologies and Microelectronics are part of the **Center of Excellence for Microelectronic Technologies**. The Center is equipped with unique instrumentation and highly experienced human resources and represents a uniquely integrated complex system with a tradition of over 60 years. This Center designs, fabricates, and characterizes microsystems and microchips (obtained by planar technologies or micromachining).

## 4.2 INFRASTRUCTURE

Since its established, ICTM has occupied 3606 m<sup>2</sup> at three different locations in Belgrade: the administrative building located at Njegoševa 12, dedicated spaces at the Faculty of Chemistry at Studentski trg 12-16 as well as at the Faculty of Technology and Metallurgy at Karnegijeva 4. The space comprises business premises, laboratory and office spaces, laboratory spaces in partner research organizations, and auxiliary rooms. This space was dedicated to ICTM employees when the Institute was established in 1961 and hasn't changed since. It currently amounts to approximately 15 m<sup>2</sup> per employee. Currently, the available space is size-limited and inadequate to support new instrumentation and equipment. Work is

continuously being done to rearrange the existing space and to adapt it to the needs of the Institute. However, the resulting space is still insufficiently large to house the existing and, even more so, to accommodate new equipment.

The Institute, like most of the leading SROs in Serbia, currently has equipment that is conditionally suitable for the realization of cutting-edge scientific research. Most of the equipment is used intensively for a long time. The reason for this is the long-term absence of strategic investments for the procurement of large and capital laboratory equipment, lack of records of existing equipment in Serbia, lack of competitive programs for the procurement of equipment at the state level, insufficiently defined, sustainable, and practical solutions for maintenance, insurance, and depreciation of equipment, as well as an insufficient number of capital projects managed by ICTM researchers or participants in them. The maintenance of outdated and depreciated equipment represents a major financial and technical problem, especially considering that no means are systematically allocated for these purposes. A part of the equipment has been renewed by implementing international and national projects in the past ten years. However, this is insufficient to carry out top scientific research and publish the results in journals with a high impact factor. A significant part of the equipment located in the Institute is outdated in terms of the condition of the instruments themselves, but also in terms of competitiveness in terms of the modernity of the methods. It is common for models owned by ICTM to be out of production, sometimes so long ago that the manufacturers no longer provide service support or suitable spare parts. The functioning of that equipment is ensured for now solely thanks to the researchers' enthusiasm, technical training, and the energy they invest.

The ICTM is recognizable by its human resources and its technical capabilities. Several ICTM laboratories are unique in the country and the wider region.

The **laboratory for Complete Identification and Structural Characterization of Unknown Organic Compounds (LabCH)** is a unique laboratory widely recognized for its capabilities in the country and the region. This laboratory has instruments for state-of-the-art structural analysis of compounds (NMR, MS, IR, UV-VIS, microanalysis, polarimetry), analytical separations of mixtures, and identification of their components (HPLC, HPLC-MS, GC, and GC-MS). The accredited Laboratory of the Department of Chemistry partly covers these resources.

The equipment in the Department of Catalysis and Chemical Engineering enables **complete analysis of the textural and adsorption properties of catalysts, their precursors and carriers, and other materials**. The Institute has a **laboratory for complete textural characterization of porous materials**, including low-temperature nitrogen physisorption and mercury porosimetry. Both methods, taken together, allow an entire range of pore sizes – super-macro, macro, meso and micropore – to be analyzed. **The adsorption properties of porous materials are studied using** temperature-programmed desorption/reduction/oxidation with pulsed chemisorption and mass-spectrometric detection – TPDR. Textural characterization and chemisorption properties, taken together, reveal the adsorption properties and surface reactivity of heterogeneous catalysts and other active materials for their specific surface area, catalytically active surface area, dispersion of active species, and surface activity of the catalysts. The researchers in the Center for Catalysis and Chemical Engineering have acquired decades of experience in textural characterization of porous materials and are the most competent personnel in Serbia and the Western Balkans for this type of work.

Specific equipment Department of Microelectronic Technologies includes a furnace for diffusion and oxidation for planar technologies, a device for laser mask fabrication and lithography (down to 5  $\mu\text{m}$ ), a thin-film deposition system by sputtering, an automatic probe, a profilometer for measuring the thickness of thin films, a device for plasma welding, a double-sided aligner, a wafer bonder with an aligner, a bonder Al, an automatic machine for cutting silicon wafers as well as instrumentation for characterization of

fabricated structures (scanning probe microscopes, spectrophotometers, FT-IR microscope, etc.). The Department of Microelectronic Technologies, which the Serbian Government accredited as a Center of Excellence, possesses equipment and human resources to **design, fabricate, and characterize microsystems and microchips** (using planar technologies and micromachining).

In addition to these three specific units, the Institute has over 100 instruments classified as large equipment.

The most important instruments include a gas chromatograph (GC) equipped with three detectors: a thermal (TD), flame-ionization (FID) and a low-resolution mass spectrometric detector (MSD), a GC with FID detector and selective detector for phosphorous and sulfur compounds (FPD), a GC with a headspace sampler, FID detector and a detector for atoms and molecules by electron capture (ECD), a GC dual-system, an ion chromatograph, a high-pressure liquid chromatograph (HPLC) coupled to a high-resolution mass spectrometer, a liquid chromatograph (LC) with a photo diode-array detector (PDA) coupled to a low-resolution mass spectrometer (MS/MS QQQ), an inductively coupled plasma mass spectrometer (ICP-MS), HPLC with a diode array detector, a device for voltammetric determination of trace amounts of microelements and toxic trace elements as well as cyclovoltammetric determination of organic additives with enrichment and successive dissolution, a cascade impactor, a mobile gas analyzer, a microwave digester and extractor, an elemental organic compound composition analyzer, <sup>57</sup>Fe Mössbauer Spectrometer, Infrared Spectrometer (FT-IR), Nuclear Magnetic Resonance Spectrometer, UV/VIS Spectrophotometer, UV 2600, UV/VIS for Plate Microtiter, Inductively Coupled Plasma Apparatus with Optical Emission Spectrometry coupled with a Mass Spectrometric Detector, an Atomic Absorption Spectrophotometer with MHS Hydride System and Compressor, an Apparatus for Determination of Total Organic and Inorganic Carbon, Potentiostat/Galvanostat VOLTALAB PG2 402, EIS SP-240, EIS SP-200, Micro Balance Module, NanoScope MultiMode SPM with Anti-Vibration Table, Optical Microscope with Camera OLYMPUS CX41, Leica DM ILM Metallographic Microscope, Pressurized Glass Reactor, High Pressure Reactor, Photocatalytic Reactor, Hydrothermal Reactor, Planetary Mill, Planetary Ball Micro Mill, Tube Annealing Furnace, Labor-Centurion 6 Heating Element Diffusion Furnaces, for Planar Technologies on Si, Polarimeter, Refractometer, Calorimeter, Respirometer, Lyophilizer, Hydrogenation System, Simultaneous Differential Thermal Analysis Device SDT Q600, Electrical Conductivity Measuring Instrument Sigmatest 2.069, Spectrum Analyzer, DSP Lock-In Amplifier 7280, Device for laser making of masks and lithography – LaserWriter LW – 405, Photoplotter MIVA 2516 T3, Spincoater, Laser cutting and engraving machine, Milli-Q® Advantage A10 and Elix®10 water treatment system, Glove box system, Air Handling Unit with Accessories, Apparatus for Ultra-High Vacuum, Programmable Two-Channel Electronic Pressure Calibrator, Gas Mixer with Control Electronics, Centrifuges, Ultracentrifuges, Device for Deep Freezing and Storage of Samples at Low Temperature (-80°C), Vacuum Evaporator, Precision Digital Balances.

### 4.3. PROJECTS

From 2017 to 2023, ICTM researchers participated in 96 national and 61 international projects and were principal and participant investigators.

#### 4.3.1 International projects

Types of international projects in which ICTM researchers participated in the previous five-year period are schematically depicted in Figure 3. A significant share is held by bilateral projects (24) and COST actions

(25), while other projects include Horizon Europe (4), Horizon 2020 (3), NATO (2), EUREKA! (3), DAAD (5), and Diaspora (2).

As seen in Figure 4, the number of received international grants per year generally increases by 2019. The COVID-19 pandemic caused a delay in the start of the implementation of a large number of projects between 2020 and 2022. These "stalled" projects continued to be implemented after the decline of the pandemic in 2022, when a significant rise in the number of active projects occurred (Figure 4). Data for 2023 show a decrease in the number of active projects, probably since most researchers were engaged in completing the pandemic-affected projects in the previous year. Notably, 58% of the international projects are led by ICTM personnel (Principal Investigators) (Figure 5).

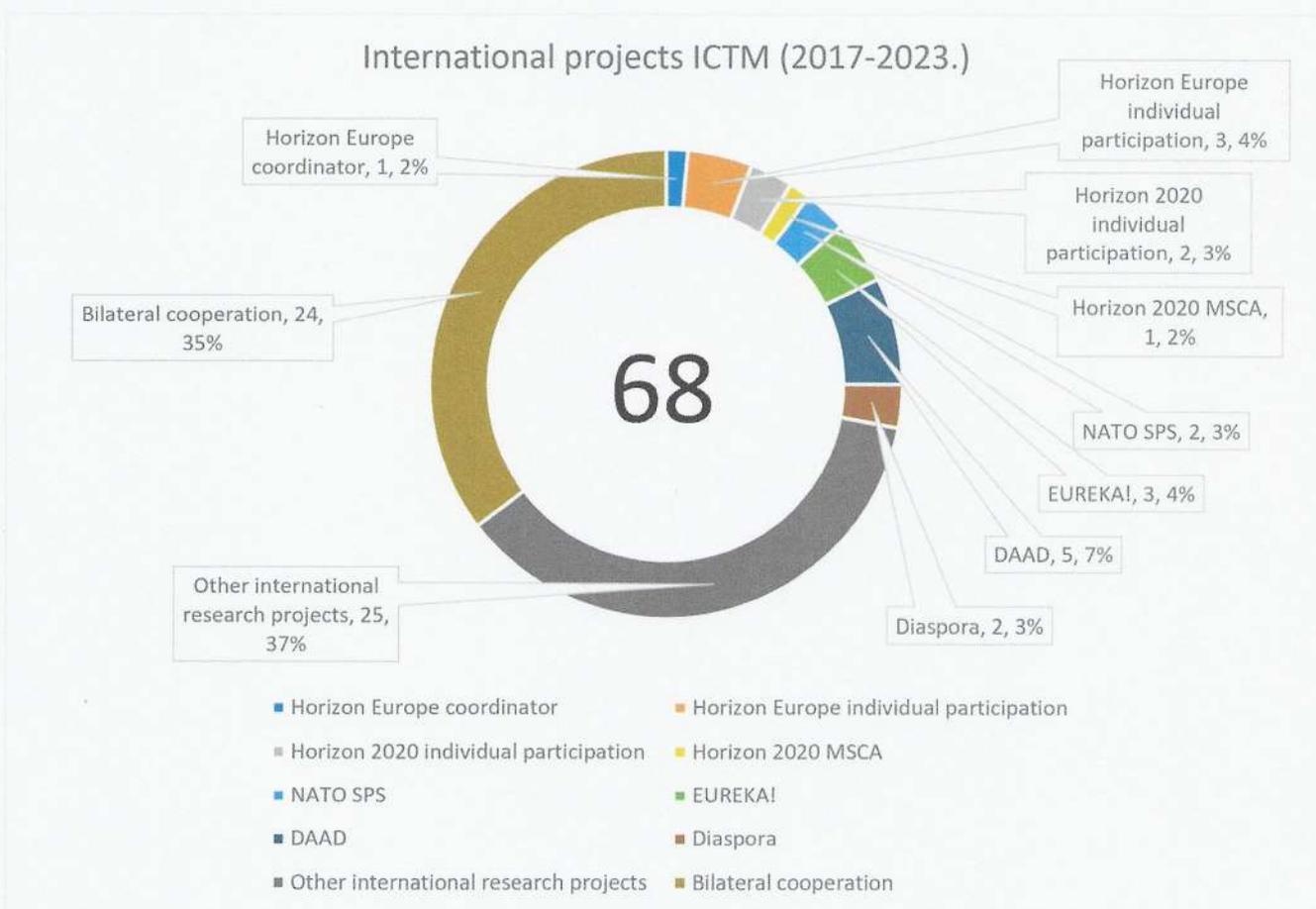


Figure 3. An overview of International projects, 2017-2023.

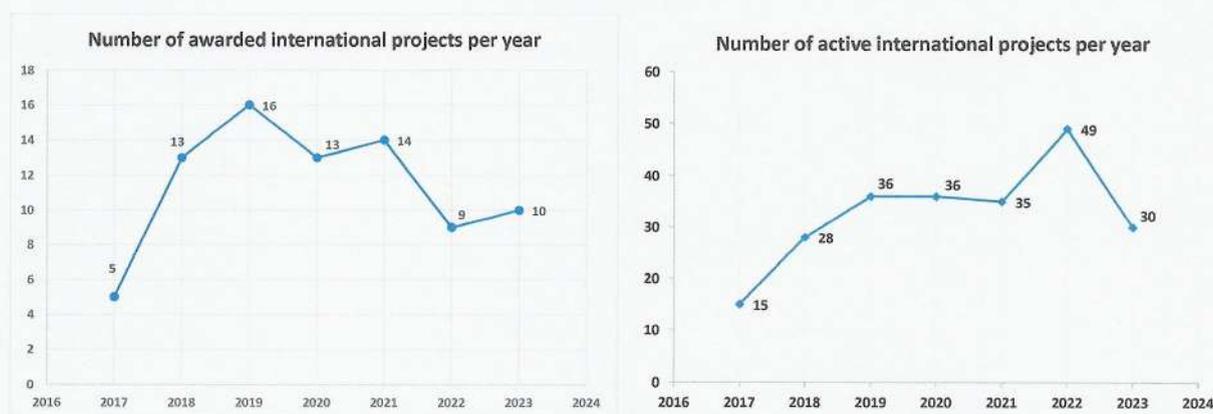


Figure 4. Number of awarded (left) and active (right) international projects, 2017 -2023.

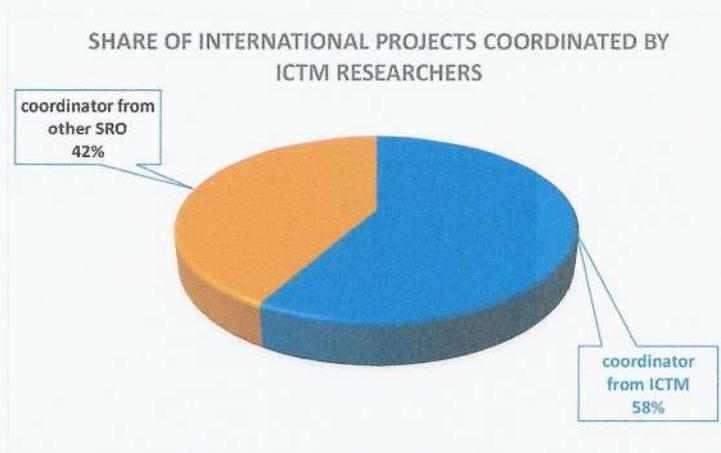


Figure 5. Share of international projects coordinated by ICTM researchers.

### 4.3.2 National projects

From 2017 to 2023, ICTM researchers participated in realizing 96 national projects. From Figure 6, the types and numbers of grants obtained at the national level can be seen. Most grants received in the past five-year period were funded by the Ministry of Science - Fundamental Research (28) and the Technological Development (10) programs. The remaining grants were obtained from the Green program aimed to connect research in academia with industry (4), IDEAS (5), PROMIS (4), COVID (1), Identities (1), Innovation Fund (15), III MNTRS (10), Serbian Academy of Science and Arts (SANU) (3), PRISMA (8), Collaboration between academia and industry) (1), UNDP (2), and others (4). Large fluctuations in received grants per year can be seen in Figure 7. In terms of the number of active national projects, it can be seen that 2019 is a turning point. The sharp drop in the number of projects is a consequence of the end of the previous project cycle and a change in the approach of the relevant Ministry to significantly reduce the number of calls, as well as the end of the practice that projects cover all researchers. The smaller number of financed projects and the greater competitiveness of calls contributed to the Institute falling from 49 projects to 13 within a year. From 2020, a slight trend of increasing the number of projects implemented in specific years can be observed. This can be connected with the increased number of received projects and the more significant number of announced calls.

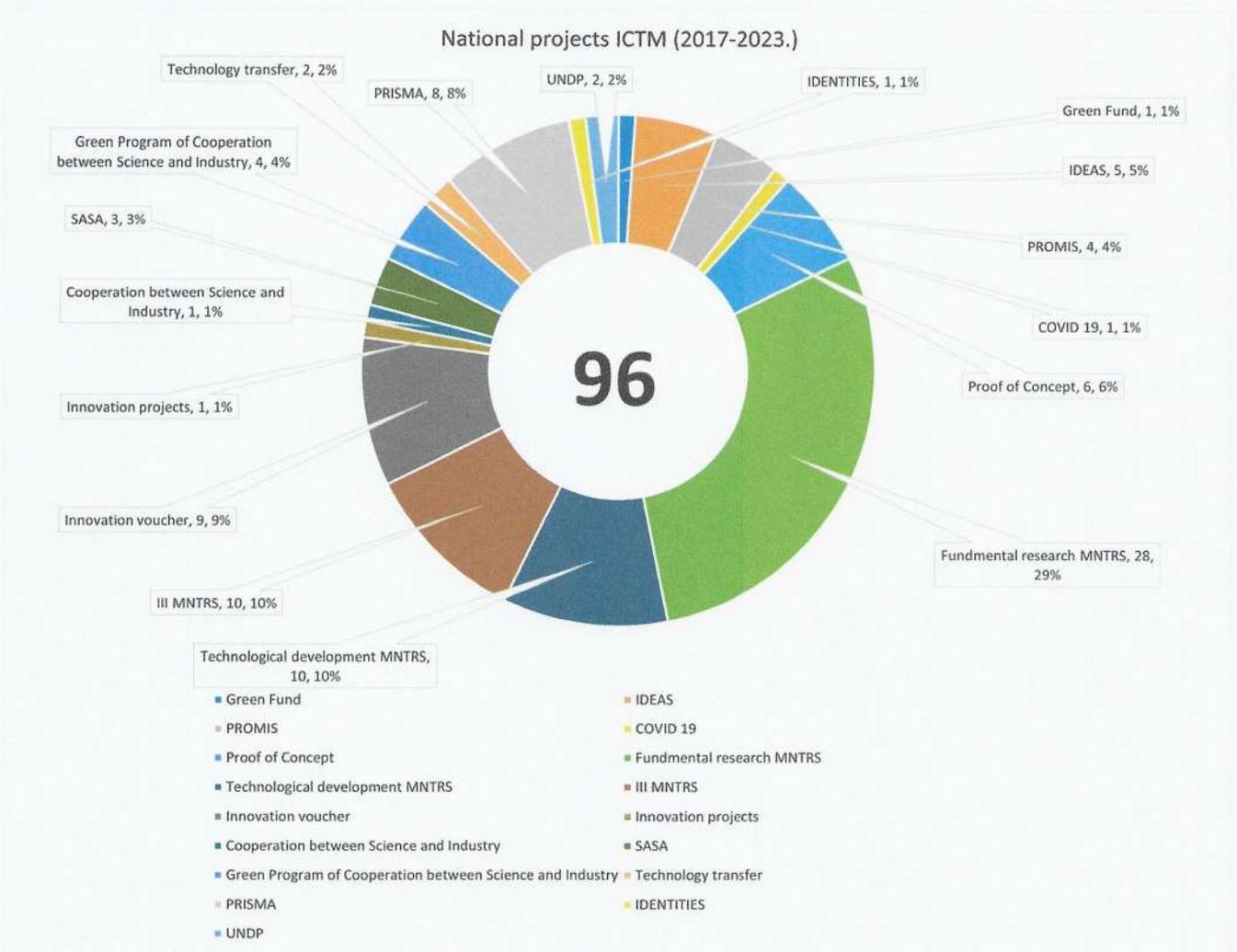


Figure 6. An overview of national projects, 2017–2023.

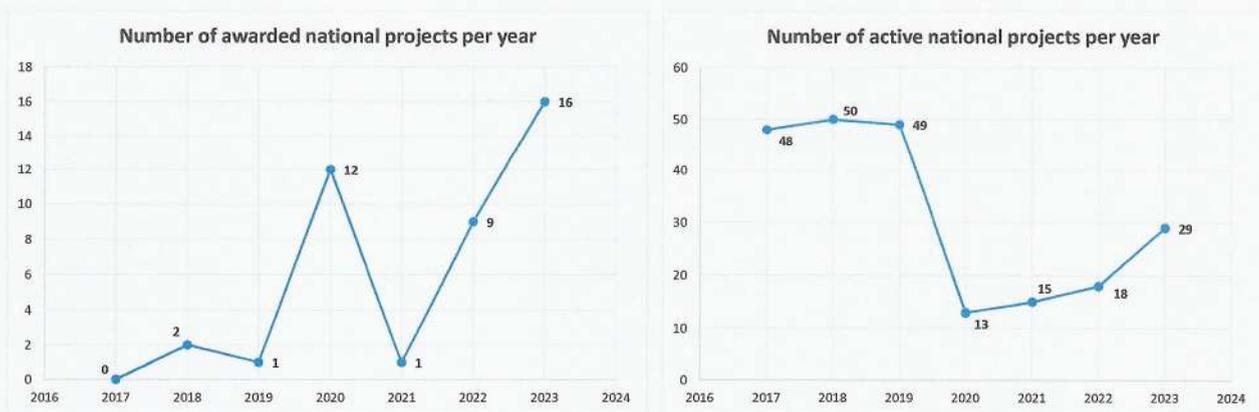
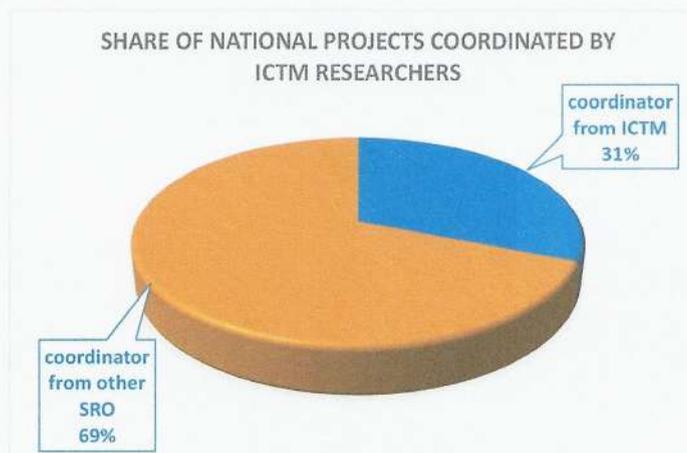
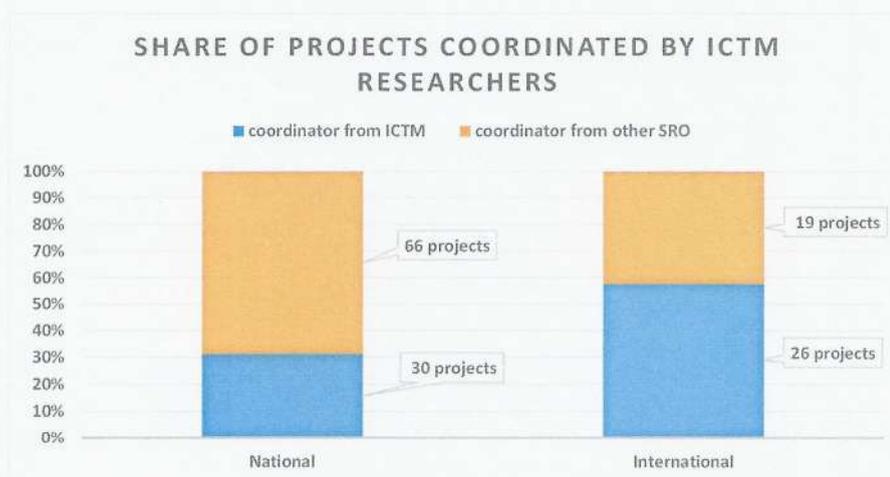


Figure 7. Number of awarded (left) and active (right) national projects, 2017- 2023.



**Figure 8.** Share of national projects coordinated by ICTM researchers.

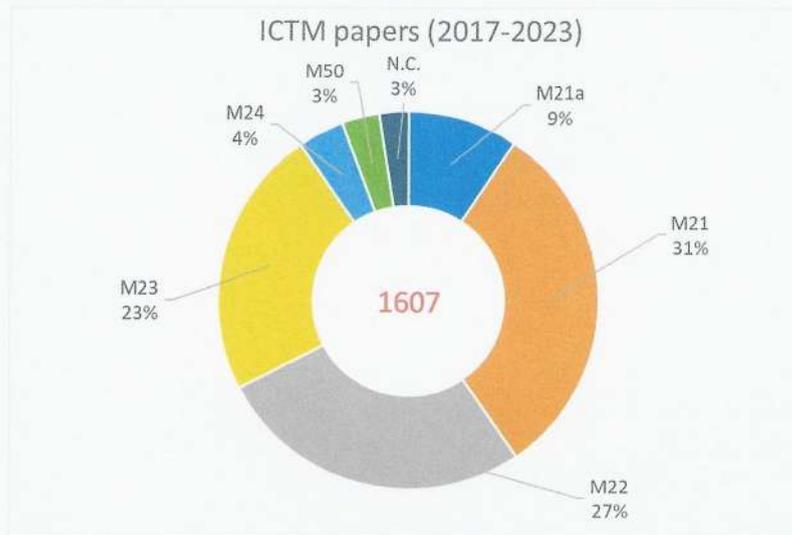
Considering the share of national projects managed by researchers from the Institute, it can be concluded that ICTM is not in a favorable position. With a share of only 31%, a significant part of the finance that the Institute could otherwise dispose of is lost. In the case of international projects, the situation is much more favorable because 58% of the projects have managers from researchers in ICTM. On the other hand, there is a more significant number of individual participation of researchers, especially in larger projects, than the participation of the Institute in the role of partner or coordinator, which is also unfavorable.



**Figure 9.** Share of projects coordinated by ICTM researchers.

#### 4.4 PUBLISHED PAPERS

ICTM researchers published 1605 papers between 2017 and 2023 (data taken from the Institute's repository). The papers are categorized by the quality of the journals in which they appear. Figure 10 illustrates the distribution of the published work according to different categories (M21a, M21, M22, M23, M24, M50 and non-categorized work – NC).

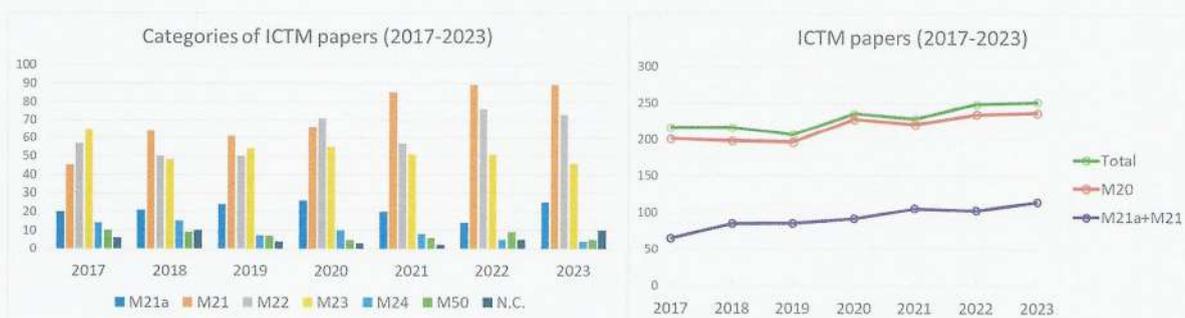


**Figure 10.** An overview of published papers between 2017 and 2023 grouped according to the Ministry of Science, Technology and Innovation classification.

The papers are of high quality, as 40% of all published papers for this period belong to the highest categories (M21a + M21).

Based on data from the e-science portal: <https://enauka.gov.rs/> listing the science institutions by the number of journal publications, conference papers, monographs, chapters in monographs, technical solutions, and other publications from 2014 until 2022, ICTM ranks 4th out of 38 institutions in the field of natural sciences and mathematics and 5th out of 56 institutions in the field of technical and technological sciences (with a total of 8,420 different publications). Of 219 scientific institutions in the Republic of Serbia, ICTM ranks 12th in productivity. ICTM publications have 16,354 citations in this period, which puts the Institute in 9th place among all scientific institutions in the Republic of Serbia, 6th place in natural and mathematical sciences, and 4th place in technical and technological sciences.

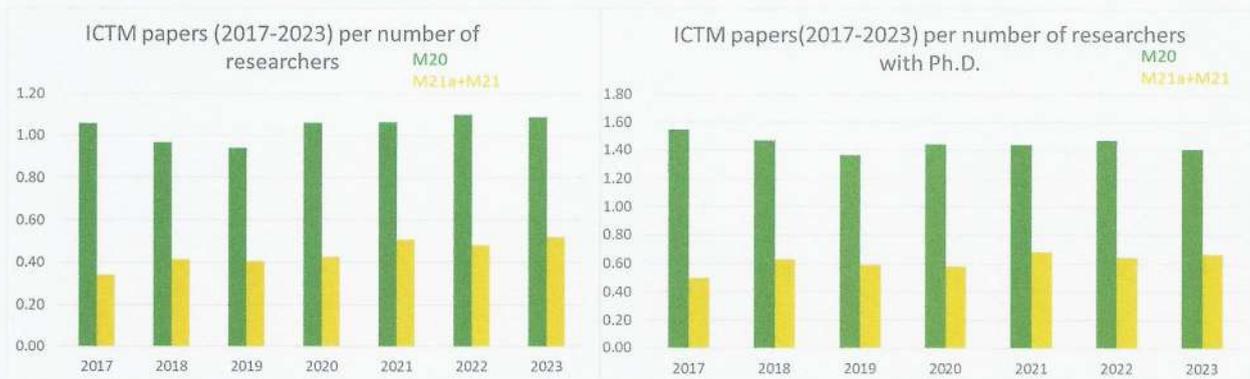
An overview of published papers in journals by year is given in Figure 11. Researchers predominantly publish in international journals (M20 categories).



**Figure 11.** An overview of published papers per year between 2017 and 2023 based on classification by the Ministry of Science and Technological Development of the Republic of Serbia (currently Ministry of Science, Technological Development and Innovations.).

Figure 11 shows that from 2017–2023, a slight increase in the number of papers occurred. In 2017, 217 papers were published (201 in the M20 category); in 2023, 252 papers were published (237 in the M20 category). There is a noticeable increase in the number of papers in the highest-quality journals (65 papers in 2017 versus 114 papers in 2022 in the (M21a + M21) category). The increase in the number of papers can partly be explained by the fact that the number of researchers increased during this period

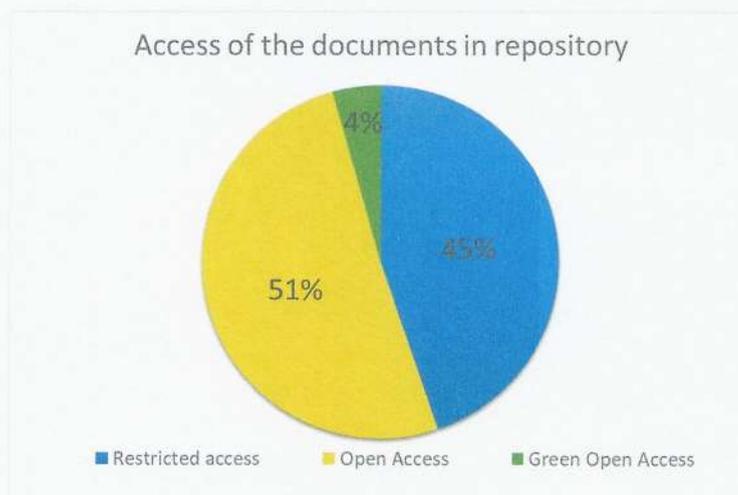
(from 205 to 214 researchers). The annual trend of the number of papers per researcher is shown in Figure 12. This number ranges from 0.94 (2019) to 1.1 (2022), or from 0.34 papers M21a + M21 (2017) to 0.52 papers M21a + M21 (2023).



**Figure 12.** An overview of the number of published papers (M20 category) and papers published in the top 30% journals (M21a+M21) per number of researchers (left) and per number of researchers with Ph.D. (right) from 2017 until 2023.

Figure 12 also shows an overview of the number of papers in the M20 category per researcher in the scientific title (PhD) – from 1.55 papers in 2017 to 1.36 papers per researcher in 2019. In 2023, 1.40 papers were published per researcher with a scientific title. A slight increase can be seen in categories M21a and M21 – from 0.50 papers per researcher in scientific titles in 2017 to 0.68 papers in 2021. In 2023, that number is 0.67 papers per researcher in a scientific title.

The Institutional Repository (<https://cer.ihtm.bg.ac.rs/>) is the digital library of the ICTM, with more than 7,400 deposited records. The repository has records since 1963 and provides access to publications and other project results that were carried out at the Institute. The repository is also of historical importance. As seen in Figure 13, more than 50% of the records in the repository are open access.



**Figure 13.** ICTM publications (restricted, open, and green-open) available in the institutional repository.

## 4.5 COLLABORATION

The Institute collaborates with businesses and other organizations by providing analytical services for testing substances, products, and materials, issuing quality certificates, having contracts for scientific

and technical collaboration, implementing research and development, and innovation projects and innovation vouchers of the Innovation Fund. Some of the important projects in the last five years include:

- (1) New aseptic high-flow industrial pump for thick, viscous, abrasive, and aggressive fluids; Contract No. 1363/18 of 10/12/2018 ICTM and NIP INOX D.O.O, Paraćin;
- (2) Development of HPLC-UV analytical method for the determination of signalling molecules of Gram-negative bacteria, Contract No. 685-01 dated 09.08.2021, IHTM, DSP Chromatography d.o.o., Belgrade and the RS Innovation Fund;
- (3) Software Package for Economic Assessment of the Feasibility of Recycling of Waste Organic Solvents, No. 837/16.10.2020., ICTM, Dualis d.o.o. Belgrade and the Innovation Fund of the Republic of Serbia;
- (4) Development and validation of analytical methods for determining the content of PAHs in medicinal and spicy herbs; ID project 727, Herba Ltd and RS Innovation Fund;
- (5) Development and production of prototypes of aluminate refractory concrete with the addition of basalt for masonry in wagons; Contract No. 1456/21.10. 2019, IHTM, Geoinvest Industrial Minerals Ltd. Arandjelovac and Innovation Fund of the Republic of Srpska;
- (6) Fabrication of a MEMS structure for a graphene microphone; ID project 90 dated 30/01/201, ICTM, Dirigent Acoustics, Belgrade and Innovation Fund of the Republic of Serbia;
- (7) Development of filter testing equipment; ICTM, Dualis Ltd. Belgrade, Innovation Fund of the Republic of Srpska;
- (8) Complete chemical and UV disinfection of protective equipment to prevent the spread of chemical and biocontamination, ICTM, Catena Alfa d.o.o., Innovation Fund of the Republic of Serbia;
- (9) Investigation of the influence of nutritional ingredients on the expression of digestive enzymes of bees (*Apis mellifera*), ICTM, Golden Bee Ltd., Innovation Fund of the Republic of Serbia;
- (10) Development of HPLC-UV analytical method for the determination of the composition of chloroquine racemic mixtures and their pharmacokinetic profiles, ICTM, Ina Soldo, Innovation Fund of the Republic of Serbia;

The Institute signed an agreement with the Office for Information Technologies and eGovernment to use the National Platform for Artificial Intelligence.

ICTM recognizes the unique importance of strengthening cooperation with outstanding researchers from the diaspora. In the past, cooperation occurred on an individual level and was based on personal interactions and friendships. In the coming period, this aspect of cooperation should be approached systematically through stronger, systemic support from the Institute. Interactions with the Serbian diaspora are not only in the interest of the Institute but are also recognized by the Ministry of Science and the Science Fund as a strategic interest of the nation and, being so, significant financial resources support it.

## 5. VISION AND MISSION

### 5.1 VISION

Creator of the future by producing innovative scientific and technological solutions that improve society as a whole.

## 5.2 MISSION

The mission of the Institute is to create cutting-edge achievements in the field of chemical sciences and related technologies to acquire and disseminate knowledge for the benefit of society as a whole through fundamental, developmental and applied research, participation in higher education, and contribution to the development and dissemination of high technologies at the national and international level.

## 5.3 VALUES

ICTM conducts its scientific, research and development activities depending on employees who are top experts in all research fields for which the Institute is accredited. All employees carry out their activities based on shared values such as (a) excellence in science and research, (b) promotion of knowledge and innovation as social values, (c) nurturing the culture of collaboration in research, (d) stimulating the dissemination of knowledge, (e) fostering an entrepreneurial spirit, (f) socially responsible science, (g) inclusiveness and diversity, and (g) tradition of trustworthy partnerships.

# 6. STRATEGIC AREAS OF DEVELOPMENT AND OBJECTIVES

## 6.1 RESEARCH AREAS

The proposed strategic research areas must be aligned with the Smart Specialization Strategy, which the state will support through fundamental and applied research, innovation and technological development initiatives. The Smart Specialization Strategy envisions four vertical priority areas: information and communication technologies, food for the future, creative industries, machinery and production processes of the future. Environmental protection is recognized as a horizontal priority area and includes energy efficiency, remediation, and air, water and soil protection. It follows the IPA (Innovations for Poverty Action) initiative. Environmental protection research is no longer sufficient to be conducted as a separate field. It is now necessary that other research areas include appropriate aspects of environmental protection and predict how the required environmental standards will be achieved. Priority should be given to research to obtain new values (products, positive impact on the market, or contribution to society) that can be achieved by incorporating the latest environmental standards. To achieve the specific objectives of the strategy, strategic areas must be adequately defined while all the current research areas are maintained, respecting the academic freedom of choice. The strategic research areas of the ICTM will be defined by a study that will be completed immediately after adopting the Strategy. Until then, the areas of research are:

### 1) **Chemistry and chemical engineering**

- i) **Organic, medicinal and bioorganic chemistry:** Synthesis of organic compounds and synthetic transformation of natural products isolated from natural substances for application in human medicine as drugs or accompanying therapeutics, using all modern methods of organic synthesis. The design of new compounds includes the application of in-silico methods (molecular docking, drug-likeness prediction, structure-based drug design (SBDD) and ligand-

based drug design (LBDD)), QSRR/QSAR analyses, bioautography and interpretation of biological activity mechanisms.

- ii) **Instrumental analysis, chemistry of natural products and natural product metabolomics:** isolation and structural characterization of secondary and endogenous metabolites from plants, cells, tissues or whole organisms, using contemporary research methods in metabolomics and instrumental structure characterization.
- iii) **Polymer chemistry:** development and research of new polymer-based materials, polymeric (nano)composites, hybrid materials, and coatings for applications in environmental protection, especially in water and air purification. These materials are also important model systems for fundamental research.
- iv) **Environmental chemistry:** Investigating the presence, migration history, and chemodynamics of pollutants in water, soil, sediments, and living organisms; risk assessment for human health and the environment. Bioremediation of polluted soils and waters and studies of optimization of biological treatments of contaminated sites in the environment.
- v) **Theoretical chemistry and molecular modeling:** development of computational methods for understanding the chemical behavior of molecules and rational development of molecules with desired properties by applying high-level quantum-mechanical calculations. These calculations can predict the behavior or the mutagenic properties of polluting organic molecules in the environment and are highly consistent with otherwise time-consuming and expensive experiments. Study of transition metal complexes with targeted applications in homogeneous and heterogeneous catalysis, magnetism, and bioinorganic chemistry and interactions in crystalline, supramolecular structures.
- vi) **Catalysis and chemical engineering:** design and synthesis of nanomaterials as catalysts and adsorbents, design of (micro)reactor systems, as well as modeling of kinetics and nonlinear dynamics of heterogeneous catalytic processes for applications in sensors, environmental protection, renewable energy sources, food industry, and medicine.
- vii) **Electrochemistry:** design of better performing, more durable and cheaper electrocatalysts for oxidation of organic and inorganic compounds in low-temperature direct liquid fuel cells. Electrochemical deposition of micro- and nanostructures from aqueous electrolytes melts and ionic liquids for industrial and environmental applications. Research in multivalent metal-air and metal-ion batteries focused on innovative methods of preparation of the cathodic and the anodic materials.
- viii) **Biochemistry and Bioanalytical Chemistry:** Studies of structure and function of microbiological, plant, animal, viral, and human biomolecules (proteins, carbohydrates, nucleic acids, etc.) and development of methods for the analysis of biological molecules, cells and viruses.

## 2) Biotechnology

Industrial Biotechnology and Environmental Biotechnology:

- i) **Innovative enzyme technologies** for producing value-added food products, biofuels and biomass-based materials using recombinant protein (GMO) technology and the existing natural repertoire of enzymes obtainable from wild-type (non-GMO) producers.
- ii) Sustainable **bioremediation methods and technologies** based on natural resources, including microorganisms, enzymes, plants, and natural adsorbents for soil purification. Studies of ecological stress in living organisms, biodegradation and metabolic pathways of xenobiotics; monitoring of metabolites in living organisms and the environment; phytoremediation and processing of contaminated biomass for the production of biofuels.

- iii) **Land management** with minimal degradation and preservation of clean water and biodiversity. Providing long-lasting, nature-based solutions to reduce the impact of climate change on soil.
- iv) Research, development, and production of **therapeutic proteins**.

### 3) **Microelectronics and microelectronic technologies**

- i) **Sensors and measuring instruments:** research, development, and implementation of sensors and measuring instruments based on structures manufactured by microelectronic and microsystem (MEMS) technologies. Applications include measurement of physical parameters of industrial processes, detection of chemical substances, biomolecules and biological agents, measurements of environmental pollution parameters in air and water, following the physiological state of an organism by measuring respiration, pulse, chemical composition of sweat and breath, food safety and the like.
- ii) **Microfluidic platforms:** development, design and implementation of microfluidic platforms and structures based on MEMS technologies for applications in chemistry, biochemistry, biology, and medicine.
- iii) **Synthesis and characterization of materials for microelectronics applications.** Examples include novel multifunctional polymeric materials and their nanocomposites, electrochemically deposited metallic coatings for applications in microelectronics.

## 6.2. KEY STRATEGIC OBJECTIVES

The key strategic objectives focus on developing and applying cutting-edge scientific and innovative solutions in chemistry, biotechnology, materials science, and microelectronics. These efforts aim to contribute to the community in areas such as health, food production, and environmental protection by collaborating with academic institutions and industry

The following strategic areas are established for the following five years:

**1. Increased excellence in research:** the main objective in this area is to enhance the scientific excellence of ICTM in fundamental and applied research. To achieve this goal in the coming period, the Institute needs to: a) revise its priority research areas, b) establish new and strengthen the existing Centers of Excellence, c) increase the quality of scientific publications, d) increase the number of competitive scientific projects that are managed by and in which ICTM researchers participate, e) strengthen cooperation with related scientific institutions abroad, f) strengthen cooperation with researchers from the diaspora, and g) strengthen its research infrastructure.

**2. Increased relevance of research [improved knowledge and technology transfer (KnTT)]:** the main objective in this area is to increase the relevance of applied research. This should be achieved by: a) strengthening the innovation potential, b) increasing the number of applied national and international patents, c) strengthening cooperation with industry and the public sector, d) increasing the number of start-ups and further development of existing companies that originated from ICTM, and e) strengthening and expanding networking of the office.

**3. Higher impact on society:** The main goal in this area is to increase the Institute's impact on society. This should be achieved by a) increasing the visibility and recognition of the Institute, b) raising the awareness of the Institute's employees about the possibilities of the Institute's impact on society, c) increasing impact on

the decision-makers by taking on advisory roles in the state administration, the University and the Serbian Government.

It should be noted that, in the past, the Institute devoted little attention to promotional activities expected to increase its visibility and make it recognizable to a broader audience outside of the immediate boundaries of the scientific community. Communication with the public used to take place sporadically, mainly at the initiative of individual researchers. The lack of communication with the decision-makers and poor participation of our researchers when the development strategies and policies at the state, Government, and University levels are being adopted partly because the ICTM personnel were only vaguely aware of these strategies and policies impact on society. Having a low impact on society results in the Institute being poorly involved in collaborative projects with the stakeholders. This situation does not align with the Institute's potential to contribute to society. The Institute, therefore, recognizes that **increasing impact on society** is a major goal for the future and is highlighted as a separate strategic area in the action plan.

**4. Strengthened capacities:** the main objective in this area is to increase the human resources of the Institute, which should be achieved by a) hiring recent graduates to revitalize the research staff, b) providing support to researchers for their continuous advancement, c) strengthening soft skills of researchers (project management, giving presentations, motivating teams, etc.), d) strengthening the capacities of KTT office, e) strengthening the capacities of the administrative services staff, f) strengthening the IT and research infrastructure, and g) supporting the performance improvement of ICTM employees.

A detailed Action Plan has been developed as part of the Institutional Strategy. Specific objectives have been stated for each of the key strategic objectives. The Action Plan defines all the necessary activities and measures to achieve the specific objectives. The strategic areas, and numbers of specific goals, activities, and indicators for each are shown in Table I.

Table I. Strategic areas, numbers of specific goals, activities and indicators

Strategic area	Number of specific goals	Number of activities	Number of indicators
1. Increased excellence in research	7	31	24
2. Increased relevance of research	5	12	12
3. Higher impact on society	2	13	6
4. Strengthened capacities	7	19	15

An assistant director has been designated as a coordinator of each strategic area and is responsible for monitoring the progress of the implementation. For each of the specific objectives, activities are planned, each with objectives and expected results, a set timeframe, designated participants, indicators to signal whether the activities have been completed, and a list of possible risks that may lead to a slowdown or complete interruption of the process. The indicators that will signal the outcome of a planned activity are expressed through quantitative values whenever possible. Baseline values have been established, and quantitative changes in these values will be measured annually to report on the degree of fulfillment of each indicator. Verification sources for each of the indicators have been set as well.

Procedures that enable effective monitoring of the implementation have been defined. This includes designating persons responsible for monitoring the implementation of activities. These persons will prepare and submit periodic reports and give recommendations for improvement. Based on the

submitted reports, the realization of the Action Plan will be analyzed. If there are significant deviations from the planned implementation of activities, the Action Plan will be revised. The Action Plan's financial part will align with the Institute's adopted financial plan for the relevant year.